Legislative Energy Horizon Institute

July 12 - 15, 2009
Boise, Idaho

INSTITUTE PARTNERS:

Pacific NorthWest Economic Region
University of Idaho
U.S. Department of Energy
National Conference of State Legislatures

LOGISTICS

Schedule
Program Objectives

NORTH AMERICAN ENERGY INDUSTRY

U.S. Energy Situation
Dick Moore

PETROLEUM

Crude Oil—Midstream & Downstream
Dick Moore

NATURAL GAS

Natural Gas Production, Transmission & Delivery
Dick Moore

Canadian Gas Overview
Gary Weilinger, Vice President, Strategic Development & External Affairs
Spectra Energy

THE ELECTRIC GRID

Power System Concepts
Power Grid Operations
Skip Collier, Course Manager
Professional Training Systems, Inc.

FUTURE ENERGY CHALLENGES

Executive Round Table Discussion
Doug Bloom, President, Western Canadian Operations
Spectra Energy

Pat Reiten, President
PacifiCorp/Pacific Power

Steve Reynolds, President & CEO
Puget Sound Energy

Lynn Westfall, Senior Vice President, External Affairs
Tesoro Corporation

SPECIAL TOPICS

Global Energy Picture
Neelesh Nerurkar, Economist
BP America, Inc.

Canadian Energy Future
Surindar Singh, Director
Alberta Energy Research Institute

Alternative Energy Sources

Public Policy Impact on Business Decisions
Mike Oldak, Senior Director, State Competitive/
Regulatory Policies
Edison Electric Institute

Independent Power Producers
Bob Kahn, Executive Director
Northwest & Intermountain Power Producers
Coalition

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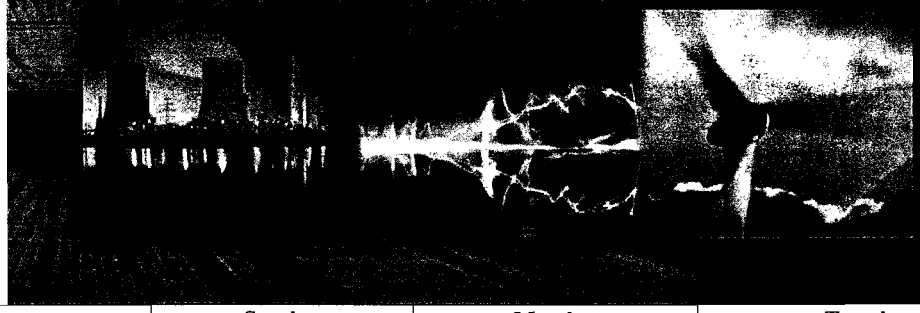

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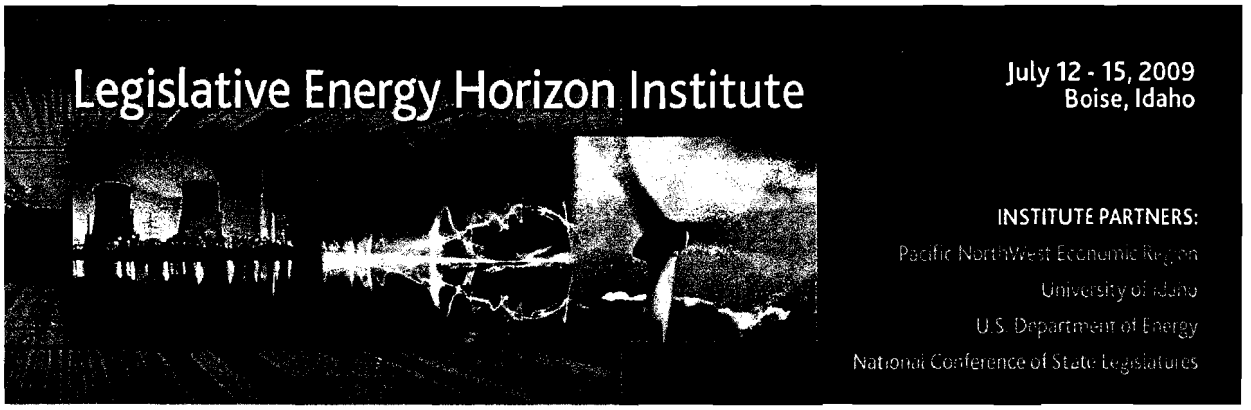
	Sunday 7/12	Monday 7/13	Tuesday 7/14	Wednesday 7/15	Thursday 7/16
8:00 a.m.	**Institute Classroom:** Salmon Room **Institute Lunch Presentations:** Snake Room	**PNWER Breakfast & Conference Launch** (John van Dongen) (Roger Woodworth) [Eagle Room]	**PNWER Breakfast Energy Efficiency** (Dean Allen) [Eagle Room]	**PNWER Breakfast** **Energy Industry Challenges** (Doug Bloom, Pat Reiten, Steve Reynolds, and Lynn Westfall) [Eagle Room]	**Idaho National Lab Policy Tour** *(optional, pre-reg. required)* (7:00am-9:00pm)
8:45 a.m.			**Power Systems Concepts** (Skip Collier) (8:45-12:15)		
9:00 a.m.					
9:15 a.m.		**U.S. Energy Situation** (Dick Moore) (9:15-10:30)		**Executive Roundtable Discussion: Energy Industry Challenges** (Doug Bloom, Pat Reiten, Steve Reynolds, and Lynn Westfall) (9:30-11:30)	
9:30 a.m.					
10:00 a.m.					
10:30 a.m.					
10:45 a.m.		**Petroleum 101** (Dick Moore) (10:45-12:00)			
11:00 a.m.					
11:30 a.m.					
12:00 p.m.		Lunch Presentation **Canadian Energy Future** (Surindar Singh) (12:00-1:30)	**PNWER Lunch Presentation** **Canadian Energy Picture** (Hon. Gary Lunn) [Eagle Room]	Lunch Presentation **Alternative Energy Sources**	
12:15 p.m.					
1:00 p.m.					
1:30 p.m.				**Public Policy Impact on Business Decisions** (Mike Oldak) (1:30-3:30)	
1:45 p.m.		**Natural Gas Production, Transmission & Delivery** (Dick Moore) (1:45-4:00)	**Power Grid Operations** (Skip Collier) (1:45-5:30)		
3:00 p.m.					
3:30 p.m.					
3:45 p.m.				**Independent Power Producers** (Robert Kahn) (3:45-5:00)	
4:00 p.m.					
4:15 p.m.		**Canadian Gas Overview** (Gary Weilinger) (Tom Huffaker) (4:15-5:30)			
5:00 p.m.	**Institute Welcome** Jeff Morris, Sponsors, Yvonne Sertich				
5:30 p.m.			**PNWER Clean Energy Technology Reception** (Hosts: Idaho National Lab & Alberta Research Council) [Eagle Room]		
6:00 p.m.	**Global Energy Picture** (Neelesh Nerurkar)			**PNWER President's Banquet** (Sponsored by the Government of Canada) [Eagle Room] (6:00)	
6:15 p.m.		**PNWER Reception/Western BBQ JR Simplot Stables** [Buses depart Convention Centre from Front St. beginning at 6:15pm]			
6:30 p.m.	**PNWER Welcome Reception- Basque Block** (Mayor David Bieter) (US Congressman Walt Minnick)				
7:00 p.m.			**Sponsor Dinner** Angell's Bar & Grill		
8:30 p.m.					



Program Objectives

Overall Objective: The Legislative Energy Horizon Institute will produce a corps of legislators with knowledge about how energy is delivered to consumers. These individiuals will bring an increased understanding of how the complex energy system works and knowledge about infrastructure, costs and timelines to their caucuses and legislatures. By working together across jurisdictional boundaries to understand our energy system, policymakers will be able to forge the necessary relationships to address multi-state energy infrastructure and policy issues.

Course Objectives:

- Provide a concrete understanding of the electric grid and how it operates.
- Describe how the various energy sectors interface to produce and deliver energy.
- Examine the rules and regulation of electric, natural gas, and petroleum infrastructure.
- Explain the regulatory, financial, and planning challenges associated with building new energy infrastructure.
- Apply technical knowledge to implement informed and effective energy policy.
- Analyze the relationship between climate and energy.

Global Energy Picture
(Neelesh Nerurkar, BP America, Inc.)
Learn:

- Where global energy markets are headed.
- How global issues are impacting energy, price volatility, security, and climate change.

U.S. Energy Situation
(Dick Moore)
Learn:

- The sources and origins of energy production and consumption.
- How industry leaders are balancing core drivers such as capital investment, rising costs and prices, climate change, and energy efficiency.

Petroleum 101
(Dick Moore)
Learn:

- About oil supply and sources.
- How oil and gas are generated at the well head.
- Market price forecast.

Canadian Energy Future—Prospects with Fossil Fuels
(Surindar Singh, Alberta Energy Research Institute)
Learn:

- About new technologies including clean coal, gasification, and carbon capture and sequestration.
- About cutting edge technology research.

Natural Gas Production, Transmission & Delivery
(Dick Moore)
Learn:

- The scope of the industry including production, pipelines and storage, and consumption.
- About natural gas supply and sources.
- About natural gas marketing.

Canadian Gas Overview
(Gary Weilinger, Spectra Energy)
Learn:

- The scope of the Canadian gas industry including production, pipelines and storage, and consumption.

Power System Concepts
(Skip Collier, Professional Training Systems, Inc.)
Learn:

- The basics of generation, transmission, and distribution.
- Basic electrical terminology, equipment construction, and equipment operating theory.
- How to communicate technical information using non-technical language.

Power Grid Operations
(Skip Collier, Professional Training Systems, Inc.)
Learn:

- About utility network operations, including control, protection, and voltage regulation.
- About distributed generation.

Energy Industry Challenges
(Doug Bloom, Spectra Energy)
(Pat Reiten, PacifiCorp)
(Steve Reynolds, Puget Sound Energy)
(Lynn Westfall, Tesoro Corporation)
Learn:

- How challenges such as state and federal initiatives, cap and trade, performance standards, and Kyoto are impacting the energy industry.

Alternative Energy Sources
Learn:

- What challenges and barrriers alternative energy sources must overcome in reaching the market place.

Public Policy Impact on Business Decisions
(Mike Oldak, Edison Electric Institute)
Learn:

- How public policy impacts energy cost and shapes business decisions.

Independent Power Producers
(Bob Kahn, Northwest & Intermountain Power Producers Coalition)
Learn:

- About the role of Independent Power Producers (IPPs) and the challenges they face.

The U.S. Energy Situation

EXPLORING CONSUMPTION & SUPPLY ISSUES

BY J. RICHARD MOORE
email = jrichardmoore@sbc.net

We all use energy every day

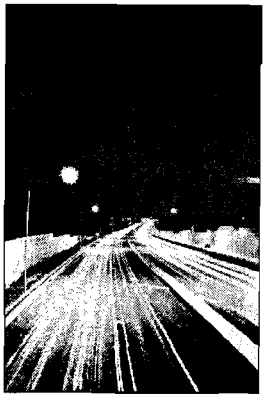
HOME, WORK & TRAVEL

Residential
heating, lighting, food & laundry

Commercial
stores, shops, entertainment & offices

Industrial
mining, processing & manufacturing

Transportation
highway, rail, air, ship & P/L



Energy
is vital to our
survival
and our
standard of living.

WE ALL HAVE A STAKE IN THIS ISSUE:
WE NEED TO BE INFORMED & INVOLVED.

Topics

- Energy consumption
- Sources/origins of energy consumed
- Concerns with current situation
- Possible solutions
- Practical considerations & appropriate policies

U.S. energy consumption

Measuring energy consumption

"BTU"

British Thermal Unit
(ability to do work)

"QUAD"

Quadrillion BTU (10^{15})

1 BTU x 1 million = 1 million BTU = 1 MM BTU
1 QUAD = 1 billion x 1 million BTU

1 QUAD is equivalent to
the annual energy consumption of
6 million U.S. households in 2007.

Energy consumption
in the U.S.

	1950	1977	1997	2007
Total (QUADS)	34.62	78.00	94.77	101.60
Per capita (MMBTU)	227	354	348	337
Per $ real GDP (MBTU)	19.48	16.42	10.89	8.78

SOURCE: EIA AER 2007, TABLE 1.5

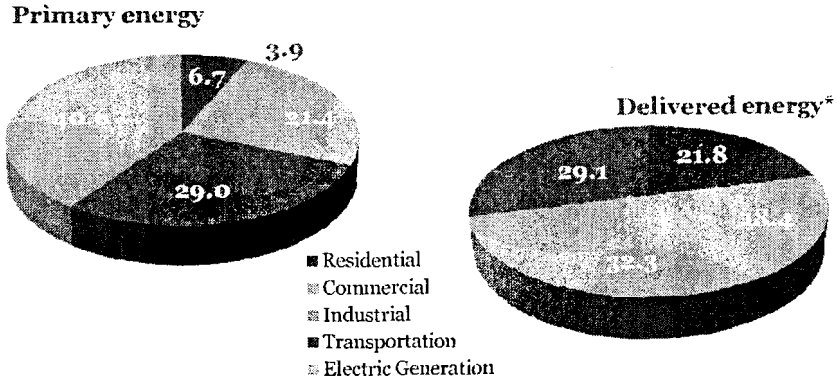
Primary
U.S. energy consumption by sector (QUADS)

SECTOR	1950	1977	1997	2007
Residential	4.85	8.21	7.04	6.69
Commercial	2.82	4.22	4.26	3.90
Industrial	13.88	23.19	23.72	21.44
Transportation	8.39	19.79	24.70	29.00
Electric Generation*	4.68	22.59	35.05	40.57
Total	34.62	78.00	94.77	101.60

*ELECTRICITY IS GENERATED FROM OTHER ENERGY SOURCES AND USED IN ALL 4 SECTORS

SOURCE: EIA AER 2007, TABLE 21.3

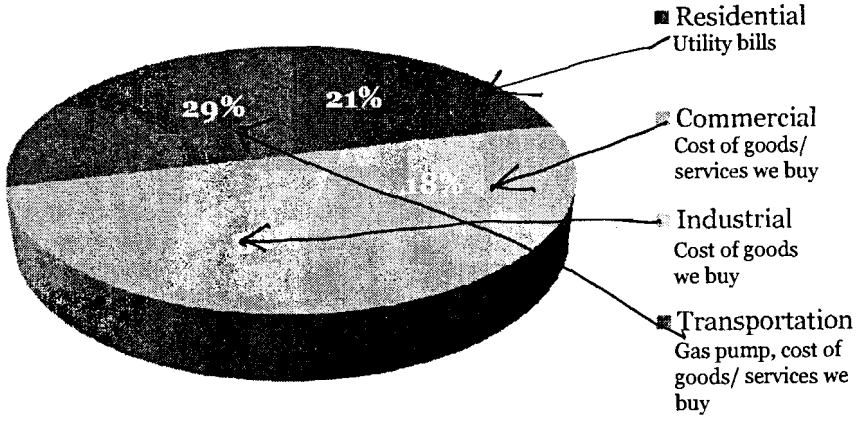
2007
U.S. energy consumption (QUADS)



* Allocation of primary energy consumed in electric generation to sectors consuming electricity.

Where do we pay energy costs?

2007 U.S. DELIVERED ENERGY CONSUMPTION

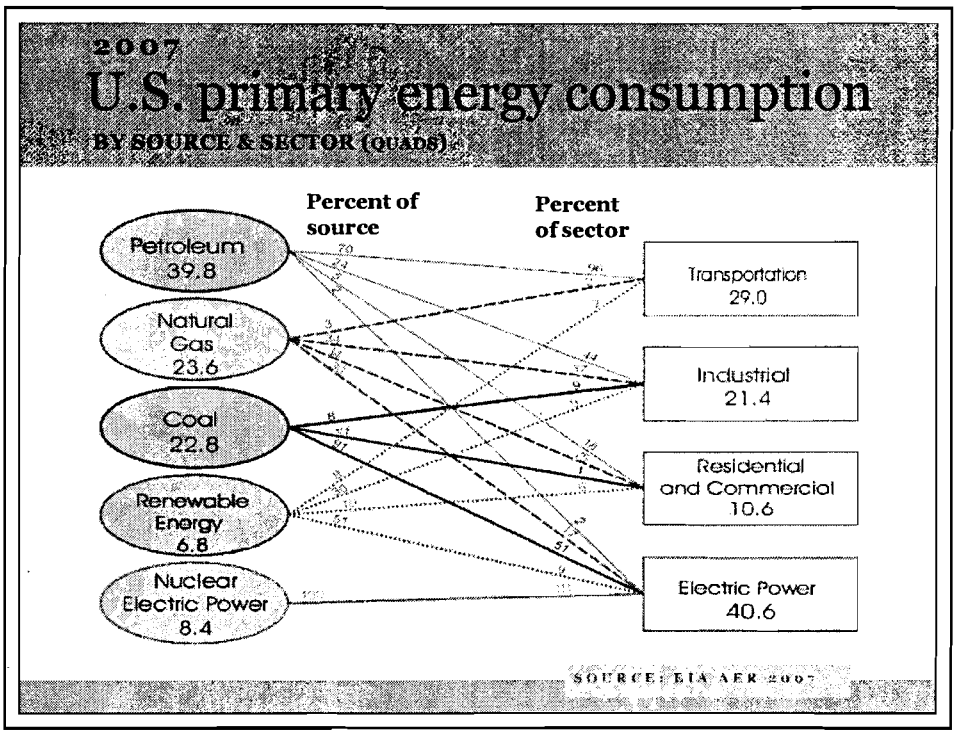


Energy consumption

- Our lives & standard of living are dependent on consumption of energy.
- U.S. energy consumption is growing, driven by population increase & rising standard of living.
- Largest & fastest growing consumption sector is electric generation.
- Payment for delivered energy consumed in residential sector not made (or cost known) when consumption occurs. More (maybe substantially more) than 50% of total energy costs paid in prices of goods & services purchased; not apparent as energy costs to us.

Sources of primary energy

CONSUMED IN THE U.S.



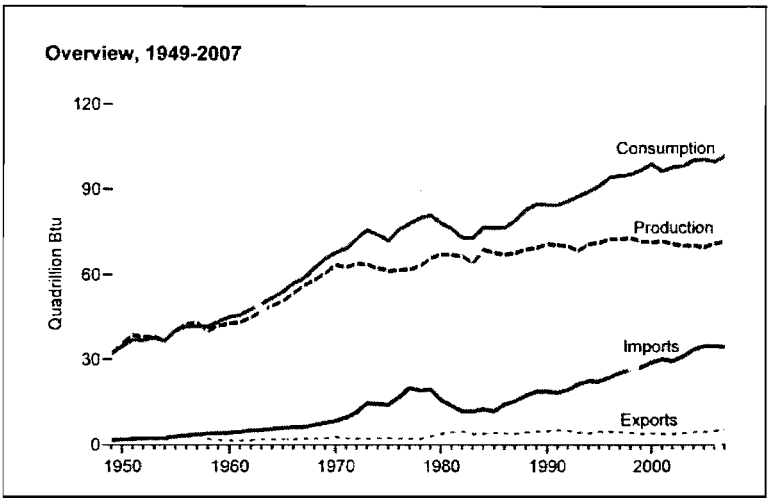
Source of Primary energy consumed (QUADS)

Energy Source	Domestic Production	Net Imports	Total Consumption
Petroleum & NGL	13.20	25.77	38.97
Natural gas	19.82	3.90	23.72
Coal	23.48	<.57>	22.91
Nuclear*	.93	7.49	8.42
Renewables	6.80	0	6.80
Inventory / Bal.**	.41	.37	.78
Total	64.64	36.96	101.60

*Nuclear based on ratio of domestic/imported uranium (9.3)
**Ratio of domestic/import to total

SOURCE: EIA AER 2007, TABLES 1.1 through 1.4, 9.3

U.S. energy production, consumption & imports



SOURCE: EIA AER 2007, FIG. 1.0

Where are we?

- Energy consumption is a vital part of our standard of living.
- We now import nearly 37% of the energy we consume.
- Imports provide 2/3 of our petroleum.
- Energy prices have been rising and volatility has increased.
- Supply security is uncertain.
- World demand is increasing.

U.S. energy situation

CONCERNS & PROBLEMS

VALID ENERGY
concerns
REQUIRE ACTION

- The cost of energy we rely on for our way of life is increasing because "cheap" energy supplies have been consumed.
- Rising energy costs can reduce our economic competitiveness & our standard of living.
- Growth in energy imports increases our exposure to economic & political threats related to supply interruptions.
- Current methods of using traditional energy resources produce undesirable environmental side effects that are expensive to mitigate.

1) More efficient use of energy

AND

expanded supplies of energy

OR,

2) Fewer people

AND

reduced standard of living

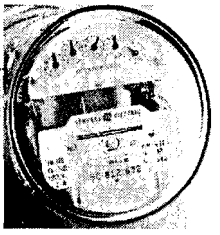
POSSIBLE SOLUTIONS

Efficiency & conservation

SOLUTION 1

More efficient use of

ENERGY



Conservation

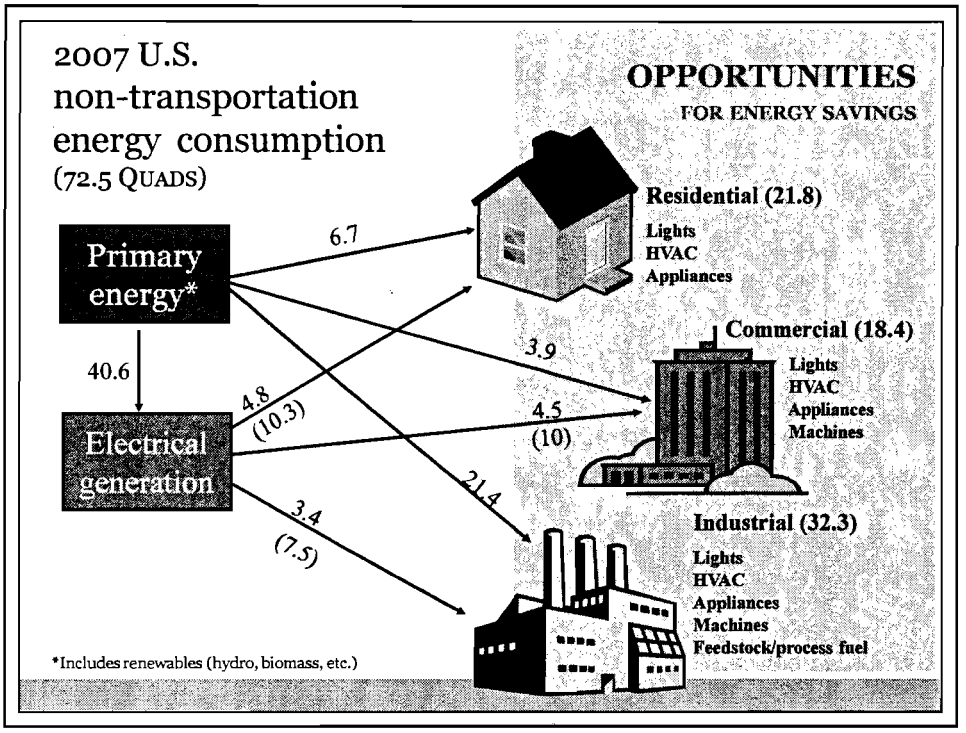
"Turn the light off as you leave"

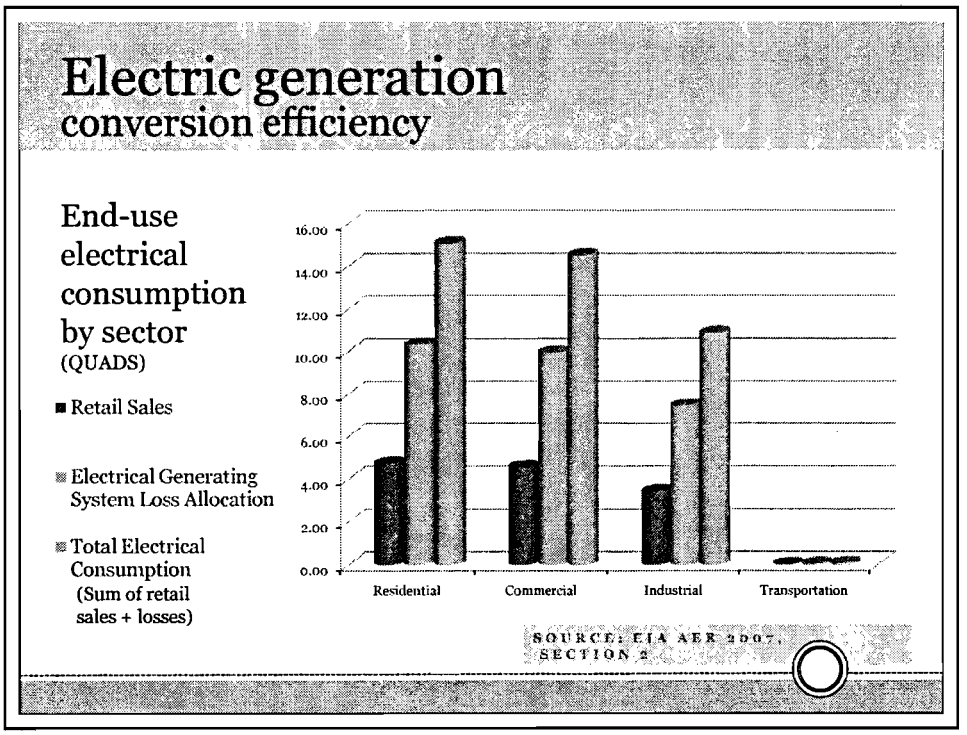
Efficiency

Use less energy to do work / capture waste
Schedule use to reduce peak demand on system
Reduce production, conversion, transmission & distribution losses

Technology

Increased efficiency will be driven by improved technology & control


2007 U.S.
non-transportation
energy consumption
(72.5 QUADS)
OPPORTUNITIES
FOR ENERGY SAVINGS
Primary energy*
40.6
Electrical generation
6.7
4.8
(10.3)
3.9
4.5
(10)
21.4
3.4
(7.5)
Residential (21.8)
Lights
HVAC
Appliances
Commercial (18.4)
Lights
HVAC
Appliances
Machines
Industrial (32.3)
Lights
HVAC
Appliances
Machines
Feedstock/process fuel
*Includes renewables (hydro, biomass, etc.)


Electric generation
conversion efficiency
End-use electrical consumption by sector
(QUADS)
Retail Sales
Electrical Generating System Loss Allocation
Total Electrical Consumption (Sum of retail sales + losses)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Residential
Commercial
Industrial
Transportation
SOURCE: EIA AER 2007, SECTION 2

6 % world's population 20 % of world's energy! Oil!!! we also create 20% of world's GDP...

6/26/2009

Thermal efficiency
of electric generation

Primary Fuel	Conversion Efficiency
Coal	
•Typical steam/electric	30-35
•Integrated gasification	39
Natural gas	
•Simple cycle gas turbine	35-40
•Combined cycle gas turbine (CCGT)	60
•Cogeneration/CCGT	90

ROOM FOR IMPROVEMENT

Improved efficiency will lower fuel consumption and emissions.

Comparison

OF ELECTRIC GENERATING PLANTS

Fuel	Capital Cost	Fuel Cost	Swing	Variable Cost
Natural Gas	Low	High	Yes	Highest
Coal	Higher	Lower	No	Lower
Nuclear	Highest	Lowest	No	Lowest
Renewables	Highest	Varies	No	Varies

Generating fleet will include mix of plants to economically meet demand.

Installed, dependable generating capacity must equal peak demand with some reserve.

Expanded energy supplies

SOLUTION 2

Expanded supplies

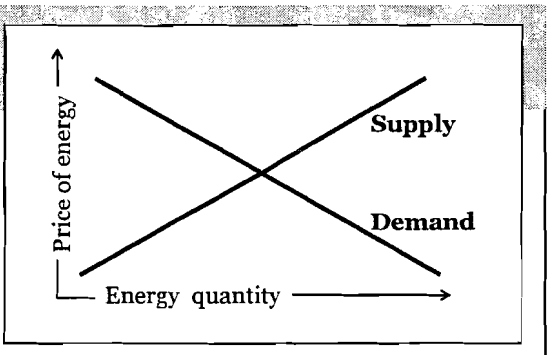
OF ENERGY

Increased production of fossil fuels

Increased utilization of nuclear power

Increased production from renewable sources

Development of totally new technology



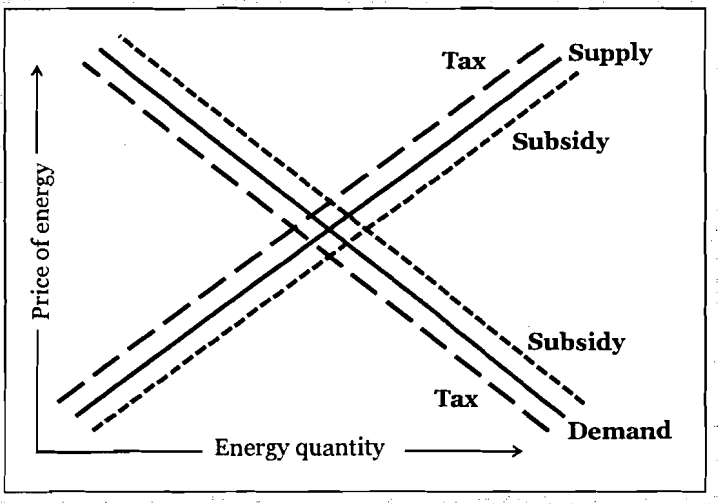
Energy
Supply & demand

Low price	**High price**
Encourages consumption	Discourages consumption
Discourages efficiency	Encourages efficiency
Discourages production	Encourages production
Result: shortage/higher prices	Result: surplus/lower prices

Government policies shift both supply & demand curves:

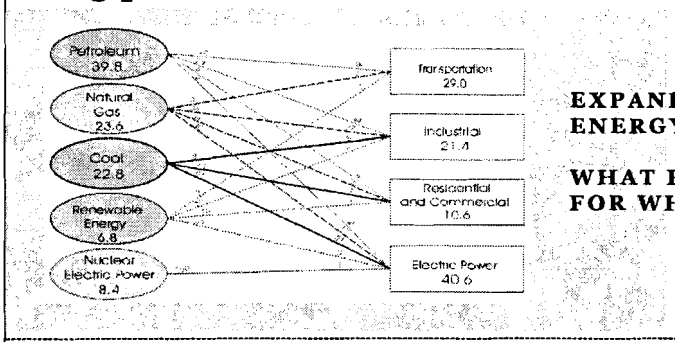
Tax
discourages production &/or consumption of target fuel.

Subsidy
encourages production &/or consumption of target fuel.



Both subsidies and taxes impose costs.

U.S. energy problems
Big picture



EXPANDED ENERGY SUPPLIES:

WHAT FUELS FOR WHAT PURPOSES?

SECTOR	PROBLEMS
Transportation fuel	Imports (petroleum) cost & security
Electric generation	Emissions (fossil fuels) cost & efficiency

Desired expanded energy sources

Economic domestic transportation fuel

Clean, economic efficient domestic electric generation fuel

Energy Source	Transportation fuel	Electric generation fuel	Technology required
Petroleum	Yes	No	---
Natural gas	Yes/maybe*	Yes	GTL
Coal	Via electricity. Maybe*	Clean coal	Battery/CTL
Nuclear	Via electricity. Maybe*	Yes	Battery
Renewables	Maybe*	Maybe*	Various

*Maybe: technology/economic hurdles to overcome

Expanded U.S. Energy Supplies

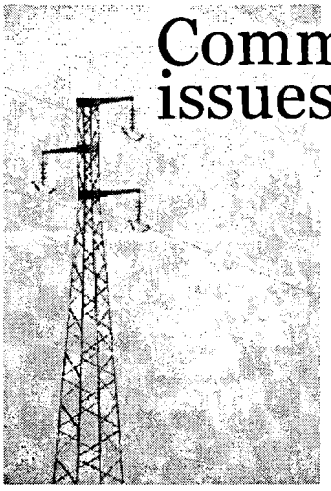
Summary

	YEARS SUPPLY OF CONSUMPTION (2007)			
	U.S.		WORLD	
Source	Proved	Potential	Proved	Potential
Oil	12	99 (1150)*	50	94 (244)*
Gas	10	67 (13,922)**	59	1209 (7,000)**
Coal	237	446	149	56
Nuclear	19	70-117	39	N/A
Renewables	N/A	N/A	N/A	N/A

*Shale & tar sands

**Hydrates

WE ARE NOT RUNNING OUT OF ENERGY;
WE ARE RUNNING OUT OF CHEAP ENERGY.



Common issues

- Access to land for production/mining
- Energy prices high enough to justify investments
- Availability of critical skills & equipment
- Government policies encouraging research & development of energy supplies & limiting harassment of project developers

INTERMEDIATE TERM U.S.ENERGY SOLUTIONS SUMMARY

SOLUTION 1

Significant room for energy consumption reductions through conservations & efficiency

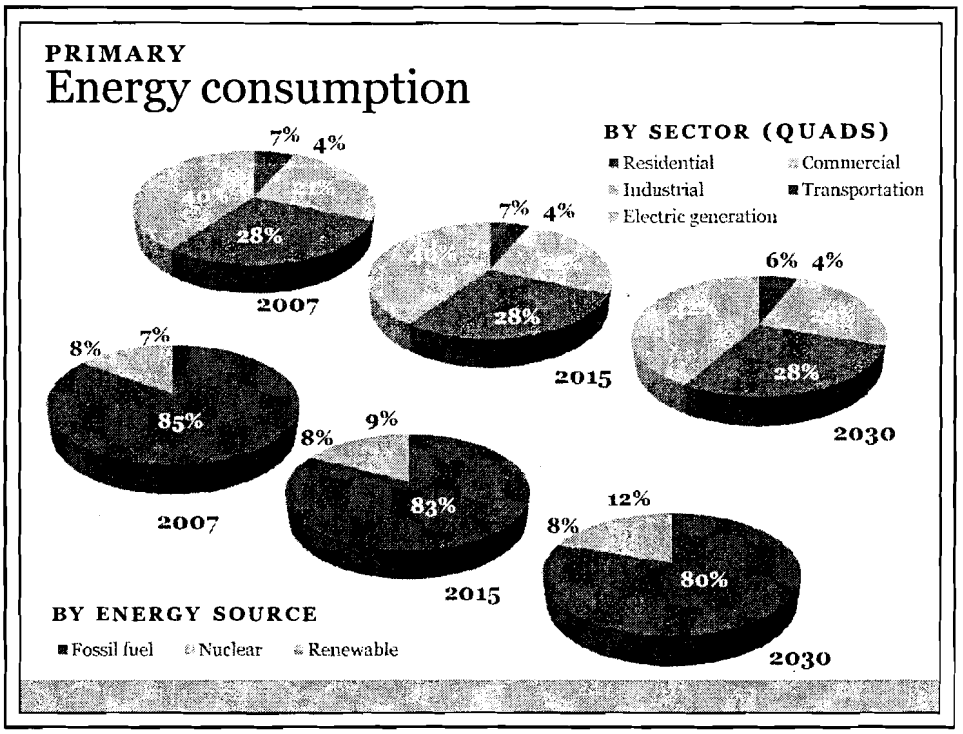
REQUIRES
- INCENTIVES
- EDUCATION

SOLUTION 2

Additional energy resources available domestically & worldwide

REQUIRES
- ECONOMIC ENERGY PRICES
- ACCESS TO LAND
- GOVERNMENT POLICIES SUPPORTING EXPANSION OF ECONOMIC DOMESTIC ENERGY SUPPLIES

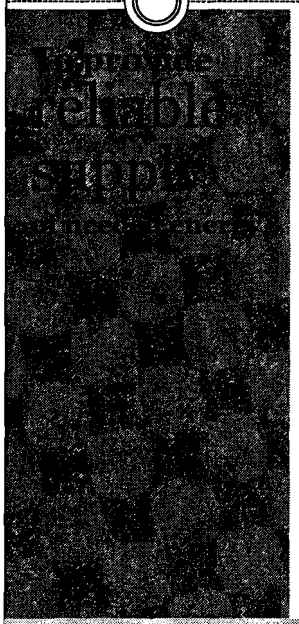
Practical constraints & appropriate policies



Lead times & required investment of representative projects

	Lead time (Years)	Size of typical project	$ Cost/ unit	Total cost
Oil/gas field				
Onshore	1-5	n/a	$2-3 MM/well	$100 MM
Offshore	8-12	n/a	$55-100 MM	$200 MM-3 billion
Alaska (PT Thompson)	8-12	5-well pkg	(delineation)	$1.3 billion
Oil refinery	3-8	300k BBL/D	$15-20k/BBL	$4.5-6 billion
Electric generation Plant				
Gas	5-6	400 mw	$.5-2.5 k/kw	$.2-.6 billion
Coal	6-8	600 mw	$1.5-2.5 k/kw	$.9-1.5 billion
Nuclear	10-12	1,350 mw	$2.5 k/kw	$3.5 billion
Wind	4-6	50 mw	$1.5-2.8k/kw	$.08-.14 billion
Transmission Lines				
Electric	1-3	n/a	$.5-3.5 MM/mi	(above ground)
Natural gas				
Onshore	1-3	n/a	$.7-6.0 MM/mi.	(avg. $2.1 MM/mi.)
Offshore	2-5	n/a	$8-12 MM/mi.	
Oil shale production	5-10	100k BBL/D	$4-6 billion	$4-6 billion

SOURCES: EIA AEO 2008, OAG, [illegible] & EXXON 8/28/08



Projects must be started years before the energy is needed.

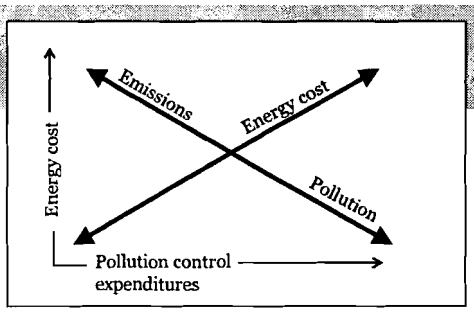
Many projects must be started each year to offset decline & meet projected growth in demand.

Projects must be undertaken when some project costs & the energy commodity price are unknown. ⟶ Risk!

Major projects require substantial expenditures on preliminary tasks (permitting, design, etc.) that may not be recovered if the project is not completed.

Once properly permitted, projects should be shielded from continuing legal/environmental harassment.

Policy Implications



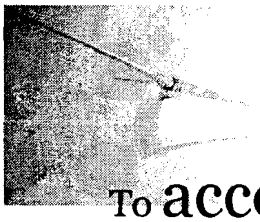
IMPACT OF POLICY ON ENERGY COST

Oil exploration & production
- Frac water re-use
- Road traffic/noise limitations

Electric generation
- Fossil fuel plant emissions
- Nuclear facility design & fuel storage/disposal

Auto emissions (miles per gallon)

Building & appliance efficiency



To **accept** inevitable cost increases & **modify** behavior, the public must **understand** energy issues.

- Cheap energy is gone.
- Cleaning up environment will add costs.
- Doing nothing is not really an option; doing the wrong thing will be expensive.
- Analysis & debate should be encouraged.
- Differing opinions should be addressed, not ridiculed.
- Media should provide complete picture to the public.
- Role for government & schools is to inform public.

IMPROVED POLICY CONSIDERATIONS INCREASE SUPPLIES OF ENERGY

Access to resources
open up federal lands & offshore, continuous federal leasing program

Standardized designs & approval procedures
nuclear power plants, coal power, CTL plants & refinery expansions

Infrastructure policies
expand/modernize/upgrade railroad & electric transmission systems, water reclamation & disposal, nuclear waste, CO_2 sequestration

Efficiency
building codes, CAFE standards, appliance standards

Education
Skills for workers (technical & scientific), conservation (general public) & economic implications (policy makers & public)

Research
Fund & incent wide range of investigations

Market system
Can be relied on to identify solutions

Thank you.

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JRICHARDMOORE@SBCGLOBAL.NET

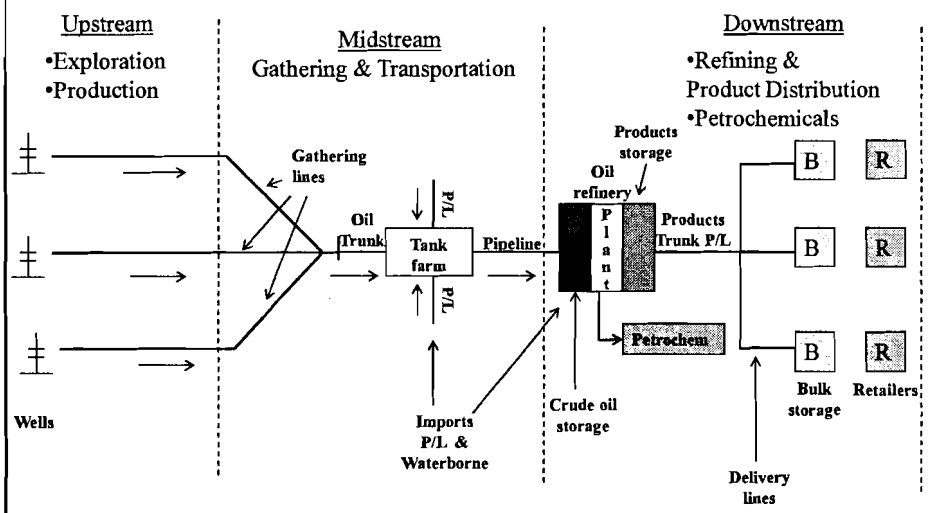
Photo credits: freedata.com
sfuckerbug.com

Crude Oil

Midstream & Downstream

J. Richard Moore

Oil Industry Segments



Crude Oil Midstream

U.S. Supplies of Natural Gas & Oil—2007

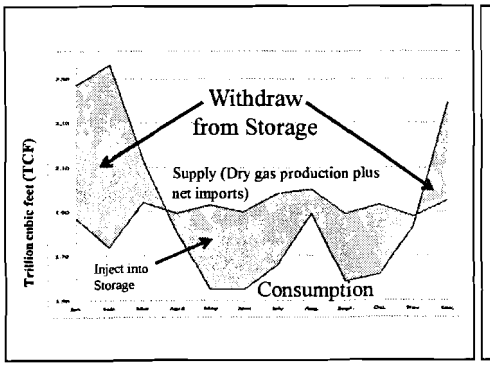
	NATURAL GAS		OIL	
	Annual (TCF)	Avg Day (BCF)	Annual (BBBLS)	Avg Day (MMBLS)
Gross Domestic Production	24.6	67.4	1.848	5.064
Dry Domestic Production	19.1	52.3	1.848	5.604
Pipeline Imports	3.8	10.4	.689 (CAN)	1.861
Waterborne Imports	.8	2.2	2.972	8.143
# of Domestic Wells	452,768	452,768	500,00	500,000
Average Production (Gross)	54,332 MCF	149 MCF/D	3,696 BBLS	10 BBLS/D

Source: EIA

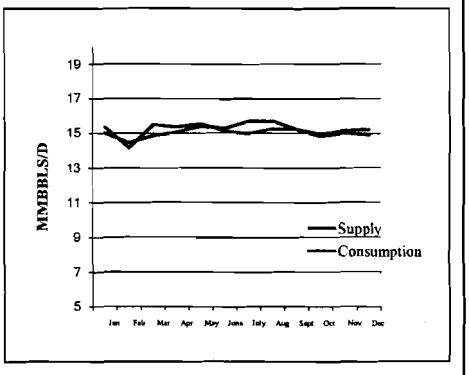
Seasonality of Demand

Natural Gas vs. Oil—2007

NATURAL GAS

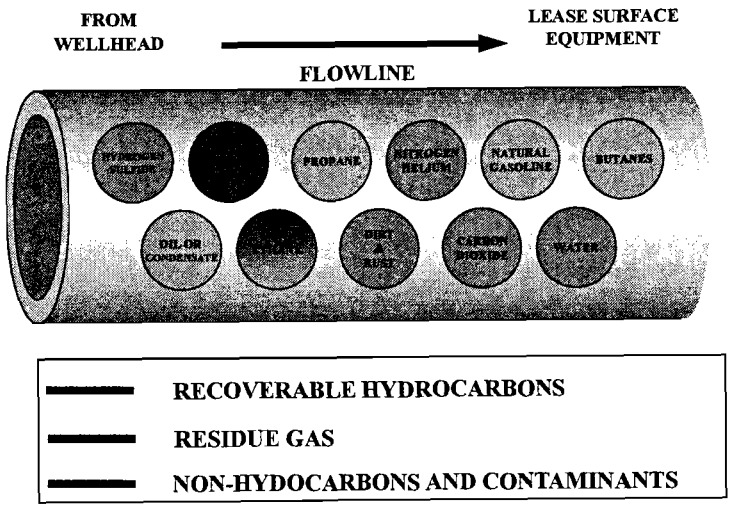


OIL

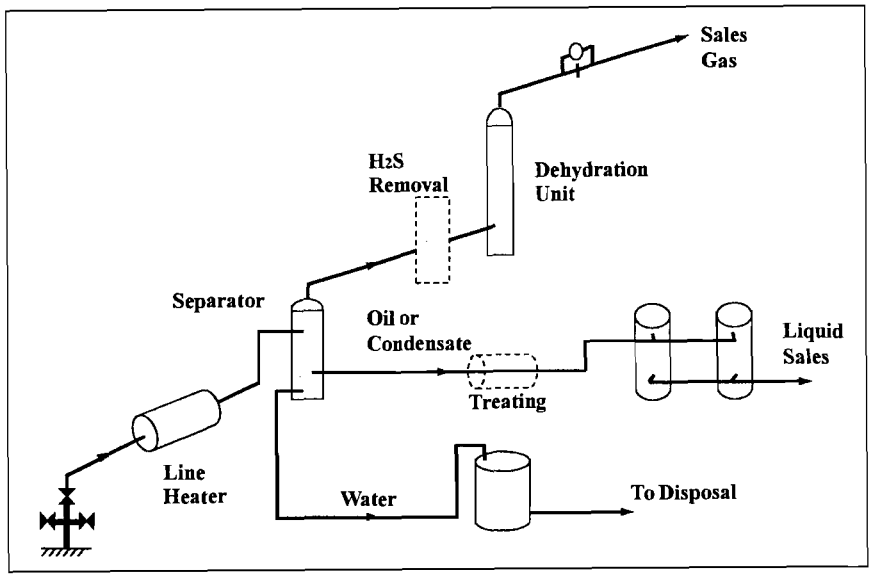


Crude Oil Gathering

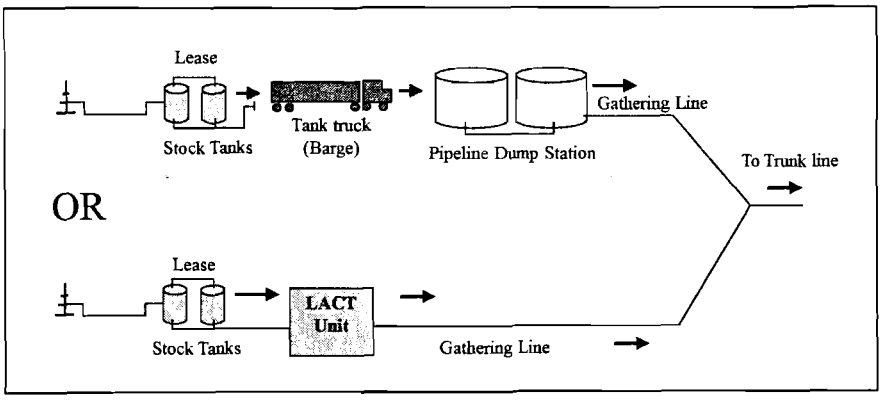
Potential Well Stream Components



Producing Well Surface Flow Schematic



Crude Oil Gathering: Place in Physical Distribution Network



Information Needed

- Volume of oil delivered
- BS&W content
- Sulfur/Gravity
- Temperature

Information Provided By

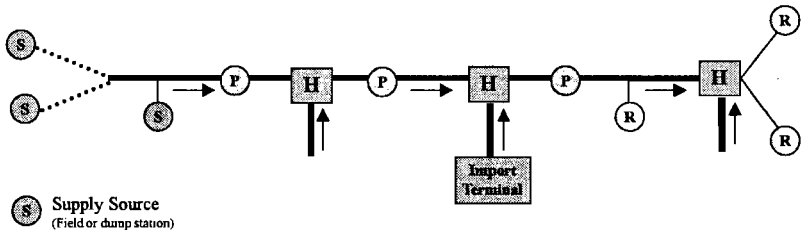
- Gauger (producer)
- Truck driver (buyer/transporter)
- LACT = Lease Automatic Custody Transfer

Oil Quality

SALES	PIPELINE TRANSPORTATION
• Sulfur/Gravity—affects price • BS&W—(1%) merchantable product • Temperature—affects volume	• Fungible system • Merchantable product • Temperature—affects volume • Gravity & sulfur banks

Crude Oil Transportation

Crude Oil Trunk Pipelines
Place in Physical Distribution Network

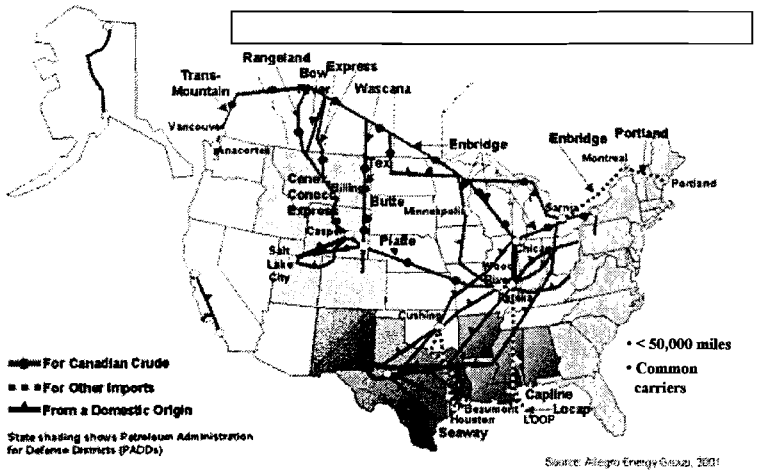


- S Supply Source (Field or dump station)
- P Pump Station
- Gathering Pipeline
- Interstate Trunk Pipeline A
- Intrastate Trunk Pipeline
- H Supply hub (tank farm)
- R Refinery
- Interstate Trunk Pipeline B
- Interstate Trunk Pipeline C

FUNCTIONS / ACTIVITIES

- **Provide high pressure / large volume, long distance transport of crude oil**
- **Uses energy from pump stations**
- **Safety & environmental regulation - DOT, OSHA, EPA, MMS, states**
- **Intrastate rate regulation – state**
- **Interstate rate regulation - FERC**

Major Crude Oil Trunk Lines in U.S.



Interstate Crude Oil Trunk Pipelines

	NUMBER OF COMPANIES	MILES OF PIPELINE	TRANSPORTED VOLUMES (B BBLS/YR)
TOTAL	79	46,658	7.039
Majors (>100 MM BBLS/YR)	19	28,652	5.197
LARGEST 10 (VOL)	10	22,222	4.018

Source: 09/01/08 O&GJ, FERC Form 6

Crude Oil Trunk Pipelines

COMMON CARRIERS

- **Have custody but not ownership of oil in pipeline's possession**
- **Require shippers to provide share of line fill & tank bottoms**
- **Accept shipments from all qualifying parties**
- **Allocate capacity based on shippers' nominations**

NOMINATION PROCEDURES

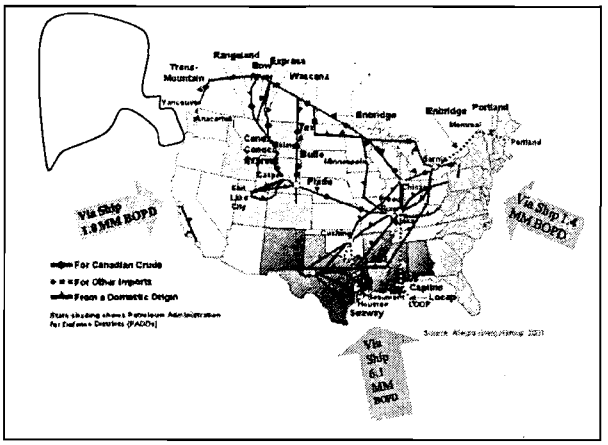
- **One class of service for all timely nominations**
- **Deliveries to trunk lines not contemporaneous with production (lease, dump station, tank farm and import terminal storage)**

Majority of U.S. oil supply is imported; most natural gas supply is domestic

Gas pipeline throughput significantly more seasonal than crude oil pipeline throughput.

Crude Oil Imports

U.S. Imports of Crude Oil



Waterborne Imports of Crude Oil

VESSEL TYPES	#	ENTER U.S. PORTS (SIZE)	PADD*
10,000-60,000 dwt (Handy)	*	Yes	I,III, V
60,000-80,000 dwt (Panamax)	*	Yes	I, III, V
80,000-120,000 dwt (Aframax)	*	Several ports	I, III, V
120,000-200,000 dwt (Suezmax)	*	Fewer ports	I, III, V
200,000-315,000 dwt (VLCC)	471	LOOP or lighter	III
320,000-550,000 dwt (ULCC)	10	LOOP or lighter	III
TOTAL	3556		
(1 dwt ≈ 7.4 BBLS)			

*PADD = Petroleum Administration for Defense District

VLCC + ULCC = 16% of vessels, but 36% of dwt	25% of waterborne imports lightered	Most lightering done in Gulf of Mexico (75%)

Crude Oil Storage

Crude Oil Storage Facilities

GENERALIZATION

Oil stored for operational reasons, natural gas stored for seasonal demand

OIL STORAGE FACILITIES MORE NUMEROUS & EXHIBIT GREATER SIZE VARIATIONS

Location	Inventory EOM 11/08	Tank size (BBLS)	Approximate #
Lease storage	17 MM BBLS	100-500	100,000 (500,000 wells)
Tank farms & pipelines	204 MM BBLS	10,000-500,000	141 Terminals
Refinery stocks	96 MM BBLS	50,000-500,000	150 Refineries
Strategic petroleum Reserve (SPR)	702 MM BBLS	(Cavern size) 6 to 35 MM BBLS	1 (62 caverns)

Crude Oil Storage

STRATEGIC PETROLEUM RESERVE (SPR)

- **Current capacity: 727 million BBLS**
- **Four sites along U.S. Gulf Coast (2 TX, 2 LA)**
- **62 caverns (6 to 35 MM BBLS capacity)**
- **Withdrawal rate: initial 4.4 MM BOPD for 90 days, declining to 1.0 MM BOPD**
- **Oil displaced with fresh water**
- **To be expanded to 1 billion BBLS**

Crude Oil Marketing

Trading Crude Oil

PHYSICAL TRADING
(Physical Commodity)

- Generate profit (buy/sell)
- Reduce costs (exchange)
- Manage supply slate (quality/timing)

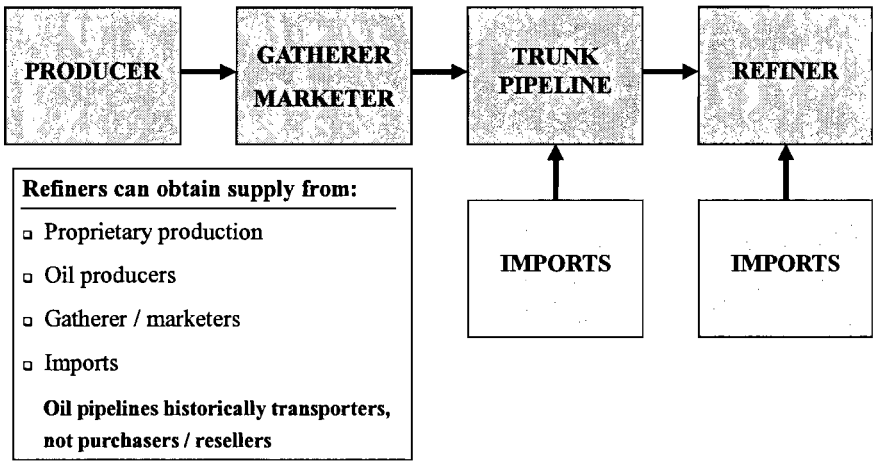
FINANCIAL TRADING
(Financial Instruments)

- Hedging (physical price)
- Margin protection (physical price risk)
- Speculation

- Opportunistic—fast action / reaction
- Market knowledge / intelligence critical

Oil Marketing Path

(Historical and Current)



Crude Oil Trading: Activities / Objectives

- **Buy / sell—generate spread**
- **Exchange—reduce transport costs**
- **Refiner crude slate quality considerations**
- **Management of sale or purchase obligations**
- **Management of transport assets**
- **Time trades**

Crude Oil Price Hedging

Crude Oil Price Hedging

Crude Oil Futures Contract

NYMEX Futures Contract Terms

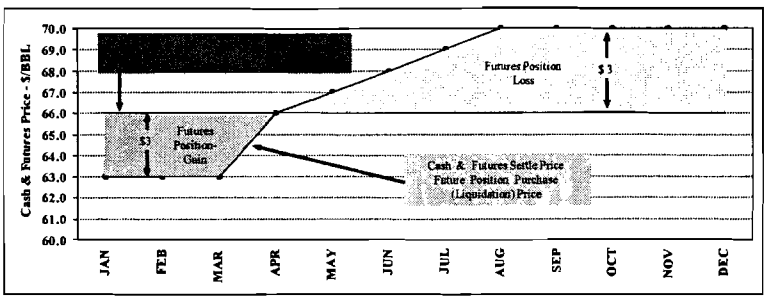
- **Quantity: 1,000 BBLS**
- **Price Quotation: $ Per Barrel**
- **Delivery Point: Cushing, OK**
- **Number of Months Listed: 72 consecutive**
- **Expiration Date: 3 days prior to 25th calendar day of the month preceding the delivery month**

Definitions

- **Spot (Prompt) Month: futures contract closest to maturity**
- **Basis: difference between cash / futures prices (location, time, etc.)**
- **12-Month Strip: average value of the next 12 months' futures price**
- **Divergence: cash / futures prices do not move in same direction / amount**

Crude Oil Producer Hedge Illustration

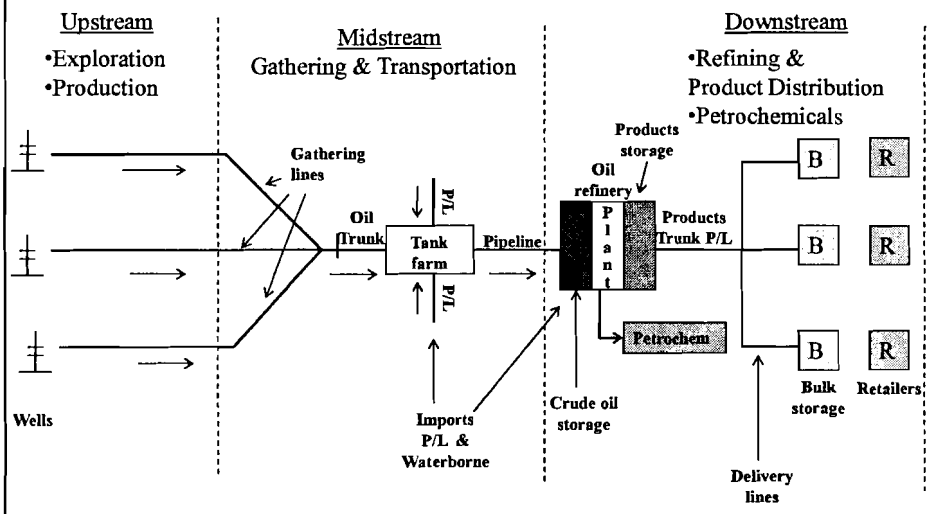
Producer sells futures to establish hedge position, then purchases offsetting quantities of futures each month to liquidate futures



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
Cash Price / Futures Settle Price	63	63	63	66	67	68	69	70	70	70	70	70	Avg = 67.42
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	Avg = 66.00
Futures Position Purchase (Liquidation Price)	63	63	63	66	67	68	69	70	70	70	70	70	Avg = 67.42
Loss / Gain on Futures Position	3	3	3	0	-1	-1	-3	-4	-4	-4	-4	-4	Avg = -1.42
Net Oil Sale Price (Cash Price + Futures Gain/Loss)	66	66	66	66	66	66	66	66	66	66	66	66	Avg = 66.00

Crude Oil Downstream

Oil Industry Segments



Crude Oil Refining

Crude Oil Refining

Why refine oil?

CONSUMER

- **Cannot use crude oil**
- **Needs motor gasoline, petrochemicals (plastics), cosmetics, paint, etc.**

OIL PRODUCER

Could not sell crude oil to consumer. Must have refiner.

REFINER

In business to make a margin. Sell refined products for more than cost of crude oil plus refining costs.

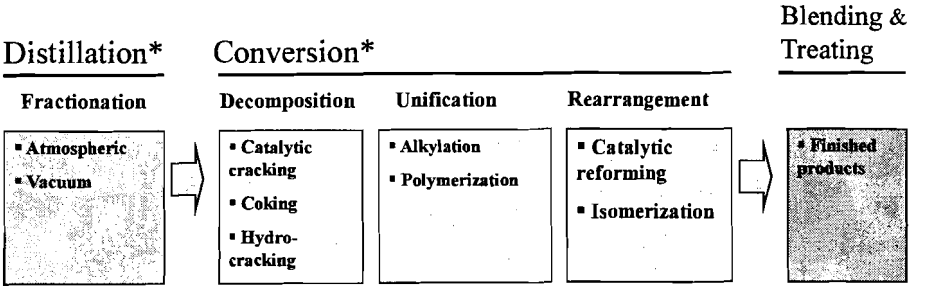
Oil Refining Capacities (US—2008)

Number of Refineries (operable)	150
Atmospheric Distillation Capacity	17.6 MM BBLS / Day
Vacuum Distillation Capacity	8.4 MM BBLS / Day
Thermal Cracking Capacity	2.6 MM BBLS / Day
Catalytic Cracking Capacity	6.2 MM BBLS / Day
Catalytic Reforming Capacity	3.9 MM BBLS / Day
Total U.S. Refinery Production (2007)	14.7 MM BBLS / Day
Total U.S. Refinery & Blending Production	18.0 MM BBLS / Day
Total U.S. Product Supplied (Demand)	20.7 MM BBLS / Day

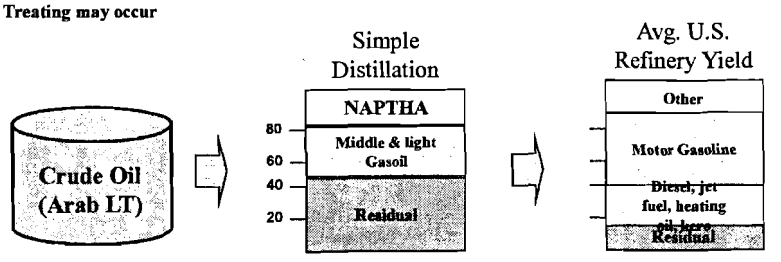
Source: EIA

Oil Refining Processes & Units

(Employing heat, pressure & catalysts)

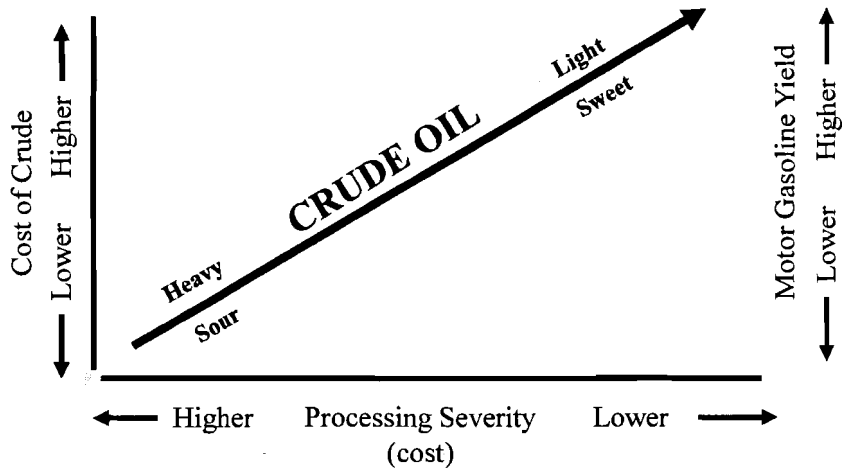


* Treating may occur



Source: EIA

Crude Slate / Yield Relationships



Typical U.S. Refinery Products Yield from Crude Oil

PRODUCT	%
LRG	4.1
Motor Gasoline	45.5
Jet Fuel	9.2
Distillate Fuel Oil	26.1
Residual Fuel Oil	4.2
Petr. Coke & Asphalt	8.1
Other	2.8
	100

Source: EIA

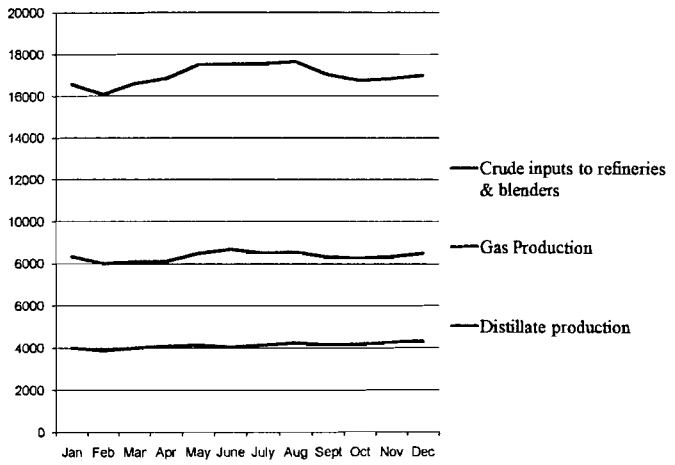
Refinery Margin

Gross Refining Margin (Per BBL)	=	Refined products revenue minus feedstock costs (for same periods) / Crude BBLS processed during period		
GRM / BBL (Last 10 years)	=	Range*	Refinery Type	Refinery Complexity
		-$1 to +$2 for	Hydroskimmers	(Least complex / severe)
		+$1 to $10 for	Cracking	(More complex / severe)
		+$3 to $18 for	Coking	(Most complex / severe)
Crack Spread	=	Value of products futures (Products produced by refinery from a BBL of crude	–	Value of Crude Oil Futures (Typical BBL of feedstock)
Recent crack Spread per Oil and Gas Journal: $ _____				
2007 GRM		$12.33 (Valero—composite of plants / regions)		

* Booz Allen 2005, Valero 10-k

Refinery Operations

Seasonal Product Mix Changes



Refining Operating /Capital Costs

OPERATING (excluding depr.)

Historical Range*: $.50-$4.50 / BBL
(> with complexity)

2007: $3.93 / BBL (Valero)

CATEGORIES
Energy (more than 50%)
Labor
Chemicals & catalysts
Environmental Compliance

CAPITAL

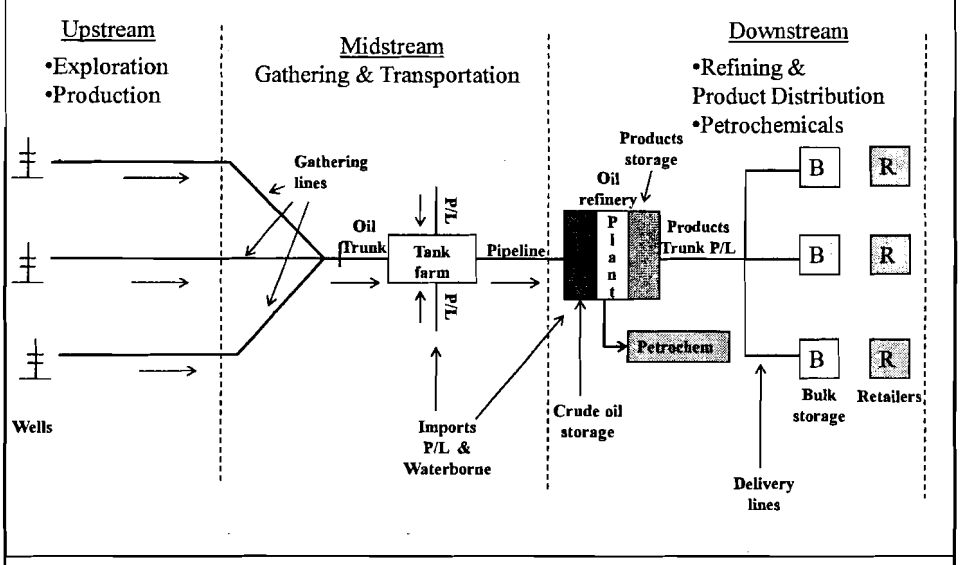
New Plant: $15-$20k per BBL/D*
Large: >100,000 BBL / Day
Lead Time: 5 Years
Permits: Environmental
Crude Supply: Secure / known price
Competition: Lower cost foreign

* Baker and Obrien 2005, O&GJ Nelson Farrar Index

Refined Products

Distribution & Marketing

Oil Industry Segments

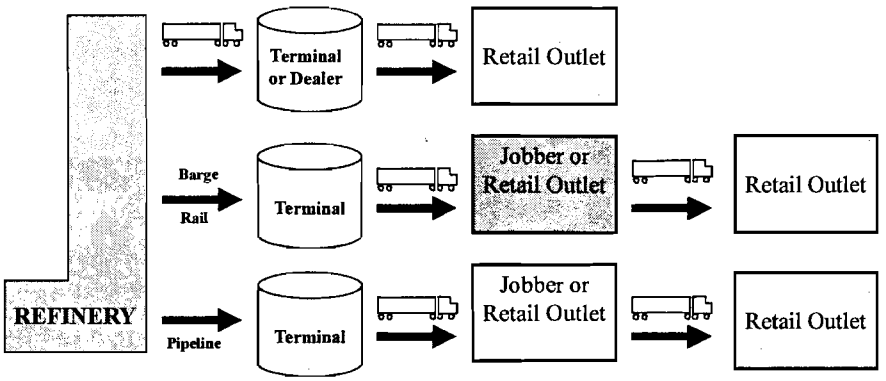


Refined Products Supply / Demand (2007-MM BBLS/D)

Refined Product	US Refineries and Blenders	Net Imports	Adjustments	Total Supplied
Finished Motor Gasoline	8.4	.4	.3	9.1
Distillate Fuel Oil	4.1	.3	--	4.4
Total Mogas & Distillate	12.5	.7	.3	13.5
Refinery Feedstock	**U.S. Production**	**Net Imports**	**Adjustments**	**Refinery Inputs**
Crude Oil	5.1	10.0	.1	15.2
Other liquids (50% Gasoline components)	.5	1.3	--	1.8
Total	5.6	11.3	.1	17.0

Source: EIA

Refined Products Distribution Network



About 60% of refined products move via pipeline

About 30% of refined products move via water

Final leg is by truck

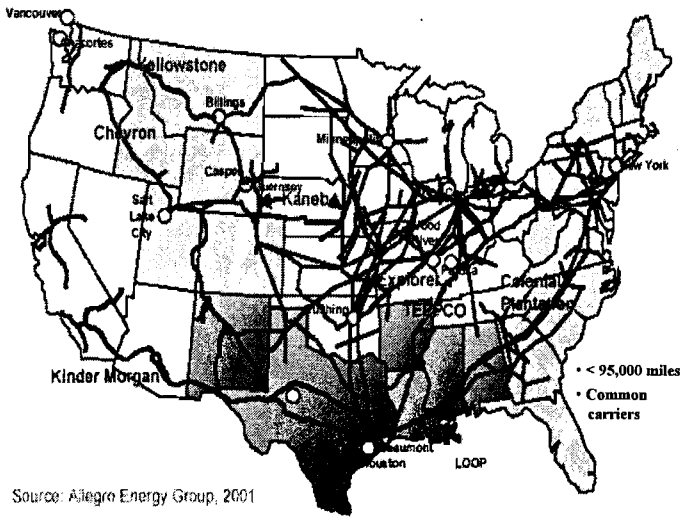
D.O.T.--BTS

Product Storage
(MM BBLS – 12/31/07)

	FINISHED MOTOR GASOLINE	AV GAS JET FUEL KEROSENE	DISTILLATE	RESIDUAL	COKE & ASPHALT	TOTAL
Refinery*	122.9	13.1	33.0	11.8	20.7	101.5
Pipeline*	40.0	15.3	34.7	2	—	90.2
Bulk Terminal*	48.5	15.0	66.0	27.5	11.0	168.0
Secondary (Dealers)	?	?	?	?	?	?
Total (15-30 Days supply)	111.4 (@9.3 = 12 days)	43.4 (@1.7 = 26days)	133.7 (@4.2 = 32days)	39.5 (@.7 = 56days)	31.7 (@1.0 = 32days)	359.7

* EIA Stocks Report

Refined Products
Pipelines



Source: Allegro Energy Group, 2001

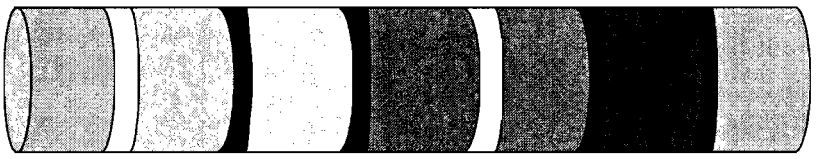
Interstate Refined Products
Pipelines

	NUMBER OF COMPANIES	MILES OF PIPELINE	TRANSPORTED VOLUMES (B BBLS/YR)
TOTAL	81	85,666	6.9
MAJORS (>100 MM BBLS/YR)	21	52,199	5.3
LARGEST 10 (VOL)	10	35,227	3.7

Source: 09/01/08 O&GJ, FERC Form 6

Refined Products Pipeline Batching

- **Fungible (most common on large trunk lines)**
- **Segregated**



Products

- **Reformulated regular gasoline**
- **Low sulfur diesel**
- **Kerosene / Jet fuel**
- **High sulfur diesel**
- **Conventional regular gasoline**
- **All premium gasoline grades**

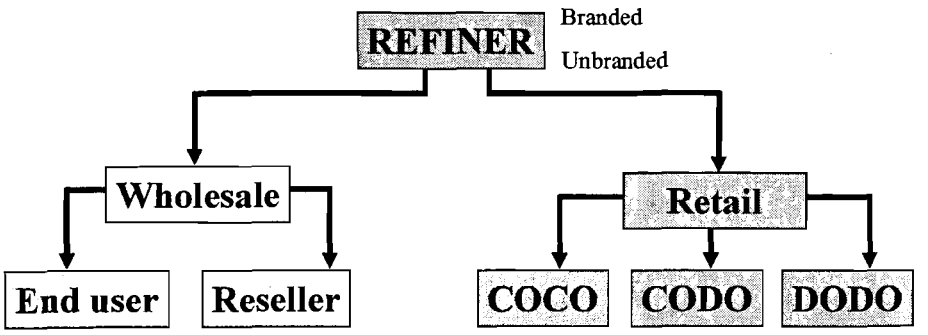
Interfaces

- **Compatible**
- **Transmix (reprocess)**

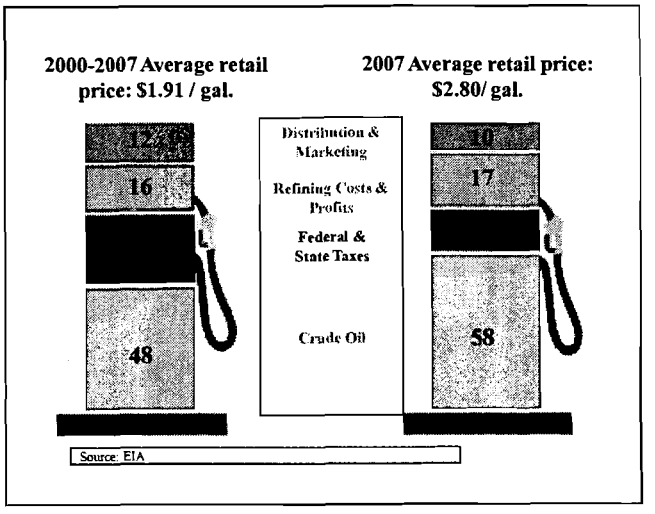
Refined Products Trading

TYPE OF TRADE	GOAL	OPPORTUNITY
Location	Save P/L or transport cost	Improve margin
Quality	Reduce costs or capture fee	Improve margin
Timing	Avoid carrying costs/ price increase	Lock in margin
Speculation	Buy low / sell high	Generate margin

Refined Products Marketing Channels



Gasoline Pump Price



Motor Gasoline Specifications

Gasoline Grades (Octane)		Fed / State Local Emissions Stds		Seasonal / Location (RVP) Variations		Potential Different Product Specs
Premium (90-93) Midgrade (88-90) Regular (85-88)	x	Oxygenated RFG (sulfur out) CBG (oxy/RFG)	x	Summer (9.0) Winter (11.5) Other (13.5) Restricted (7/7.8)	=	
3		3		5		45

Products Pipeline	Geographic Area	Gasoline Product Codes (Specs)	Diesel Product Codes (Specs)
Colonial	Southeast	13 (38 Voc/RVP)	16
TEPPCO	South/Midwest/East	4 (12 RVP)	4
Explorer	South/Midwest	18	4 (8)
Kinder Morgan	West (TX to CA)	12 (48 RVP)	4

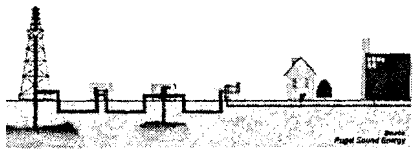
Source: EIA

Refined Products—Issues

- Motor gasoline—octane, RVP, additives
  - Number of grades (specifications) – supply/cost
  - Seasonal change in RVP, etc.
- Motor gasoline—ethanol (E(10), E(85))
- Diesel—low sulfur, biodiesel
  - Increasing distillate demand in U.S. & worldwide
  - Historically mutually beneficial U.S. & Europe diesel / motor gasoline demand & relationship
- Seasonality of demand

Thank
you

Natural Gas



From prospect to burner tip

J. Richard Moore

U.S. Natural Gas / Electric Industries

Industry Comparisons / Contrasts

- Both provide energy to industrial, commercial and residential customers.
- Facilities making deliveries to consumers in both industries are rate regulated utilities.
- Electric industry is larger: 3-4 X in $ value of deliveries to consumers.
- Gas industry not vertically integrated.
- Gas can be stored - electricity cannot.

Electric Industry Interest in Gas

- Gas is fuel for electric generation (20% cap).
- Some electric companies have purchased gas utilities – gas now part of product line.
- Gas is competitor in some cases.
- Deregulation experience of gas may be instructive for electric industry.

U.S. Natural Gas Industry - Segments

Gas Industry Function	Gas Industry Segment	Electric Industry Function
EXPLORATION → PRODUCTION	UPSTREAM	GENERATION
GATHERING / PROCESSING → TRANSMISSION	MIDSTREAM	TRANSMISSION
DISTRIBUTION → CONSUMERS	DOWNSTREAM	DISTRIBUTION → CONSUMERS

U. S. Natural Gas Industry - Scope

Production

Gross Withdrawals	24.6 TCF/YR
Dry Production	19.1 TCF/YR
Producing Gas Wells	452,768
Gas Well Average	149 MCF/D
Production:	10 to 30,000 MCF/D Well
Producers:	6,800 Companies, (20 Majors)

Pipelines & Storage

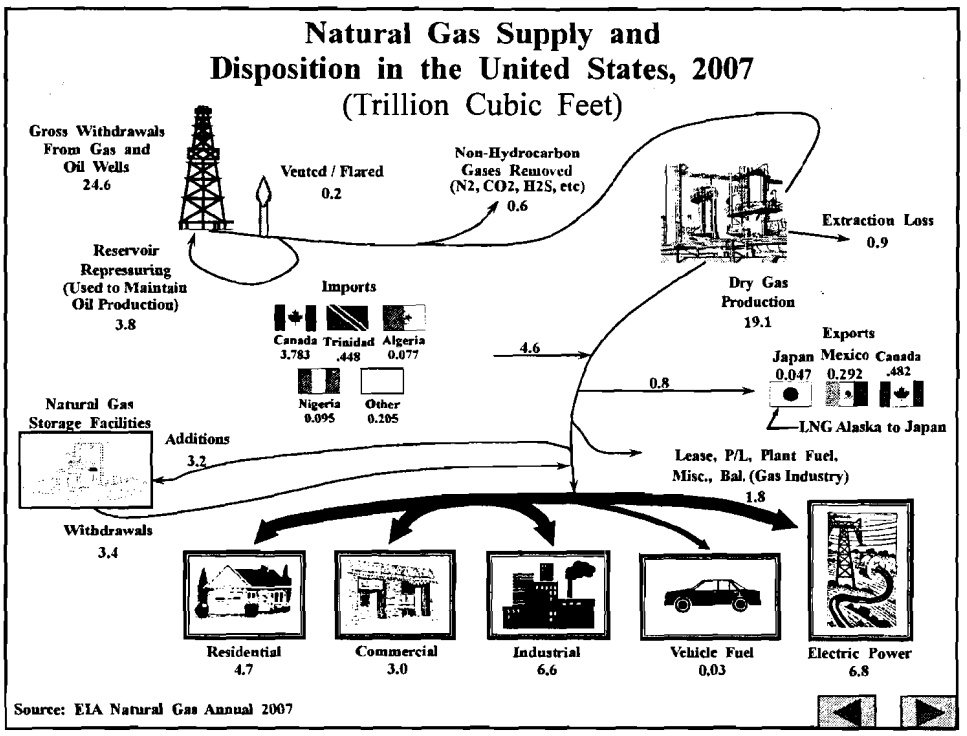
Natural Gas Pipelines*	1,520,200 Miles
Gathering Lines*	19,100 Miles
Transmission Lines	300,000 Miles
Distribution Lines	1,201,100 Miles
Storage Facilities (394)	4,600BCF Capacity * (Working Gas)

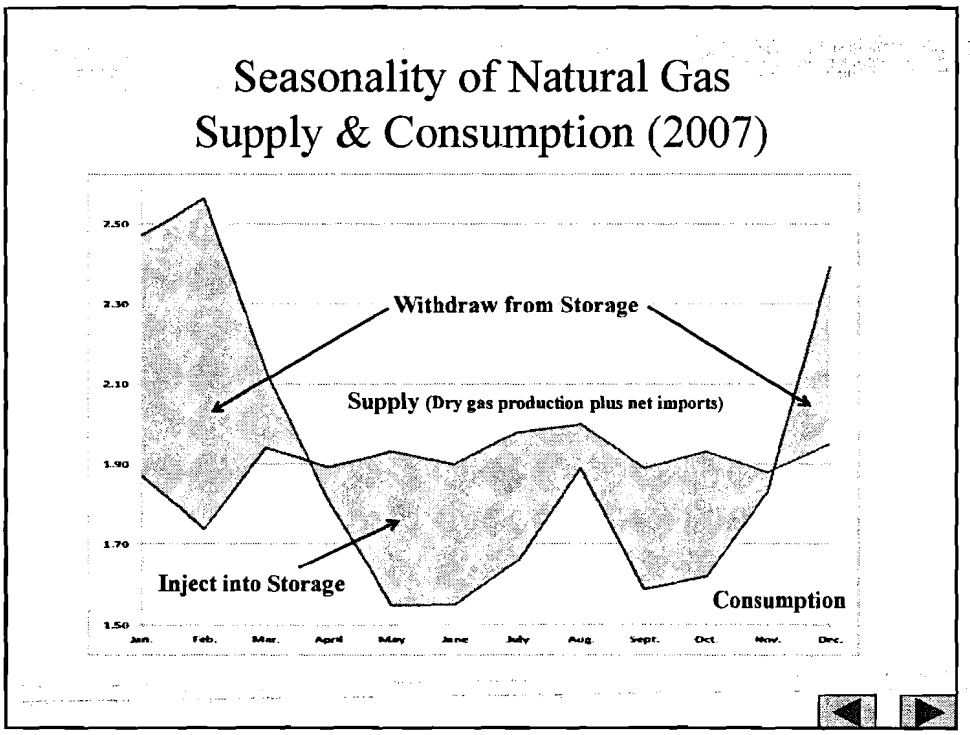
Consumption

	#	Volume
Consumers	70.4 MM	21.2 TCF/YR
Residential	64.9 MM	4.7 TCF/YR
Commercial	5.3 MM	3.0 TCF/YR
Industrial	.2 MM	13.4 TCF/YR
Lease, P/L		1.8 TCF/YR
Consumption:	.2 to 400,000 MCF/D Customer	

* Utility Pipelines (AGA)

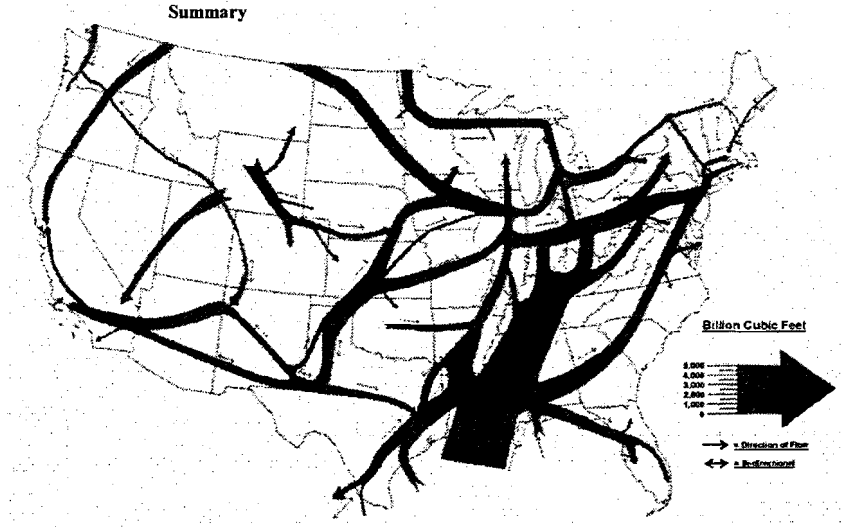
Source: EIA Natural Gas Annual 2007
AGA Gas Facts 2007


Natural Gas Supply and
Disposition in the United States, 2007
(Trillion Cubic Feet)
Gross Withdrawals From Gas and Oil Wells 24.6
Vented / Flared 0.2
Non-Hydrocarbon Gases Removed (N2, CO2, H2S, etc) 0.6
Extraction Loss 0.9
Reservoir Repressuring (Used to Maintain Oil Production) 3.8
Imports
Canada 3.783
Trinidad .448
Algeria 0.077
Nigeria 0.095
Other 0.205
Dry Gas Production 19.1
4.6
Exports
Japan 0.047
Mexico 0.292
Canada .482
0.8
LNG Alaska to Japan
Natural Gas Storage Facilities
Additions 3.2
Withdrawals 3.4
Lease, P/L, Plant Fuel, Misc., Bal. (Gas Industry) 1.8
Residential 4.7
Commercial 3.0
Industrial 6.6
Vehicle Fuel 0.03
Electric Power 6.8
Source: EIA Natural Gas Annual 2007


Seasonality of Natural Gas
Supply & Consumption (2007)
2.50
2.30
2.10
1.90
1.70
1.50
Withdraw from Storage
Supply (Dry gas production plus net imports)
Inject into Storage
Consumption
Jan.
Feb.
Mar.
April
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.

⑩Map Pattern of Gas Movements

⑩Principal Interstate Natural Gas Flow Summary

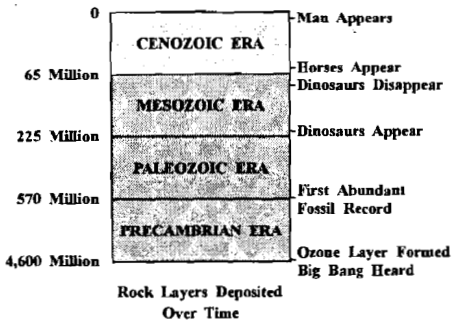


⑩Source: EIA

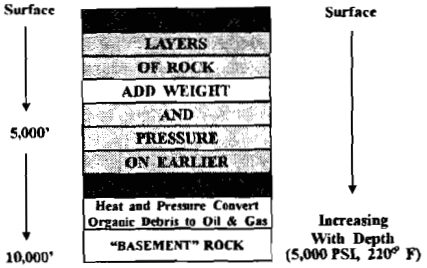
Natural Gas Formation and Exploration

Geology and Natural Gas Formation

GEOLOGIC TIME



OIL AND GAS FORMATION

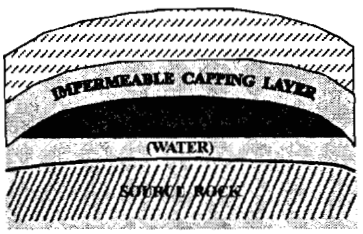


Natural Gas Reservoir Requirements

Reservoir Rocks (Sedimentary)

Name	Example	Requirements
Source	Limestone	Porosity and Permeability
Reservoir	Sandstone	
Cap/Trap	Shale	Impermeability

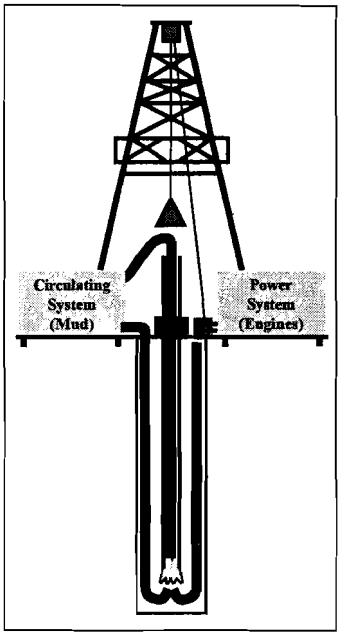
Reservoir Requirements



Drilling a Well

Preliminary

1. Identify Prospect
   A. Seismic
   B. Log Correlation
2. Obtain Mineral Lease
3. Obtain Drilling Permit
4. Prepare Site



Major Rig Systems

3. Circulating - Pumps and Mud
4. Power - Engines (Diesel / Electric)

Contract & Design Issues

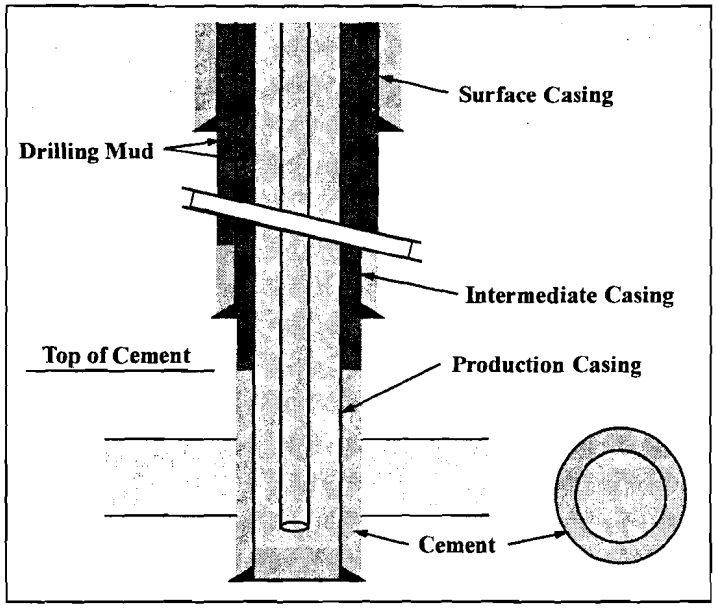
1. Drilling Contract
   A. Rate: Day, Footage, Turnkey
   B. Equipment & Start Date
2. Design Casing Program
3. Evaluate Surface Equipment Requirements

Activities While Drilling

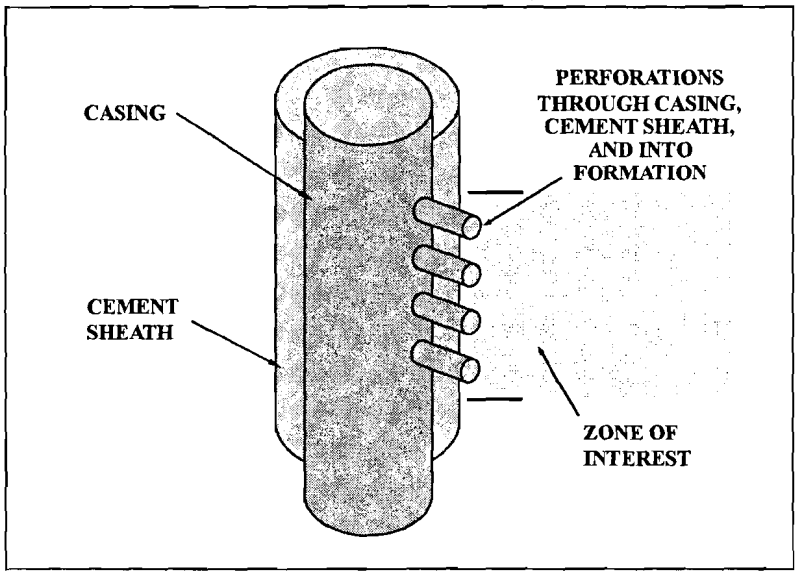
1. Well Control - Blow Outs / Lost Holes
2. MWD - Directional Wells
3. Logging and Analysis
4. Decision to Complete
5. Tight Hole - Confidential

Completion and Production Operations

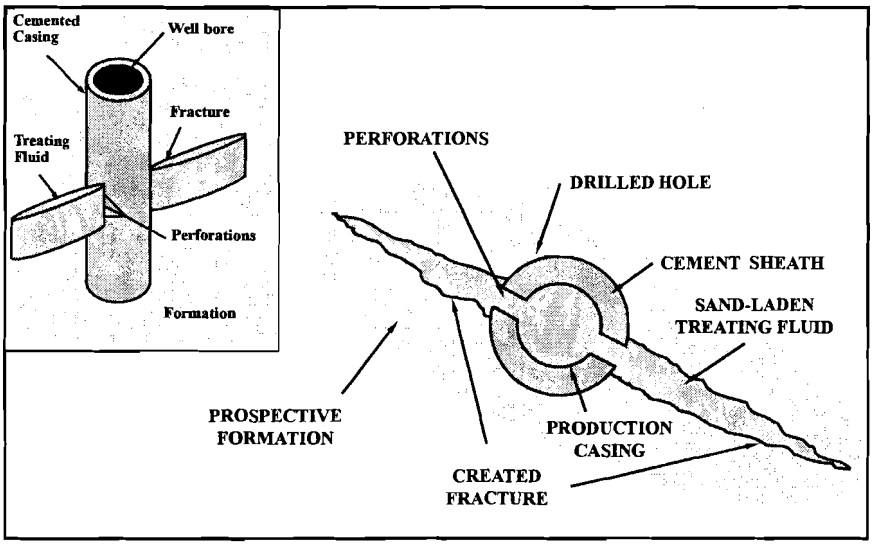
Cased Well After Emplacement of Completion Fluid



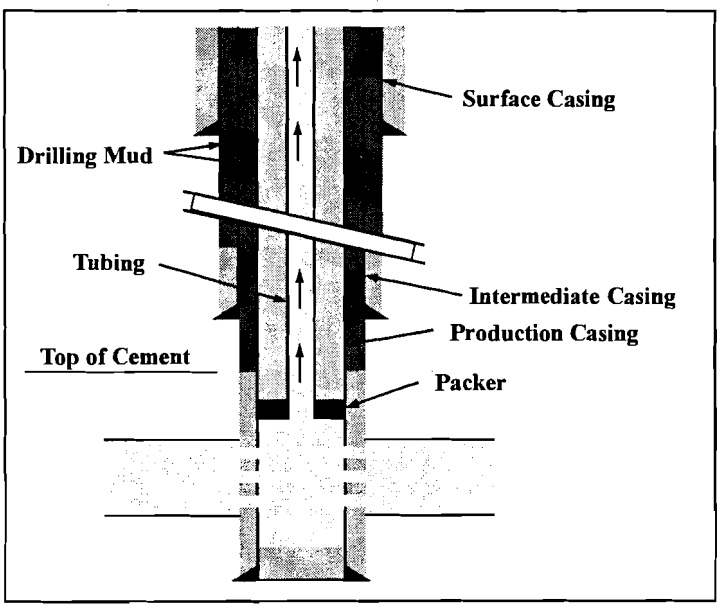
Schematic of Perforated Casing



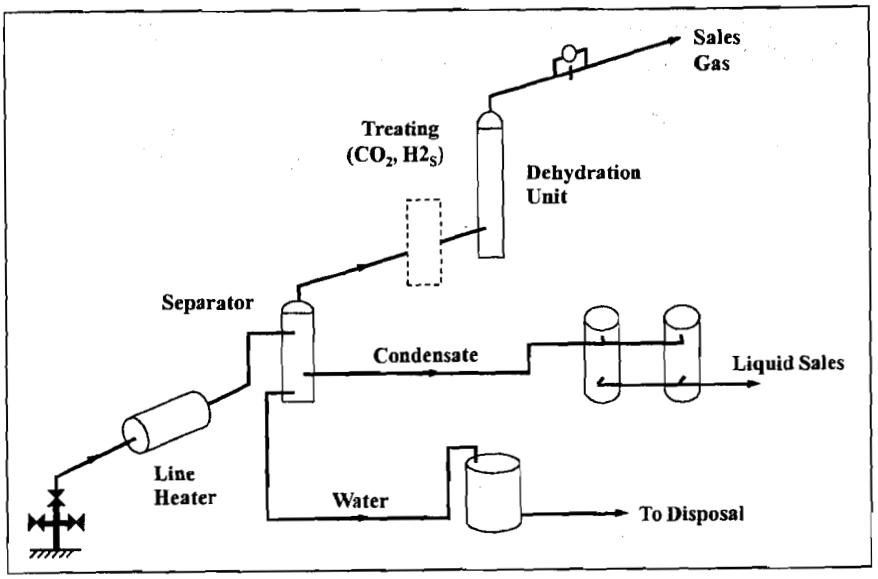
Hydraulic Fracture Schematic



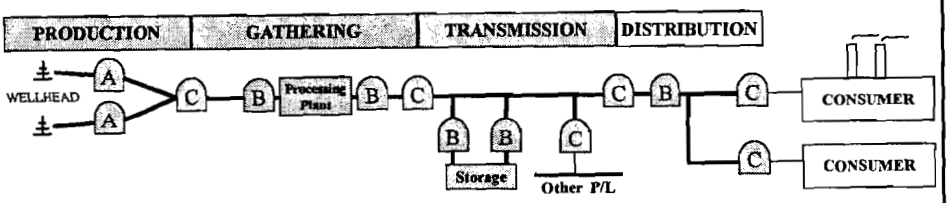
Cased Well Producing



Gas Well Surface Flow Schematic



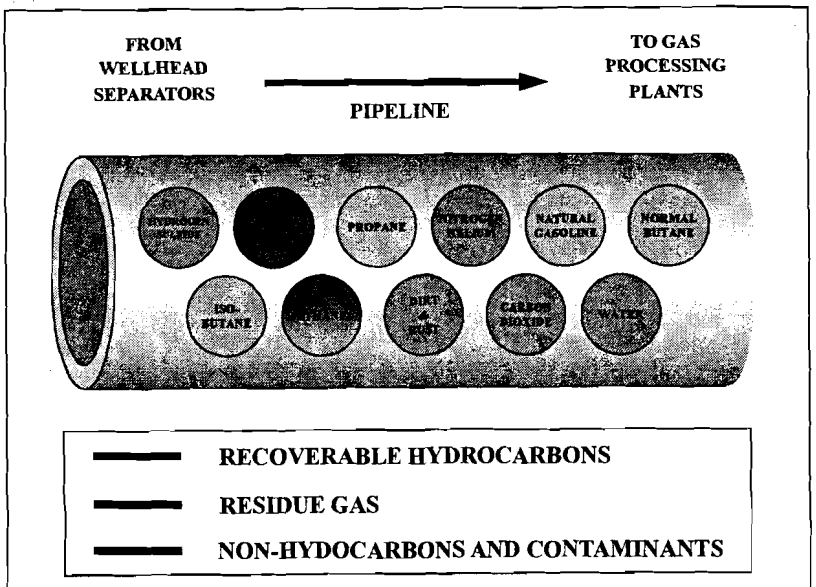
Measurement of Natural Gas



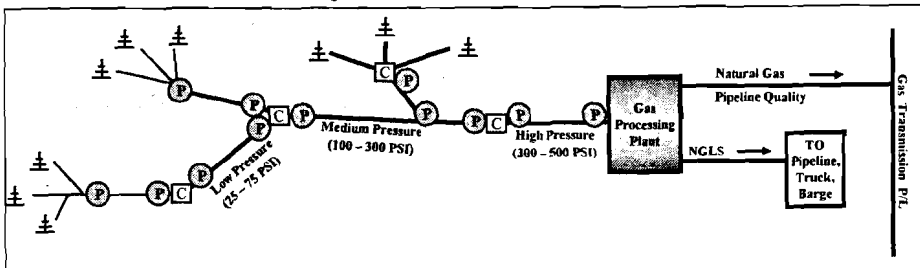
Measurement Process (Steps in Calculating MMBTU)	Measurement Purpose (Meter Function)	Meter Types (Equipment Types)	Meter Selection Issues
• Measure Gas Volume (MCF) • Analyze Gas – Determine Heating Value (BTU/FT^3) • Calculate Quantity of Energy Delivered Volume x Heating Value = MMBTU (MCF) x (BTU/FT^3) = MMBTU	A Allocation B Balancing (Operations) C Custody (Sales)	• Orifice Meter • Diaphragm Meter • Rotary Meter • Turbine Meter • Sonic Meter	• Volume to be Measured • Volume Fluctuations • Meter Cost / Operation • Meter Function

Natural Gas Gathering and Processing

Typical Natural Gas Stream



Natural Gas Gathering and Processing
Place in Physical Distribution Network



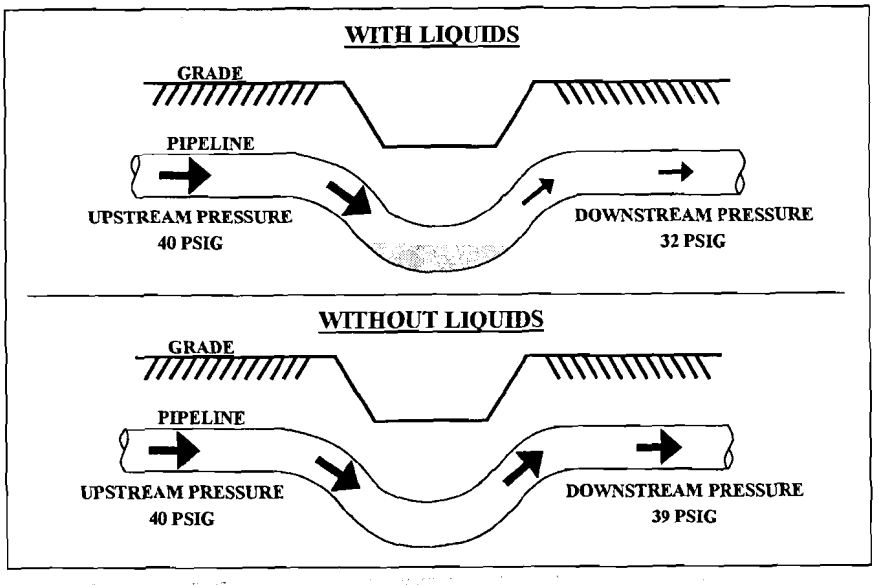
Site / Facilities

- Wellhead
- Compressor
- Pig Launcher/Retriever
- High Pressure Gathering Line
- Medium Pressure Gathering Line
- Low Pressure Gathering Line
- Gas Transmission Pipeline

Functions / Activities

- Gathering – Connects Wells to Transmission Pipeline System
- Compression – Raises Pressure of Gas From Wellheads Permitting Gas to Flow Into Transmission System. Lengthens Well Life.
- Treating – Removes Impurities
- Processing – Removes NGLS

Effect of Liquids Accumulation On Pipeline Efficiency



Pipeline Corrosion

Corrosion

Internal Corrosion

- Problem: Microbially Induced Corrosion (MIC)
  Solution: Inhibitors (Coat Pipe), Biocides (Kill Bugs)
- Problem: Chemical Corrosion (Acid Gas)
  Solution: Inhibitors (Coat Pipe), Remove H_2S & CO_2 and Remove Water.

External Corrosion

- Pipe Wraps / Coating
- Cathodic Protection

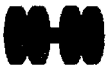
Issues

- Safety
- Maintenance Expense

Pigs

Utility Pigs (Foam, Solid Cast Plastic, Spheres)

- Cleaning: Remove Deposits
- Sealing: Remove Liquids



Squeegee Pig

Brush Pig

In Line Inspection Tools (Smart Pigs)

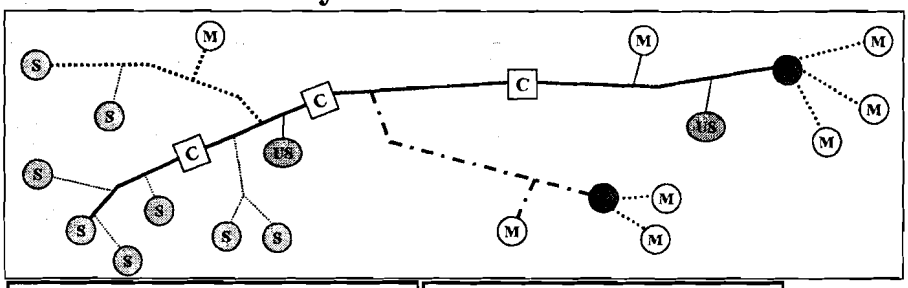
- Measurements: Wall Thickness, Diameter
- Detection: Leaks, Cracks, Corrosion
- Photographic Inspection

Gel Pigs

- Gelled Liquids
- Used in Trains Within P/L
- Clean Up, Corrosion Inhibition

Natural Gas Transmission

Natural Gas Transmission Pipelines
Place in Physical Distribution Network



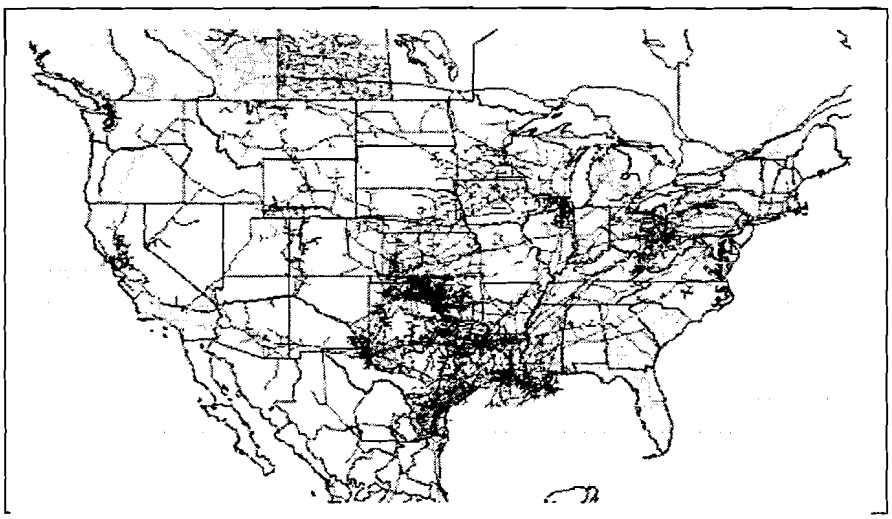
SITE / FACILITIES

- S — Supply Source
- M — Market
- Gathering Lines
- Intrastate Transmission Pipeline
- Interstate Transmission Pipeline "A"
- Interstate Transmission Pipeline "B"
- City Gate
- Local Distribution Company Pipelines
- C — Compressor
- US — Underground Storage

FUNCTIONS / ACTIVITIES

- Provide high pressure / long distance transportation of gas
- Pipeline uses pressure from reservoir or compressors (pumps) to move gas
- Pipeline uses storage facilities and line pack to meet supply / demand swings
- Safety & environmental regulation - DOT, OSHA, EPA, MMS
- Intrastate rate regulation - state agencies
- Interstate rate regulation - FERC

Natural Gas Transportation Pipeline Network



Source: EIA

Interstate Natural Gas Transmission Pipelines

	NUMBER OF COMPANIES	MILES OF PIPELINE	TRANSPORTED VOLUMES (TCF/YR)
TOTAL	121	198,318	37.1
Majors (> 50 BCF YR)	77	192,189	36.5
LARGEST 10 (VOL)	10	99,043	16.4

Source: 09/01/08 O&GJ, FERC Form 2

Natural Gas Transmission Pipeline Custody vs. Ownership

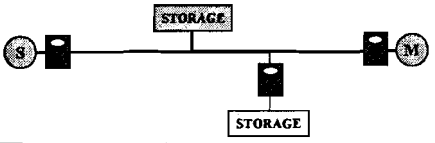
PIPELINE OWNS GAS

Custody and Ownership Transfer Point

Pipeline Owns All Gas in its Custody

- Pipeline controls receipts/deliveries to achieve operational stability and serve demands
- Storage and line pack are tools used to deliver gas commodity
- No balancing problems/issues

PIPELINE IS TRANSPORTER ONLY



Custody Transfer Point (ownership may transfer at multiple points)

Custody Transfers To/From Pipeline When Gas Enters/Leaves System

Pipeline Does Not Own All Gas in its Custody

- Pipeline monitors receipts/deliveries controls only if shipper not in compliance with contract
- Use of storage and line pack determined by shippers' actions and may be subject of charges in addition to transport fees
- Major balancing problems/issues

Services Offered by Natural Gas Transmission Pipelines

I. TRANSPORTATION ONLY PIPELINES (INTERSTATE)

A. Transportation:	Firm, interruptible, no-notice (swing)
B. Storage:	Firm, interruptible
C. Other:	Treating, blending, balancing parking

II. COMMODITY SALE & TRANSPORTATION PIPELINES (INTRASTATE)

A. Transportation, storage & other services
B. Gas supply (sale) & service

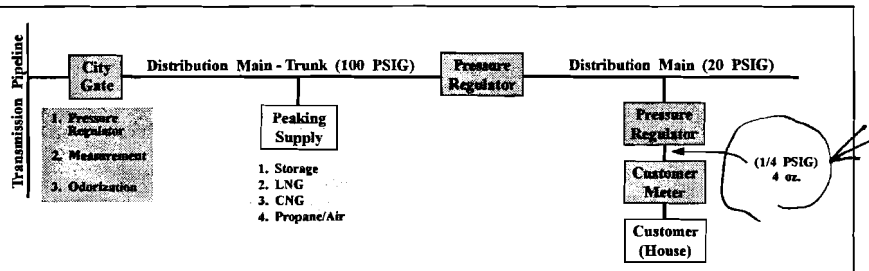
Natural Gas Transmission Pipeline Operations

- Tariff / Contractual Provisions Specify Rights and Obligations of Parties

Item / Issue	Shipper	Pipeline
Nominations	Submits Prior to 1st of Month	Aggregates – Allocates Capacity if Necessary
Gas Receipts / Deliveries	Should Monitor Throughout Month	Monitors (Daily) During Month – Issues Imbalance Notices
Imbalance / Overrun	Must Correct by Adjusting Receipts / Deliveries	Calculates and May assess Penalties on Shippers
Curtailment	Order to Reduce Receipts and / or Deliveries	Order Issued to Reserve Capacity For Critical Customers
Operational Flow Order	Order to Adjust Receipts and / or Deliveries	Order Issued to Correct Imbalance
Penalties, Overrun or Storage Charges, Etc.	Fees Paid For Unauthorized Use of Capacity	Means of Controlling Shippers Conduct

Natural Gas Distribution

Natural Gas Distribution
Place in Physical Distribution Network



max / minimum pressure

Local Distribution Utilities

Miles of Pipe	
Steel	559,400
Plastic	601,900
Other	39,800
Total	1,201,100

Type	Number	Regulation
Investor Owned	335	State
Municipal	860	Local

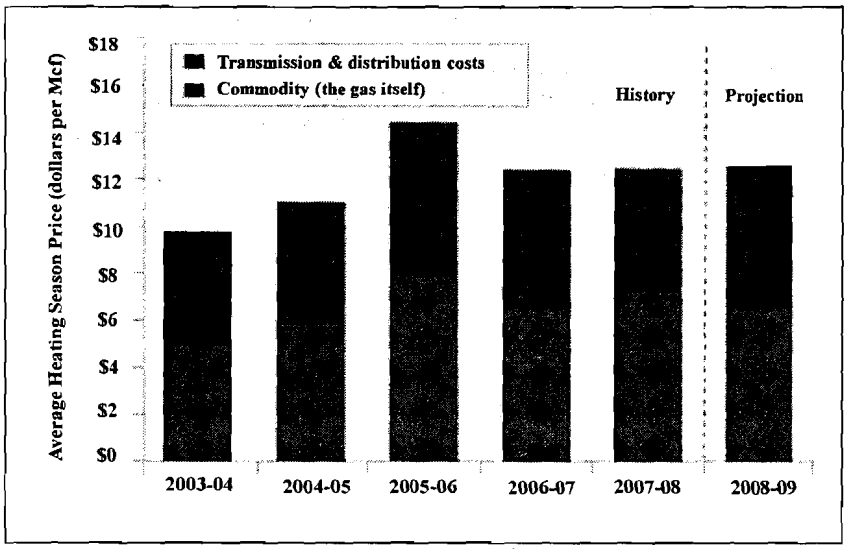
LDC Deliveries	
Residential	4.9 Trillion BTU
Commercial	3.1 Trillion BTU
Industrial	3.9 Trillion BTU
Elec. Gen.	1.8 Trillion BTU
Total	13.7 Trillion BTU

Source: AGA Gas Facts 2007

65 % residential users in U.S.

Natural Gas Distribution

Components of Delivered Residential Gas Price *



Source: EIA (Brochure) Residential Gas Prices 11-08

Natural Gas Distribution Issues

consumer driven

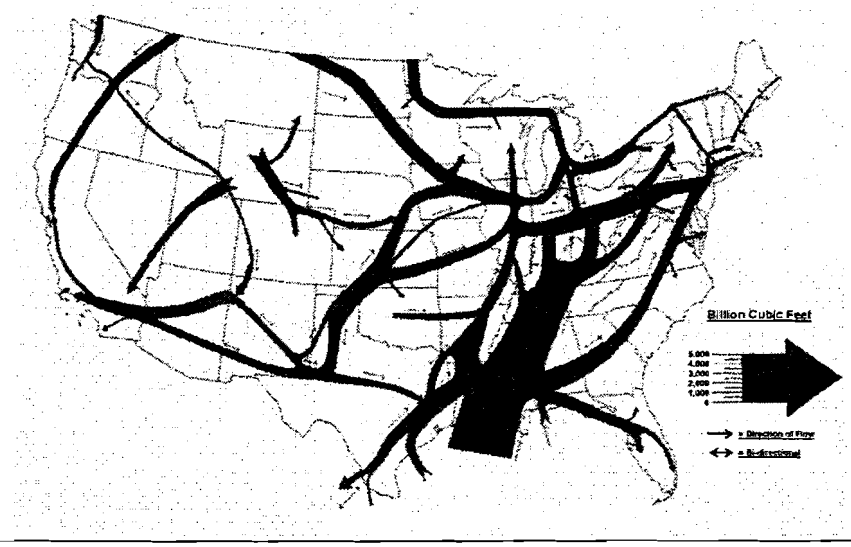
- ❑ Seasonality of Demand - meeting peaks economically
- ❑ Fragmented Regulation - state / local vs. national
- ❑ Retail Competition - commodity sale vs. gas delivery
- ❑ Information Needs - custody vs. ownership
- ❑ Balancing - receipts vs. Deliveries
- ❑ Rate strategy – incent conservation & efficiency

*

Natural Gas Supply

Map Pattern of Gas Movements

Principal Interstate Natural Gas Flow Summary



Source: Energy Information Administration, Office of Oil and Gas, Natural Gas Division

U.S. Natural Gas Supply - Potential Sources

Source / Area	Potential Gas Reserves (TCF)	Issues
Recoverable Resource (2006)		
Alaska	259	Access / Pipeline / Economics
Onshore Lower 48	955	Access / Pipeline / Economics (Unconventional Gas)
Offshore Lower 48	319	Access / Pipeline
Subtotal Unproved	1,533	
Proved Reserves	211	
Total U.S. Potential Reserves	1,744	
Canada (NEB-Conventional)	N/A	Pipeline / Economics
LNG	N/A	New Terminals / Economics
Hydrates (U.S.)	200,000 - 320,000	Technology / Economics

unreliable #'s!

Source: EIA

U.S. Dry Natural Gas Supply / Forecasted Sources

	2007		2015		2030	
Source	TCF	%	TCF	%	TCF	%
U. S. Dry Production						
Lower 48 - Onshore	15.9	69	16.5	73	16.7	68
Lower 48 - Offshore	3.0	13	3.5	15	4.9	20
Alaska	0.4	2	.3	1	2.0	9
Total U. S. Dry Production	19.3	84	20.3	89	23.6	97
Imports (Net)						
Pipeline	3.1	13	1.1	5	-0.1	0
LNG	0.7	3	1.3	6	0.8	3
Total Imports	3.8	16	2.4	11	.7	3
Total U. S. Dry Supply	23.2	100	22.7	100	24.4	100

- Unconventional gas (Tight Gas, Shale, CBM) growth offsets decline in conventional lower 48 onshore production
- Alaska gas pipeline begins operation in 2020 (5 yrs later than 06AEO)
- LNG imports surpass pipeline imports in 2015 (4 yrs later than 06AEO) but decline by 2030.

Source: EIA Annual Energy Outlook (AEO) 2009

Unconventional Gas Sources

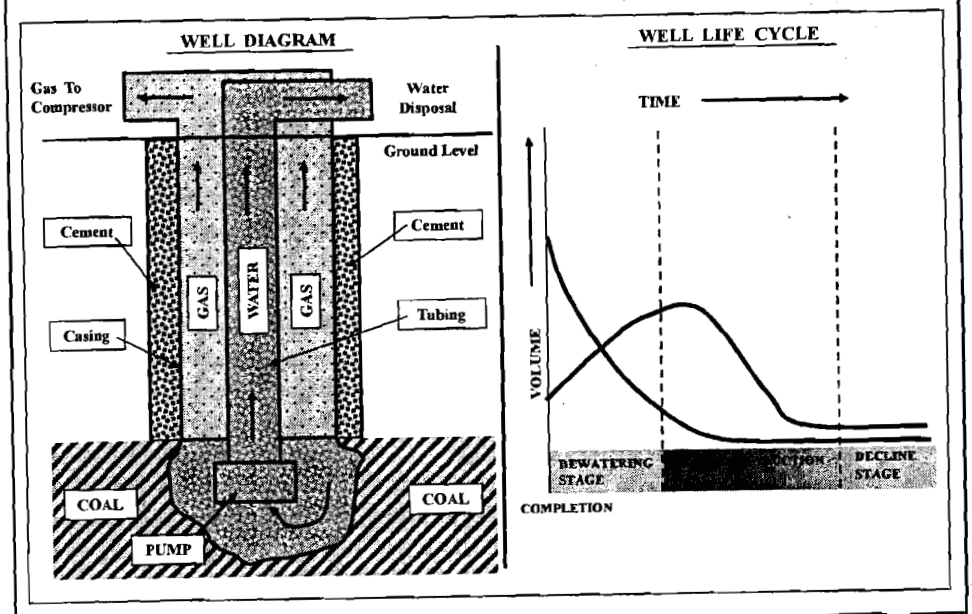
Category	Extraction Difficulty	Solution	Recoverable TCF
Deep Gas (15,000'+)	Drilling Cost	Technology / Higher Gas Prices	90
"Tight" Gas	Low Production Rates (Low Permeability)	Fracture / Acid Stimulation Horizontal Wells	254 (6,000)
Shale (Devonian)	Low Production Rates	Fracture Stimulation	55
Coal Bed Methane	Low Production Rates/ Water Disposal	Improved Drilling & Production Technology CO_2 Injection	60 (700)
Geo-Pressurized Zone (10,000 – 25,000 Ft)	Depth and High Pressure	Improved Drilling & Production Technology	1,100 (5,000-49,000)
Methane Hydrates	Extracting Methane from Ice Crystal Lattice	Not Yet Known	Unknown (200,000)

Coal Bed Methane

- Coal is both source rock & reservoir rock
- Coal stores 6 to 7 times as much gas as equivalent rock volume of conventional gas reservoir
- Water disposal is problem
- US: 700 TCF of resource
  100 TCF recoverable

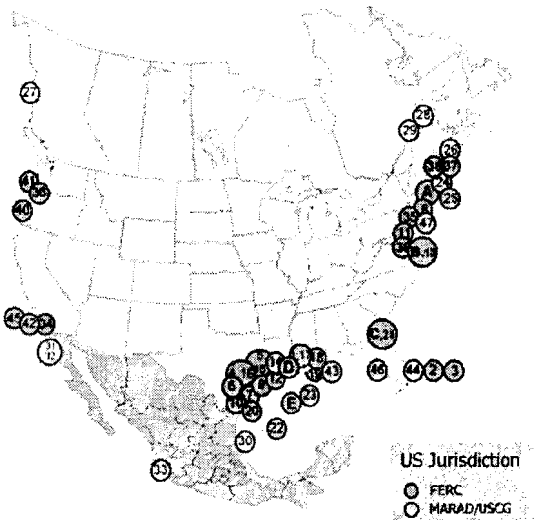
Coal Rank	Gas Content	Water Present	Seam Thickness
Lignite	Increasing		
Sub-Bituminous	↓	↑	↑
Bituminous			
Anthracite		Increasing	Increasing

Coal Bed Methane - Production



Liquefied Natural Gas (LNG)

Existing and Proposed North American LNG Terminals



U.S. LNG Import Terminal Expansion

Existing Terminals (Capacity-expansion)

- Everett, MA (1.0 bcf/d-no change)
- Cove Point, MD. (1.0 / 1.8 bcf/d-2008)
- Elba Is., GA (1.2/2.1 bcf/d-2009/12)
- L. Charles, LA (1.8/2.1 bcf/d-*2008)
- Gateway, GOM (.5 bcf/d-no change)

Existing terminals = 5.8 bcf/d

(Expansions to existing terminals = 1.7 bcf/d=30%)

New Terminals (Capacity-start up)

- Hackberry, LA (1.5 bcf/d-2009
- Sabine Pass, LA (2.6 bcf/d-*2008; 4.0 bcf/d-2009)
- Sabine Pass, TX (2.0 bcf/d-2009)
- Freeport, TX (1.5 bcf/d-*2008)

New terminals = 9.0 bcf/d -2009

In North America

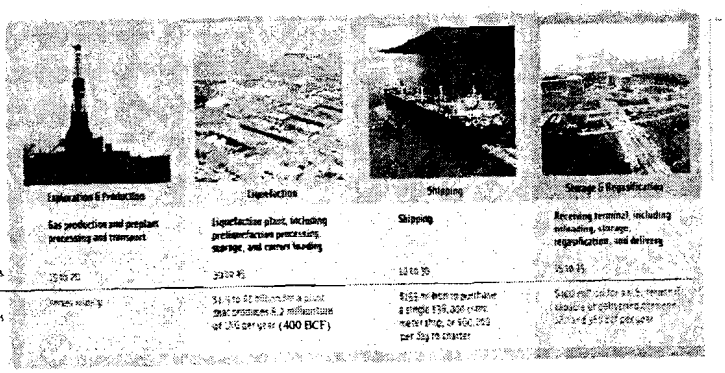
13 additional terminals approved

25 other projects on file with regulators

21 more projects in planning stages

Source: EIA, web 02/09

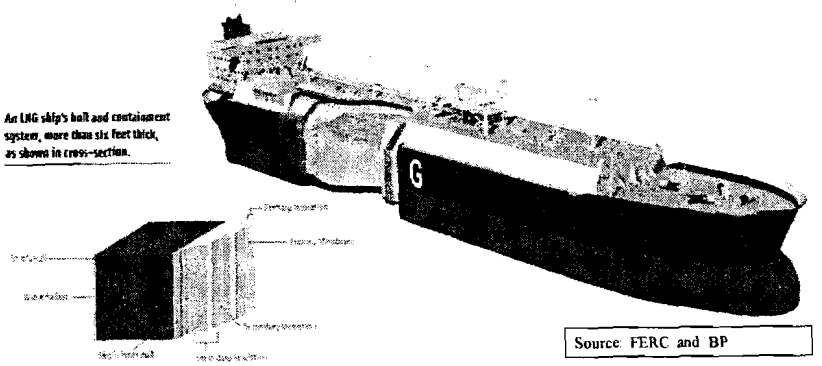
LNG Value Chain



- US 2007 Imports of LNG = 771 BCF = 10% of World Market (2002 = 4%)
- Worldwide Proved Gas Reserves = 6,254 TCF (60 Times 2007 Worldwide Consumption)

Source: FERC

LNG SHIPPING



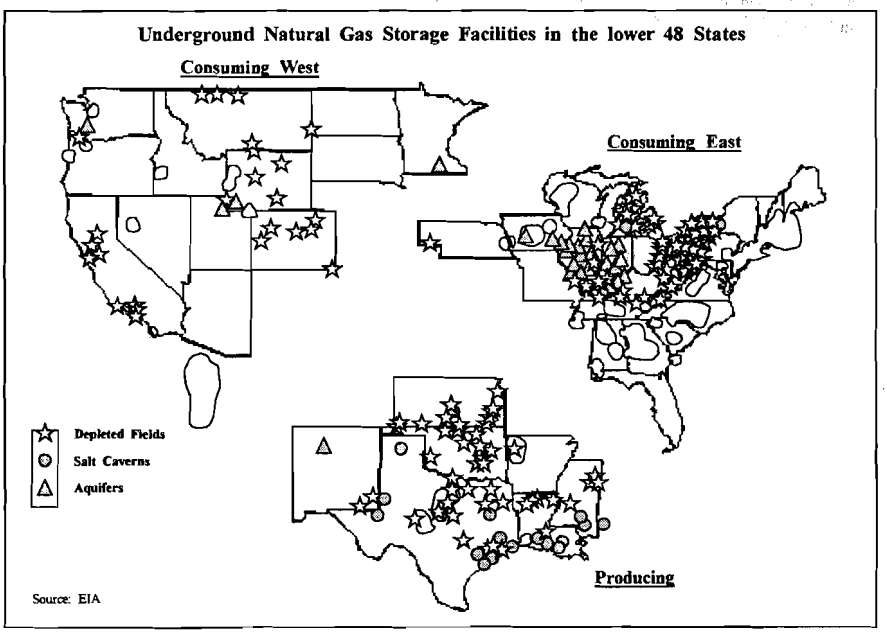
Source: FERC and BP

- 250 Vessels in LNG Trade 12/07, 120 Ships on Order
- LNG Transported at - 163 C (-260°F) and Atmospheric Pressure (1/600 Reduction)
- Ship Fuel may be Cargo "Boil Off" = 0.15% per day or dual fuel (Diesel; reliquefaction onboard)
- Standard Vessel is Increasing from 125,000m^3 /138,000m^3 (3 BCF) to 145,000m^3 /250,00m^3

Source: EIA and FERC, O&G J (June 08), LNG Observer (Apr 07)

Natural Gas Storage

Underground Natural Gas Storage Facilities



U. S. Underground Gas Storage Facilities

Statistics

Type	Sites		Working Gas Capacity		Daily Deliverability		Working Gas / Deliverability Ratio
	#	%	BCF	%	MMCF/D	%	
Depleted Gas / Oil	320	81	3,437	86	61,930	74	55
Aquifer	44	11	399	10	8,326	10	48
Salt Cavern	30	8	174	4	13,376	16	13
Total	394	100	4,010	100	83,632	100	48

Source: EIA Natural Gas Storage Developments Oct. 06

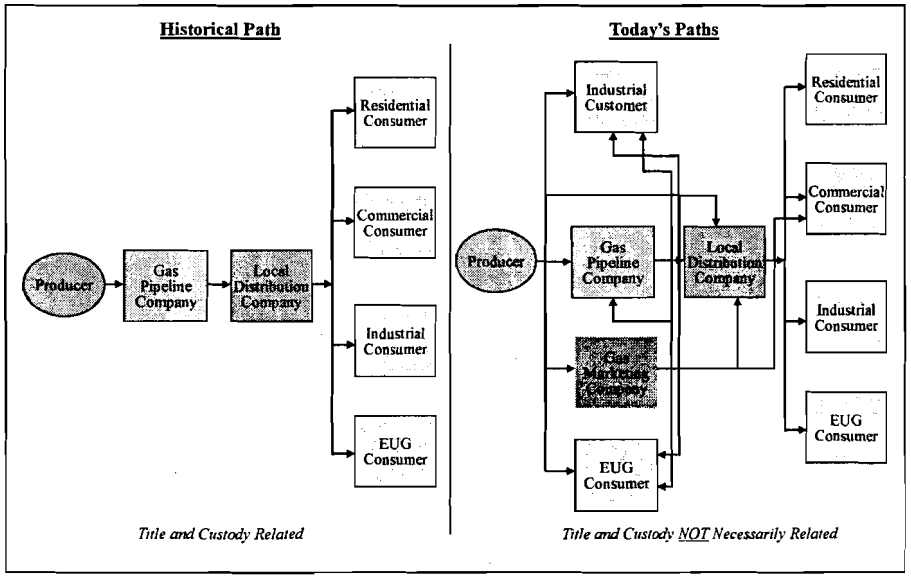
U. S. Underground Gas Storage Facilities

Characteristics (Generalization)

Type	Cost To Build	Base Gas Requirement	Working Gas Capacity	Daily Deliverability
Depleted Reservoir	Least	Higher (50%)	Larger	Less
Aquifer	More	Highest (50-80%)	Larger	Less
Salt Dome	Most	Lowest (20-30%)	Smaller	Greatest

Natural Gas Marketing

Natural Gas Marketing Paths



Natural Gas Marketing

Players in the Open Access Environment

	Producers	Marketer	Pipeline	Local Utility	Consumer
Types	Independent Major	Affiliated Independent	Interstate Intrastate	Investor Owned Municipal	Residential/Commercial Industrial
Examples	Devon Exxon	El Paso Coral	TENNESSE GAS P/L HOUSTON PIPELINE	ATMOS MEMPHIS	McDonalds Franchise EUG Plant
Contribution	Gas Well Gas Oil Well Gas	Supply Aggregation Logistics Management	Transportation Storage	Supply Aggregation Transportation	Market For Gas Market For Services
Price Regulated	No	No	Yes	Yes	No
Objectives	Produce Reserves Generate Cash	Margin on Gas Margin on Services	Fee For Service Return on Capital	Fee For Service Return on Capital	Secure Supply Minimum Cost

Oil & Gas Price Hedging

Risk Mitigation – Protection Comes at a Cost

PRODUCER

- **Naturally long in physical commodity**
  (Seller of physical commodity)
- **Revenue risk – commodity price fluctuation**
- **Hedge – fixed price physical sale contract**
- **Hedge – sell futures contract (financial – establish equal & opposite position)**

CONSUMER

- **Naturally short in physical commodity**
  (Buyer of physical commodity)
- **Expense risk – commodity price fluctuation**
- **Hedge – fixed price physical purchase contract**
- **Hedge – buy futures contract (financial – establish equal & opposite position)**

Financial hedge concept – cash prices (physical market) and futures prices move in tandem. Loss in one market should be offset by gain in the other.

Natural Gas Price Hedging
Natural Gas Futures Contract

NYMEX Futures Contract Terms

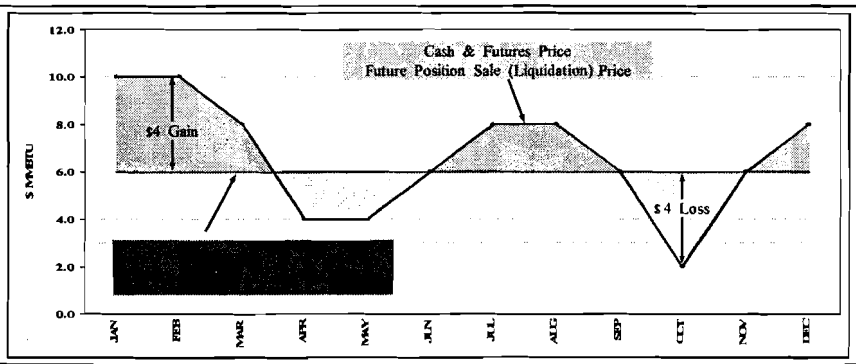
- **Quantity: 10,000 MMBTU**
- **Price Quotation: $ Per MMBTU**
- **Delivery Point: Henry Hub - Sabine, LA.**
- **Number of Months Listed: 72 consecutive**
- **Expiration Date: 3 days prior to first calendar date of delivery month (expired futures go to delivery)**

Definitions

- **Spot (Prompt) Month: futures contract closest to maturity**
- **Basis: difference between cash / futures prices (location, time, etc.)**
- **12-Month Strip: average value of the next 12 months futures price**
- **Divergence: cash / futures prices do not move in same direction / amount**

Natural Gas Consumer Hedge Illustration

Consumer purchases futures to establish hedge, then sells offsetting quantities of futures each month to liquidate futures position



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
Cash Price / Futures Settle Price	10	10	8	4	4	6	8	8	6	2	6	8	Avg = 80/12 = $6.66
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	
Futures Position Sale (Liquidation Price)	10	10	8	4	4	6	8	8	6	2	6	8	
Futures Gain/Loss	4	4	2	-2	-2	0	2	2	0	-4	0	2	Avg = 8/12 = $0.66
Net Gas Cost (Cash + Futures Gain/Loss)	6	6	6	6	6	6	6	6	6	6	6	6	Net = $6.00

Natural Gas Price Hedging

Types of Instruments Available

	Futures Contract	Futures Option	Swap Contract
Commitment			
Buyer	Buy Commodity	Right to Futures Position	Make Payment if Due
Seller	Sell Commodity	Obligation to Provide Position	Make Payment if Due
Regulation	Yes (CFTC & NYMEX)	Exchange Yes OTC No	No
Delivery Capability	Yes	No	No
Term	72 Months	Exchange 72 Months OTC - Open (Years)	Open (Years)
Costs			
Margin	Yes	Depends	No
Administrative	Highest	Lower	Lowest

Natural Gas Price Hedging

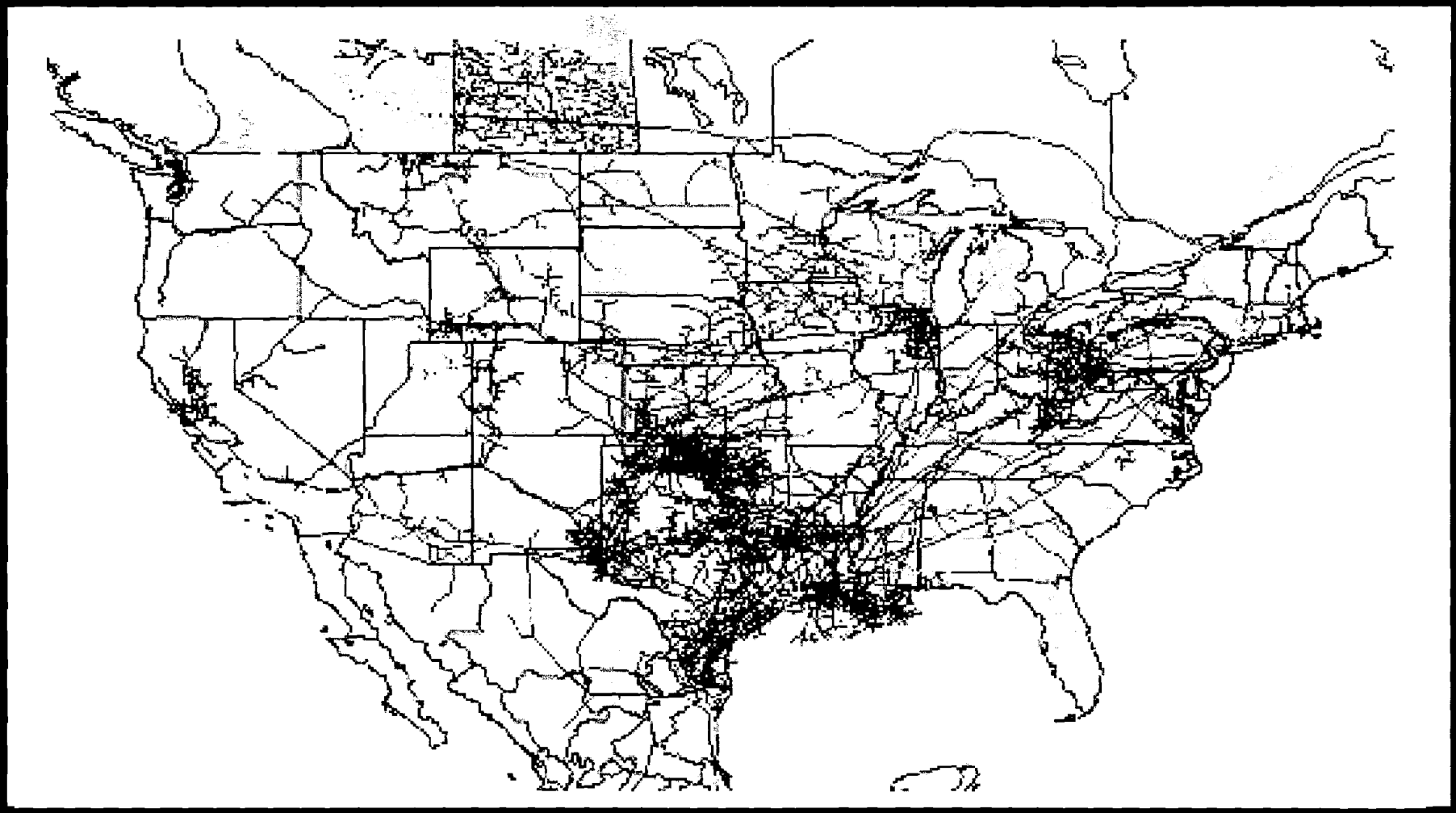
Considerations of Players

	Gas Producers	Gas Marketers	Financial Speculators	Local Utility (LDC)	Consumer
Purpose	Price Floor	Fix Margin (On Physical)	Trade Gain (On Paper)	Fix/Cap Gas Cost	Price Ceiling
Objective	Secure Cash Flow (For Drilling/ Acquisition)	Secure Value in Contracts	Trading Business	Respond to Competitive & Regulatory Pressures	Limit Gas Cost
Risk	Basis Differentials Produced vs. Hedged Volume NRI Counter Party Risk	Basis Differentials Counter Party Risk Keep Book Balanced	Price Volatility Counter Party Risk	Basis Differentials Purchased vs. Hedged Volume Regulatory Hindsight Counter Party Risk	Basis Differentials Consumed vs. Hedged Volume Counter Party Risk

THE END

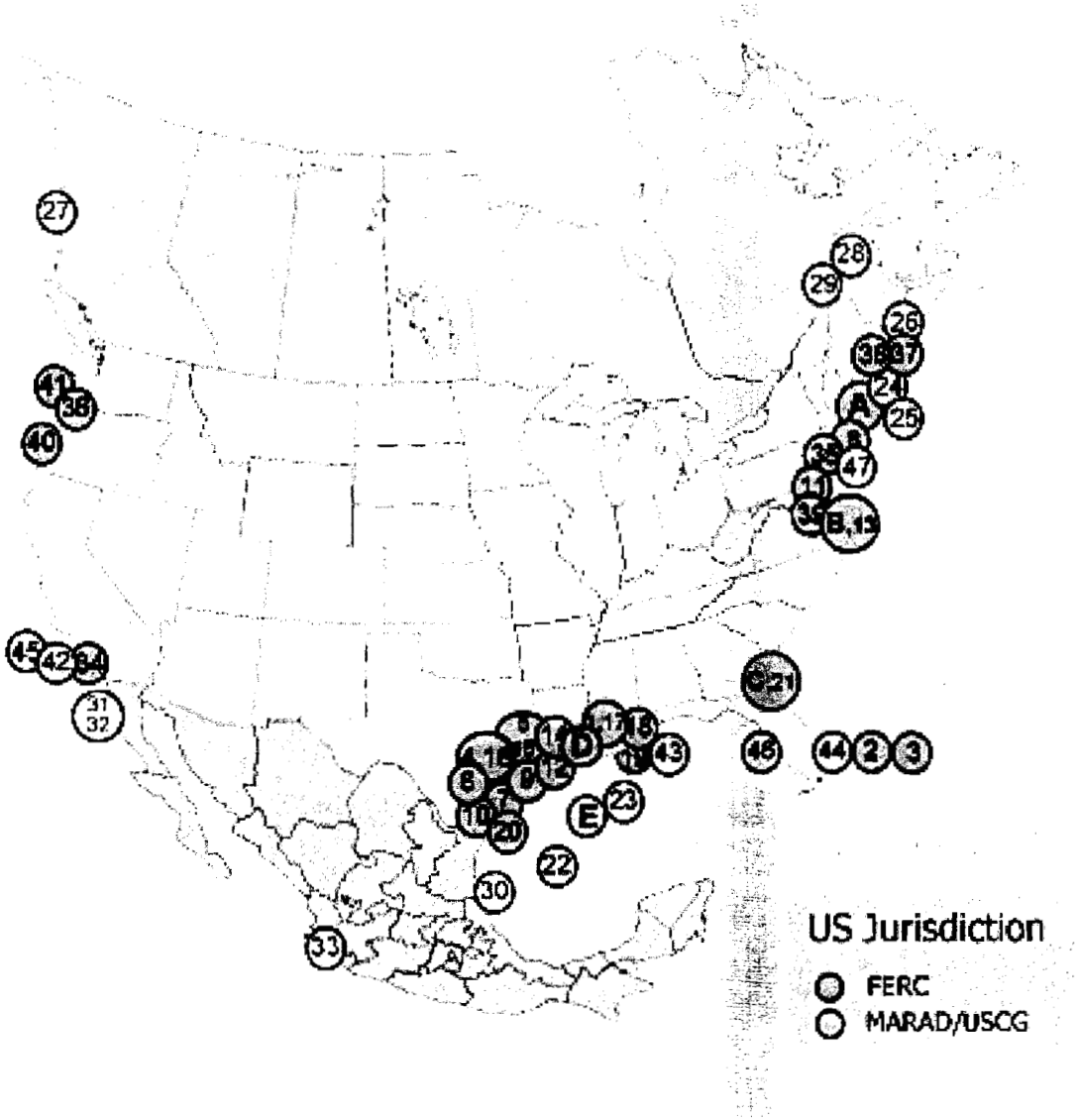
THANK YOU

Natural Gas Transportation Pipeline Network



Source: EIA

Existing and Proposed North American LNG Terminals



CONSTRUCTED

A. Everett, MA : 1.035 Bcfd (DOMAC - SUEZ LNG)
B. Cove Point, MD : 1.0 Bcfd (Dominion - Cove Point LNG)
C. Elba Island, GA : 1.2 Bcfd (El Paso - Southern LNG)
D. Lake Charles, LA : 2.1 Bcfd (Southern Union - Trunkline LNG)
E. Gulf of Mexico: 0.5 Bcfd (Gulf Gateway Energy Bridge - Excelerate Energy)

APPROVED BY FERC

1. Hackberry, LA : 1.8 Bcfd (Cameron LNG - Sempra Energy)
2. Bahamas : 0.84 Bcfd (AES Ocean Express)*
3. Bahamas : 0.83 Bcfd (Calypso Pipeline)*
4. Freeport, TX : 1.5 Bcfd (Cheniere/Freeport LNG Dev.)
5. Sabine, LA : 2.6 Bcfd (Sabine Pass Cheniere LNG)
6. Corpus Christi, TX: 2.6 Bcfd (Cheniere LNG)
7. Corpus Christi, TX : 1.1 Bcfd (Vista Del Sol – 4Gas)
8. Fall River, MA : 0.6 Bcfd (Weaver's Cove Energy/Hess LNG)
9. Sabine, TX : 2.0 Bcfd (Golden Pass - ExxonMobil)
10. Corpus Christi, TX: 1.0 Bcfd (Ingleside Energy - Occidental Energy Ventures)**
11. Logan Township, NJ : 1.2 Bcfd (Crown Landing LNG - BP)
12. Port Arthur, TX: 3.0 Bcfd (Sempra Energy)
13. Cove Point, MD : 0.8 Bcfd (Dominion)
14. Cameron, LA: 3.3 Bcfd (Creole Trail LNG - Cheniere LNG)
15. Sabine, LA: 1.4 Bcfd (Sabine Pass Cheniere LNG - Expansion)
16. Freeport, TX: 2.5 Bcfd (Cheniere/Freeport LNG Dev. - Expansion)
17. Hackberry, LA : 0.85 Bcfd (Cameron LNG - Sempra Energy - Expansion)
18. Pascagoula, MS: 1.5 Bcfd (Gulf LNG Energy LLC)
19. Pascagoula, MS: 1.3 Bcfd (Bayou Casotte Energy LLC - ChevronTexaco)
20. Port Lavaca, TX: 1.0 Bcfd (Calhoun LNG - Gulf Coast LNG Partners)
21. Elba Island, GA: 0.9 Bcfd (El Paso - Southern LNG)

APPROVED BY MARAD/COAST GUARD

22. Port Pelican: 1.6 Bcfd (Chevron Texaco)
23. Offshore Louisiana : 1.0 Bcfd (Main Pass McMoRan Exp.)
24. Offshore Boston: 0.4 Bcfd (Neptune LNG - SUEZ LNG)
25. Offshore Boston: 0.8 Bcfd (Northeast Gateway - Excelerate Energy)

CANADIAN APPROVED TERMINALS

26. St. John, NB : 1.0 Bcfd (Canaport - Irving Oil/Repsol)
27. Kitimat, BC: 1.0 Bcfd (Kitimat LNG - Galveston LNG)
28. Rivière-du- Loup, QC: 0.5 Bcfd (Cacouna Energy - TransCanada/PetroCanada)
29. Quebec City, QC : 0.5 Bcfd (Project Rabaska - Enbridge /Gaz Met/Gaz de France)

MEXICAN APPROVED TERMINALS

30. Altamira, Tamaulipas : 0.7 Bcfd (Shell/Total/Mitsu)
31. Baja California, MX : 1.0 Bcfd (Energia Costa Azul - Sempra Energy)
32. Baja California, MX : 1.5 Bcfd (Energy Costa Azul - Sempra Energy - Expansion)
33. Manzanillo, MX: 0.5 Bcfd

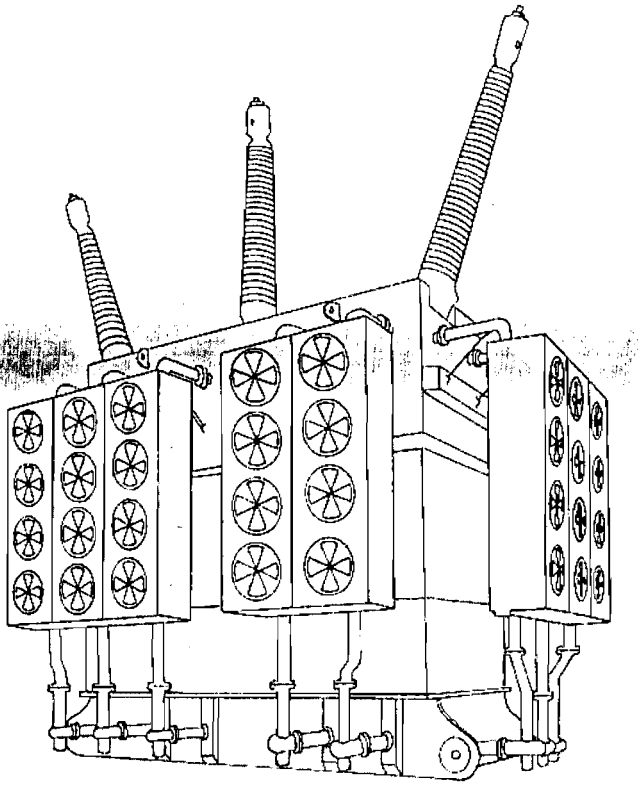
PROPOSED TO FERC

34. Long Beach, CA : 0.7 Bcfd, (Mitsubsh/ConocoPhillips - Sound Energy Solutions)
35. LI Sound, NY: 1.0 Bcfd (Broadwater Energy - TransCanada/Shell)
36. Bradwood, OR: 1.0 Bcfd (Northern Star LNG - Northern Star Natural Gas LLC)
37. Pleasant Point, ME : 2.0 Bcfd (Quoddy Bay, LLC)
38. Robbinston, ME: 0.5 Bcfd (Downeast LNG - Kestrel Energy)
39. Baltimore, MD: 1.5 Bcfd (AES Sparrows Point – AES Corp.)
40. Coos Bay, OR: 1.0 Bcfd (Jordan Cove Energy Project)
41. Astoria, OR: 1.5 Bcfd (Oregon LNG)

PROPOSED TO MARAD/COAST GUARD

42. Offshore California : 1.4 Bcfd, (Clearwater Port LLC - NorthernStar NG LLC)
43. Gulf of Mexico: 1.4 Bcfd (Brenville Offshore Energy Terminal - TORP)
44. Offshore Florida: 1.9 Bcfd (SUEZ Calypso - SUEZ LNG)
45. Offshore California: 1.2 Bcfd (OceanWay - Woodside Natural Gas)
46. Offshore Florida: 1.2 Bcfd (Hoegh LNG - Port Dolphin Energy)
47. Offshore New York: 2.0 Bcfd (Safe Harbor Energy - ASIC, LLC)

ELECTRIC UTILITY SYSTEM OPERATION



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INTRODUCTION

This text is specifically designed to be used in Professional Training Systems, Inc.'s courses.

This text and the associated classroom instruction are designed to acquaint students with electrical terminology, equipment construction, and equipment operating theory.

The text and classroom instruction are not intended for those individuals seeking specific information on the maintenance or operation of specific electrical equipment. Any work undertaken on electrical equipment should be performed by individuals fully experienced and qualified to do so. The work undertaken should be done so only after having fully discussed the planned work with those ultimately responsible for the subject equipment, AND only after reading the instruction, operation and maintenance manuals provided by the equipment manufacturer.

For those individuals seeking training in electrical equipment maintenance or operation on specific equipment, Professional Training Systems, Inc. can be contacted regarding the particular areas.

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ELECTRIC UTILITY SYSTEM OPERATION

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THE ELECTRIC UTILITY SYSTEM
- AN OVERVIEW -

An electrical utility system is made up of four primary areas consisting of generation, transmission, subtransmission and distribution. Generation is comprised of the total system required to convert some initial form of energy into electrical energy. The initial form of energy may be in the form of burning oil, gas or coal (fossil fuel), moving water (hydro), nuclear fission (nuclear), heat from the earth (geothermal), or wind. In all of these cases, the end result of converting the initial form of energy is to spin a magnet in coils of electrical conductors. Figure 1 shows a typical utility system with steam generation.

Transmission is the portion of the utility system that is used to get the power from a source of generation to the large substations on the outskirts of populated areas. For a larger utility system, transmission voltages typically range from 230 kV up to 765 kV. Larger industries often take their power from the transmission system.

Subtransmission is used to get the power from the outskirts of a populated area into the distribution substations inside the populated areas. Typical subtransmission voltages range from 46 kV up to 161 kV. Medium size industries often take their power from the subtransmission system.

The distribution system takes the power from the distribution substations and distributes it to the remaining customers. These customers typically include smaller industries, commercial establishments and residential customers. Distribution voltages typically range from 2,400 volts up to 38 kV.

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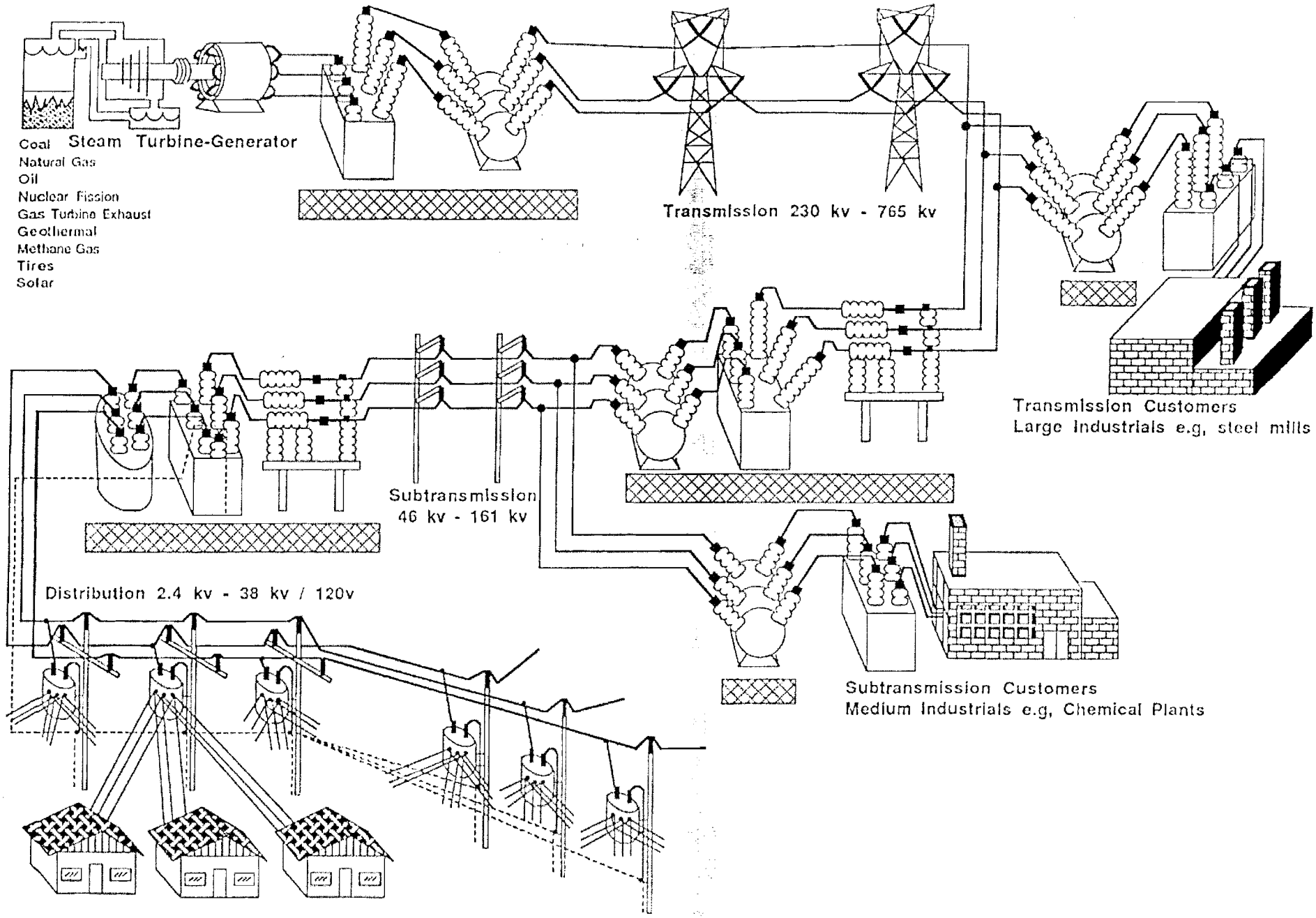

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TYPICAL ELECTRICAL SYSTEM

Figure 1

ELECTRICAL PREFIXES

Electrical values are frequently much larger or much smaller than the common counting numbers. For example, the power generated by a utility company is in the millions of watts, and the power received from a communications transmitter may be in the millionths of a watt.

To avoid having to use many zeroes, abbreviations are used. One of these is M which represents 10^6 or 1,000,000. The quantity 5M would then represent 5,000,000.

The table below lists some of the more commonly used abbreviations, prefixes, multipliers and values frequently used in the electrical world.

ABBREVIATION	PREFIX	MULTIPLIER	VALUE
T	tera	10^{12}	1,000,000,000,000
G	giga	10^{9}	1,000,000,000
M	mega	10^{6}	1,000,000
k	kilo	10^{3}	1,000
m	milli	10^{-3}	0.001
µ	micro	10^{-6}	0.000001
n	nano	10^{-9}	0.000000001
p	pico	10^{-12}	0.000000000001

EXAMPLES

1200 MW = 1200 megawatts = 1,200,000,000 watts

13.8kv = 13.8 kilovolts = 13,800 volts

500 ma = 500 milliamps = 0.500 amps

22 µf = 22 microfarads = 0.000022 farads

◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆

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VOLTAGE

****

* Unit of measurement: Volt *

* Abbreviation: "V" on drawings & in specifications. "E" in equations *

* Other names: Potential, electrical potential, potential difference, electromotive force, EMF *

* Instruments for measuring: Voltmeter, Oscilloscope *

****

Potential energy has the ability to perform work. Water behind a dam, a large rock teetering on the edge of a cliff, and an axe being held above a piece of wood are examples of potential.

> *If* the dam should break, the water would destroy anything in its path
> *If* the rock should fall, it would crush anything unfortunate to find itself on the point of impact
> *If* the axe is allowed to drop onto a piece of wood, the wood would be split

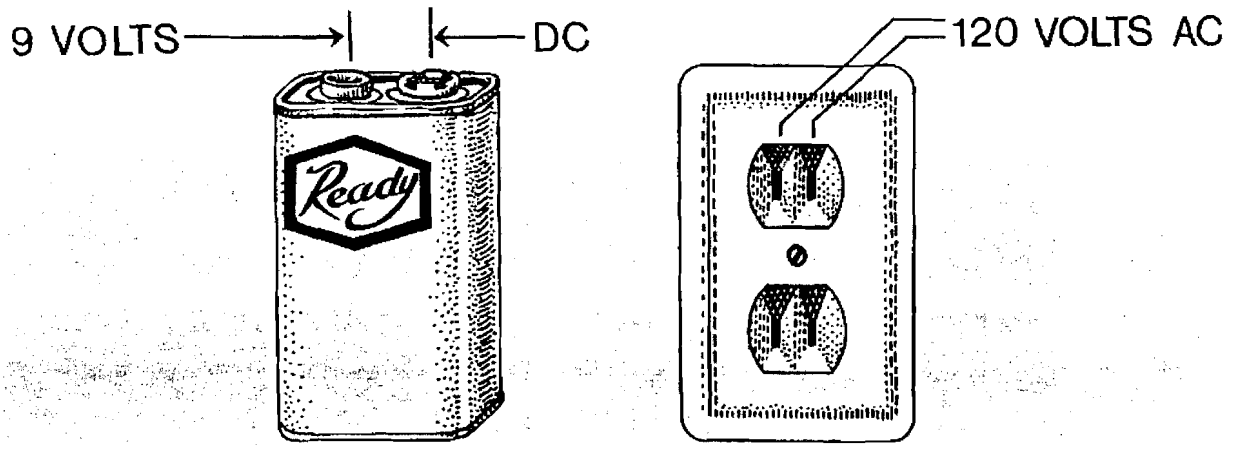
Notice that in each of the examples of potential energy, the word "if" appears. Potential energy does work only if it is allowed to do so.

The electrical equivalent of these examples is voltage. **VOLTAGE HAS THE POTENTIAL TO PERFORM WORK, BUT ACTUALLY DOES NOTHING BY ITSELF.**

Voltage is potential energy and cannot be seen or heard. Voltage has the following characteristics.

- ☞ **A push or force**
- ☞ **Does nothing by itself**
- ☞ **Has potential to do Work**
- ☞ **Appears between two points**
- ☞ **"Always there"**

Figure 1 shows the two points across which a voltage appears on a battery and electrical outlet. Figure 2 shows the effect of high voltage on human hair.



Battery & Outlet Voltages

Figure 1

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Courtesy: Bonneville Power Administration

EFFECT OF HIGH VOLTAGE FIELD ON HAIR
Figure 2

♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

DIRECT CURRENT (DC) VOLTAGE

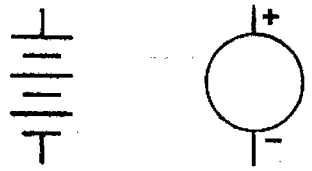
Unit of measurement: DC Volts, Volts DC

Abbreviation: VDC, DCV

Definition: The average value is not zero

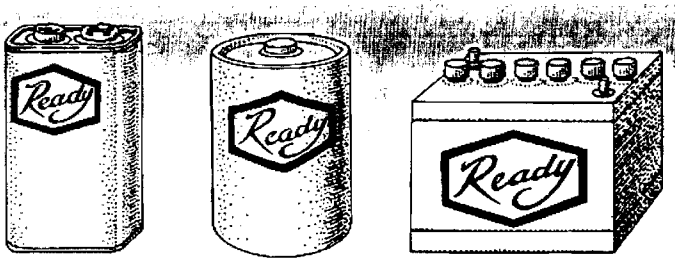
Instruments for measuring: DC voltmeter and oscilloscope

Symbols:



Battery DC Voltage Source

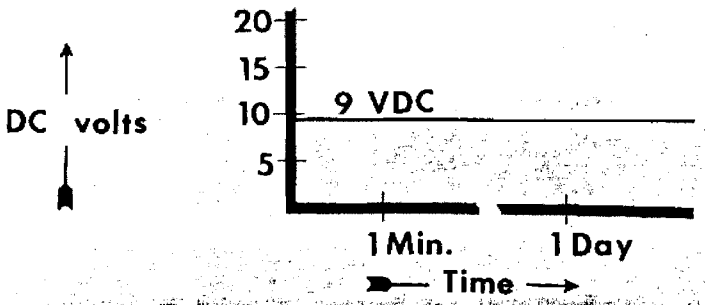
Batteries are the most common source of DC voltage. Wet-cell batteries, such as those found in automobiles, have a liquid inside. Dry-cell batteries, such as those found in flashlights and portable radios, have a paste inside. Both wet-cell and dry-cell batteries produce DC voltage. Three of the more common types of batteries are shown in Figure 1.



BATTERIES

Figure 1

Figure 2 is a graph of a DC voltage waveform produced by a 9-volt battery. The average value of this waveform is not zero. DC voltages always have a non-zero average value.



GRAPH OF 9 VOLTS DC

Figure 2

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AC (ALTERNATING CURRENT) VOLTAGE

60% of ELEC is FOR ELEC MOTORS

30% all lights

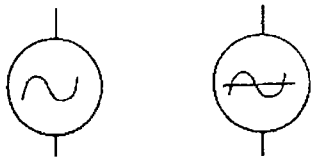
10% = heat & electronics

****

* Unit of Measurement: AC Volts, Volts AC *

* Abbreviation: V, VAC, ACV *

* Definition: A voltage whose average value is zero *

* Symbol:  *

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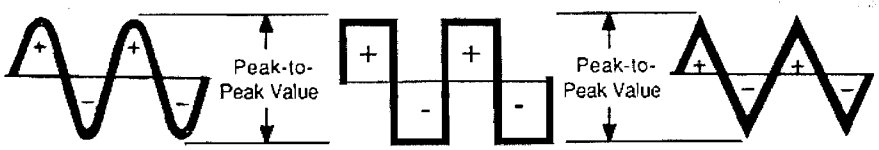
The most common source of AC voltages are electrical utility companies. Virtually all residences, industries and commercial buildings are supplied with AC voltages.

The "alternating" designation comes from the fact that the voltage swings from positive to negative every half-cycle, with the positive and negative swings having equal or approximately equal value. Examples of these voltage swings are shown in the three examples provided below. Note that in each of the waveforms the average value is zero; there are equal areas above and below the zero axis.



AC WAVEFORMS

Figure 1

When compared to the sine wave, the square-wave and saw-tooth waveforms have limited application. Their greatest use is in the areas of communications and other types of complex electronics. Electrical utilities and their residential, commercial, and industrial customers use AC voltage in the form of a sine wave for practically all AC applications.

RMS VALUES

The sine wave, square wave and saw-tooth waveforms in Figure 1 have the same frequency (they cross the axis at the same points), they have the same peak value, and they have the same average value of zero. Because they are the same in these three ways, another method needs to be used to distinguish how the waveforms differ.

The amount of work that can be done by each of the waveforms is determined by the area between the waveform and the axis. Therefore, the method used to distinguish between different alternating-current wave-forms should be a measure of this area. The method used is called **root mean square** or RMS. Figure 2 shows a sine wave.

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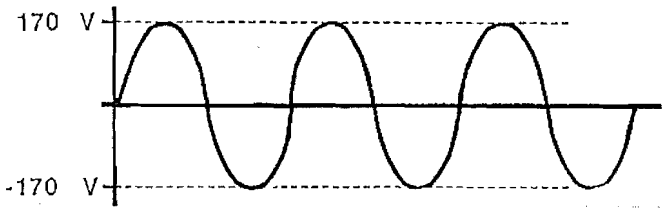
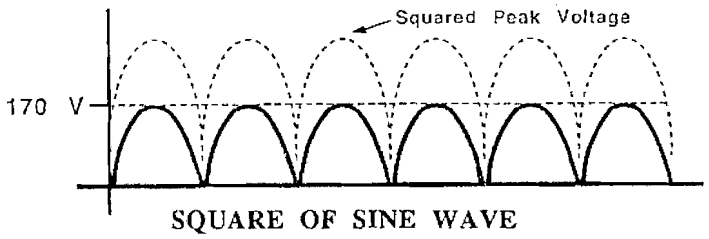


SINE WAVE

Figure 2

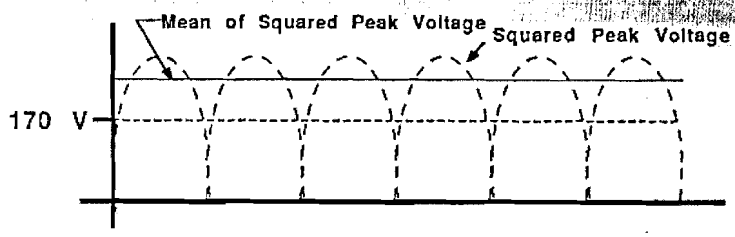
The first step in determining the RMS value is to square the waveform. This removes the negative sign of the lower portion of the waveform. The result of squaring the sine wave is shown in Figure 3.



SQUARE OF SINE WAVE

Figure 3

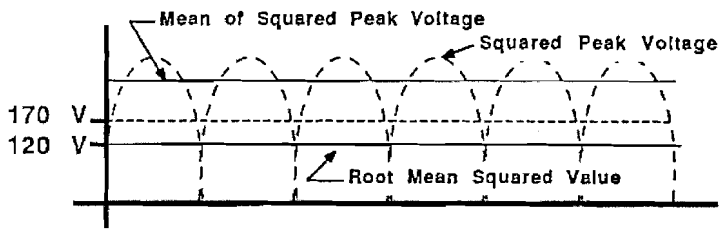
Next, the average, or mean, of the squared value is determined. Figure 4 shows the mean of the squared sine wave.



MEAN OF SQUARED SINE WAVE

Figure 4

Finally, since the waveform was squared initially, the square root is taken. The result is the root mean square or RMS value. Figure 5 shows the RMS value.



ROOT MEAN SQUARE VALUE

Figure 5

For a sine wave, the RMS value is 0.707 of the peak value. Alternating-current voltages are always described by their RMS value, unless specifically identified as peak (or peak-to-peak). To get the peak value, the RMS voltage can be divided by 0.707, or multiplied by 1.414. For the standard household 120 volts, the peak voltage is approximately 170 volts.

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GENERATION OF A MAGNETIC SINE WAVE

Virtually all AC voltage produced by electrical utilities is produced by spinning a magnet. (The exceptions are a few of the many wind generators, a small amount of solar voltaic, and a small number of fuel cells.) If a magnet is rotated about its axis, a stationary reference point close to the magnet would experience a magnetic sine wave that would alternate between a magnetic north pole and a magnetic south pole.

In the illustration below, a person (the stationary reference point) is looking at a rotating magnet. At position A, the person would see the north pole of the magnet as having the same strength as the south pole because they are the same distance from the observer. Since they are equal and opposite, the net result is zero. This is indicated as zero on the graph.

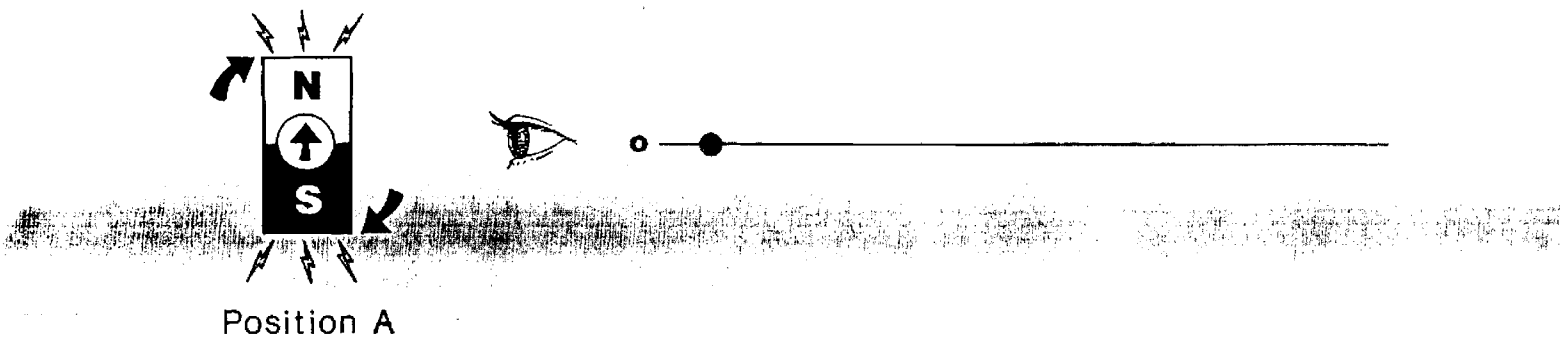

Figure 1

A quarter turn later (position B), the north pole of the magnet is at its closest to the observer. This results in the north pole's magnetic strength being a maximum. This is indicated as a peak north on the graph.

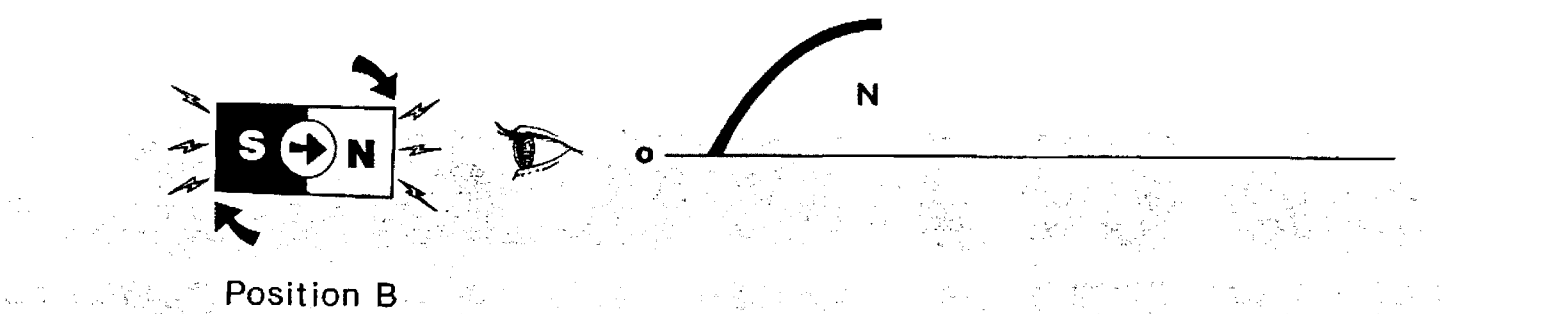

Figure 2

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Another quarter turn (to position C) puts the magnet in a position of equal magnetic strength with respect to the stationary reference point. This is again indicated as a zero on the graph.

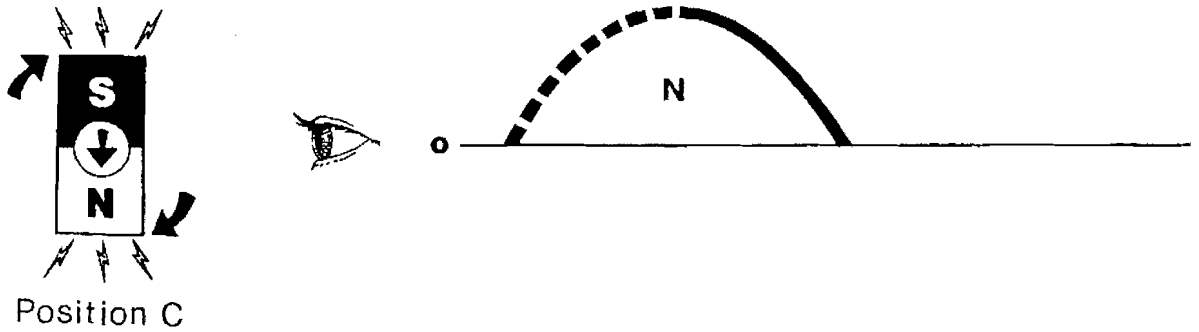

Figure 3

The next quarter turn (to position D) puts the magnet in a position in which the south pole exerts it maximum field strength. This is indicated as a south peak on the graph below.

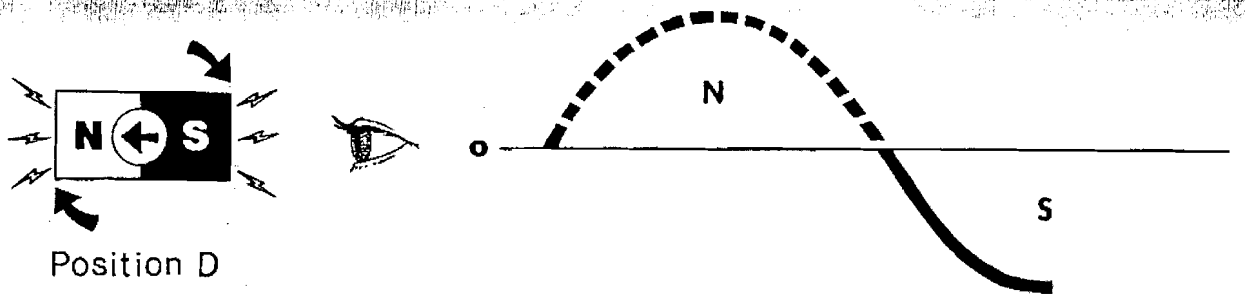

Figure 4

The final quarter turn in the cycle puts the magnet back at its beginning position (position E). A complete section or "cycle" of a magnetic sine wave has been generated.

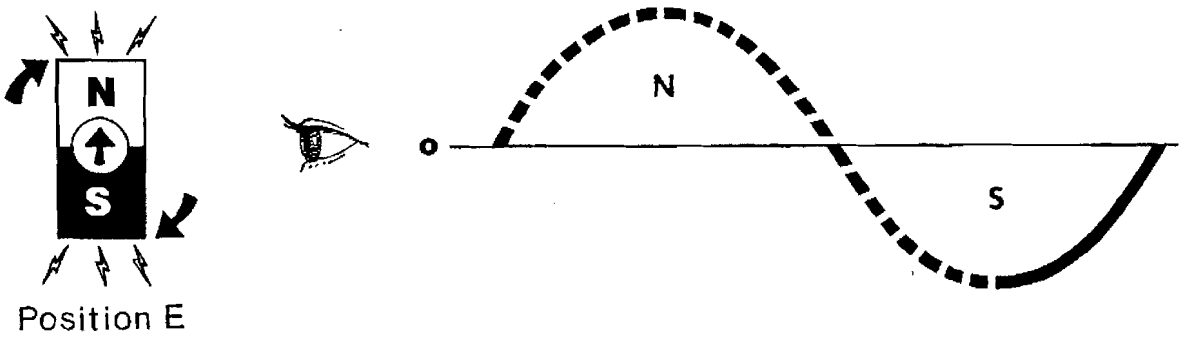

Figure 5

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SINGLE-PHASE AC GENERATION

A magnet placed inside a coil of wire and rotated produces a voltage sine wave that appears between the ends of the wire. This is called single-phase (1Ø) generation because a single sine wave is produced. The drawing below illustrates the magnet and coil of wire.

Figure 1

A hollow iron cylinder, such as the one shown below, is used to provide mechanical support for the coil of wire. This iron cylinder is called a stator.

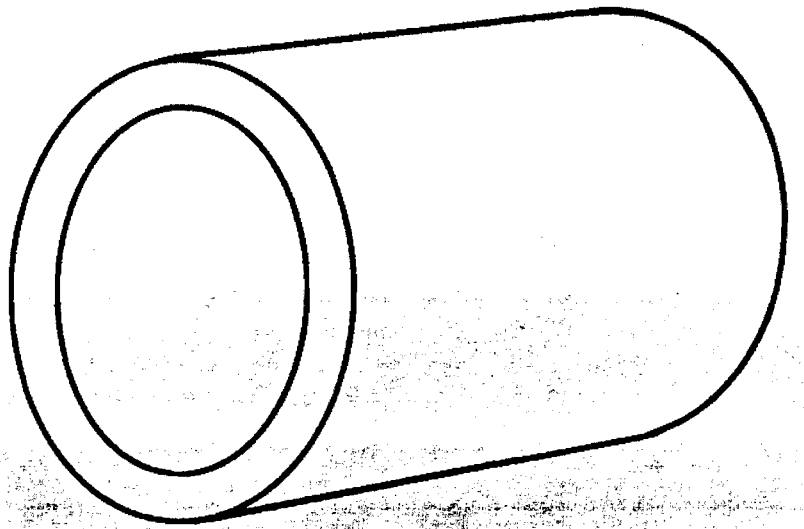

Figure 2

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Slots running the length of the cylinder are cut on the inner diameter of the iron cylinder as shown below. These slots are called stator slots.

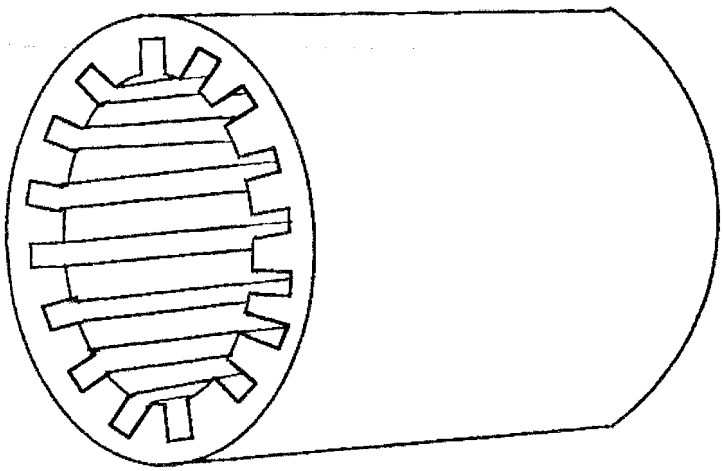

Figure 3

A continuous conductor is then looped back and forth in the slots as shown below. This wire is insulated to keep it from touching the iron cylinder. This wire is called a stator winding (because it is wound back and forth), a stator coil, a stator conductor, or in cases in which the wire is very large, it is called a stator bar.

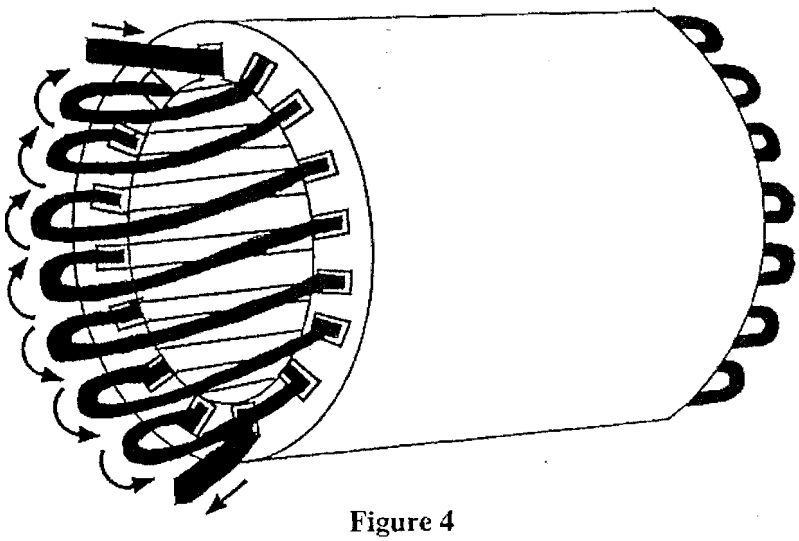

Figure 4

The stator is made of an iron that can be magnetized. When the magnet rotates inside the stator, a magnetic field is produced in the stator. This magnetic field rotates around the stator at the same speed as the magnet is rotating. This magnetic field in the stator is significantly stronger than a magnetic field produced in air, and this results in a higher output voltage.

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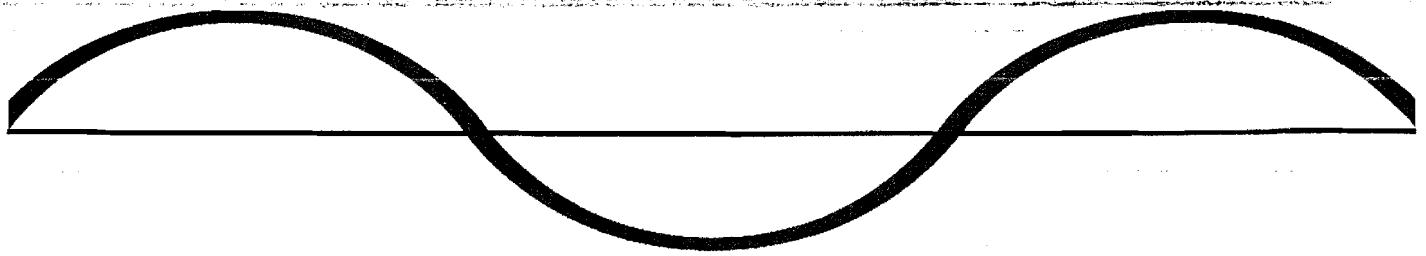
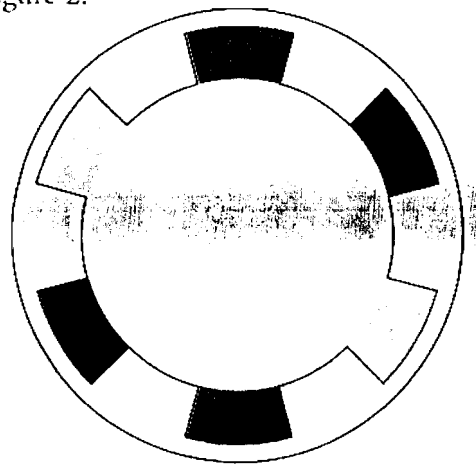
THREE PHASE GENERATION

A single-phase voltage is produced on a conductor that is looped inside an iron cylinder with a magnet rotating inside the cylinder. This is a single-phase generator and produces the single-phase wave form shown in Figure 1.



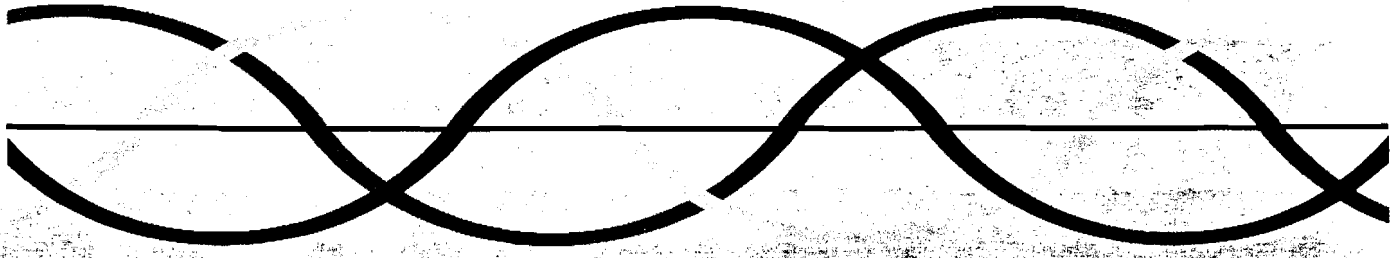
SINGLE PHASE SINE WAVE
Figure 1

Adding two more conductors results in a three-phase generator as illustrated in Figure 2.



THREE PHASE STATOR
Figure 2

As a magnet rotates past the red conductor in Figure 2, the voltage sine wave shown in red in Figure 3 is produced. As the magnet passes the blue and yellow conductors respectively, the yellow and blue voltage sine waves are produced. These three wave forms make up what is called three-phase voltage.



THREE PHASE VOLTAGE SINE WAVES
Figure 3

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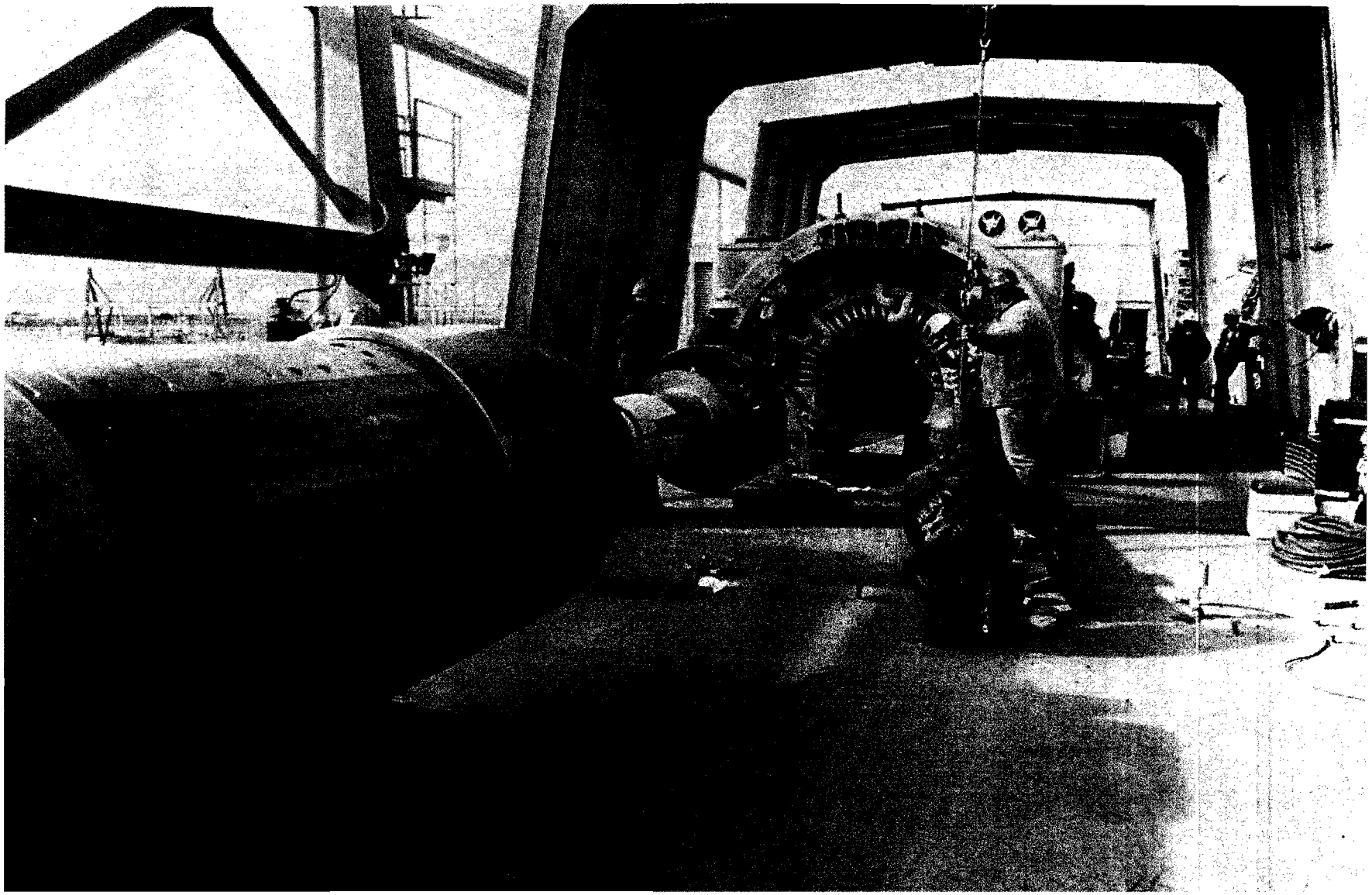


Courtesy: Arizona Electric Power Cooperative

GENERATOR FIELD AND STATOR

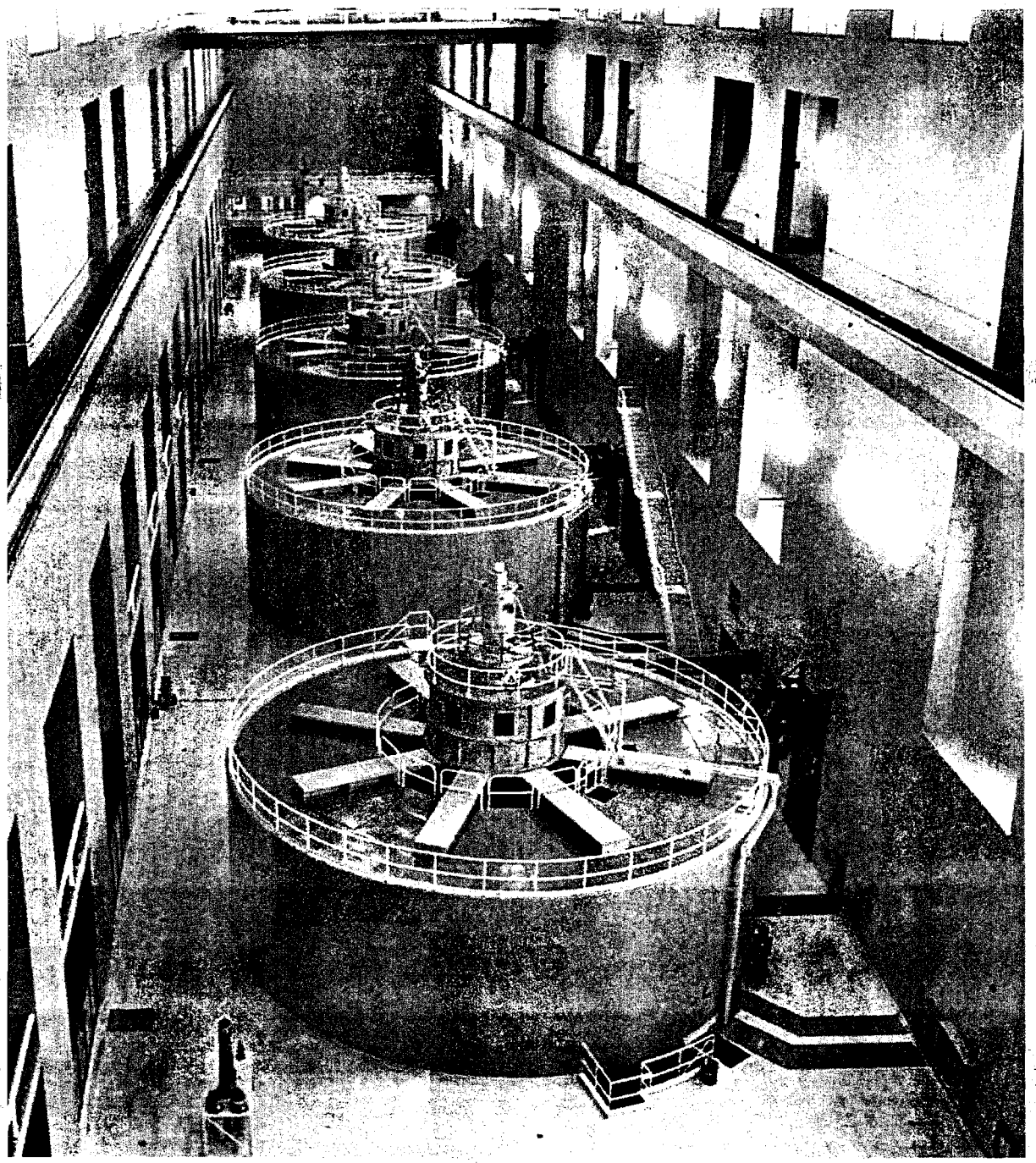
Figure 4

♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

GENERATOR STATOR

The generator's iron cylinder is called a stator. The magnet that rotates inside the stator is called the field or rotor. Figure 4 shows a generator stator with the field removed.

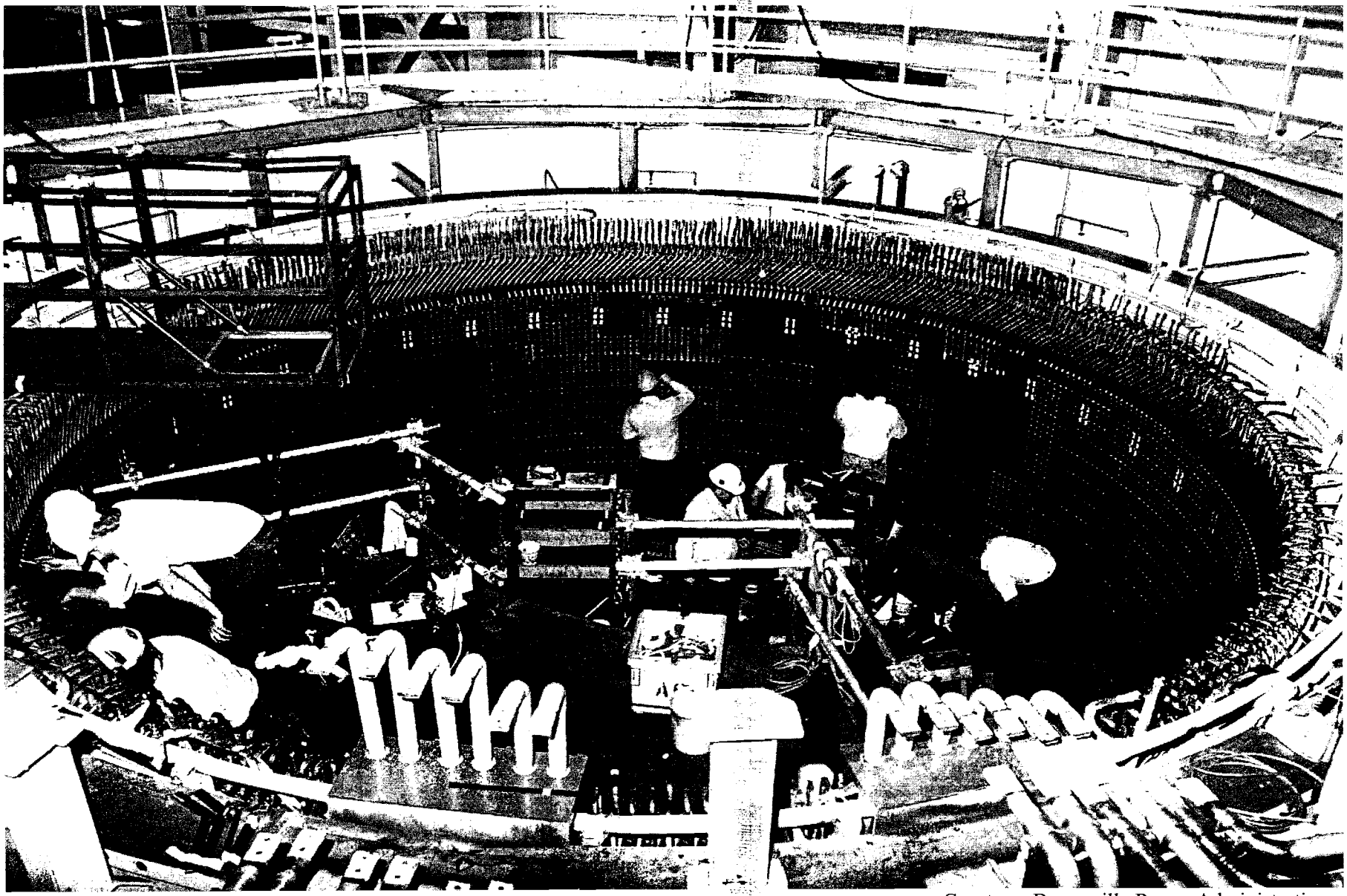
Figure 5 shows operating hydroelectric generators. Figures 6, 7 and 8 show workers winding a large hydroelectric generator stator.



Courtesy: Bonneville Power Administration

OPERATING HYDROELECTRIC GENERATORS

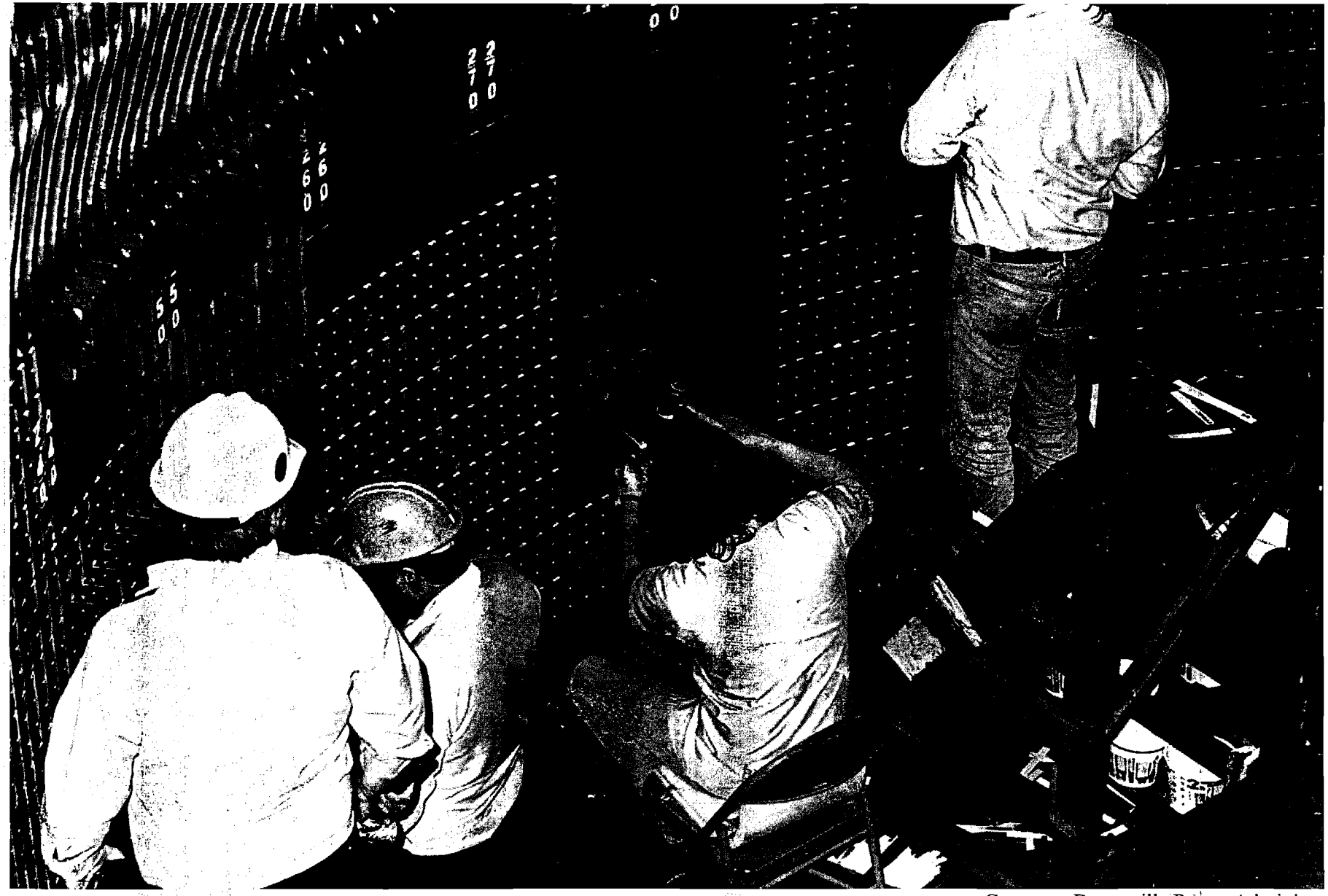
Figure 5



Courtesy: Bonneville Power Administration

WORKERS WINDING HYDROELECTRIC GENERATOR STATOR

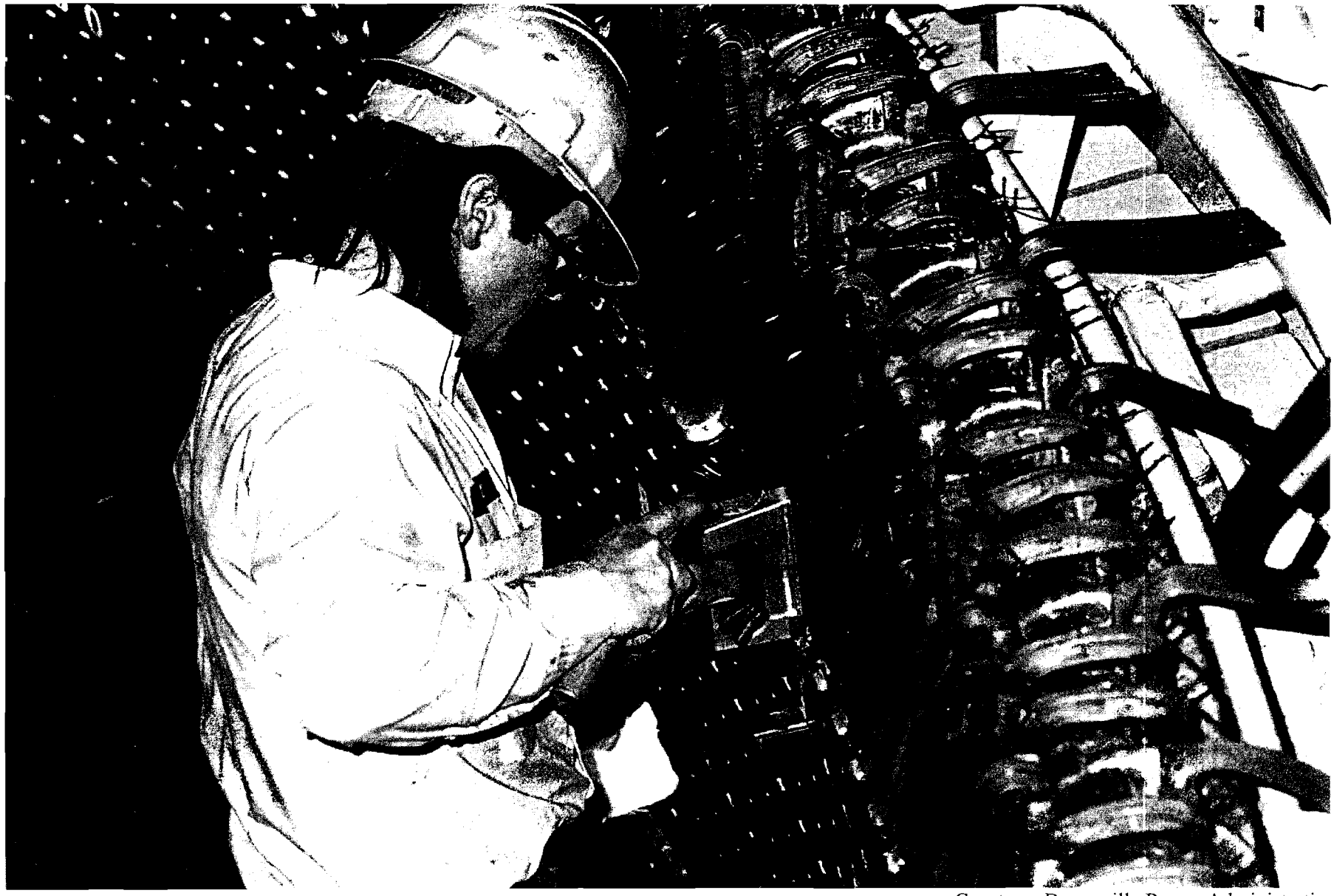
Figure 6



Courtesy: Bonneville Power Administration

WORKERS WINDING HYDROELECTRIC GENERATOR STATOR

Figure 7



Courtesy: Bonneville Power Administration

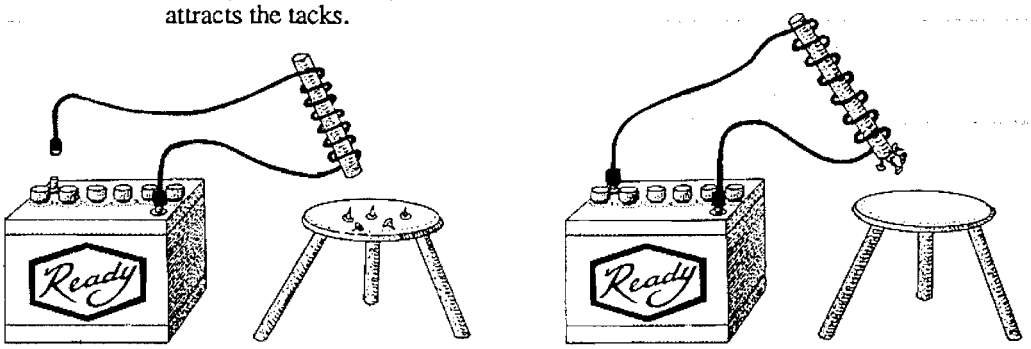
WORKER WINDING HYDROELECTRIC GENERATOR STATOR

Figure 8

GENERATOR FIELD

The generator field (the generator magnet) is not a permanent magnet such as the magnets found in toys or those used to hold household cabinets closed. This is because permanent magnets are not strong enough to provide the power levels required in utility and industrial generators. To provide the necessary magnetic-field strength, electromagnets are used.

An electromagnet can be made by winding a conductor around a piece of iron, and connecting the two ends of the conductor to a voltage source. In Figure 9a, the tacks are not being attracted by the iron bar. When the ends of the conductor are connected to the battery terminals, Figure 9b, the iron bar becomes a magnet and attracts the tacks.



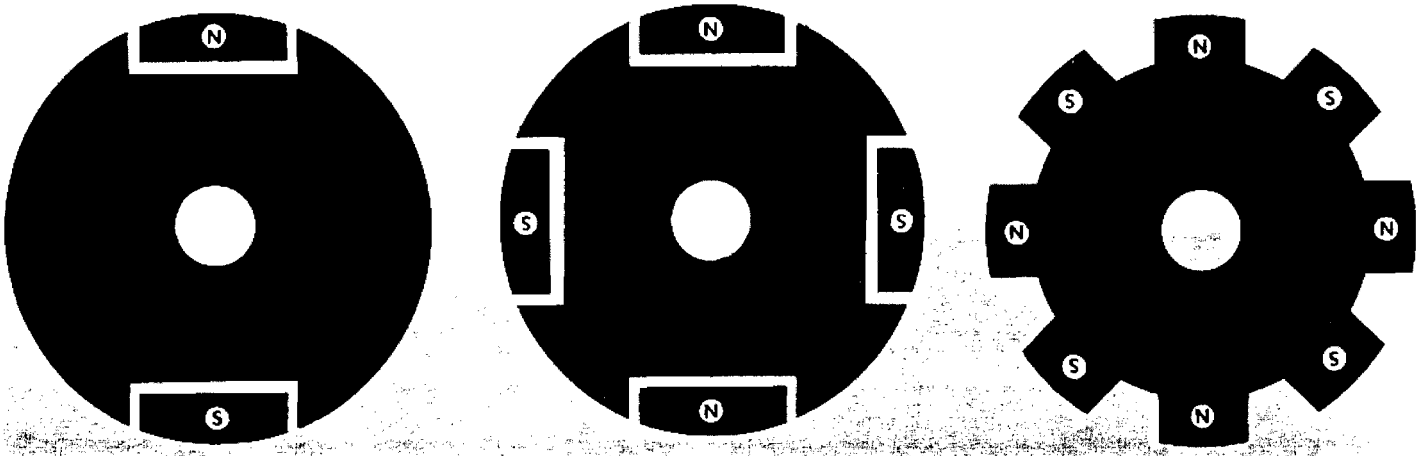
DC CURRENT PRODUCING A MAGNET

Figure 9a Figure 9b

The same principle is used to create a magnetic field in the rotating part of a generator. A DC voltage is applied to a conductor wound on the field, and the field becomes a magnet.

GENERATOR FIELD (ROTOR) POLES

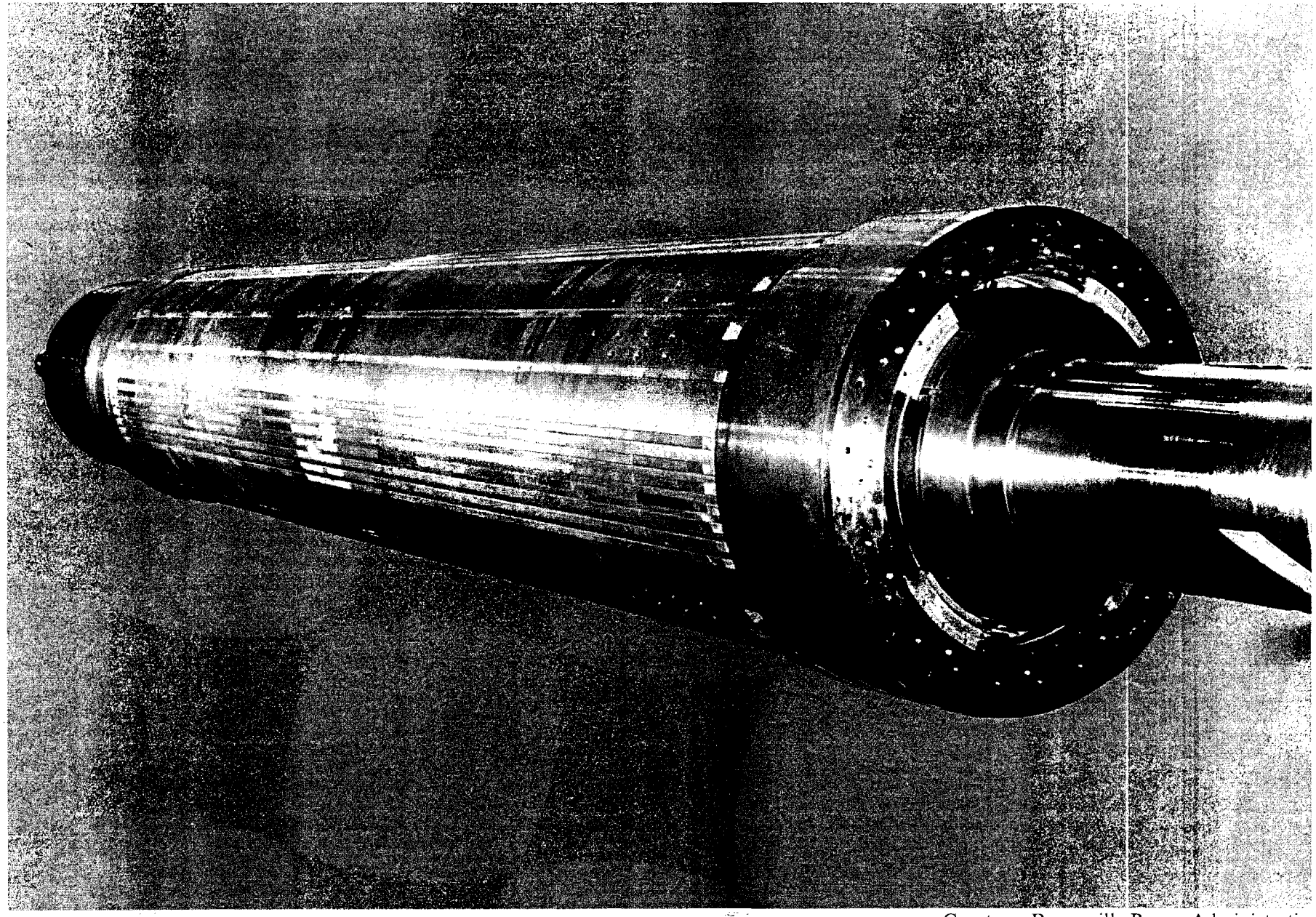
The generator field is made up of pole-pairs. A pole-pair consists of one north pole and one south pole. A 2-pole field has one pole-pair consisting of one north pole and one south pole; a 4-pole field has two pole-pairs consisting of two north poles and 2 south poles; an 8-pole filed has four pole-pairs consisting of 4 north poles and 4 south poles. Figure 10 shows 2-pole, 4-pole and 8-pole fields.



GENERATOR FIELD POLES

Figure 10

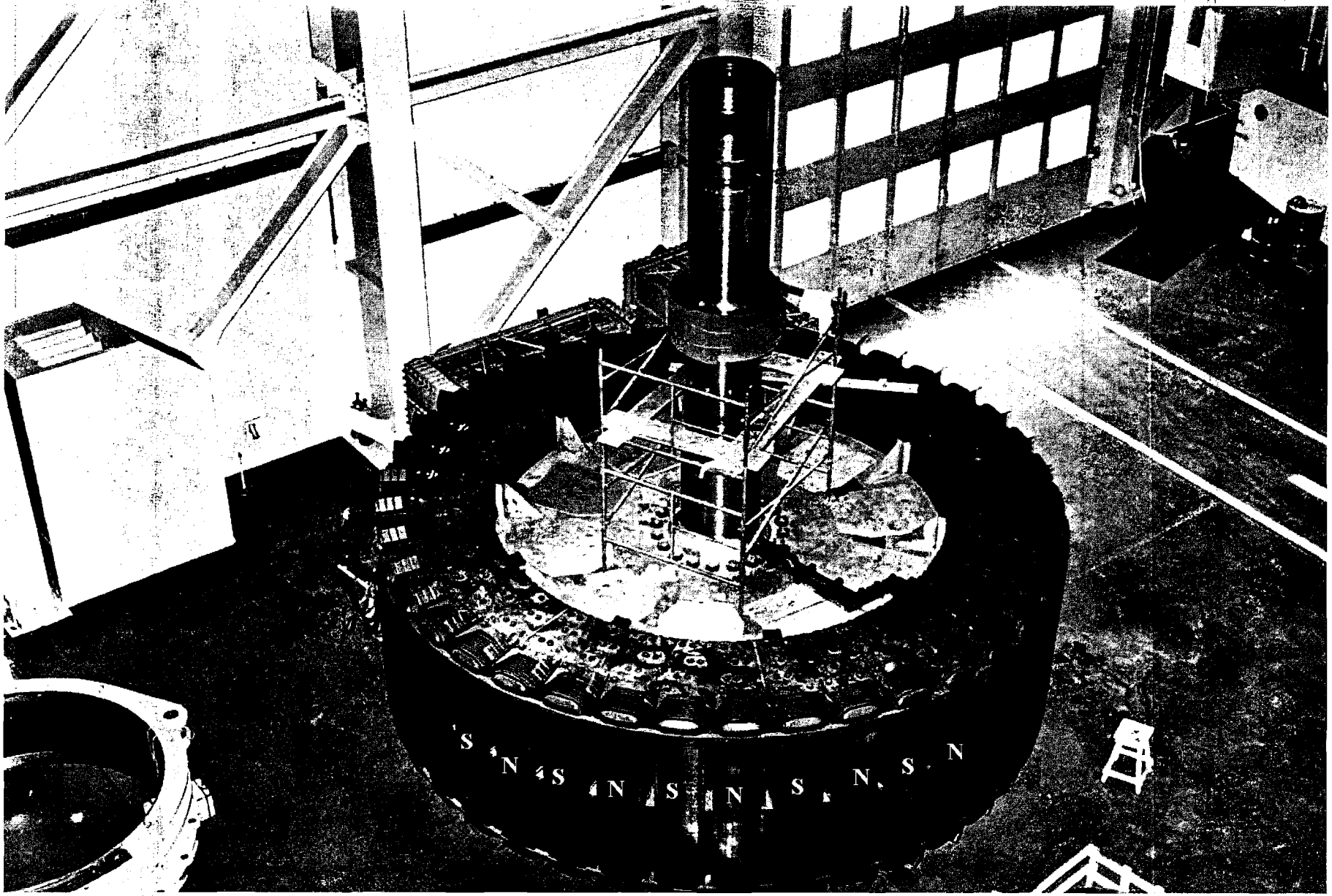
The number of poles in a generator field is directly related to the rotational speed of the field. This relationship is defined by the following equation.



Courtesy: Bonneville Power Administration

GENERATOR FIELD FROM STEAM PLANT

Figure 11



Courtesy: Bonneville Power Administration

HYDROELECTRIC FIELD WITH SALIENT FIELD POLES

Figure 12

$$(1)\ \text{Number of poles} = \frac{\text{Frequency x 60 x 2}}{\text{Revolutions per minute}}$$

The standard frequency in the United States and Canada is 60 Hertz, resulting in

$$(2)\ \text{Number of poles} = \frac{7200}{\text{Revolutions per minute}}$$

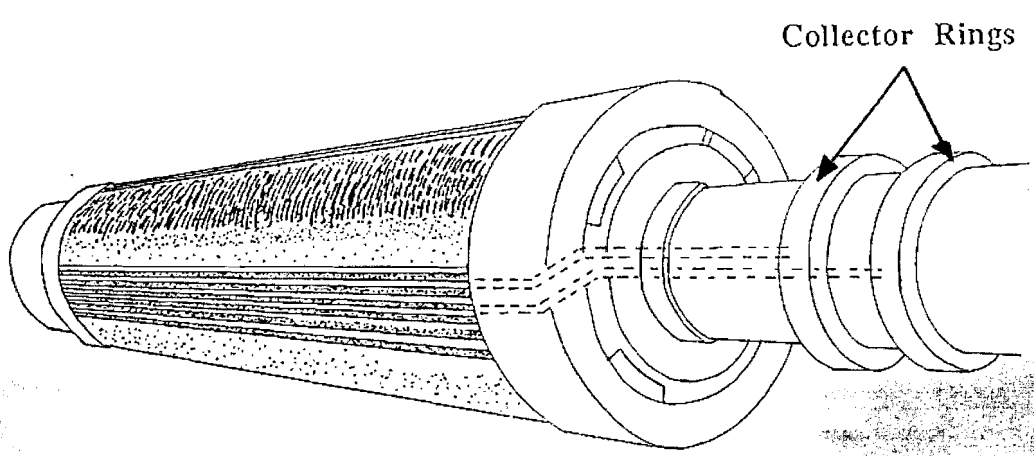
The equation can also be written as

$$(3)\ \text{Revolutions per minute} = \frac{7200}{\text{Number of poles}}$$

A 2-pole generator spins at 3,600 revolutions per minute (RPM); a 4-pole unit would spin at 1,800 RPM and an 80-pole generator would spin at 90 RPM.

In Figure 10, the 2-pole and 4-pole fields have the poles inside the circumference. Figure 11 is a photograph of this type of field. The 8-pole unit in Figure 10 has poles that protrude. Poles that protrude are called salient-poles. (Salient is defined in the dictionary as "projecting or jutting beyond a surface.) The salient-pole design is less costly to manufacture. A salient-pole design, however, is used for slower speed generators; the centrifugal force would throw the windings off the field poles at higher speeds. Figure 12 shows a salient-pole field for a large hydroelectric generator.

The fact that the field is constantly spinning (at 3,600 RPM for a 2-pole generator) provides a challenge in connecting the DC voltage source to the conductors wound on the field. The easiest way to accomplish this is to mount two metal rings, called collector rings, on the shaft (Figures 13 & 14). The two ends of the conductor wound on the field are brought along the shaft to the collector rings. One end of the conductor is connected to one ring, and the other end of the conductor is attached to the other ring.



GENERATOR FIELD WITH COLLECTOR RINGS

Figure 13

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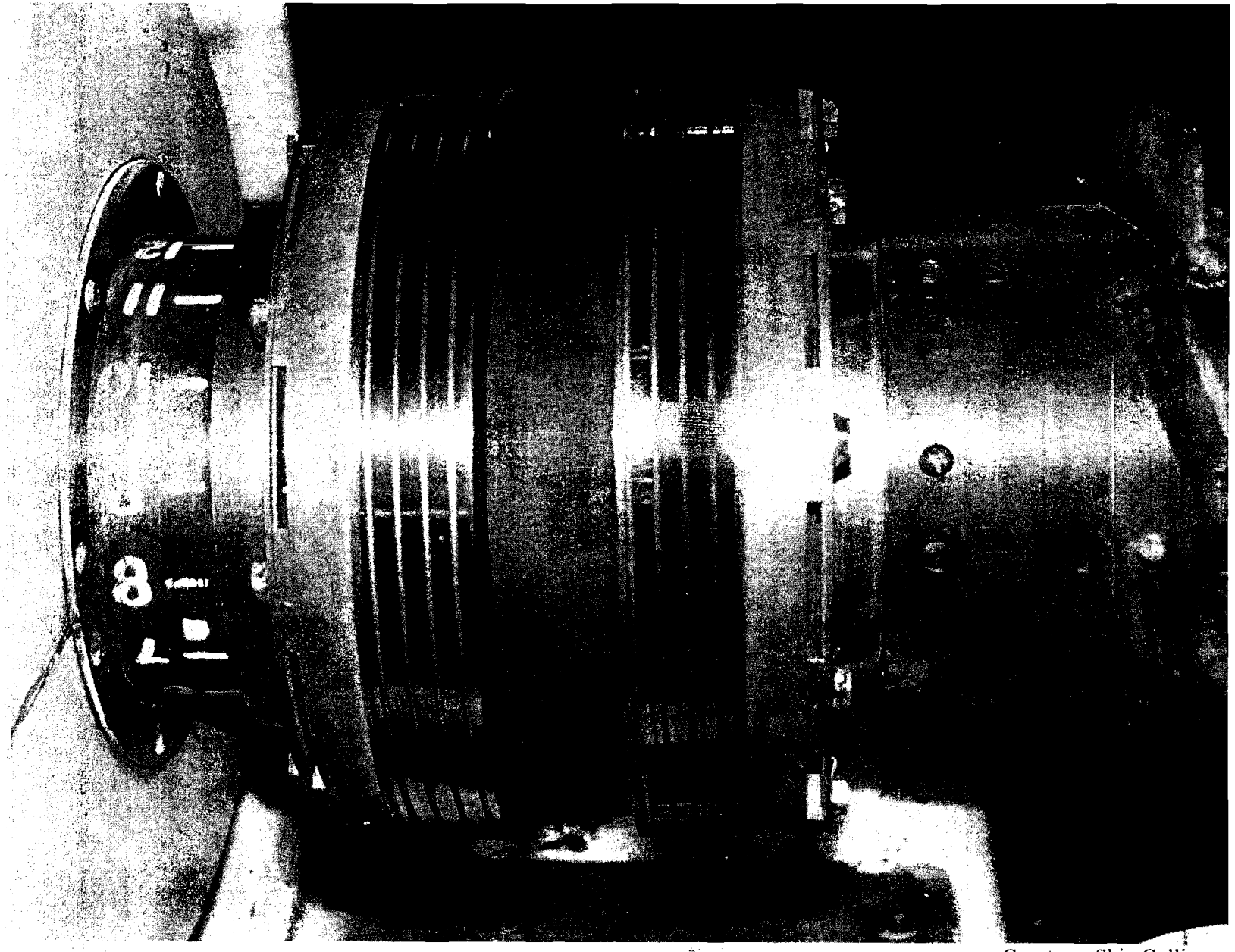


Courtesy: Skip Collier

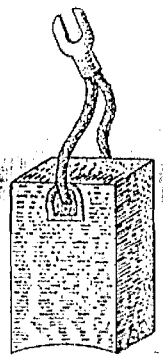
GENERATOR FIELD COLLECTOR RINGS

Figure 14

Carbon blocks, called brushes, ride on the surface of the collector rings as the collector rings spin; spring pressure keeps them tightly against the collector rings. The positive terminal of the DC power source is connected to one of the rings and the negative terminal is connected to the other ring.

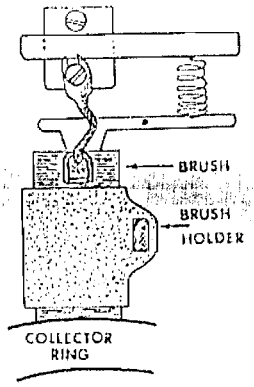
DC current flows from the positive terminal of the source, through the positive brush, into the positive collector ring, and through the field winding; the current then continues through the negative collector ring, through the negative brush, and back to the negative terminal of the source. This current makes field into a magnet.

All the equipment and components used to make the generator field into a magnet are part of what is called the generator's "excitation system."



CARBON BRUSH

Figure 15a



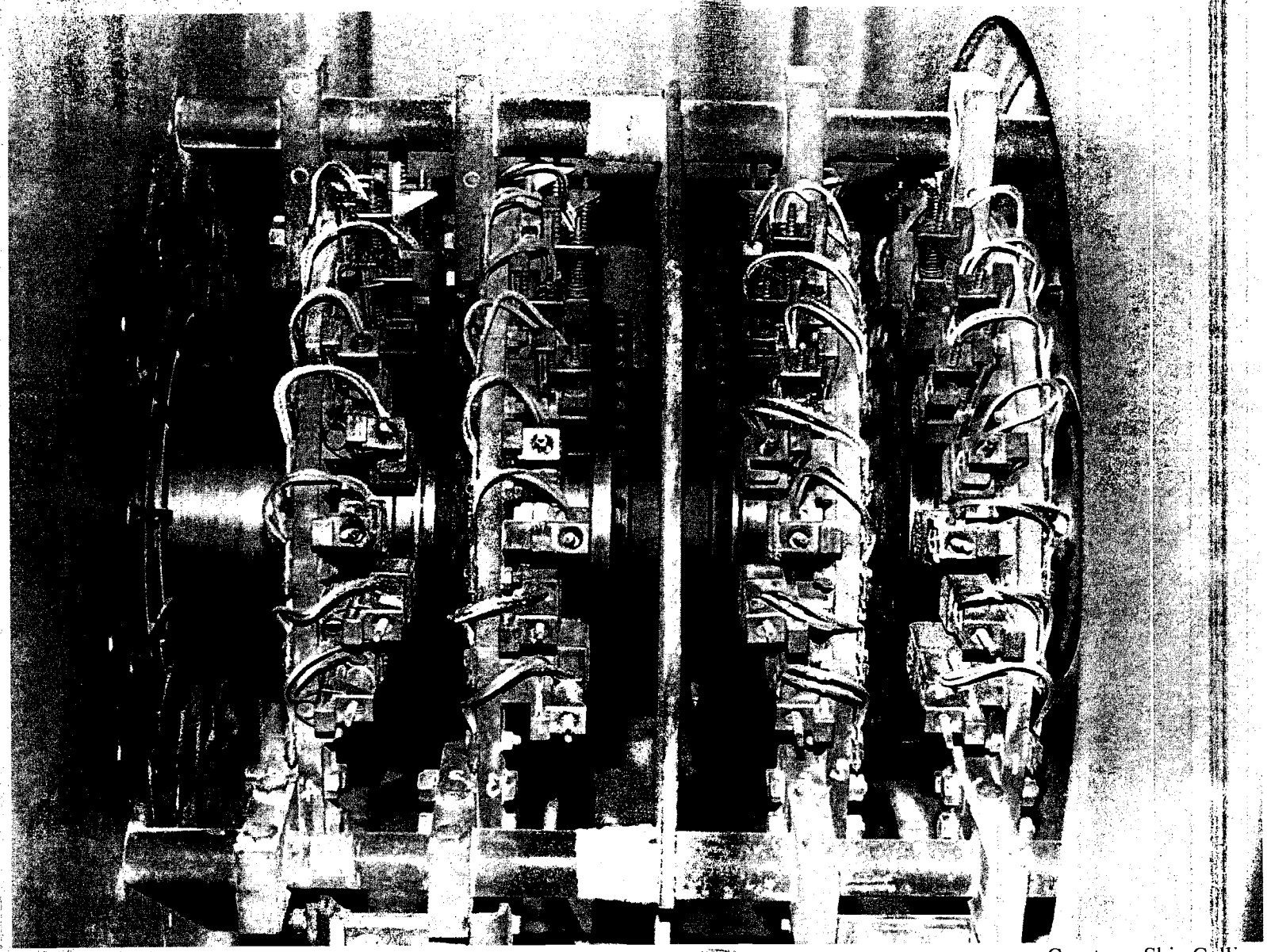
CARBON BRUSH ASSEMBLY

Figure 15b

The amount of excitation current required in utility generators is such that a single brush cannot carry the current; therefore, multiple brushes are mounted on each of the collector rings. Figure 16 shows multiple brushes on collector rings.

A turbine is large fan that is coupled to the generator field. The force that spins the turbine-generator provides the name of the type of generation; when steam provides the force, it is called a steam turbine-generator (Figure 17 shows a portion of a steam turbine); when water provides the force, it is called a hydroelectric turbine generator.

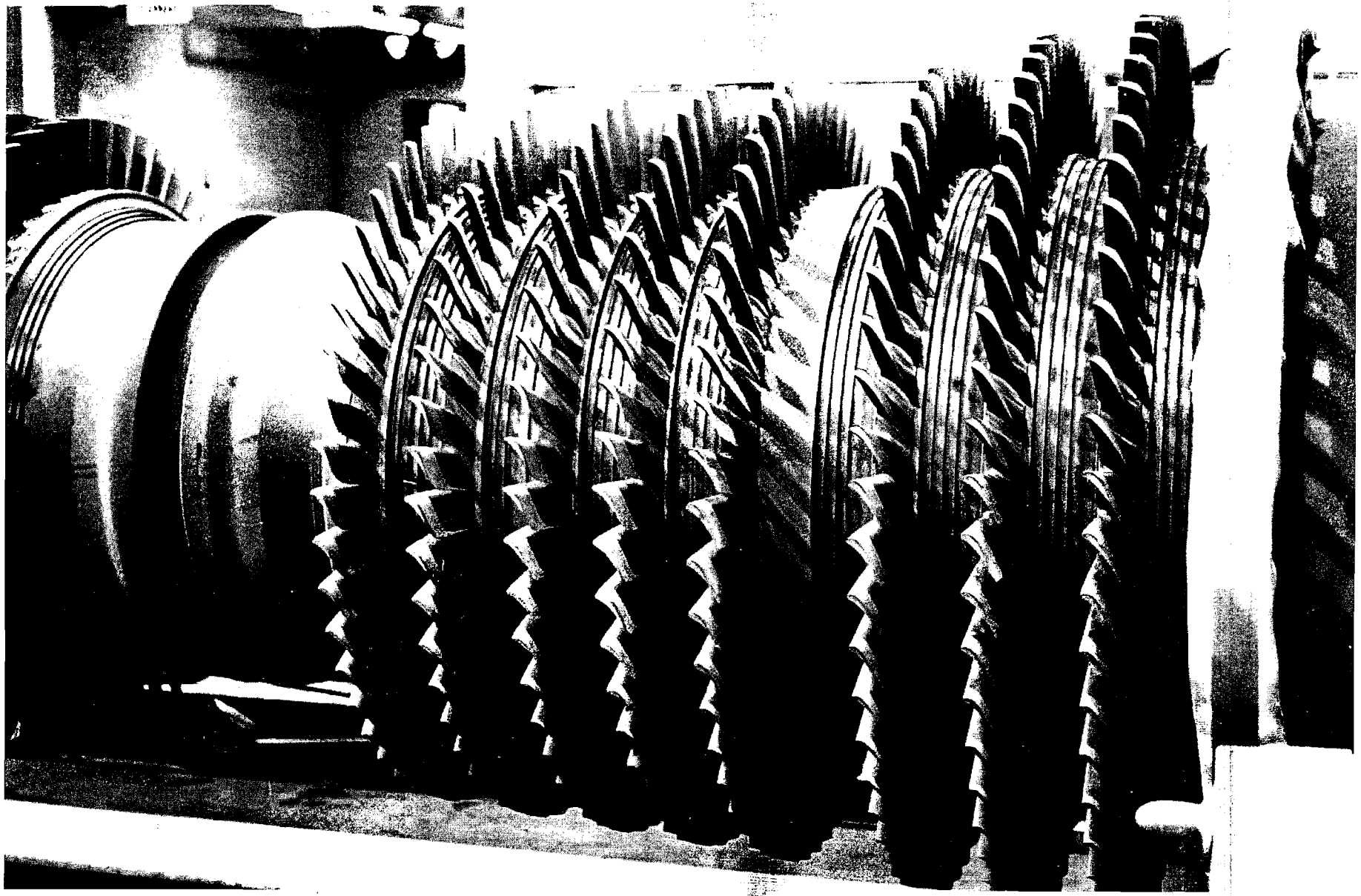
When hot exhaust gas from a jet engine is used to spin the turbine-generator, it is called a gas turbine, combustion turbine or jet turbine. Diesel generators do not have a turbine coupled to the generator field; instead, the crankshaft from a diesel engine spins the generator field.



Courtesy: Skip Collier

MULTIPLE BRUSHES ON COLLECTOR RINGS

Figure 16



Courtesy: Skip Collier

STEAM TURBINE

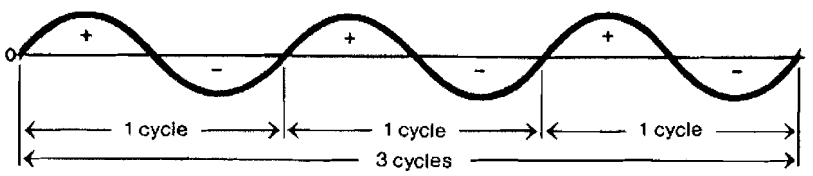
Figure 17

♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

FREQUENCY

```
*****************************************
*                                       *
*  Unit of measurement: Hertz           *
*  Abbreviation: HZ                     *
*  Definition: The number of cycles per second *
*  Instrument for measuring: Frequency meter, frequency *
*                            counter    *
*                                       *
*****************************************
```

An AC signal alternates between a positive and negative value. Each time the signal goes from zero, to a positive value, to zero, to a negative value, and back to zero, one cycle is completed. This is illustrated on the waveform shown in Figure 1.



CYCLES OF A SINE WAVE

Figure 1

Frequency is the number of these cycles occurring in one second. One cycle is one hertz. Three hertz would be three complete cycles occurring in 1 second. ALL ELECTRIC UTILITIES IN THE UNITED STATES PRODUCE A 60 HERTZ SIGNAL (60 cycles each second).

Until the mid-1960's, frequency was designated by cycles-per-second (also written cycles/second). At that time, the cycles-per-second unit of measurement for frequency was changed to hertz as a tribute to Heinrich Rudolf Hertz (1857-94), a German physicist who worked in the area of electromagnetic phenomena.

Electric utilities maintain frequency very close to 60 hertz. When the total generation in a system equals the total load, the frequency is exactly 60 hertz. When the total generation in a system exceeds the total load, the frequency rises above 60 hertz. When the total generation in a system is less than the total load, the frequency drops below 60 hertz.

Figure 2 shows the frequency of the pacific Northwest electrical system. Figure 3 shows a frequency chart in Kansas City and the effect when 2000 megawatts of generation was lost by Duke Power in North Carolina. Figure 4 shows the frequency deviations resulting from California's January 19, 1994 Northridge earthquake.

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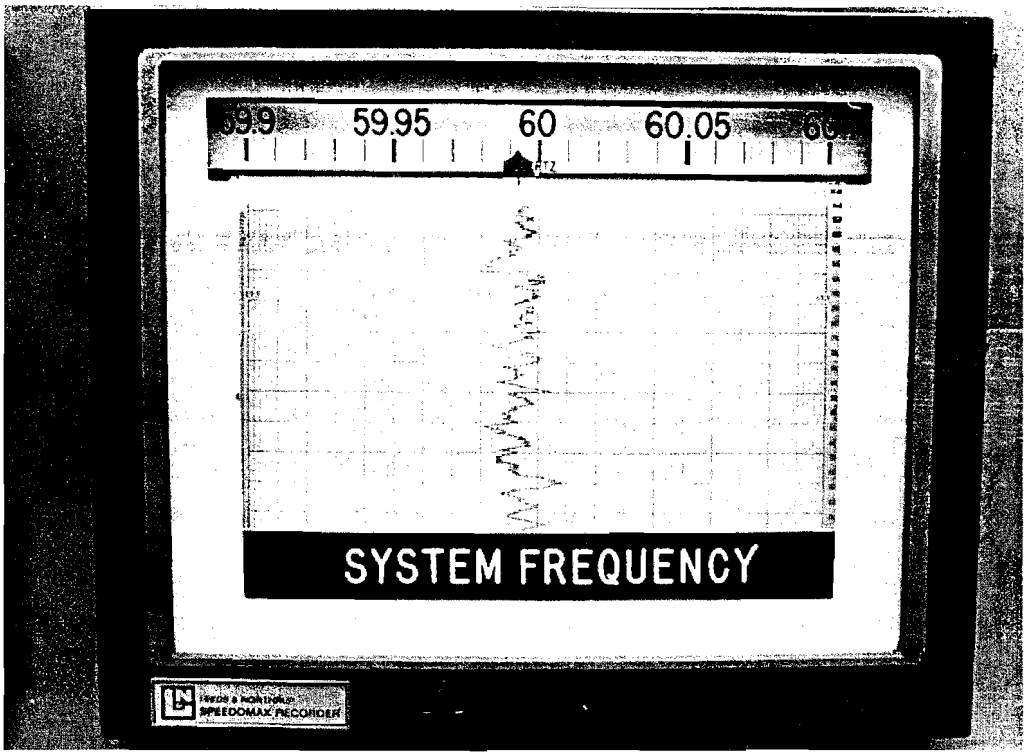
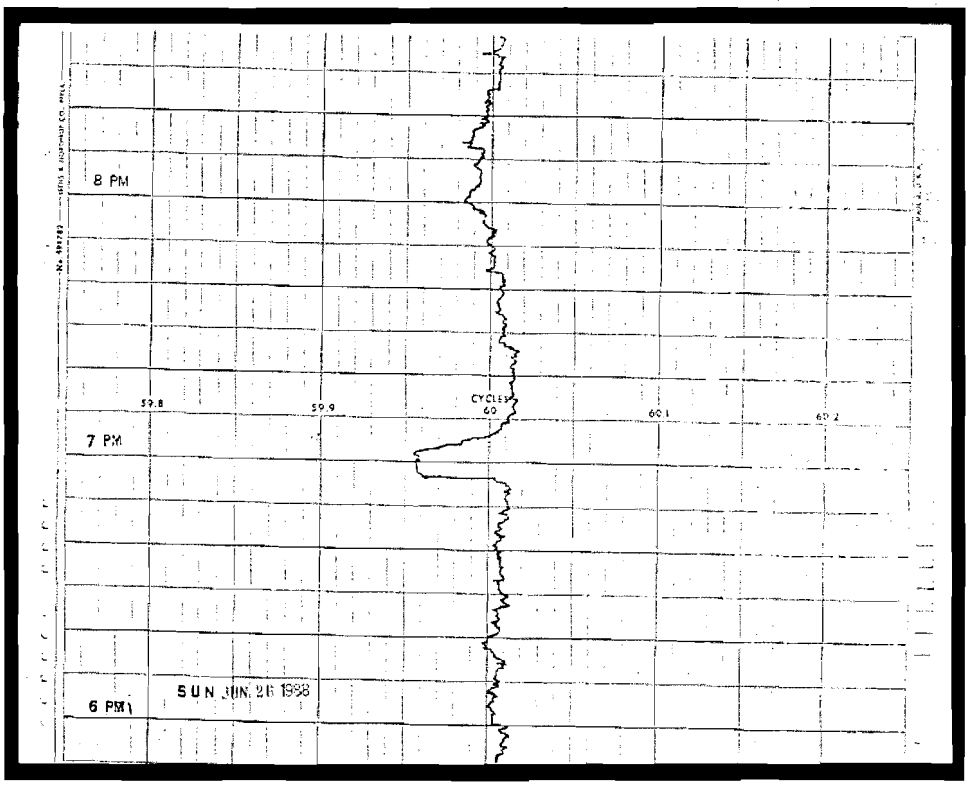


Courtesy: Bonneville Power Administration

PACIFIC HORTHWEST SYSTEM FREQUENCY

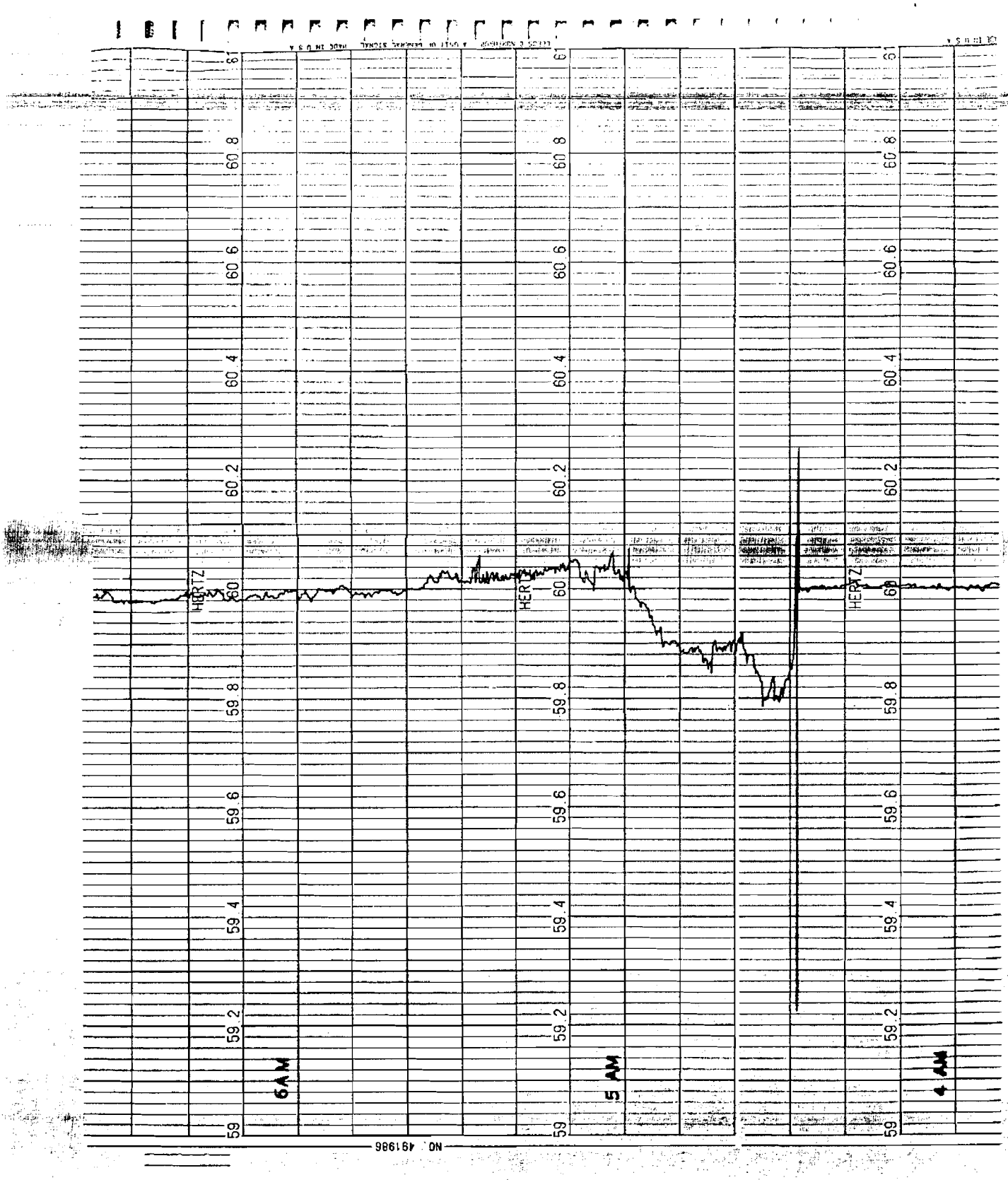
Figure 2



Courtesy: Kansas City Power & Light

FREQUENCY DIP IN KANSAS CITY WHEN DUKE POWER LOST 2OOO MEGAWATTS OF GENERATION

Figure 3



Frequency Resulting From California's January 1994 Northridge Earthquake

Figure 4

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VOLTAGE RANGES

Various standards are in use for segmenting voltages into ranges. These standards are used in electrical utilities. They have direct application for utilities' industrial, commercial and residential customers. One standard for voltage ranges divides voltages into low, medium, high, extra-high and ultra-high groups. These ranges are

Low voltage	0-600 volts
Medium voltage	601-15,000 volts
High voltage	15,001-229,000 volts
Extra-high voltage	230 kv - 999 kv
Ultra-high voltage	1000 kv and higher

Some typical low voltages and their uses are

1.5 - 12 VDC	Voltage ranges of common dry-cell batteries.
12 VDC	Voltage of automobile electrical systems.
120/240 vac	The standard voltages found in residences. The 120-volt circuits supply standard lighting and outlet circuits. The 240-volt circuits supply water heaters, ranges, clothes dryers, larger air conditioners, heat pumps and larger shop tools.
480 vac	The voltage most common for motors in industrial applications. Also very common in larger commercial buildings.

Key portions of an electrical utility system (transmission, subtransmission, and distribution) are partially described by their voltages. While in some utilities, transmission voltages can be as low as 34.5 kv, the ranges given below are consistent with those used in larger electric utility systems.

Transmission	230 kv - 765 kv
Sub-transmission	46 kv - 161 kv
Distribution	120 v - 38 kv

Equipment designed for 120 volts should be designed, at a minimum, using the American National Standards Institute (ANSI) guidelines. ANSI C84.1 provides a consensus guideline for voltages. It states that residential voltages should be between 114 volts and 126 volts at the service entrance, and between 110 volts and 126 volts at the point of use.

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CURRENT

****

* Unit of measurement: amperes, amps *

* Abbreviation: A on drawings, I in equations *

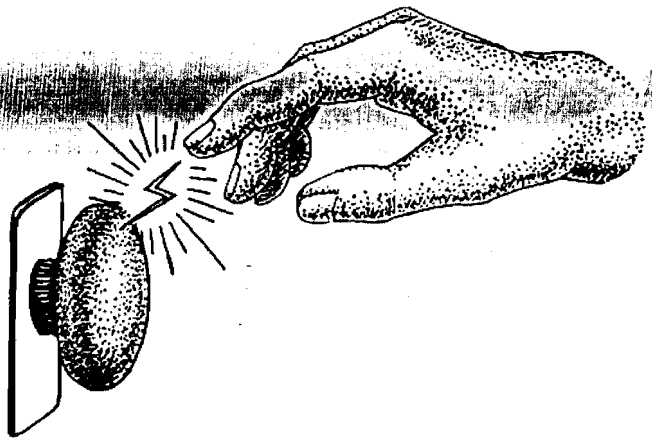
* Definition: The flow of electrons *

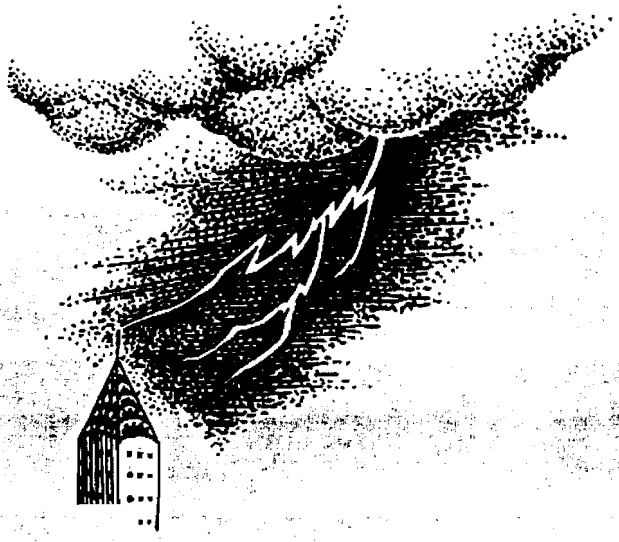
* Instrument for measuring: AC or DC ammeter *

* *

****

Voltage is potential energy that exhibits a push or force, but which does nothing by itself. Everyone has experienced walking across a carpet, and then receiving a shock when reaching for a door-knob. While walking across the carpet, a voltage difference is built up between the person and the doorknob. As the person's hand gets closer and closer to the doorknob, the voltage difference pushes current through the air between the person and the door knob. The small spark that is seen is actually current flowing. Another example occurs during a lightning storm when a voltage is built up between the clouds and the earth. The magnitude of the voltage increases to a point where the voltage pushes the current through the air. Lightning is current flowing through the air.





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Voltage is constantly attempting to push current. It can do so, however, only when a suitable path is provided. In the two examples just given, voltage is attempting to push current through the air. As a hand nears the doorknob, the path is shortened to the point that the voltage has enough force to push the current through the air. In the lightning example, the distance between the ground and clouds remains essentially the same, but the voltage between the two continues to increase until the voltage is strong enough to push the current through the air.

Although voltage can push current through air, air is not a good conductor. The better the conductor, the lower the voltage can be to push a given amount of current. Copper is a very good conductor. All modern households use copper wire inside the walls, and all appliance cords use copper wire. When an appliance is plugged into an outlet and turned on, the 120 volts pushes current out of one of the slots in the outlet, through one of the copper conductors in the appliance cord, through the appliance, and back to the other slot in the outlet through the other conductor in the appliance cord. This simple example illustrates some of the fundamental characteristics of current. Five of the most fundamentals concepts of current are, **current...**

- ☞ **is what flows**
- ☞ **is pushed and pulled by voltage**
- ☞ **always returns to its source**
- ☞ **never decreases in value in its loop**
- ☞ **"produces heat"**

A concise relationship between voltage and current can be stated as follows.

Voltage will always be there first. Voltage always tries to push and pull current. When a path is provided (a complete loop), current will then flow.

In the appliance example, 120 volts always tries to push and pull current. When a toaster is plugged in and turned on, 10 amps leave the outlet from one slot, 10 amps flow through the appliance, and 10 amps return to the outlet via the other slot.

TYPICAL CURRENTS

Electric mixer	1 amp
Color TV	1.2 amps
Clothes washer	4.3 amps
Clothes dryer	20 amps
Toaster	10 amps
Range	50 amps

A pattern can be seen with the appliances listed above. Those appliances that draw the most current are those that use electrical energy for heating purposes. This is a general rule in the electrical field.

♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

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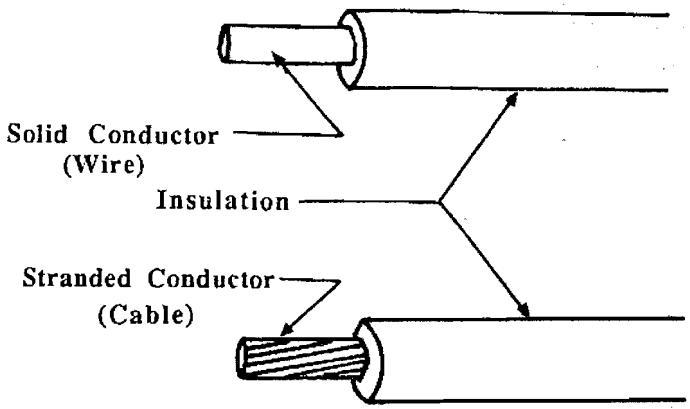
CONDUCTORS

A conductor is anything that provides a path for current flow. Air is normally not a conductor, but becomes a conductor when lightning occurs. The most common conductors in electrical systems are made of copper or aluminum, with copper being the better conductor. Copper is the more common conductor used inside electrical equipment.

While aluminum is not as good a conductor as copper, aluminum's light weight and relatively low cost make it the choice for many applications in utility and industrial applications. Among the most common of these applications are the conductors used in transmission lines, and the rigid bare tubular overhead conductors easily seen in most substations.

The rigid bare tubular overhead conductors are called buses. A bus is a conductor that is rigid. Most bus that is exposed to the elements is not insulated, is generally made of aluminum, and has a hollow circular cross section similar to a water pipe; bus found inside equipment may or may not be insulated, is generally made of copper, and normally has a solid rectangular cross section.

Conductors are specified by the size of the copper or aluminum, and by the type of insulation. Rectangular bus is specified by its physical dimensions such as 1/4 inch by 4 inches. Tubular bus is specified by the diameter of the bus, and by the thickness of the walls of the tube.



Wire and cable are specified by the diameter of the conductor, and by the type of insulation. Larger diameter cable uses thousands-of-circular-mils (MCM or KCM or KCMil) as the unit of measurement. Smaller diameter wire and cable uses the American Wire Gauge (AWG) unit of measurement. Both of these units of measurements are included in the table on page E111-2, and are shown on page E111-3.

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INSULATION

The insulation specification on all insulated wire and cable has two primary components. One of these is the voltage rating. This rating specifies the maximum voltage that should be applied to the conductor. A 15 kv (15,000-volt) cable, for example, could be used on a 12.4 kv system, a 13.2 kv system, a 13.8 kv system or a 14.4 kv system; but could not be used when the voltage exceeded 15 kv.

The other component for specifying insulation covers the heat-resistance characteristics of insulation. As current flows, it produces heat. The higher the current, the greater the temperature. The heat caused by the current heats the insulation and excessive heat destroys the insulation. For this reason, insulation must be specified for a maximum allowable temperature. Since the current produces the heat, the heat-resistance characteristic of each type of insulation is specified by a maximum current level. The maximum current levels for some of the more common types of insulation are included in the table provided below.

By increasing the heat-resistance characteristics of the insulation, more current can be carried. There is, however, another alternative. The amount of copper or aluminum can be increased which will allow more current to flow without any increase in temperature. The effect of conductor size on the amount of allowable current for the same type of insulation can also be seen in the table provided below.

Conductor Data of Single Insulated Conductors, Rated 0 through 2000 Volts, In Free Air and Based on Ambient Air Temperature of 30°C (86°F).

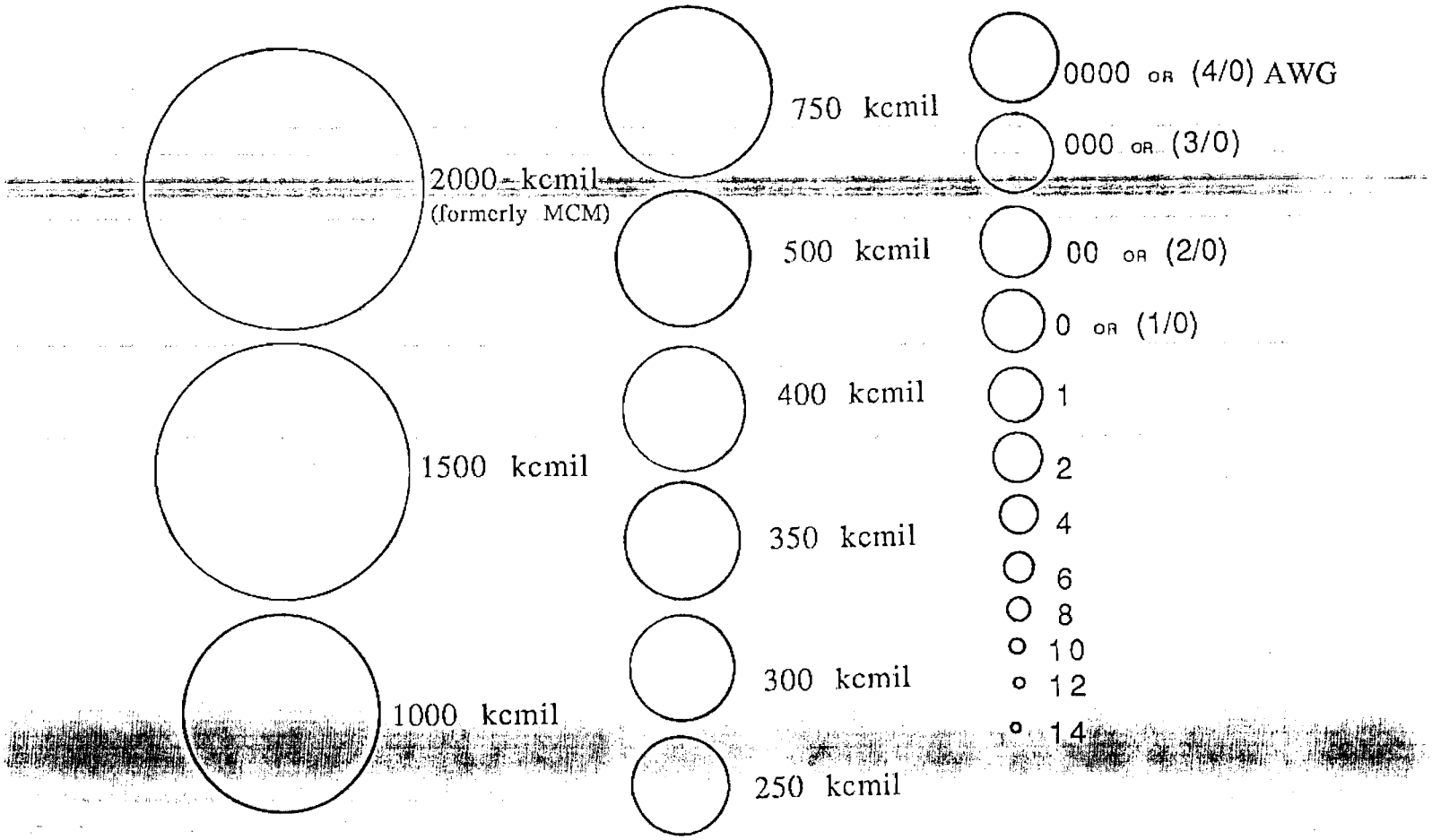
Insulation Temperature Rating		60°C		75°C		85°C		90°C	
Type of Conductor		CU	AL	CU	AL	CU	AL	CU	AL
Size of Conductor (AWG/KCMil)	Diameter in inches	Current in Amperes							
2000	1.63	1155	960	1385	1150	1505	1250	1560	1335
1500	1.41	980	795	1175	950	1275	1035	1325	1075
1000	1.15	780	625	935	750	1020	815	1055	845
750	0.998	655	515	785	620	855	675	855	700
500	0.813	515	405	620	485	675	525	700	545
400	0.728	455	355	545	425	595	465	615	480
350	0.681	420	330	505	395	550	430	570	445
300	0.630	375	290	445	350	485	380	505	395
250	0.575	340	265	405	315	440	345	455	355
4/0	0.528	300	235	360	280	390	305	405	315
3/0	0.470	260	200	310	240	335	265	350	275
2/0	0.419	225	175	265	210	290	225	300	235
1/0	0.373	195	150	230	180	250	195	260	205
1	0.332	165	130	195	155	215	165	220	175
2	0.292	140	110	170	135	185	145	190	150
3	0.260	120	95	145	115	160	125	165	130
4	0.232	105	80	125	100	135	105	140	110
6	0.184	80	60	95	75	100	80	105	80
8	0.146	60	45	70	55	75	60	80	60
10	0.128	40	35	50	40	55	40	55	40
12	0.116	30	25	35	30	40	30	40	35
14	0.073	25	--	30	--	30	--	35	--

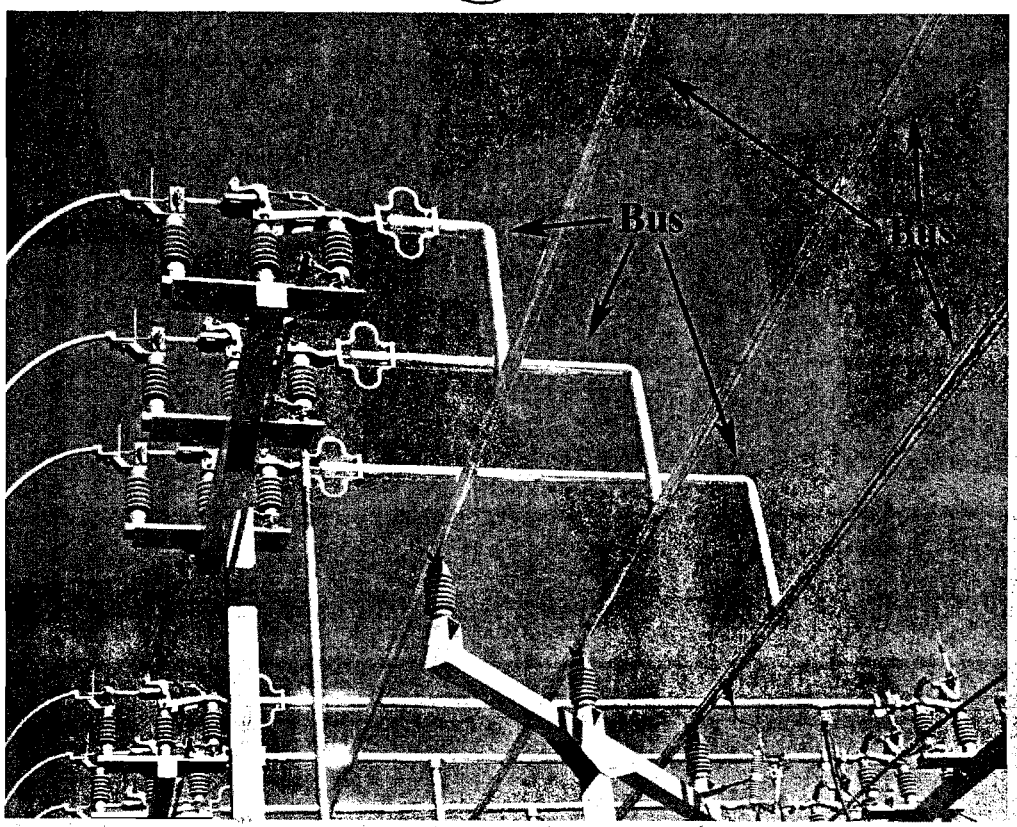
Types of Insulation: 60°C - TW
75°C - FEPW,RH,RHW,THW,THWN,XHHW,ZW
85°C - V
90°C - TA,TBS,SA,AVB,SIS,FEP,FEPB,RHH,THHN,XHHW,MI

SOURCE: National Electrical Code® 1987

NOTE: The data provided above is for reference purposes only. current carrying capabilities of conductors may be modified by the National Electrical Code®. Any determination of wire size and type of insulation for an actual application must use the National Electrical Code® as the guide.

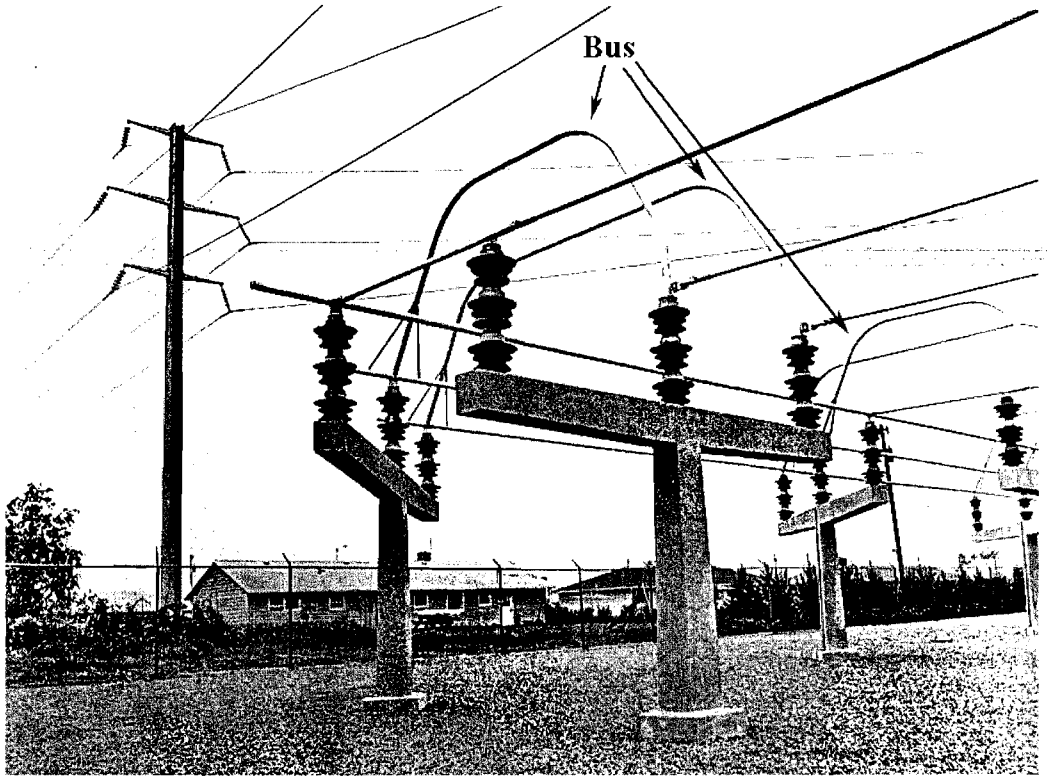
Wire and Cable Sizes





Courtesy: Skip Collier

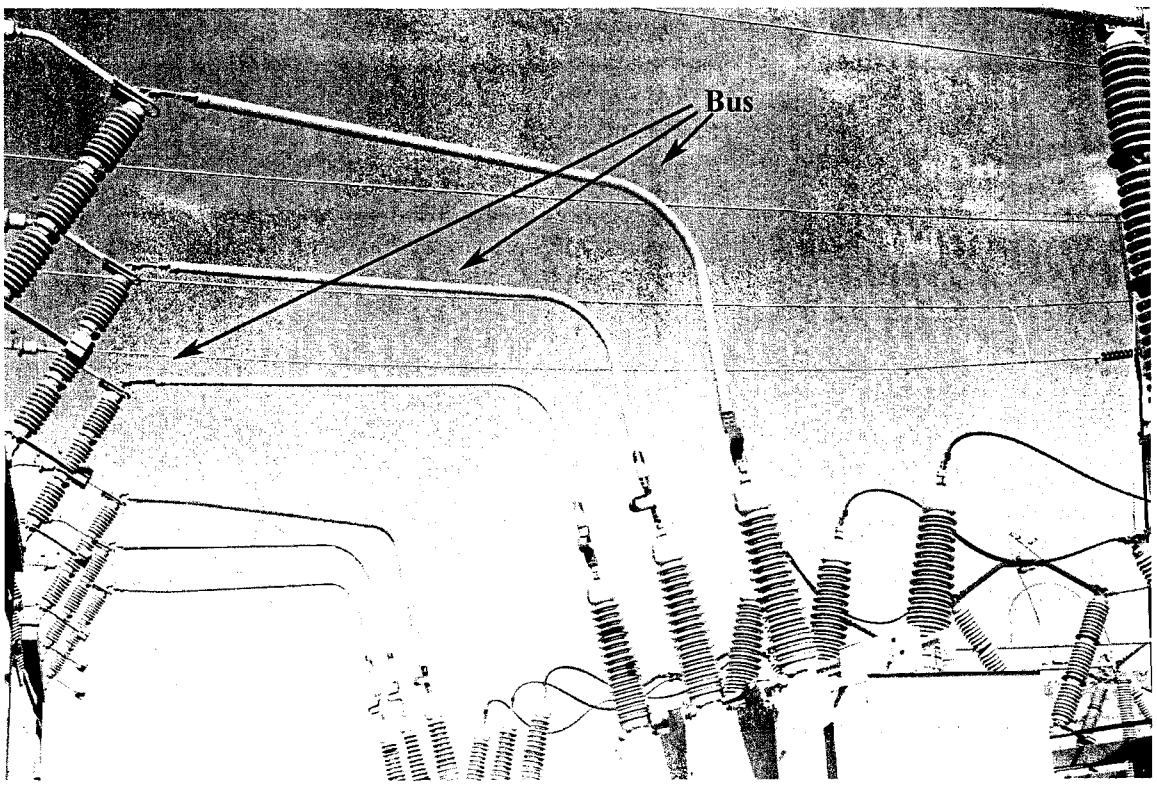
Bus
Figure 1



Courtesy: Bonneville Power Administration

BUS

Figure 2



Courtesy: Skip Collier

BUS

Figure 3

♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

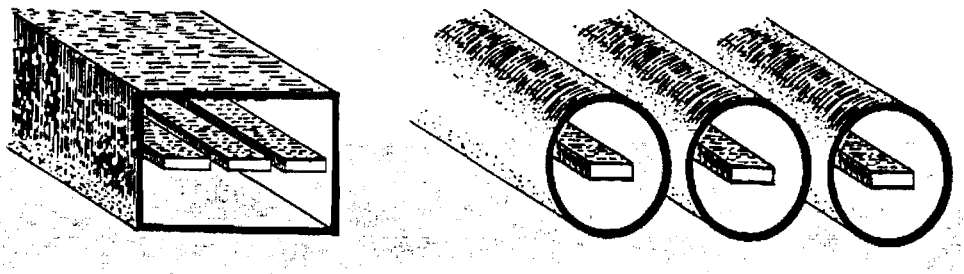
CONDUIT AND BUS DUCT

Conduit is pipe that contains wire or cable. The purpose of conduit is to provide physical protection for the insulation of the wire or cable that run inside the conduit. This protection is from damage that could be caused by moisture, chemicals, people or animals.

The most common materials from which conduit is made are steel, aluminum, fiberglass-reinforced epoxy and polyvinyl chloride (PVC). The size of conduit is directly dependent on the sizes of the conductors in the conduit. The reason for this is that since heat is one of insulation's worst enemies, the heat generated in a conduit must not rise to a level that would damage the insulation. To ensure this, a maximum number of conductors of a specific size (AWG or MCM, KCM or kcmil) is specified by the National Electrical Code®. When conductors of different sizes are placed in the same conduit, the conductors cannot fill more than a specified percentage of the total volume of the conduit. These limits ensure that there is enough air in the conduit to allow adequate cooling. If these limits were exceeded, the conduit would become an oven heated by the current flowing through the conductors. This oven would bake the insulation to a point to where it would fail, thus causing an outage.

Bus Duct is an enclosure that contains bus. Usually the bus is copper, and this copper bus may or may not be insulated. Bus duct is used to keep rodents, people, and dust and other contaminants away from the bus.

Bus comes in two basic designs, non-segregated-phase bus duct and isolated-phase bus duct. Non-segregated-phase bus duct normally has a rectangular cross section, is made of steel and contains the three phases side-by-side. Isolated-phase bus duct normally is tubular. Isolated-phase bus duct has one bus-duct "tube" for each of the three phases. Figure 1 shows both non-segregated-phase bus duct and isolated-phase bus duct. Figure 2 shows non-segregated-phase bus duct in an actual application.



NON-SEGREGATED-PHASE BUS DUCT ISOLATED-PHASE BUS DUCT

Figure 1

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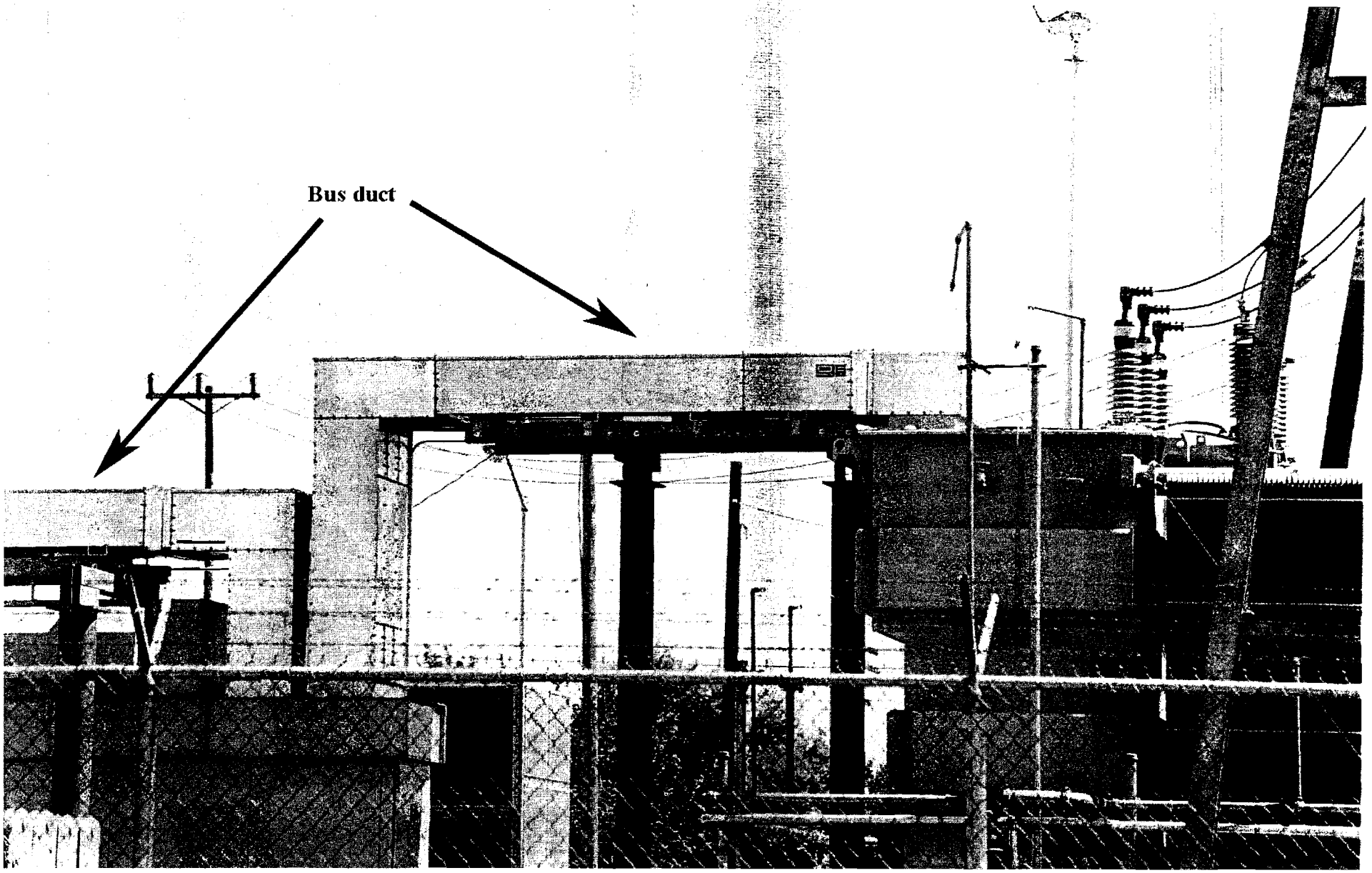


Courtesy: Skip Collier

Bus Duct

Figure 2

♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

GROUNDING

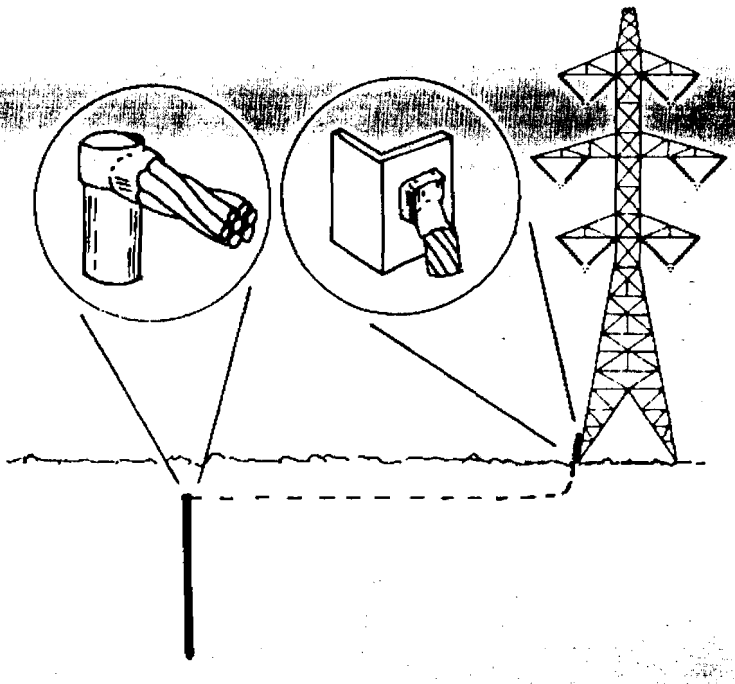
****

* Definition: Connecting an object to the earth with an electrical conductor. *

* Symbol: *

****

In the simplest terms, grounding is connecting an object to the earth with an electrical conductor such as copper. One of the common ways in which this is done is driving an 8-foot copper rod into the ground, connecting a bare copper cable to the rod, and connecting the other end of the cable to the equipment or object that is being grounded.



Grounding on overhead transmission and distribution systems provides lightning with an easy path to ground. This decreases lightning-caused outages. Grounding also prevents or minimizes equipment damage when a problem occurs. Grounding provides workers with a safer environment. The safer environment is illustrated in the example in which an energized conductor comes into contact with a metal cabinet at the same time a worker is touching the cabinet. If the cabinet

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is properly grounded, the majority of the current that flows from the conductor and through the cabinet will flow into the ground through the grounding rod. If, however, the cabinet does not have a good ground, a large amount of current may flow through the worker and then into the ground. If the latter occurs, the worker may be injured or killed.

The ability of a ground to minimize equipment damage occurs as a result of an electrical failure. In a particular type of failure, the system voltage can increase to a level at which the insulation is destroyed due to the high voltage. This can occur when the electrical system is not grounded. Grounding the system prevents the voltage from increasing above the design level, and this in turn, prevents the destruction of the insulation.

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RESISTORS

****

* Unit of Measurement: Ohm *

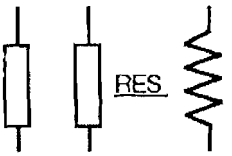
* Abbreviation: R, RES *

* Purpose: Limiting or reducing current flow *

* Instrument for Measuring: Ohmmeter *

* *

* *

* Symbol:  *

* *

* *

****

Voltage pushes and pulls current through a conductor. Current is the flow of electrons. A good conductor, such as copper, is a material in which the electrons are easily pushed and pulled by the voltage. An insulator is a material in which the electrons are extremely difficult to move, such as in glass.

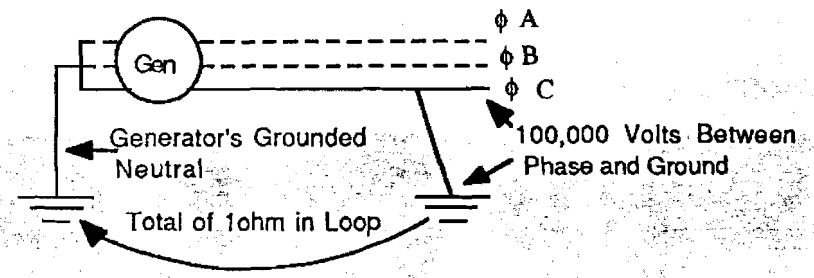
A resistor is a device that has electrical characteristics between those of a conductor and an insulator. Its electrons are more tightly bound than in a good conductor, but they still can be moved by voltage. Since the electrons do not move as easily in a resistor, when the same voltage is applied less current will flow in a resistor than in a good conductor. The purpose of a resistor is to limit the flow of current in a circuit.

In Figure 1, there is 1 ohm in the ground loop. The generator will push 100,000 amps in the ground loop, as shown in the following calculations.

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}}$$

$$= \frac{100{,}000\ \text{V}}{1\ \Omega}$$

$$= 100{,}000\ \text{amps}$$



PHASE GROUNDED WITHOUT GROUNDING RESISTOR

Figure 1

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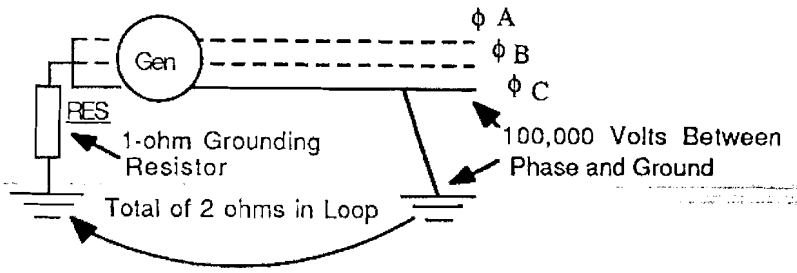


PHASE GROUNDED WITH GROUNDING RESISTOR

Figure 2

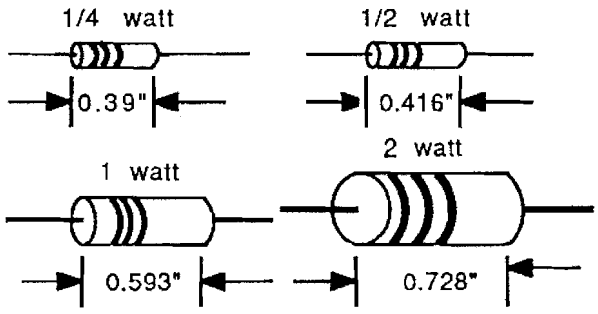
When a 1-ohm resistor is placed in the neutral-grounding circuit, as shown in Figure 2, the total resistance in the ground loop will be increased to 2 ohms. The current in the ground loop will be reduced to 50,000 amps. This will result in less equipment damage.

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}}$$

$$= \frac{100{,}000\ \text{V}}{2\ \Omega}$$

$$= 50{,}000\ \text{amps}$$

Resistors in control and communication circuits are usually wire-wound or made of a carbon composition. Carbon-composition resistors come in 0.25-watt, 0.50-watt, 1-watt, and 2-watt. The actual sizes of the resistors in these wattages are shown in Figure 3.



CARBON-COMPOSITION RESISTOR SIZES

Figure 3

Carbon-composition resistors use color coding of bands on the resistors to represent their ohmic value and their tolerance. The first band represents the first digit of the value, the second band represents the second digit, the third band represents the multiplier, and the fourth band, when present, represents the tolerance. These values are given in the table in Figure 4.

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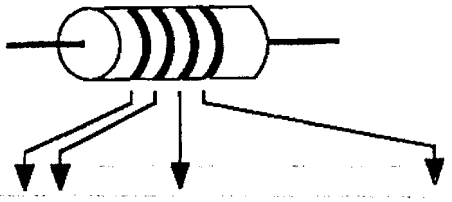

COLOR	VALUE	MULTIPLIER			TOLERANCE
Black	0	10^0	=	1	--
Brown	1	10^1	=	10	±1%
Red	2	10^2	=	100	±2%
Orange	3	10^3	=	1,000	±2%
Yellow	4	10^4	=	10,000	±4%
Green	5	10^5	=	100,000	--
Blue	6	10^6	=	1,000,000	--
Violet	7	10^7	=	10,000,000	--
Gray	8	10^8	=	100,000,000	--
White	9			-	--
Gold	-	0.1			±5%
Silver	-	0.01			±10%
Black or no color	-	-			±20%

Composition non-insulated resistors have a black body
Composition insulated resistors have a colored body
Wire-wound resistors have the first color band double width

CARBON-COMPOSITION RESISTOR COLOR CODING

Figure 4

Many of the resistors used in industrial and utility applications are much larger than the color-coded resistors. These power resistors normally vary in size up to 20 inches in length, and 2 inches in diameter. The electrical characteristics of typical power resistors are provided in the table in Figure 5.

Wattage Range	Current Range	Resistance Range
125-190 watts	0.25-50 amps	0.077-2000 ohms
280-440	0.25-96	0.049-4500
425-700	1.0-96	0.075-450
600-950	1.0-96	0.10-610
750-1220	1.0-96	0.13-780

POWER-RESISTOR DATA

Figure 5

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OHM'S LAW

Voltage pushes and pulls current through a conductor. The amount of current that can be pushed and pulled through a conductor is dependent on the resistance of the conductor. The relationship between voltage, current and resistance is defined by Ohm's Law. One of the Ohm's Law equations is

$$(1) \qquad \text{Current} = \frac{\text{Voltage}}{\text{Resistance}}$$

Assume that a toaster with a 12-ohm heating element is plugged into a 120-volt outlet and turned on. The amount of current flowing through the toaster would be calculated as follows.

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}}$$

$$= \frac{120 \text{ volts}}{12 \text{ ohms}}$$

$$= 10 \text{ amps}$$

Equations 1 is used to calculate current when voltage and resistance are known. When the current and resistance are known the voltage can be calculated using Ohm's Law in the format shown as equation 2.

$$(2) \qquad \text{Voltage} = \text{Current} \times \text{Resistance}$$

Assume that 2 amps are flowing through a 4-ohm resistor. The voltage produced across the resistor would be calculated as follows.

$$\text{Voltage} = \text{Current} \times \text{Resistance}$$

$$= 2 \text{ amps} \times 4 \text{ ohms}$$

$$= 8 \text{ volts}$$

The third format for the Ohm's Law equation allows resistance to be calculated when voltage and current are known. This equation is

$$(3) \qquad \text{Resistance} = \frac{\text{Voltage}}{\text{Current}}$$

If a 24-volt circuit has 12 amps flowing through it, the resistance of the circuit would be

$$\text{Resistance} = \frac{\text{Voltage}}{\text{Current}}$$

$$= \frac{24 \text{ volts}}{12 \text{ amps}}$$

$$= 2 \text{ ohms}$$

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POWER (WATTAGE)

```
*********************************
*  Unit of measurement: Watts, kilowatts, megawatts  *
*                                                     *
*  Abbreviations: W, KW, MW for watts                 *
*                 P for power                         *
*  Definition: Electrical work. Calculated by         *
*              multiplying voltage by current*        *
*                                                     *
*********************************
```

*** Note:** The calculation of power in this section is limited to DC circuits, and to single-phase AC circuits with a resistive load.

Voltage by itself does no work. Current by itself does no work. The two must act together to produce work. The power produced by voltage and current working together is measured in watts. It is calculated by multiplying the voltage by the current.

(1) **POWER = VOLTAGE X CURRENT**

Given a 120-volt source that is pushing 0.5 amps through a device, the power consumption is

$$\begin{aligned} \textbf{POWER} &= \textbf{VOLTAGE X CURRENT} \\ &= 120 \text{ volts X } 0.5 \text{ amps} \\ &= 60 \text{ watts} \end{aligned}$$

When a 60-watt light bulb in a 120-volt circuit is turned on, the current flowing through it is 0.5 amps. The wattage of a device can be calculated by multiplying the voltage by the current. When the wattage and voltage are known, the current can be calculated by dividing the wattage by the voltage.

(2) $$\textbf{CURRENT} = \frac{\textbf{WATTAGE}}{\textbf{VOLTAGE}}$$

When a 1200-watt toaster is plugged into a standard 120-volt outlet, the current flowing in the circuit is calculated as follows.

$$\begin{aligned} \textbf{CURRENT} &= \frac{\textbf{WATTAGE}}{\textbf{VOLTAGE}} \\ &= \frac{1200 \text{ watts}}{120 \text{ volts}} \\ &= 10 \text{ amps} \end{aligned}$$

Wattage is the measurement of electrical power. Horsepower is the measure of mechanical power. The relationship of the two is

746 Watts = 1 Horsepower

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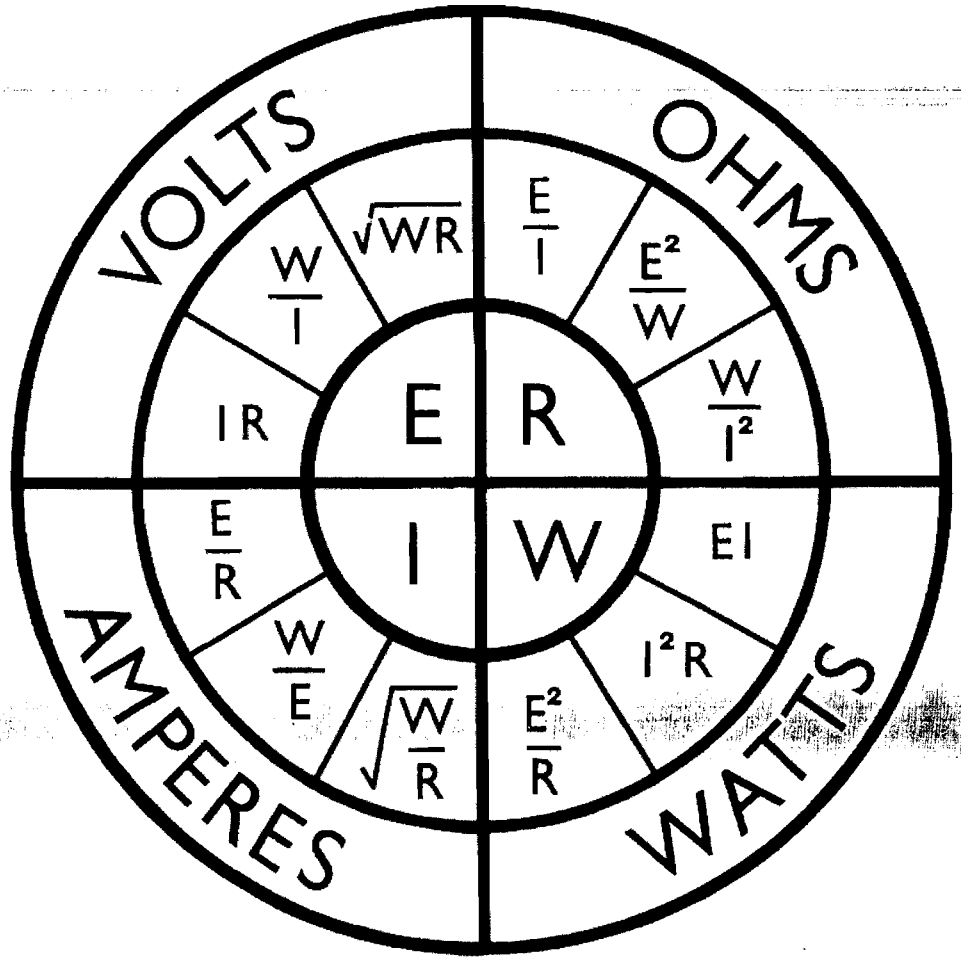

OHM'S LAW WHEEL

The Ohm's Law Wheel, shown above, provides the equations for determining voltage, resistance, wattage and current. It applies to DC circuits, and to single-phase AC circuits that have a resistive load.

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ELECTRICAL ENERGY CONSUMPTION

```
*********************************
*  Unit of Measurement: Kilowatt-hours        *
*  Measured with: Watt-hour meter             *
*  Abbreviation: kWh or kWhr                  *
*  Definition: Power consumed in an interval of time  *
*  Calculated by:  Power consumed multiplied by the  *
*                  interval of time           *
*                                             *
*********************************
```

Electrical power is calculated by multiplying the voltage by the current. Electrical utility companies, however, do not use power as the primary billing component because power has no time associated with it. For instance, if a 1200-watt toaster is used for 1 minute, it is using 1200 watts of power. If it is used for 10 minutes, it is still using 1200 watts of power. In both cases, the power consumption is the same.

In order to bill customers, utilities use energy. Energy combines the power consumption AND the length of time the power is used. This is calculated by multiplying the power consumption by the time (normally in hours) in which it is consumed. In equation form, this is expressed as:

Energy Consumption = Power X Time

For example, if a toaster is plugged into a 120-volt outlet, turned on, and draws 10 amps for 2 hours, the energy consumption would be calculated as follows

Energy Consumption = Power X Time
= 120 volts x 10 amps x 2 hours
= 1200 watts x 2 hours
= 2400 watt-hours
= 2.4 kilowatt-hours (or 2.4 kWh)

It is very easy to calculate the energy consumption when the power does not vary. This situation, however, is virtually non-existent. When the power level varies minute-by-minute, calculating the energy consumption mathematically becomes much more difficult. Utility companies perform this "calculation" with electro-mechanical or solid-state watt-hour meters.

Figure 1 on the next page is a drawing of the dials of an electro-mechanical watt-hour meter. Figure 2 shows a residential watt-hour meter. Current flow produces a magnetic field that causes a disk to rotate. Increased current levels cause the disk to turn faster, and decreased current levels cause the disk to turn slower. The shaft of the disk is connected by gears to the set of dials shown in Figures 1 and 2. These dials accumulate the total energy consumption.

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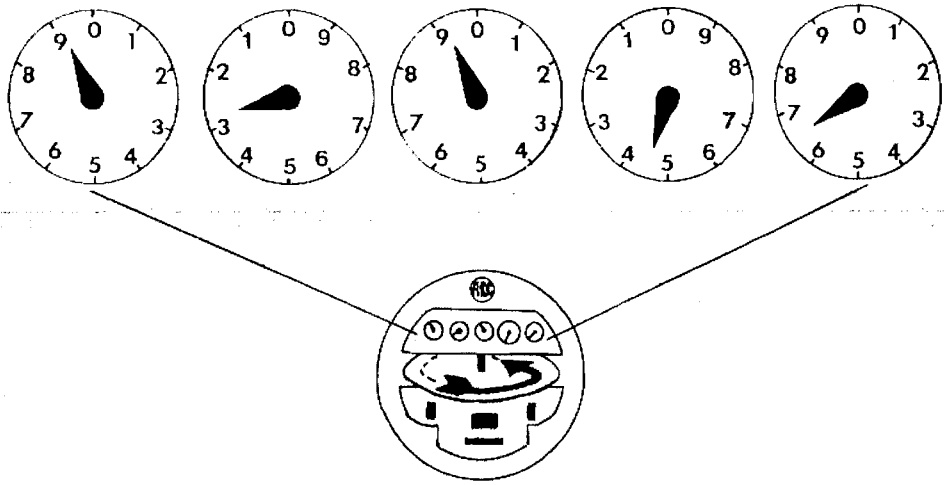
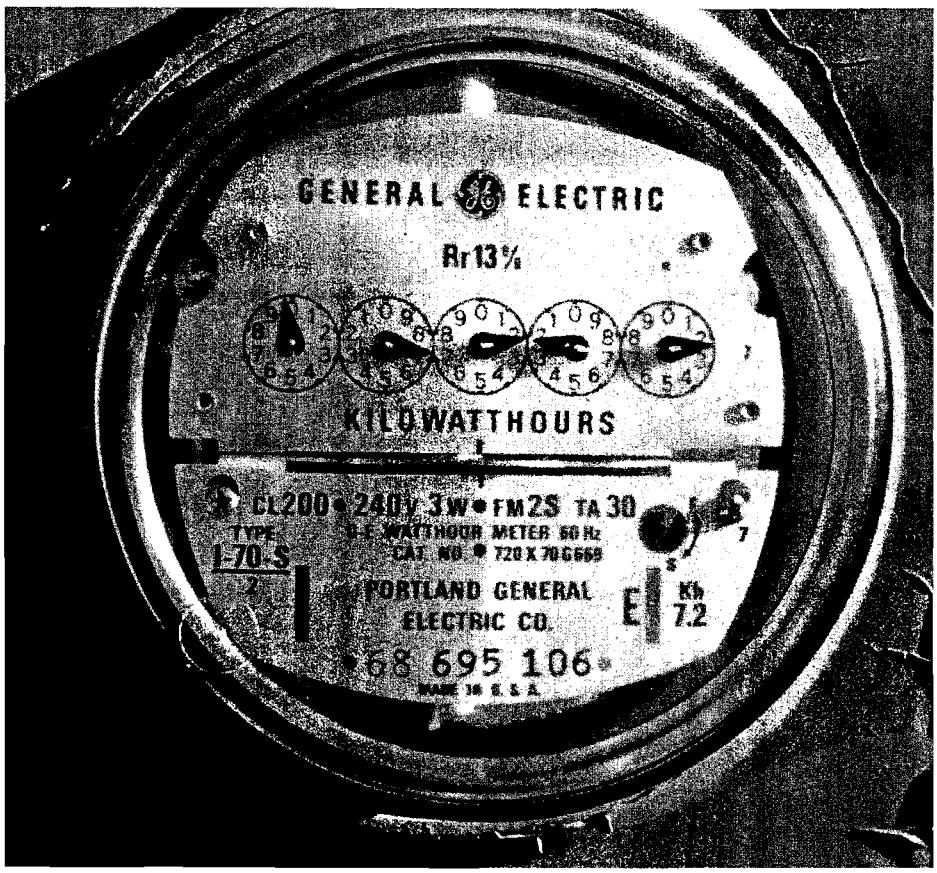


WATT-HOUR METER DIALS

Figure 1



Courtesy: Skip Collier

RESIDENTIAL WATT-HOUR METER

Figure 2

♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

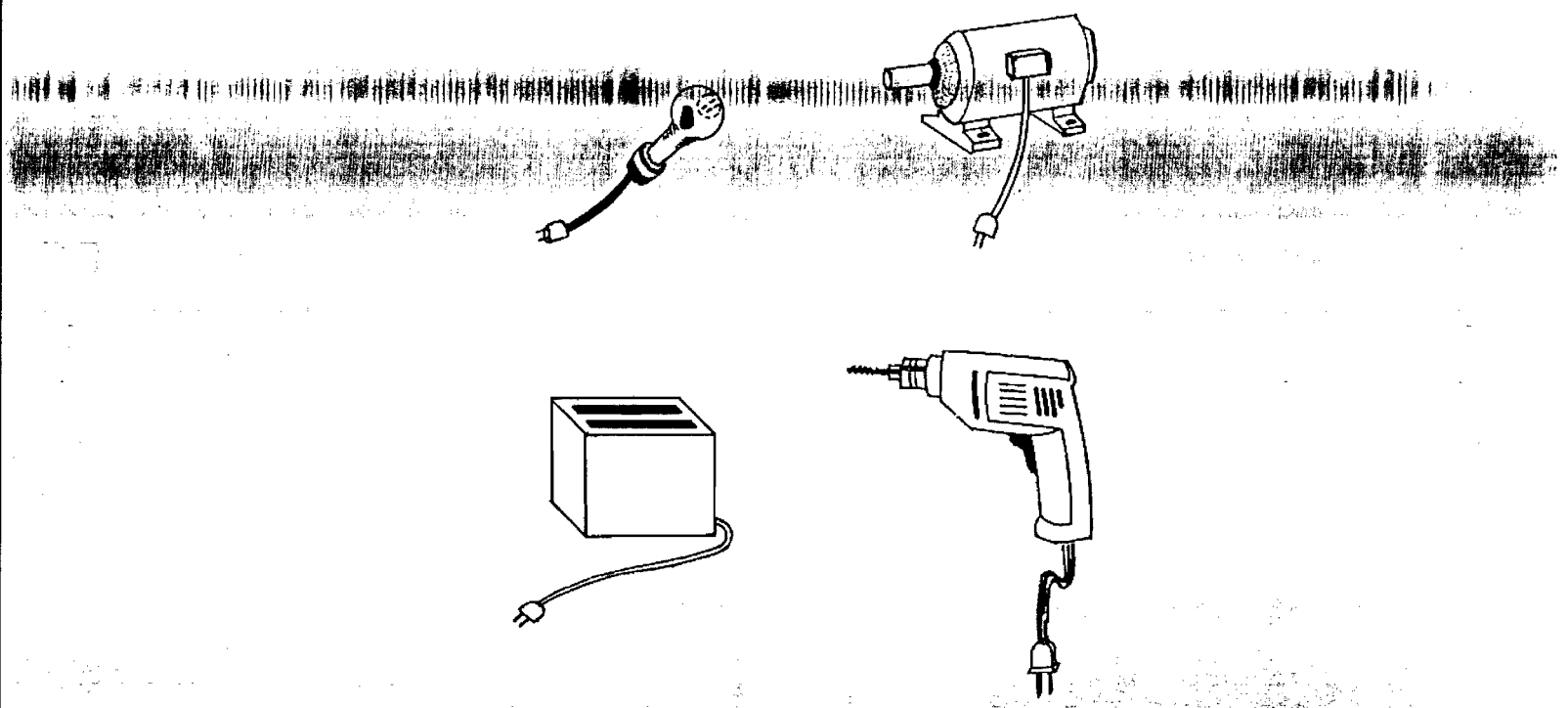
LOAD

A load is any device or system that draws current from a voltage source. (Load is also called demand) A load can be a light bulb, a motor, an industrial plant, an entire city, or anything else that draws current.

When a circuit, device or system is described as fully loaded, it is drawing the maximum recommended current from the voltage source. Any additional current will cause overheating and subsequent damage. The term "overloaded" means that some part of the system is overheated.

The determination of whether or not a system is fully loaded can be done by merely comparing the magnitude of the current that is flowing with the maximum rated current.

When current is drawn from a voltage source, the resultant quantity is power. Another way to look at load (or demand) is to consider it as power consumption. Power is measured in watts; therefore, load (or demand) is also measured in watts. Figure 1 shows some examples of load devices.



EXAMPLES OF LOAD DEVICES

Figure 1

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CAPACITORS

****

* Unit of Measurement: Farads *

* Abbreviation: f *

* Purpose: To temporarily store voltage *

* *

* *

* Symbols: *

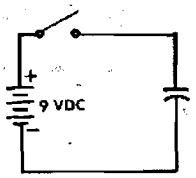
* *

* *

****

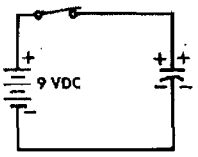
A capacitor is a temporary voltage-holding or voltage-storing device. Capacitors are made with two conductive plates separated by an insulating material. When voltage is applied across the plate, an electrical charge builds up on the plates (one becomes positive and the other negative) since current cannot easily flow through the insulating material.

In Figure 1, no voltage is applied across the capacitor when the switch is open. When the switch is closed (Figure 2), electrons attempt to flow but pile up on one of the plates making the plate negative. A positive charge builds up on the other plate as the electrons leave. When the switch is opened, the charges remain on the plates (Figure 3) but slowly dissipate.



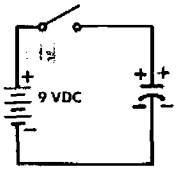
No Voltage on Capacitor

Figure 1



Voltage Applied To Capacitor

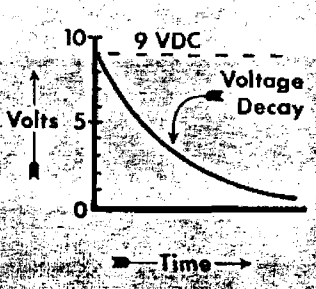
Figure 2



Voltage Remains After Source is Disconnected

Figure 3

The graph of the capacitor's voltage as its dissipates or decays is shown in Figure 4.



DECAY OF CAPACITOR VOLTAGE

Figure 4

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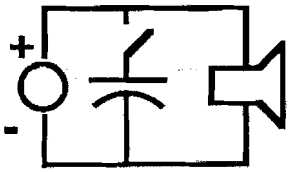
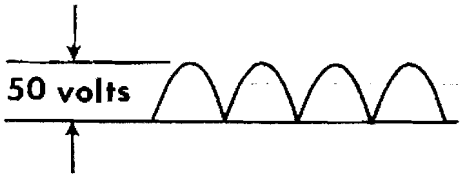
Figure 5 shows a circuit with a DC voltage source, a capacitor, a switch to connect or disconnect the capacitor, and a speaker. Figure 6 shows the shape of the voltage source's DC waveform.

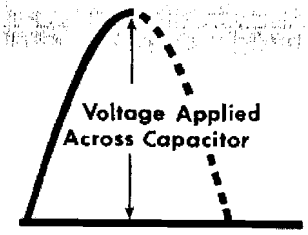


SPEAKER CIRCUIT
Figure 5

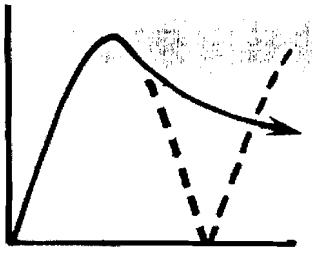


HIGH-RIPPLE-DC VOLTAGE
Figure 6

When the switch is open, the capacitor is not part of the circuit. The voltage applied to the speaker then has the same shape as the source signal shown in Figure 6. This high-ripple voltage produces an objectionable hum from the speaker. When the switch is closed, the source voltage is applied across the capacitor. As the source voltage builds from zero to a peak, this voltage is also applied to the capacitor (Figure 7) and the capacitor charges to the peak 50 volts. As the waveform reaches the peak and starts back to zero (indicted by the downward dashed line in Figure 8), the capacitor, as a voltage-storing device, attempts to hold the voltage at 50 volts. As the capacitor loses its energy, the capacitor voltage decays towards zero as shown by the solid arrow is Figure 8.

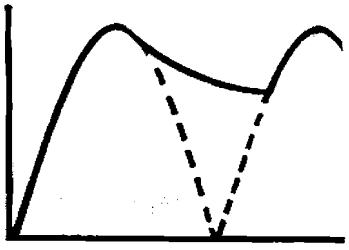


VOLTAGE APPLIED
TO CAPACITOR
Figure 7



VOLTAGE DECAY
OF CAPACITOR
Figure 8

However, before the voltage can decay back to zero, the source voltage returns to zero and starts upward towards a peak. The source voltage catches the decaying capacitor voltage and recharges it back to the peak voltage (Figure 9). This discharge-recharge action continues, resulting in the waveform shown in Figure 10. The dashed waveform in Figure 10 is the source voltage. The solid waveform is the voltage applied to the speaker that allows the desired communication.



VOLTAGE BEING "HELD UP"
BY THE CAPACITOR
Figure 9

VOLTAGE APPLIED
TO THE SPEAKER
Figure 10

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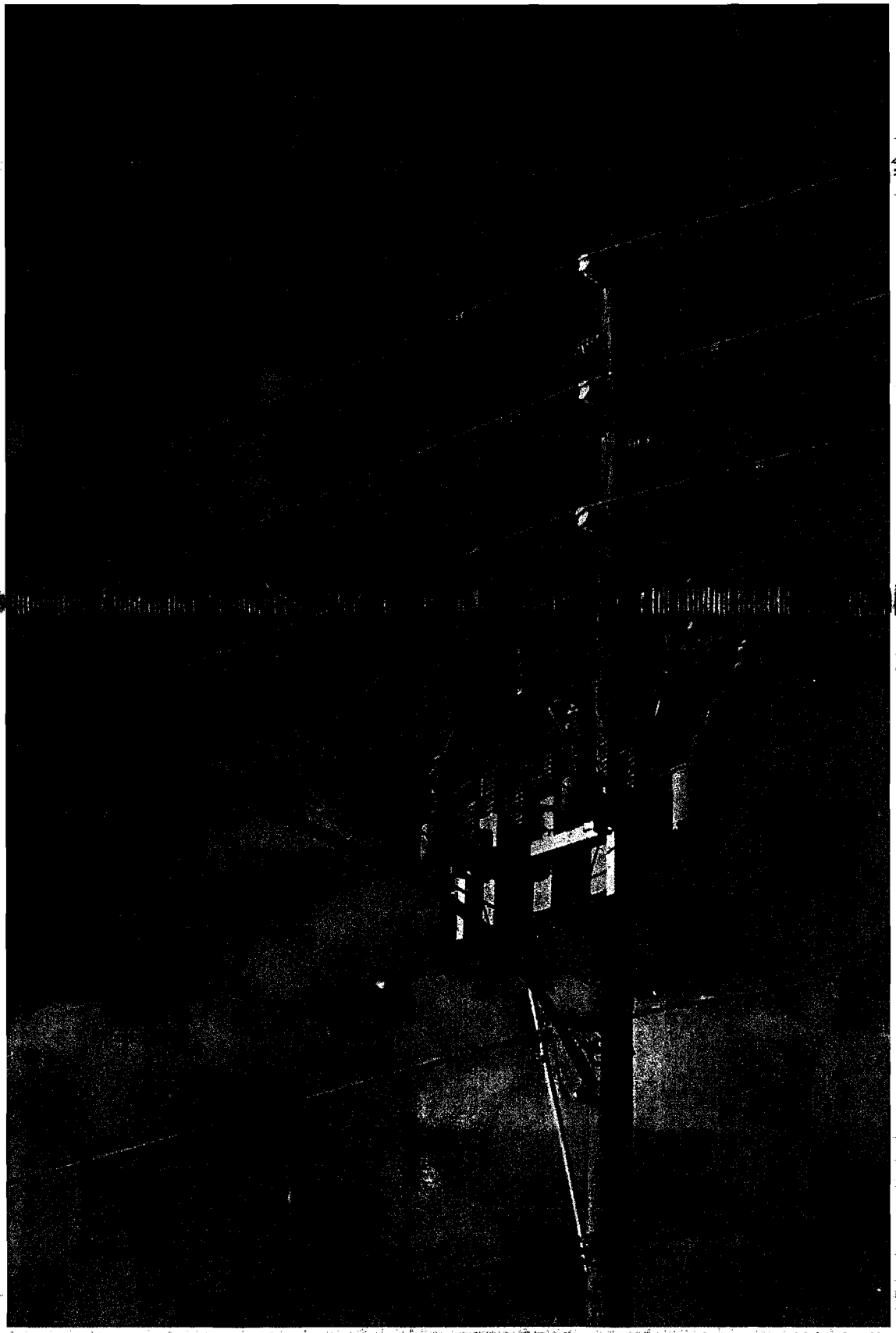


Courtesy: Skip Collier

POLE MOUNTED SWITCHED CAPACITORS

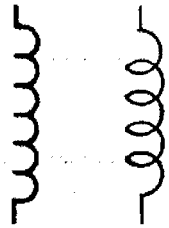
Figure 11

♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

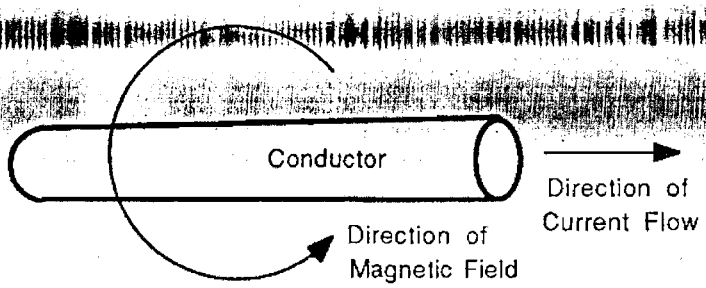
INDUCTORS

Unit of measurement: Henry
Abbreviation: H
Function: Temporarily stores current
Description: A coil of conductor
Other name: Reactor

Symbols:



When current flows, a magnetic field is produced. The direction of this magnetic field, assuming positive to negative current flow, is shown in Figure 1.



CURRENT FLOW AND ITS ASSOCIATED MAGNETIC FIELD

Figure 1

The magnetic fields have energy. Inductance (represented by an "L") is a measure of this energy. When a conductor is wound into a coil, the magnetic fields reinforce each other and the total inductance increases.

Inductors are coils of conductors that store current in the form of a magnetic field. The more turns there are in the coil, the greater the inductance, and the greater the ability to store current. Some inductors are constructed with an iron core such as shown in Figure 2. Others are coils of conductors with only the cooling fluid (normally air or insulating oil) in the center.

IRON-CORE INDUCTOR

Figure 2

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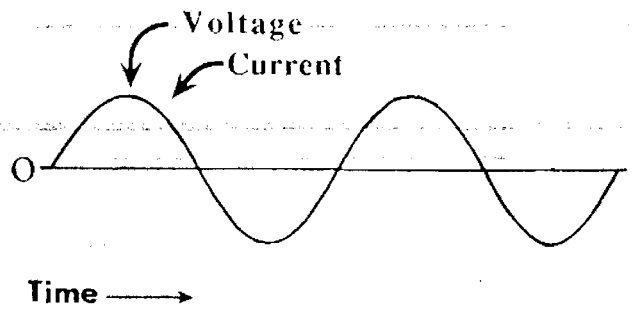
RESISTIVE, INDUCTIVE AND CAPACITIVE CIRCUITS

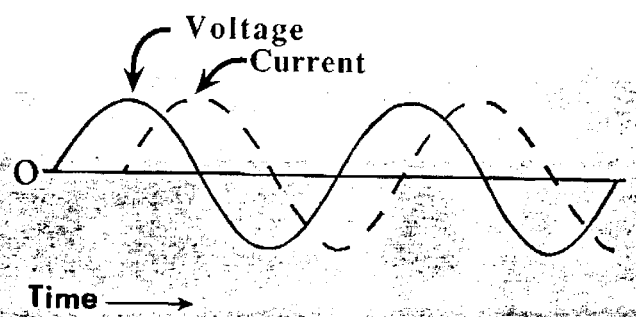
Electrical circuits can be classified into one of three categories depending on the type of load. These categories are resistive, capacitive and inductive. In a resistive circuit, the voltage and current waveforms are in-phase and cross the time axis at the same time. This is shown in Figure 1.



RESISTIVE CIRCUIT

Figure 1

In inductive and capacitive circuits, the voltage and current waveforms do not cross the axis at the same time. **In an inductive circuit, the inductive devices momentarily retard the current. This causes the current waveform to cross the axis later in time.** Since the voltage is not being retarded, the voltage waveform crosses the axis at the same time it does in a resistive circuit. Inductive circuits are lagging because the current lags the voltage. This lagging characteristic of the voltage and current waveforms is shown in Figure 2.



INDUCTIVE CIRCUIT

Figure 2

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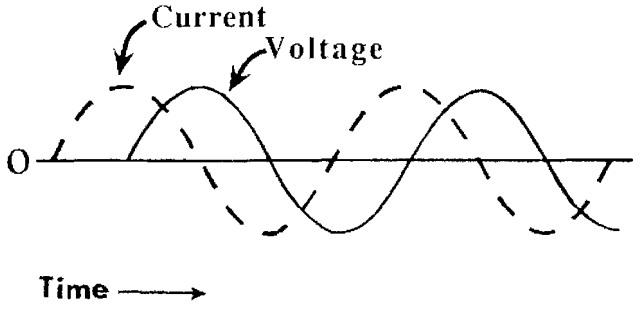
In a capacitive circuit, the capacitive devices momentarily store the voltage. Thus causes the voltage waveform to cross the axis later in time. Since the current is not being stored, the current waveform crosses the axis at the same time it does in a resistive circuit. Capacitive circuits are leading because the current leads the voltage. This leading characteristic of the voltage and current waveforms is shown in Figure 3.



CAPACITIVE CIRCUIT

Figure 3

The relationship between voltage and current waveforms in inductive and capacitive circuits can be remembered using the following phrase.

ELI THE ICEMAN

In the name ELI, the "E" represents voltage, the "L" represents an inductive circuit, ("L" is the designation for inductance), and "I" represents current. In the name ELI, reading from left to right, the voltage comes before the current. This is also the relationship of the voltage and current waveforms in an inductive circuit.

In the word ICE, the "C" represents a capacitive circuit. In the word ICE, reading from left to right, the current comes before the voltage. This is also the relationship of the voltage and current waveforms in a capacitive circuit.

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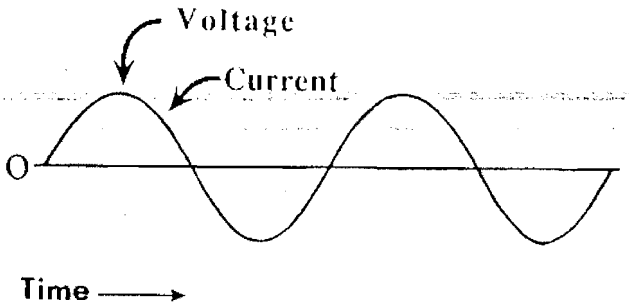
POWER FACTOR

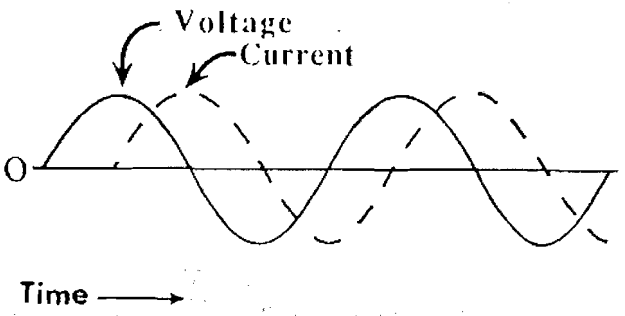
Power factor can be described as the displacement of the voltage and current waveforms from each other in an electrical circuit. The position of the current waveform, with respect to the voltage waveform, determines if the power factor is leading, lagging, or unity. IN A UNITY-POWER-FACTOR CIRCUIT, THE CURRENT AND VOLTAGE WAVEFORMS CROSS THE AXIS AT THE SAME TIME. (See Figure 1) UNITY POWER FACTOR OCCURS IN A RESISTIVE CIRCUIT.



RESISTIVE CIRCUIT

Figure 1

IN A LAGGING-POWER-FACTOR CIRCUIT, THE CURRENT CROSSES THE TIME AXIS AFTER THE VOLTAGE CROSSES. (See Figure 2.) LAGGING POWER FACTOR OCCURS IN AN INDUCTIVE CIRCUIT.



INDUCTIVE CIRCUIT

Figure 2

IN A LEADING POWER FACTOR CIRCUIT, THE CURRENT WAVEFORM CROSSES THE TIME AXIS BEFORE THE VOLTAGE WAVEFORM CROSSES. (See Figure 3.) LEADING POWER FACTOR OCCURS IN A CAPACITIVE CIRCUIT.

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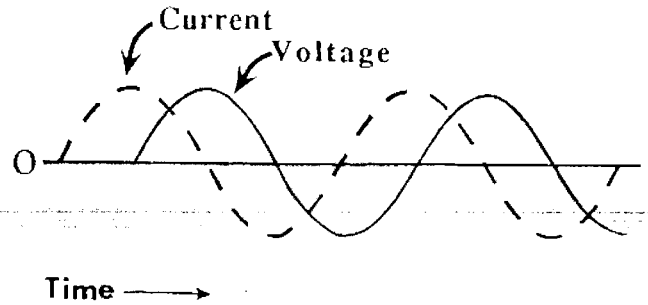


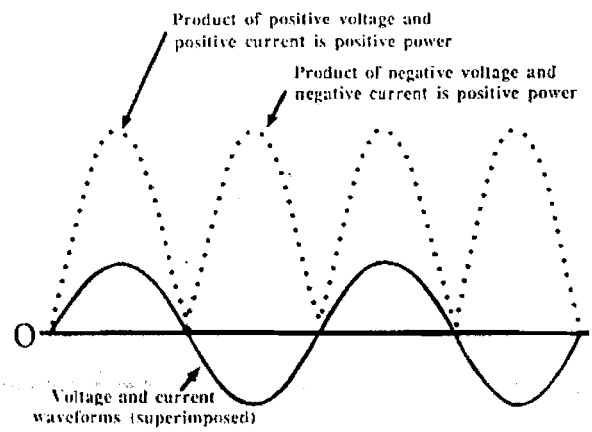
CAPACITIVE CIRCUIT

Figure 3

Unity power factor is also called a power factor of one, and a power factor of 100%. As the power factor moves from unity, it moves away in either a leading or lagging direction. A power factor of 95% leading is also called a 0.95 leading power factor. A 95% lagging power factor is also called 0.95 lagging.

The most economical point of operation is at unity power factor. Most industrial and commercial customers, however, would operate at between 0.99 and 0.75 lagging power factor, if the power factor were not corrected. The lower the power factor, the less economical the systems operate. Electric utilities want their customers to operate with power factors in the high 90's. Those customers that do not, are assessed a financial charge if their average power factor is below a certain power factor such as below 95%.

The reason that unity power factor is desirable can be seen in Figures 4, 5 and 6. In Figure 4, current is always positive when voltage is positive. Power is calculated by multiplying voltage by current, and when both are positive, the result is positive power. In Figure 4, current is always negative when voltage is negative. A negative value times a negative value produces a positive value, which again results in positive power for the negative half-cycles.



POWER PRODUCED IN A RESISTIVE CIRCUIT

Figure 4

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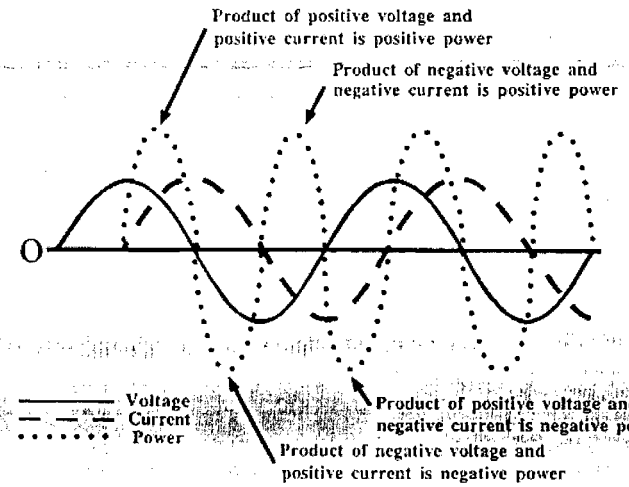
As the current waveform begins to lag the voltage waveform, only a portion of the current is positive when the voltage is positive in the positive-voltage half-cycle. This still produces positive power. However, the remaining portion of the current is negative when voltage is positive and this produces negative power which counteracts the positive power. As the current waveform becomes more and more lagging, the amount of negative power increases until the amount of negative power equals the positive power. In this situation, the actual work-producing power in the circuit is zero. This would occur with a 100% inductive load and is shown in Figure 5. It has a lagging power factor of zero. (Likewise, in the negative-voltage half-cycle, the positive power is cancelled by the negative power.)



POSITIVE POWER AND NEGATIVE POWER IN A PURELY INDUCTIVE CIRCUIT

Figure 5

The same situation occurs when the current waveforms leads the voltage waveform, with the amount of negative power becoming closer to the amount of positive power as the power factor approaches zero in the leading direction. Figure 6 shows the relationship of positive power and negative power in a purely capacitive circuit. In figure 6, the amount of positive power equals the amount of negative power and the net work-producing power is zero.

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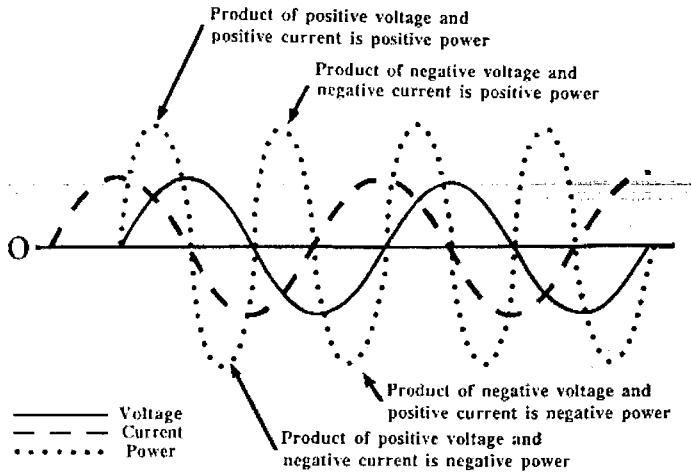

POSITIVE POWER AND NEGATIVE POWER IN A PURELY CAPACITIVE CIRCUIT

Figure 6

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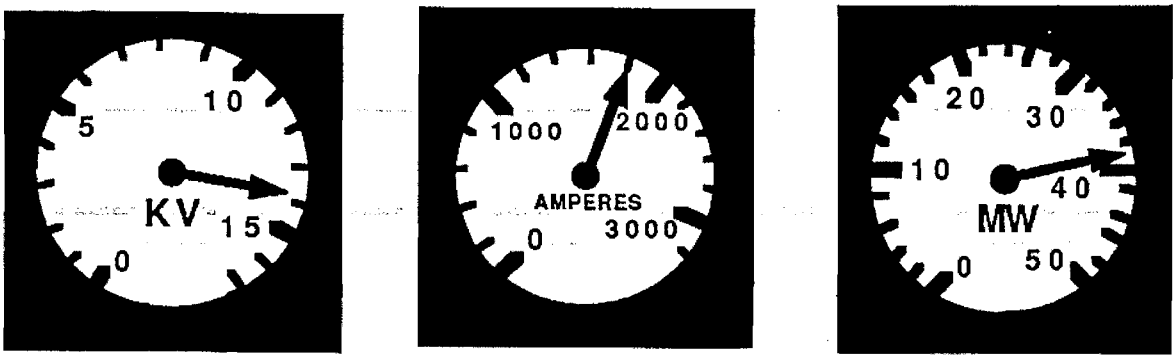
DETERMINATION OF POWER FACTOR

Calculating power factor can be done by using the voltage, current, and wattage readings on an electrical system; and then substituting these readings into a power-factor equation. The meters used to provide these readings are shown in Figure 1.

VOLTMETER AMMETER WATTMETER



METERING FOR DETERMINING POWER FACTOR

Figure 1

The equation used for a single-phase system is

$$(1) \quad \text{Power Factor } 1\emptyset = \frac{\text{Watts}}{\text{Volts X Amps}}$$

The equation used for a 3-phase system is

$$(2) \quad \text{Power Factor } 3\emptyset = \frac{\text{Watts}}{\text{Volts X Amps X } \sqrt{3}}$$

Assume that the readings on a 3-phase system are 13,800 volts, 1,800 amps and 38.7 megawatts. These readings are substituted into the equation, and the power factor calculated. The calculations to determine the power factor on this system are

$$\text{Power Factor } 3\emptyset = \frac{\text{Watts}}{\text{Volts X Amps X } \sqrt{3}}$$

$$= \frac{38{,}700{,}000 \text{ watts}}{13{,}800 \text{ volts X } 1{,}800 \text{ amps X } 1.73}$$

$$= \frac{38{,}700{,}000 \text{ watts}}{42{,}973{,}200 \text{ volt-amps}}$$

$$= 0.90$$

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DETERMINATION OF THREE-PHASE POWER

Single-phase AC power (with a resistive load) and DC power can be calculated by multiplying volts by amps. In a three-phase system, however, two others factors enter into the equation. One of these is the square root of three. The other is power factor. (Power factor also applies to single-phase systems.) In a three-phase circuit containing only resistive loads, the power (in watts) is calculated by multiplying the voltage by the current and by the square root of three.

$$\text{Power}_{\text{(in watts)}} = \text{Volts} \times \text{Amps} \times \sqrt{3}$$
$$= \text{Volts} \times \text{Amps} \times 1.73$$

Assuming a 13.8kv (13.8 kilovolts) system carrying 1800 amps of resistive load, the power in watts would be calculated as follows.

$$\text{Power}_{\text{(in watts)}} = \text{Volts} \times \text{Amps} \times \sqrt{3}$$
$$= 13{,}800 \text{ volts} \times 1800 \text{ amps} \times 1.73$$
$$= 43 \text{ megawatts (MW)}$$

In the example above, the power factor was assumed to be unity (or one or 100%) which indicates a resistive load. If the load is either inductive or capacitive, the calculation of power in watts must include multiplying by the power factor.

The general equation for calculating three-phase power in watts is

(1) $$\textbf{Power}_{\textbf{(in watts)}} = \textbf{Volts} \times \textbf{Amps} \times \sqrt{3} \times \textbf{Power Factor}$$

If the system that was assumed for the example above has a power factor of 87% (0.87), the calculation would be

$$\text{Power}_{\text{(in watts)}} = \text{Volts} \times \text{Amps} \times \sqrt{3} \times \text{Power Factor}$$
$$= 13{,}800 \text{ v} \times 1800 \text{ a} \times 1.73 \times 0.87$$
$$= 37.4 \text{ megawatts}$$
$$= 37.4 \text{ MW}$$

The general equation for calculating three-phase power in volt-amps is

(2) $$\textbf{Power}_{\textbf{(in volt-amps)}} = \textbf{Volts} \times \textbf{Amps} \times \sqrt{3}$$

In the system that was assumed for the example above, the volt-amps would be calculated as

$$\text{Power}_{\text{(volt-amps)}} = \text{Volts} \times \text{Amps} \times \sqrt{3}$$
$$= 13{,}800 \text{ v} \times 1800 \text{ a} \times 1.73$$
$$= 43{,}024{,}142 \text{ volt-amps (VA)}$$
$$= 43{,}000 \text{ kilovolt-amps}$$
$$= 43{,}000 \text{ KVA}$$
$$= 43 \text{ megavolt-amps}$$
$$= 43 \text{ MVA}$$

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REACTANCE, IMPEDANCE AND REACTIVE POWER (VARs)

****

* Definition of reactance: Equivalent resistance of *
* inductance and capacitance *
* Unit of measurement of reactance: ohms (Ω) *
* Abbreviation for inductive reactance: X_L *
* Abbreviation for capacitive reactance: X_C *
* ---------- *
* Definition of impedance: Total resistance, inductive *
* reactance and capacitive reactance *
* Unit of measurement of impedance: ohms (Ω) *
* Abbreviation for capacitive reactance: Z *
* ---------- *
* Definition of reactive power: Non-work producing *
* power *
* Unit of measurement of *
* reactive power: Volt-Amps Reactive *
* Abbreviation for reactive power: VARs *

****

Inductive Reactance

Reactance can be looked upon as the equivalent resistance of inductance and capacitance. The equivalent resistance of inductance is called inductive reactance (X_L) and is measured in ohms. Inductive reactance is calculated using the formula

(1) $$X_L = 2\pi f L$$

where π = 3.14
f = frequency in hertz
L = inductance in henrys
X_L is in ohms

Given a coil with an inductance of 0.2 henry, the inductive reactance of the coil would be calculated as follows.

$$\begin{aligned} X_L &= 2\pi f L \\ &= (2)(3.14)(60 \text{ hertz})(0.2 \text{ henry}) \\ &= 75.36 \text{ ohms} \end{aligned}$$

Assume that a 120-volt 60-hertz voltage source is connected to the 0.2 henry coil. The current flowing through the coil would be calculated using Ohm's Law (I = E/R) with X_L substituted for R as shown in Equation 2.

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(2) $$I = \frac{E}{X_L}$$

$$= \frac{120 \text{ volts}}{75.36 \text{ ohms}}$$

$$= 1.59 \text{ amps}$$

Capacitive Reactance

The equivalent resistance of capacitance is called capacitive reactance (X_c) and is also measured in ohms. Capacitive reactance is calculated using the formula

(3) $$X_C = \frac{1}{2\pi f C}$$

where $\pi = 3.14$
f = frequency in hertz
C = capacitance in farads
X_C is in ohms

Given a 220 microfarad capacitor, the capacitive reactance would be calculated as follows.

$$X_C = \frac{1}{2\pi f C}$$

$$= \frac{1}{(2)(3.14)(60 \text{ hertz})(220 \times 10^{-6} \text{ farads})}$$

$$= 12 \text{ ohms}$$

Assume that a 120-volt, 60-hertz voltage source is connected to the 220 microfarad capacitor. The current flowing through the capacitor would be calculated using Ohm's Law ($I = E/R$) with X_C substituted for R as shown below.

$$I = \frac{E}{X_C}$$

$$= \frac{120 \text{ volts}}{12 \text{ ohms}}$$

$$= 10 \text{ amps}$$

Impedance

Impedance is the total resistance, inductive reactance and capacitive reactance in an electrical component, circuit or system. Just as resistance, inductive reactance and capacitive reactance are measured in ohms, impedance is also measured in ohms. Impedance, however, is not a straight addition or subtraction of resistance, inductive reactance and capacitive reactance. For instance, given a circuit containing 10 ohms of resistance, 8 ohms of inductive reactance, and 4 ohms of capacitive reactance, the total would be neither 22 ohms nor 14 ohms. This is because the phase angles must be taken into account when combining the three quantities.

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In a resistive circuit, the voltage and current waveforms are in-phase (zero-degree offset). This offset is shown in Figure 1 using a vector for the resistive component. (A vector is an arrow that has both direction and magnitude) The resistance vector is zero degrees from a horizontal axis; this represents a zero-degree offset.

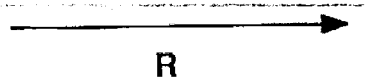

Figure 1

In an inductive circuit, the current lags the voltage by 90 degrees. The inductive-reactance vector (X_L) is shown in Figure 2 with a 90-degree phase shift from the resistive vector.

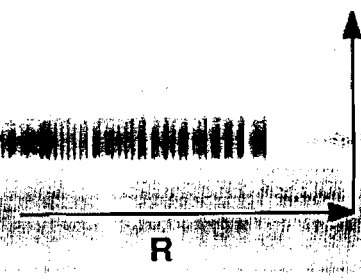

Figure 2

In a capacitive circuit, the current leads the voltage by 90 degrees. The capacitive-reactance vector (X_C) is shown in Figure 3 with a 90-degree phase shift from the resistive vector.

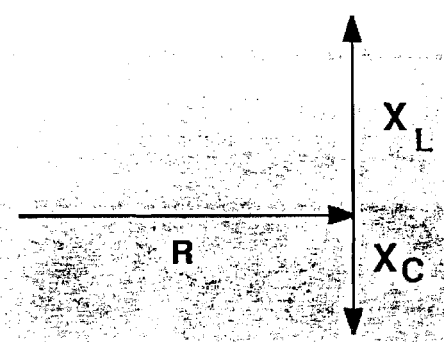

Figure 3

Since equal amounts of inductive reactance and capacitive reactance cancel each other, the capacitive reactance in Figure 3 cancels an equal amount of inductive reactance. The result is inductive reactance minus capacitive reactance, or $X_L - X_C$. This is shown in Figure 4.

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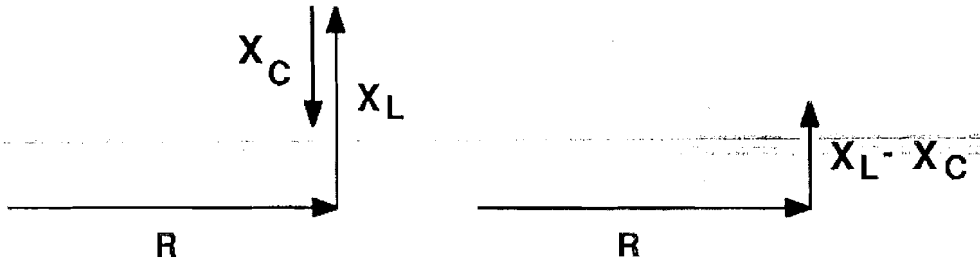

Figure 4

Resistance (R) and the net sum of all inductive reactance and capacitive reactance ($X_L - X_C$ or $X_C - X_L$) form two sides of a triangle. The third side of the triangle, the hypotenuse, is impedance and is represented by Z. This is shown in Figure 5.

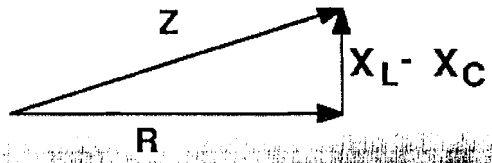

Figure 5

Using the Pythagorean Theorem, impedance can be calculated as follows

$$Z^2 = R^2 + (X_L - X_C)^2$$

$$\sqrt{Z^2} = \sqrt{R^2 + (X_L - X_C)^2}$$

$$Z = \sqrt{R^2 + (X_L - X_C)^2} \quad (4)$$

Given the circuit containing 10 ohms of resistance, 8 ohms of inductive reactance and 4 ohms of capacitive reactance, the impedance can now be calculated as follows.

$$\begin{aligned} Z &= \sqrt{R^2 + (X_L - X_C)^2} \\ &= \sqrt{10^2 + (8 - 4)^2} \\ &= \sqrt{10^2 + 4^2} \\ &= \sqrt{100 + 16} \\ &= \sqrt{116} \\ &= 10.8 \text{ ohms} \end{aligned}$$

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Reactive Power

The triangle in Figure 5 can be changed into what is called the **Power Triangle.** When current flows through the resistive component, power in the form of watts is the result. When current flows through the reactive component, power in the form of volt-amps reactive (VARs) is the result. The total current flowing through the resistive and reactive components (through the impedance) results in volt-amps. These quantities are shown in Figure 6.

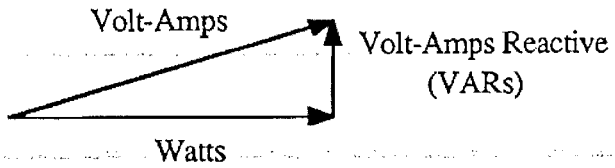

Figure 6

Power factor is equal to the resistive power (watts) divided by the total power (volt-amps). (Equation 5.)

$$(5)\quad \textbf{Power Factor} = \frac{\textbf{Watts}}{\textbf{Volt-Amps}}$$

When watts (W) and volt-amps reactive (VARs) are known, volt-amps (VA) can be calculated using the Pythagorean Theorem.

$$VA^2 = W^2 + VAR^2$$

$$\sqrt{VA^2} = \sqrt{W^2 + VAR^2}$$

$$(6)\quad VA = \sqrt{W^2 + VAR^2}$$

The power-factor equation can then be written as

$$(7)\quad \text{Power Factor} = \frac{W}{\sqrt{W^2 + VAR^2}}$$

When a utility measures a customer's power factor, recording wattmeters and recording varmeters are normally used. At the end of the billing period, the watthours (W-H) and VAR-hours (VAR-H) are substituted into Equation 8 to give the average power factor for the billing period.

$$(8)\quad \text{Power Factor}_{\text{Average}} = \frac{W\text{-}H}{\sqrt{W\text{-}H^2 + VAR\text{-}H^2}}$$

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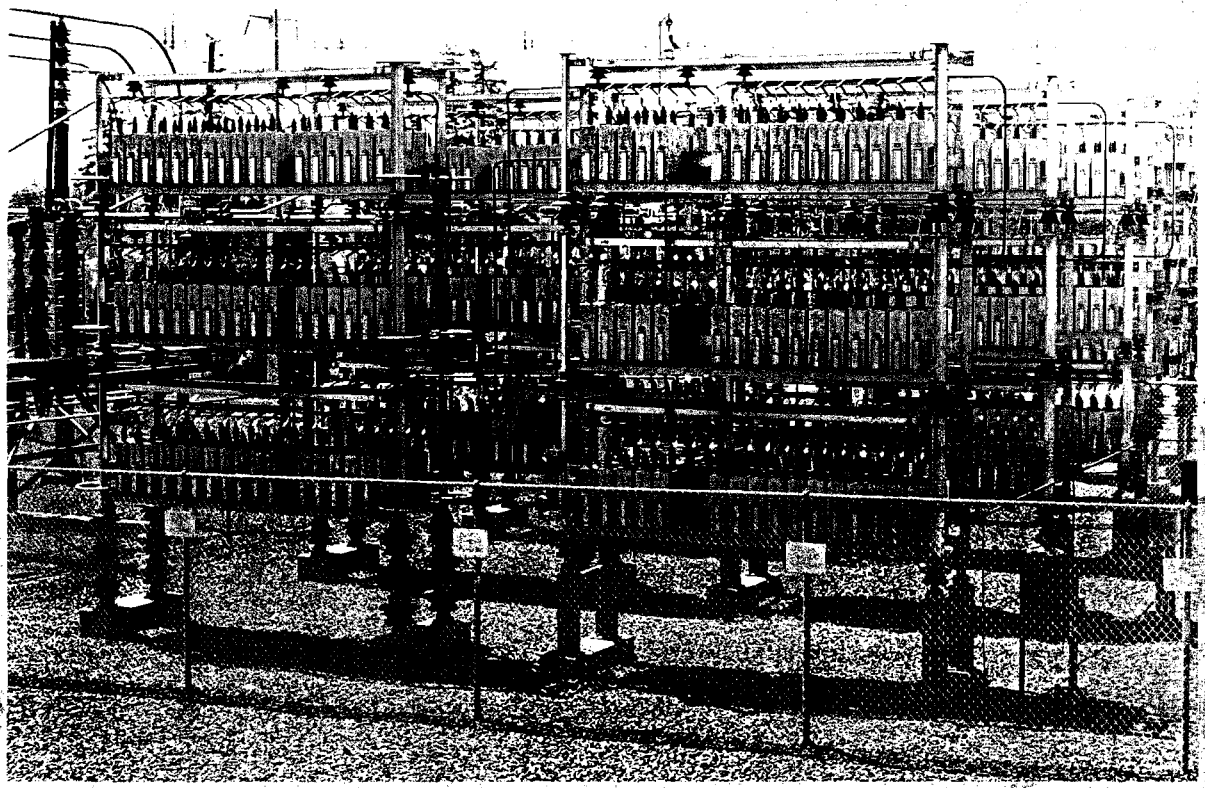
POWER FACTOR CORRECTION

A power factor other than unity or 100%, results in extra costs for the utility. As a power factor moves away form unity, in either a leading or lagging direction, the utility must provide more power; equipment must have a higher power rating, while handling the same amount of work-producing power (watts). The additional power, and oversized equipment, cost a utility more money. In order to recoup these additional costs, a utility usually charges a customer an extra charge, called a power factor charge, a reactive charge or a kVAr charge. The most common method is to implement a charge if the average power factor drops below a certain level. The most common of the minimum allowable power factor levels are in the range of 90% to 97%. Some utilities, however, set a power factor level as low as 80%, while other utilities set a power factor level as high as 98%.

Since most of a utility's larger customers have large loads with lagging (inductive) characteristics, the extra charge is usually incurred unless corrective action is taken. Because capacitance in a system cancels inductance, capacitors can be added to an electrical system with a lagging power factor in order to move the power factor [illegible] When the [illegible] inductive load is substantial, many capacitors have to be used to provide the desired level of power factor correction. The photograph below shows such a group of capacitors. This capacitor bank is similar to those found in many larger substations.



Courtesy: Westinghouse Electric Corp.

POWER FACTOR CORRECTION CAPACITOR BANK

Figure 1

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♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

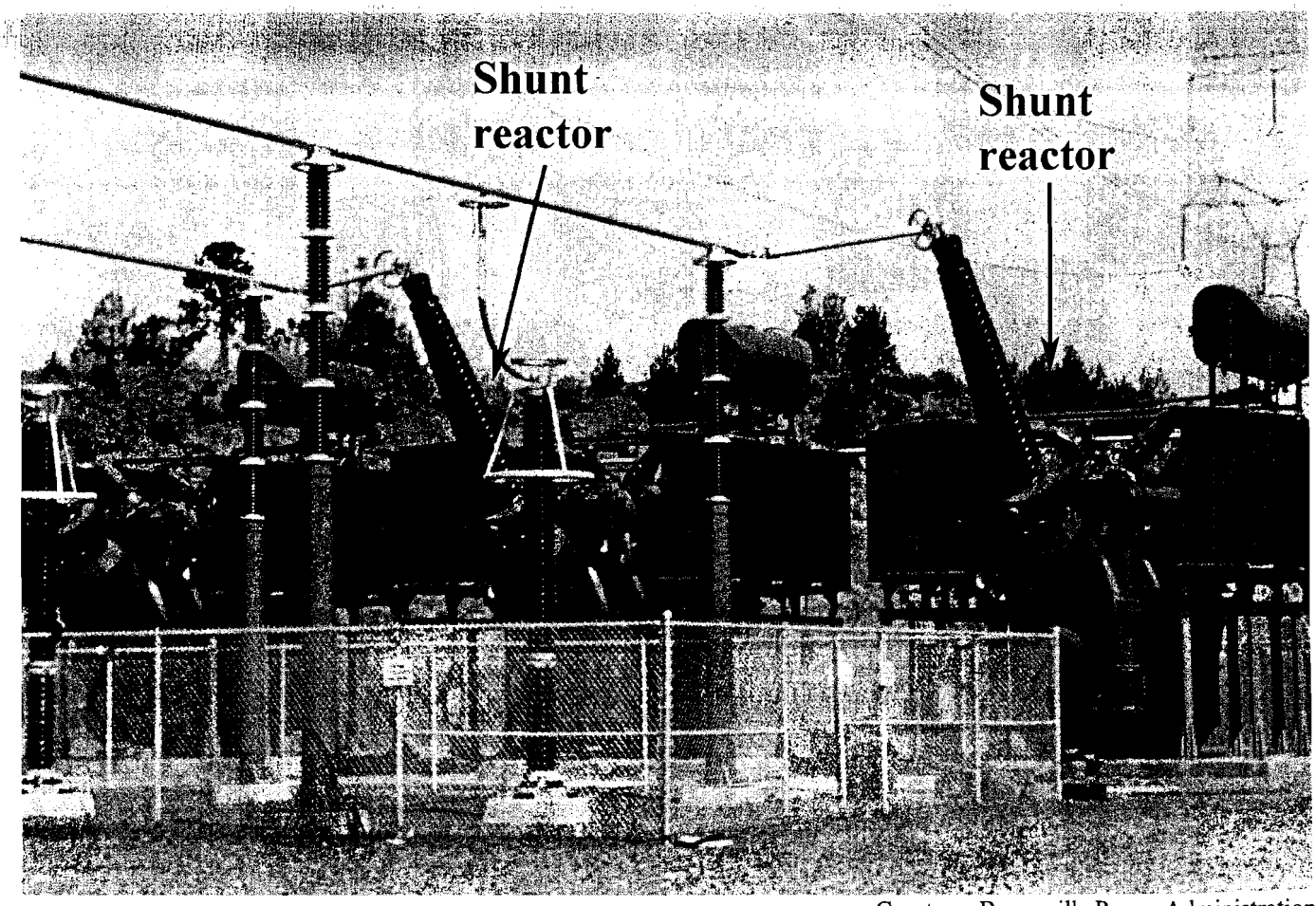
SHUNT REACTORS

Air, an insulator, separates the phases of a transmission line. A capacitor is two conductors separated by a dielectric (an insulator). A transmission can therefore look like a three-phase capacitor with the air between the conductors being the insulator.

When a transmission line is heavily loaded, the normal inductive load counteracts the capacitive effects of the transmission line. Under lightly conditions, however, there is not enough inductive load to cancel the line capacitance. When this happens, the transmission line becomes a giant three-phase capacitor.

Under these lightly loaded conditions, large coils of wires called shunt reactors are connected to the transmission. These shunt reactors provide inductive load to offset the line capacitance. This also provides voltage control by reducing the high voltage that can occur because of the phase-to-ground voltage being increased by the capacitance.

The photograph below in Figure 1 shows two of three single-phase shunt reactors. Each reactor's coil is enclosed in an oil-filled tank similar to large transformers. Figure 2 on the next page shows three air-cooled shunt reactors.



Courtesy: Bonneville Power Administration

OIL COOLED SHUNT REACTORS
Figure 1

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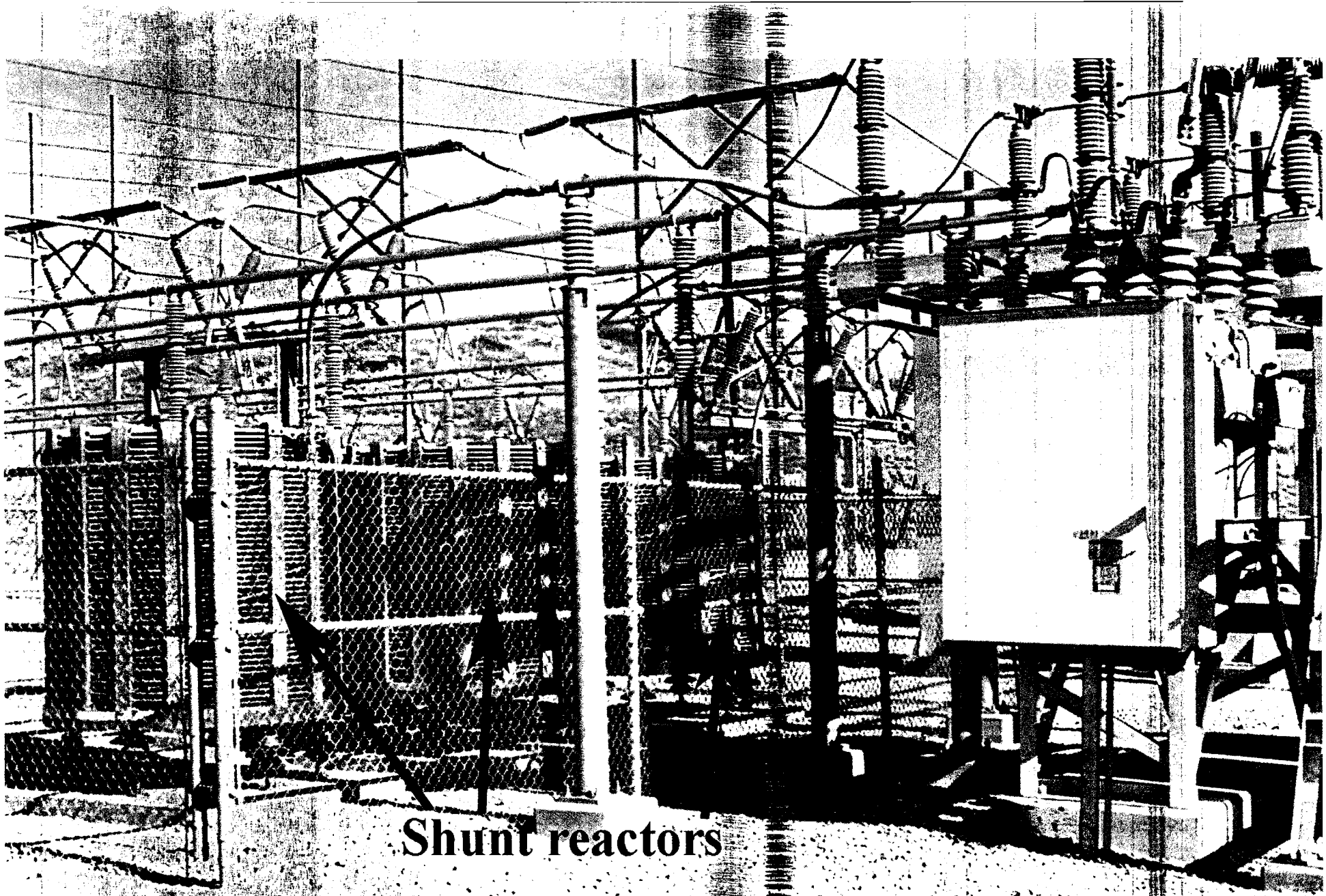
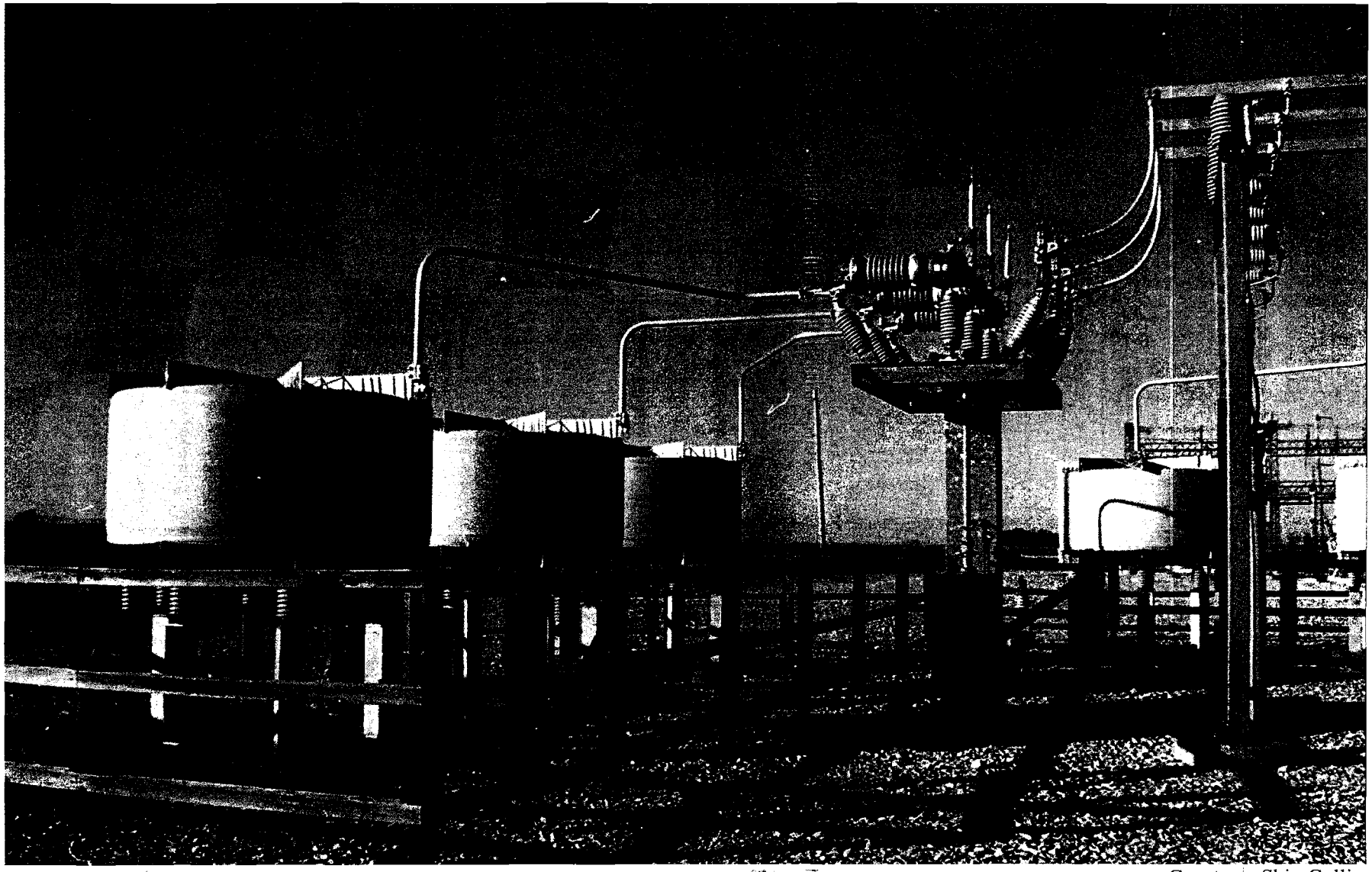


Courtesy: Skip Collier

AIR COOLED SHUNT REACTORS
Figure 2



Courtesy: Skip Collier

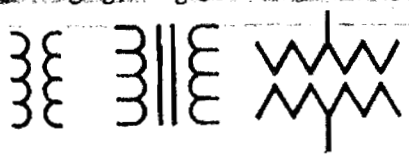
AIR-COOLED SHUNT REACTORS

Figure 3

♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

VOLTAGE TRANSFORMER

****

* Specified by: Voltages, power rating in volt-amps, *
* type of cooling *
* Abbreviation: XFMR *
* Function: Changing voltage levels *
* *
* Symbols:  *
* *
* *

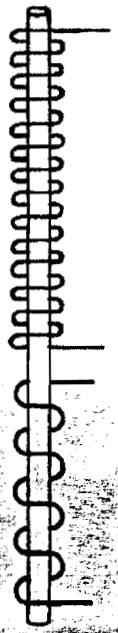
****

A voltage transformer is a piece of equipment used to change AC voltage levels, such as from 12,470 volts to 120/240 volts. Most transformers are voltage transformers; any transformer not specifically identified as a current transformer will be a voltage transformer. Voltage transformers consist of two conductors wrapped around an iron core (Figure 1). The ratio of the number of turns of the two conductors is called the turns ratio. For instance, if one winding has 100 turns of conductor and the second winding has 1000 turns, the turns ratio is 10 to 1. The voltage ratio is the same as the turns ratio. In this example, a voltage of 1,200 volts applied to the 1000 turn winding would produce 120 volts on the 100 turn winding.

The largest of the voltage transformer are called power transformers. They increase the 10 kv to 25 kv produced by an electrical utility generator to a transmission voltage level that

One Winding of a Single-Phase transformer

Figure 1



Both Windings of a Single-Phase Transformer

Figure 2

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is normally between 115 kv and 765 kv. Distribution transformers are smaller-in-size voltage transformers used to reduce voltages down to a level that can be used by the customers of an electrical utility. These include the pole-mounted transformers found in older electrical areas, and the pad-mount transformers found in newer electrical systems.

Potential transformers are voltage transformers used to measure voltages for metering and protective circuitry. These transformers can decrease a transmission voltage of 500 kv down to a level of 120 volts. Control power transformers are the smallest of the voltage transformers. They are used to decrease a voltage down to a level that can be easily and safely used for control circuitry; examples are changing from 480 volts to a control voltage of 120 volts, or changing from 120 volts to a control voltage of 24 volts.

The power into a voltage transformer is equal to the power out of the transformer. In equation form for a three-phase transformer, this is expressed as

$$\text{Power}_{in} = \text{Power}_{out}$$

$$V_{in} \times A_{in} \times \sqrt{3} = V_{out} \times A_{out} \times \sqrt{3}$$

If a transformer has a 13,800 volts and 10,000 amps coming in, and 138,000 volts out, the output current would be 1,000 amps. Its power rating would be 239,023,010 volt-amps or 239 MVA.

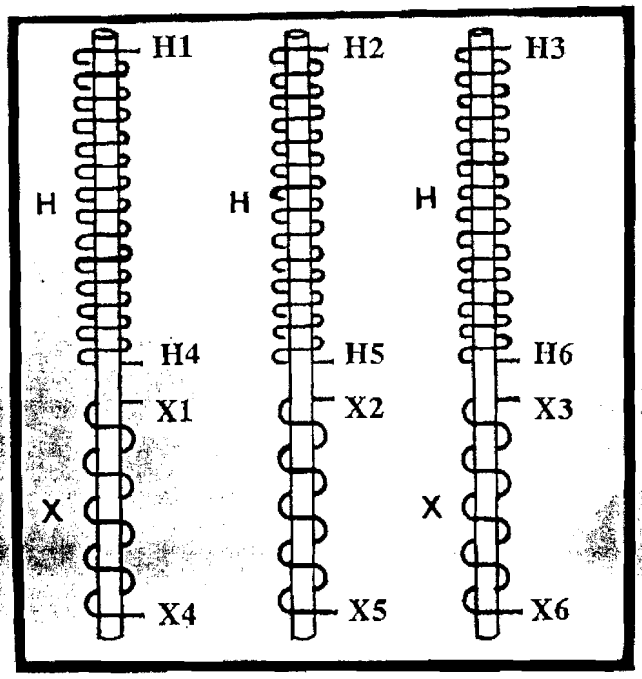
$$13{,}800\,V_{in} \times 10{,}000\,A_{in} \times \sqrt{3} = 138{,}000\,V_{out} \times 1{,}000\,A_{out} \times \sqrt{3}$$

$$239{,}023{,}010\,VA_{in} = 239{,}023{,}010\,VA_{out}$$

$$239{,}023\,KVA_{in} = 239{,}023\,KVA_{out}$$

$$239\,MVA_{in} = 239\,MVA_{out}$$

A single-phase transformer has one low-voltage winding and one high-voltage winding on an iron core. A three-phase transformer has three iron cores with a low-voltage winding and a high-voltage winding on each core. Figure 3a below shows a drawing of a three-phase transformer.



THREE-PHASE TRANSFORMER WINDINGS

Figure 3a

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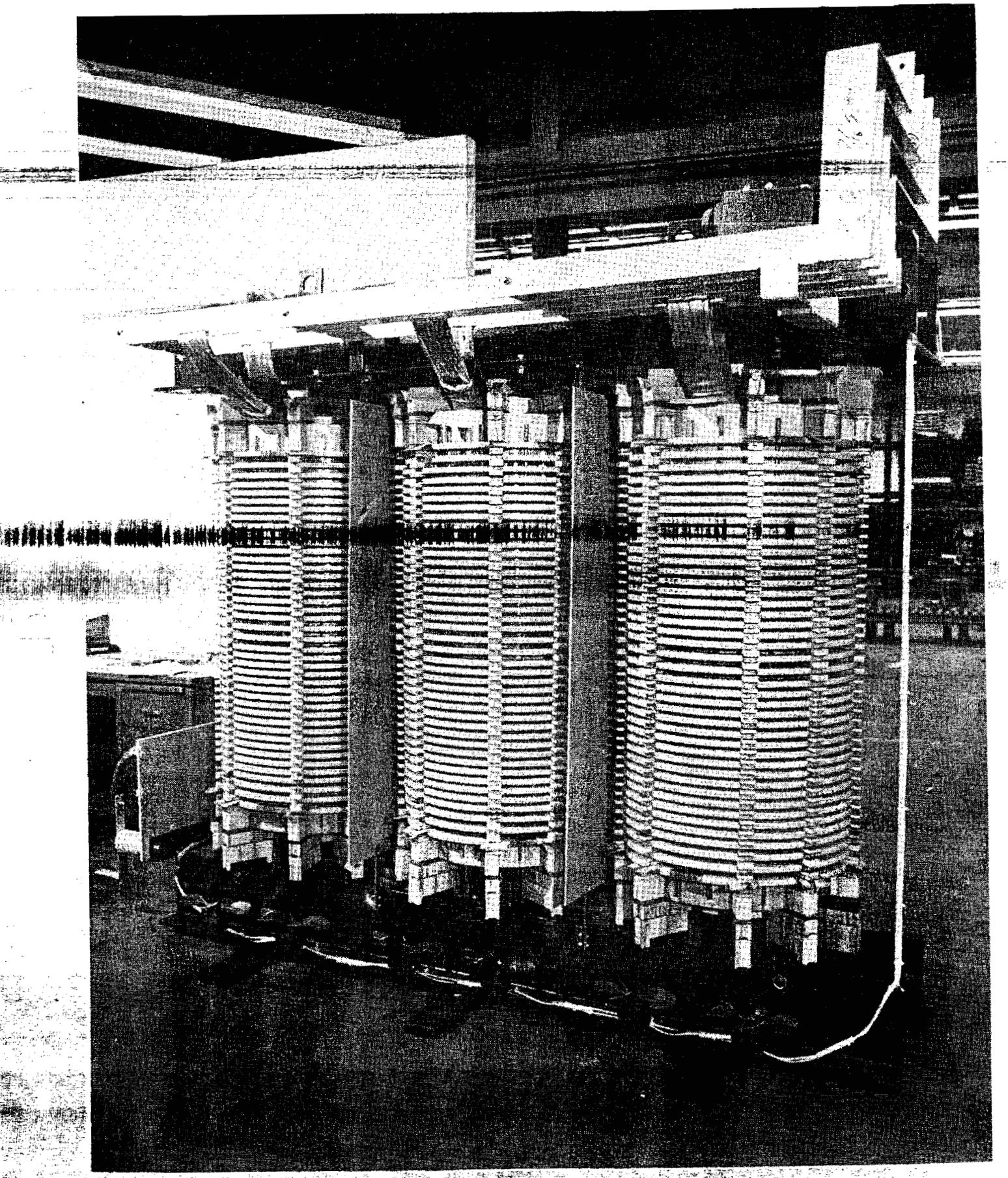

Courtesy: GTE Electrical Equipment

E124-3

THREE-PHASE TRANSFORMER WINDINGS

Figure 3b

The amount of power that a transformer can handle is limited by the internal temperature of the transformer. Transformer specifications include the type of cooling. The current flowing through the windings creates heat. The windings are immersed in various fluids to transfer heat away from the windings. These fluids include air, freon, oil and, in the past, polychlorinated biphenyls (PCBs). Larger air-cooled transformers (also called dry-type) are normally enclosed in a vented sheet-metal cabinet. The other types of transformers are enclosed in a completely sealed tank.

Radiators are used on virtually all larger transformers (See Figure 4). The radiators increase the tank surface area that is exposed to the air, thereby providing better cooling. For an oil-filled transformer (the most common type for transformers larger than 10 KVA), the oil-to-air heat transfer is identified by OA for Oil-to-Air.

Oil pumps can be installed on oil-filled transformers to increase the flow of oil around and through the windings. This also increases the cooling rate. This is identified by FO for Forced Oil.

Fans can be installed on any type of transformer to increase the cooling rate. On oil-filled transformers the fans are attached to the radiators to help keep the oil cool by cooling the surface of the radiators (See Figure 4). This is identified by FA for Forced Air.

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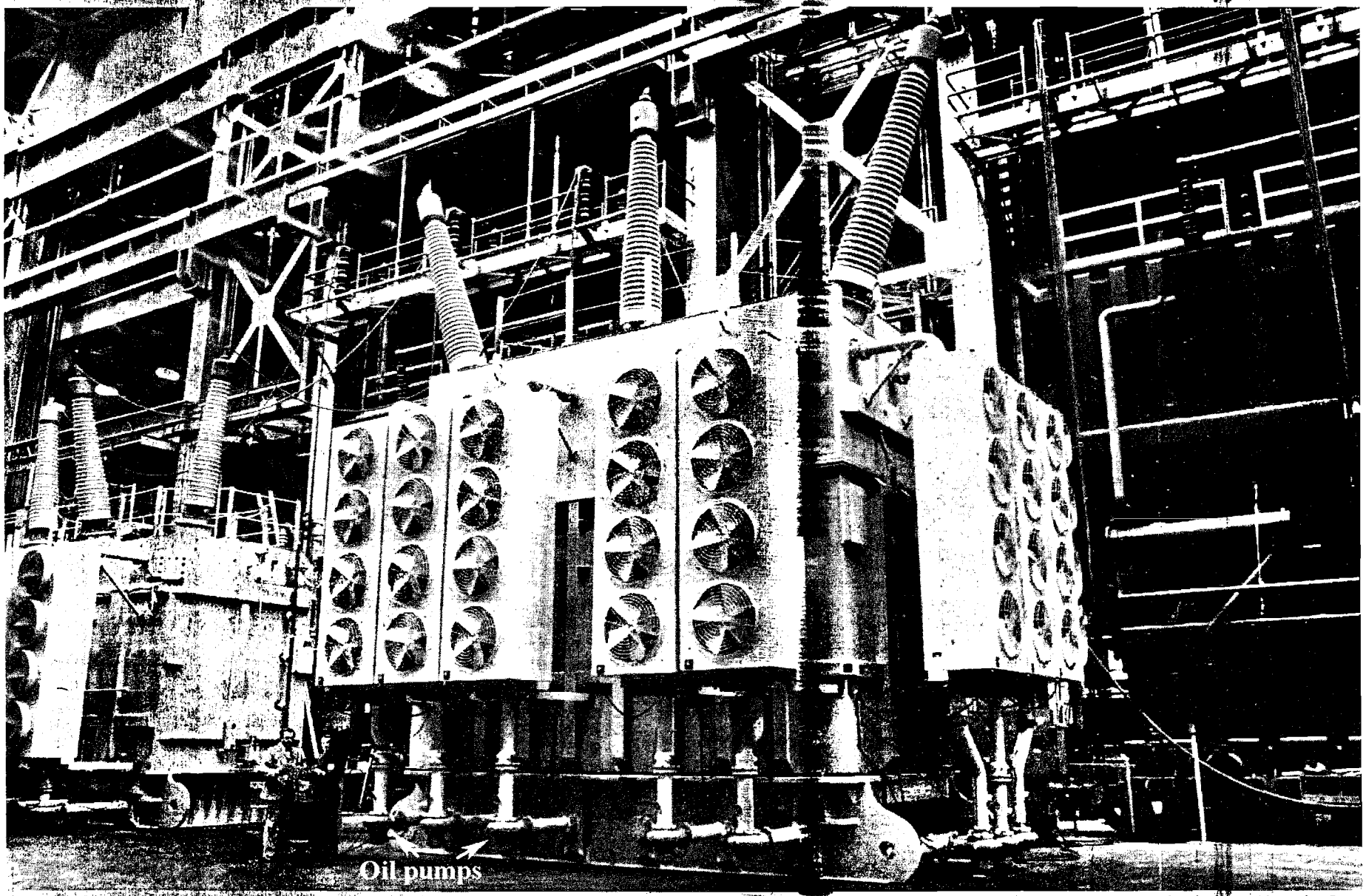
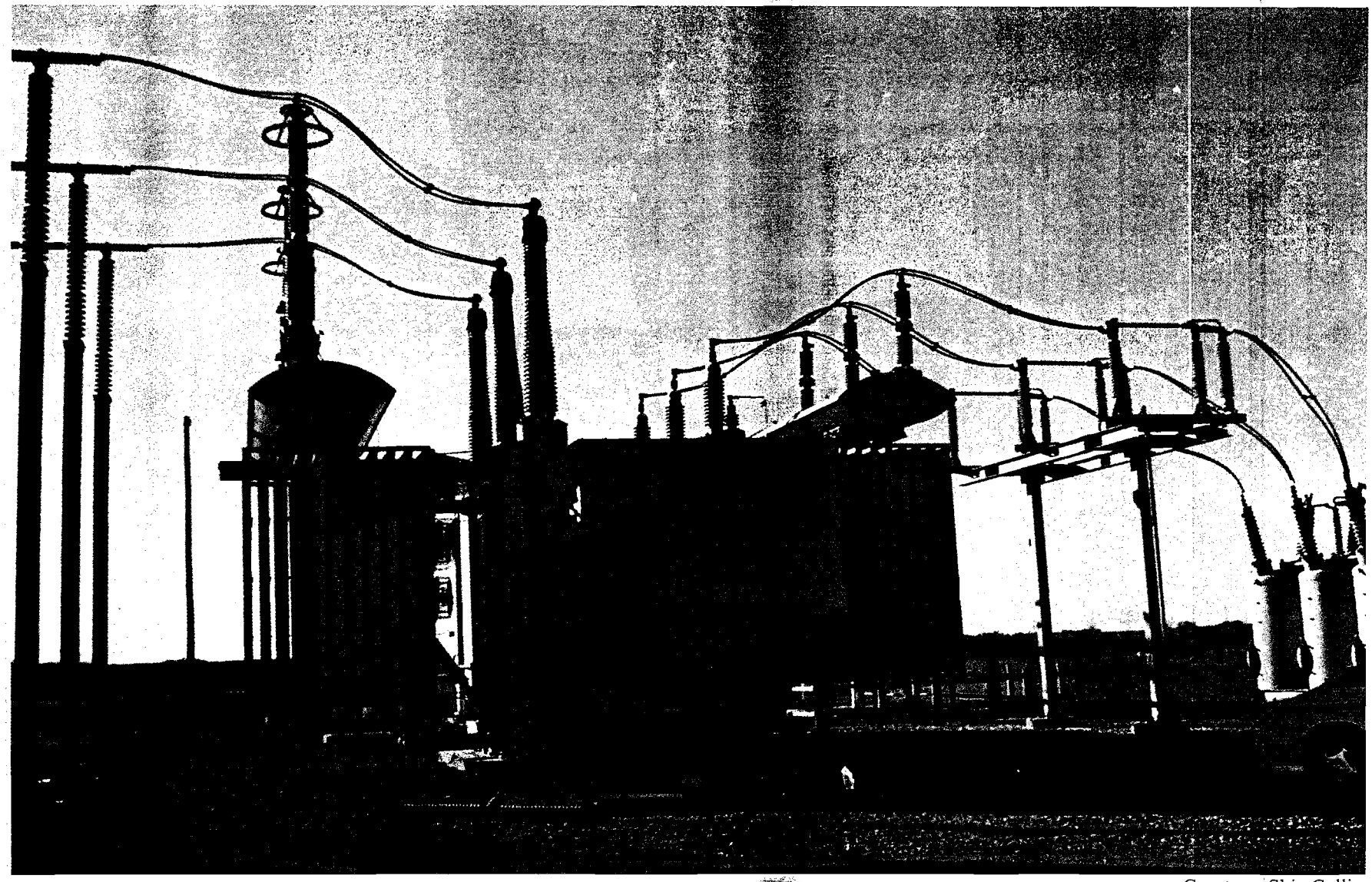


Courtesy: Westinghouse Electric Corp.

POWER TRANSFORMER
(910 MVA 3-PHASE TRANSFORMER FOR ARKANSAS POWER & LIGHT)
Figure 4



Courtesy: Skip Collier

POWER TRANSFORMER

Figure 5

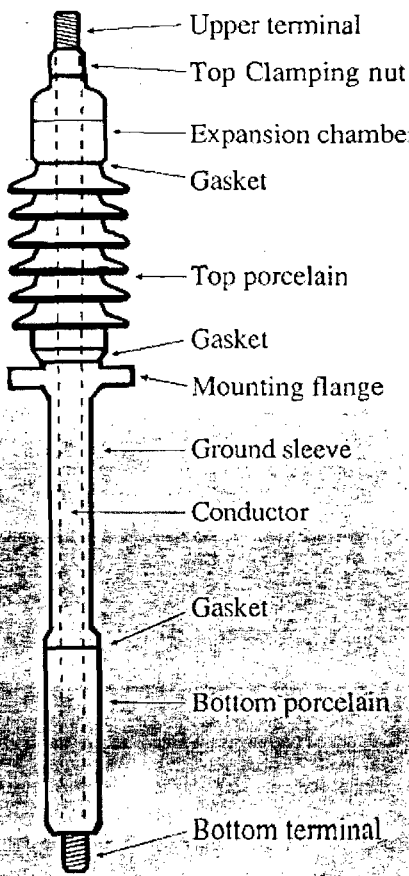
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

BUSHINGS

The leads from the transformer windings, to which the external connections are made, are somewhat flexible. If these leads were brought through holes drilled in the steel tank in order to make the external connections, this flexibility would allow the wind, vibration and other forces to continually move the leads. This continual movement would eventually lead to the failure of the leads.

A bushing is a rigid conductor that is placed between the transformer-winding leads and the external conductor. A bushing usually consists of a solid copper rod surrounded by porcelain. The porcelain provides the insulation. Most bushings are filled with oil or sulphur hexaflouride (SF_6) gas. On oil-filled or SF_6-filled bushings, the copper rod is surrounded by oil or SF_6 gas which provides additional insulation. The copper rod, and oil or SF_6 gas, are inside the porcelain.

Internal connections are made at the bushing ends that are inside the transformer tank. External connections are made at the bushing ends that are outside the transformer tank. The distance between the external connection point and the transformer tank has to be great enough to prevent the voltage from pushing the current across the bushing's surface to the tank. The distance the bushing protrudes from the tank provides the necessary insulation to prevent this possibility. For this reason, the higher the voltage [illegible] between the top of the bushing and the transformer tank. Figure 1 illustrates the main parts of medium and high voltage bushings. The table adjacent the bushing gives selected voltages and the corresponding bushing height.



Voltage Rating	Approximate Height of Bushing Above Tank
15 kv	12 inches (1 foot)
23 kv	21 inches (1.75 feet)
34.6 kv	25 inches (2 feet)
46 kv	28 inches (2.3 feet)
69 kv	35 inches (3 feet)
115 kv	50 inches (4.2 feet)
138 kv	58 inches (4.8 feet)
161 kv	73 inches (6 feet)
196 kv	87 inches (7.3 feet)
230 kv	96 inches (8 feet)
345 kv	130 inches (10.8 feet)
500 kv	200 inches (16.7 feet)

E125-1

MEDIUM & HIGH VOLTAGE BUSHING

Figure 1

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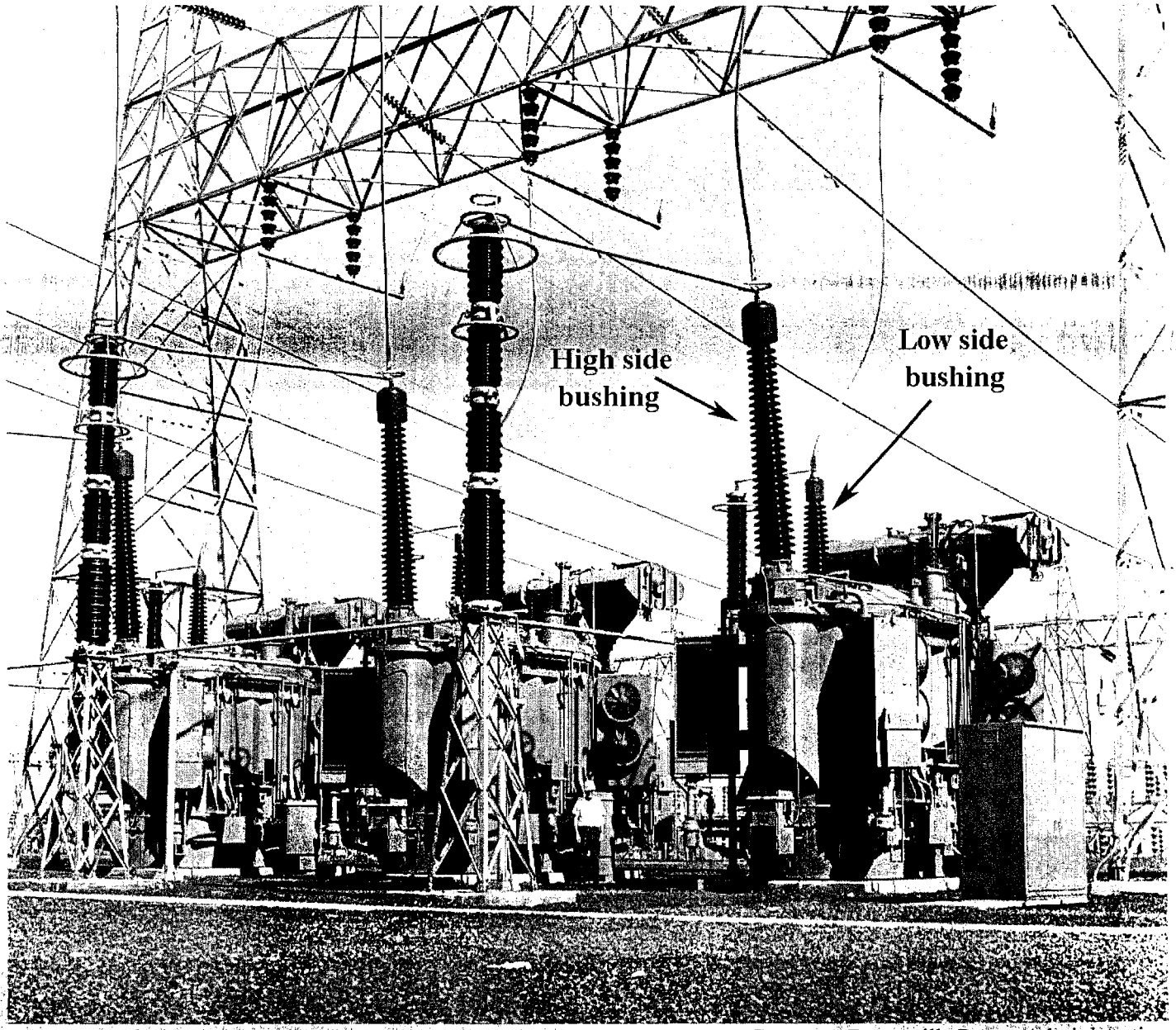
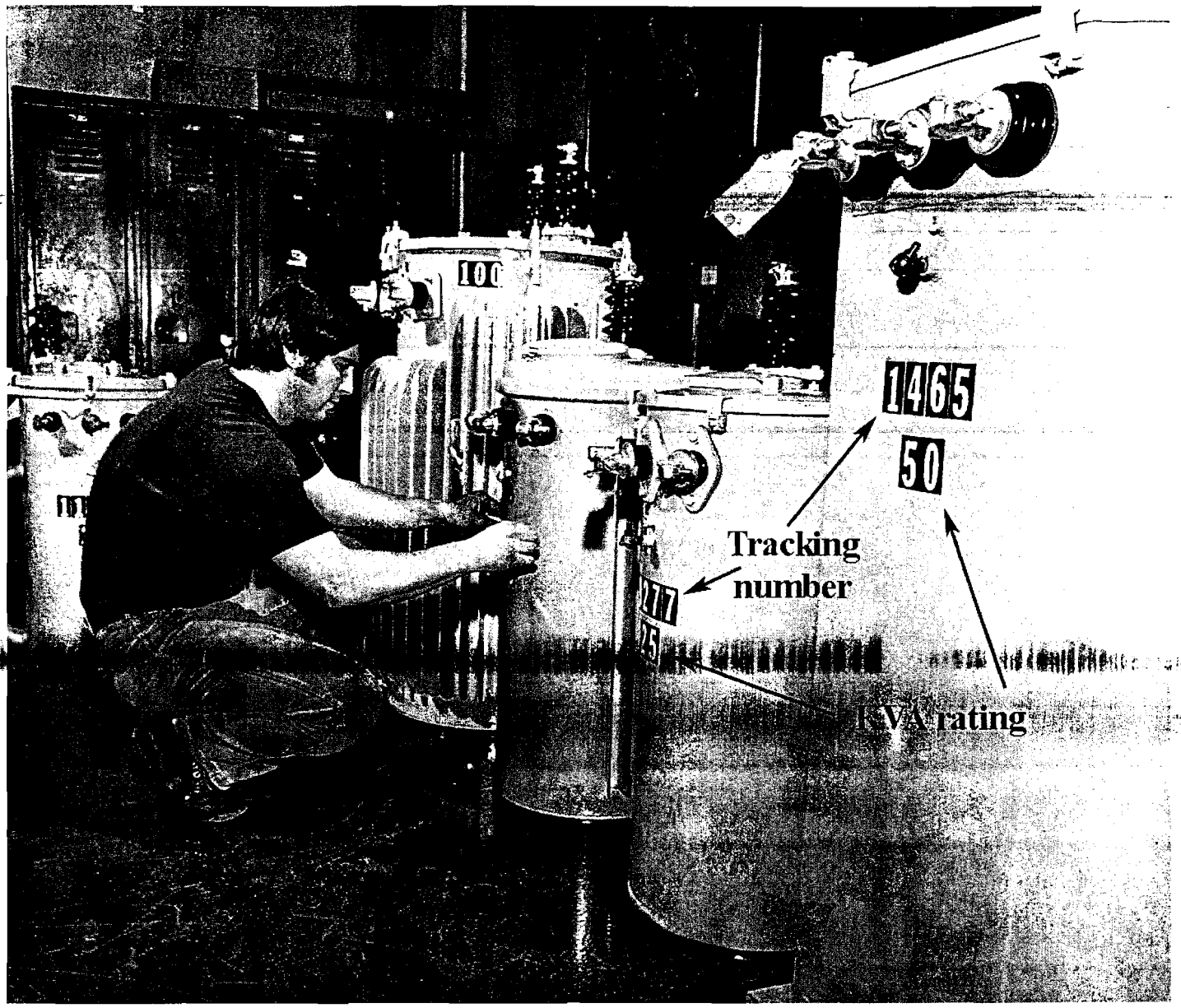
Figure 2., below, is a photograph of three single-phase transformers. By comparing the height of the man in the photo to the heights of the bushings, both the high-side and low-side voltages of the transformers can be estimated.

On some transformers, the windings leave the tank from the side, rather than from the top, such as those shown in Figure 3 on the next page. On these designs, the bushings are called side-wall bushings because they are installed on the side wall of the transformer.



Courtesy: Bonneville Power Administration

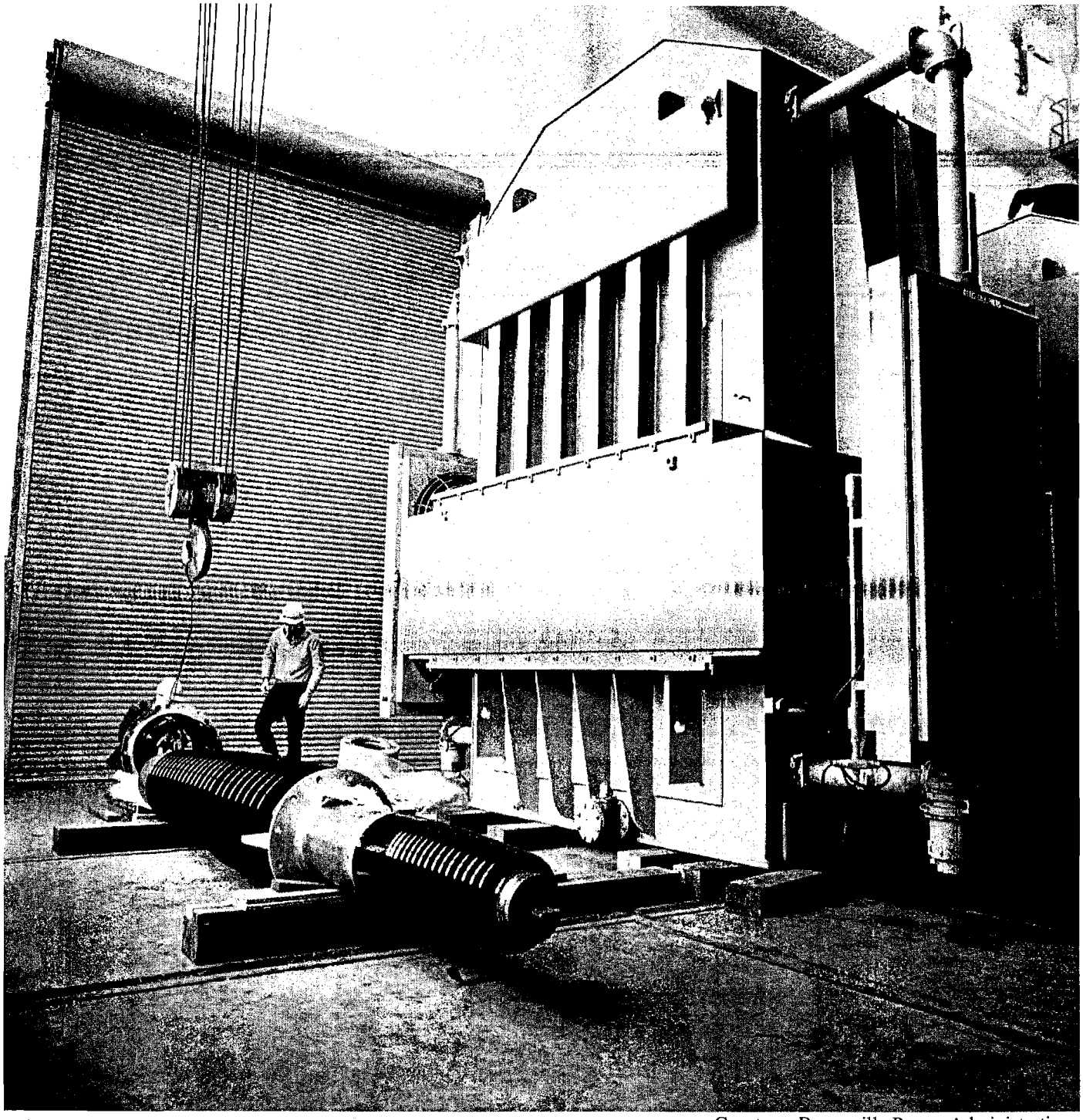
THREE SINGLE-PHASE TRANSFORMERS
Figure 2



Courtesy: Portland General Electric Co.

DISTRIBUTION TRANSFORMER WITH SIDE WALL BUSHINGS

Figure 3



Courtesy: Bonneville Power Administration

BUSHING BEFORE INSTALLTION

Figure 4

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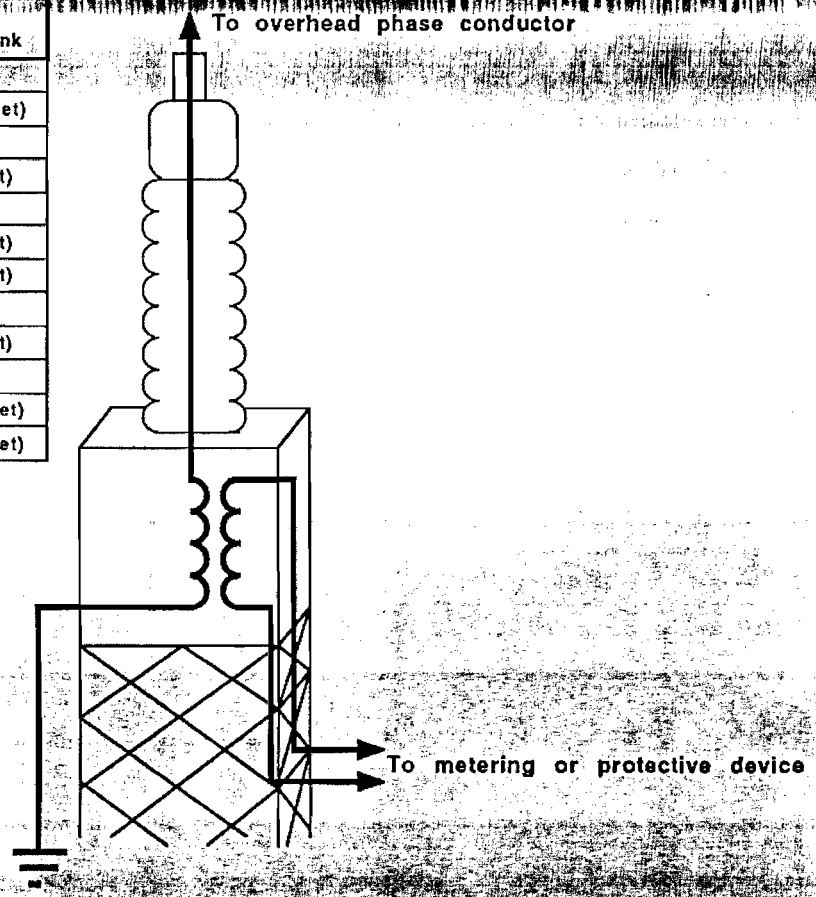
POTENTIAL TRANSFORMERS

Voltage transformers consist of power transformers, distribution transformers and potential transformers. Power transformers are the largest and are found at generating plants and large substations. Distribution transformers include the pole-mounted and pad-mount transformers that supply power to residential and commercial customers. The third general category of voltage transformers are potential transformers. Potential transformers are used to measure voltage. For example, a potential transformer would be used to step the voltage on a 12,470 volt distribution line down to 124.7 volts so that it can be metered. The lower voltage is also used for protective relaying such as overvoltage and undervoltage relaying. Potential transformers also provide a voltage that can be fed into the system control center's Supervisory Control and Data Acquisition (SCADA) system or Energy Management System (EMS).

Most potential transformer are connected phase-to-neutral. Only a few are connected phase to phase. Figure 1 includes a drawing of a potential transformer and a chart showing the bushing height. Figure 2, 3 and 4 are photographs of phase-to-neutral potential transformers. Figure 5 is a photograph of a phase-to-phase potential transformer.

Voltage Rating	Approximate Height of Bushing Above Tank
15 kv	12 Inches (1 foot)
23 kv	21 Inches (1.75 feet)
34.6 kv	25 Inches (2 feet)
46 kv	28 Inches (2.3 feet)
69 kv	35 Inches (3 feet)
115 kv	50 Inches (4.2 feet)
138 kv	58 Inches (4.8 feet)
161 kv	73 Inches (6 feet)
196 kv	87 Inches (7.3 feet)
230 kv	96 Inches (8 feet)
345 kv	130 Inches (10.8 feet)
500 kv	200 Inches (16.7 feet)



POTENTIAL TRANSFORMER

Figure 1

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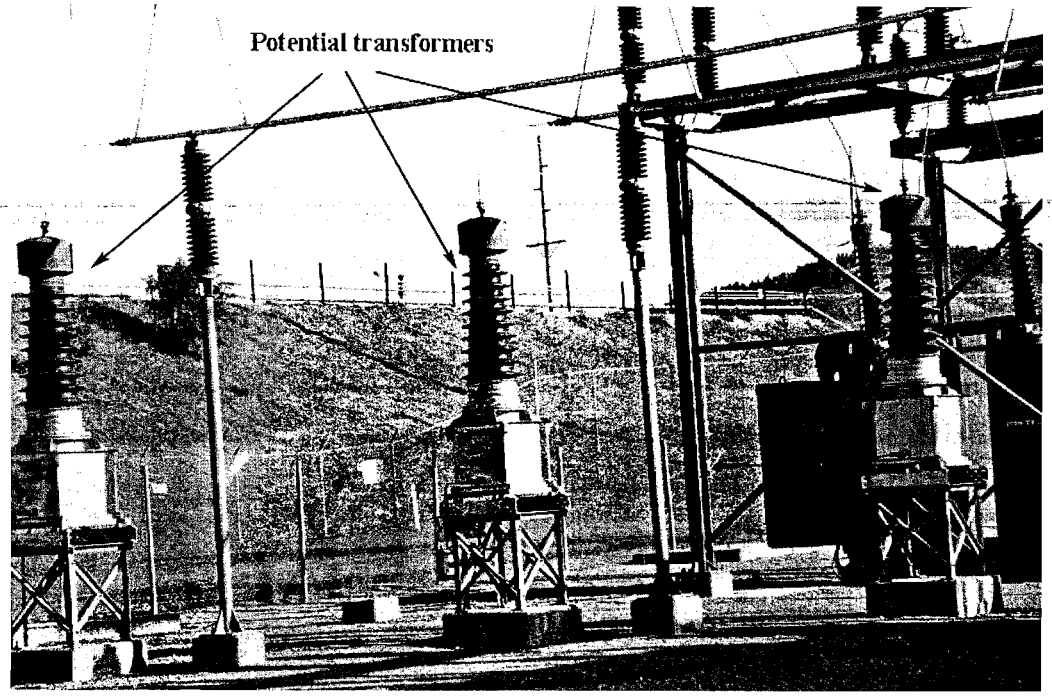
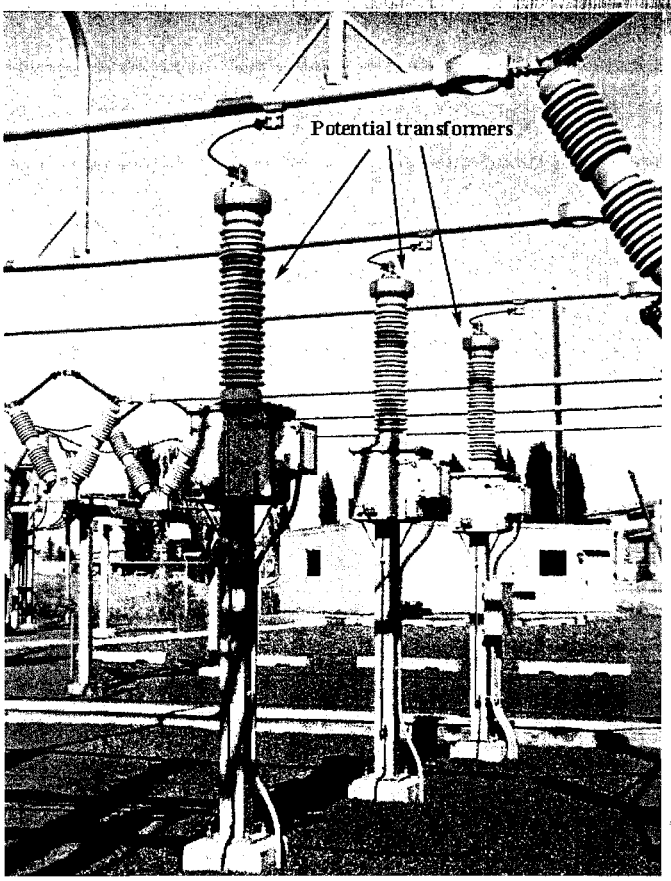


Courtesy: Skip Collier

PHASE TO NEUTRAL POTENTIAL TRANSFORMERS

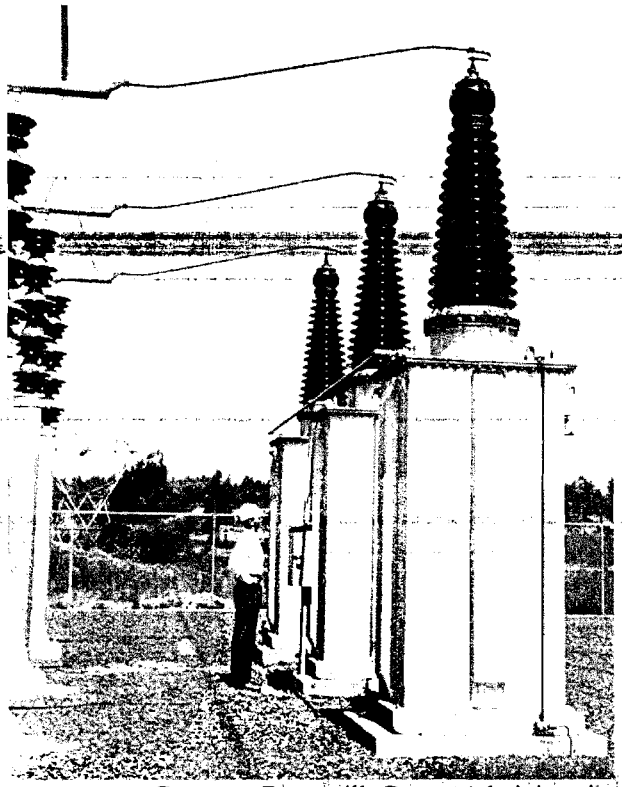
Figure 2



Courtesy: Skip Collier

PHASE TO NEUTRAL POTENTIAL TRANSFORMERS

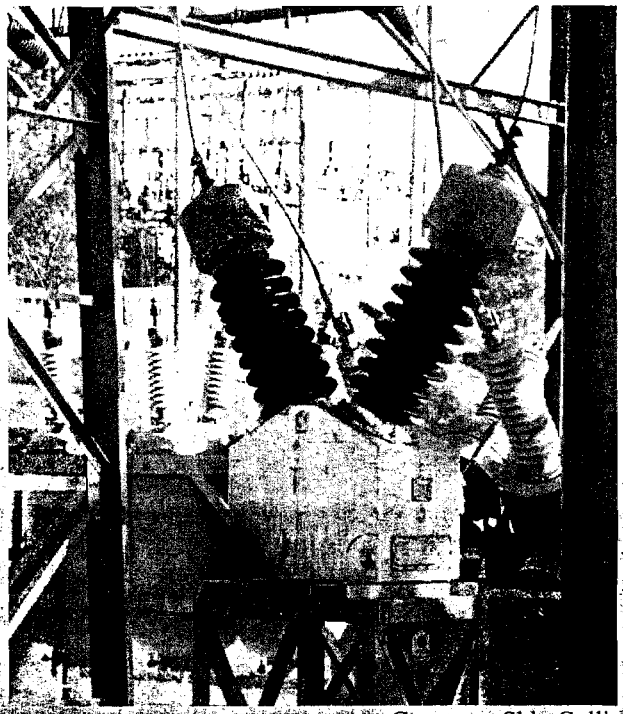
Figure 3



Courtesy: Bonneville Power Administration

PHASE-TO-NEUTRAL POTENTIAL TRANSFORMERS

Figure 4



Courtesy: Skip Collier

PHASE-TO-PHASE POTENTIAL TRANSFORMERS

Figure 5

♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

CURRENT TRANSFORMERS

Specified by: Insulation voltage rating, primary and secondary current ratings

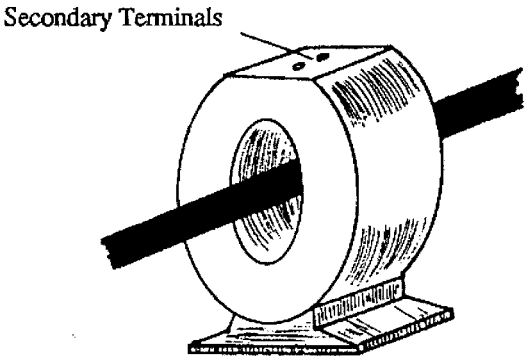
Abbreviation: CT

Function: Measuring current

Symbol:

Current transformers are used to measure the current flowing in a conductor. They do this by measuring the electromagnetic field surrounding a conductor. The electromagnetic field produces a lower current in the current transformer that is proportional to the current being measured. In commercial, industrial and utility electrical systems, the current flowing in the current transformer (the secondary current) usually has a maximum rating of 5 amps. The primary rating of a current transformer is usually the maximum current rating of the conductor being measured. If, for example, a 2000 amp conductor is being measured, a 2000:5 current transformer would be used. Conductors rated 600, 800, 1200 and 3000 amps would be measured with current transformers rated 600:5, 800:5, 1200:5 and 3000:5 respectively.

The conductor carrying the current that is being measured passes through the center of the current transformer. This is illustrated in Figure 1.



WINDOW-TYPE CURRENT TRANSFORMER

Figure 1

The two main types of current transformers are the window (or doughnut) type shown in Figures 1, 2 and 3, and the bar type shown in Figure 4.

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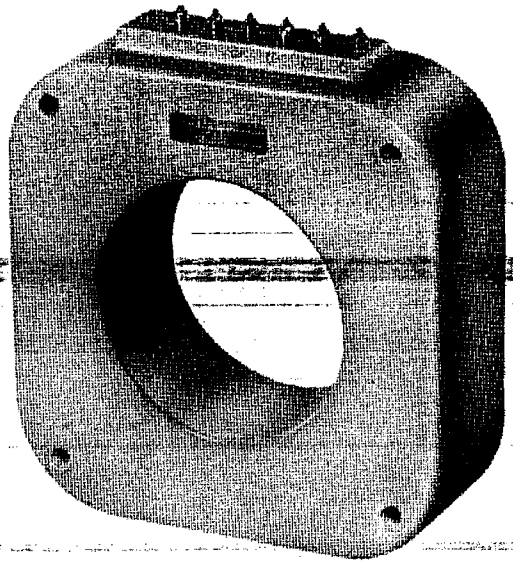
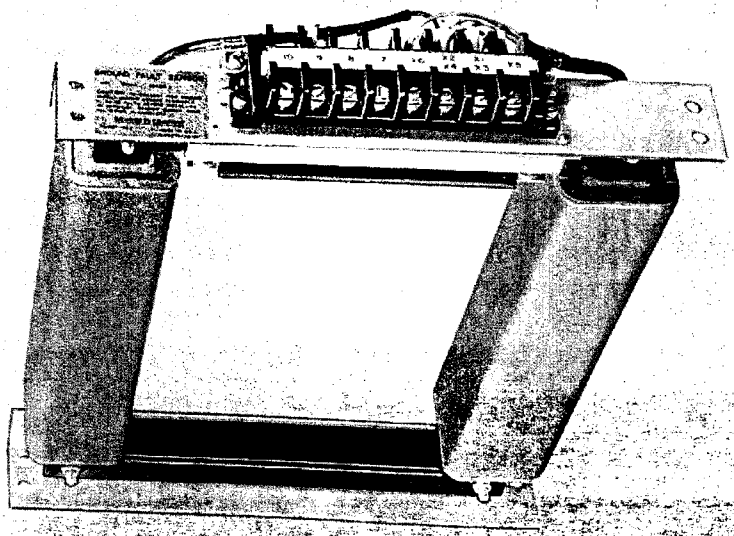


Courtesy: Square D Company

MULTI-RATIO WINDOW-TYPE CURRENT TRANSFORMER

Figure 2

The current transformer in Figure 2 is a multi-ratio current transformer. Five taps on it secondary windings allow the transformer to be used for five different current ranges. Its primary use is by engineers and instrument technicians who must measure currents in different systems.

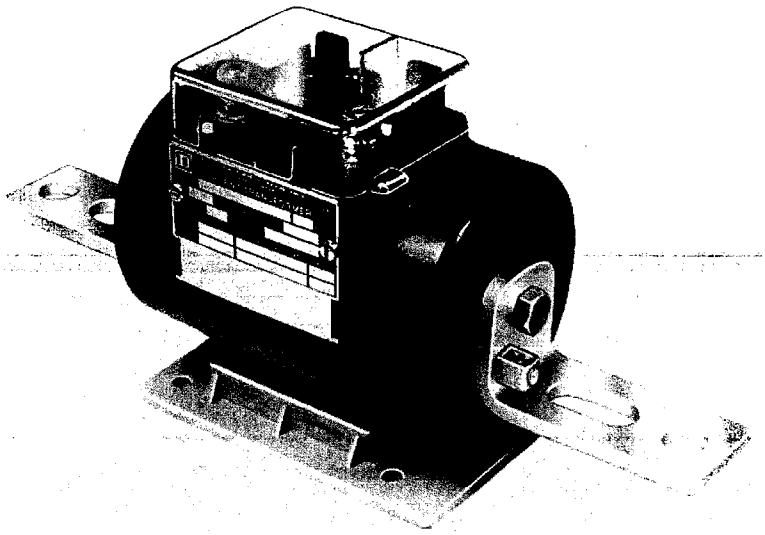


Courtesy: Square D Company

SPLIT-CORE CURRENT TRANSFORMER

Figure 3

The current transformer in Figure 3 is a split-core current transformer. A split-core current transformer is constructed so that the unit can be opened, slipped over a conductor, and closed.



Courtesy: Square D Company

BAR TYPE CURRENT TRANSFORMER
Figure 4

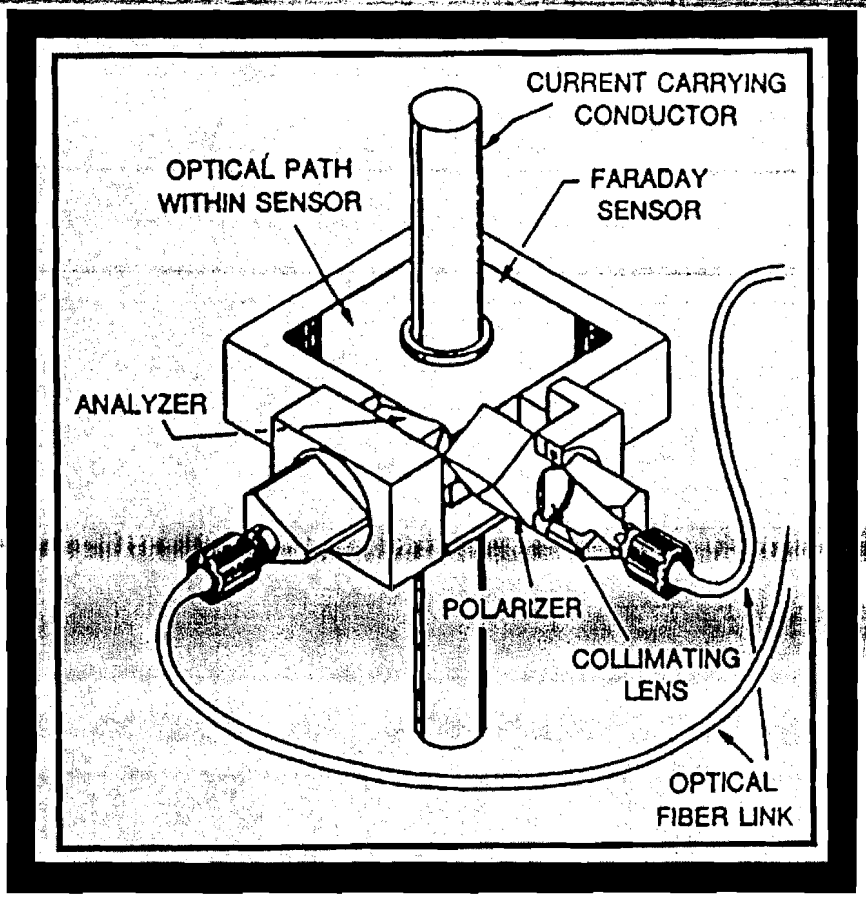
Figure 4 shows a bar-type current transformer. In a bar-type current transformer, a short length of bus bar is permanently mounted inside the current transformer's winding. This bus carries the current that is being measured. To install a bar-type current transformer, the conductor must be cut. One end of the cut conductor is connected to one end of the bus bar, and the other end of the cut conductor is connected to the other end of the bus bar. This results in the current that is being measured flowing through the bus bar.

Note: Current transformers should never have the secondary terminals disconnected when the current being measured is flowing. A dangerously high voltage will instantaneously appear the moment the secondary is disconnected. If a current transformer is installed and not being used, a jumper must be installed between the secondary terminals.

The Tennessee Valley Authority's Research and Development Division helped develop a magneto-optic current transducer that can be used in place a current transformer. This device relies on the Faraday affect discovered by Michael Faraday in 1845.

When a block of glass is placed in a strong magnetic field, it becomes optically active. When polarized light passes through the glass in a direction parallel to the applied magnetic field, the plane of the light is rotated. The amount of rotation is proportional to the strength of the magnetic field.

By measuring the rotation, the strength of the magnetic field can then be used to determine the amount of current that is producing the magnetic field. Figure 5 illustrates the key components for measuring the rotation of the polarized light in a magneto-optic current transducer.

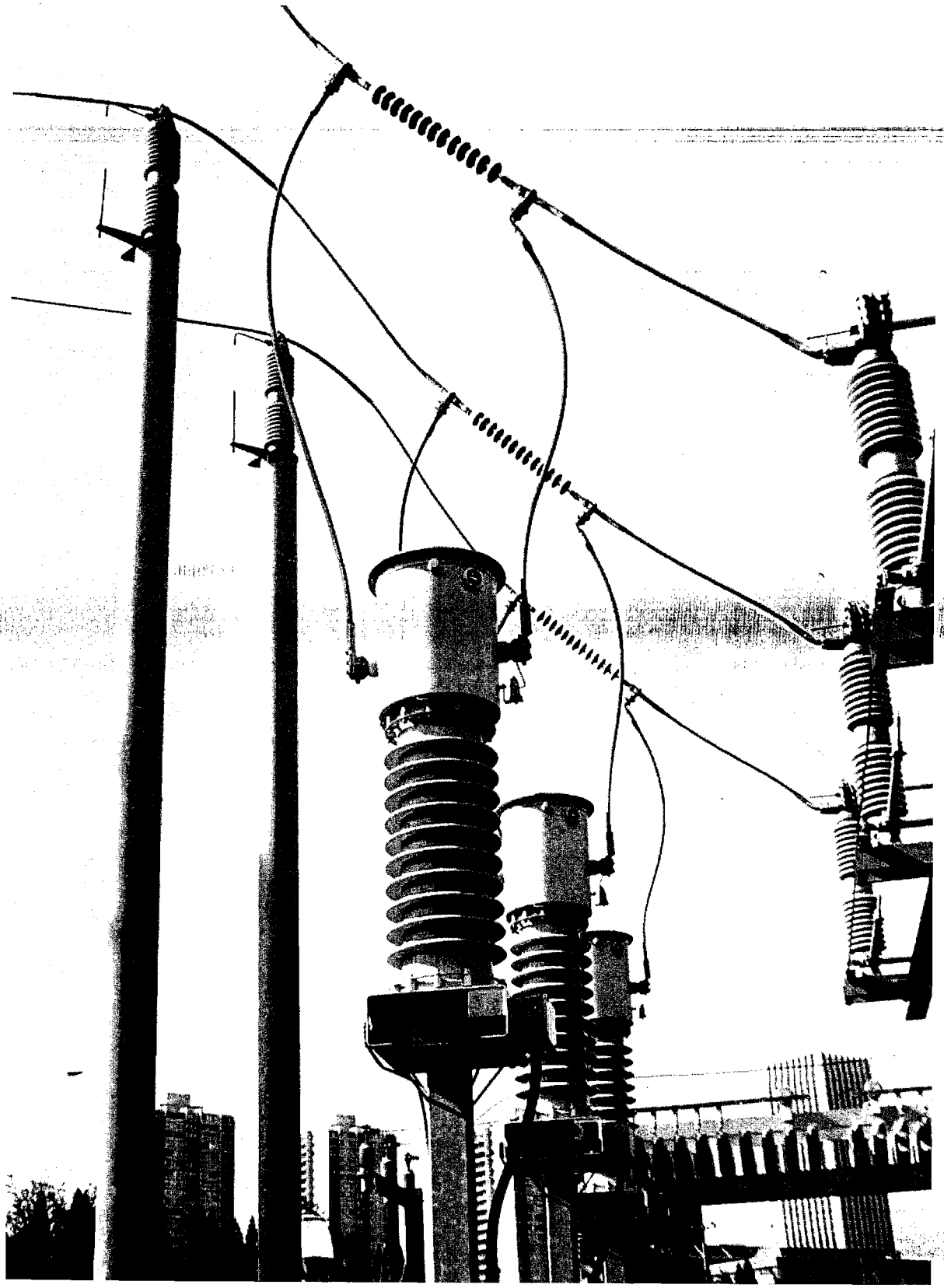


Courtesy: Tennessee Valley Authority

MAGNETO-OPTIC CURRENT TRANSDUCER

Figure 5

Figure 6 shows a 115 KV current transformer. It is bar-type current transformer in an oil-filled tank.



Courtesy: Skip Collier

115 KV CURRENT TRANSFORMER

Figure 6

♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

CIRCUIT BREAKERS

****

* Specified by: Voltage, full-load current, interrupt- *
* ing current, and the medium *
* in which the contacts open *
* Abbreviation: CB,OCB, ACB, VCB, PCB, GCB *
* Function: To interrupt the flow of current *
* *
* Symbol: *
* *
* *

****

Circuit breakers are used to disconnect a part of an electrical system when a problem occurs. These problems can include excessive current, high voltage, low voltage, low frequency, any many other less-common occurrences.

Under normal operation, current flows from the source, through the circuit breaker, to the load. When a circuit breaker opens to disconnect a part of the system that is experiencing a problem, the flow of current is broken inside the circuit breaker.

Circuit breakers consist of two metal current-carrying contacts per phase. These contacts open to break the flow of current, and close to allow current to flow. In Figure 1, a set of contacts is shown in the closed position, and then in the open position.

Open **Closed**

CIRCUIT BREAKER CONTACTS

Figure 1

The length of time it takes a circuit breaker to interrupt the flow of current after the contacts open is specified in cycles. (Each cycle is 1/60 of a second) In a 3-cycle circuit breaker, the current would flow for no longer than 3 cycles (1/20 of a second) before being extinguished.

The medium in which the contacts open to interrupt the flow of current determines the type of circuit breaker. If the contacts open in oil to interrupt the flow of current, the circuit breaker is called an oil circuit breaker (abbreviated OCB). Figure 2 shows a transmission-voltage oil circuit breaker. Each of the three tanks is oil filled, and each contains a set of contacts.

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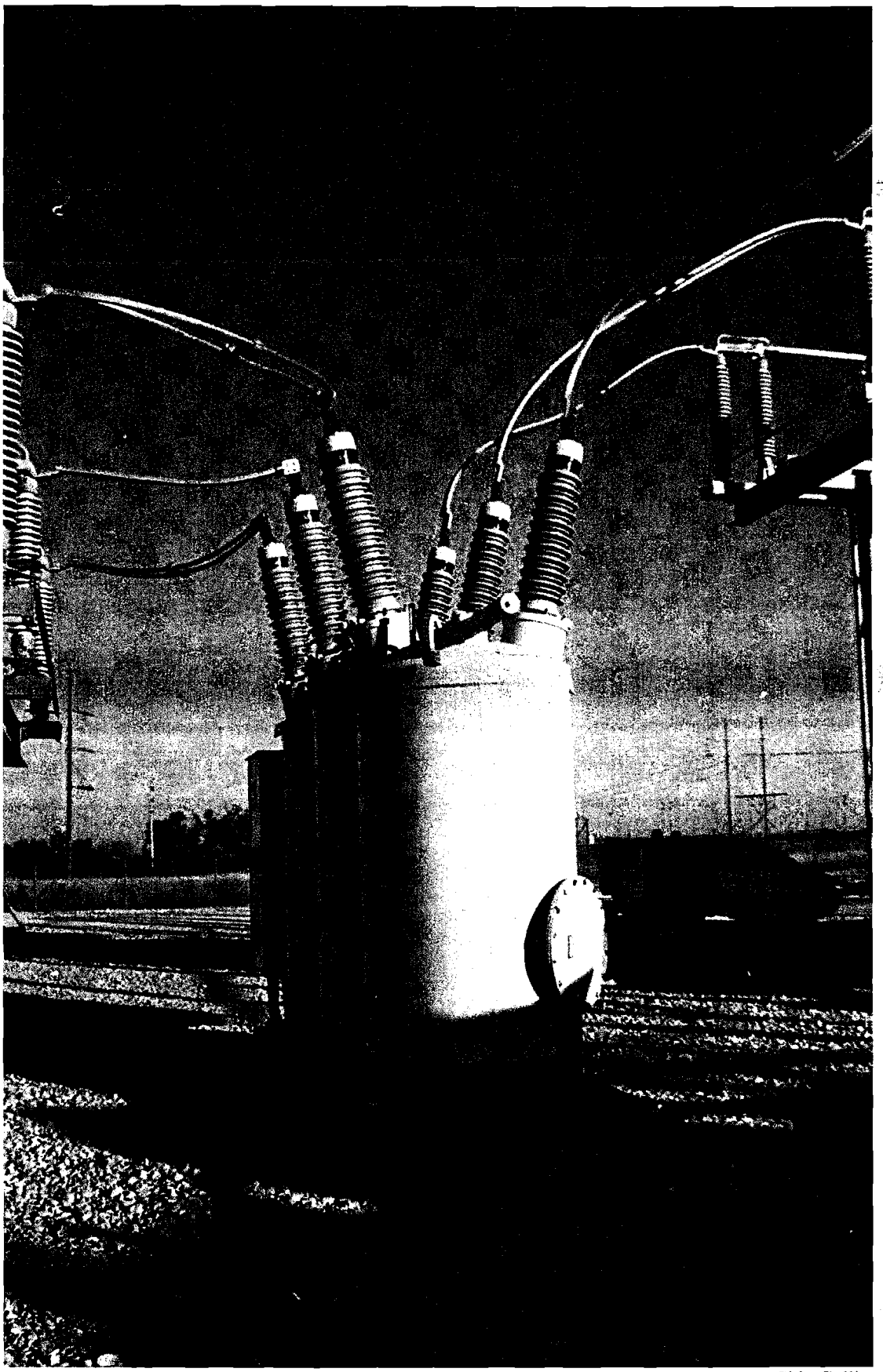
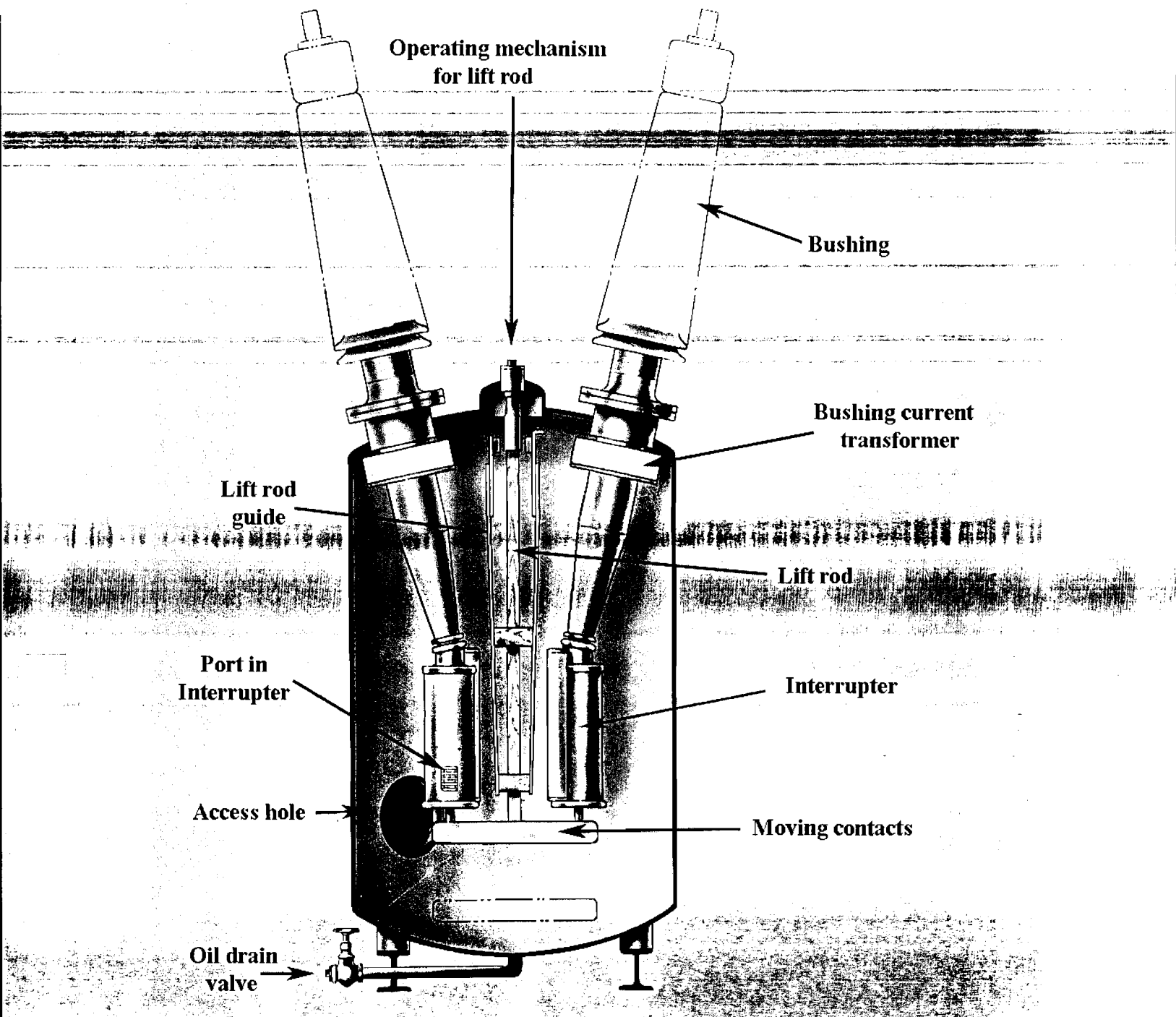


Courtesy: Skip Collier

OIL CIRCUIT BREAKER

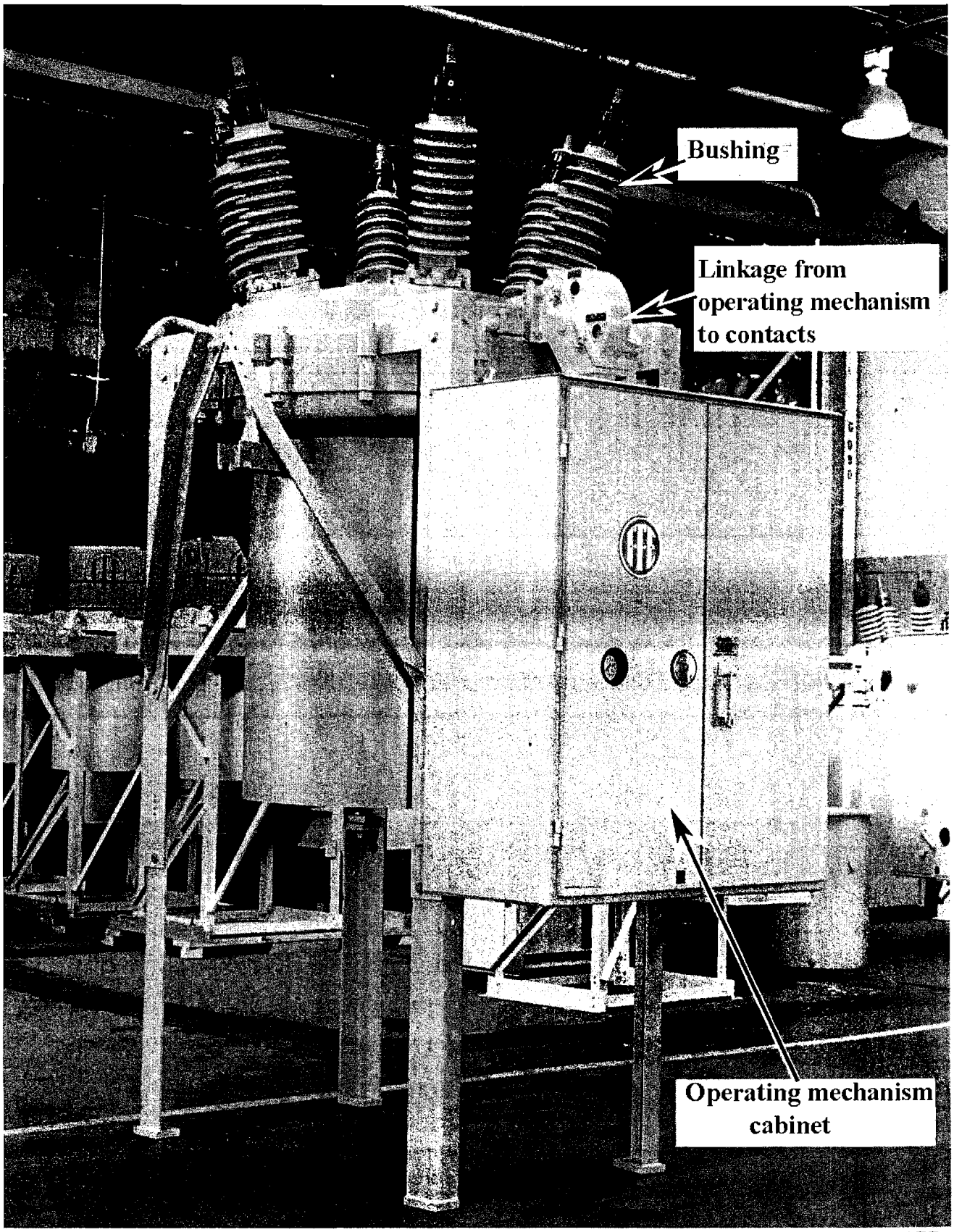
Figure 2



Courtesy: ABB

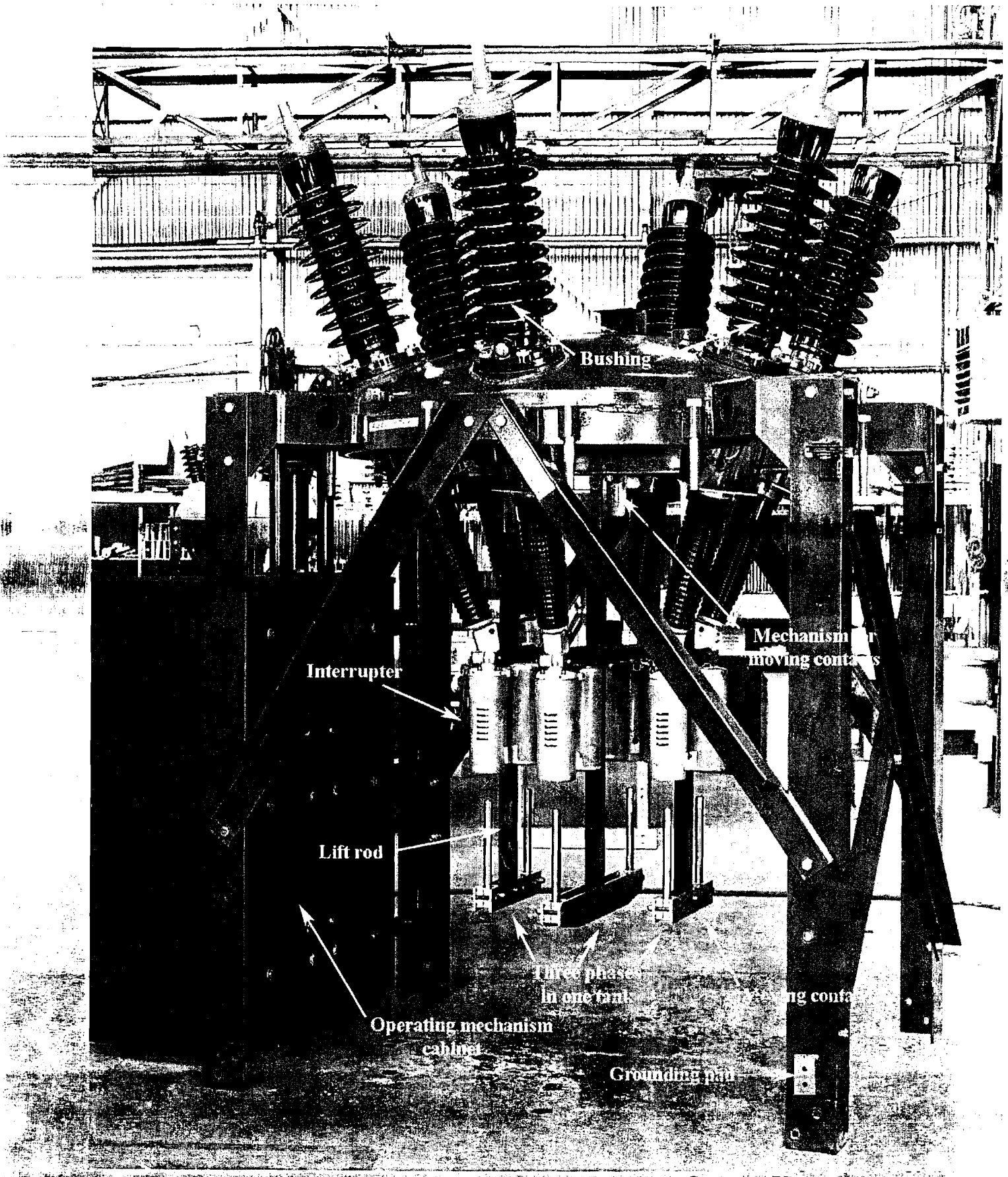
CROSS SECTION OF AN OIL CIRCUIT BREAKER

Figure 3



Courtesy: ABB

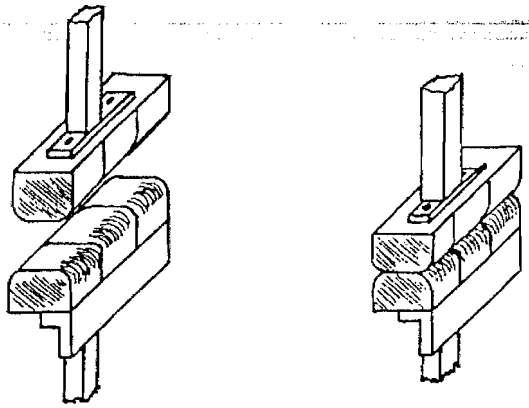
SUBTRANSMISSION OIL CIRCUIT BREAKER
(3 PHASES IN ONE TANK)
Figure 4



Courtesy: ABB

SUBTRANSMISSION OIL CIRCUIT BREAKER
(WITH TANK REMOVED)
Figure 5

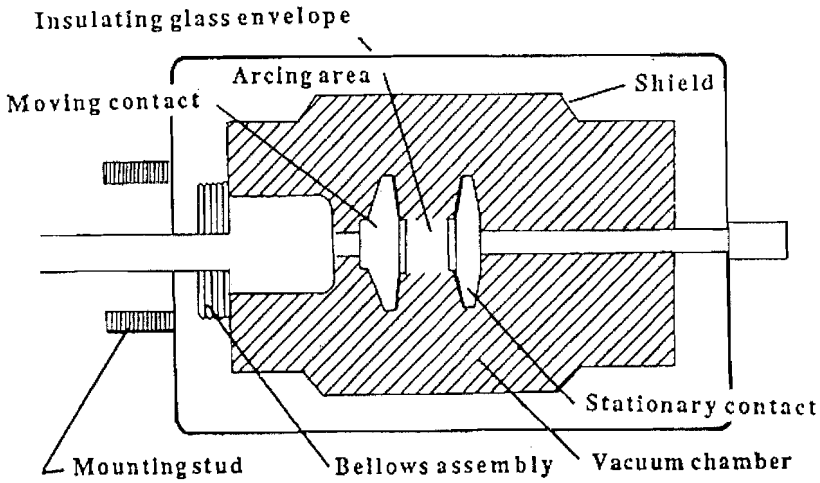
In an air circuit breaker, the contacts open in air (see Figure 6). Air circuit breakers are the most common type of circuit breakers and are used primarily for low voltage (rated 600 volts or less).



AIR CIRCUIT BREAKER CONTACTS

Figure 6

Vacuum circuit breaker contacts open in a sealed vacuum chamber (Figure 7). A vacuum is an excellent insulator. This allows the contacts to separate a relatively short distance, but yet still interrupt the flow of current.



VACUUM CIRCUIT BREAKER CONTACTS

Figure 7

Air-blast circuit breakers use a stream of high-pressure air blowing between the contacts, as they open, to extinguish the arc. Figure 8 and Figure 9 are photographs of air-blast circuit breakers.

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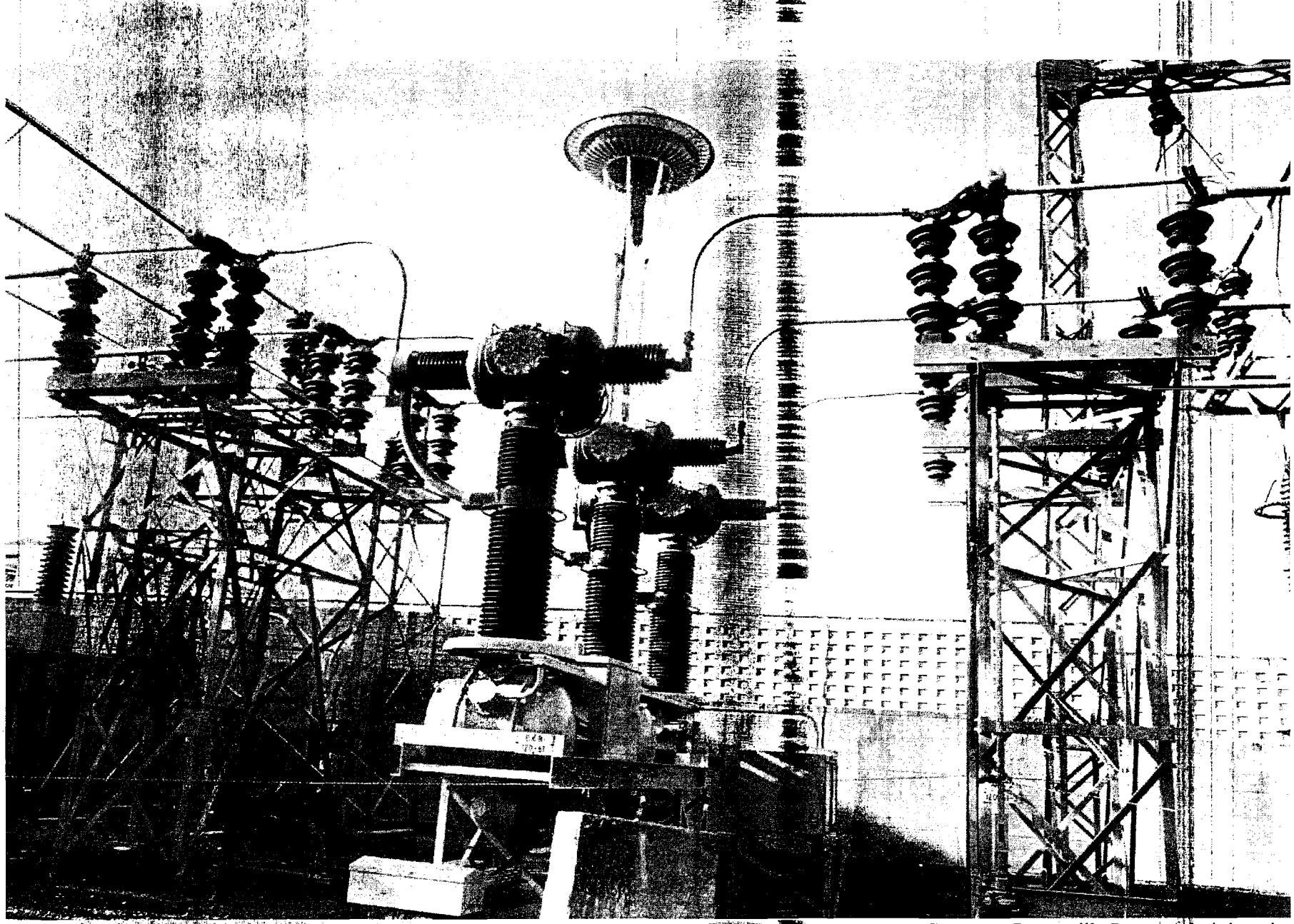
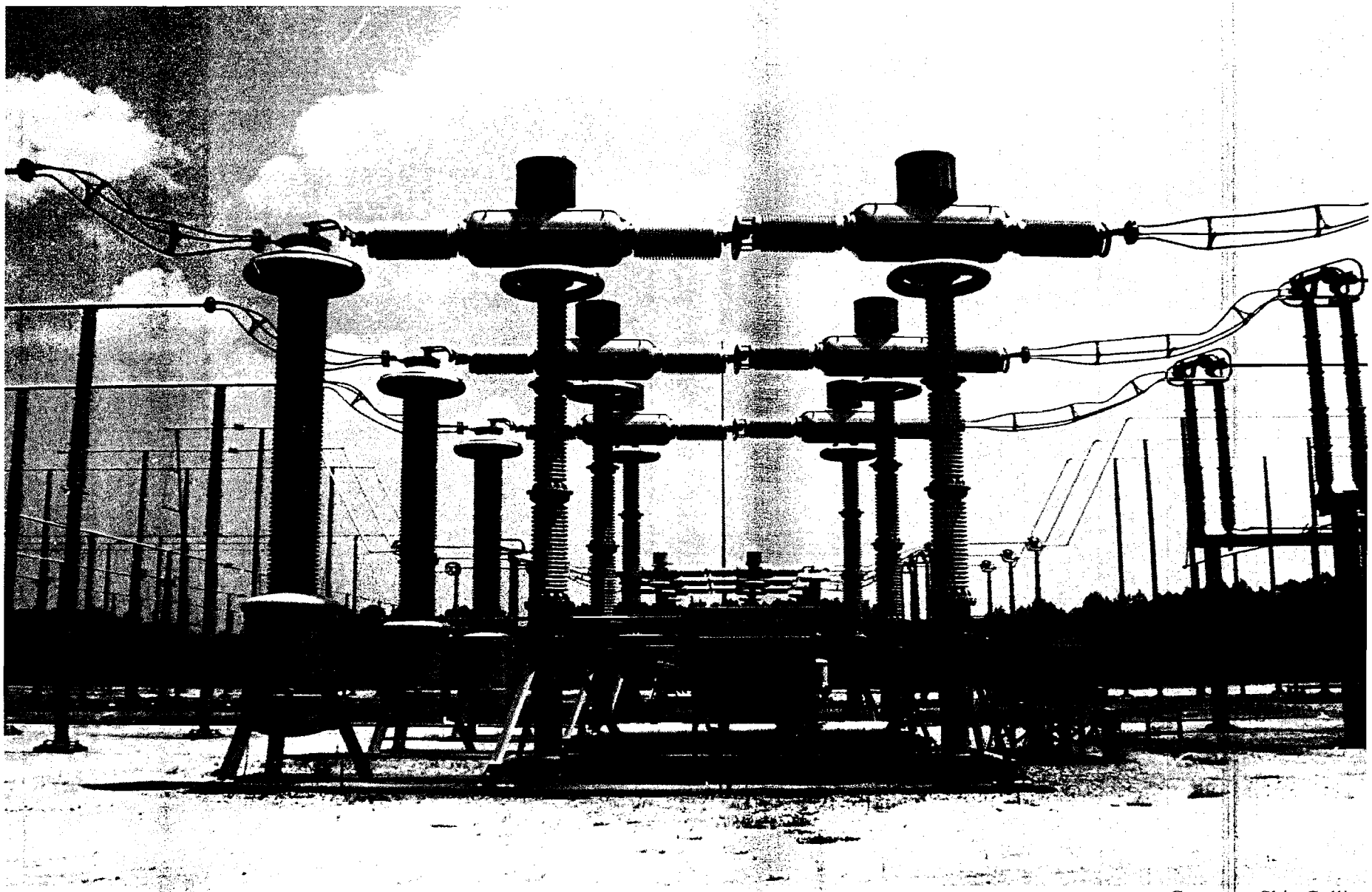


Courtesy: Bonneville Power Administration

AIR-BLAST CIRCUIT BREAKER

Figure 8

♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦



Courtesy: Skip Collier

AIR-BLAST CIRCUIT BREAKER

Figure 9

♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

SF_6 CIRCUIT BREAKERS

SF_6-insulated circuit breakers and SF_6 high-voltage switches are the latest development in modern protective switchgear. SF_6, sulphur hexaflouride, is an inert gas possessing greater dielectric (insulating) strength than insulating oil. It is non-toxic, non-flammable, odorless, colorless, tasteless, heavier than air, and highly stable.

SF_6 circuit breakers have replaced oil circuit breakers, in new construction, for transmission and subtransmission applications, and compete with vacuum circuit breakers for distribution applications. They offer very low maintenance relative to that required for oil circuit breakers.

SF_6 equipment is particularly applicable for interrupting leading current, such as that occurring from lightly loaded transmission lines and from capacitor banks. This is because the high dielectric strength of SF_6 assures restrike-free operation.

In some designs, the contacts are in a main tank containing [illegible] SF_6 [illegible] strength of SF_6 gas increases with pressure.) There is a second pressurized tank that has higher pressure SF_6 gas. In this two-pressure design, the higher pressure gas is blown between the circuit breaker contacts as they open. This stream of higher pressure gas helps extinguish the arc.

Figure 10 is a photograph of a 3-phase SF_6 circuit breaker using a two-pressure system. (It is a modification of the air-blast circuit breakers shown in Figures 8 and 9.) Each phase has three heads in series, each containing contacts. A high-pressure SF_6 system blows gas between the contacts as they pull open. Figures 11, 12, and 13 show variations of the two-pressure design.

In a single-pressure SF_6 circuit breaker, the contacts pull open in a pressurized SF_6 tank and the arc is extinguished. Figure 14 and 15 show the single-pressure design with each phase in a separate tank. Figures 16 shows a single-pressure design with the three phases in a single tank.

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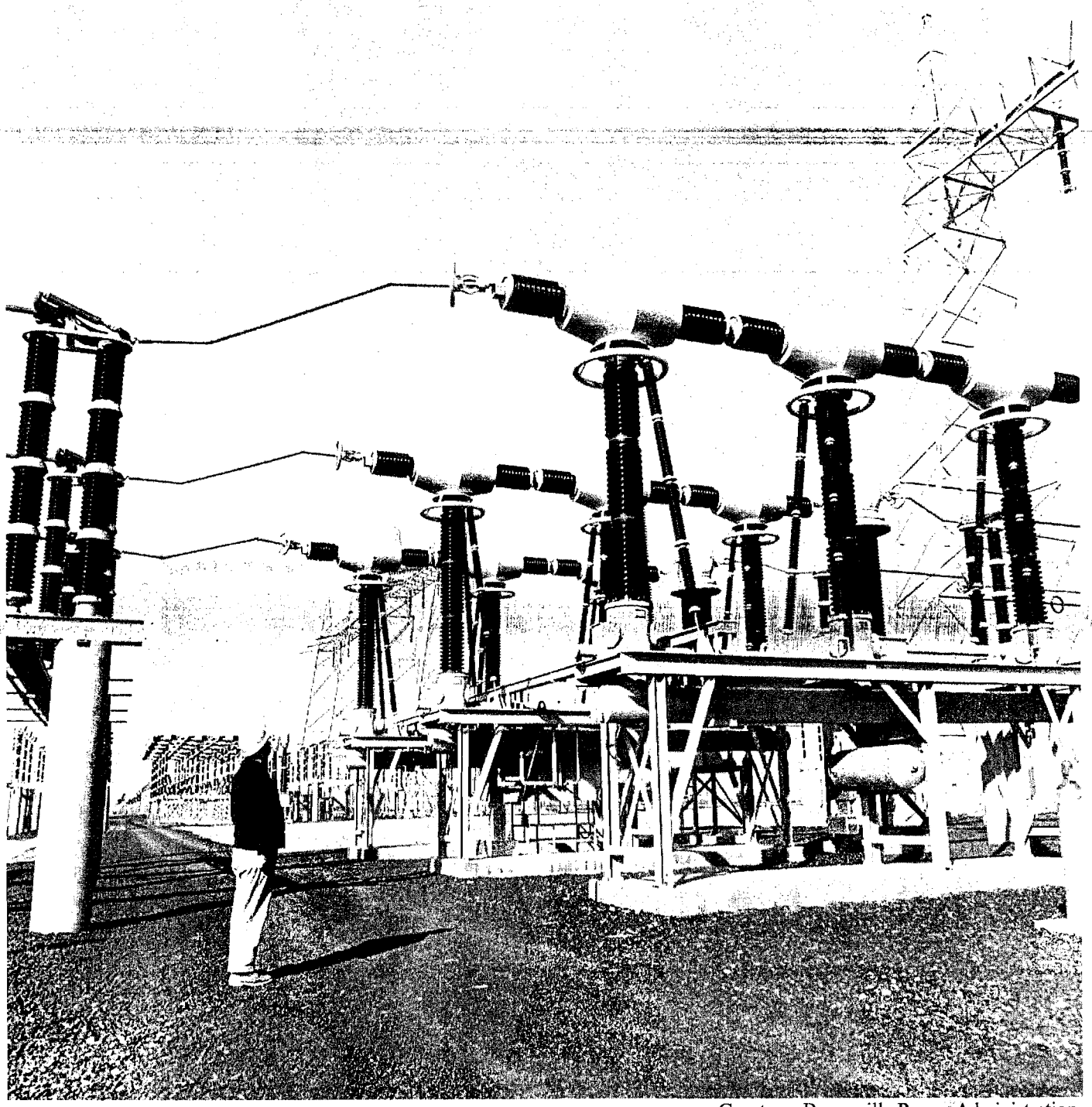
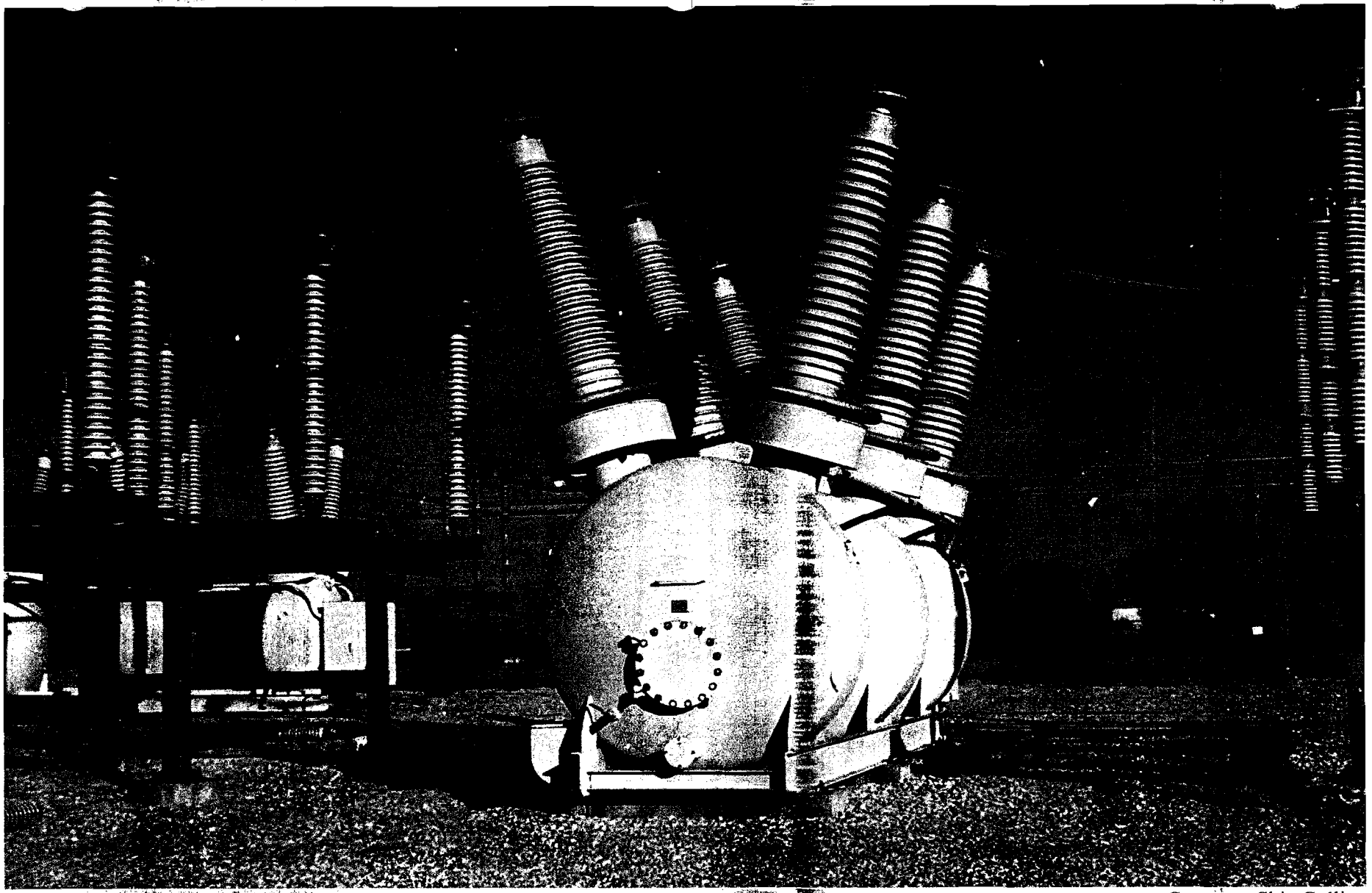


Courtesy: Bonneville Power Administration

SF_6 CIRCUIT BREAKER

Figure 10

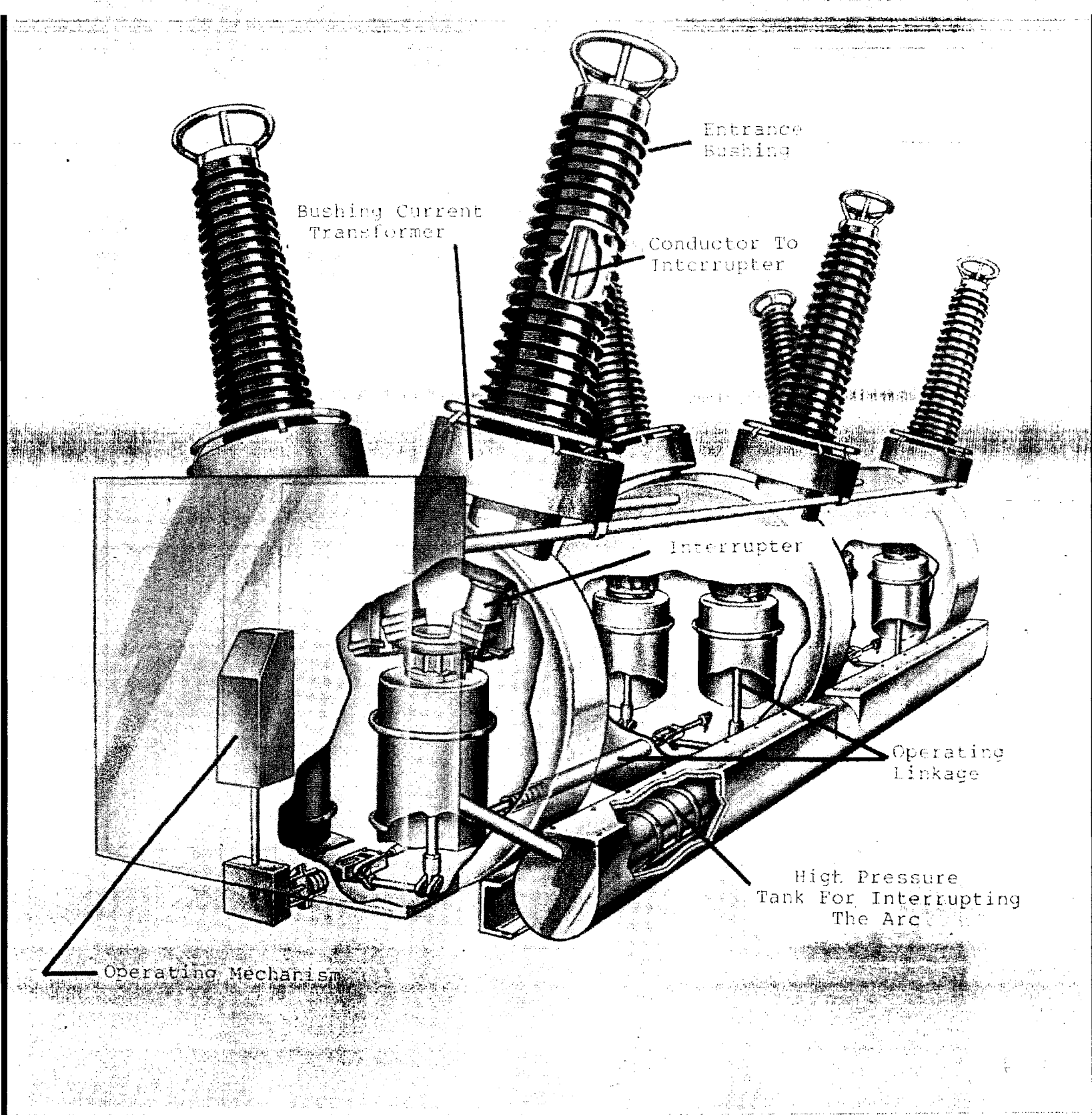


Courtesy: Skip Collier

SF_6 CIRCUIT BREAKER

Figure 11

♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

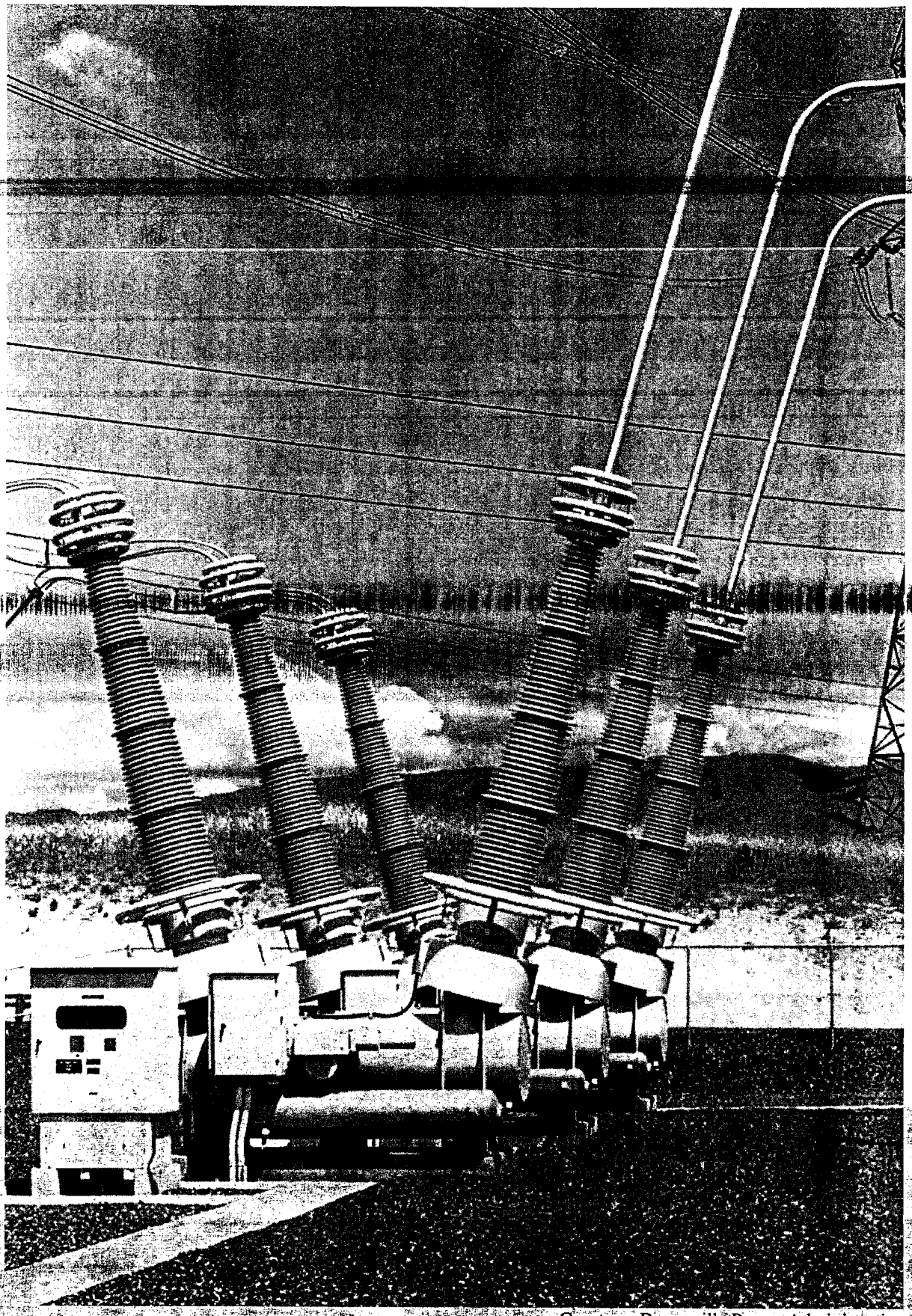


Courtesy: The Bonneville Power Administration

E127-12

CUT-AWAY VIEW OF AN SF_6 CIRCUIT BREAKERS

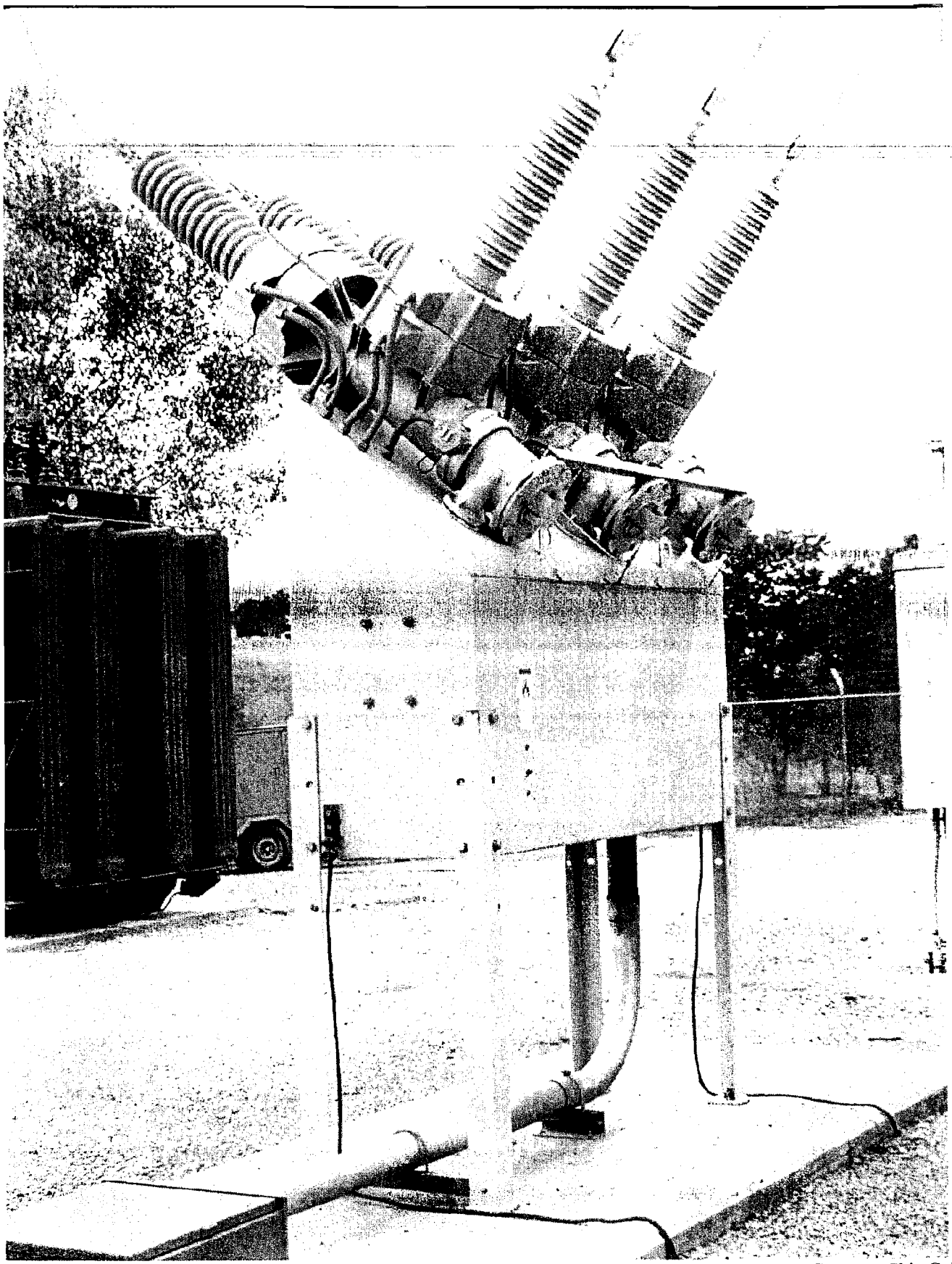
Figure 12



Courtesy: Bonneville Power Administration

SF_6 CIRCUIT BREAKER

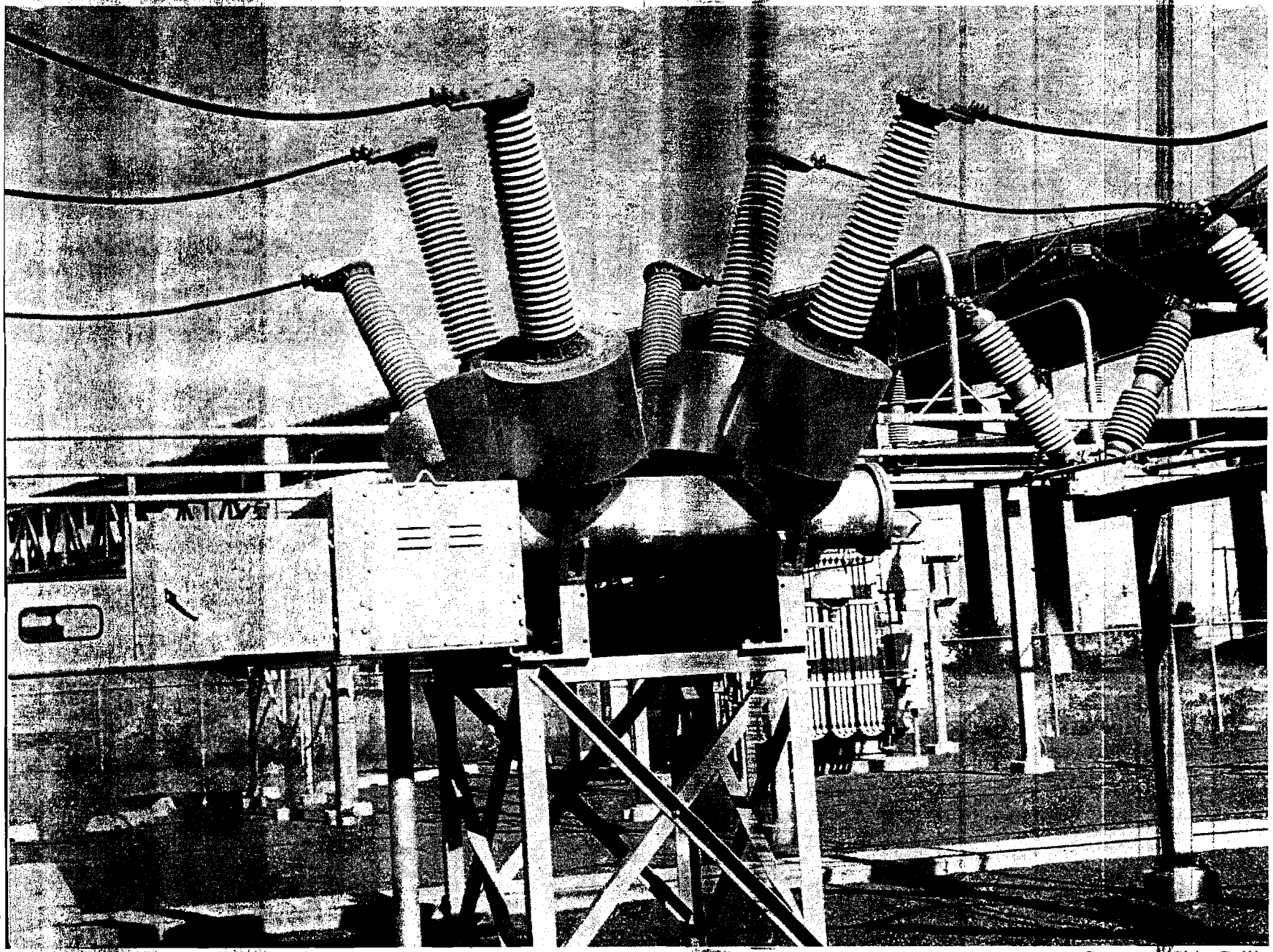
Figure 13



Courtesy: Skip Collier

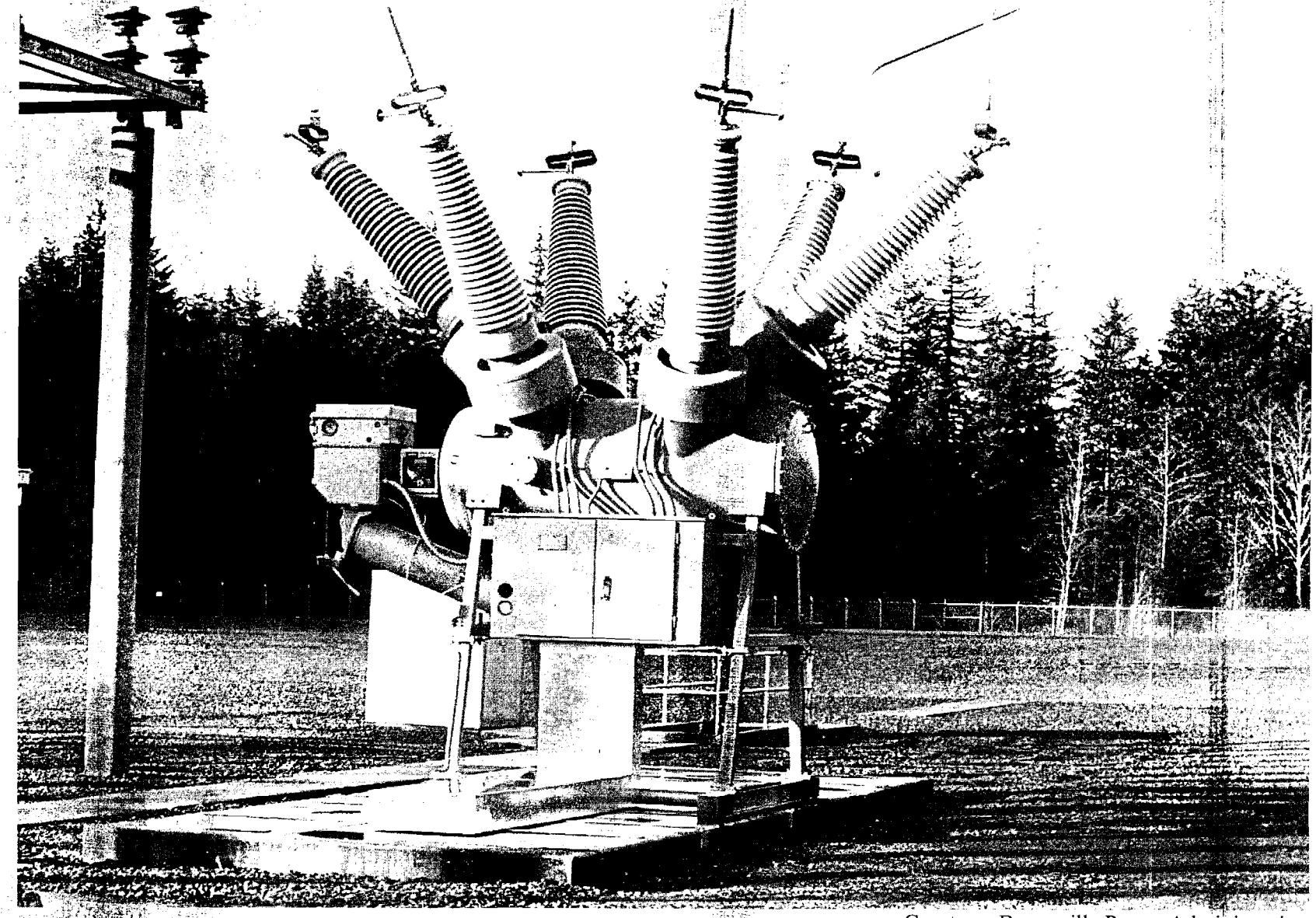
SF_6 CIRCUIT BREAKER

Figure 14



Courtesy: Skip Collier

SF_6 CIRCUIT BREAKER
Figure 15



Courtesy: Bonneville Power Administration

SF_6 CIRCUIT BREAKER

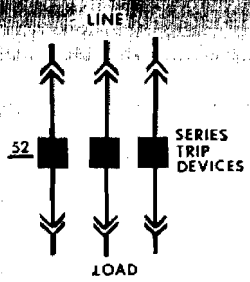
Figure 16

♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

CIRCUIT BREAKER CONTROLS

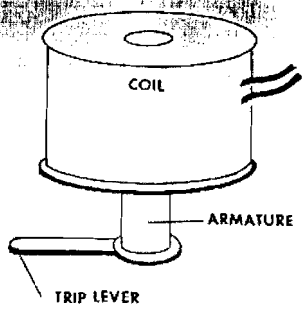
All circuit breakers have two basic operations. One is the closing operation. The other is the opening operation. On larger circuit breakers, both operations normally can be performed electrically, using a switch or push-button, and mechanically, using a lever (or push-rod) assembly mounted in the breaker's control cabinet.

In addition to the electrical and mechanical operations initiated by a person, circuit breakers also have one or more automatic circuits that open the breaker when a problem occurs. There are two basic automatic methods used. One method uses a series trip device. In a series trip device, the current flowing through the circuit breaker flows through the series trip device. When the current increases because of a problem, this increased current also passes through the series trip device. On magnetic-type series trip devices, the increased current causes increased magnetic forces, and these magnetic forces actuate the breaker's opening mechanism. On thermal-type series trip devices, the increased current causes an increased temperature, and this temperature is used to actuate the breaker's opening mechanism. Because a series trip device must be able to continually carry a breaker's full-load current, series trip devices are normally found only on smaller breakers. It is rare to find series trip devices on anything but low voltage (600 volts or less) breakers.



SERIES TRIP

Figure 1



SHUNT TRIP DEVICE

Figure 2

The second basic method for tripping a circuit breaker uses a shunt trip device. In the shunt-trip-device method, the current flowing through the breaker does not flow through the shunt trip device. The shunt trip device is usually a solenoid which is an electrical coil with an iron rod, called an armature, (see Figure 2) that is pulled into the coil by the coil's magnetic forces. The armature part of the solenoid is used to release compressed steel springs.

Figure 3 shows a typical circuit for energizing a shunt trip device. When any of the contacts (52PB, 51, or 59) close, current flows from the positive fuse to the negative fuse through the circuit breaker's shunt trip coil (52/TC). The coil pulls the armature, and the circuit breaker trips.

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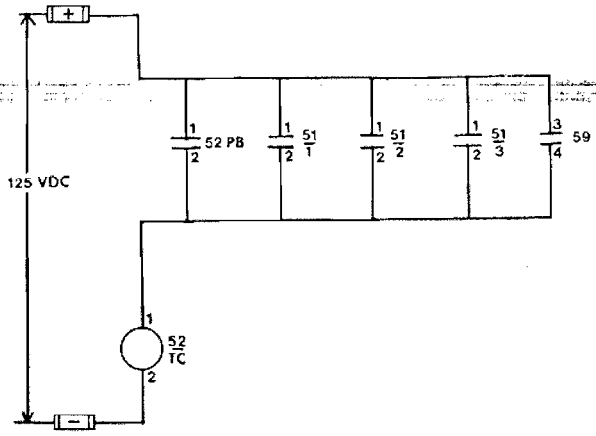
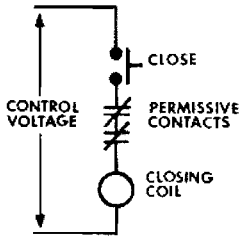


TYPICAL SHUNT TRIP CIRCUIT

Figure 3

In addition to the tripping operation, circuit breakers must also have a closing operation. The closing of a circuit breaker is normally done using compressed springs, using pressurized air (a pneumatic system), or using hydraulic oil pressure (a hydraulic system). An electrical closing operation uses another solenoid to release the compressed springs, to release the compressed air, or to release hydraulic oil. The force of the spring, air or oil is used to close the breaker. Figure 4 shows a typical electric circuit for closing a circuit breaker.



TYPICAL CLOSING CIRCUIT

Figure 4

Figure 5 shows the components of a system using springs to close a circuit breaker. Figure 6 shows the components of a pneumatic closing system. Figure 7 shows an air tank mounted below the cabinet containing the circuit breaker's operating mechanism. Figure 8 shows the components of a hydraulic closing system.

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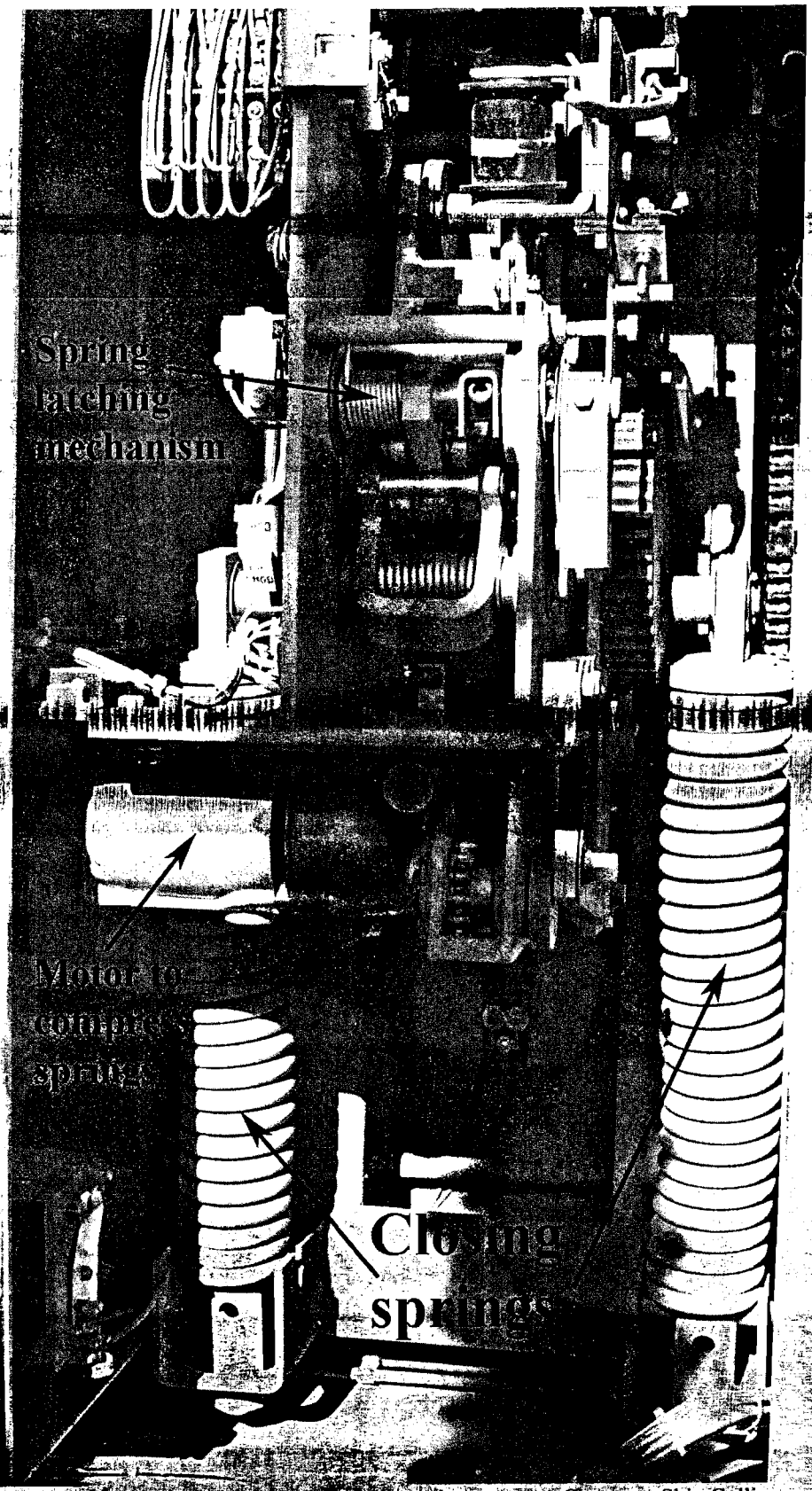
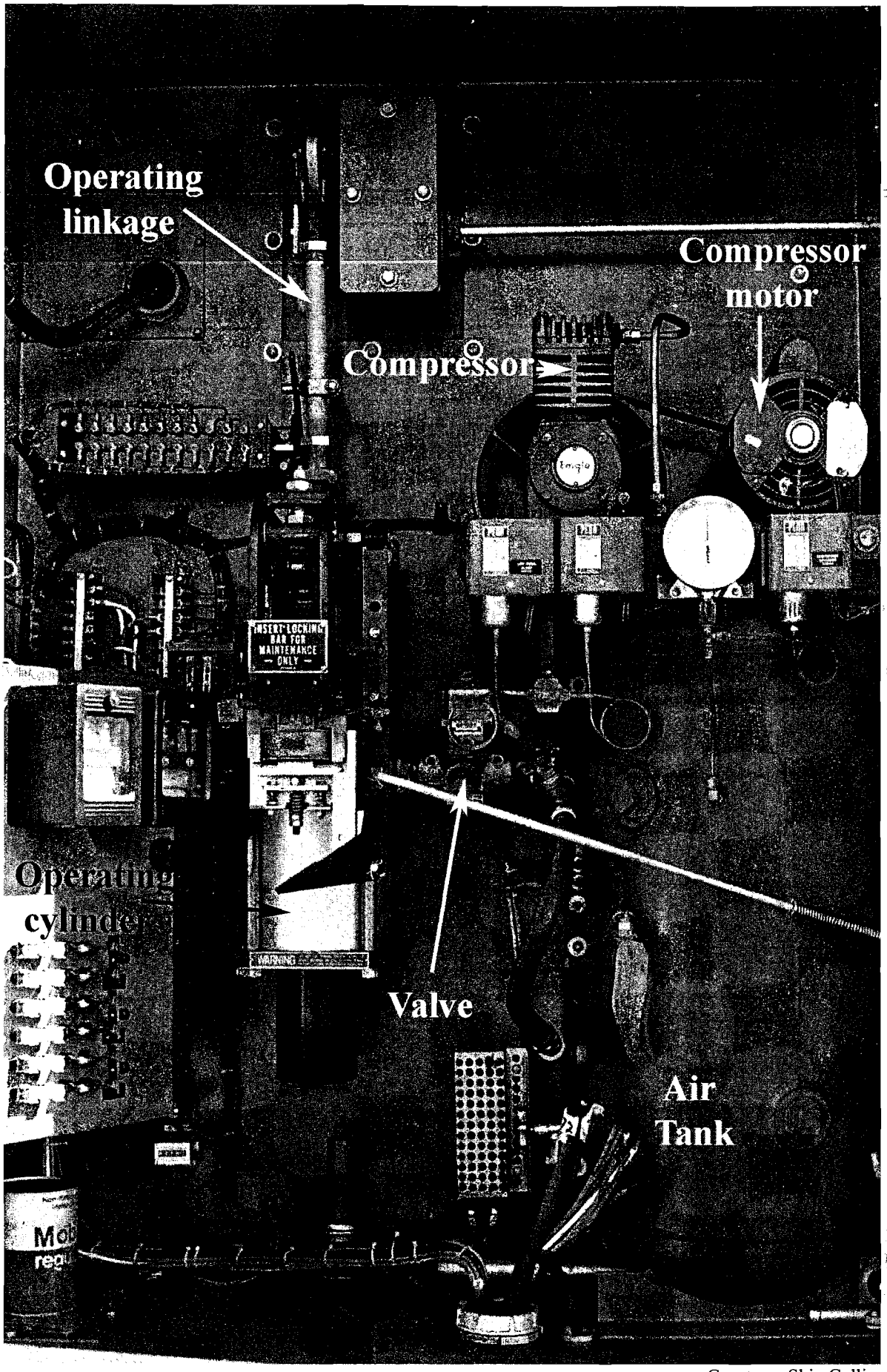


Courtesy: Skip Collier

SPRING SYSTEM FOR CLOSING CIRCUIT BREAKER

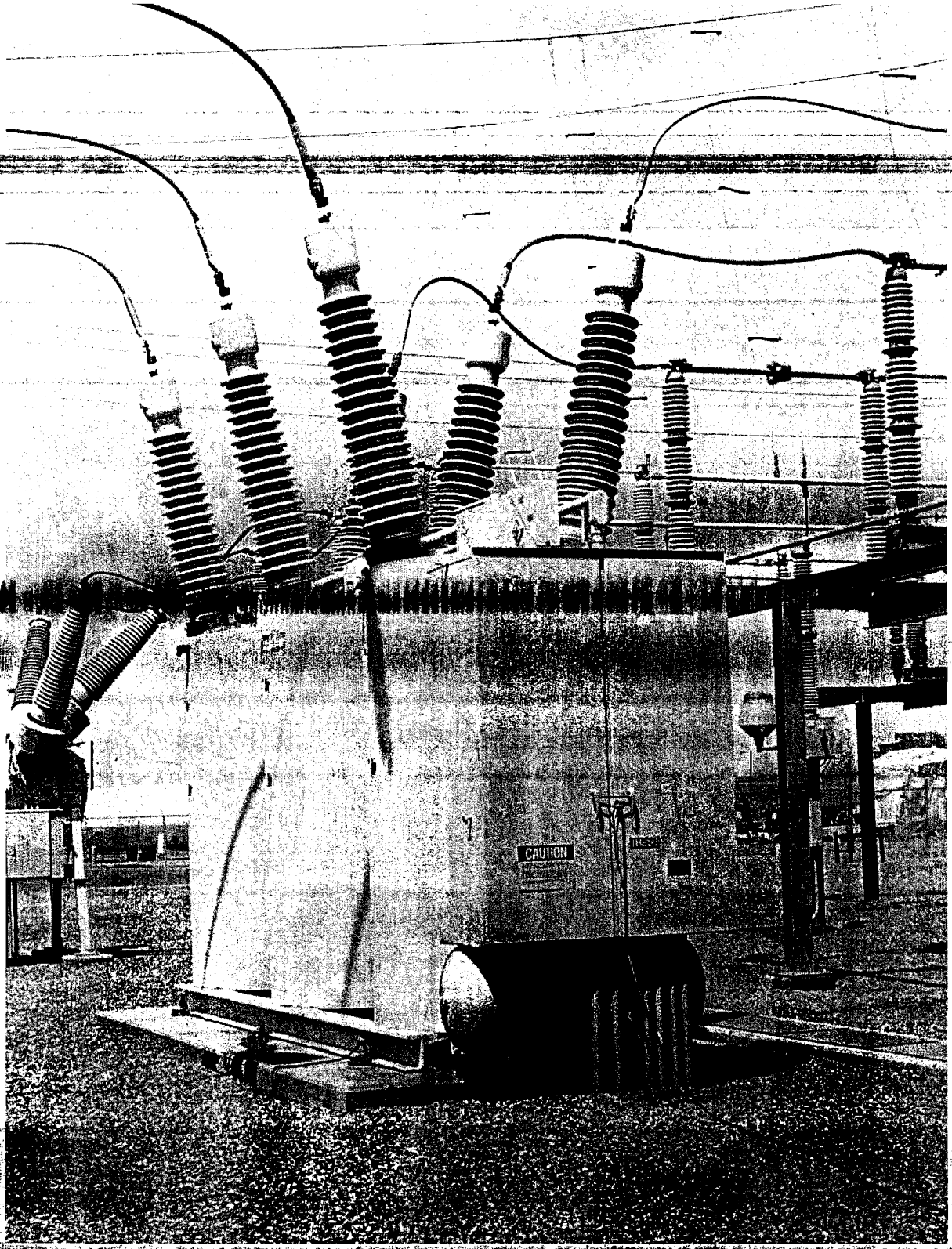
Figure 5



Courtesy: Skip Collier

PNEUMATIC SYSTEM FOR CLOSING CIRCUIT BREAKER

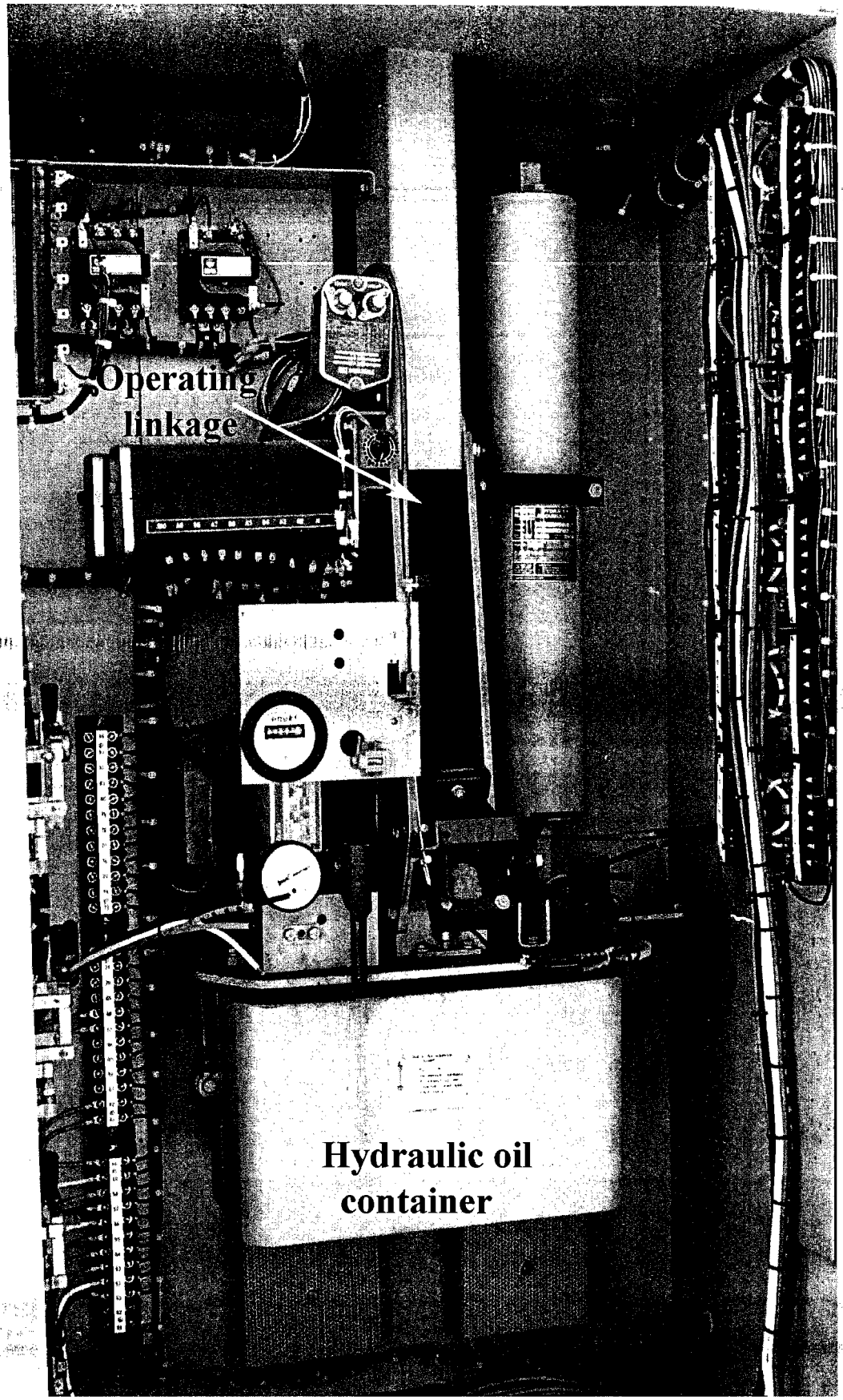
Figure 6



Courtesy: Skip Collier

CIRCUIT BREAKER WITH EXTERNAL AIR TANK

Figure 7



Courtesy: Skip Collier

HYDRAULIC SYSTEM FOR CLOSING CIRCUIT BREAKER

Figure 8

♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

RECLOSERS

Reclosers are circuit breakers with an automatic reclose feature. They are used to minimize outage time when temporary problems occur. These temporary problems include those caused by trees, animals, lightning, wind, ice and snow.

Modern reclosers can be adjusted to reclose after a certain time interval. Figure 1 shows a sample time sequence for a recloser.

First Reclose	Second Reclose	Third Reclose	Fourth Reclose
Instantaneous	5 Seconds	10 Seconds	Lockout

RECLOSE TIMES FOR A RECLOSER

Figure 1

Most feeder circuit breakers in distribution substations have been modified to make them into reclosers . This is done by adding a reclose relay.

[illegible] versions of these pole-mounted reclosers can also be set for specifc times between reclose operations. Figure 2 shows three single-phase reclosers.

The reclosers in Figure 2 are oil filled and are called oil circuit reclosers or OCRs. Reclosers also use a vacuum and SF_6 gas in which the arc is interrupted.

Reclosers, like circuit breakers, must be able to interrupt the maximum possible fault current. Vacuum and SF_6 gas provide higher fault-current interrupting ratings.

Faults and Fault Current

A fault is an event in which a problem occurs resulting in current returning to its source through an un-intended path. The current that flows during a fault is called fault current. The un-intended path in which the current is flowing determines the type of fault.

When a tree branch falls across A and B phases resulting in current flowing between the phases through the tree branch, it is called a phase-to-phase fault (or line-to-line fault). When a larger tree branch falls across all three phases and current is flowing between all three phases, it is called a 3-phase fault. When a phase breaks and falls to the ground resulting in current flowing back to the substation through the ground, it is called a phase-to-ground fault (or line-to-ground fault, or ground fault).

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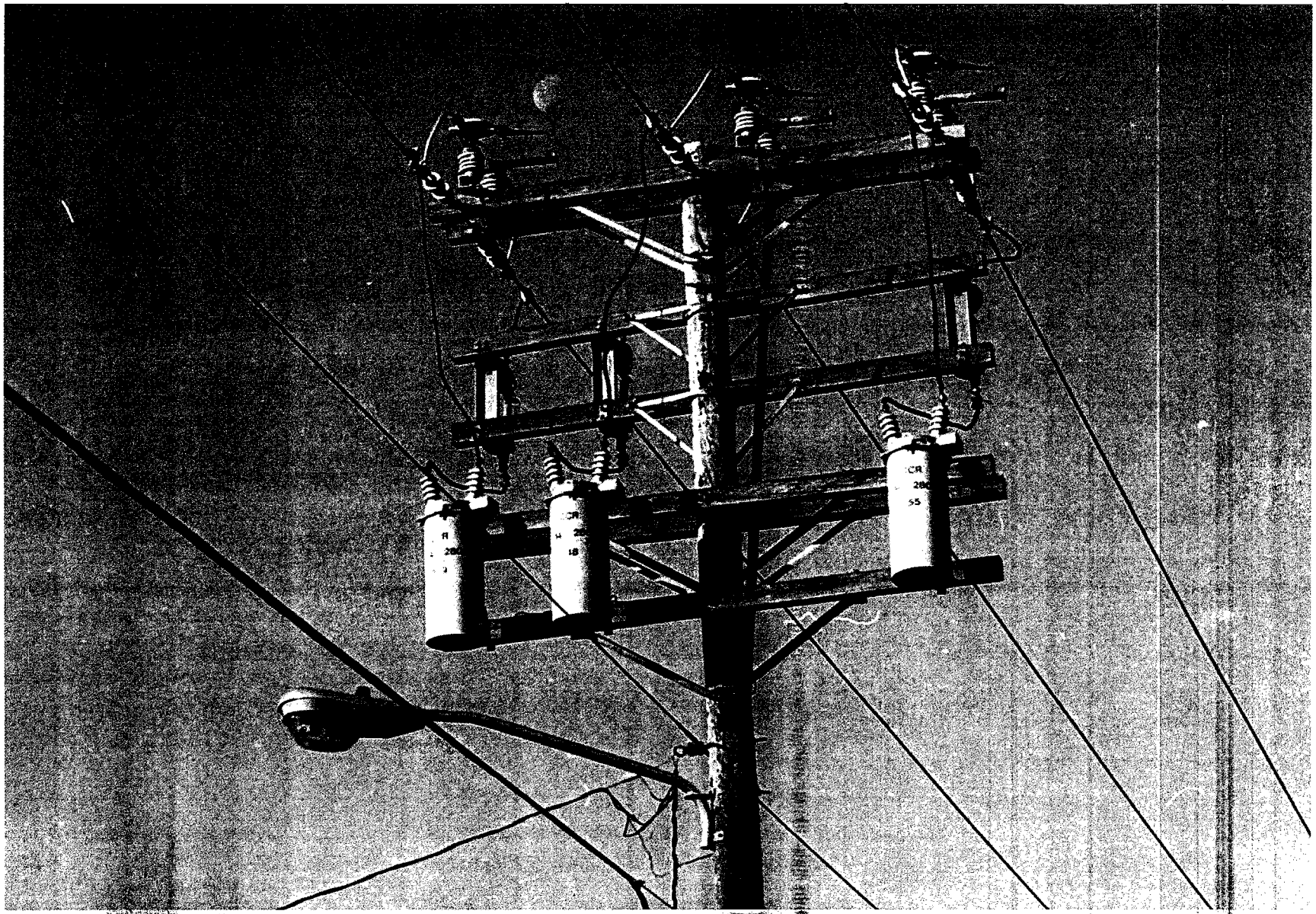


Courtesy: Skip Collier

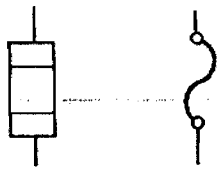
SINGLE PHASE POLE MOUNTED RECLOSERS

Figure 2

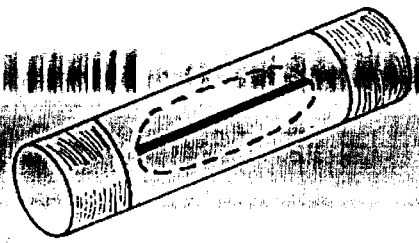
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

FUSES

Function:	Interruption of the flow of current
Specified by:	Maximum continuous-current rating
	Maximum interrupting-current rating
	Voltage
	Time it takes to interrupt the current

Symbols: 

Fuses are used to protect an electrical system from excessive current. A thin piece of conductor runs from the center of one metal end of the fuse to the center of the other end. (See Figure 1)



CUT-AWAY VIEW OF A FUSE

Figure 1

At any current level above the rated current of the fuse, the thin piece of conductor will melt, thus breaking the circuit. For example, a 15-amp fuse will melt open at current levels above 15 amps.

Figure 2 shows a transformer with three fuses on the incoming side. If the transformer experiences an internal failure, the fuse will disconnect the transformer from the energized incoming line. This will minimize damage to the transformer, but even more importantly, disconnecting the transformer will allow the energized line to continue supplying other customers.

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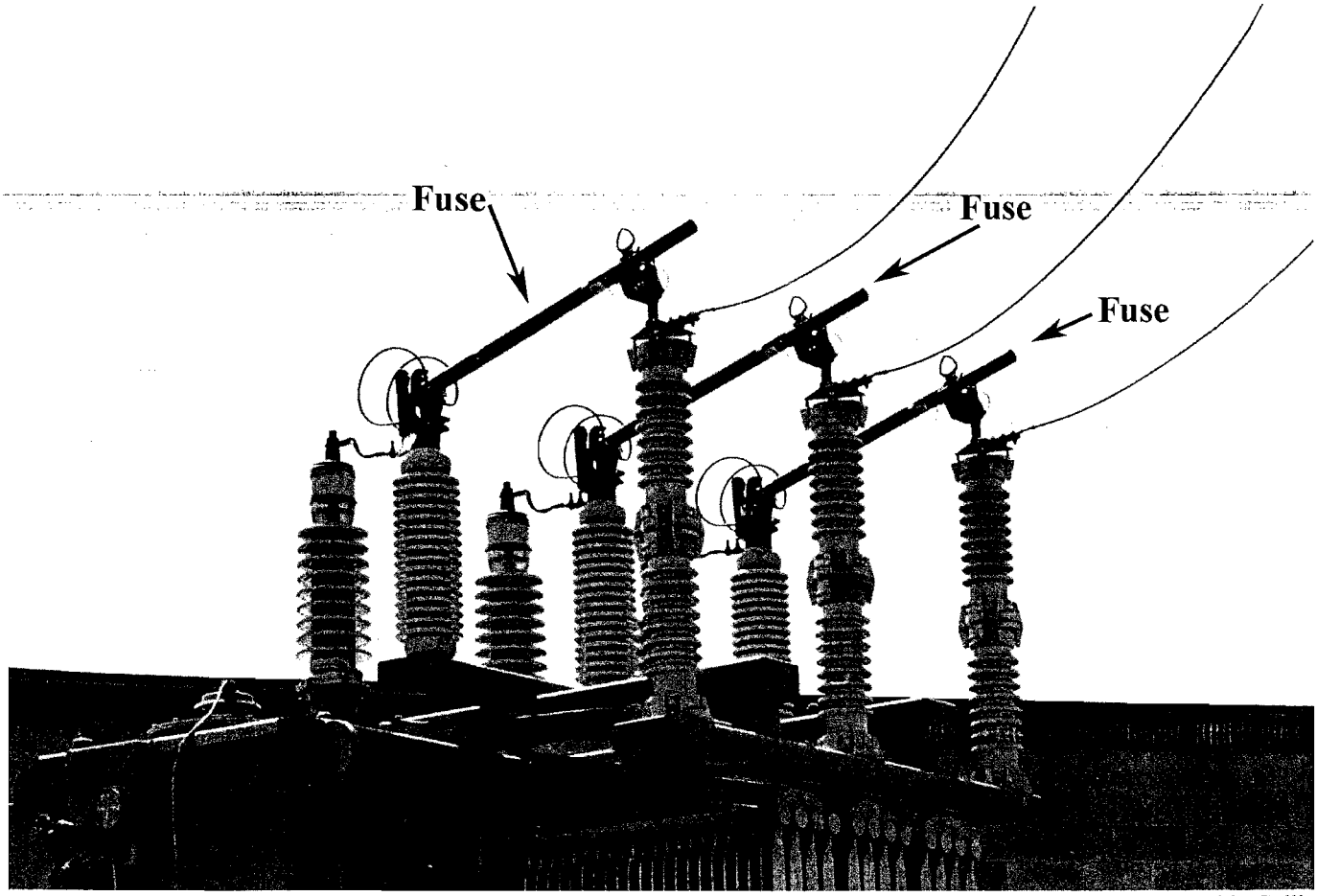
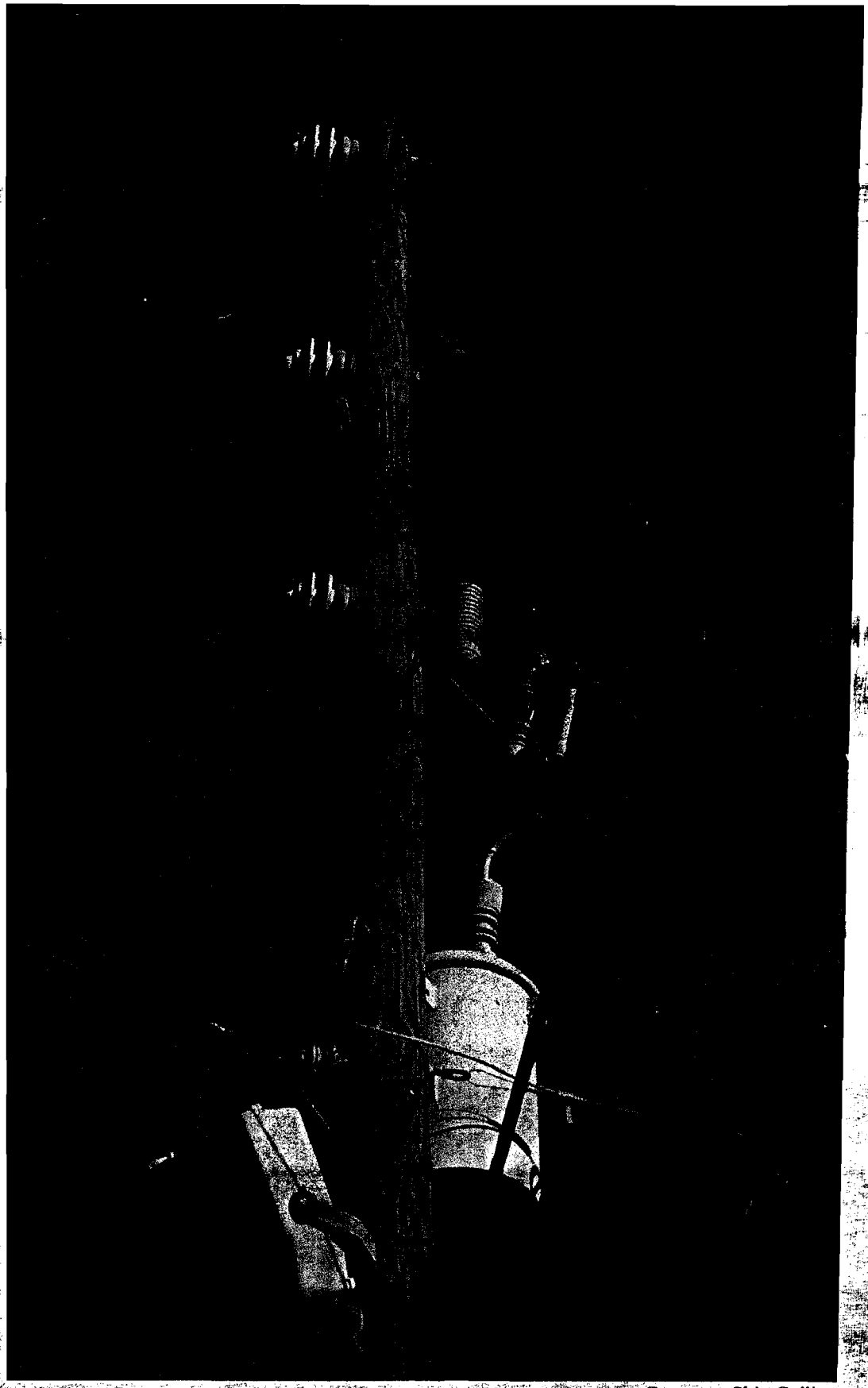


Courtesy: Skip Collier

TRANSFORMER WITH HIGH SIDE FUSES

Figure 2

Figure 3 shows a pole-mounted transformer with a lightning arrestor and fuse; the fuse is just above the transformer. This type of fuse is called a cut-out; it is designed to fall open when the fuse link melts open. The lightning arrestor is to the left of the cutout next to the pole.



Courtesy: Skip Collier

POLE MOUNTED TRANSFORMER WITH LIGHTNING ARRESTOR AND CUTOUT

Figure 3

♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

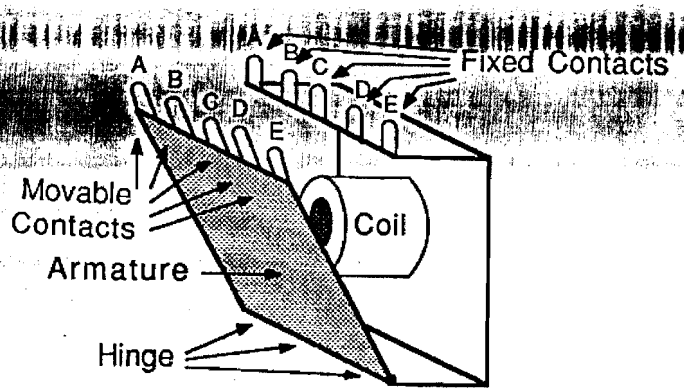
CONTROL RELAYS

****

* Specified by: Type, coil voltage, number and *
* type of contacts, and current *
* rating of contacts *
* Function: The controlling of one or more signals *
* by a specified event or action *
* *
* Symbol: *
* *
* *

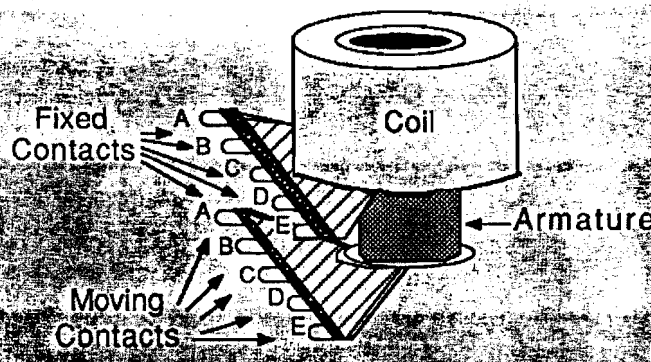
****

Electro-mechanical control relays are constructed with an operating coil, armature and contacts. When the coil is energized it becomes a magnet and pulls the armature to, or into, the coil. Normally open contacts close, and normally closed contacts open. (Contacts are identified with the coil de-energized.) The two most common electro-mechanical relays are the hinged-armature type shown in Figure 1, and the plunger type shown in Figure 2.



HINGED ARMATURE RELAY WITH FIVE NORMALLY OPEN CONTACTS

Figure 1



PLUNGER TYPE RELAY WITH FIVE NORMALLY OPEN CONTACTS

Figure 2

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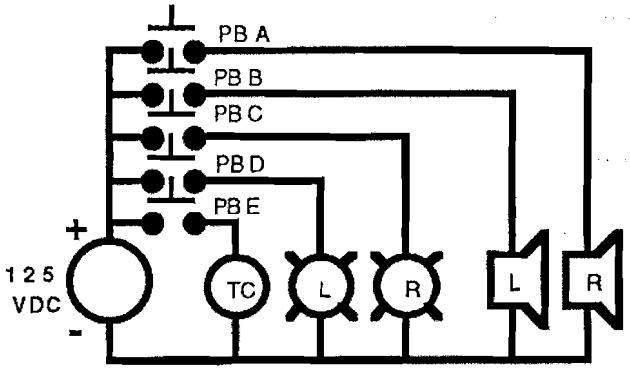
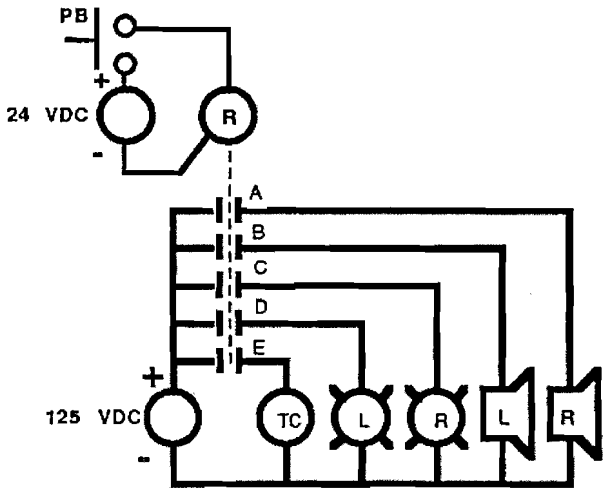
Figure 3 shows a circuit with five pushbuttons (PB A through PB E). Pushbutton E, when closed, energizes the circuit breaker trip coil (TC). This causes the circuit breaker to open. Closing pushbutton D causes a local light to come on, pushbutton C causes a remote light to come on, pushbutton B causes a local horn to sound, and pushbutton A causes a remote horn to sound.



CIRCUIT USING FIVE PUSHBUTTONS FOR CIRCUIT BREAKER OPENING AND ALARMS

Figure 3

In Figure 4, the pushbutton circuit has been replaced with a relay circuit. The relay has a coil "R" and five normally open contacts "A through E". The relay can be either the hinged-armature relay shown in Figure 1 or the plunger-type relay shown in Figure 2. When pushbutton PB is pressed, the 24-volt "R" coil is energized and contacts "A through E" close. The circuit breaker trips, the two lights come on, and the two horns sound.



CIRCUIT USING ONE PUSHBUTTON AND RELAY FOR CIRCUIT BREAKER OPENING AND ALARMS

Figure 4

♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

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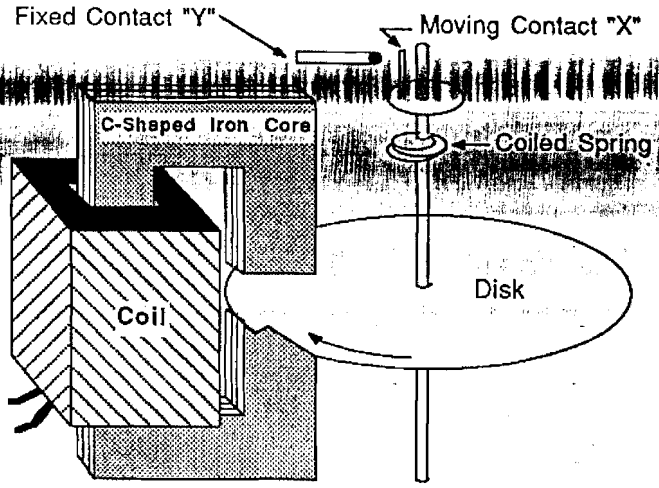
PROTECTIVE RELAYS

Protective relays are designed to operate when a specific undesirable event occurs. When the event occurs, the protective relays senses the event, and then causes some type of corrective or protective action. The name of a protective relay indicates what the relay protects against. An overspeed relay, for instance, protects against excessive speed such as in a turbine-generator. An overvoltage relay protects against high voltage.

The most common protective relay is the overcurrent relay. This relay protects against heating damage caused by excessive current. This protection is normally accomplished by opening a circuit breaker that de-energizes the overheated equipment. The relay shown in Figure 1 is an induction-disk type. It provides time-overcurrent protection which means that high levels of excessive current cause the relay to operate quickly, and low levels of overcurrent current cause the relay to operate more slowly.



INDUCTION DISK RELAY

Figure 1

Figure 2 shows a circuit that uses an induction-disk relay to provide overcurrent protection. The coil "OC" of the time-overcurrent relay monitors the level of current produced by the current transformer. The coiled spring is adjusted so that the disk begins to rotate at any current level above 500 amps in the primary conductor. The moving contact "X" comes around and makes contact with the stationary contact "Y". When the contacts touch, current from the 24-volt source energizes the relay coil "R" which in turn closes contacts "A" through "E". (Examples of hinged-armature-relay and plunger-relay with "R" coils and "A-through-E" contacts are shown in Figure 3.) When contacts "A through E" in Figure 2 close, the circuit breaker trips, local and remote lights go on, and local and remote horns sound.

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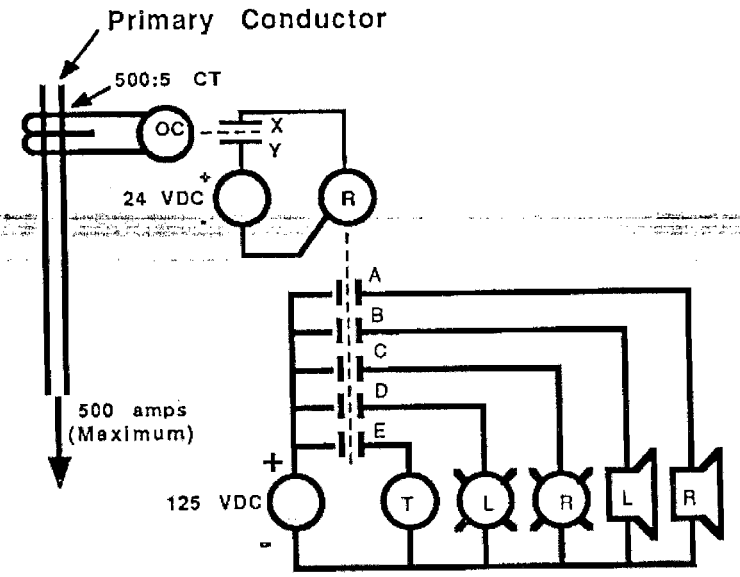
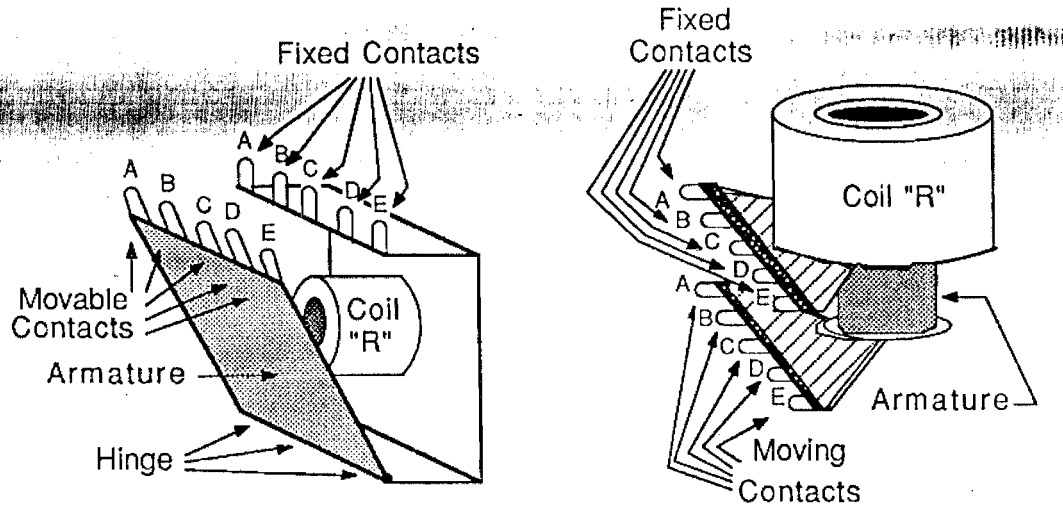


OVERCURRENT PROTECTION CIRCUIT

Figure 2



Hinged Armature Relay **Plunger-Type Relay**

RELAYS USED IN CONJUNCTION WITH
INDUCTION DISK RELAYS

Figure 3

Figure 4 is a photograph of a state-of-the-art transmission line relay. It provides complete transmission line protection. When a fault occurs, the relay causes a circuit breaker to open. It can also generate an eleven-cycle event report following each system disturbance consisting of four cycles of prefault data and seven cycles of postfault data. Included in the data are voltage, current, fault location, date and time.

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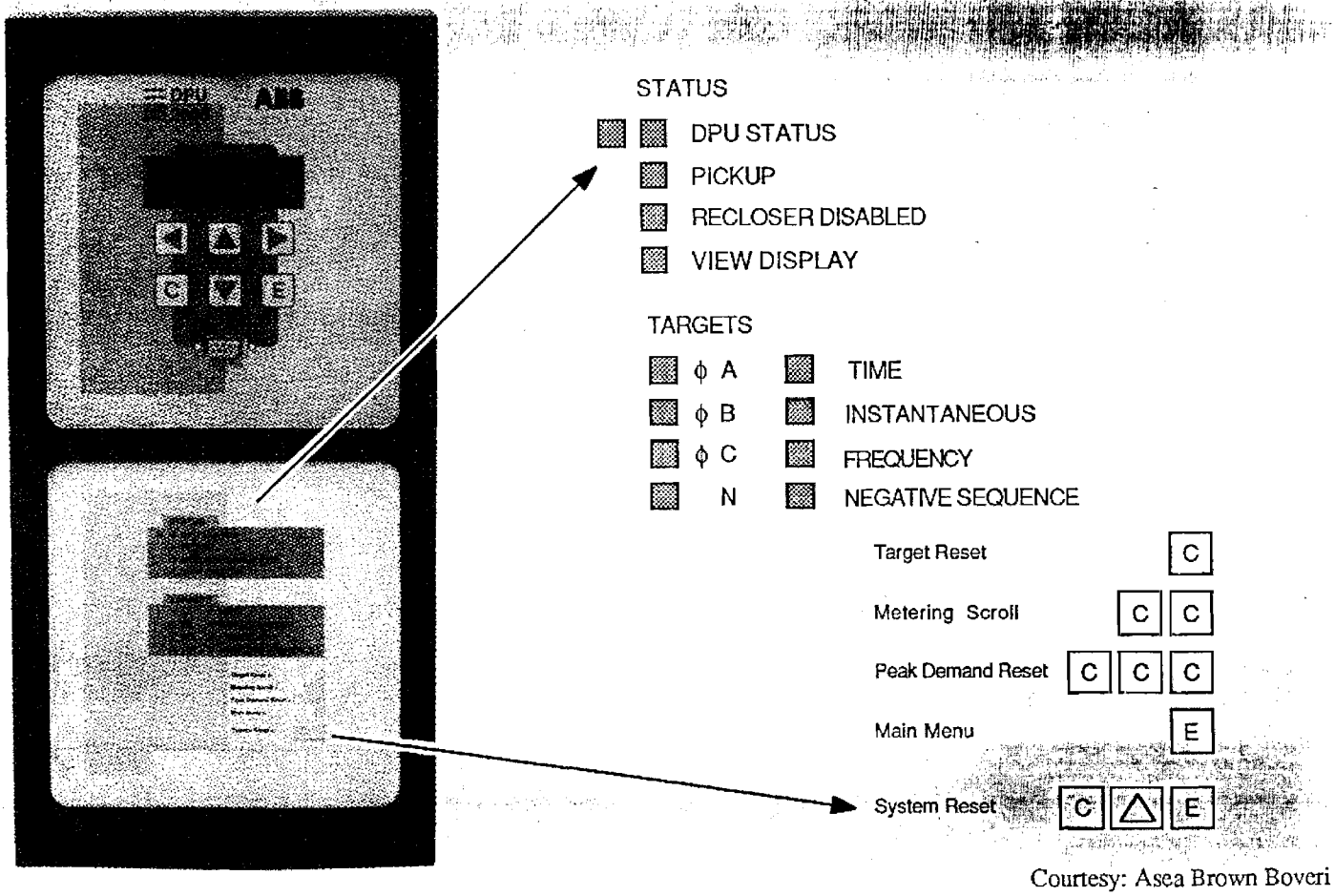
Courtesy: Schweitzer Engineering Laboratories

TRANSMISSION PROTECTIVE RELAY

Figure 4

Modern solid state distribution relays, such as the one in Figure 5, can provide multiple functions in a single relay. Some of these multiple functions are

Three-phase overcurrent protection (time & instantaneous)
Ground-fault protection
Multi-shot reclosing
Underfrequency load shedding and restoration
Undervoltage protection
Overvoltage protection
Negative Sequence
Distance to the fault
Metering of voltages
watts
vars
kwh
kvarh
power factor
frequency
peak demand amps
peak demand watts
peak demand vars
Fault summary with records
Accumulation of breaker interrupting duty
Operations records
Counters for overcurrent trips
breaker operations
reclosures



Courtesy: Asea Brown Boveri

MULTIFUNCTION DISTRIBUTION PROTECTIVE RELAY

Figure 5

◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆

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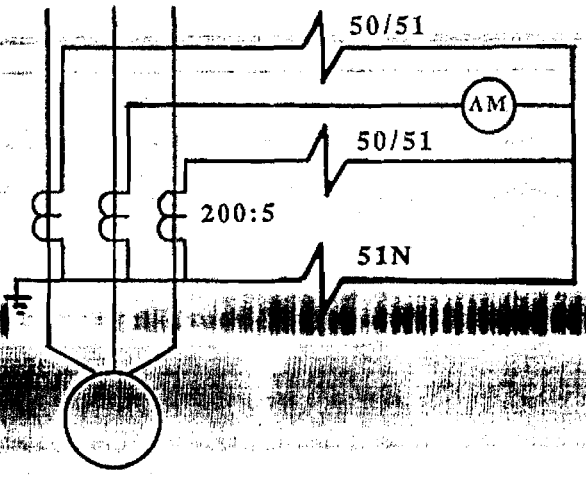
BASIC OVERCURRENT PROTECTION

Current levels slightly higher than the rated level cause excessive heating which destroys insulation; higher current levels destroy insulation much faster, melt metal and can cause fires. Because of the great amount of damage that can be done, and because above-system-rating levels of current are not unusual, overcurrent protection is the most common type of electrical protection.

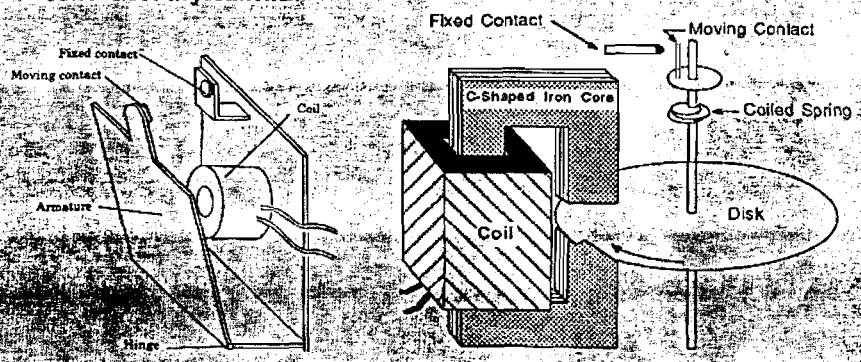
For any electrical system to have effective overcurrent protection, two criteria must be met. One is a protective scheme that rides through momentary overloads which return to normal current levels before any damage is done by the overheating. The second is a protective scheme that quickly detects high values of overcurrent, and quickly sends a signal to circuit breaker to open. The circuit in Figure 1 meets both of these criteria through its use of 50/51 relays.



BASIC OVERCURRENT PROTECTION CIRCUIT

Figure 1

The "50" portion of the relays provides instantaneous protection for very high levels of overcurrent. A hinged-armature relay is often used for this. The "51" portion of the relays provides time-overcurrent protection that allows for low-value momentary overloads without opening a circuit breaker. An induction disk relay is often used for this. This 51N device monitors current in the neutral circuit. The hinged-armature and induction-disk relays are shown in Figure 2. While many systems use the hinged-armature and induction disk relays for overcurrent protection, these technologies are dated. The more modern systems use electronic relays to accomplish the same function. Often they appear to be nothing more than boxes with buttons for adjustments.



HINGED-ARMATURE RELAY INDUCTION-DISK RELAY

Figure 2

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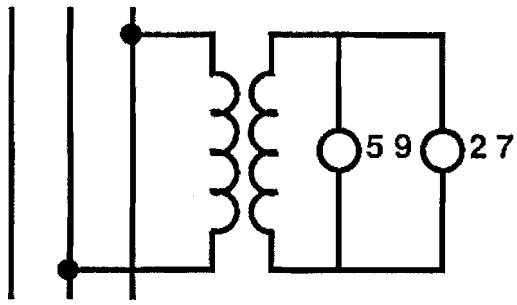
BASIC OVERVOLTAGE AND UNDERVOLTAGE PROTECTION

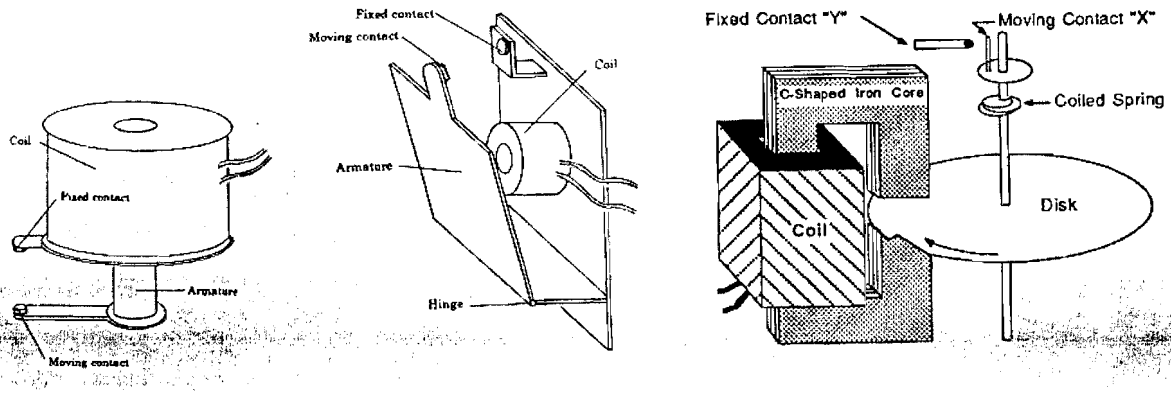
Low voltages on an electrical system cause motors to overheat and prematurely fail. High voltages can destroy electronic control, computer and communication equipment; and if high enough, voltage can destroy the insulation in any type of equipment. To protect against these situations, low-voltage and high-voltage protection circuits are incorporated into many electrical systems. These circuits are called undervoltage protection and overvoltage protection circuits. Figure 1 shows the basic circuit for both undervoltage (27 relay device) and overvoltage (59 relay device).



BASIC OVERVOLTAGE AND UNDERVOLTAGE CIRCUIT

Figure 1

Contacts on each of these relays are used to open circuit breakers, or to provide warning alarms when low voltage or high voltage occur. The basic types of electromechanical relays used for undervoltage and overvoltage protection are shown in Figure 2. Overvoltage circuits use normally open contacts that close when the relay is pulled in by the high voltage. The closing of these contacts open the circuit breaker, or provides the alarm signal for overvoltage. Undervoltage circuits use normally closed contacts. In this application, the relay is pulled in at normal voltages. When the voltage drops, the relay's springs pull the armature away from the coil, and the contacts close. The closing of these contacts open the circuit breaker, or provides the alarm signal for undervoltage. The induction-disk relay on the right in Figure 2, provides a time delay that allows the system to ride through momentary rises and dips in voltage without opening circuit breakers, and without causing alarms.



Plunger-Type Relay **Hinged-Armature-Type Relay** **Induction-Disk Relay**

Figure 2

◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆

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DIODES

****

* Function: Converting AC to DC *

* Other name: Rectifiers *

* *

* Symbol *

* *

****

Solid state diodes are the most fundamental of the many solid state devices that include, among others, transistors, thyristors, integrated circuits and microprocessors. The prefix "di" in the word diode means two. The "two" refers to two dissimilar materials that are bonded together. The two dissimilar materials actually refer to the same material, such as silicon, that in a manufacturing process is separated into two batches. One batch is made positive and the other batch is made negative. A small amount from each batch is then bonded together to produce a diode. Figure 1 represents the positive and negative materials. Figure 2 represents the positive and negative materials after bonding.

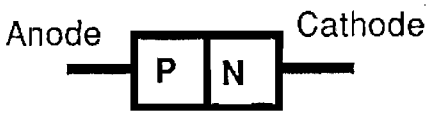
Positive and Negative Diode Materials

Figure 1

Bonded Positive and Negative Diode Materials

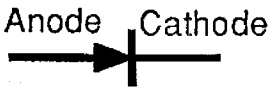
Figure 2

The positive-material side of a diode is called the anode and the negative-material side is called the cathode. Conductors are bonded to the anode and cathode. This is represented in Figure 3 with the symbol for the diode shown in Figure 4.



Anode and Cathode of a Diode

Figure 3



Diode Symbol

Figure 4

When the anode side of the diode is made positive with respect to the cathode side, the diode changes its electrical characteristics and acts like a conductor. This is shown in Figure 5.

POSITIVE INPUT CAUSES DIODE TO CONDUCT

Figure 5

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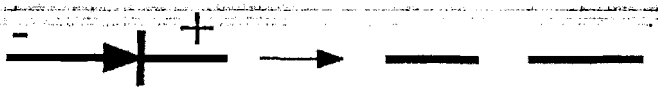
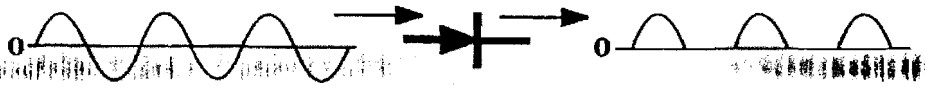
When the anode side of the diode is made negative and the cathode side positive, the diode acts like a non-conductor or an open circuit. This blocks current flow. This is shown in Figure 6.



NEGATIVE INPUT CAUSES DIODE TO BLOCK

Figure 6

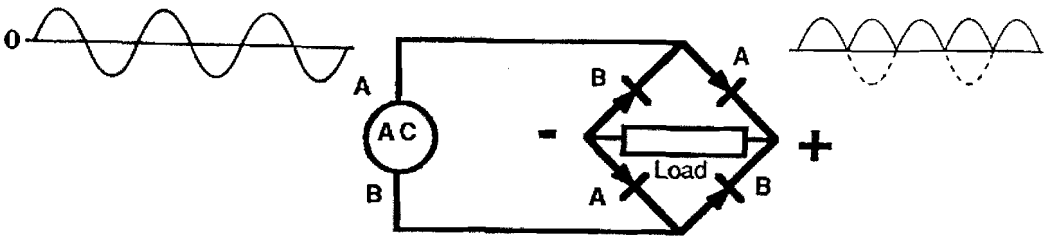
When an AC signal is put into the diode, the positive portion of the signal passes through the diode and the negative portion is blocked. The resulting output is DC. This process is called rectification. (Diodes are also called rectifiers). The resulting half-wave rectification from a single diode is shown in Figure 7.



RECTIFIER ACTION OF A DIODE

Figure 7

Full-wave rectification can be achieved using the circuit shown in Figure 8. When The "A" terminal of the voltage source is positive, the diodes marked "A" conduct. When The "B" terminal of the voltage source is positive, the diodes marked "B" conduct. This results in full-wave rectification.



FULL-WAVE RECTIFIER BRIDGE

Figure 8

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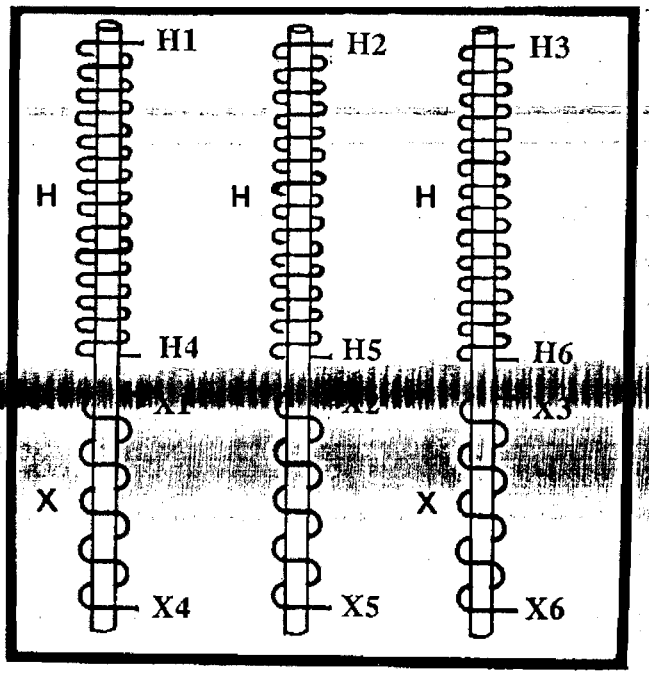
TRANSFORMER CONNECTIONS

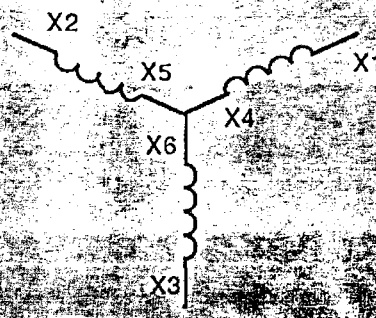
Figure 1 shows the three higher-voltage (H) and three lower-voltage (X) windings of a three-phase transformer. (The windings in Figure 1 are shown in the same tank, but the type of connections that can be made, can also be made with three single-phase transformers. The first single-phase transformer would have windings H_1 and H_4, and X_1 and X_4. The second single-phase transformer would have windings H_2 and H_5, and X_2 and X_5. The third single-phase transformer would have windings H_3 and H_6, and X_3 and X_6.)



THREE-PHASE TRANSFORMER WINDINGS

Figure 1

One of the standard transformer connections is a wye or "Y" connection. This type of connection is called a wye because one end of each winding is tied together at a common point called the neutral connection; and if these windings were drawn symmetrically, the result would be a wye shape. (Figure 2.)



WYE CONNECTION

Figure 2

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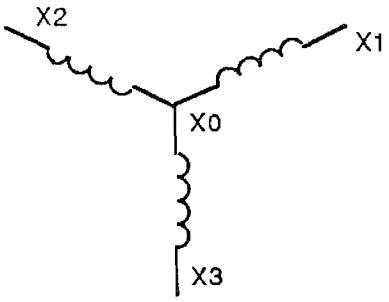
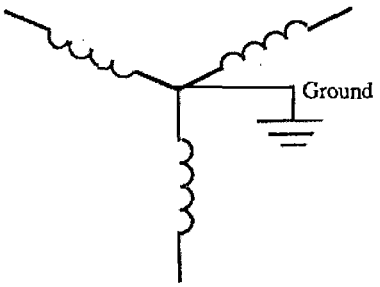
The neutral connection in Figure 2 would be made by connecting X_4, X_5 and X_6. The X_1, X_2 and X_3 leads would go to three bushings, normally identified as X_1 bushing, X_2 bushing and X_3 bushing. Often there is a need to bring the neutral point of a wye connection externally from a transformer tank. When this is done, a fourth bushing is often used and is normally identified as X_0 (Figure 3a).

The X_0 or neutral point is commonly used as the grounding point in a grounded-wye system, and is shown in Figure 3b as it would appear on an electrical drawing.





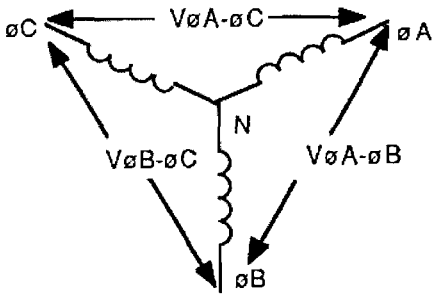
NEUTRAL CONNECTION (X0)

Figure 3a

GROUNDED NEUTRAL

Figure 3b

The wye-connected transformer produces two usable voltages. One voltage is called the phase-to-phase voltage (also called line-to-line voltage) and appears between X_1 and X_2, between X_2 and X_3, and between X_3 and X_1 (Figure 4).



PHASE-TO-PHASE VOLTAGES

Figure 4

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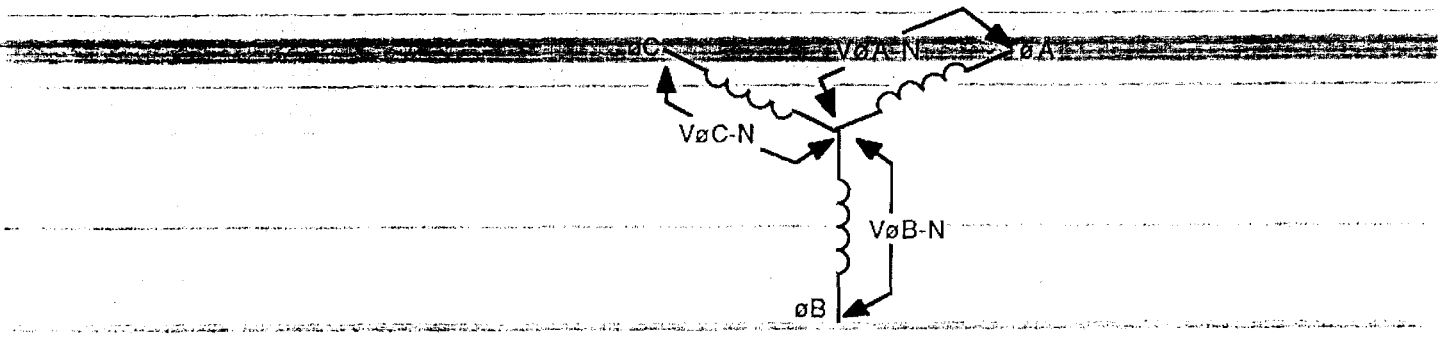
The other 3-phase voltage is called the phase-to-neutral voltage (also called line-to-neutral voltage) and appears between X_1 and X_0, between X_2 and X_0, and between X_3 and X_0 (Figure 5).



PHASE-TO-NEUTRAL VOLTAGES

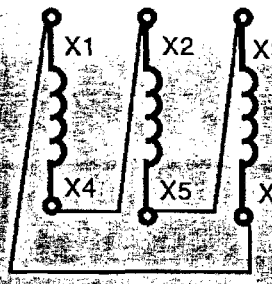
Figure 5

When the neutral is grounded, the phase-to-neutral voltage is often called the phase-to-ground voltage or line-to-ground voltage. When an electrical system uses the phase-to-neutral voltage, four conductors are used. This is called a 3-phase, 4-wire system, with the four wires coming from the X_0, X_1, X_2 and X_3 bushings. The relationship of phase-to-phase and phase-to-neutral voltages is expressed by Equation 1 Below.

$$(1) \quad \text{Voltage}_{\text{Phase-to-Neutral}} = \frac{\text{Voltage}_{\text{Phase-to-Phase}}}{\sqrt{3}}$$

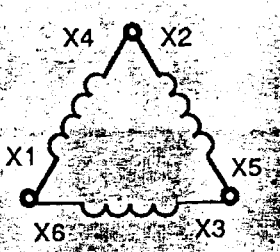
Some of the common 3-phase, 4-wire systems are 208Y/120, 480Y/277, 4160Y/2400, and 12,470Y/7200.

The second common transformer connection is called the delta connection. The lower-voltage windings in the transformer in Figure 1 can be connected delta by connecting X_4 to X_2, X_5 to X_3, and X_6 to X_1. These connections are shown in Figure 6a. When the three winding are drawn so that they are symmetrical, an equilateral triangle is formed (Figure 6b).



DELTA CONNECTION

Figure 6a



DELTA CONNECTION

Figure 6b

This triangle has the same shape as the Greek letter delta; therefore, this type of connection is called a delta connection. The corners of the triangle would be connected to the lower-voltage bushings which would be identified as X_1, X_2 and X_3.

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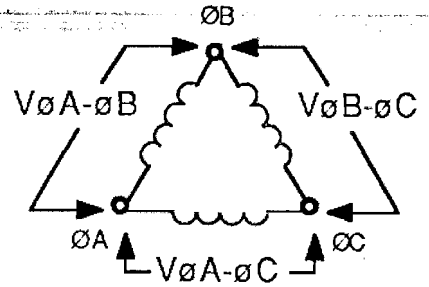
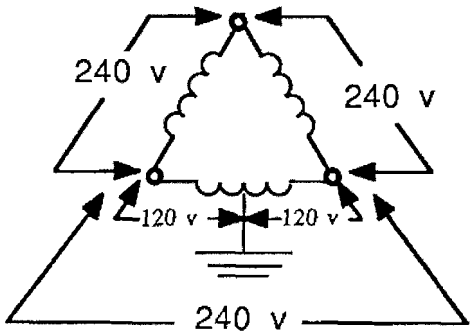
A delta transformer has one 3-phase voltage that would appear between X_1 and X_2, between X_2 and X_3, and between X_3 and X_1. These voltages are shown in Figure 7.



PHASE-TO-PHASE VOLTAGES (DELTA CONNECTION)

Figure 7

Grounding a delta transformer winding can be done at any one of the corners, or in the center of one of the three windings. When grounded in the center of a winding, there will be two equal single-phase voltages appearing across each half of that winding (in addition to the 3-phase voltage) An example of these voltages are shown in Figure 8.



PHASE-TO-PHASE & PHASE-TO-GROUND VOLTAGES (DELTA CONNECTION)

Figure 8

Transformers can be connected in any wye-delta combination. The connections can be wye-wye, delta-delta, delta-wye or wye-delta on the higher- and lower-voltage windings. Most transformer nameplates give the type of connection for both the higher- and lower-voltage windings. The transformer nameplates also indicate which lower-voltage winding and which higher-voltage winding are on the same iron core.

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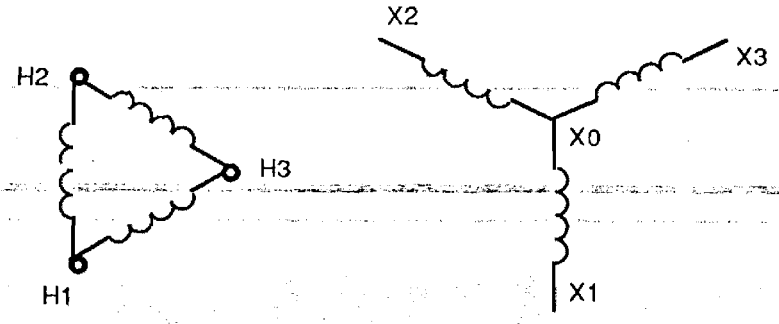
Figure 9 shows how this can be determined from the nameplate information. In Figure 9, the X_1-X_0 winding would be on the same piece of iron as the H_1-H_2 winding. This is indicated by both winding going in the same direction (both are vertical). Matching-directions indicate that the X_2-X_0 winding would be on the same piece of iron as the H_2-H_3 winding, and the X_3-X_0 winding would be on the same piece of iron as the H_1-H_3 winding. This can also be seen by analyzing Figure 1.



DELTA-WYE CONNECTION
Figure 9

Figure 10 is a photograph of a nameplate on a transformer. The KVA ratings with different types of cooling, and the low voltage and high voltage connections are shown.

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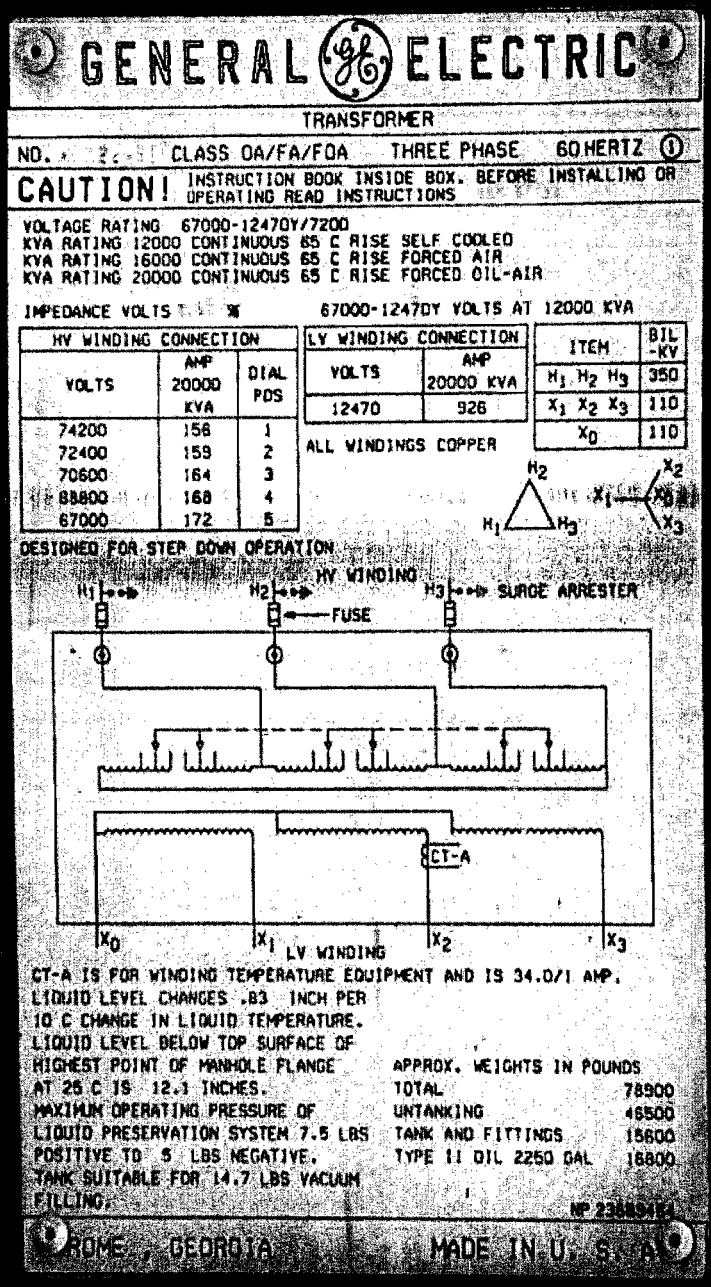


GENERAL ELECTRIC

TRANSFORMER

NO. CLASS OA/FA/FOA THREE PHASE 60 HERTZ

CAUTION! INSTRUCTION BOOK INSIDE BOX. BEFORE INSTALLING OR OPERATING READ INSTRUCTIONS

VOLTAGE RATING 67000-12470Y/7200
KVA RATING 12000 CONTINUOUS 65 C RISE SELF COOLED
KVA RATING 16000 CONTINUOUS 65 C RISE FORCED AIR
KVA RATING 20000 CONTINUOUS 65 C RISE FORCED OIL-AIR

IMPEDANCE VOLTS % 67000-12470Y VOLTS AT 12000 KVA

HV WINDING CONNECTION		
VOLTS	AMP 20000 KVA	DIAL POS
74200	156	1
72400	159	2
70600	164	3
68800	168	4
67000	172	5

LV WINDING CONNECTION	
VOLTS	AMP 20000 KVA
12470	926

ALL WINDINGS COPPER

ITEM	BIL -KV
H_1 H_2 H_3	350
X_1 X_2 X_3	110
X_0	110

DESIGNED FOR STEP DOWN OPERATION

CT-A IS FOR WINDING TEMPERATURE EQUIPMENT AND IS 34.0/1 AMP.
LIQUID LEVEL CHANGES .83 INCH PER 10 C CHANGE IN LIQUID TEMPERATURE.
LIQUID LEVEL BELOW TOP SURFACE OF HIGHEST POINT OF MANHOLE FLANGE AT 25 C IS 12.1 INCHES.
MAXIMUM OPERATING PRESSURE OF LIQUID PRESERVATION SYSTEM 7.5 LBS POSITIVE TO 5 LBS NEGATIVE.
TANK SUITABLE FOR 14.7 LBS VACUUM FILLING.

APPROX. WEIGHTS IN POUNDS	
TOTAL	78900
UNTANKING	46500
TANK AND FITTINGS	15600
TYPE II OIL 2250 GAL	16800

ROME, GEORGIA MADE IN U. S. A.

Courtesy: Skip Collier

TRANSFORMER NAMEPLATE

Figure 10

♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

DISTRIBUTION TRANSFORMER CONNECTIONS

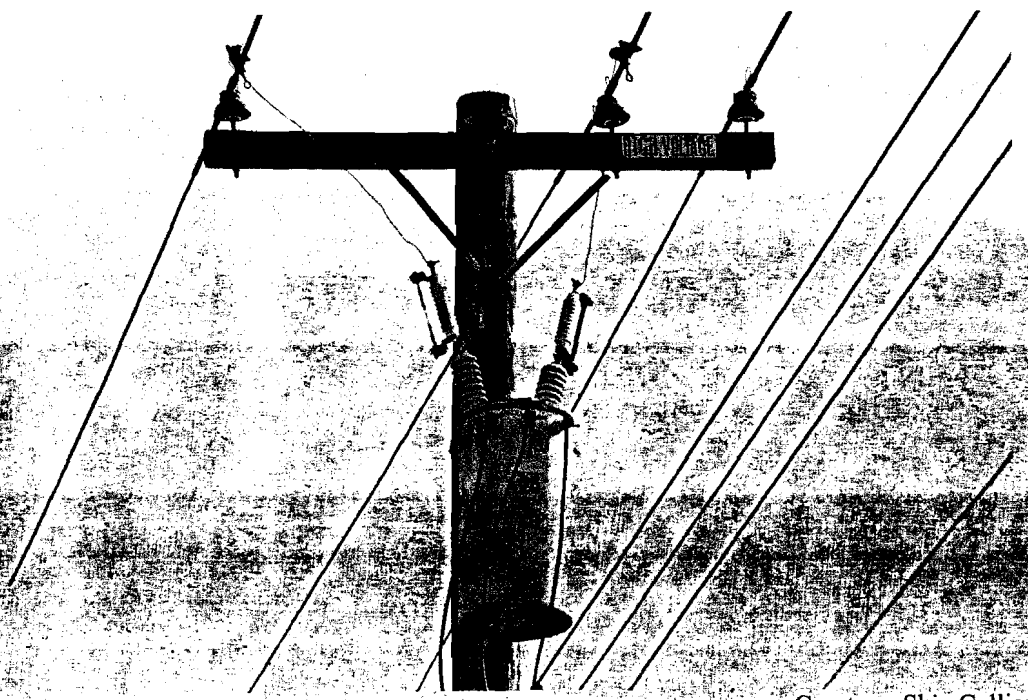
The single-phase transformers in the distribution systems of electric utilities can be connected phase-to-phase (also called line-to-line), or phase-to-neutral (also called phase-to-ground). Phase-to-phase refers to single-phase transformers being connected between two phases, such as between phase A and phase B, to serve single-phase loads. Phase-to-neutral refers to refers to single-phase transformers being connected between one the phases and neutral to serve single-phase loads. Phase-to-phase systems are also called delta systems, and phase-to-neutral systems are also called wye systems. Phase-to-phase systems are common in the state of California; phase-to-neutral systems are common in the remaining 49 states and in Canada.

Single-Phase Transformers Connected Phase-to-Phase

In a phase-to-phase system, each end of a single-phase transformer's high voltage winding has a voltage on it; therefore, each end the winding must exit the tank through a bushing to keep the conductors away from the steel tank.

When single-phase transformers are connected to a three-phase source, the single-phase loads should be balanced as much as possible. This means that the single-phase loads connected between phases A and B should approximate the loads connected between phases B and C, which [illegible] phases A [illegible] When a new distribution line is installed, the initial attempt at balancing is done by having the total transformer KVA (KiloVolt Ampere) rating connected between phases A and B approximating the total KVA connected between phases B and A, and approximating the total KVA connected between phases A and C. In equation form this would be expressed as Equation 1 where the KVA is the nameplate KVA (normally painted on the outside of the transformer tank.

(1) $$\mathbf{KVA}_{(\text{ØA to ØB})} = \mathbf{KVA}_{(\text{ØB to ØC})} = \mathbf{KVA}_{(\text{ØA to ØC})}$$



Courtesy: Skip Collier

TRANSFORMER CONNECTED BETWEEN A AND B PHASES

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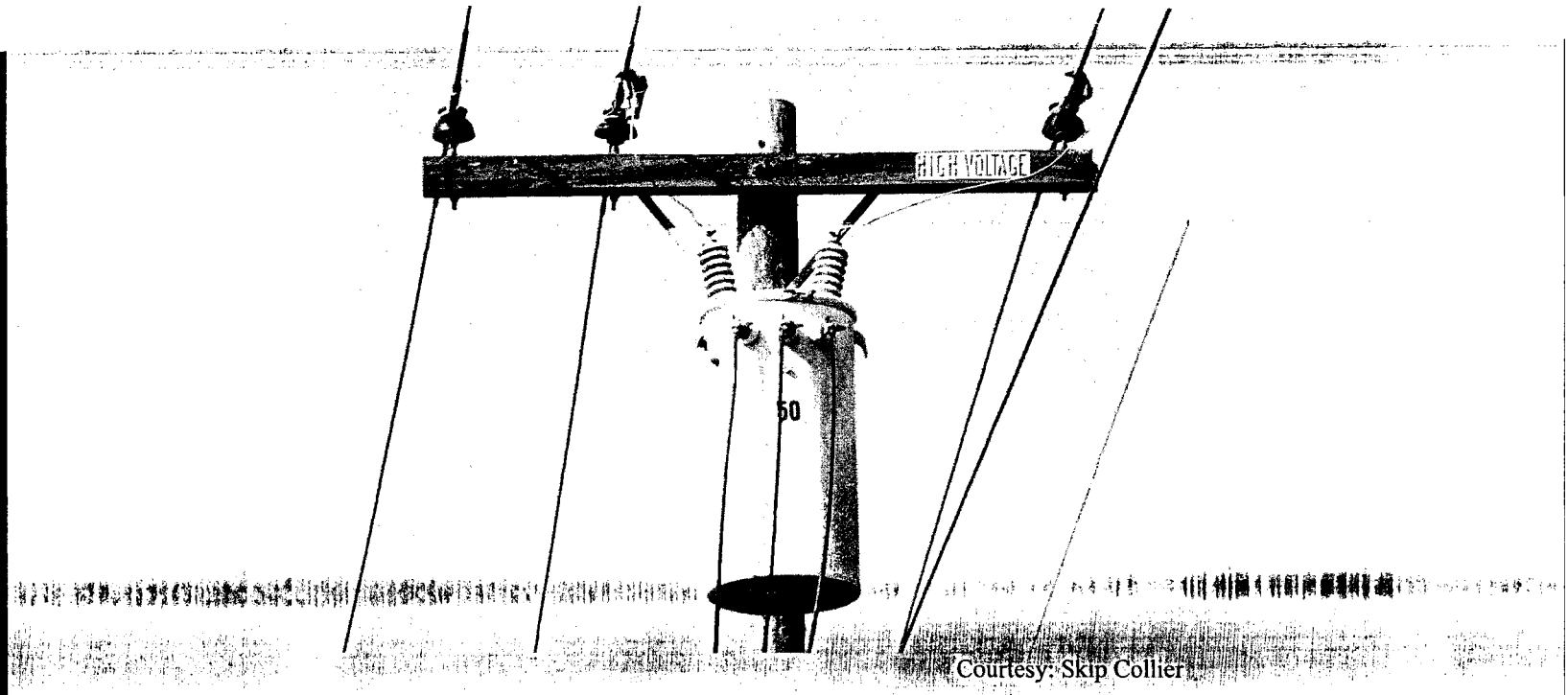
Figure 1

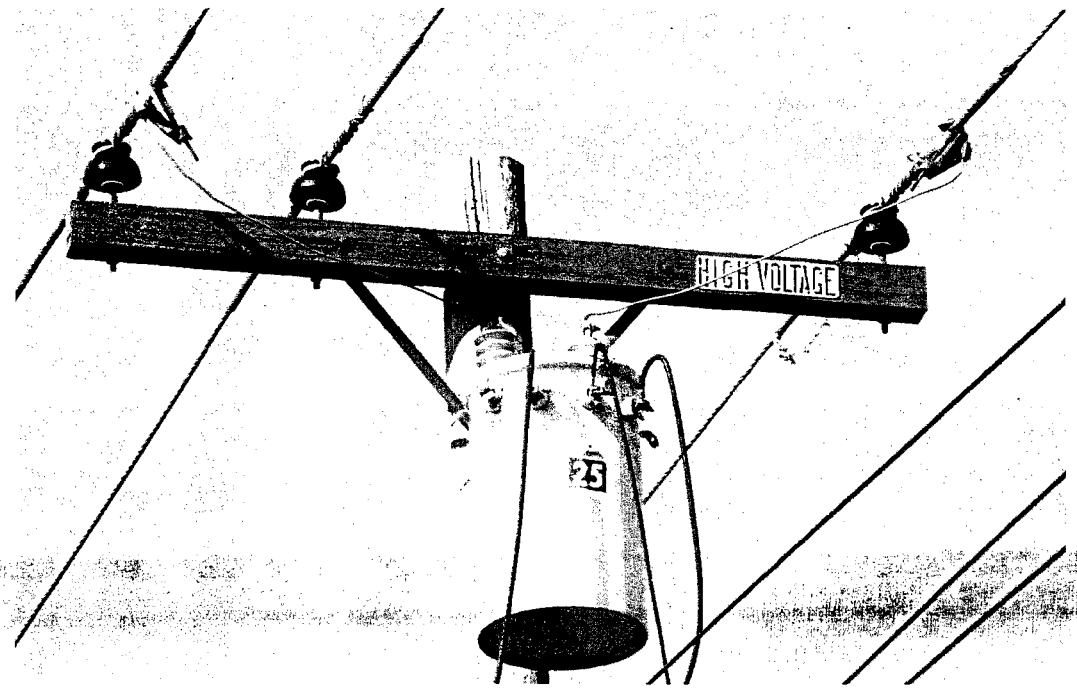
Figures 1, 2 and 3 show pole-mounted distribution transformers connected phase to phase between A and B phases, between B and C phases and between A and C phases.



Courtesy: Skip Collier

TRANSFORMER CONNECTED BETWEEN B AND C PHASES

Figure 2



Courtesy: Skip Collier

TRANSFORMER CONNECTED BETWEEN A AND C PHASES

Figure 3

Single-Phase Transformers Connected Phase-to-Neutral

In a phase-to-neutral-connected system, one side of a single-phase transformer's high-side windings is connected to one of the phases. It therefore has a voltage on it, and has a bushing to keep the voltage away from the transformer's steel tank. The other side of the high-side winding is connected to the neutral. The neutral is grounded. It therefore has no voltage on it and does not require a bushing.

Some phase-to-neutral-connected transformers have only one bushing when connected as described in the preceding paragraph. Other phase-to-neutral-connected transformers have two bushings with the bushing on the non-phase-connected-side of the winding being connected to the neutral conductor.

Figures 4 and 5 show the phase and neutral connections of a two-bushing pole-mounted distribution transformer. Figure 6 shows the ground conductor at the bottom of the same pole as it enters the ground.

Balancing the load on a phase-to-neutral system consists of connecting the load so that the kVA connected between phase A and neutral equals the kVA connected between phase B and neutral, and which equals the kVA connected between phase C and neutral. In equation form, this would be expressed as follows:

$$kVA_{\phi A-N} = kVA_{\phi B-N} = kVA_{\phi C-N}$$

Phase-to-Phase Systems Versus Phase-to-Neutral Distribution Systems

It is more expensive to use phase-to-phase distribution systems when compared to phase-to-neutral distribution systems. One reason is the voltage rating of the transformer insulation must be higher in phase-to-phase systems, and the cost of insulation increases as the voltage increases. Another factor that will increase the cost of phase-to-phase distribution systems is that both sides of the high-side windings will need to have fusing and lightning protection; in a phase-to-neutral system only the phase-connected side will need fusing and lightning protection. Also, a one-bushing transformer may be used in a phase-to-neutral system which decreases the cost of the transformer.

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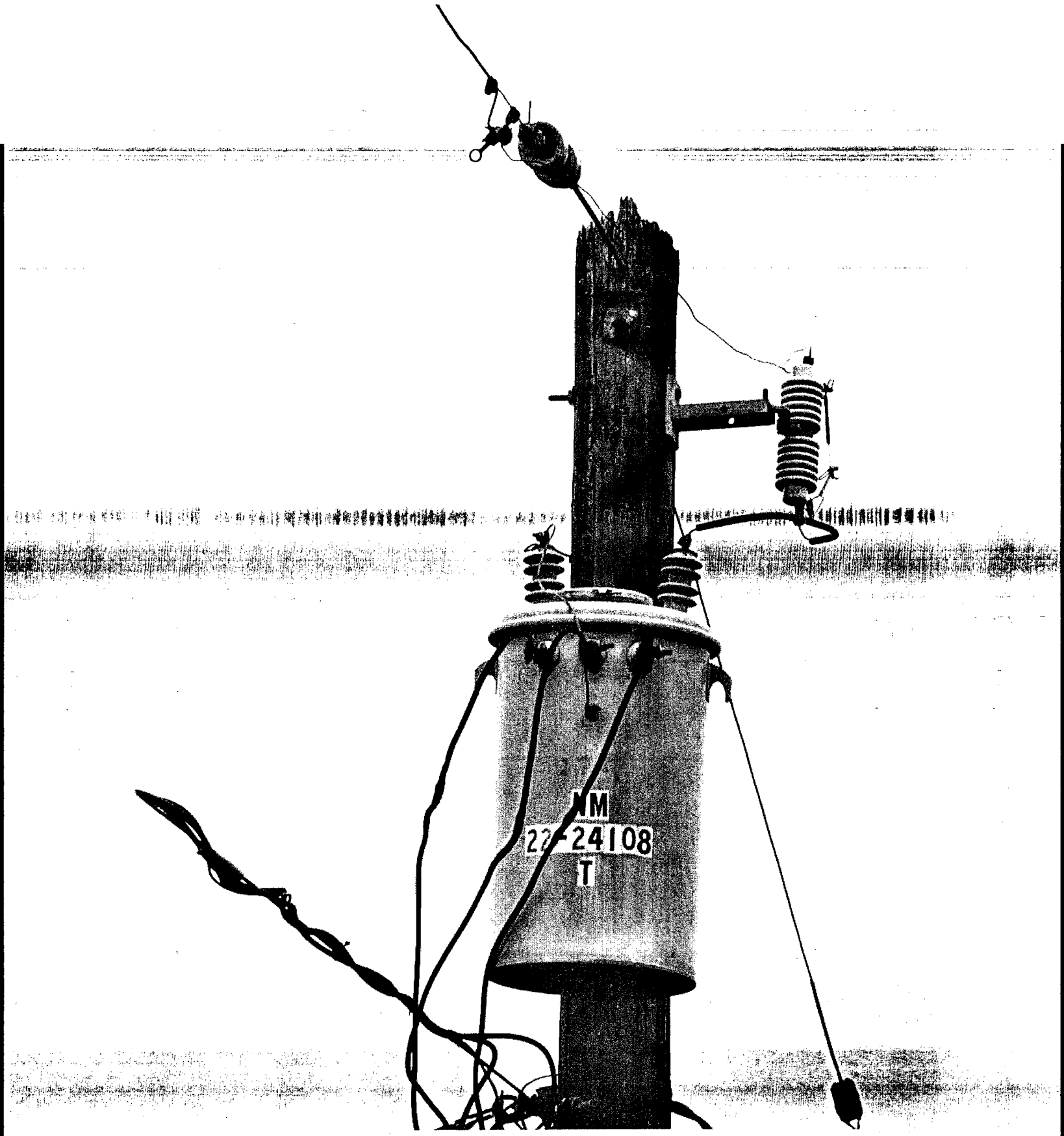
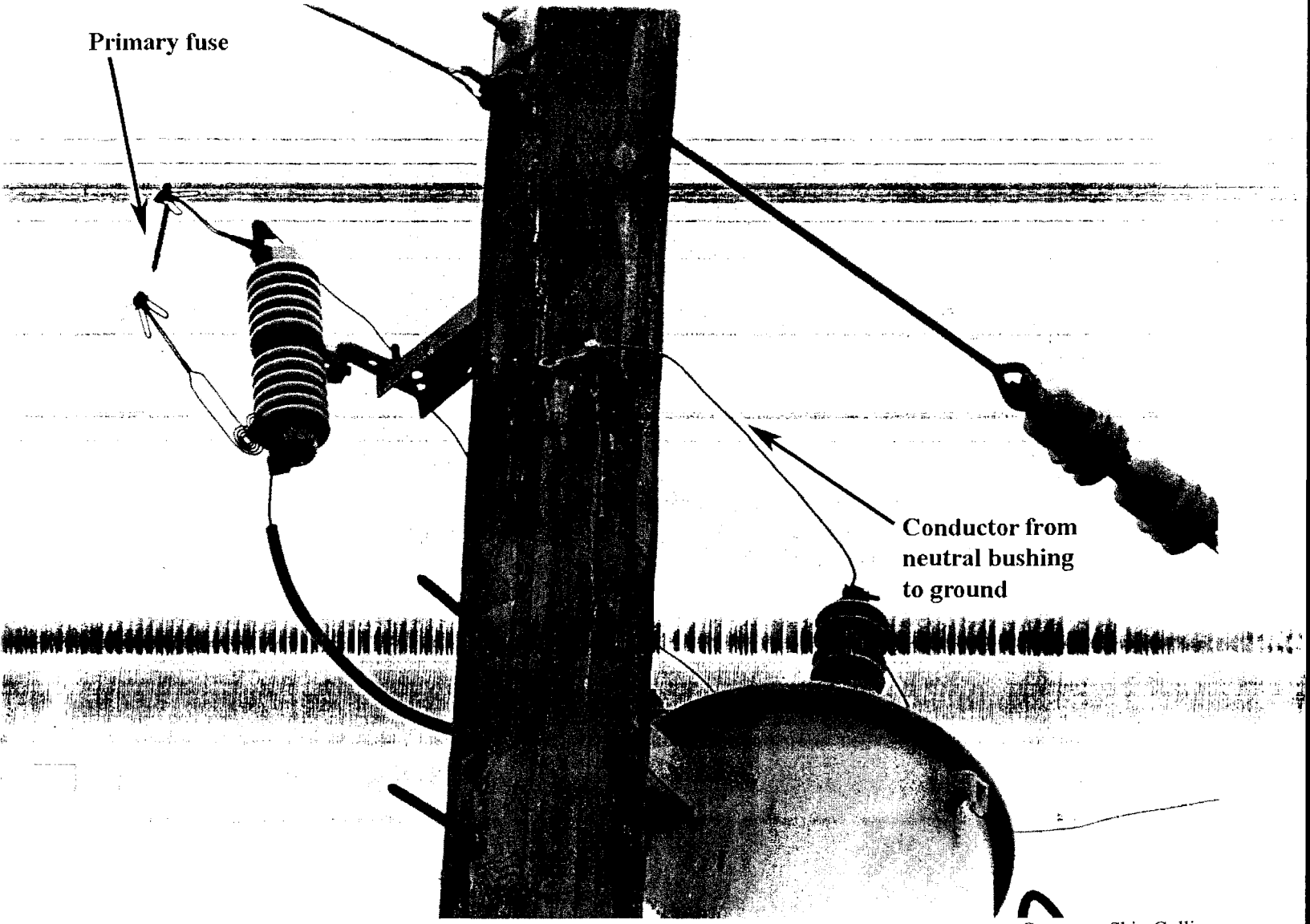


Courtesy: Skip Collier

SINGLE PHASE TRANSFORMER CONNECTED PHASE TO NEUTRAL

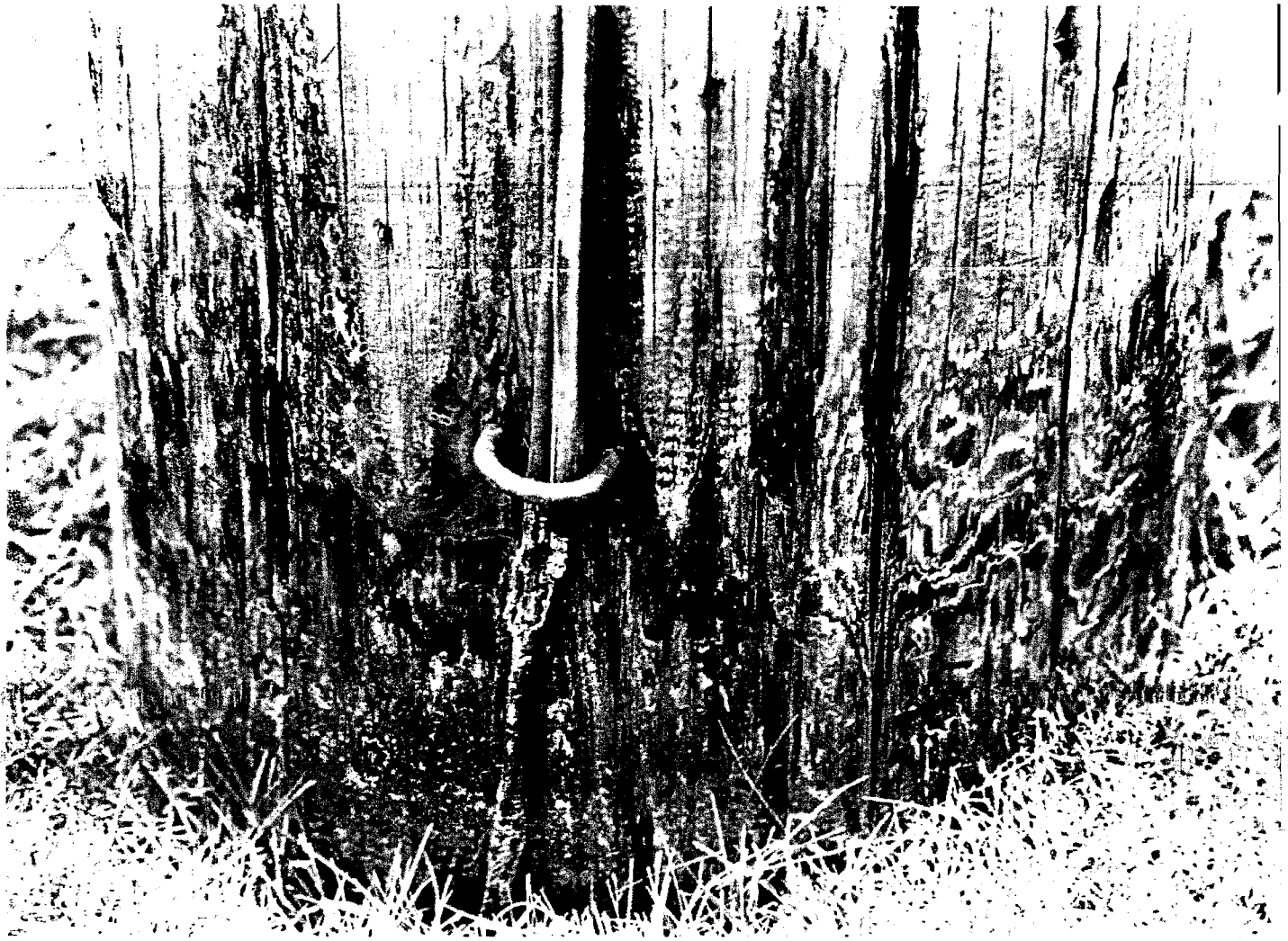
Figure 4



Courtesy: Skip Collier

PHASE TO NEUTRAL CONNECTED TRANSFORMER SHOWING GROUND AND HIGH SIDE FUSE

Figure 5



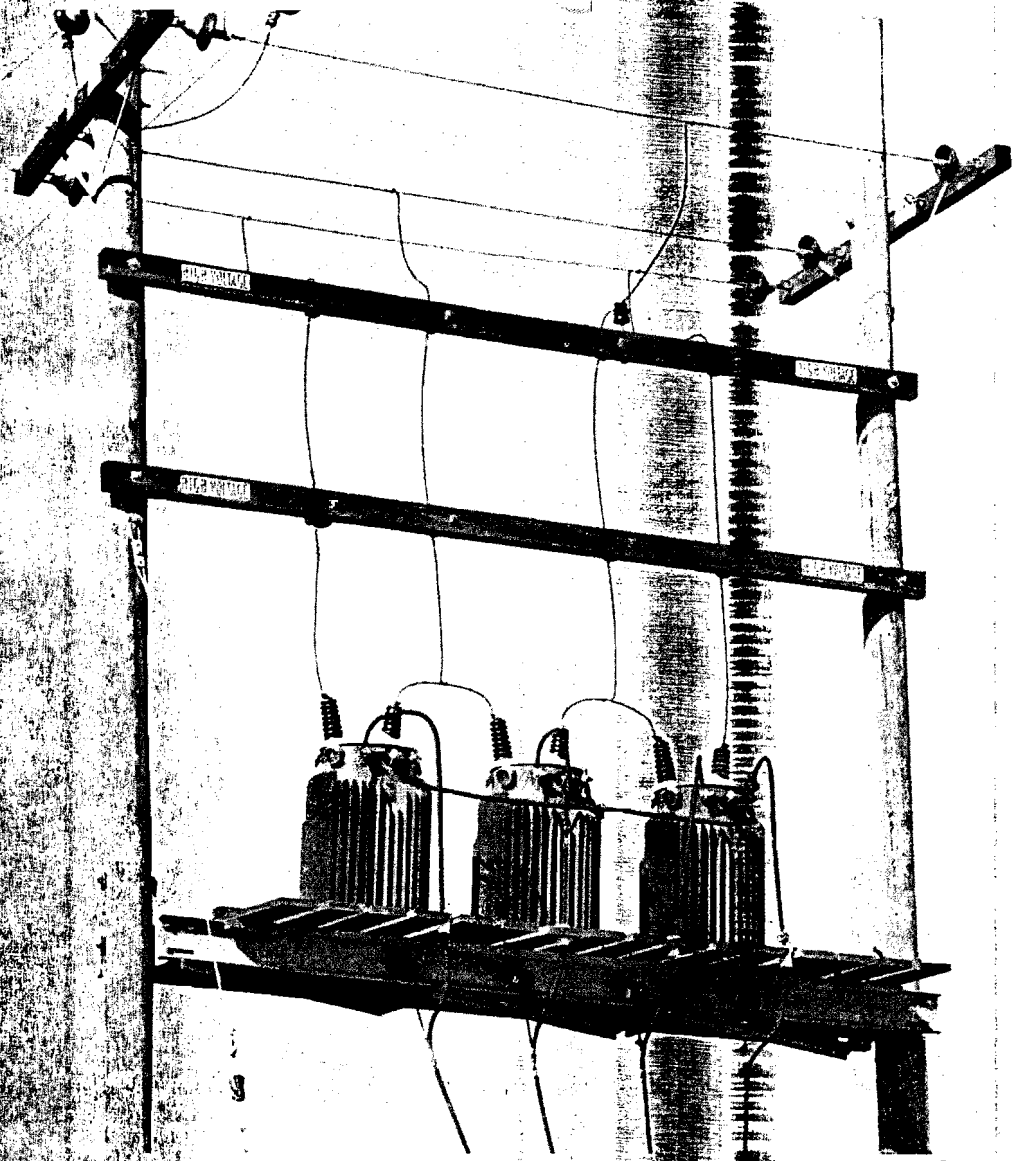
Courtesy: Skip Collier

BASE OF UTILITY POLE SHOWING CONDUCTOR FROM NEUTRAL BUSHING GOING INTO GROUND

Figure 6

Single phase transformers connected to serve a 3-phase load

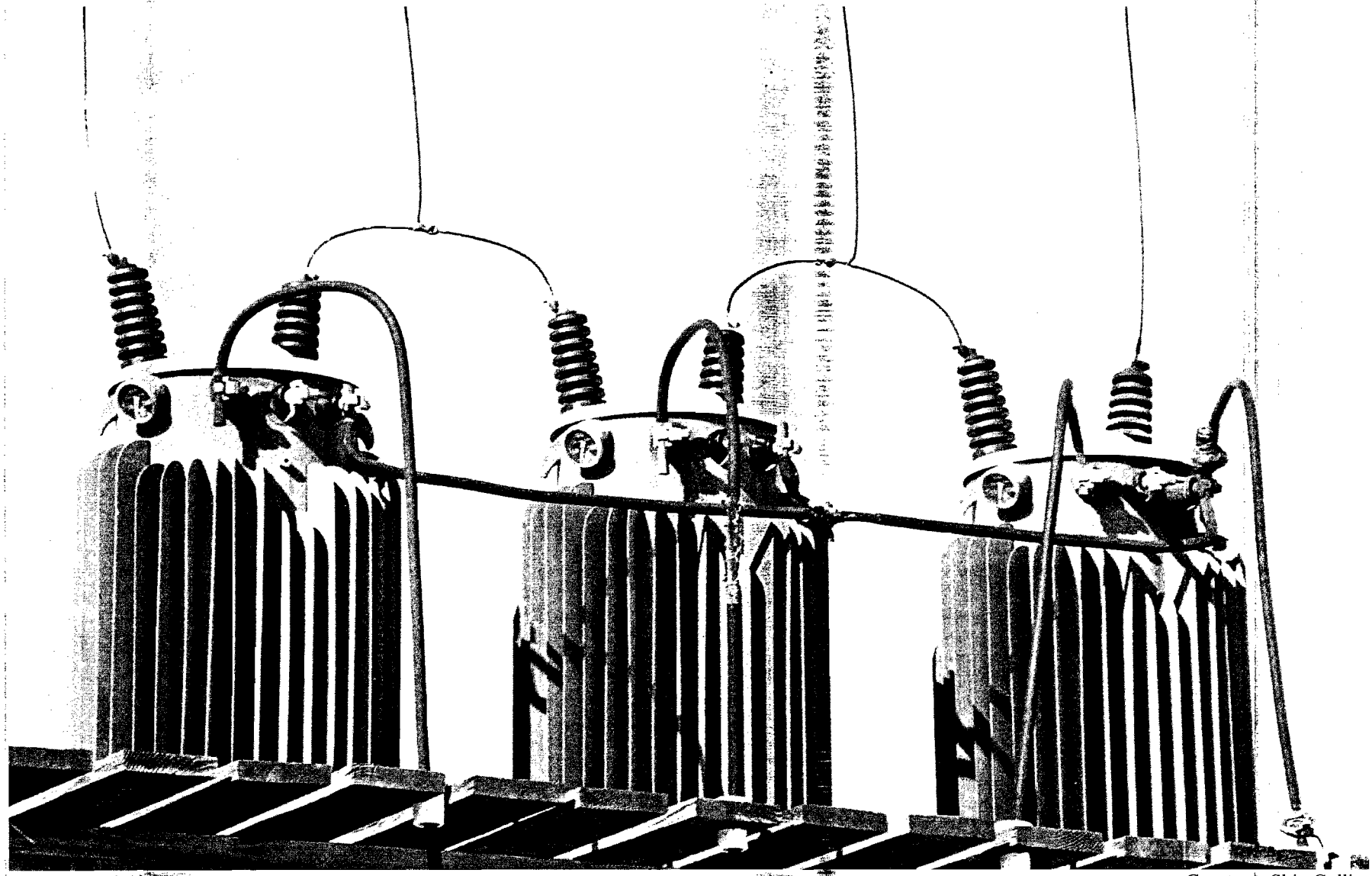
Figure 7 and 8 show three single-phase transformers connected to serve a three-phase load. Figure 7 shows a method of connecting the high-side bushings to the overhead distribution lines. Figure 8 shows a method of connecting the low-side bushings to provide three-phase power.



Courtesy: Skip Collier

THREE SINGLE-PHASE TRANSFORMERS CONNECTED TO SERVE A THREE-PHASE LOAD

Figure 7



Courtesy: Skip Collier

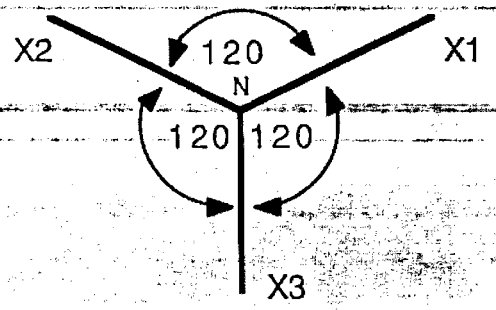
SECONDARY CONNECTIONS OF THREE SINGLE PHASETRANSFORMERS CONNECTED TO SERVE A THREE PHASE LOAD

Figure 8

♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

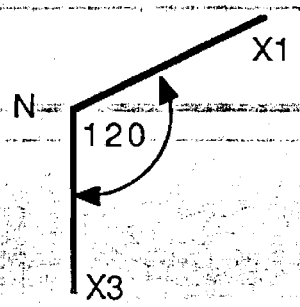
DERIVATION OF THE SQUARE-ROOT-OF-THREE FACTOR FOR PHASE-TO-NEUTRAL VOLTAGES

The value of a phase-to-neutral voltage is the phase-to-phase voltage divided by the square root of three. The derivation of the square-root-of-three factor can be done using basic mathematics. In Figure 1, the phase-to-phase voltages would appear between X1, X2 and X3 legs. The three legs are 120 degrees apart as indicated. The portion formed by the X1 and X3 legs is shown in Figure 2.



WYE CONNECTION

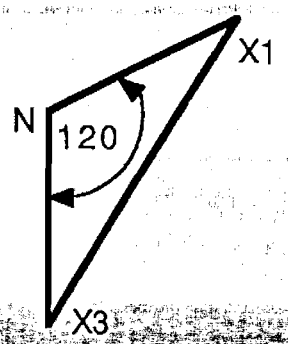
Figure 1



PORTION OF WYE

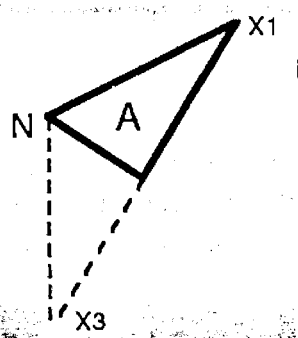
Figure 2

Connecting X1 to X3 results in the triangle shown in Figure 3. Figure 4 shows the results of bisecting the 120-degree angle. The "A" triangle in Figure 4 can be rotated to produce the triangle shown in Figure 5.



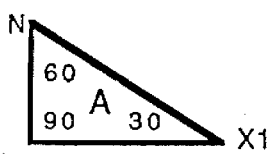
TRIANGLE FORMED BY CONNECTING X1 TO X3

Figure 3



TRIANGLES FORMED BY BISECTING THE 120-DEGREE ANGLE

Figure 4



"A" TRIANGLE ROTATED 60 DEGREES

Figure 5

In a 30-60-90-degree triangle, the longest leg is always twice the shortest leg. Assigning the value of two to the hypothenuse results in the vertical side having a value of one. This is shown in Figure 6. The Pythagorean Theorem is now brought into use. The Pythagorean Theorem states that in a right triangle with sides A and B and hypothenuse C, such as in Figure 7, the sum of squares of each side equals the square of the hypothenuse.

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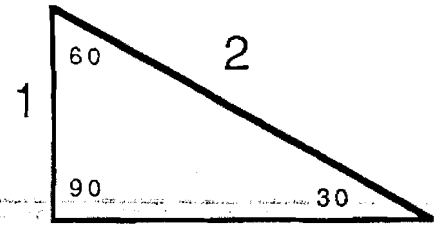
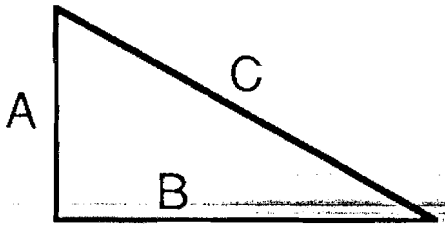


RIGHT TRIANGLE WITH LONGEST SIDE TWICE THE SHORTEST SIDE

Figure 6



RIGHT TRIANGLE WITH SIDES A, B AND C

Figure 7

In equation form, this is written as $C^2 = A^2 + B^2$. Substituting 2 for C and 1 for A in the equation yields

$$C^2 = A^2 + B^2$$

$$2^2 = 1^2 + B^2$$

$$2^2 - 1^2 = B^2$$

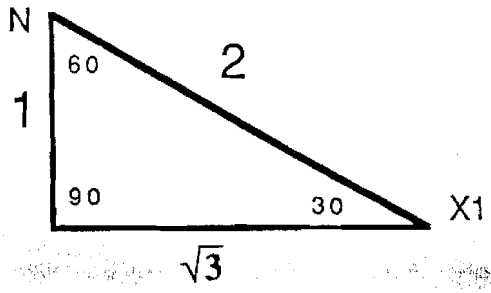
$$B^2 = 2^2 - 1^2$$

$$B^2 = 4 - 1$$

$$B^2 = 3$$

$$B = \sqrt{3}$$

The relationship of the phase-to-phase and phase-to-neutral voltage can be determined by assigning the value of 2 to the phase-to-neutral voltage as shown in Figure 8. The $\sqrt{3}$ value is one-half of the phase-to-phase voltage as indicated in Figure 8. This results in the total phase-to-phase voltage being $2\sqrt{3}$. Dividing both the phase-to-neutral voltage and the phase-to-phase by two, results in the relationship of $\sqrt{3}$ to 1 between them.



RELATIVE VALUES OF PHASE-TO-NEUTRAL AND PHASE-TO-PHASE VOLTAGES

Figure 8

◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆

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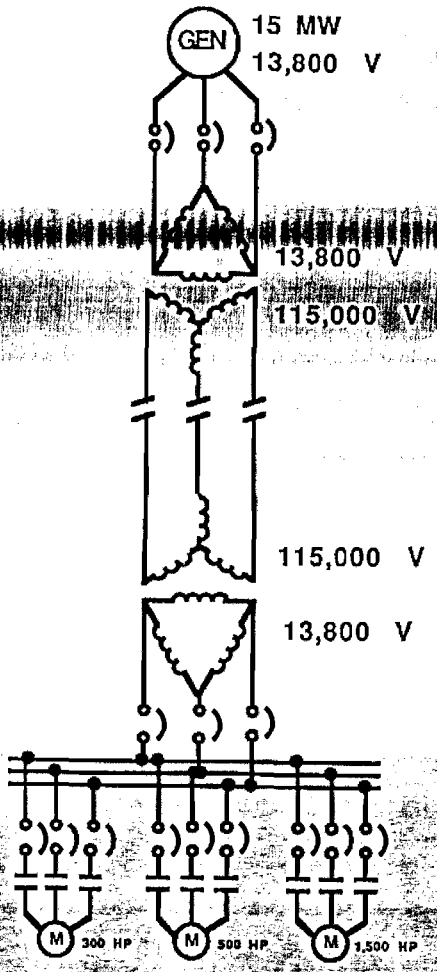
ELECTRICAL DRAWINGS

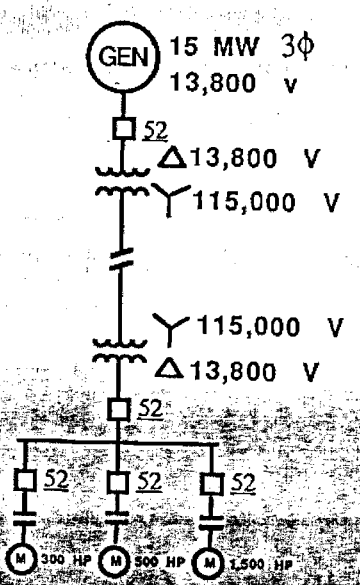
Electrical drawings are used to represent electrical circuits and systems in a simplified and somewhat standardized format. Each component and piece of equipment has a symbol (some have two or three symbols). Lines are drawn between the components, or equipment, showing the connections.

The two most common types of electrical drawings are the elementary or schematic drawing shown in Figure 1, and the one-line or single-line drawing shown in Figure 2. The elementary shows each conductor as a line. The one-line condenses the three conductors of a 3-phase, or the two conductors of a single-phase system, into a single line. The elementary provides more detailed information; the one-line provides a more general overview of a circuit or system.



ELEMENTARY DRAWING

Figure 1



ONE-LINE DRAWING

Figure 2

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AMERICAN STANDARD DEVICE FUNCTION NUMBERS

1. Master Element
2. Time-delay Starting or Closing, Relay
3. Checking or Interlocking Relay
4. Master Contactor
5. Stopping Device
6. Starting Circuit Breaker
7. Anode Circuit Breaker
8. Control Power Disconnecting Device
9. Reversing Device
10. Unit Sequence Switch
11. Reserved for future application
12. Over-Speed Device
13. Synchronous-Speed Device
14. Under-Speed Device
15. Speed or Frequency Matching Device
16. Reserved for future application
17. Shunting or Discharge Switch
18. Accelerating or Decelerating Device
19. Starting-to-Running Transition Contactor
20. Valve
21. Distance Relay
22. Equalizer Circuit Breaker
23. Temperature Control Device
24. Reserved for future application
25. Synchronizing or Synchronous-Check Device
26. Apparatus Thermal Device
27. Undervoltage Relay
28. Flame Detector
29. Isolating Contactor
30. Annunciator Relay
31. Separate Excitation Device
32. Directional Power Relay
33. Position Switch
34. Master Sequence Device
35. Brush-Operating or Slip-Ring-Short-Circuiting Device
36. Polarity or Polarizing Voltage Device
37. Undercurrent or Underpower Relay
38. Bearing Protective Device
39. Mechanical Condition Monitor
40. Field Relay
41. Field Circuit Breaker
42. Running Circuit Breaker
43. Manual Transfer or Selector Device
44. Unit Sequence Starting Relay
45. Atmospheric Condition Monitor
46. Reverse-Phase or Phase-Balance Current Relay
47. Phase-Sequence Voltage Relay
48. Incomplete Sequence Relay
49. Machine or Transformer Thermal Relay
50. Instantaneous Overcurrent Or Rate-of Rise Relay
51. A-C Time Overcurrent Relay
52. A-C Circuit Breaker
53. Exciter or D-C Generator Relay
54. Reserved for future application
55. Power Factor Relay
56. Field Application Relay
57. Short-Circuiting or Grounding Device
58. Rectification Failure Relay
59. Overvoltage Relay
60. Voltage or Current Balance Relay
61. Reserved for future application
62. Time-Delay Stopping, or Opening, Relay
63. Liquid or Gas Pressure or Vacuum Relay
64. Ground Protective Relay
65. Governor
66. Notching or Jogging Device
67. A-C Directional Overcurrent Vacuum Relay
68. Blocking Relay
69. Permissive Control Device
70. Rheostat
71. Liquid or Gas-Level Relay
72. D-C Circuit Breaker
73. Load-Resistor Contactor
74. Alarm Relay
75. Position Changing Mechanism
76. D-C Overcurrent Relay
77. Pulse Transmitter
78. Phase Angle Measuring or Out-of-Step Protective Relay
79. A-C Reclosing Relay
80. Liquid or Gas Flow Relay
81. Frequency Relay
82. D-C Reclosing Relay
83. Automatic Selective Control or Transfer Relay
84. Operating Mechanism
85. Carrier or Pilot-Wire Receiver Relay
86. Locking-Out Relay
87. Differential Protective Relay
88. Auxiliary Motor or Motor Generator
89. Line Switch
90. Regulating Device
91. Voltage Directional Relay
92. Voltage and Power Directional Relay
93. Field Changing Contactor
94. Tripping or Trip-Free Relay

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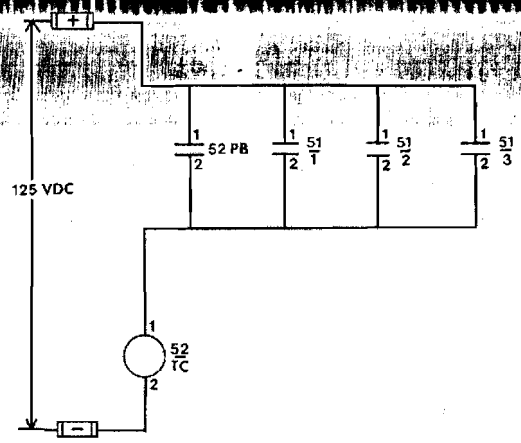
A standard has been developed that assigns numbers to many of the more common types of control and protective electrical equipment. This minimizes lengthy written names. This standard is provided as Figure 3.

Electrical systems are typically represented in elementary or one-line format. Individual pieces of equipment, however, often use additional types of drawings in conjunction with the elementary. These other drawings are the connection and interconnections drawings. Both of these are often called "wiring" diagrams because they indicate where each individual conductor is terminated.

A connection drawing indicates where each conductor internal to a piece of equipment is connected. An interconnection drawing indicates where each conductor leaving or entering the piece of equipment is connected. This information makes the connection and interconnection drawings necessities when working on electrical control and protective circuits.

Figure 4 shows a typical circuit for electrically opening a circuit breaker. Closing the pushbutton, or any of the three overcurrent-relay contacts, causes the trip coil to be energized. The trip coil, when energized, causes the circuit breaker to open.



TYPICAL ELEMENTARY FOR CIRCUIT BREAKER TRIP CIRCUIT

Figure 4

The elementary drawing shown in Figure 4 does not indicate how the components are wired. Figure 5 is a connection drawing (or wiring diagram) and provides the connection information. The actual use of Figure 5 begins with picking a starting point such as the positive fuse (UA). The top of the fuse, point 3, goes to point 2 on the AA terminal block. Since no other conductor is found at point 2 on the terminal block, it has go to, or come from, an external connection.

The bottom of the positive fuse, point 4, is connected to point 2 on the A terminal block. From there, a conductor goes to point 1 on relay BC. From point 1 on the BC relay, the conductor goes to point 1 on relay BB, then to point 1 on relay BA, and finally to point 1 on the BD pushbutton. This completes the positive portion of the circuit shown in Figure 5.

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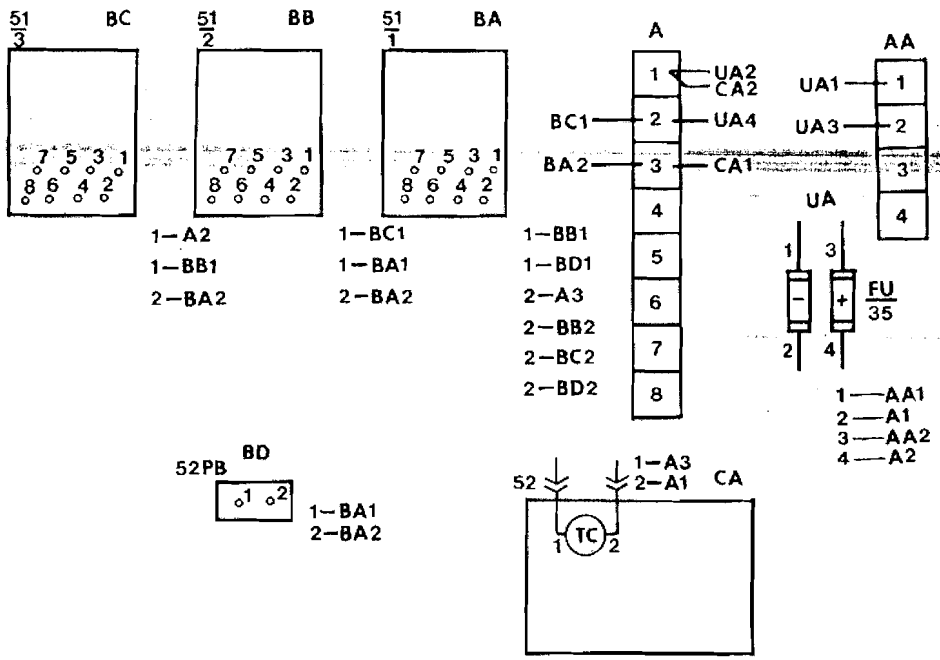
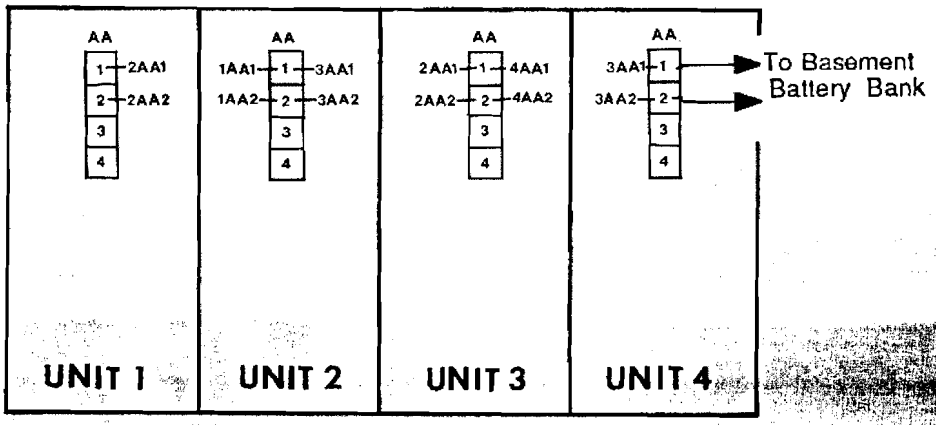


CONNECTION (WIRING) DRAWING

Figure 5

Connection drawings are used to show wiring connections within a piece of equipment. External connections are show on interconnection drawings such as that shown in Figure 6.

When tracing the connection on the top of the positive fuse in Figure 5, it was found to terminate on point 2 of the AA terminal block. In Figure 6, it is seen that the point 2 on the AA terminal block in unit 1 is connected to point 2 on the AA terminal block in unit 2, which is connected to point 2 on the AA terminal block in unit 3, which is connected to point 2 on the AA terminal block in unit 4. From there, the connection goes to the positive terminal of the batteries in the basement.



INTERCONNECTION DRAWING

Figure 6

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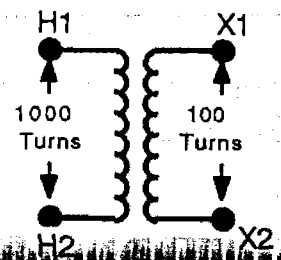
TAP CHANGERS

The voltage on a system decreases as the distance from the source transformer or generator increases. For example, the voltage 10 miles from a source transformer will be less than the voltage 1 mile from the transformer. The voltage at any point on a system also decreases as the current on the system increases. This is indicated by Ohm's Law. (Voltage = Current x Impedance or E = IZ)

Because of the voltage drop caused by the impedance of the conductor and the flow of current, corrective action must be taken to keep the voltage within the allowable range. One of the methods to keep voltage within the allowable range is a tap changer.

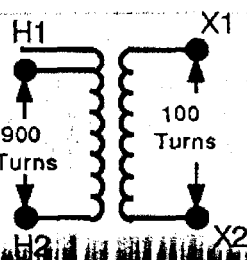
Tap changers change the ratio of the input winding to the output winding. By doing so, the output voltage is changed. Figures 1, 2 and 3 show high- and low-side windings and the result of using taps to change the input-to-output ratios.



Turns Ratio of 10:1

10 kV INPUT PRODUCES 1000 VOLTS OUTPUT

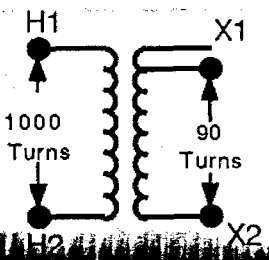
Figure 1



Turns Ratio of 9:1

DECREASING HIGH-SIDE TURNS RESULTS IN 10 kV IN PRODUCES 1,111 VOLTS OUT

Figure 2

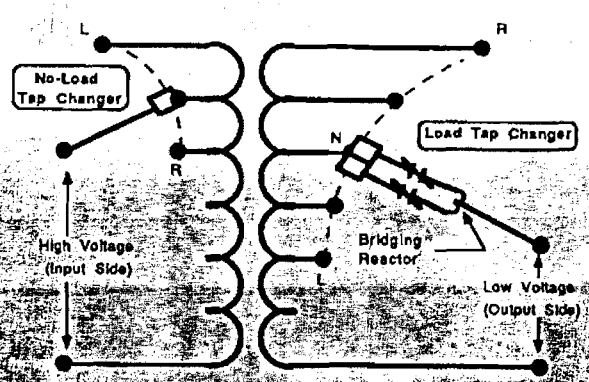


Turns Ratio of 11.1:1

DECREASING LOW-SIDE TURNS RESULTS IN 10 kV IN PRODUCES 900 VOLTS OUT

Figure 3

Tap changers are devices that mechanically change a connection point in a winding. Figure 4 shows transformer windings with a no-load tap changer (NLTC) on the high side, and a load tap changer (LTC) on the low side. In some utilities a load tap changer is called a tap change under load (TCUL).



TRANSFORMER WITH NO-LOAD TAP CHANGER AND LOAD TAP CHANGER

Figure 4

No-load tap changers require that no current be flowing in the winding when the tap change is made. This requires that the transformer be de-energized before the tap change is made.

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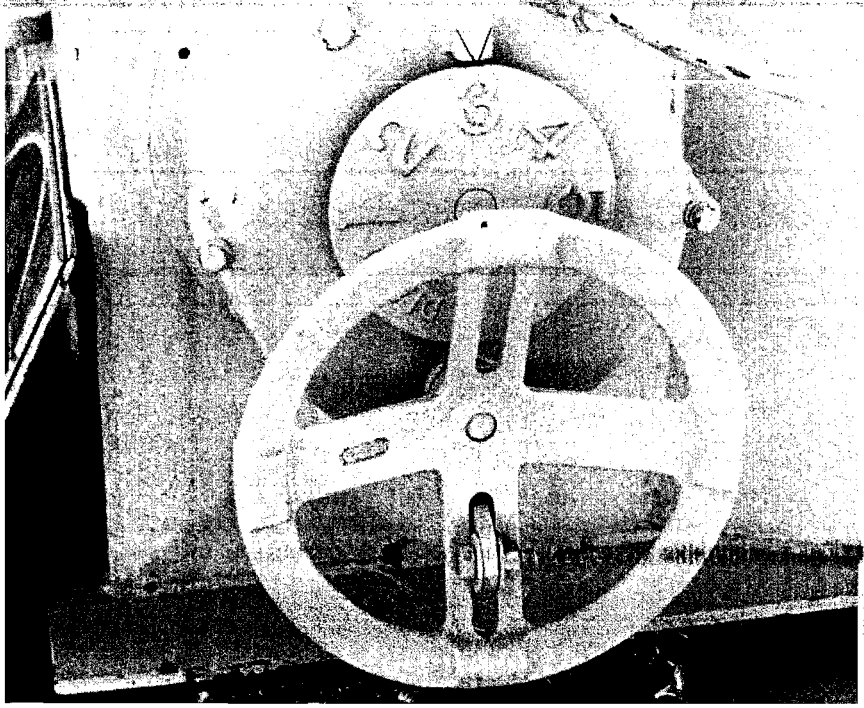
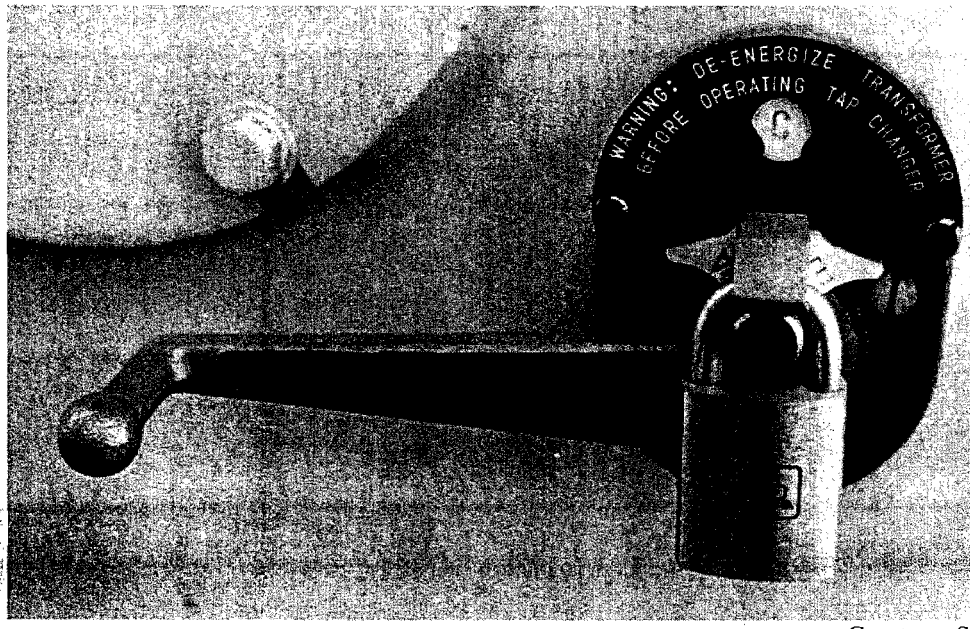
Figures 5, 6 and 7 are photographs of no-load tap changing mechanisms.



Courtesy: Skip Collier

NO LOAD TAP CHANGER OPERATING MECHANISM

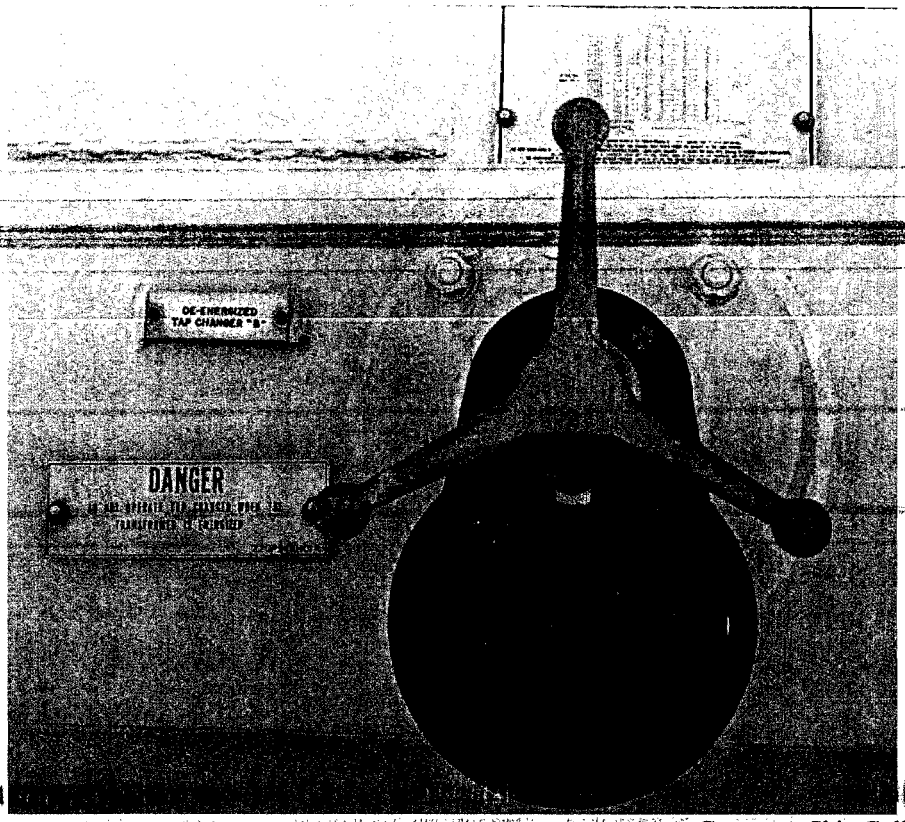
Figure 5



Courtesy: Skip Collier

NO LOAD TAP CHANGER OPERATING MECHANISM

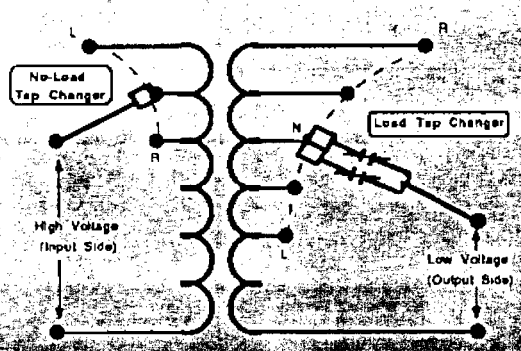
Figure 6



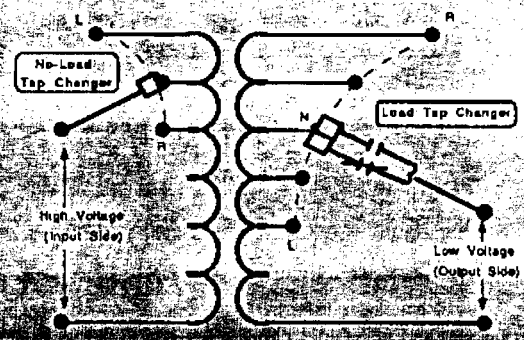
Courtesy: Skip Collier

NO LOAD TAP CHANGER OPERATING MECHANISM
Figure 7

Load tap changers allow tap changes to be made under load conditions without an interruption of power. The sequence of operations for a load tap changer begins with both contacts on the same tap. This is shown in Figure 8. The upper set of contacts open and break current flow through the upper path (Figure 9). The upper-path current immediately transfers to the lower path and the customer never loses power.

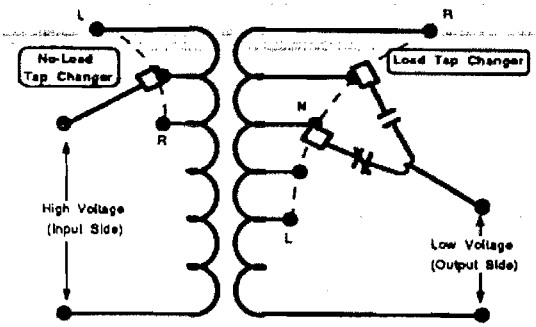


LOAD TAP CHANGER IN INITIAL POSITION
Figure 8



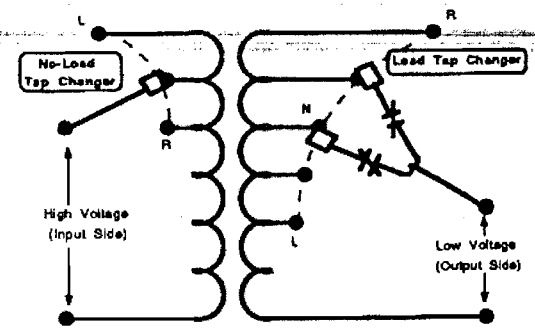
CONTACTS OPEN AND BREAK CURRENT FLOWING THROUGH UPPER PATH
Figure 9

Once the total current is flowing in the bottom path, the upper connector lifts off the initial tap and moves to the next tap (Figure 10). After the upper connector has moved and reconnected, its contact closes, allowing current to flow through both paths. This is called the bridging position and is shown in Figure 11.



UPPER CONTACT ON NEXT HIGHER TAP

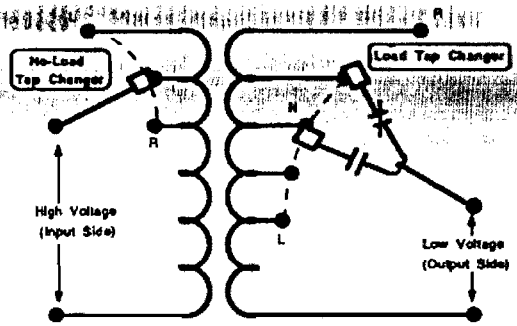
Figure 10



CONTACTS IN BRIDGING POSITION

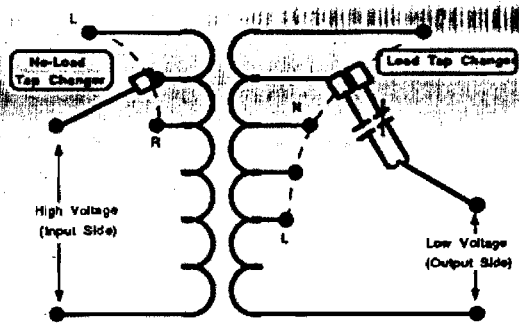
Figure 11

Once current is established in both connectors, the lower contacts open and transfer its current to the upper path (Figure 12). The lower connector then moves to the next higher tap and sets down next to the upper connector (Figure 13).



LOWER CONTACTS OPEN AND TRANSFER CURRENT TO UPPER CONTACTS

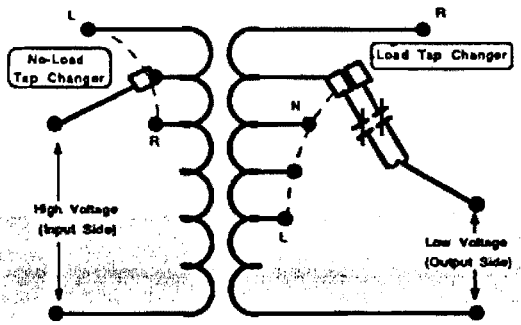
Figure 12



LOWER CONNECTOR MOVES TO NEXT HIGHER TAP

Figure 13

After the bottom connector has moved to the next upper tap, the bottom contacts close (Figure 14). Current flows through both connectors and the tap change is complete.



BOTTOM CONTACTS CLOSE TO COMPLETE TAP CHANGE

Figure 14

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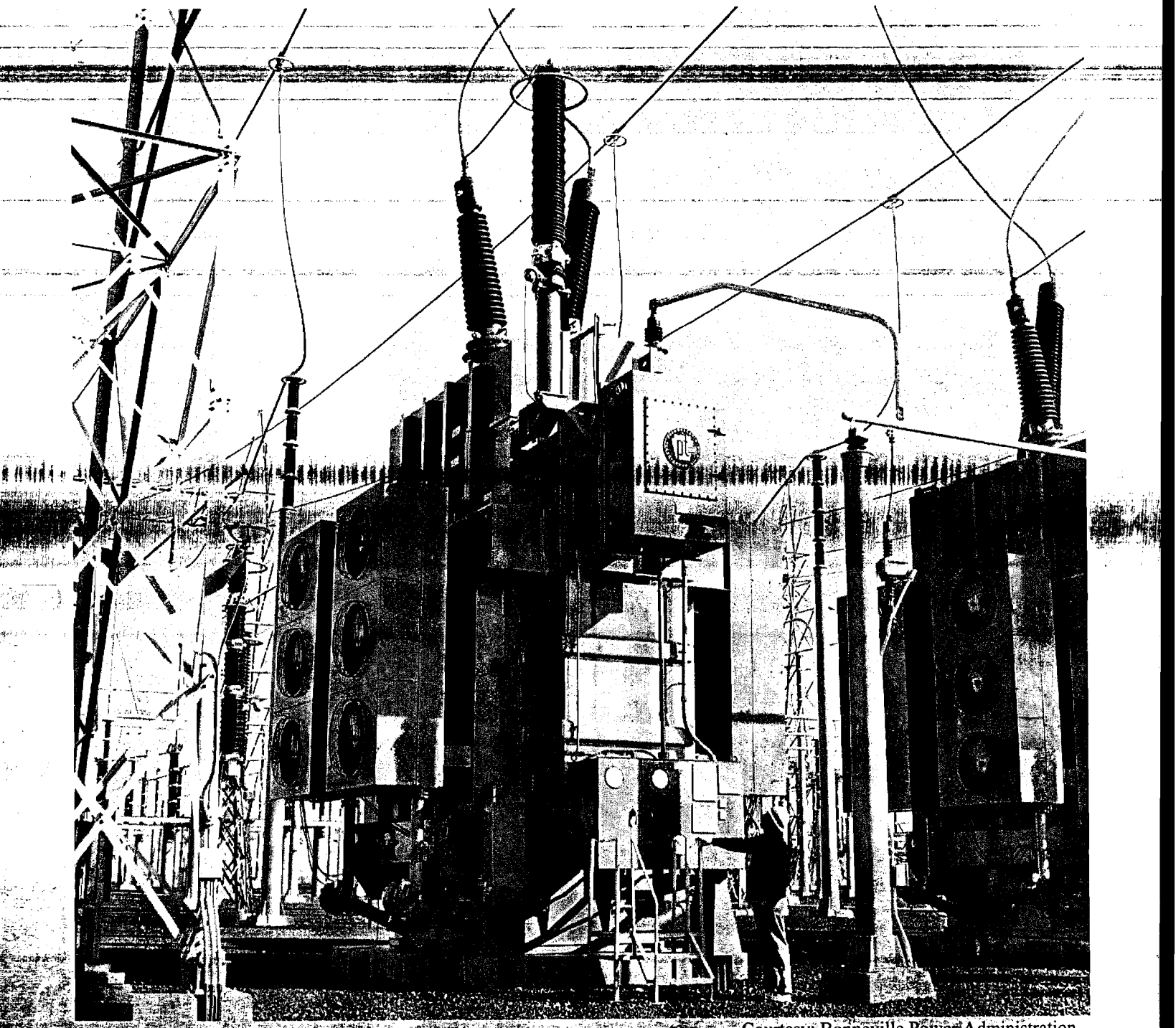
Figure 15 shows a single-phase transformer with a load tap changer. Figure 16 shows a load-tap-changer position indicator.



Courtesy: Bonneville Power Administration

SINGLE PHASE TRANSFORMER WITH LOAD TAP CHANGER

Figure 15

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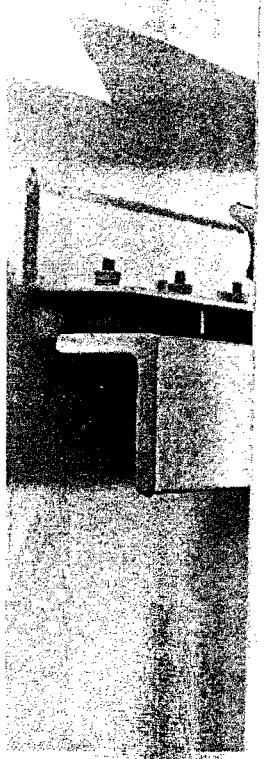
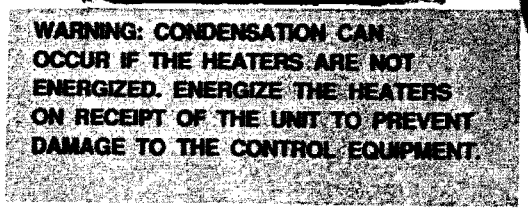
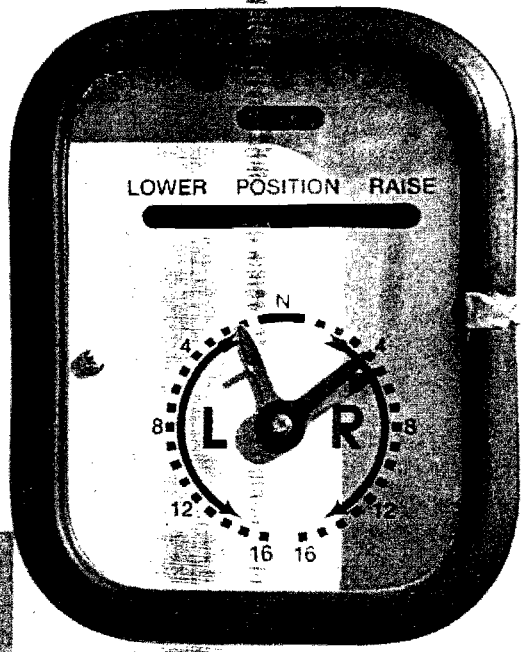
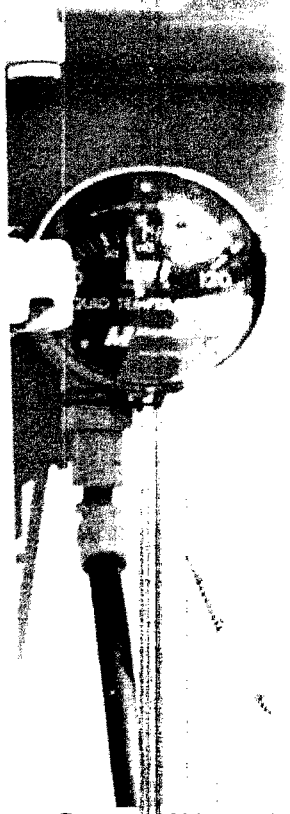








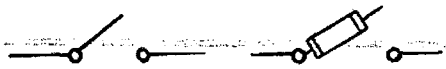
Courtesy: Skip Collier

LOAD-TAP-CHANGER POSITION INDICATOR

Figure 16

♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

ELECTRICAL DISCONNECT SWITCHES

Definition:	Devices used to connect and disconnect portions of an electrical system
Other names:	Disconnects, switches, cutouts, fused disconnects, circuit switchers, circuit interrupters, load interrupters
Symbols:	

A switch is a device used to connect and disconnect a component from an electrical system, or to connect and disconnect portions of electrical systems. The standard residential light switch is the most common of the many types of disconnect switches. Its purpose is to connect and disconnect a light from the rest of the system. The switches used in utility and industrial applications, although much larger, operate in the same manner. These larger switches are closed to connect to the system, and they are opened to disconnect from the system.

Figure 1 shows a vertically opening high-voltage disconnect switch. It is shown in the open position. The three vertical arms swing downward to the right to close the switch. This connects the transformer on the left side of the photograph to the aluminum bus on the right. The switch in Figure 1 will not break load current without damaging itself. For this reason, it is called a no-load-break switch. In order for it to open when current is flowing, a circuit breaker in the circuit must open first to interrupt the flow of current.

Figure 2 shows a horizontally opening high-voltage disconnect switch in the open position. The six arms, three on the left side and three on the right side, swing towards the camera (that took the photograph) and latch together when closed. This switch will break full load current and is called a load-break switch. Figure 3 is a no-load-break switch often called a "V" break switch.

As current-interrupting technology has improved, the levels of current that a switch can interrupt has increased. Switches, however, cannot break the higher fault currents. Circuit breakers must be able to interrupt maximum fault currents, and so circuit breakers must be used in applications with higher fault currents.

One advantage that switches have over circuit breakers is that most switches provide a visible air gap between the energized and de-energized parts of the system when in the open position. Circuit breakers do not provide a gap that can be easily seen by crews working on the system. Therefore, when working on a system, opening a circuit breaker to de-energize a portion of a system is not as safe as opening a switch.

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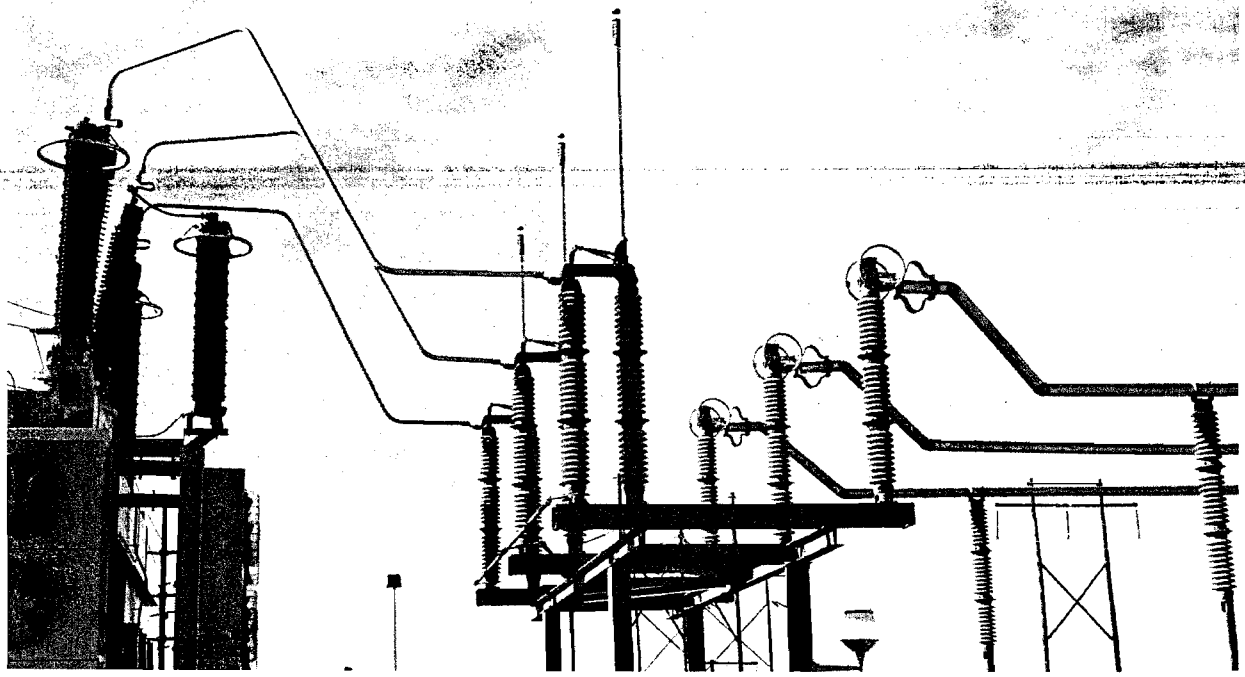
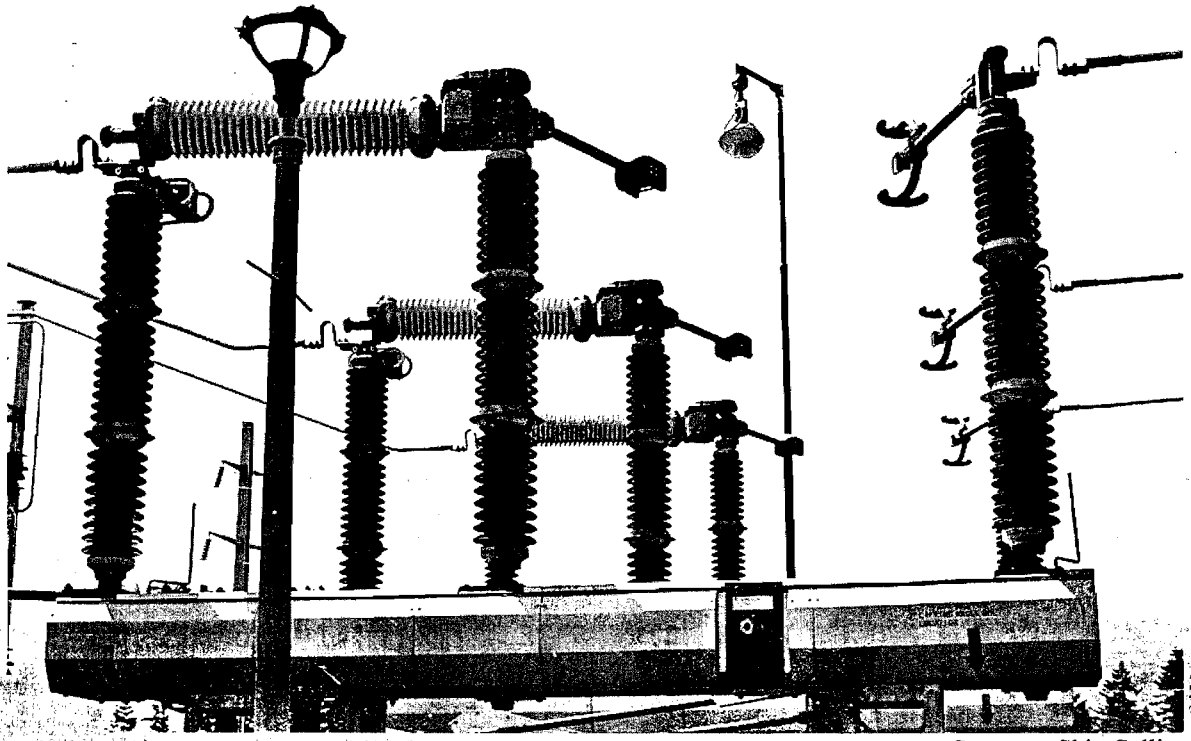


Courtesy: Skip Collier

VERTICALLY OPENING DISCONNECT SWITCH

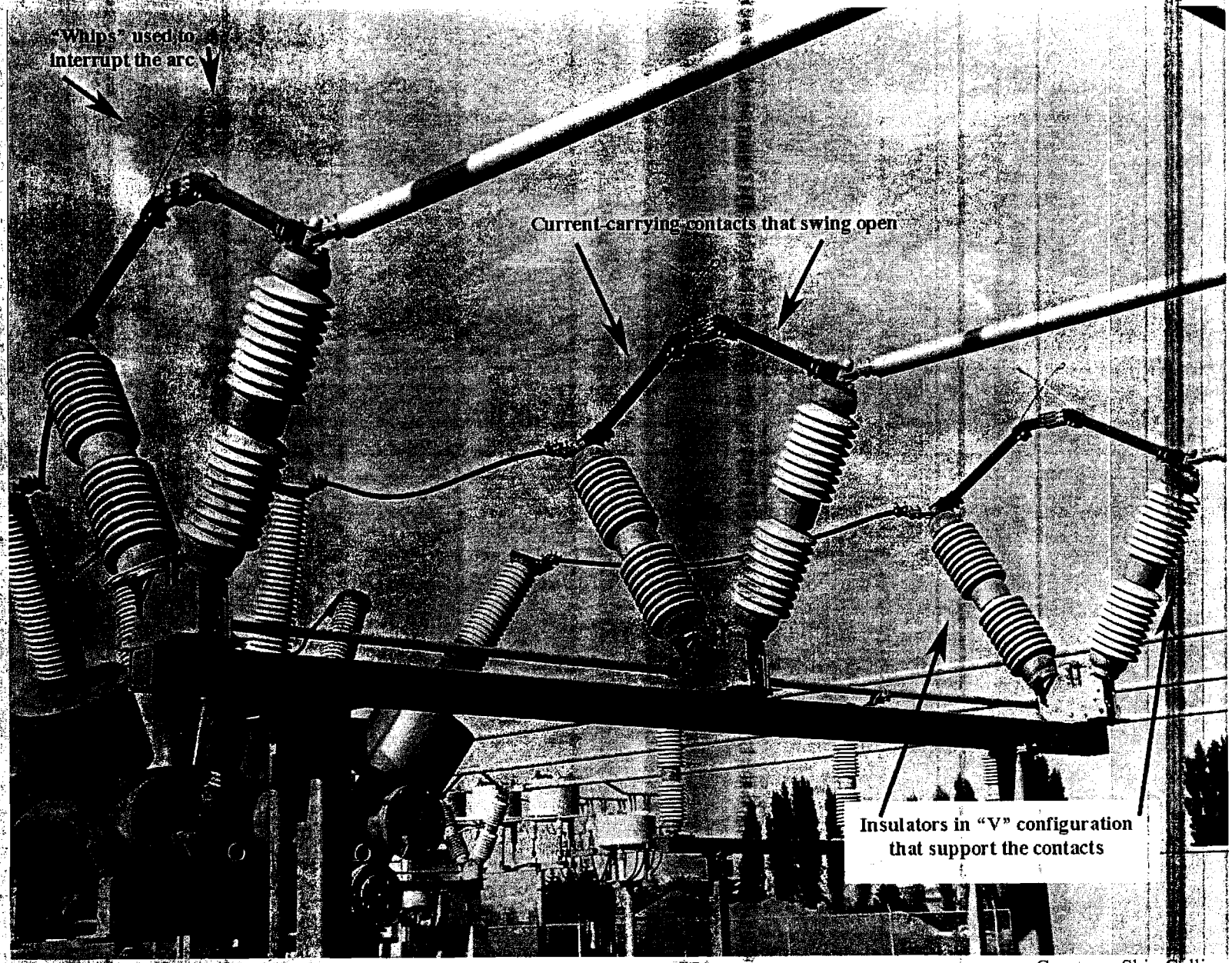
Figure 1



Courtesy: Skip Collier

HORIZONTALLY OPENING DISCONNECT SWITCH

Figure 2



Courtesy: Skip Collier

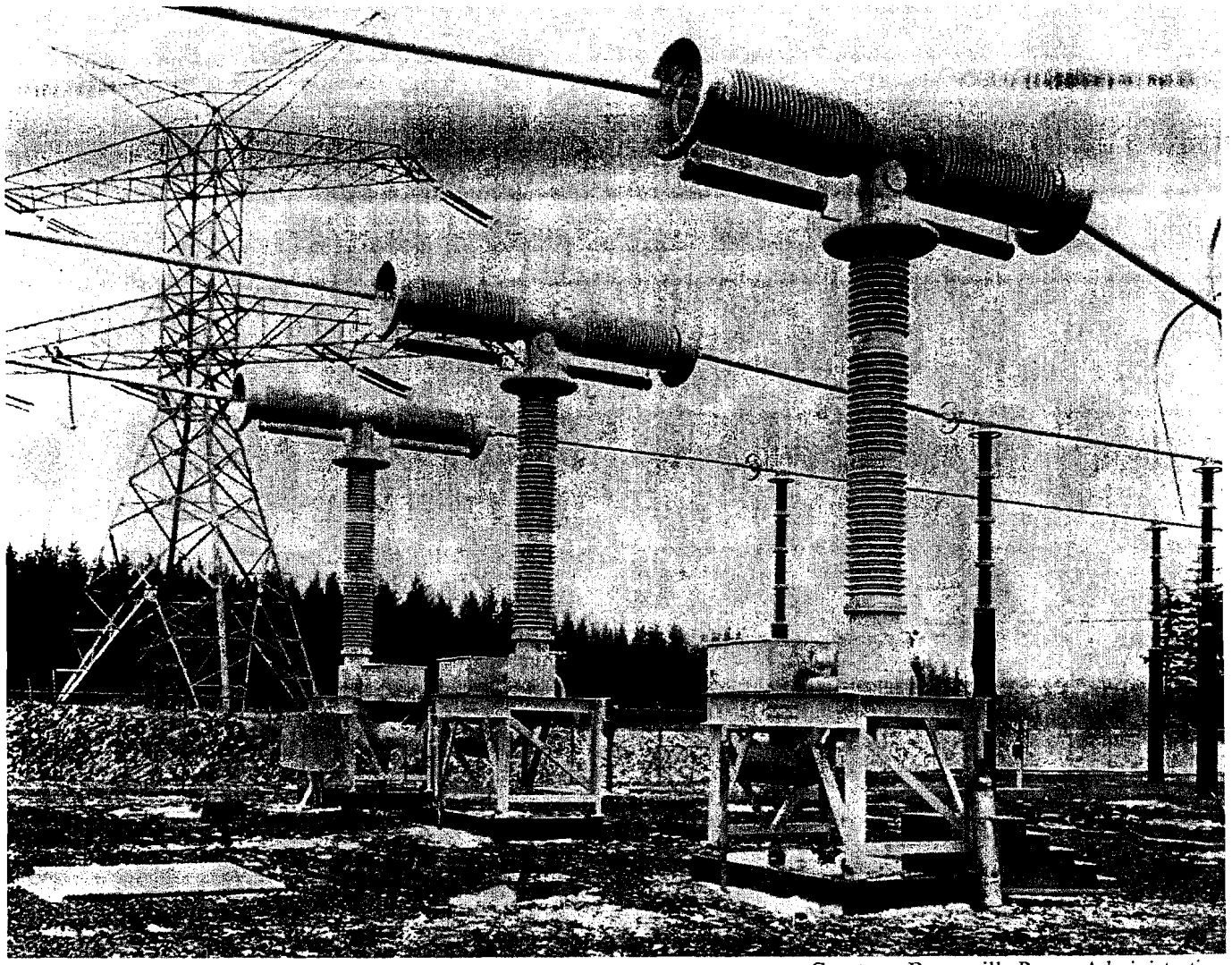
"V" BREAK DISCONNECT SWITCH

Figure 3

SF_6 REACTOR CAPACITOR SWITCHES

A system's power factor varies due to changes in reactive load. Shunt reactors and capacitors are used to keep the power factor within a desired range. Shunt reactors are switched into the system to offset capacitance during periods of light load. Capacitors are switched into the system to offset system inductance during high-load periods. Sulphur hexafluoride-insulated (SF_6) reactor-capacitor switches were developed to perform this switching.

Figure 1 is a photograph of a 500 kV reactor-capacitor switch at the Bonneville Power Administration's Raver Substation located near Seattle, Washington. The switch was developed by Westinghouse Electric Corporation under a joint contract funded by the Electric Power Research Institute (EPRI) and the Bonneville Power Administration.



Courtesy: Bonneville Power Administration

SF_6 REACTOR CAPACITOR SWITCH

Figure 1

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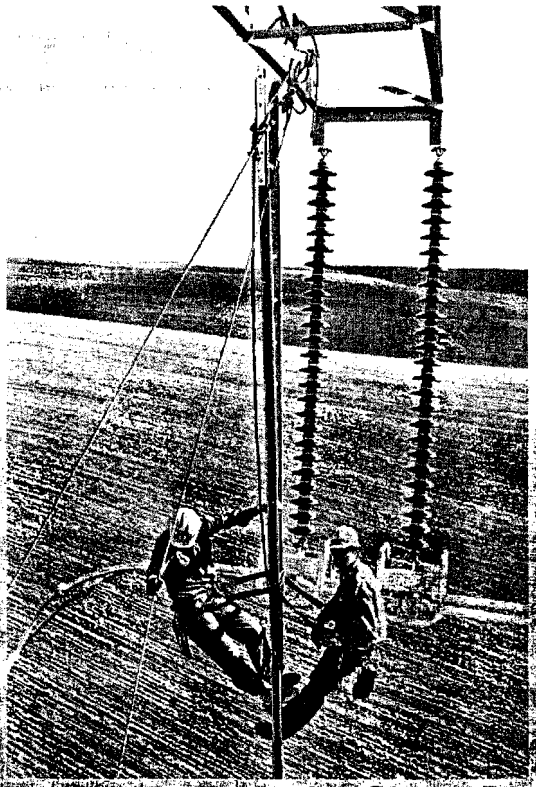
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

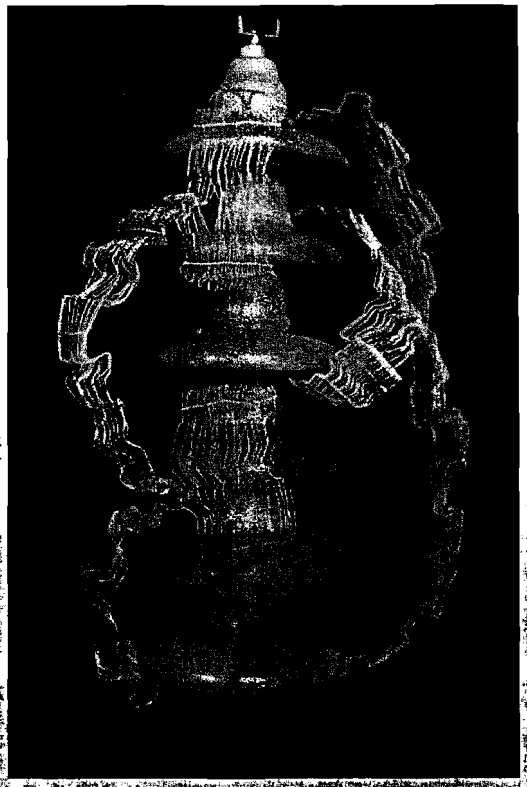
TRANSMISSION LINES

The voltage produced by a generator is raised by a step-up transformer to a transmission level. This step-up in voltage is done to keep the transmission conductors relatively small. By analyzing the equation for electrical power (Power = Voltage X Current), it can be seen that for a fixed amount of power, as the voltage increases the amount of current decreases. This principle of higher voltage and lower current results in smaller transmission conductors being necessary.

Overhead transmission conductors are not insulated. Therefore, a higher voltage results in the requirements of the distance above the terrain being greater, the distances between the phases being greater and the length of the suspension insulators being greater.

Figure 1 shows two line workers suspended from a tower cross-arm next to suspension insulators. The suspension insulators support the conductors, and provide the necessary clearance (distance) between the conductor and cross-arm. Figure 2 shows a flashover (current flowing across the surface of a suspension insulator). Figure 3 shows the connection between porcelain suspension insulators and the conductors. Figure 4 shows a polymer suspension insulator.





Courtesy: Bonneville Power Administration

LINE WORKERS NEAR SUSPENSION INSULATORS
Figure 1

FLASHOVER ON PORCELAIN SUSPENSION INSULATORS
Figure 2

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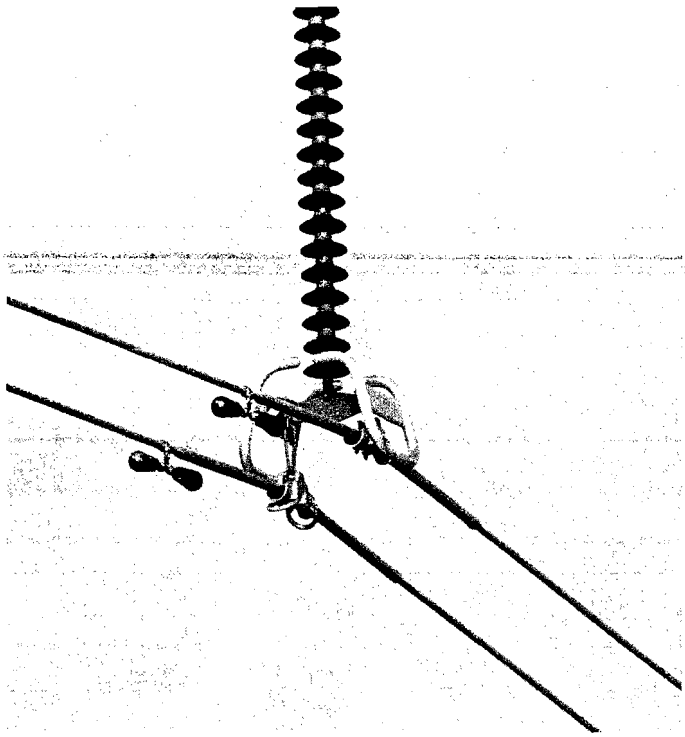


Courtesy: Bonneville Power Administration

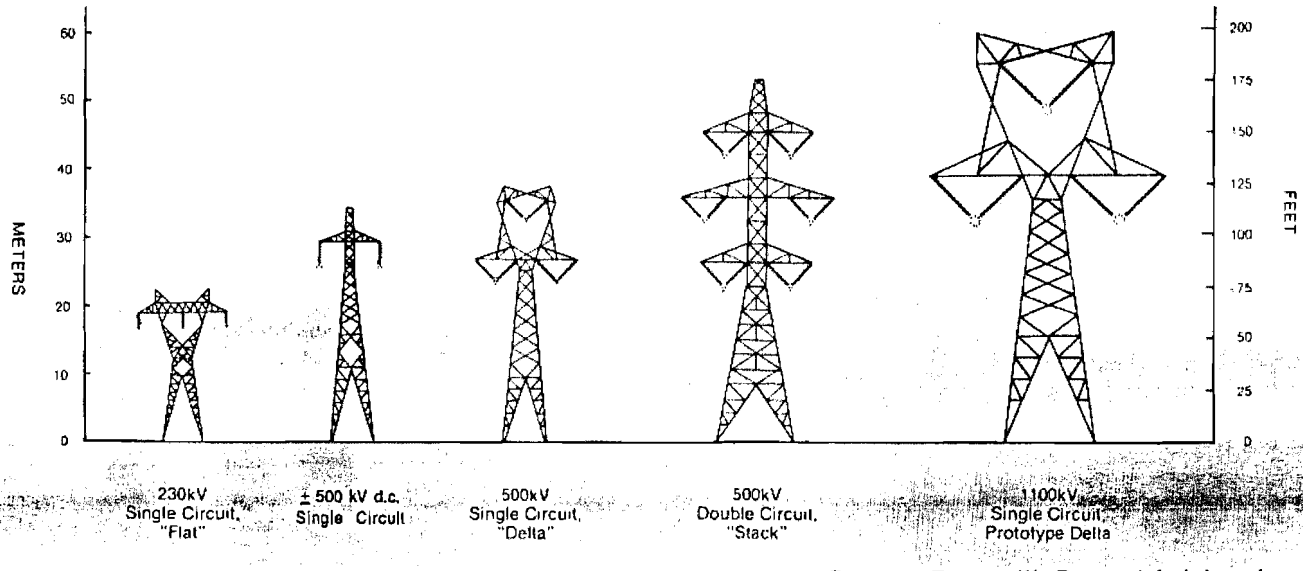
SUSPENSION INSULATORS HOLDING CONDUCTORS

Figure 3

POLYMER SUSPENSION INSULATOR

Figure 4

The design of transmission-line towers varies from utility to utility. Figure 5 shows the configuration of typical Bonneville Power Administration designs. The heights (in meters on the left and feet on the right) are averages for level terrain. Actual heights vary depending on terrain and environmental factors.



Courtesy: Bonneville Power Administrations

TRANSMISSION TOWERS

Figure 5

♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

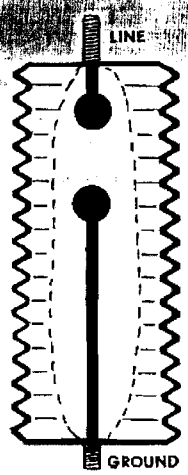
TRANSMISSION SYSTEMS AND LIGHTNING

Lightning tends to hit the highest object around, and if the object is metal, it is almost sure to be hit by lightning. Because of their heights, transmission lines and overhead distribution systems are likely targets of lightning. In order to help protect against lightning, shield wires are run above the conductors. These shield wires are grounded at selected towers or poles. When lightning hits the shield wire, the lightning current has a path to ground through one of the ground connections.

Shield wires do not provide 100-percent protection from lightning. A lightning strike that hits one of the conductors places a high-energy waveform on the line. If the voltage level of the waveform is greater than that which a suspension insulator can withstand, the energy in the lightning strike will cause a flashover at a suspension insulator. The energy then goes to ground through the tower.

If the lightning-induced voltage is not great enough to cause a flashover at a suspension insulator, the lightning energy is dissipated as it travels down the transmission line. If, however, a lightning strike is close to a substation, the energy can reach substation equipment before it is dissipated. If the equipment happens to be a transformer, a very expensive failure of the transformer can result.

Surge arrestors, previously called lightning arrestors, are used to protect transformers. Early surge arrestors incorporated a gap design. (See Figure 1)



GAP-TYPE SURGE (LIGHTNING) ARRESTOR

Figure 1

Under normal conditions, the transmission voltage is not high enough to push current across the air gap. The higher voltage caused by the lightning strike, however, should be great enough to arc across the gap. When this happens, the lightning energy should flow to ground, thus bypassing the transformer. Figure 2 shows surge arrestors on a transformer.

A modern surge-arrestor design uses metal-oxide semiconductor material. The resistance of the metal-oxide material decreases as the voltage increases. At normal voltage the metal-oxide material looks like an open circuit. As the voltage increases its resistance decreases until it becomes a very good conductor and takes the lightning energy to ground.

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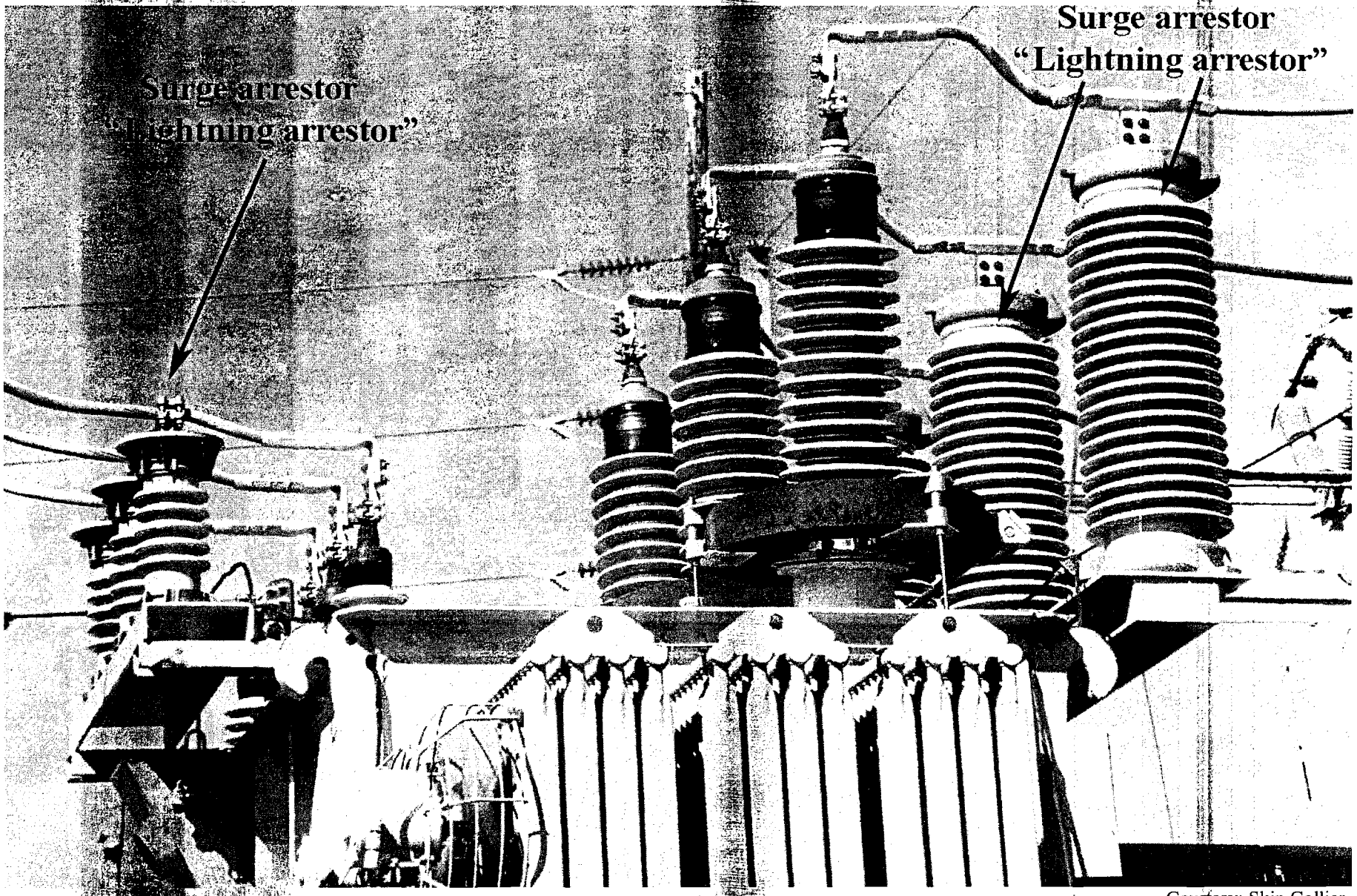


Courtesy: Skip Collier

TRANSFORMER WITH SURGE ARRESTORS

Figure 2

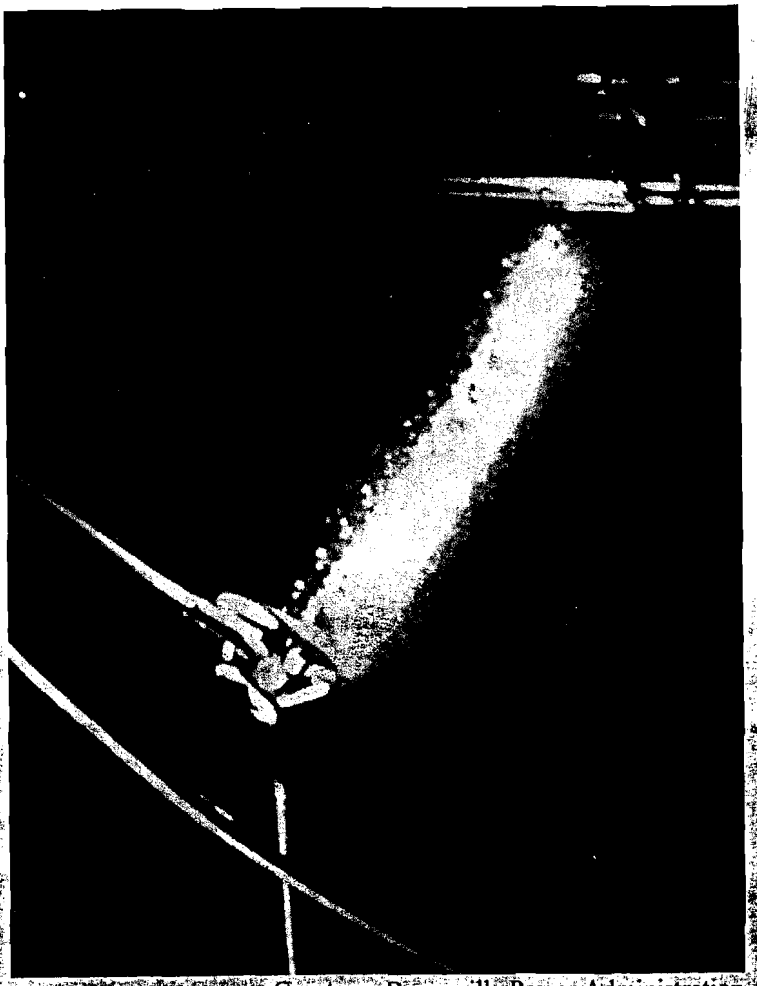
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

CORONA

Corona is an undesirable phenomenon that occurs when there is high voltage applied to a small area. This high voltage causes the surrounding air, which is normally a good insulator, to ionize and become a conductor. Power losses occur, and radio and television interference result in the surrounding areas. Insulation damage can also result.

Corona increases with increased humidity and can often be seen in high-voltage substations in the form a bluish glow around conductors. It is accompanied by a hissing, buzzing or crackling sound.

Since corona is caused by a high voltage applied to a small area, it can be minimized by eliminating sharp corners and other "pointed" areas such as nicks on conductors. This prevents voltage from being concentrated on a small area.



Courtesy: Bonneville Power Administration

CORONA

Figure 1

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♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

AUTOTRANSFORMERS

Transformers are used when power is being transferred from part of a system to another part, such as from a higher voltage system to a lower voltage system. Normally this is done with a two-winding transformer. However, when the voltages in the two systems are relatively close to each other, a one-winding transformer can be used. A one-winding transformer is called an autotransformer and is less expensive than a two-winding transformer. Figure 1 shows the internal configuration of an autotransformer.

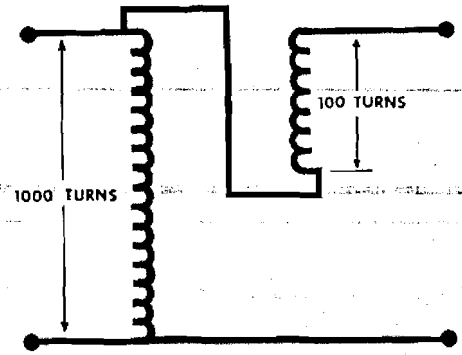

Figure 1

In Figure 1 it might appear that there are actually two windings. The 100-turn winding, however, is merely a continuation of the 1000-turn winding and is wound on the same iron core.

The ratio of the two parts of the windings in Figure 1 is 10 to 1. If 500 volts were applied to the 1000-turn portion of the winding, 50 volts would be induced on the 100-turn portion (Figure 2).

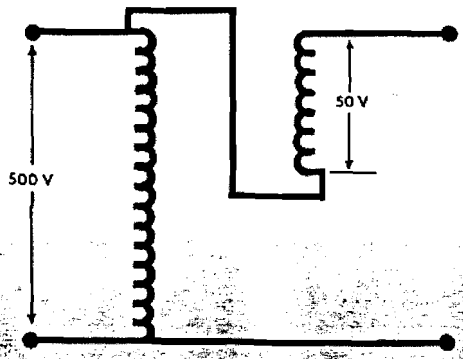

Figure 2

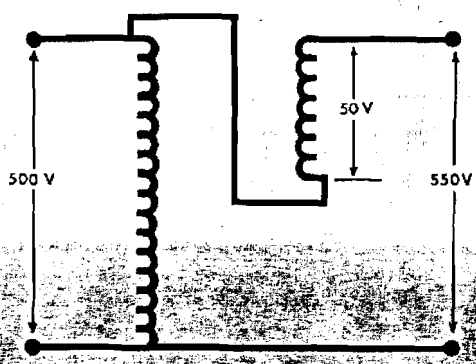

Figure 3

One portion of the autotransformer winding in Figure 2 has 500 volts across it, and the other portion has 50 volts across it. The output would be 550 volts (Figure 3). This autotransformer could then be used to connect a 500-volt system to a 550-volt system.

In a transmission system, the two voltages would be much greater that 500 volts and 550 volts. An electrical utility autotransformer, for example, might be 115 kv to 345 kv. Another might be 345 kv to 500 kv. Although the voltages are much higher, the one-winding design would still apply. Figure 4 shows three single-phase autotransformers.

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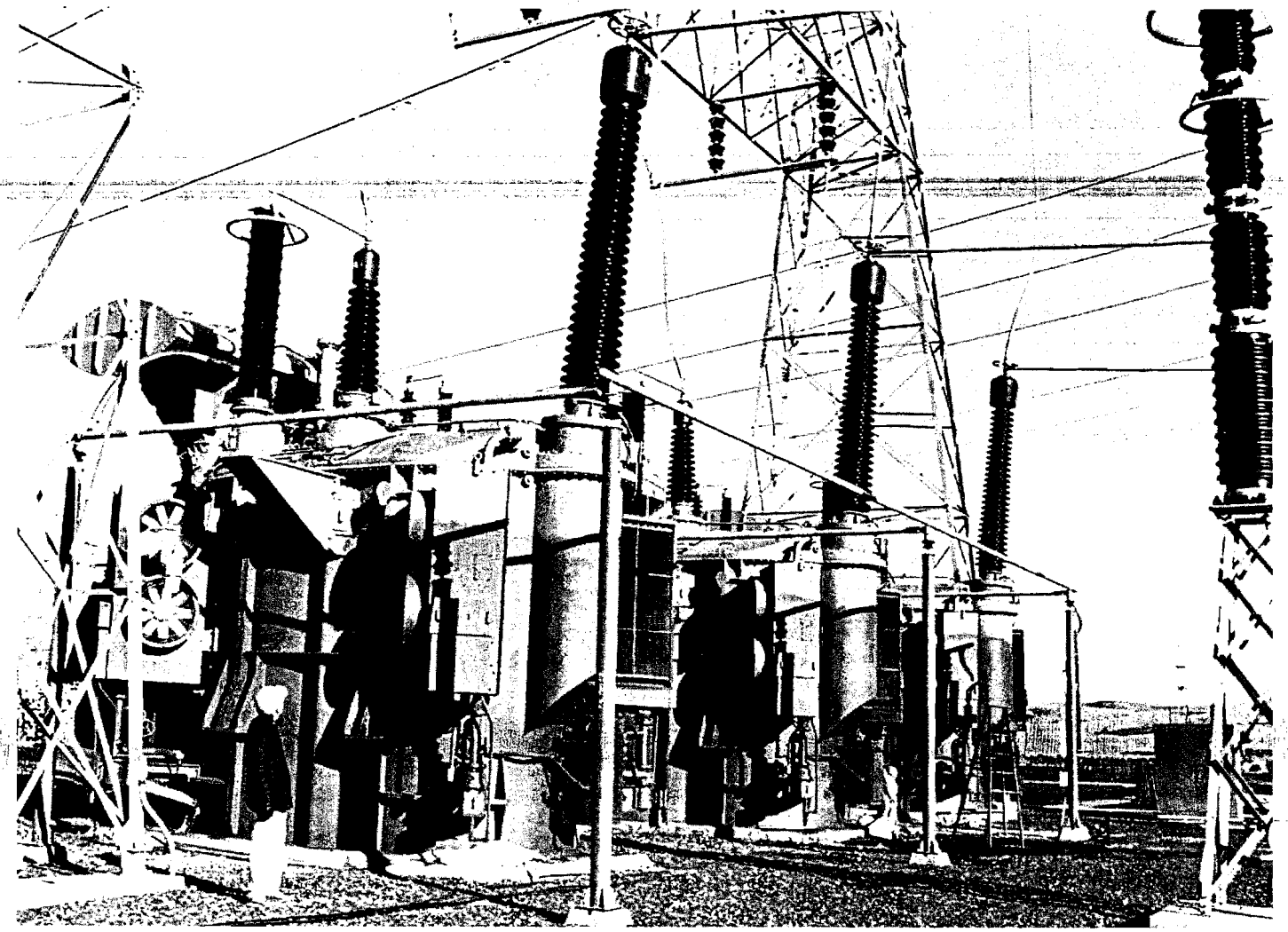
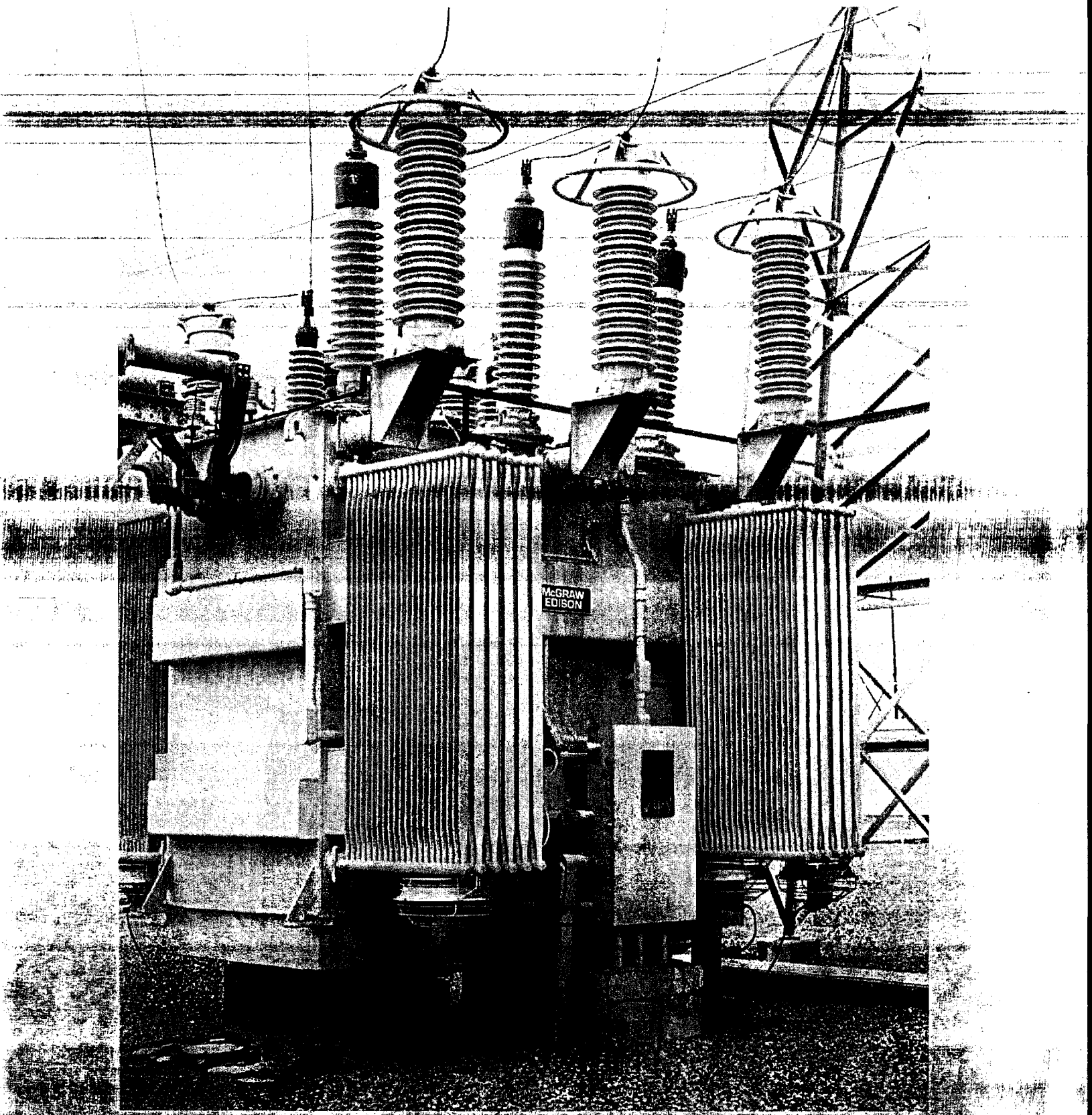


Courtesy: Bonneville Power Administration

THREE SINGLE PHASE AUTOTRANSFORMERS

Figure 4

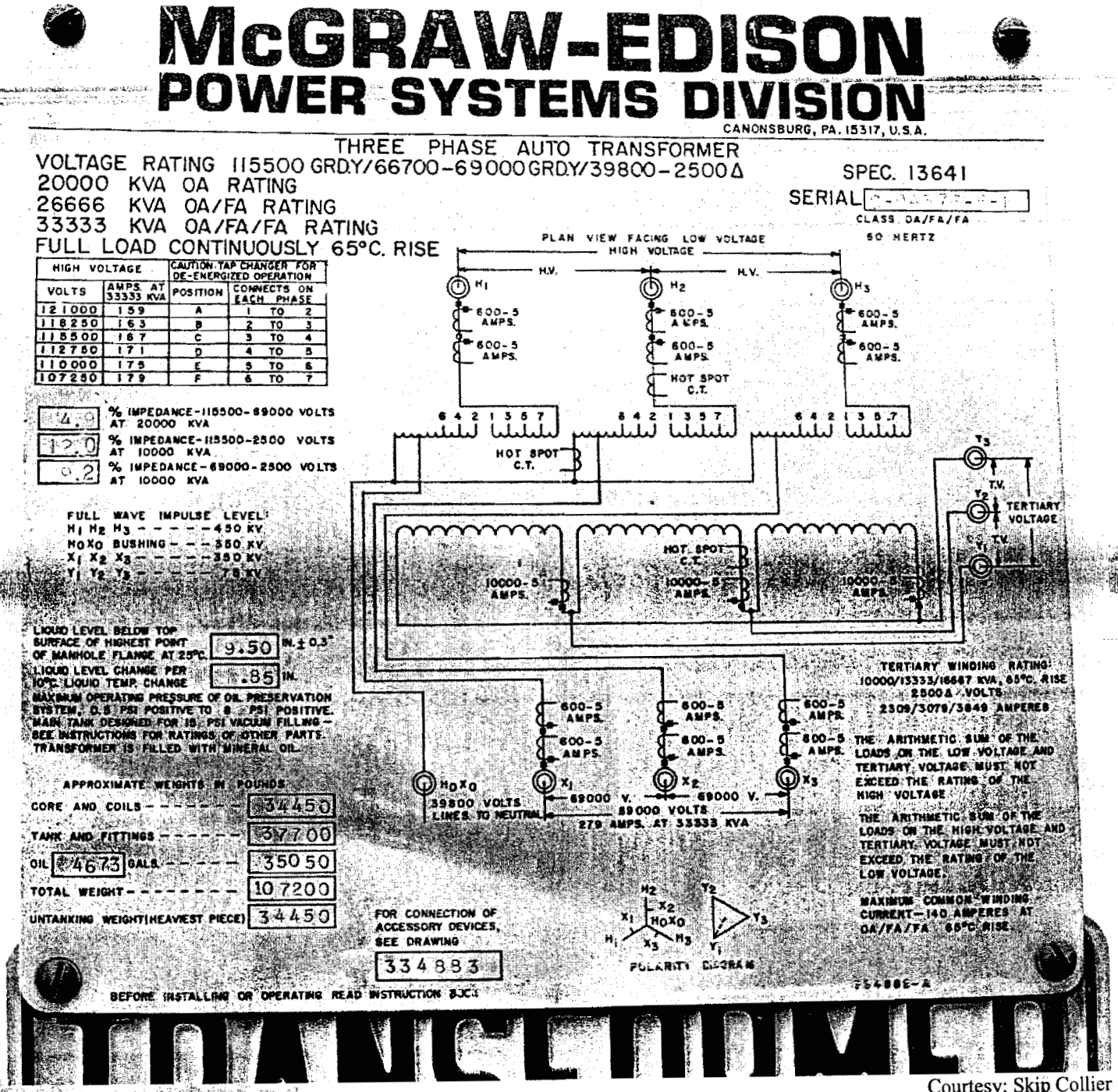
Figure 5 shows a three-phase autotransformer; Figure 6 shows the nameplate of the same three-phase transformer.



Courtesy: Skip Collier

THREE PHASE AUTOTRANSFORMER

Figure 5



Courtesy: Skip Collier

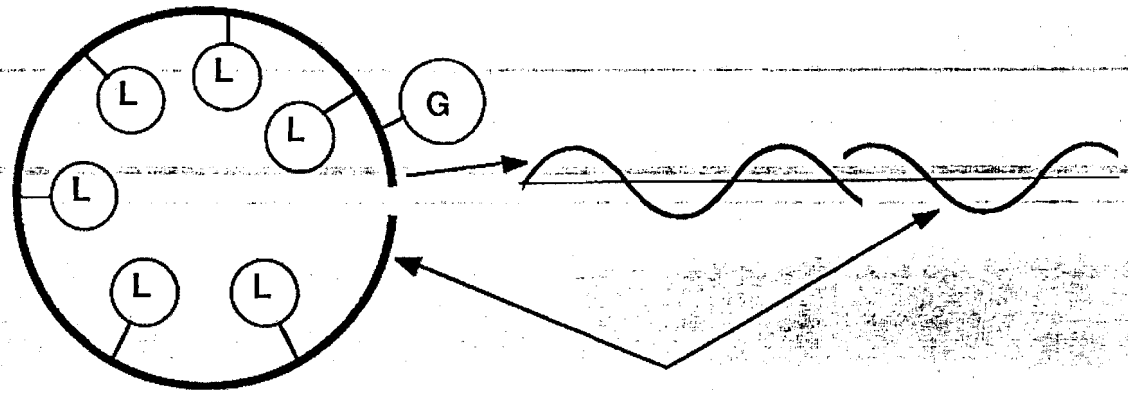
NAMEPLATE ON THREE PHASE AUTOTRANSFORMER

Figure 6

♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

PHASE SHIFTING (PHASE ANGLE) TRANSFORMERS

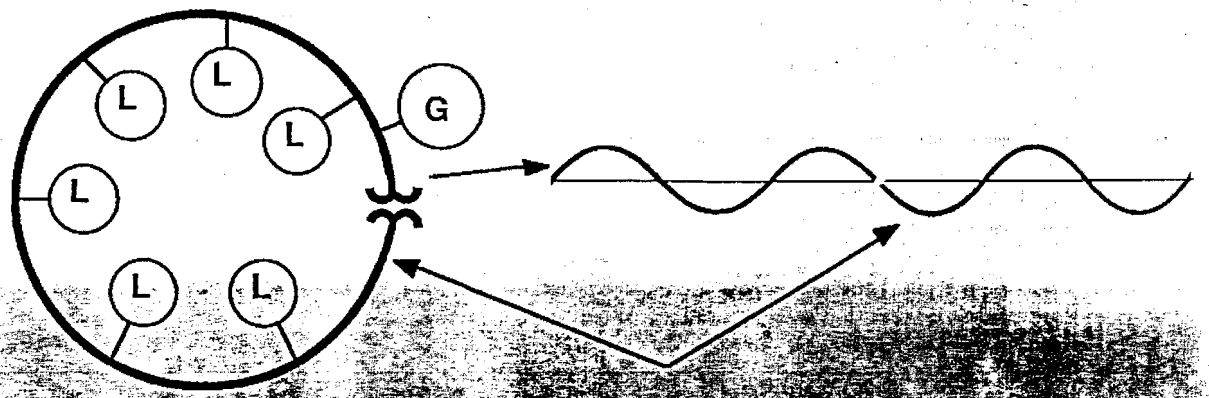
When a transmission line makes a loop over several hundred miles, the voltage sine waves at the point where the loop is to be completed will be out of phase. If the phase difference is excessive, the loop cannot be connected. This is shown in Figure 1.



LOOP WITH OUT-OF-PHASE VOLTAGES AT CLOSURE POINT

Figure 1

A phase-shifting transformer can be used to bring the two sinewaves into phase. This is shown in Figure 2.



LOOP WITH PHASE SHIFTING TRANSFORMER TO MATCH VOLTAGES AT CLOSURE POINT

Figure 2

The second use of phase shifting transformers is to direct power flow in a loop system. A phase shifting transformer can be used to push power along the desired transmission line. A phase shifting transformer can also be used to block undesired power flow in a transmission line.

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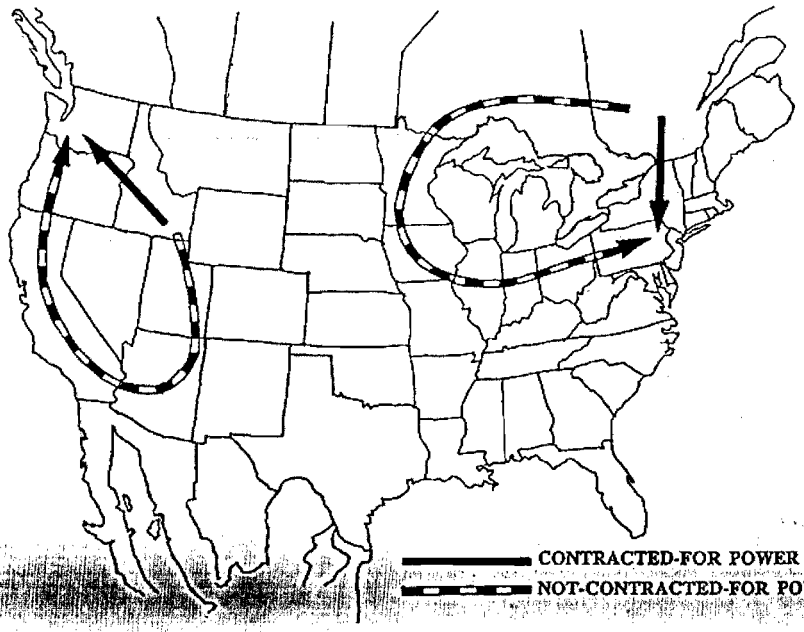
Figure 3 shows examples of loop flow. (Loop flow is power flowing to a load in a not-contracted-for transmission line.) A phase shifting transformer can be used to block loop flow when placed in the not-contracted-for transmission line. It can be used to force power through the contracted-for transmission line when placed in the contracted-for line.



POWER FLOW IN TRANSMISSION SYSTEMS

Figure 3

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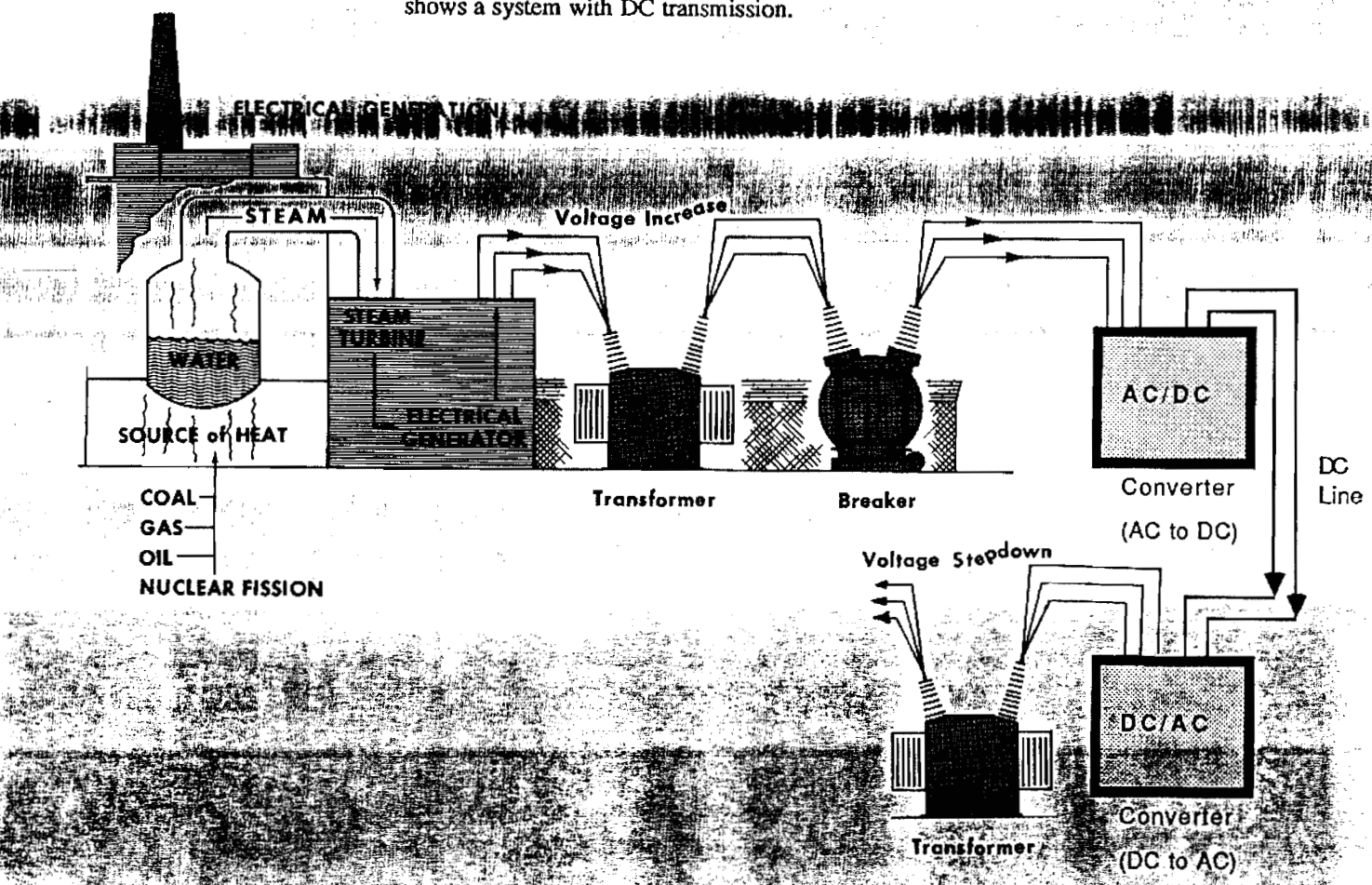
DC TRANSMISSION

Most transmission systems use AC voltage. Using AC voltage, however, incurs both resistive and reactance losses in the transmission lines, and also in each transformer. Of these losses, the inductive-reactance loss is normally the greatest. DC lines do not have inductive losses. Because of less losses, DC transmission is more economical for the transmission of power. DC transmission has had two primary drawbacks that prevent it from being used for transmission exclusively. These are

1. The cost of the equipment to change AC to DC at the sending end, and then from DC back to AC at the receiving end is very expensive.

2. No circuit breakers capable of breaking DC current at transmission voltages.

The high cost of the equipment to change AC to DC (called rectifiers), and to change DC to AC (called inverters) makes DC transmission economical only for long distances. Figure 1 shows a system with DC transmission.



Courtesy: Gould-Brown Boveri (for AC portion)

UTILITY ELECTRICAL SYSTEM WITH DC TRANSMISSION

Figure 1

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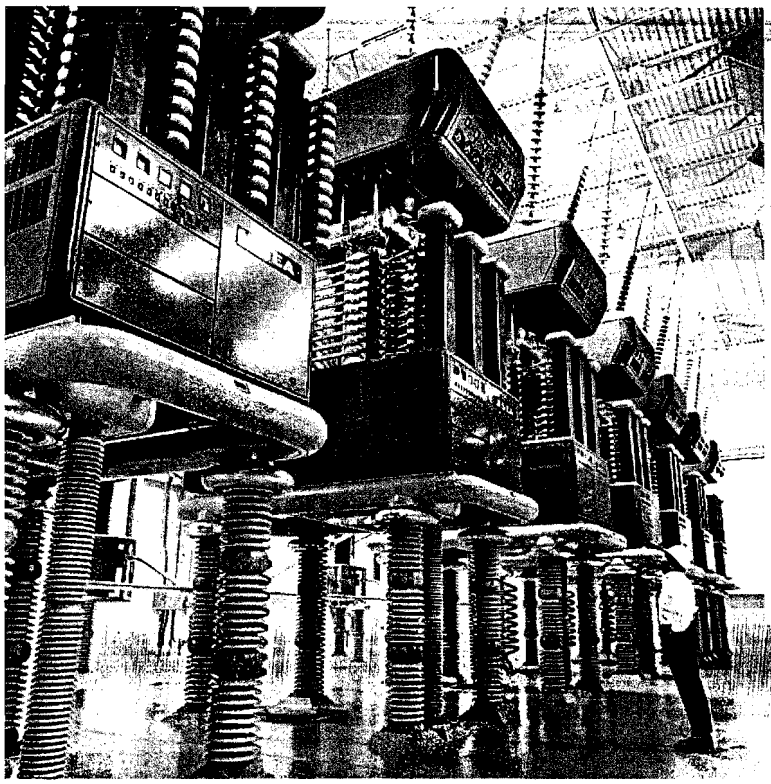
(A facility that can operate both as a rectifier when sending power, and as an inverter when receiving power is called a converter station.) Figure 2 show the initial mercury-arc valves used in the converter stations on the ±500 KVDC line that runs from The Dalles, Oregon to Sylmar, California.



Courtesy: Bonneville Power Administration

AC-TO-DC AND DC-TO-AC CONVERTERS (CALLED VALVES)

Figure 2

Figure 3 shows modern solid-state thyristors used instead of mercury-arc valves. As transmission-level solid-state technology has advanced, the cost of converter stations has dropped (relative to the cost of AC substations). The break-even distances for DC transmission lines has decreased accordingly.

When DC transmission was first used, there were no DC circuit breakers; circuits had to be broken on the AC side of the converter stations. In the mid-1980's, a transmission-level DC circuit breaker was developed. Without DC circuit breakers, each branch off a DC transmission line had to rely on the AC circuit breaker on the AC side on the sending converter station. Any problem on any branch would take out the entire DC line. Now, DC circuit breakers allow each branch from the DC line to have its own circuit breaker. A problem in any branch causes that branch's DC circuit breaker to trip and isolate that branch; the remaining part of DC line continues to operate.

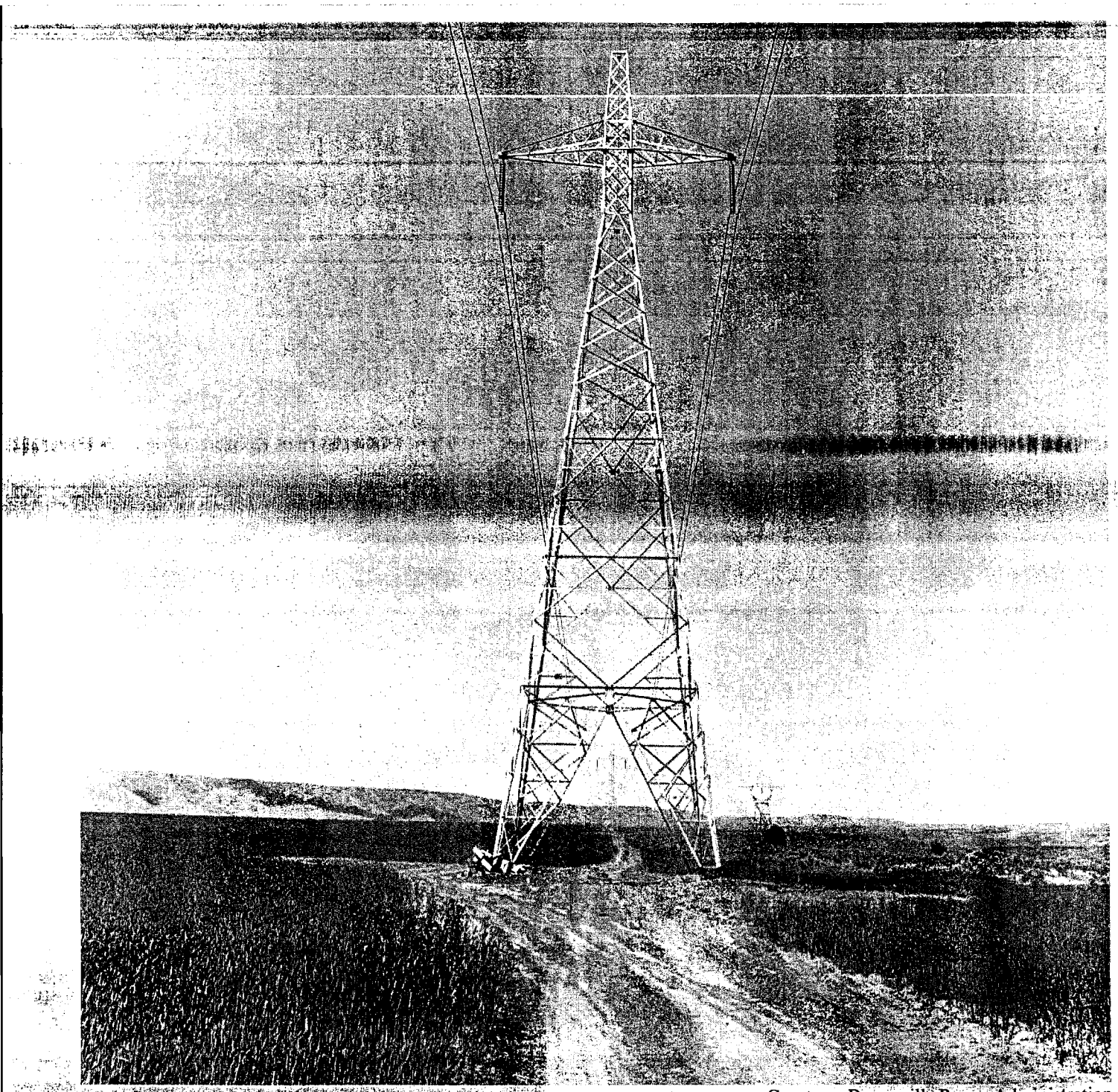
It was expected that the development of a DC circuit breaker would result in much more DC transmission being built, but to date, that has not been the case.

Courtesy: Bonneville Power Administration

SOLID STATE THYRISTOR VALVES

Figure 3

A DC transmission line with its two lines (one positive and one negative just like a battery) is very distinctive when compared to a typical AC transmission line with its three lines (one for each phase). A DC transmission line is shown in Figure 4.



Courtesy: Bonneville Power Administration

DC TRANSMISSION LINE

Figure 4

♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

STEP VOLTAGE REGULATORS

Step voltage regulators are used to maintain voltage between preset minimum and maximum levels. The basic parts of a step voltage regulator are an autotransformer winding and a load tap changer. The autotransformer part (a single-winding transformer) is shown in Figure 1.

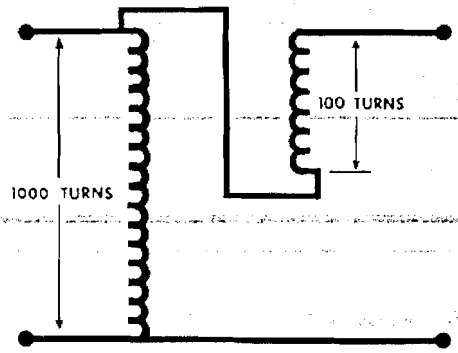


Figure 1

Figure 2 shows the autotransformer winding with an input of 500 volts and an output of 550 volts. The 550 volt output is a result of the 50 volts that are induced on the 100-turn secondary winding being added to the 500 volts on the primary winding. In the autotransformer shown in Figures 2 the 100-turn winding is connected in an additive direction because the 50 volts adds to the 500 volts to obtain the output of 550 volts.

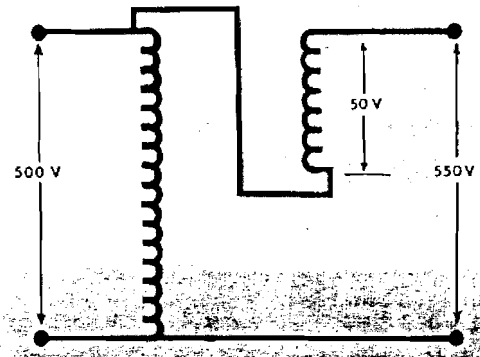


Figure 2

If, however, the 100-turn winding is connected in a subtractive direction (Figure 3), the input voltage would still be 500 volts but the output voltage would be 450 volts. This is because the 50 volts now subtracts from (rather than adds to) the 500-volt portion of the winding.

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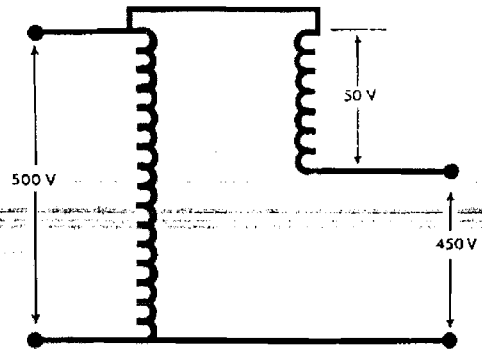

Figure 3

In a step voltage regulator, the winding that is energized by an external voltage source is called the exciting or excitation winding; the fewer turns winding in which a voltage is induced is called the regulator winding.

The voltage-regulating feature of a step voltage regulator is obtained by changing the number of turns in the regulator winding. This is done with a load tap changer.

In order to allow both additive and subtractive connections, two items are required. One is a connection from the excitation winding to a point in the load tap changer. This conductor is connected at point "A" in the excitation winding and ends in the load tap changer at point "B." The output voltage will be 500 volts with the tap-changer contacts on the "B" terminal. (The "B" terminal is identified as the Neutral position in an actual regulator.)

The second of the required items is a reversing switch that allows connecting the excitation winding to either end of the regulator winding.

The option of connecting to either end of the regulator winding provides the additive and subtractive options. In order to move the reversing switch, the tap-changer contacts must be on the "B" terminal; if not the circuit will be broken while the reversing switch is making a change in position.

In Figure 4, the reversing switch is in the additive (Raise) position and the output voltage range is 500 volts to 550 volts.

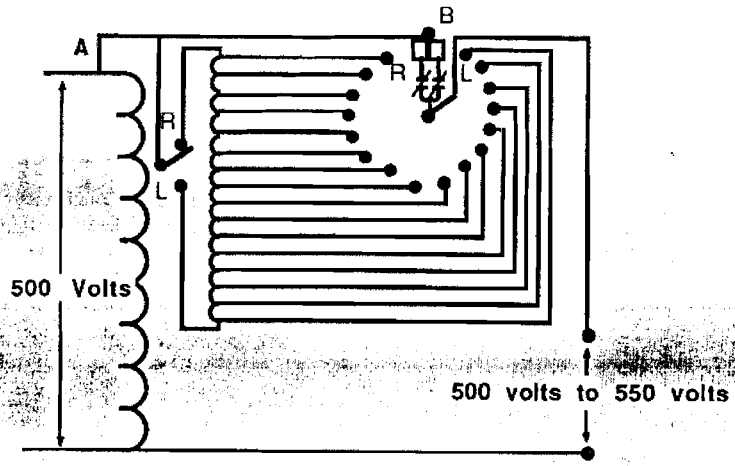

Figure 4

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In Figure 5, the reversing switch is in the subtractive (lower) position. The output voltage range is 450 volts to 500 volts.

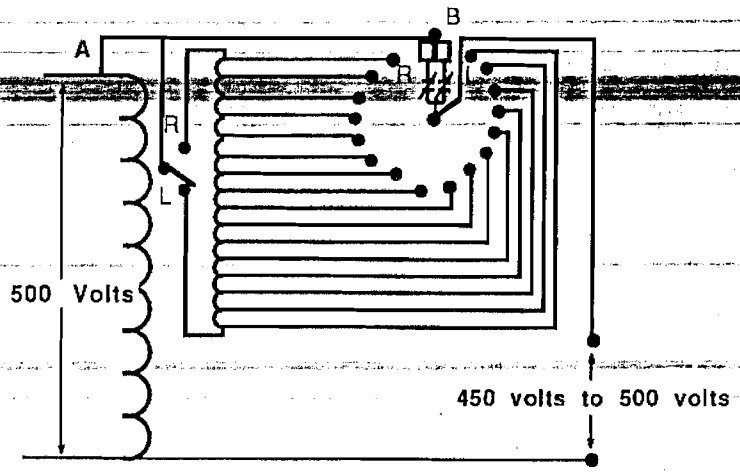
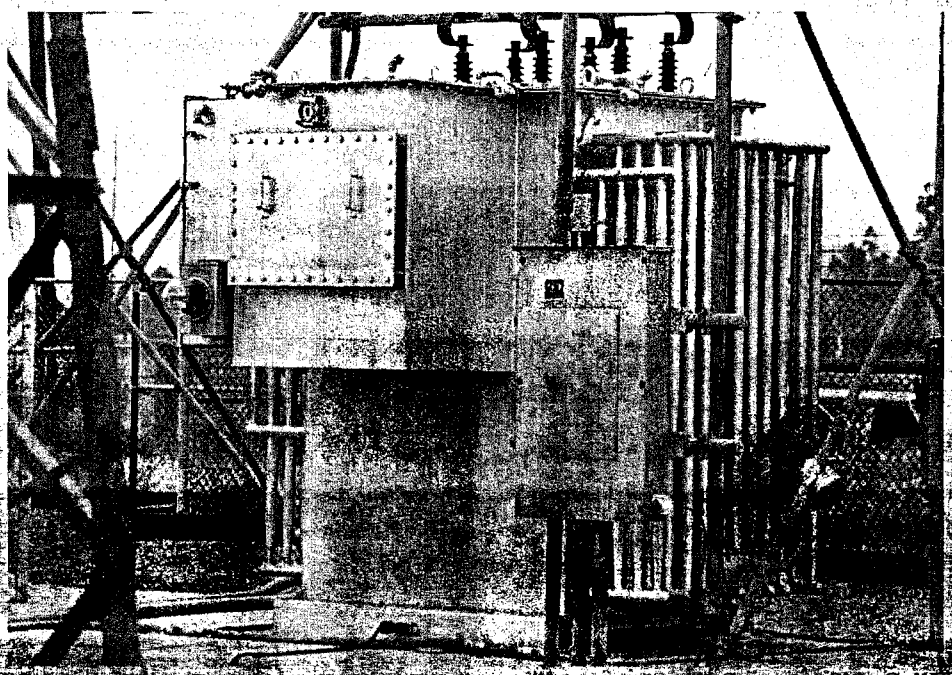


Figure 5

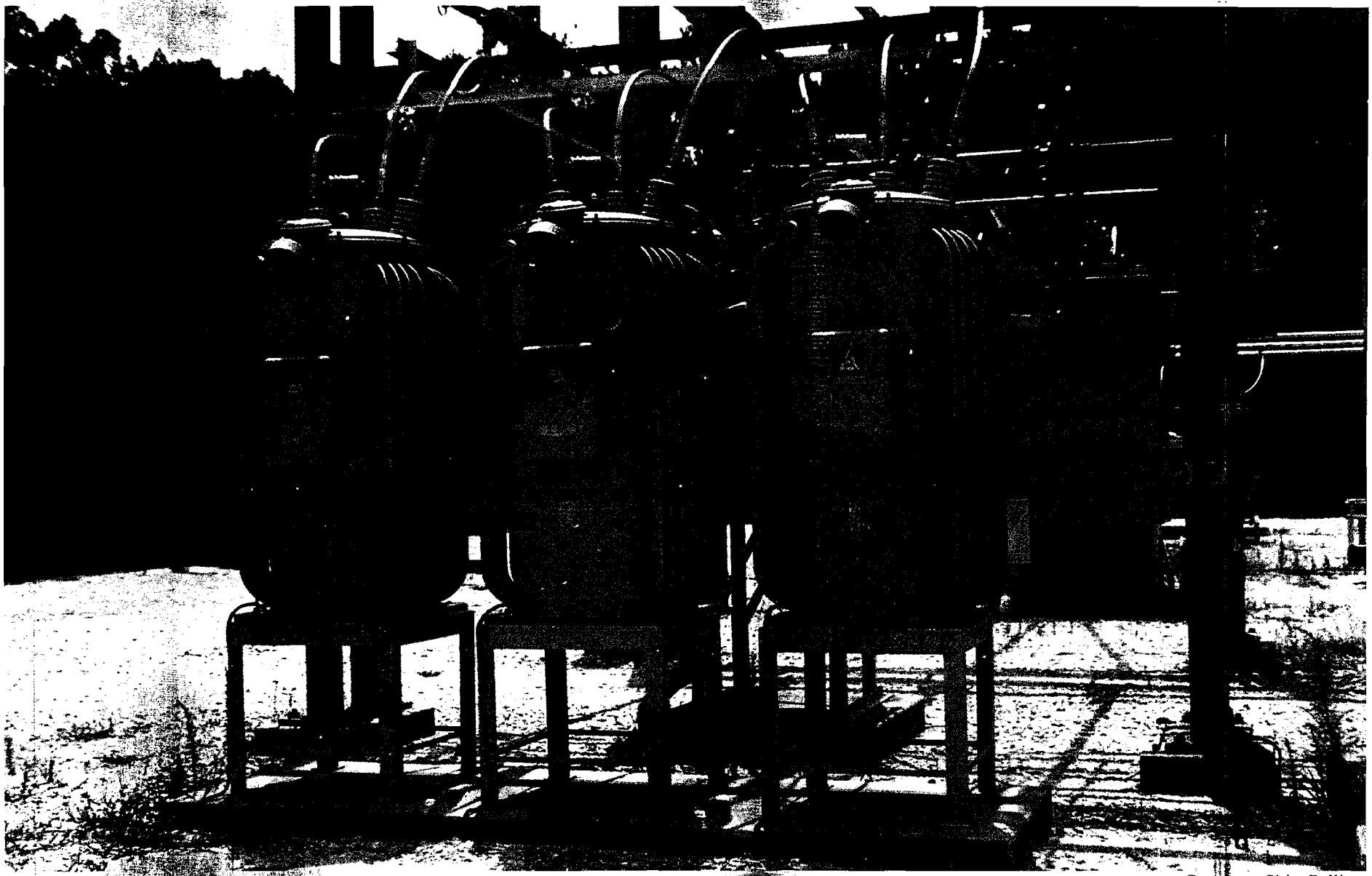
Figure 6 shows a 3-phase voltage regulator at the Vacaville Substation near Sacramento California. [illegible] tors in a substation. Figures 8 and 9 show three single-phase voltage regulators in a distribution line.



Courtesy Skip Collier

Step Voltage Regulator

Figure 6



Courtesy: Skip Collier

SINGLE PHASE VOLTAGE REGULATORS

Figure 7

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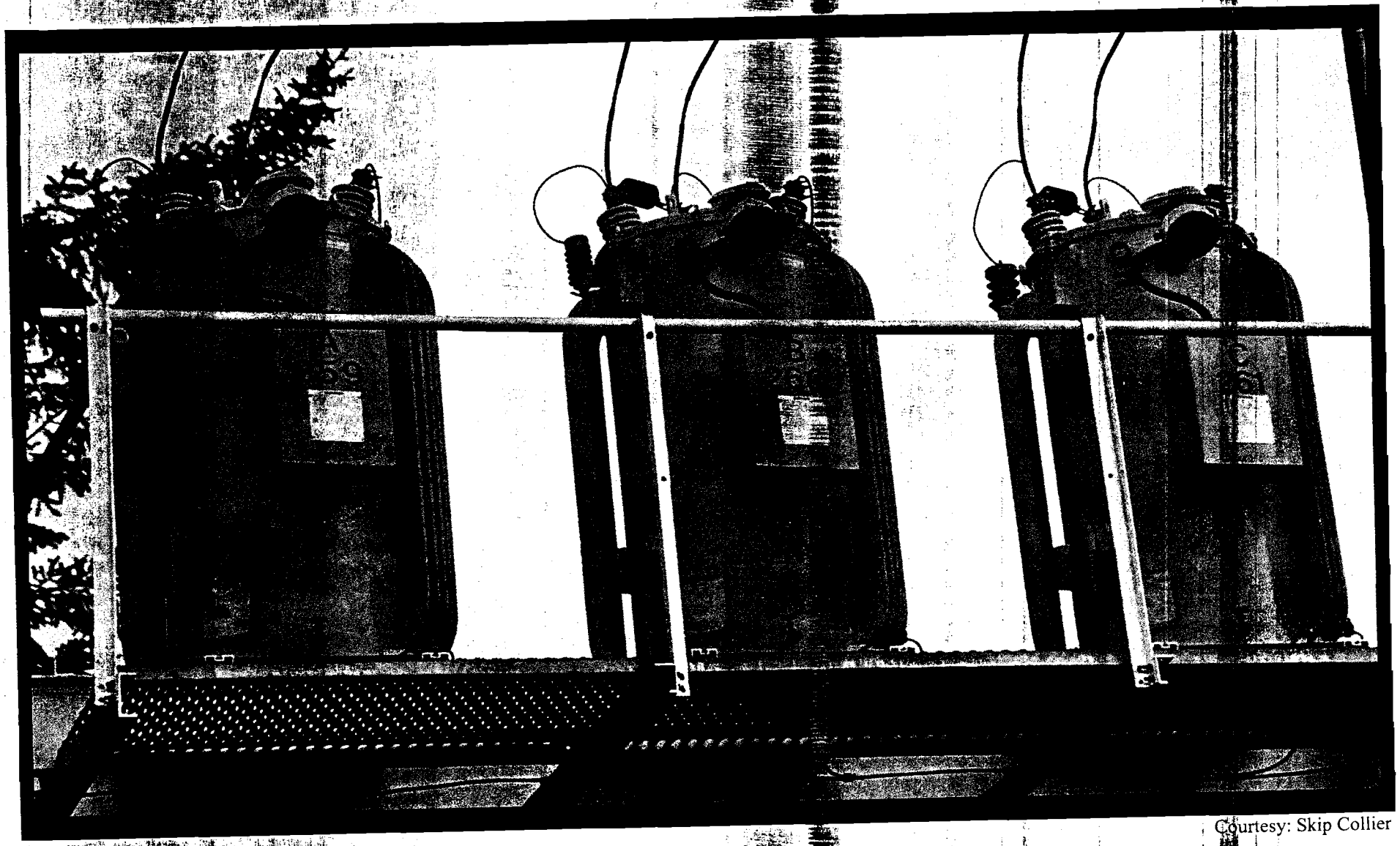
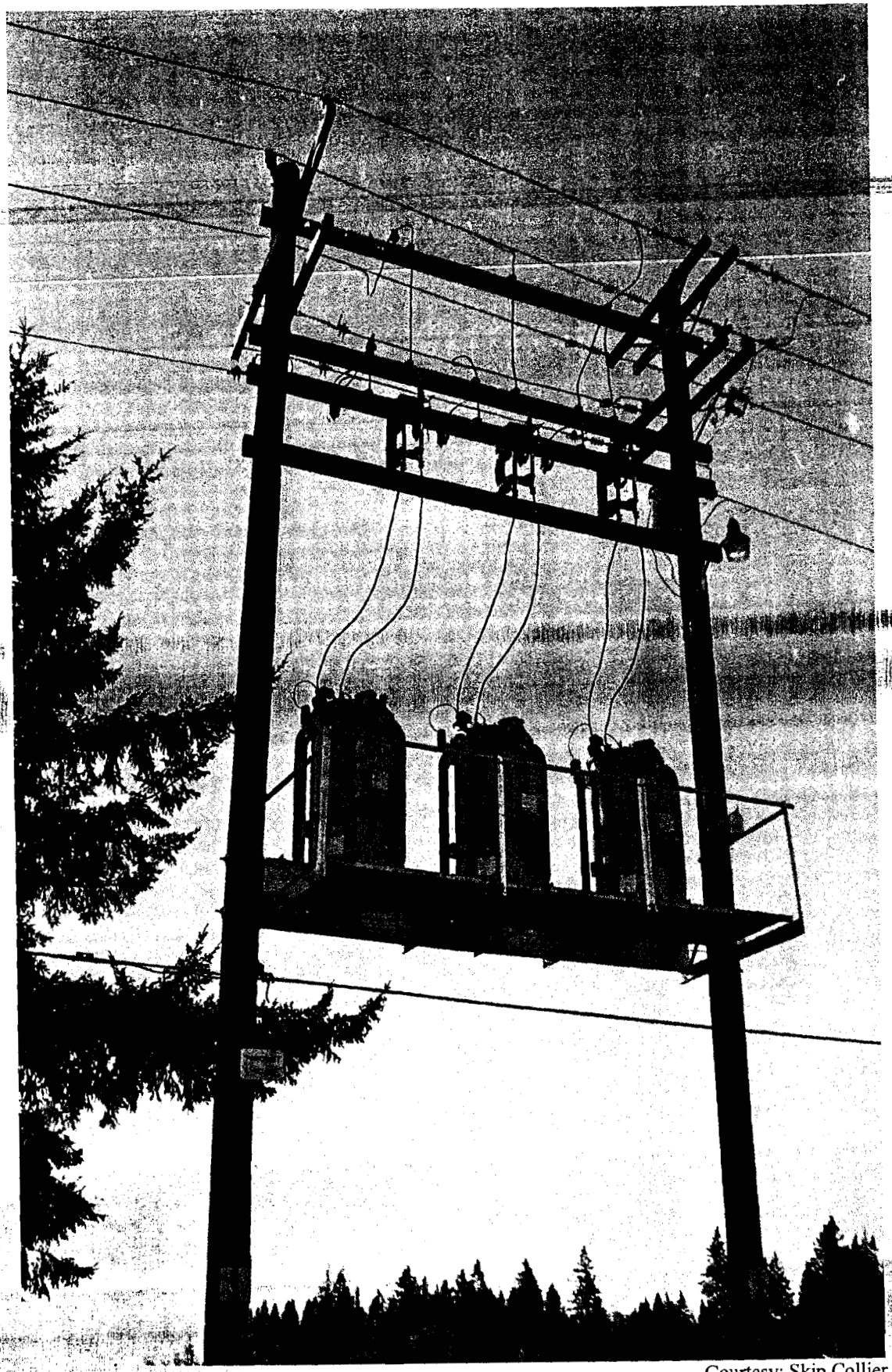


Courtesy: Skip Collier

SINGLE-PHASE VOLTAGE REGULATORS

Figure 8



Courtesy: Skip Collier

SINGLE PHASE VOLTAGE REGULATORS

Figure 9

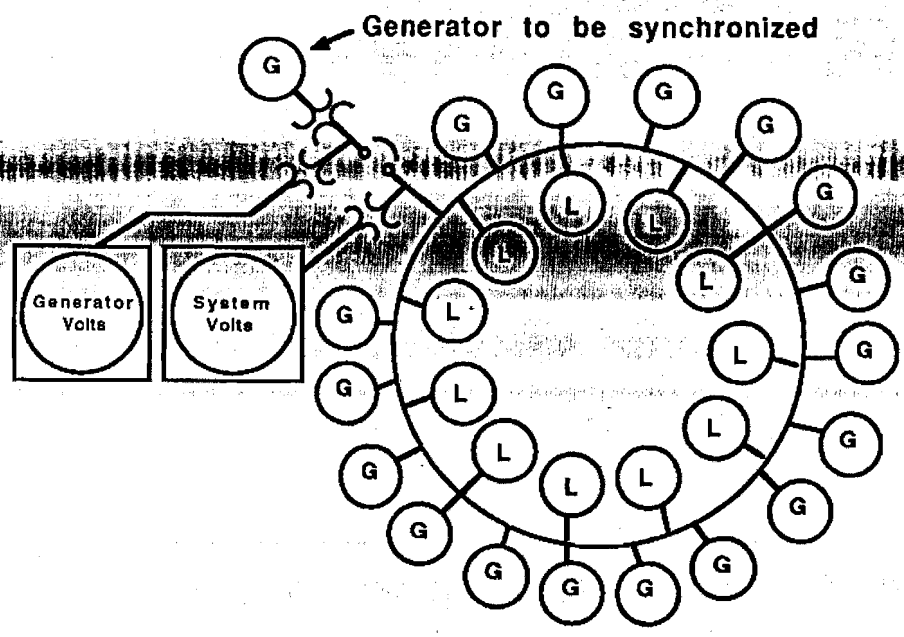
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦

SYNCHRONIZING

Synchronizing is the procedure of connecting a generator to an operating electrical system. (Synchronizing a generator is also called paralleling the generator, going on-line and coming on-line.) The act of synchronizing is extremely simple, consisting only of closing a circuit breaker that connects the generator to the operating system. Figure 1 shows a utility system with a generator that is to be synchronized. The prerequisites for synchronizing are extremely critical. These prerequisites are

1. The phase sequence of the generator must be the same as the other generators in the system
2. The frequencies must be the same
3. The voltages at the point of connection must be the same
4. The voltages must be in phase

Correct Phase Sequence In order for the phase sequence to be the same, the generator to be synchronized must be running in the same direction electrically as the operating generators. Figure 2 shows an example in which the phase sequence of two generators is different.



UTILITY GENERATION SYSTEM

Figure 1

This results in the situation in which if any two phases are in-phase, the others are not. This results in potentially destructive forces appearing between the generator and the operating system at the moment of synchronizing.

Since turbine-generators are designed to rotate in a single direction, the prerequisite of correct phase rotation is a concern only during a start-up, after work in which the generator's 3-phase output conductors are disconnected, or after work in which the metering is disconnected. When the phase rotation is found to be incorrect, any two of the phases from the generator to be synchronized can be interchanged to provide the correct phase rotation.

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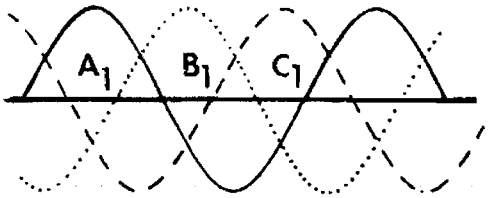
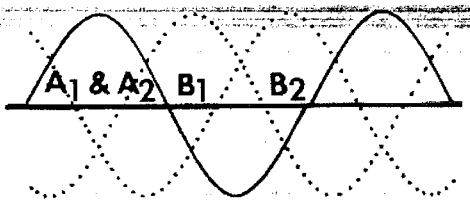
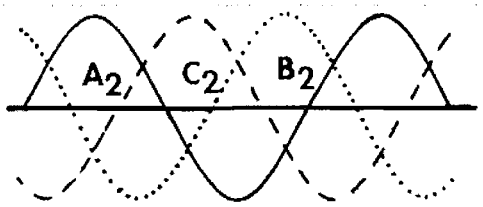


GENERATOR PHASE ROTATION A-B-C



RELATIONSHIP OF "B" PHASES WHEN "A" PHASES ARE IN PHASE



GENERATOR PHASE ROTATION A-C-B

Figure 2

Correct Frequency In order to synchronize a generator, the generator must have the same frequency as the operating system. Virtually all electrical power produced in the United States and Canada is 60 Hertz. Any generator that is connected to these 60 Hertz systems must then also be producing 60 Hertz.

Frequency is determined by the number of field poles in the generator, and the generator's speed. Since the number of field poles is fixed, the generator's speed must be changed to adjust frequency. The speed of a generator is controlled by the mechanical power being applied to turn the generator field. To change the generator's speed, the operator either increases or decreases this mechanical power. In hydroelectric generators, the amount of water flow is adjusted. In steam units, the amount of steam is adjusted. In gas turbine units and in diesel units, the amount of fuel is adjusted. Once the correct frequency is obtained, automatic speed regulators maintain the proper speed.

Equal Voltages In order for the two electrical systems to be tied together, the voltages must be the same at the point of connection. In Figure 1, if the system voltmeter is reading 500 kv, then the generator voltage would be adjusted so that the voltage on the system side of the step-up transformer would also read 500 kv. (The actual generator voltage might be 20,500 volts, but on the system side of the step-up transformer, the voltage would be 500 kv.)

The generator voltage would be adjusted by increasing or decreasing the excitation current; increasing the excitation current raises the generator voltage, and decreasing the excitation current lowers the generator voltage. The generator operator would watch the generator voltmeter (usually placed next to the system voltmeter on the control panel such as illustrated in Figure 1), and would then adjust the generator voltage to match the system voltage.

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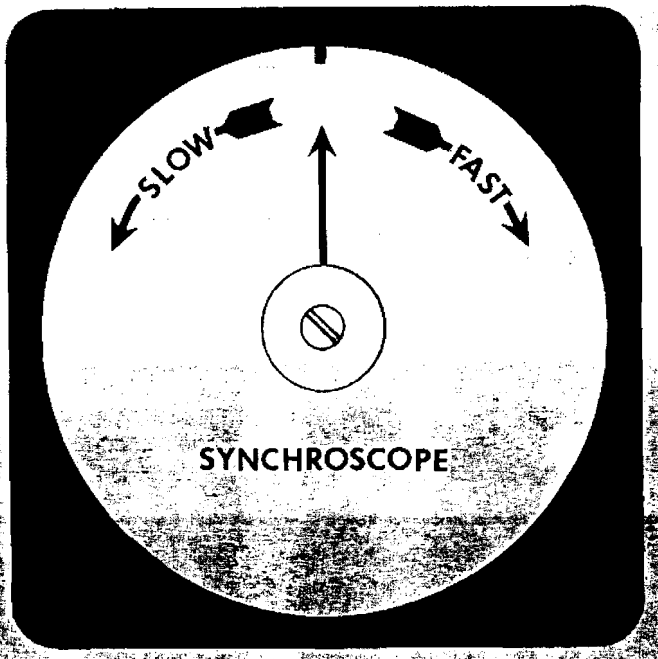
Correct Voltage Phasing The fourth prerequisite for synchronizing involves comparing a particular phase (A, B or C) of the operating system with the same phase (A, B or C) of the generator to be synchronized. (The comparison of only one phase is required because if the phase rotations of the systems are the same, the other phases will be in-phase when the selected phases are in-phase.)

The phase matching is normally accomplished using a synchroscope such as illustrated in Figure 3. The indicator (the arrow) rotates in a clockwise direction when the generator speed is greater than the operating system's speed. The indicator rotates in a counterclockwise direction when the generator speed is less than the operating system's speed. When the indicator is at the 12:00 position, the generator is exactly in-phase with the operating system. When the indicator is in the 6:00 position, the respective systems are 180 degrees out of phase, the worst condition for synchronizing.

Normal procedure is to synchronize with the generator running slightly faster than the system, which means the indicator will be turning in the clockwise direction. When the indicator is approximately at 11:30, the operator turns a switch that closes the generator's breaker. With the mechanical lag time in the breaker's closing mechanism, when the breaker's contacts actually close, the indicator is on 12:00.



SYNCHROSCOPE

Figure 3

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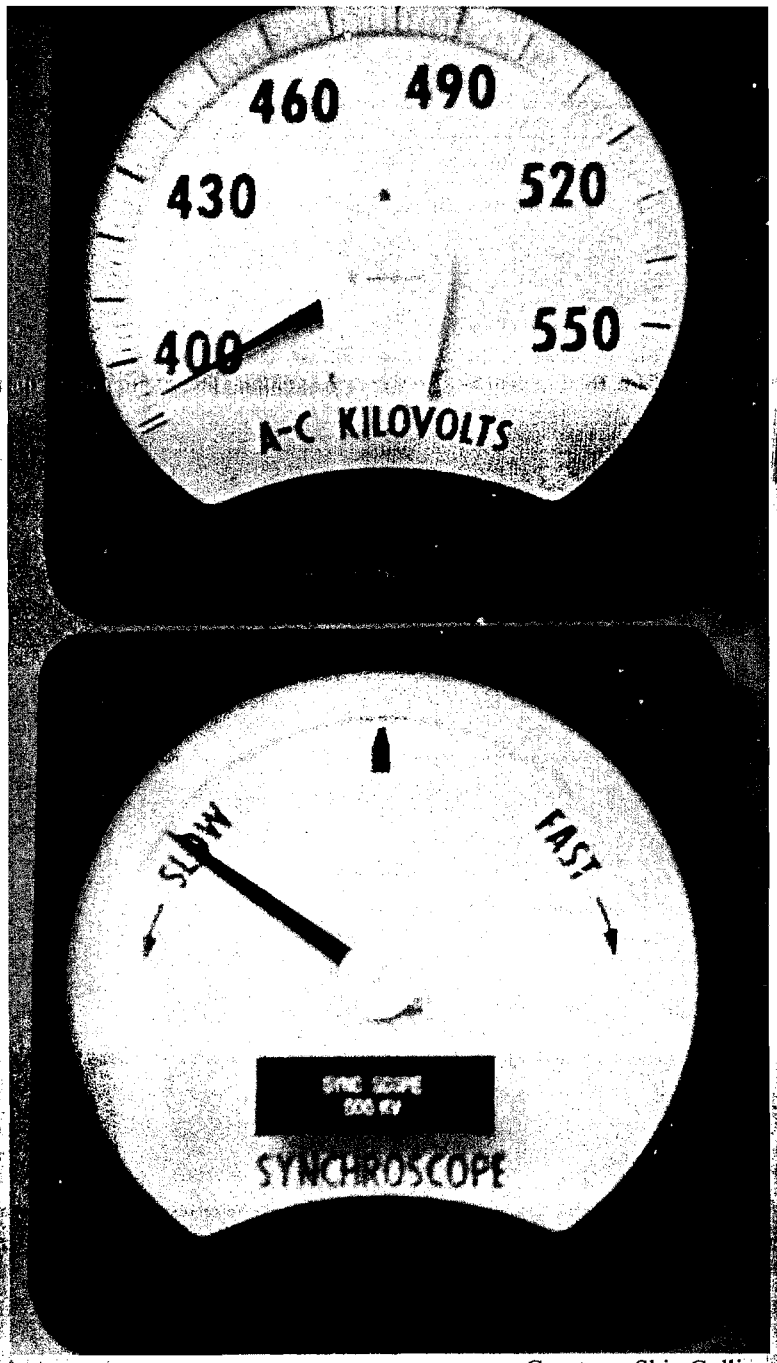
SYNCHROSCOPE

Figure 4 is a photograph of a synchroscope and voltmeter. The voltmeter shown gets its signal from one side of the open synchronizing circuit breaker. An identical voltmeter, not shown, would get its signal from the other side of the open circuit breaker. The operator would first match the voltages using the two voltmeters, and then would close the circuit breaker when the synchroscope is at 12:00.



Courtesy: Skip Collier

SYNCHROSCOPE AND VOLTMETER

Figure 4

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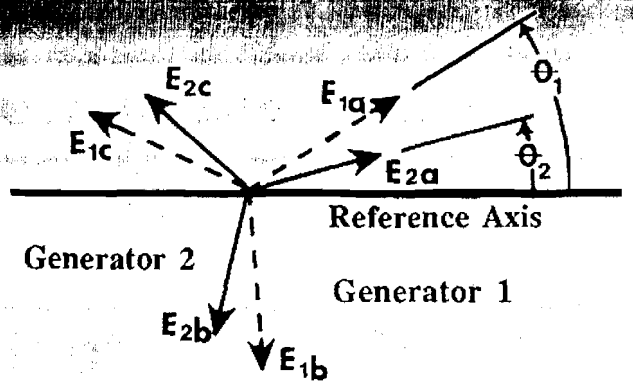
ELECTRICAL SYSTEM STABILITY

A utility electrical system is a balance between the total load and the total generation. There is another balance in the system. This consists of the balance between the generators operating in the system. The stability of a system refers to the ability of the generators within the system to maintain these balances, thereby allowing them to "ride through" system disturbances without losing synchronism with the system.

Just as power is transferred from a generator to a motor, power can also be transferred from one generator to another. The total amount of power that can be transmitted between generators without losing synchronous is called the "power limit" or the "stability limit."

The power transmitted within a system can be illustrated with the aid of phasor diagrams. In Figure 1, the phasor representations of two generators are shown by E_1 for one generator, and E_2 for the other. The a, b and c represent each generator's 3-phase voltage. The length of each generator's phasor is determined by that generator's voltage. The displacement from the reference axis (θ) is determined by the relative positions of each generator's field.



VOLTAGE AND PHASE RELATIONSHIPS BETWEEN GENERATORS 1 AND 2

Figure 1

Figure 2 shows the two generators when connected in a system. Impedance Z is shown between the two generators. It includes internal generator impedance as well as all external impedance.

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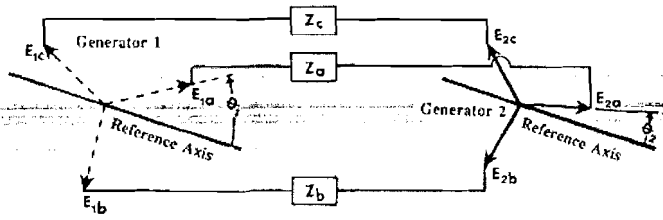

GENERATORS 1 AND 2 CONNECTED THROUGH AN IMPEDANCE "Z"

Figure 2

When the generators' voltages are unequal, reactive power will flow. When the generators' phase angles are unequal, in-phase or work producing power will flow. The power transferred between two machines can be calculated using the equation below.

$$(1)\quad \text{Power} = \frac{E_1 \times E_2}{Z} \text{SIN}\, \theta_{12}$$

Where: E_1 and E_2 are the generator voltages
Z is the total Impedance between generators
θ_{12} is the phase angle between machines

Once a system disturbance occurs, various sub-systems operate to maintain stability. One of these sub-systems is the automatic voltage regulator found on each generator. These voltage regulators are an integral part of the excitation systems of generators, and are designed to constantly monitor and adjust for variations in generator voltage.

Another sub-system is a circuit incorporated into each generator's excitation system to provide proper sharing of reactive power among the generators in a system. This circuit is called a droop circuit, or compensation circuit, and is adjusted at the time of the initial start-up; it has no external controls or adjustments for the generator operator.

Automatic relaying to remove any generator falling out of synchronism provides another means of preserving system stability. The automatic voltage regulator and the droop circuits are constantly adjusting generators to maintain system stability when minor disturbances occur. The automatic relaying removes a generator that has fallen out of synchronism when more serious disturbances occur.

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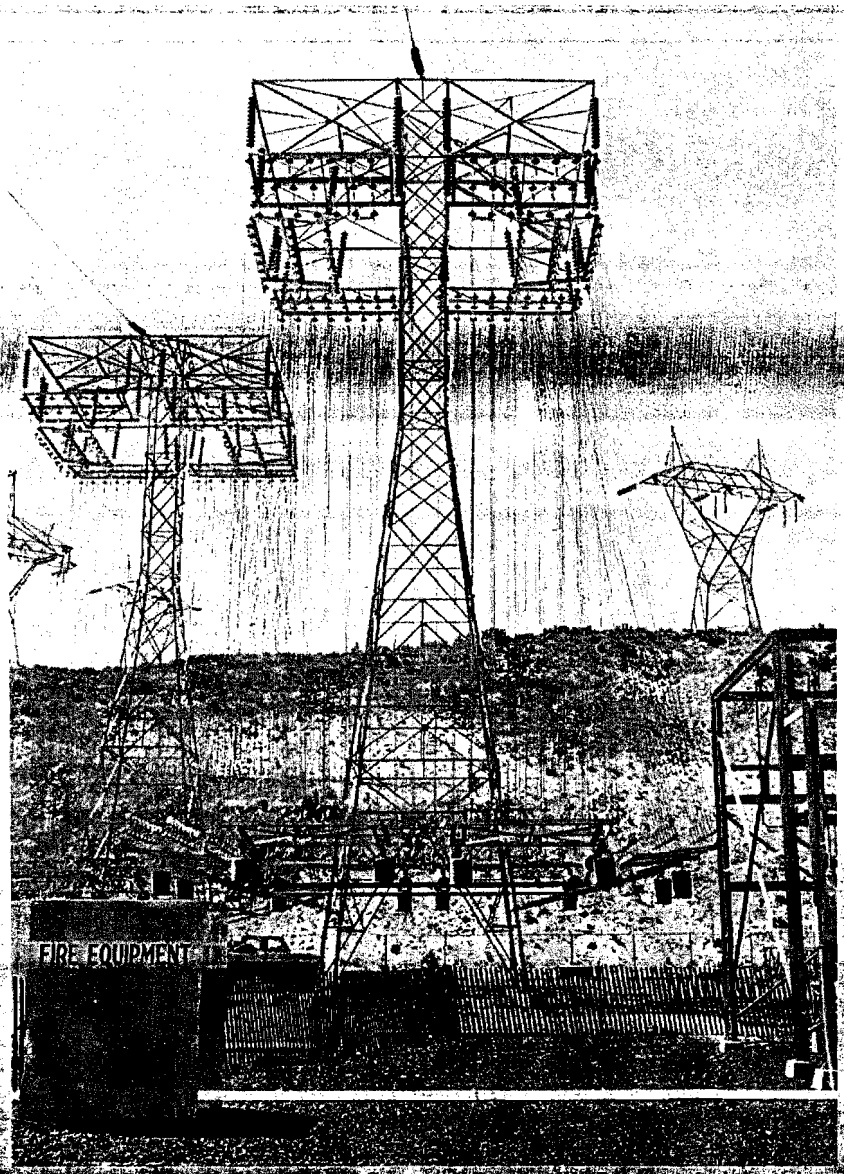
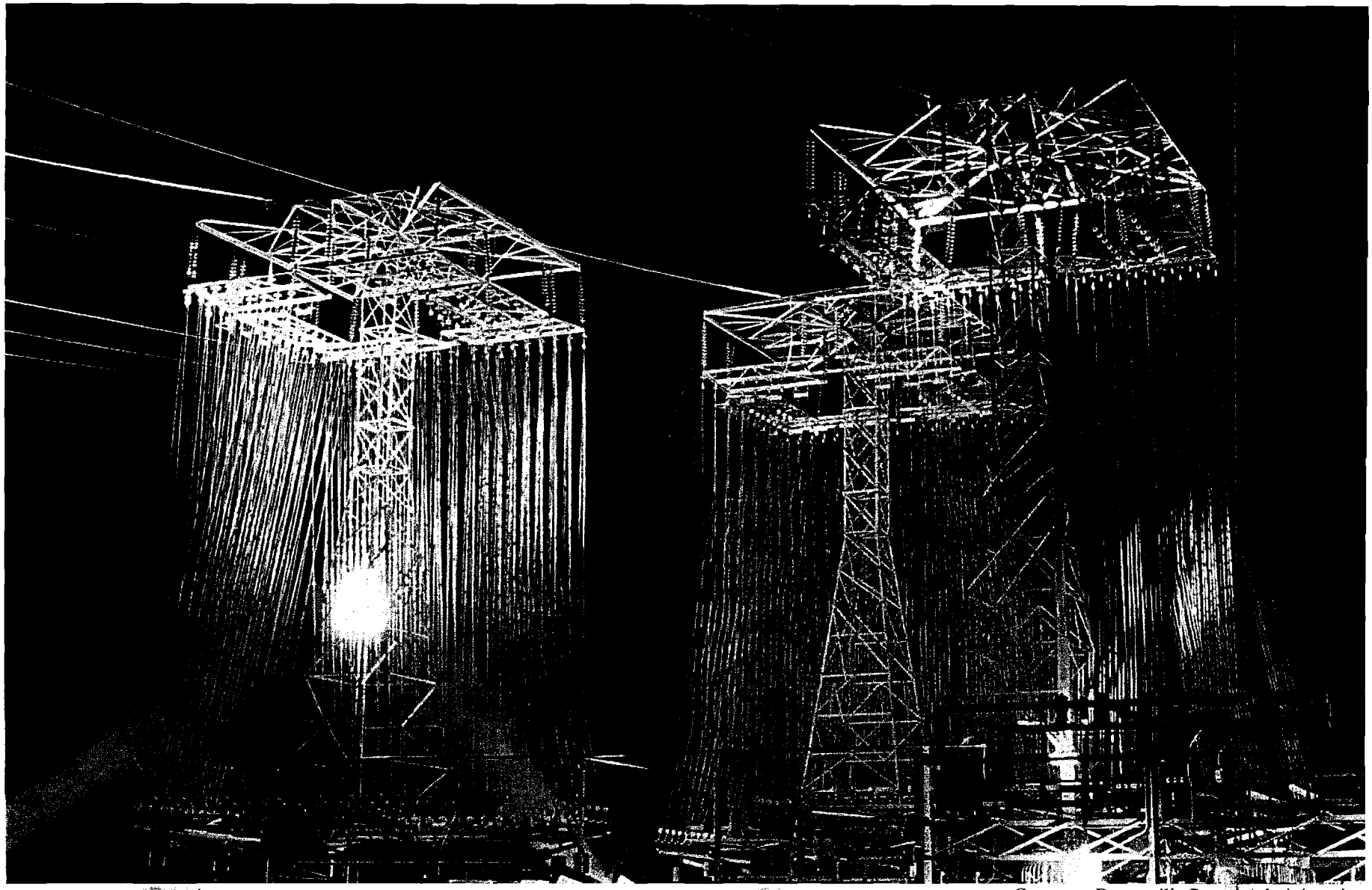
System disturbances on large power grids may require more elaborate methods of maintaining stability. One such method is the dynamic breaking resistor used in the Bonneville Power Administration system in the Pacific Northwest. This resistance brake (Figures 3 & 4) consists of one tower per phase, each supporting three miles of one-half-inch diameter stainless steel wire. The three breaking resistors are switched into the system as a unit for about one-half second when a disturbance occurs. During this one-half second, the resistance brake absorbs excess electrical energy which helps to maintain system stability.



Courtesy Bonneville Power Administration

DYNAMIC BRAKING RESISTOR (DAY)

Figure 3



Courtesy: Bonneville Power Administration

DYNAMIC BRAKING RESISTOR (NIGHT)

Figure 4

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GENERATOR LOADING

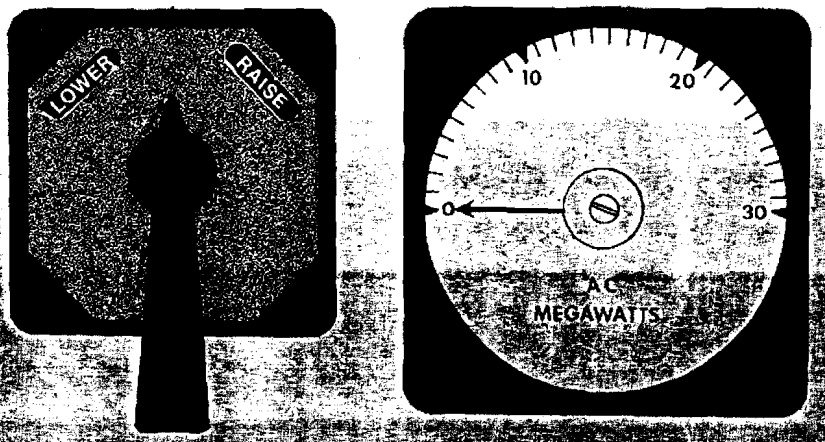
Once a generator is synchronized to a system, it is ready to pick up a portion of the system load. This is called loading that generator. Load (power) is picked up by increasing the mechanical power that spins the generator's field (magnet). Before synchronization, increasing the mechanical power increases the speed of the generator field. After synchronization, the generator's field is locked in with all of the other generators' fields, and the speed cannot be changed. When the mechanical power is then increased, the generator increases its power output rather than increasing in speed.

In a steam turbine-generator, a steam valve is opened to allow more steam into the turbine in order to increase the output megawatts. In a hydroelectric unit, the amount of water flowing through the turbine is increased. In a gas turbine-generator (also called combustion turbine), the amount of fuel is increased. In each of these cases, the power output curve follows the mechanical power curve. (More steam, more water or more fuel results in more power; and conversely, less steam, less water or less fuel results in less power.)

In all cases, the mechanical power is controlled by a switch called a governor switch (which control the amount of steam, water or fuel).

In Figure 1, a governor switch is shown next to a wattmeter. When the operator turns the switch to the raise position, the mechanical power to the turbine increases. The indicator on the wattmeter continues to increase as long as the switch is in the raise position, until the generators reaches its maximum output. Moving the switch to the lower position decreases the output. By moving the switch to the raise position when loads increase, and to the lower position when loads decrease, the generator output follows the load.

Governor Control **Generator Power Output**



GOVERNOR SWITCH AND WATTMETER FOR CONTROLLING A GENERATOR'S POWER OUTPUT

Figure 1

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LOAD SHEDDING

Loads can be decreased when an electrical system becomes overloaded (when the load exceeds the generation). Load shedding is a systematic procedure for decreasing or disconnecting selected loads. The purpose of load shedding is to match load to generation. Load shedding can be either manually performed, or done automatically by relays. Manual load shedding is normally done when there is a relatively long time before the total generation will be exceeded by the total load. One example of this would be a generating plant experiencing a problem that would prevent it from producing full output when it was needed an hour later. Another example would be a load that was higher than the forecast, with the daily peak load yet to occur, and the utility not being able to produce or purchase the generation to meet the load. With manual load shedding, the system operators operate a switch that opens a circuit breaker, thereby dropping the load on that circuit breaker. A good load shedding plan not only identifies which circuit breakers to open, and in what sequence, it also gives the criteria under which each circuit breaker should be open. The identification of which circuit breakers to open is based on how the particular utility assigns priorities to its customers. Hospitals, for example, are a high priority for all utilities and would be one of the last loads to be disconnected. For some utilities, residential customers are a low priority and are one of the first to be disconnected; while for other utilities, residential customers are a high priority and are one of the last to be disconnected.

The time-a-circuit-breaker-should-be-left-open part of the of the load shedding plan allows outages to be spread among the customers in the same priority class. For example, assume a utility places residential customers in the lowest priority and that the town or city is divided into northeast, southeast, southwest and northwest quadrants. A manual load shedding plan might call for the northeast section to be disconnected for the first 15 minutes every hour, the southeast to be disconnected for the next 15 minutes, then the southwest, and finally the northwest. This is called a rolling blackout.

The ideal procedure for load shedding requires a load shedding plan to be implemented at the time a system is constructed, or at the time one is modified. This is because loads can then be best allocated to the various circuit breakers based on the assigned priorities for disconnecting. This would prevent an industrial customer with an interruptible power contract (provides cheaper power to the customer for the utility's right to disconnect at any time) from being placed on the same circuit breaker as a hospital.

Automatic load shedding also protects against a blackout, but responds much faster than manual load shedding. The situation that automatic load shedding protects against, occurs when large amounts of power-producing generation are suddenly lost. As soon as the generation is lost, the remaining generators start to slow down because they are unable to carry the existing load. As they begin to slow, the system frequency begins to drop below 60 hertz. Underfrequency relays monitor the frequency. At preselected frequencies, the underfrequency

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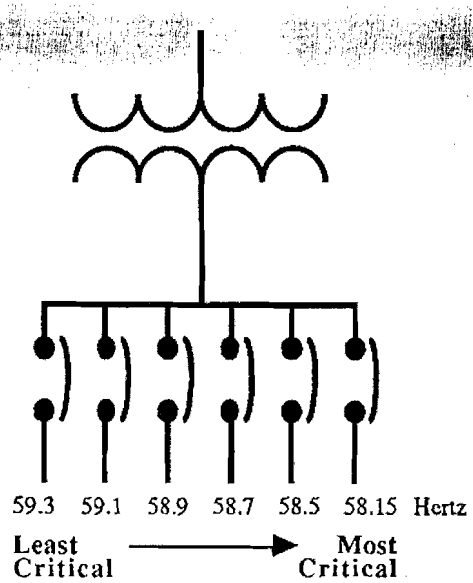
relays open circuit breakers to disconnect the loads. The underfrequency limit varies from utility to utility, with it normally being around 59 hertz. For example, the Los Angeles Department of Water and Power (serves all of Los Angeles) begins load shedding at 59.1 hertz; Sunflower Electric Cooperative, a modern generating and transmission utility in south western Kansas begins load shedding at 58.8 hertz.

Automatic load shedding, just as with manual load shedding, has a systematic plan to disconnect load based on a priority system. Unlike manual load shedding, an automatic load shedding plan normally does not call for switching the outage among the customers. It does, however, have a plan for reconnecting the loads in a specific sequence.

Figure 1 shows a portion of a typical electrical system used for automatic load shedding. When the load exceeds generation to the extent that the generators slow down to the first underfrequency setting of 59.3 hertz, the circuit breaker serving the least critical load opens and disconnects this load. If the frequency stops dropping, the next circuit breaker will not open. If, however, there is still too much load and the frequency drops to the next underfrequency setting of 59.1 hertz, the next circuit breaker opens. This sequence continues until the generation matches the load and the frequency stops dropping, or until all of the loads are disconnected.



LOAD SHEDDING CIRCUIT BREAKERS

Figure 1

A **Brownout** is a method of shedding load without actually disconnecting loads. In a brownout, the utility (or utilities) reduce the system voltage. In the power equation (Power = E^2 / R) it can be seen that the power consumption decreases as the square of the voltage for resistive loads. For example, when 120 volts is reduced to 100 volts (83.3% of 120 volts), the power consumption is 69.4% of the original level. (The square of 83.3% is 69.4%.)

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SYNCHRONOUS CONDENSERS

The synchronous condenser is the largest and most expensive of the power-factor-correcting devices. Because of their initial costs and high maintenance cost, they are used primarily by electric utilities, and not by industrial customers.

A synchronous condenser is essentially a non-work-producing synchronous motor. It can supply both capacitive and inductive reactive power. The reactive power supplied is controlled by controlling the excitation current of the condenser. Lowering the excitation current causes the condenser to act like a shunt reactor; raising the excitation current causes it to act like a capacitor.

Unlike capacitors and reactors that add reactive power in discrete blocks, synchronous condensers gradually add reactive power. The reactive blocks of power added by capacitors results in voltage instantaneously rising or dropping. This can cause major problems for certain customers such as steel mills with induction-heating furnaces. Synchronous condensers do not cause these abrupt voltage changes. Figure 1 shows a synchronous condenser.

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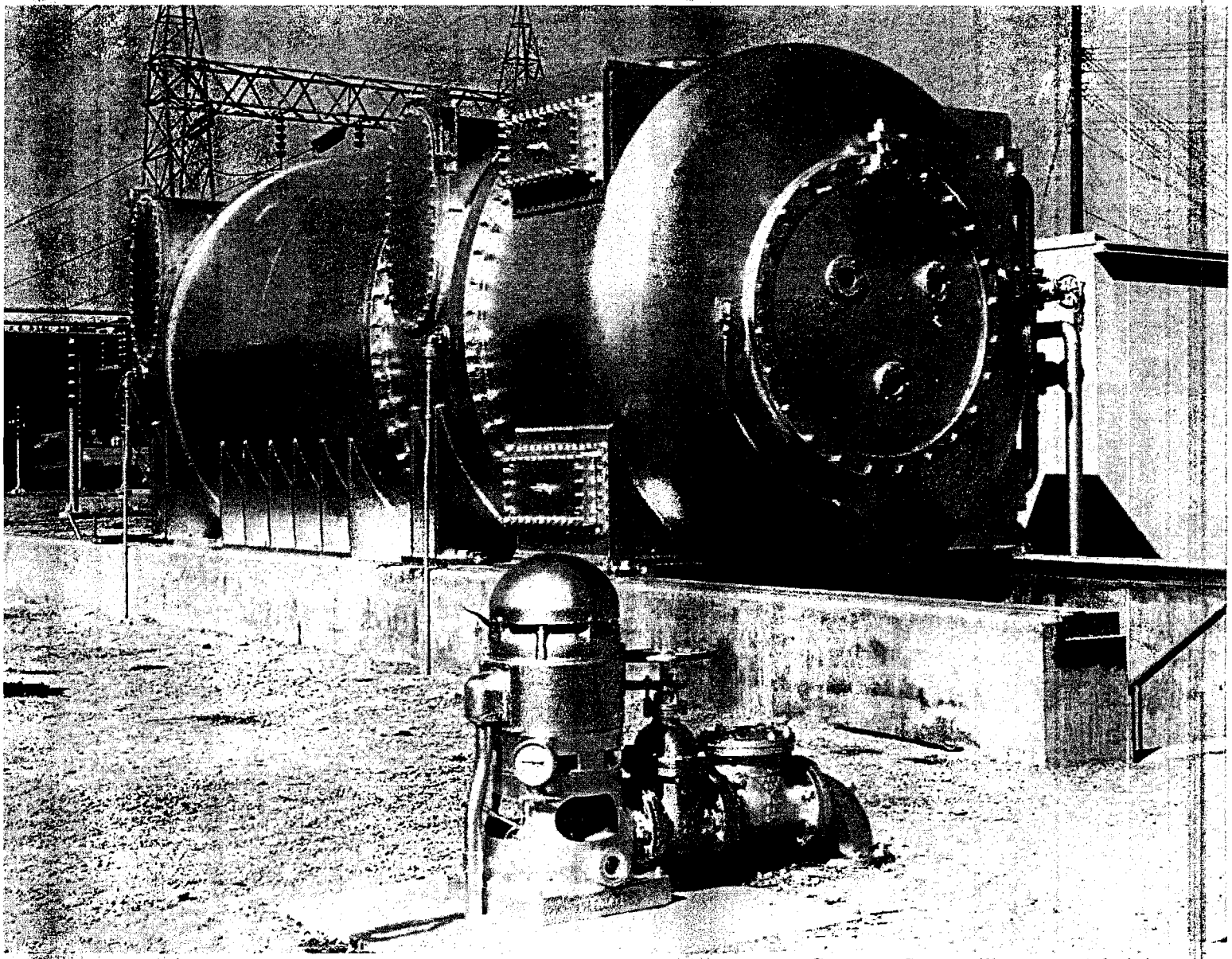

Courtesy: Bonneville Power Administration

SYNCHRONOUS CONDENSER

Figure 1

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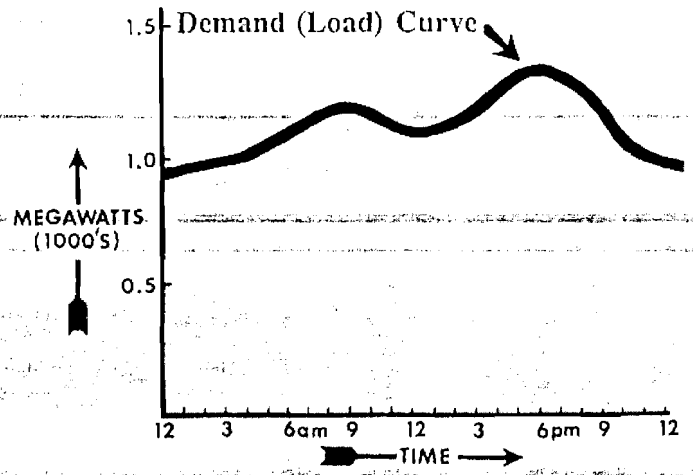
DEMAND CURVES

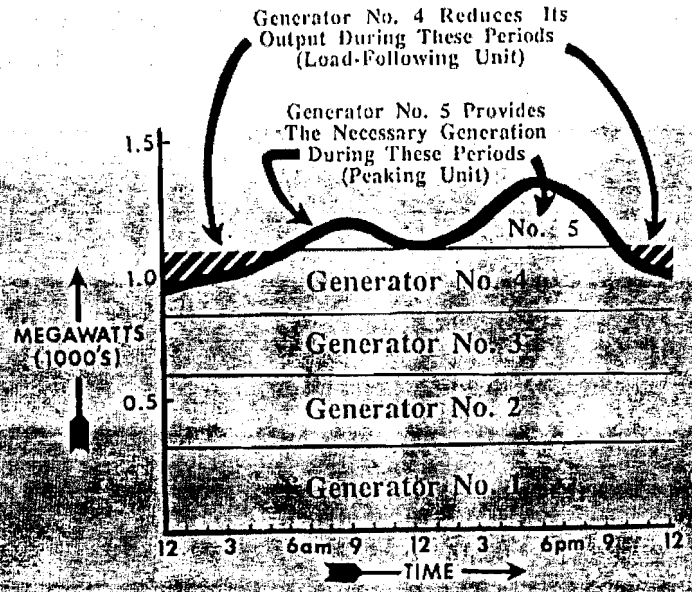
Demand, also called load, is usually measured in watts, kilowatts or megawatts. In order to have adequate generation for the load, utilities use demand curves (also called load curves) to predict load. Demand curves have the demand (load) on the y-axis, and time on the x-axis. A daily demand curve, shown in Figure 1, has the hours of the day on the x-axis and megawatts on the y-axis.



DAILY DEMAND CURVE

Figure 1

A demand curve is used by a utility to forecast generation requirements on an hour-by-hour basis. This allows the utility to plan its generation requirements (Figure 2). In Figure 2, generators 1 through 4 would provide necessary generation from approximately 10:00 p.m. until 6:00 a.m. Between 6:00 a.m. and 10:00 p.m., generator 5 would provide the necessary generation.



DAILY DEMAND CURVE WITH GENERATOR SCHEDULING

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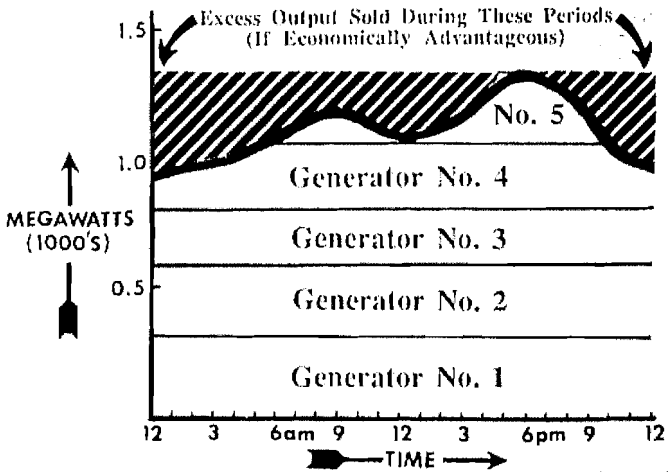
Figure 2

The shape of the demand curve for any day, such as for a Wednesday, varies very little from week to the next. Therefore, the demand curve from the previous Wednesday can used to forecast the demand for the following Wednesday. Any difference in weather between the two Wednesdays will be used to adjust the forecast for the coming Wednesday. Many utilities also use the Wednesday demand curve from a year ago, to help forecast the coming Wednesday's curve; if the year-ago curve and the week-ago curve have the same shape, this reinforces the likelihood that the week-ago curve is a good predictive tool. In additional to using week-ago and year-ago demand curves to forecast daily demand, special events must be factored into the forecast. Special events could include holidays, large customers coming back after a maintenance period, large customers disconnecting from the system for maintenance, and a grand opening for a large shopping mall.

A daily demand curve also allows a utility to plan its daily sales. This is shown in Figure 3. The shaded area shows the generation that is available for sale. Some of the output from generator 4 would be available for sale between 10:00 p.m. and 6:00 a.m. All of the output form generator 5 would be available during these same hours. A portion of generator 5's outputs would also be available between 6:00 a.m. and 10:00 p.m., except for the peak period at 6:00 p.m.



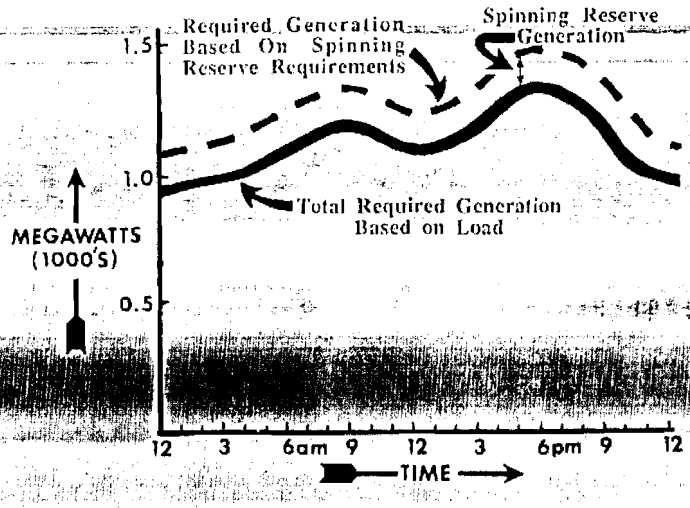
DAILY DEMAND CURVE FOR SCHEDULING GENERATION SALES

Figure 3

The demand curve is used to forecast the demand for power; it is however, only a forecast and utilities maintain standby generation (extra generation) to meet sudden unforeseen increases in load. This standby generation is also used to replace lost generation when

an operating generator suddenly decreases its output. When this extra generation is running and connected to the system, it is called spinning reserve.

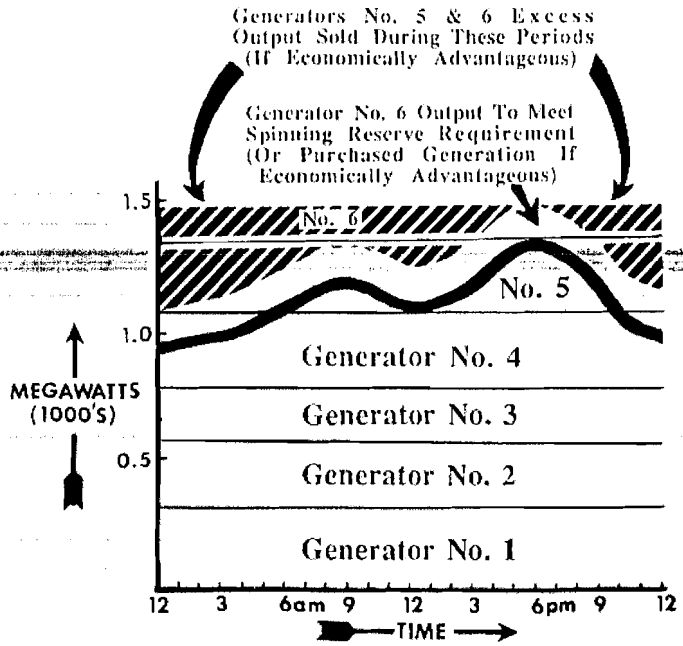
Some of a utility's spinning reserve is usually contractually required in order to help maintain a system's reliability when generators suddenly disconnect. The spinning reserve requirement for reliability is usually in the range of 5% to 7% of a utility's total generation. Any spinning reserve above the contractually required 5% to7% is used to when the actual load is greater than the available generation. A demand curve with spinning reserve is shown in Figure 4.



DAILY DEAMND CURVE WITH SPINNING RESERVE

Figure 4

Figure 5 shows a typical daily demand curve that includes a spinning reserve requirement. Generator 5 provides peaking power and can meet spinning reserve requirement except between approximately 3:00 p.m. and 9:00 p.m. During this time period, generator 6 provides the spinning reserve requirement. During the rest of the time, the output from generator 6 (shaded area) can be sold. Likewise, the shaded portion of generator 5's output can be sold.

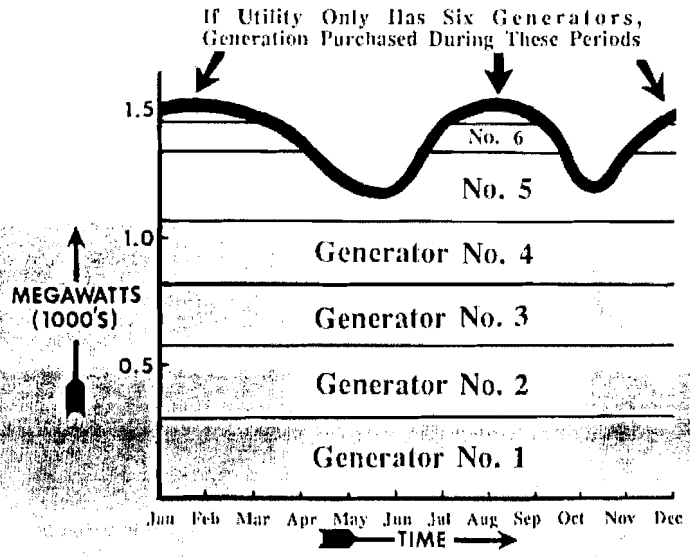


DAILY DEAMND CURVE WITH SPINNING RESERVE FOR GENERATION SCHEDULING

Figure 5

An annual demand curve (Figure 6) is used for long-range planning for the sale and/or purchase of generation. In Figure 6, the utility would have to purchase generation from late November (or early December) until late March (or early April), and then again during July and August.

An annual demand curve is also used to schedule maintenance outages of a utility's generation and transmission systems. During the month of May, for example, generator 6 and any four other generators can provide the necessary output. This would allow maintenance on the remaining generator during this period, without having to purchase additional generation.



ANNUAL DEMAND CURVE

Figure 6

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DEMAND FACTOR (LOAD FACTOR)

Demand factor (also called load factor) is a measure of the ratio between the total energy that would be required if the demand was constant at the peak value, and the actual energy being used. This ratio is calculated by taking the actual energy consumed for a specific period of time, and dividing it by the peak demand multiplied by the length of the time period in hours.

For example, assume that a utility system generated a total of 24,000 megawatt-hours in a 24 hour period, and the peak demand in the same 24-hour period was 2,000 megawatts. The demand factor would be calculated as follows.

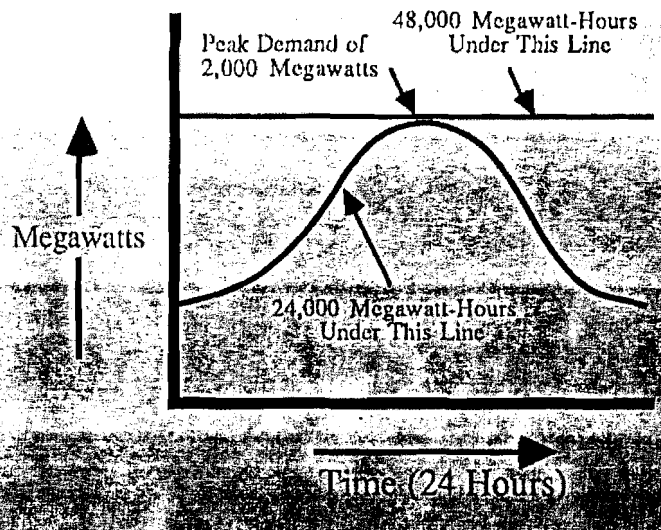
(1) Demand factor $= \dfrac{\textit{Actual Energy Consumed}}{\textit{Peak Demand x Time}}$

(2) $= \dfrac{24{,}000\ MWH}{2{,}000\ MW\ x\ 24\ Hr}$

(3) $= \dfrac{24{,}000\ MWH}{48{,}000\ MWH}$

(4) $= 0.5$ or 50%

Figure 1 shows a graphical representation of the relationships expressed in Equation 1.



DEMAND FACTOR CURVES

Figure 1

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The demand factor can also be calculated by dividing the average demand by the peak demand. This is shown in Equations 5 through 7.

$$\text{(5)} \quad \text{Demand factor} = \frac{\textit{Average Demand}}{\textit{Peak Demand}}$$

$$\text{(6)} \quad = \frac{1{,}000\ MW}{2{,}000\ MW}$$

$$\text{(7)} \quad = 0.5 \text{ or } 50\%$$

Equation 5 is derived from Equation 1 by dividing the numerator and denominator by the time. In the example, the 24,000 megawatt-hours (the actual energy consumed) would be divided by 24 hours resulting in 1,000 average megawatts as shown in Equation 6. (To look at it another way, during the 24-hour period, the average demand was 1,000 megawatts.)

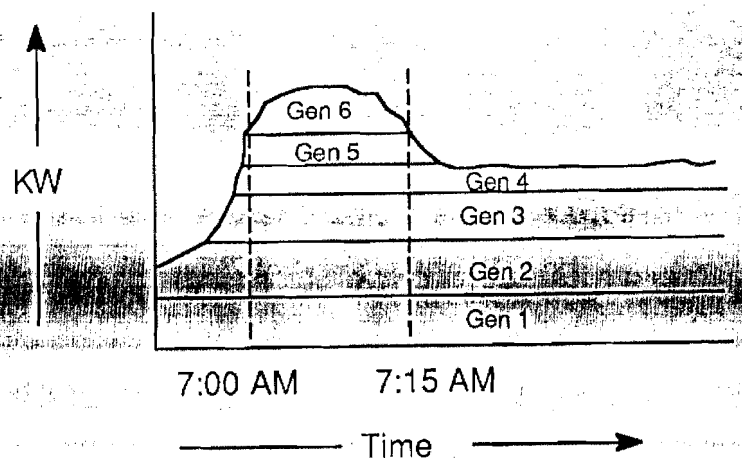
Dividing the denominator in Equation 1 by the time gives the peak demand. The 48,000 megawatt-hours divided by 24 hours gives 2,000 megawatts which was the peak demand. This is also shown in Equation 6.

The ideal demand factor is one. This occurs when the energy consumption is constant with no peaks and valleys on the demand curve. As the demand factor moves towards zero, it becomes worse because it means the peaks and valleys on the demand curve are more pronounced. This results in a utility having to build generation plants whose output the utility may be able to use only part of the time (unless the excess generation can be sold), or the utility has to buy energy on the spot market to meet the generation needs during the peaks. Either of these alternatives can be very expensive.

DEMAND CHARGES

Users of electrical energy can have demand charges that can rapidly increase or decrease. This can result in the supplying utility having to rapidly increase or decrease its generation in response to these changes, or having to buy short-term energy on the spot market. Both of these alternatives are very expensive.

Figure 1 shows a period of time in for an early-morning increase in energy usage. At its peak, between 7:00 a.m. and 7:25 p.m., it takes six generators to meet customer demand. Generator 6 runs for only 15 minutes and then shuts down. If generator 6 is a gas turbine, it burns a lot of costly fuel, and it also increases generator maintenance costs.



DEMAND CURVE WITH ALLOCATED GENERATORS

Figure 1

Demand charges can be used to encourage customers to stop the practice of using large amounts of energy in a short period of time. Demand charges are based on the highest 15-minute, or highest 30-minute, average energy consumption in a billing period. The customer then pays a demand charge, such as $10 per kilowatt, on the highest 15-minute or 3-minute average in the billing period.

Figure 2 shows an early morning demand curve. The average consumption is 1,000 kW. A customer subject to a $10 per kilowatt charge would then be charged a demand charge of $10,000; this charge would be in additional to the energy charge and power factor charge.

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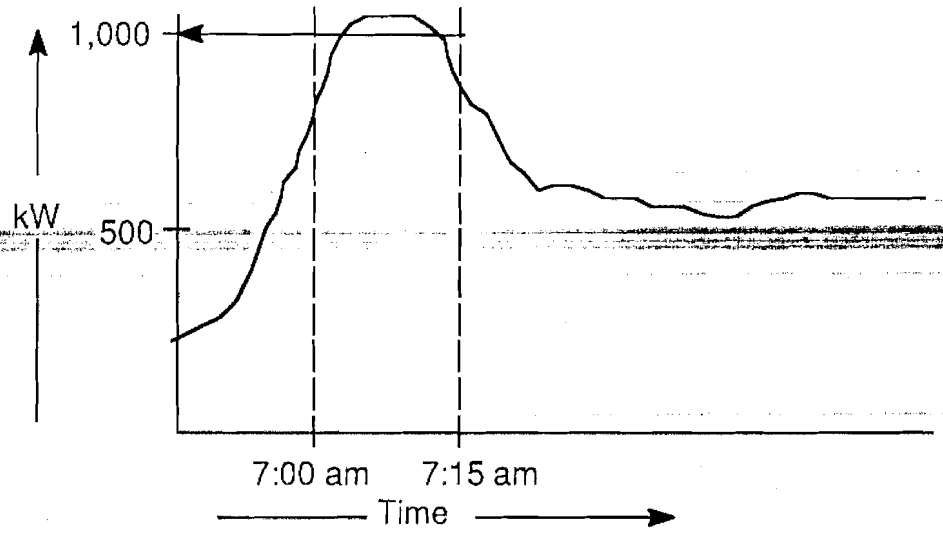


DEMAND CURVE
WITH 15-MINUTE DEMAND

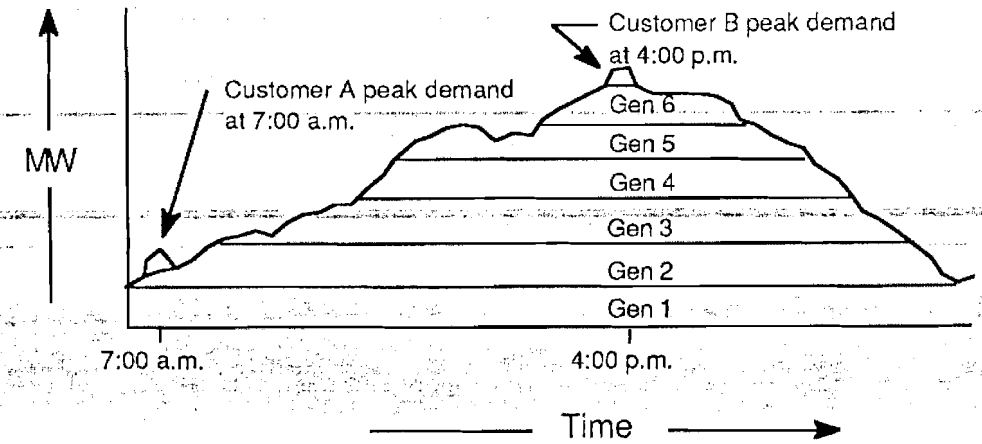
Figure 2

Many utilities will ratchet the demand charge over a 12-month period. This would mean, using the same example, that the demand charge for each of 12 consecutive months could not go lower than $10,000, or a minimum of $120,000 for the 12-month period. For example, a customer having a January demand charge of $10,000 based on a peak demand occurring on January 3, after a Christmas shutdown, would pay $10,000 each month through and including December. This would result in a total of $120,000 in demand charges for the 12-month period. Demand charges during the 12-month ratchet period cannot go lower, but they can go higher.

If on March 20 the customer demand charges are $20,000, a new 12-month ratchet begins; for the 12 months beginning with March and ending with February, the customer would pay $20,000 each month for a total of $24,000 during the 12-month period.

Many utilities also have coincident and non-coincident demand charges. Coincident and non-coincident refer to how a customer's demand curve compares to the supplying utility's demand curve. Coincident means that the customer's demand peaks at the same time as the supplying utility reaches its peak demand. Non-coincident demand means that the customer's peak demand occurs when the supplying utility's system is operating in an off-peak mode.

Figure 3 shows a supplying utility's demand curve with both coincident and non-coincident demand curves shown. At 7:00 a.m. there is a significant amount of generation available and so the customer's demand at 7:00 a.m. is non-coincident. At 4:00 p.m. extra generation is scarce (and therefore more costly to provide) and so the customer demand at 4:00 a.m. is a coincident demand.



SYSTEM DEMAND CURVE WITH COINCIDENT AND NON-COINCIDENT CUSTOMER DEMAND PEAKS

Figure 3

Controlling Demand Charges

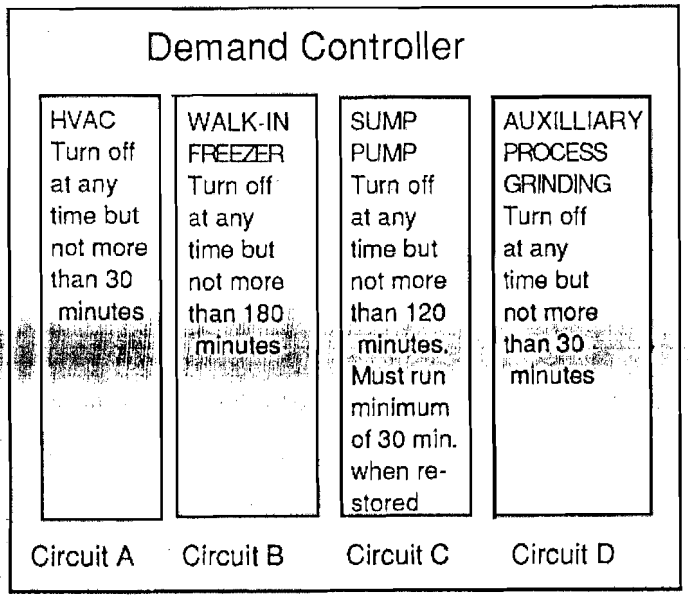
Demand charges are usually very controllable by a customer. Demand can often be decreased by simply changing work patterns in a facility. Schedules can be used identifying the sequence and timing of equipment being turned on and off. Audible alarms, when high-demand thresholds are being approached, can signal operators to turn off certain equipment.

Demand controllers, particularly in new installations, provide an excellent method of controlling demand charges. Demand controllers can be programmed to monitor the demand in a facility, and then turn equipment off and on in a pattern to minimize demand peaks. Figure 4 shows an example of a demand controller with its programming.

Demand controllers can be most economically supplied in new construction because the applicable circuits can be identified during the design process. The initial construction can then wire these circuits so that they are controllable by the demand controller.

When demand controllers are installed in existing facilities, the labor costs to properly isolate the necessary circuits can be significant, thus lengthening the payback period.

The design engineer will attempt to design the system so that the demand controller controls circuits with minimum impact on operations; but it may take months to fine tune the demand controller once the facility is operating. Even with significant labor costs when installed in an existing facility, demand controllers can have a relatively short payback period. They function invisibly, relative to operations, as they minimize demand charges.



SAMPLE DEMAND CONTROLLER WITH PROGRAMMING

Figure 4

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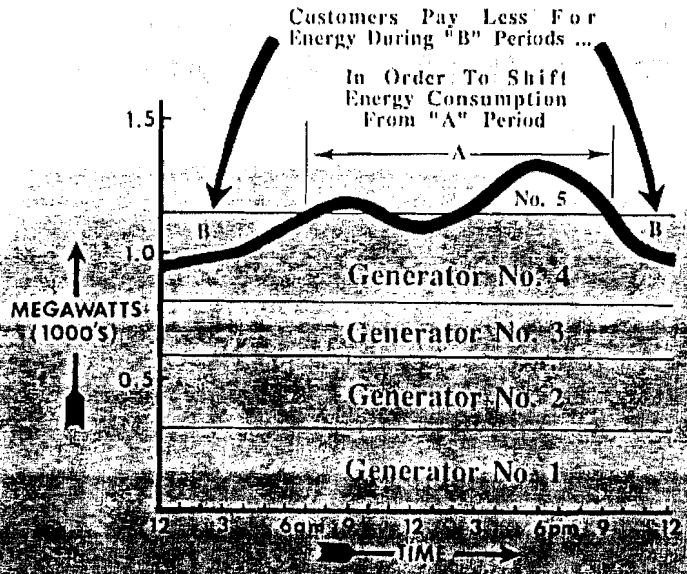
TIME-OF-USE PRICING

Utilities must meet their peak demand with an equivalent amount of generation. This peaking generation is normally the most expensive generation. If a utility can get its customers to reduce energy consumption during the peak periods, less of the expensive peaking generation needs to be used.

A utility's ability to reduce energy consumption during peak periods can result in savings from as simple as not having to purchase peaking generation to not having to build and operate costly peaking generators, such as gas-turbine (also called combustion-turbine) generators.

Time-of-use pricing (also called time-of-day pricing when applied to a 24-hour day) allows a utility to charge less for energy used during off-peak periods, and to charge more for energy used during peak periods. This price differential can be a major incentive to shift energy-usage patterns, particularly for customers with high energy bills. Time-of-use pricing requires a two-part watt-hour meter that totals the energy used during off-peak periods, and also totals energy used during peak periods. This is called time-of-use (or time-of-day) metering.

Although not uncommon for all classes of utility customers in Europe, time-of-use pricing in the United States and Canada is much more common for non-residential customers. As electrical load continues to grow, however, and utilities experience longer and longer lead times in siting and building generating facilities, time-of-use pricing for all classes of customers will become more common.



DEMAND FACTOR CURVES AND TIME-OF-USE PRICING

Figure 1

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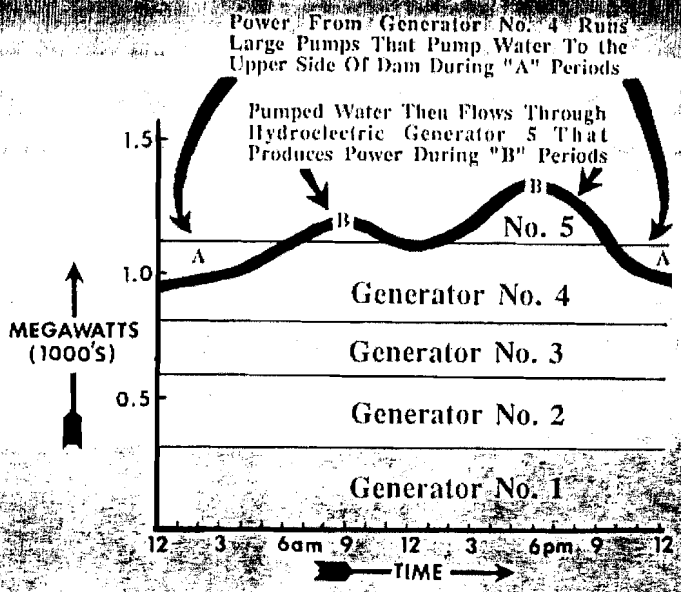
PUMPED STORAGE

Utilities use the most cost-effective generation to meet their demand. For peak-demand periods, this is often purchased generation. In some cases, fossil-fuel-fired generators are used for peaking, and in other cases hydroelectric generators are used. In some instances, however, a utility will use a more expensive generator, with surplus off-peak power, to run a hydroelectric generator as a motor to pump water to the upper side of a dam. This water is allowed to run through the turbine-generators during peak-demand periods to produce power at the times it is needed. This operation is called pumped storage.

Pumped storage becomes economically viable when there is a large differential in price between off-peak power and on-peak power. Usually the greatest differential occurs when a utility can operate nuclear or large coal-fired generators at night, and gas turbines during the day.

Figure 1 shows a daily demand curve for a hydroelectric system that uses the output from generator 4 to provide the pumping power from approximately 10:00 p.m. until 7:00 a.m. The water that was pumped is stored, and then to flow through turbine-generator 5 to provide peaking power for the late-morning and evening peaks.



DEMAND CURVE WITH HYDROELECTRIC PUMPED STORAGE

Figure 1

Traditional hydroelectric pumped storage, such as shown in Figure 2, requires water near elevated terrain. This eliminates traditional pumped hydroelectric storage for much of the United States and Canada.

Figure 3 shows a more modern pumped-storage design. The lower reservoir can be an abandoned coal mine or a natural cavern. At night water is pumped to the surface, and during peak-demand periods the water flows down

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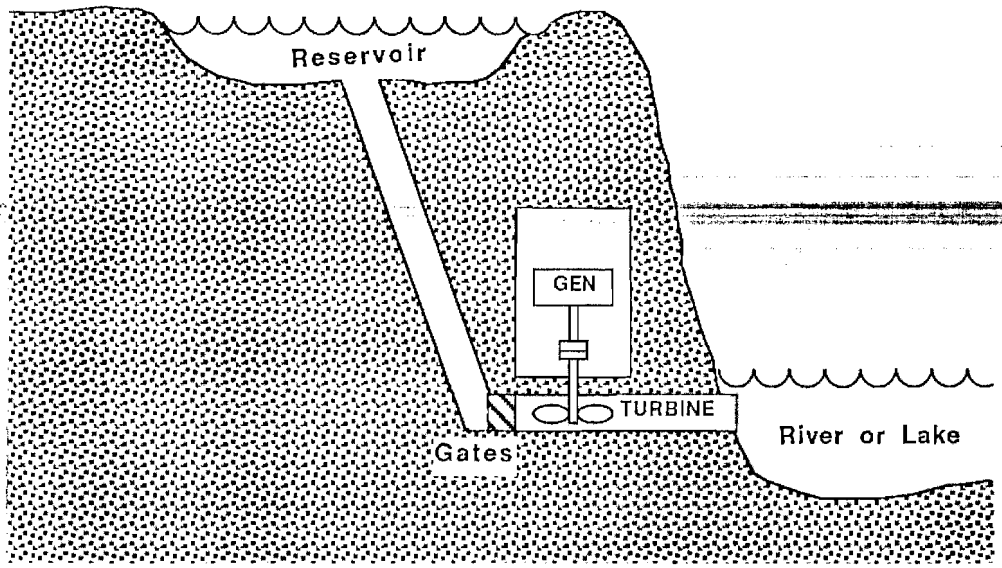
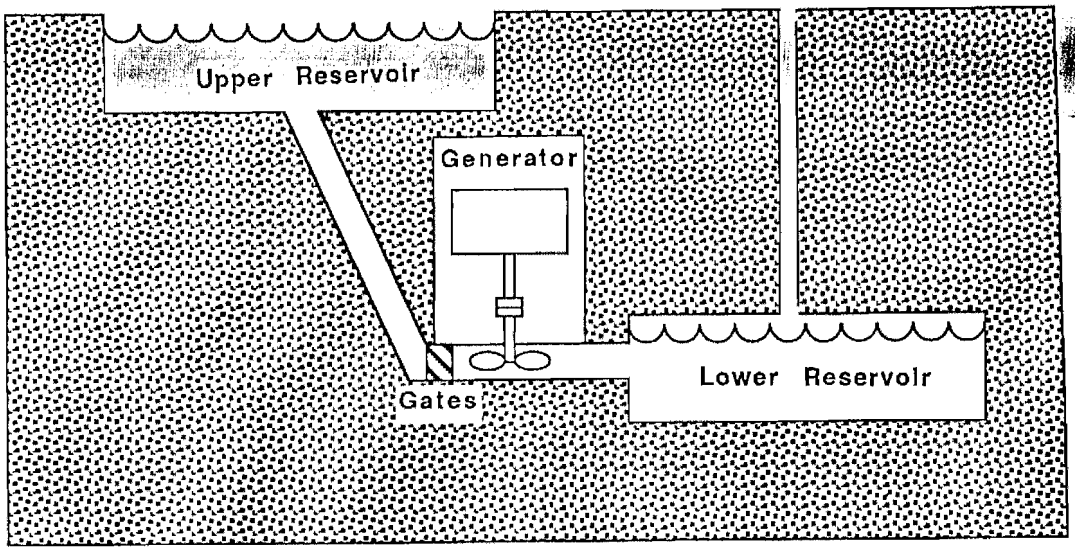
and through the turbines.



HYDROELECTRIC PUMPED STORAGE WITH TRADITIONAL DESIGN

Figure 2

This design eliminates fish and other environmental concerns because it is a closed system.



HYDROELECTRIC PUMPED STORAGE WITH MODERN DESIGN

Figure 3

Another type of pumped storage requires no water. It is called Compressed Air Energy Storage or CAES. Off-peak power is used to run large compressors that compress air into natural caverns. The compressed air is then stored until peaking generation is needed the next day. The compressed air is then released to spin a turbine-generator, thus providing the necessary peaking generation. The first compressed-air-energy-storage system in the United States began commercial operation on May 31, 1999. It is located in McIntosh, Alabama, and is owned by Alabama Electric Cooperative.

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TRANSMISSION INTERTIES

Transmission interties are the transmission lines and associated equipment that tie together different utilities' systems. One such intertie is the Pennsylvania-New Jersey-Maryland (PJM) intertie. Another is the intertie that connects Southern California and the Pacific Northwest.

The purpose of interties is to allow one utility's unused generation capacity to supply another utility's load. This results in cost benefits to both the generating and purchasing utilities. It is a cost benefit to the generating utility when that utility can sell its unused generation, thereby bringing in extra revenues. It is a cost benefit to the purchasing utility when that utility does not have to build additional generating plants.

The operators of the PJM intertie monitor both load, and cost of generation for each generator in the system. This ensures that the power being generated is the cheapest possible. Temperatures and humidity are forecasted hourly in order to project demand. The total load projection for the system is then adjusted to allow for errors in the forecast, and to allow for the worst electrical accident statistically likely in a 10-year period. Enough generators are then called upon to provide this level of power.

The initial intent for the Pacific Northwest-to-Southern California intertie, the longest in the United States, was for a seasonal exchange. During the summer months, power would flow from the Pacific Northwest with its mild summers and relatively light loads, to Southern California for its air conditioning loads. During the winter, power would flow from Southern California with its mild winters and relatively light loads, to the Pacific Northwest for its heating loads. The same seasonal exchange is possible between any two areas that have this seasonal difference.

Any time there is an exchange of power over an intertie system, the power-sales contract between the generating and purchasing utilities must include the intertie costs. These costs, called wheeling costs, are charged by the utility (or utilities) that own the transmission lines over which the power must flow. These wheeling costs are analogous to the toll cost paid by motorists using a toll bridge or toll road.

Just as highways and bridges have a limit on the maximum number of cars that travel at the same time, an intertie system can carry only so much power. It is not uncommon for two utilities to be unable to buy and sell power at the desired time because the connecting intertie system is fully loaded. An example of this is the relatively inexpensive hydroelectric power in Canada that could be sold to utilities in the southern parts of the United States, if there were sufficient intertie capacity.

One of the problems that decrease intertie capacity for many of the interties in the United States is loop flow. Loop flow is power flow that does not take the shortest distance from the generating utility to the purchasing utility, but instead takes a longer route.

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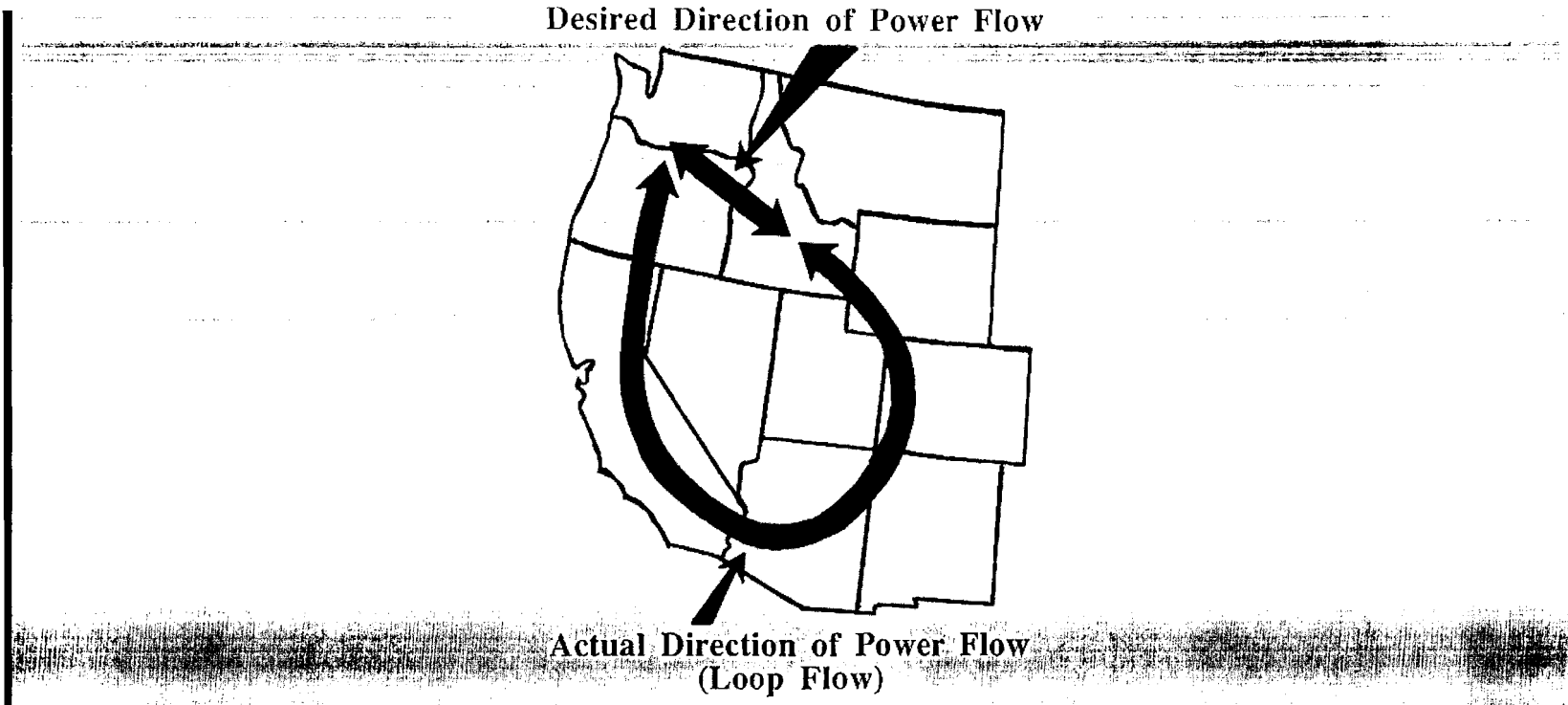
A classic example of loop flow is illustrated in a situation in the western States. Power which should flow between Idaho and Oregon-Washington, instead flows through California, Arizona, Colorado and Wyoming (Figure 1).



CLASSIC LOOP FLOW EXAMPLE

Figure 1

Loop flow is caused by power flow taking the path of least resistance, or in the case of an ac system, taking the path of least impedance. Loop flow problems can be remedied by reducing the impedance of the line over which the power should flow; or by installing phase-shifting transformers that push power in a specified direction.

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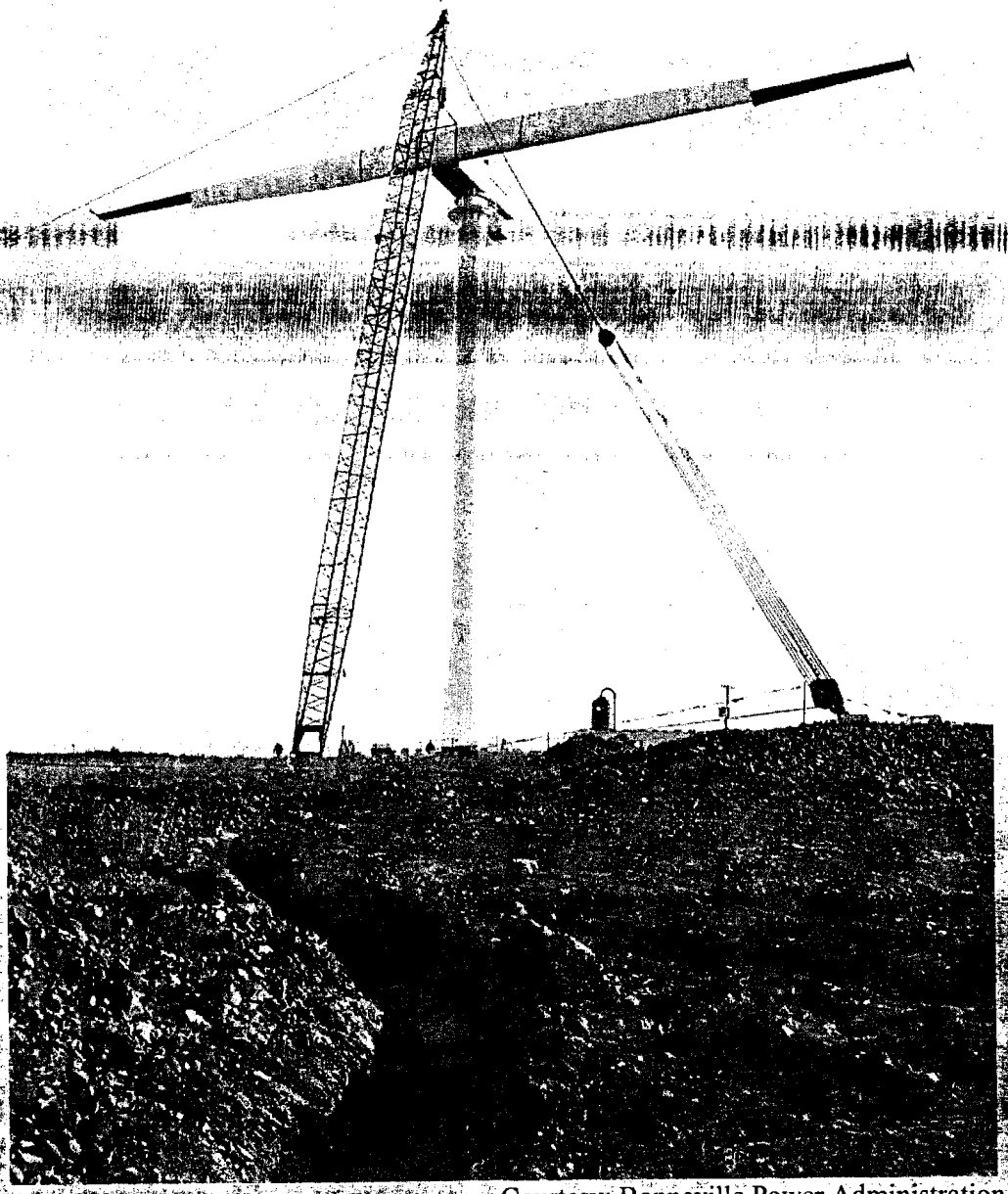
WIND POWER GENERATION

Figure 1 and 2 are photographs of a large-scale wind-powered generation project undertaken in the 1970's and 1980's at a site near Goldendale, Washington. President Ronald Reagan mandated they be dismantle even though the Bonneville Power Administration offered to stop operating them during his administration.

These wind generators, along with those at several other sites, provided the knowledge that has allowed wind generators to advance to where they are now commercially viable. Figures 3 and 4 show portions of a large wind farm near Mohave, California.



Courtesy: Bonneville Power Administration

LARGE SCALE WIND GENERATOR

Figure 1

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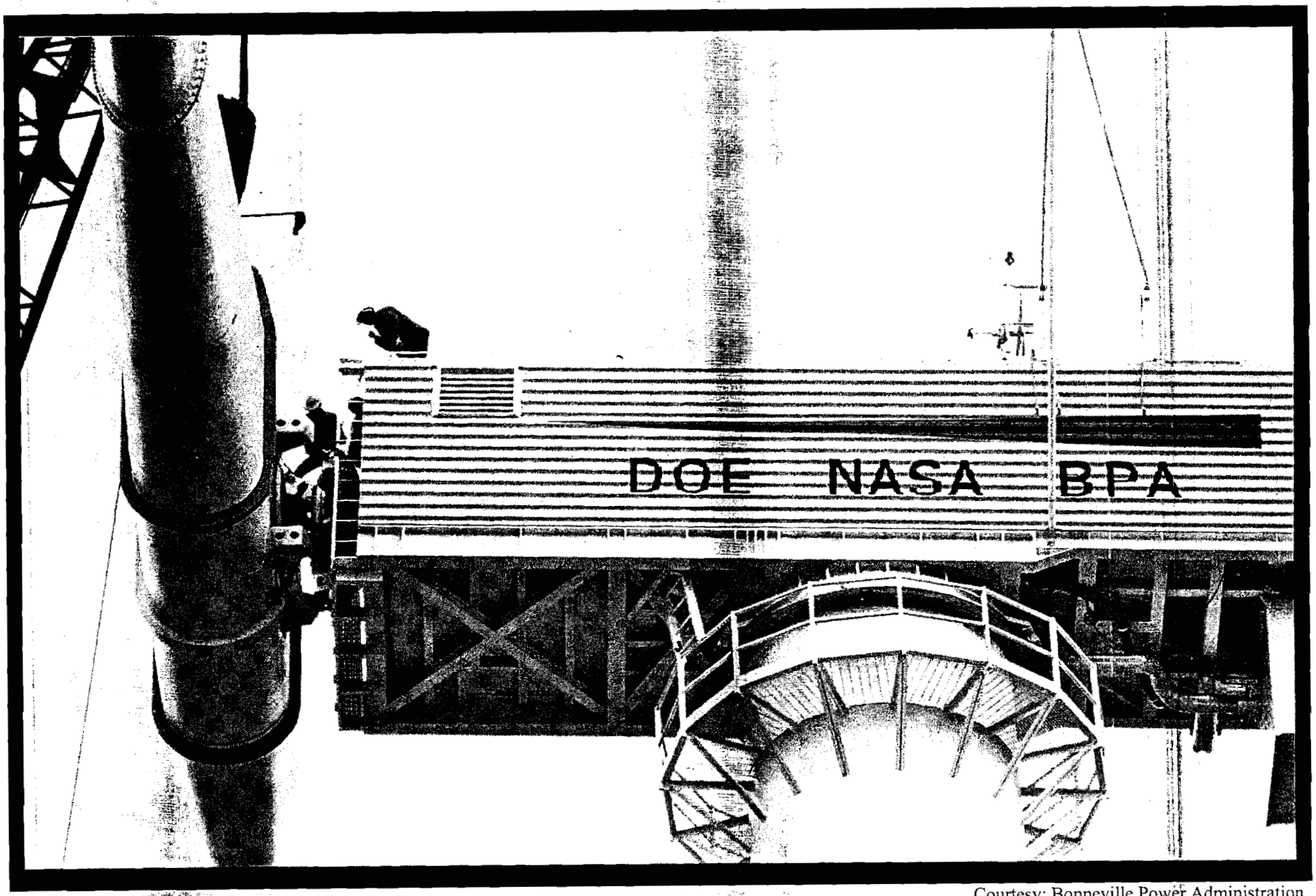
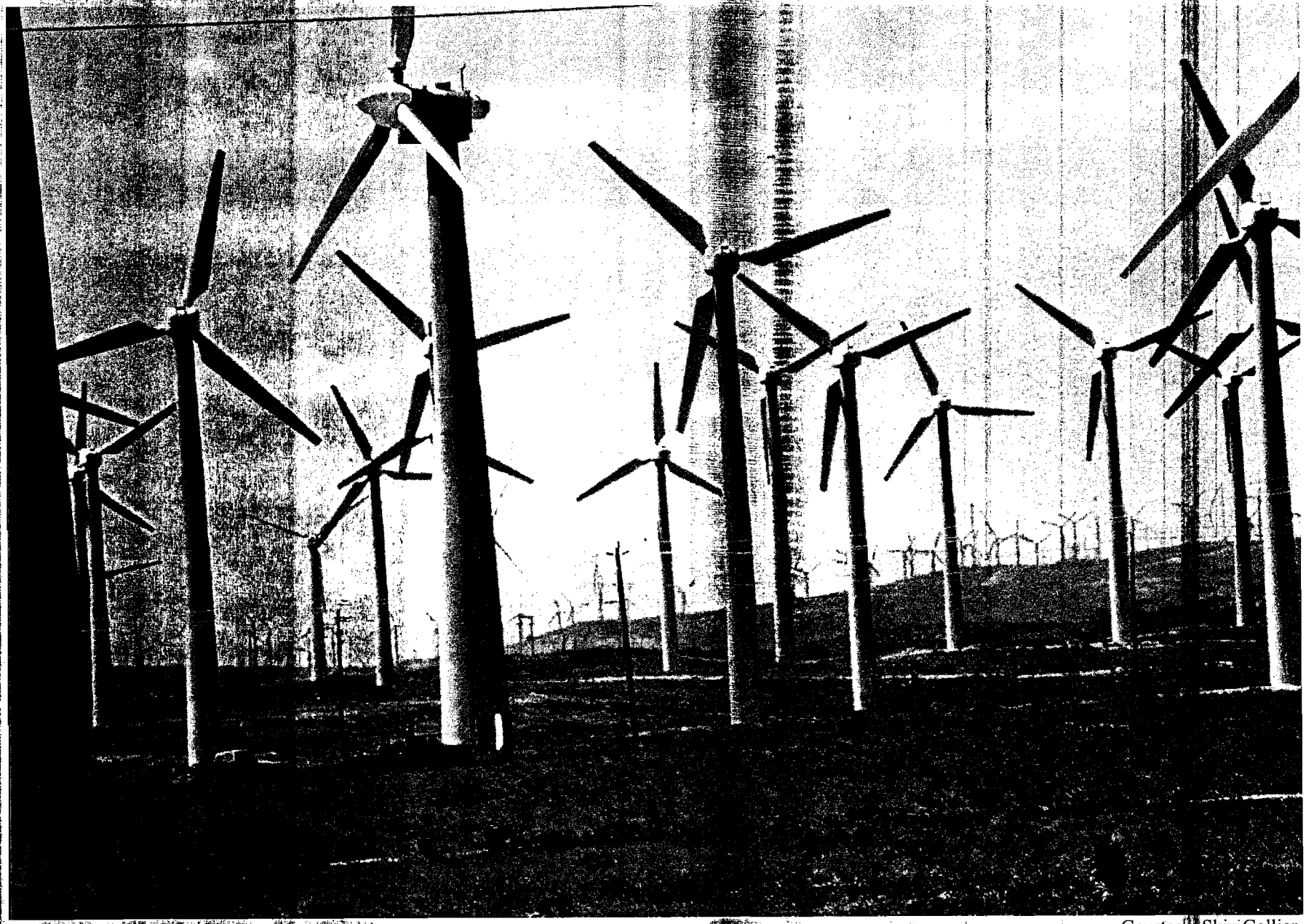


Courtesy: Bonneville Power Administration

LARGE SCALE WIND GENERATOR

Figure 2



Courtesy: Skip Collier

SMALL SCALE WIND GENERATOR
Figure 3

Courtesy: Skip Collier

SMALL SCALE WIND GENERATOR
Figure 4

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Abbreviations

μ	– Greek letter micro - represents: 0.000001
Ω	– Greek letter omega - represents Ohms
ϕ	– Greek letter phi - represents: Phase
A	- **A**mpere - the measure of current and named after *Andre-Marie Ampere*
C	- **C**apacitance - the ability of two conductors, separated by an insulator, to store energy in a voltage charge
CT	- **C**ombustion **T**urbine
CT	- **C**urrent **T**ransformer
E	- Voltage (used in equations) - historically based from the term **E**lectromotive force
EMF	- **E**lectrom**o**tive **F**orce (another name for voltage)
EMF	- **E**lectrom**a**gnetic **F**ield
EMS	- **E**nergy **M**anagement **S**ystem - advanced computer system used in system control centers to monitor and control remote equipment
F	- **F**arad - the measure of the ability of a capacitance to store energy in a voltage charge - named after *Michael Faraday*
H	- **H**enry - the measure of the ability of an inductance to store energy in a magnetic field - named after *Joseph Henry*
Hz	- **H**ertz - the measure of frequency and named after *Heinrich R. Hertz*. Frequency was measured in cycles per second, but was changed to Hertz in the 1960s. One Hertz is one cycle per second
I	- Current (used in equations) - historically based from the French word **I**ntensity - current is the flow of electrons, or flow of holes
k	- kilo - 1,000
kVAr	- kilo**V**olt-**A**mps **R**eactive - A measure of the non-work producing power
kVArh	- kilo**V**olt-**A**mps reactive **h**our - A measure of the non-work producing energy
kW	- kilo**W**atts - a measure of work-producing power
kWh	- kilo**W**att-**h**our - the measure of electrical energy
L	- Inductance - the ability of a circuit to store energy in a magnetic field
LTC	- **L**oad **T**ap **C**hanger - device added to a transformer when the transformer is being built to provide control of the voltage out of the transformer (same as a TCUL)
M	- **M**ega - 1,000,000
MVAr	- **M**ega**V**olt-**A**mps **R**eactive - A measure of the non-work producing power

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MVArh - MegaVolt-Amps reactive hour - A measure of the non-work producing energy

MW - MegaWatts - a measure of work-producing power

MWh - MegaWatt-hour - the measure of electrical energy

m - milli - 0.001

P - Power

PT - Potential Transformer

R - Resistance - the measure in Ohms of the ability of a material to block current flow

SCADA - Supervisory Control And Data Acquisition - computer system used in system control centers to monitor and control remote equipment

TCUL - Tap Change Under Load - device added to a transformer when the transformer is being built to provide control of the voltage out of the transformer (same as an LTC)

V - Volts - the measure of voltage which is electrical push that pushes electrons and named after *Alessandro Volta*

VAr - Volt-Amps reactive - A measure of the non-work producing power

VAr-h - Volt-Amps reactive-hour - A measure of the non-work producing energy

W - Watt - a measure of work-producing power and named after *James Watt*

Wh - Watt-hour - the measure of electrical energy

X - Reactance - equivalent resistance, measured in ohms, caused by capacitance and interacting magnetic fields in an alternating current circuit

X_C - Capacitive reactance - equivalent resistance, measured in ohms, caused by capacitance in an alternating current circuit

XFMR - Transformer

X_L - Inductive reactance - the equivalent resistance, measured in ohms, caused by interacting magnetic fields in an alternating current circuit

Z - Impedance - the total Ohms in an alternating current circuit consisting on all the ohms of resistance, ohms of inductive reactance, and ohms of capacitive reactance

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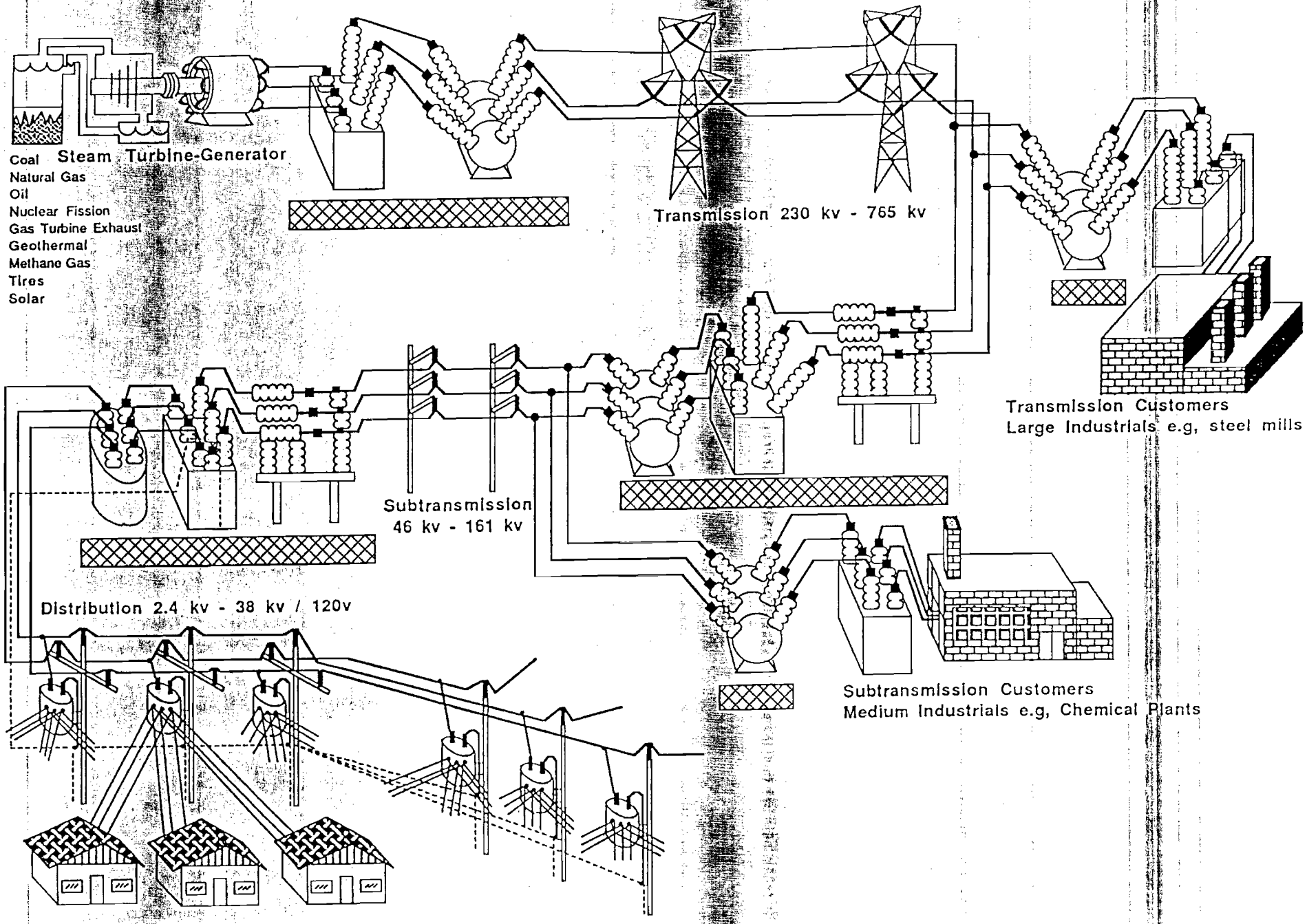

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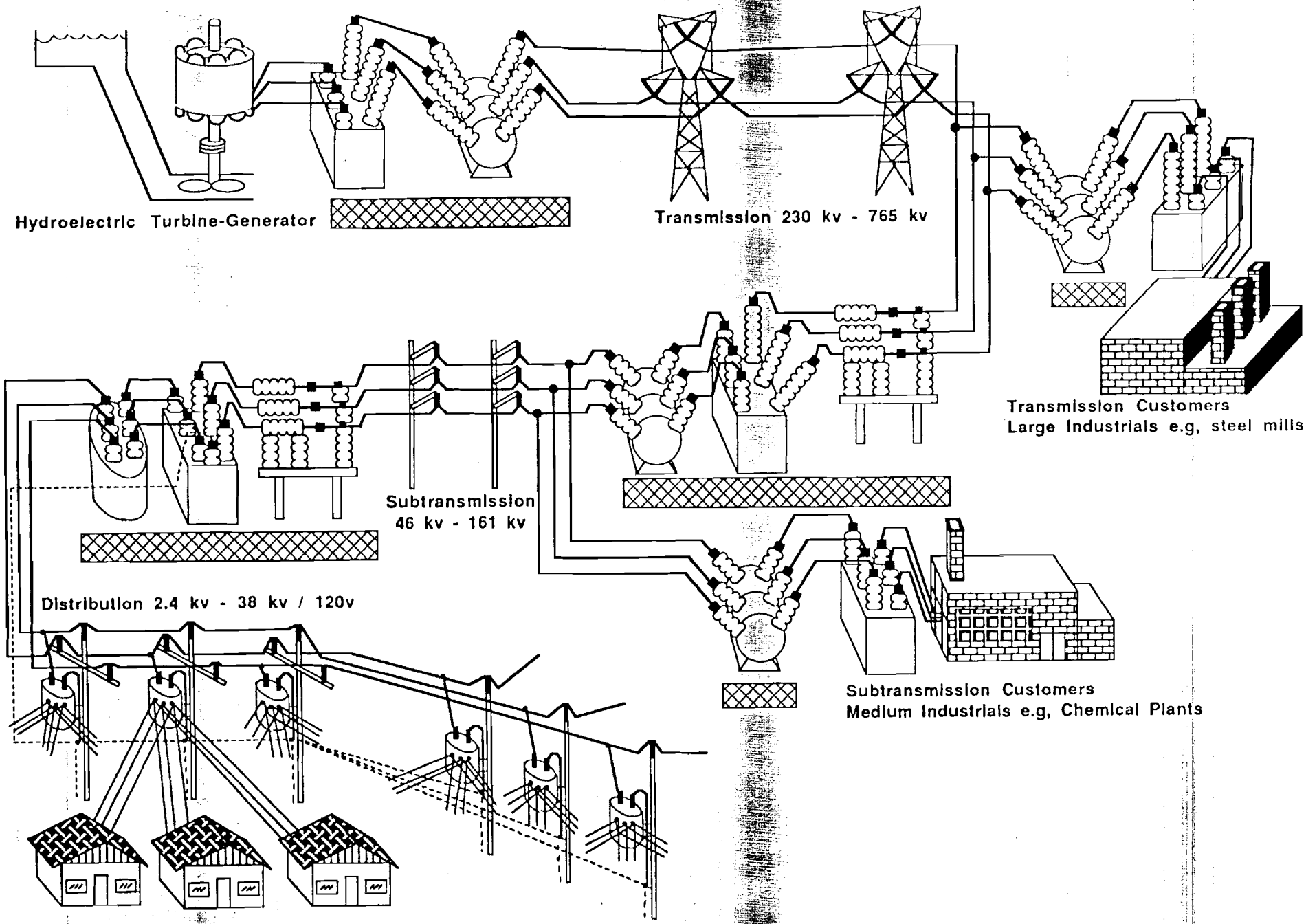

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Volatility and Structural Change

Neelesh Nerurkar
Economist

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Outline

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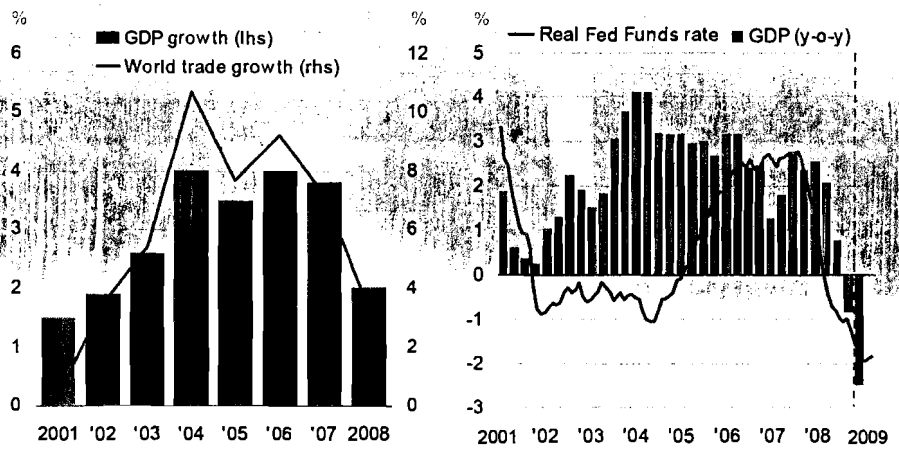
- Introduction
- Volatility and Structural Change
- Fuel by Fuel
- Conclusion

The Economy



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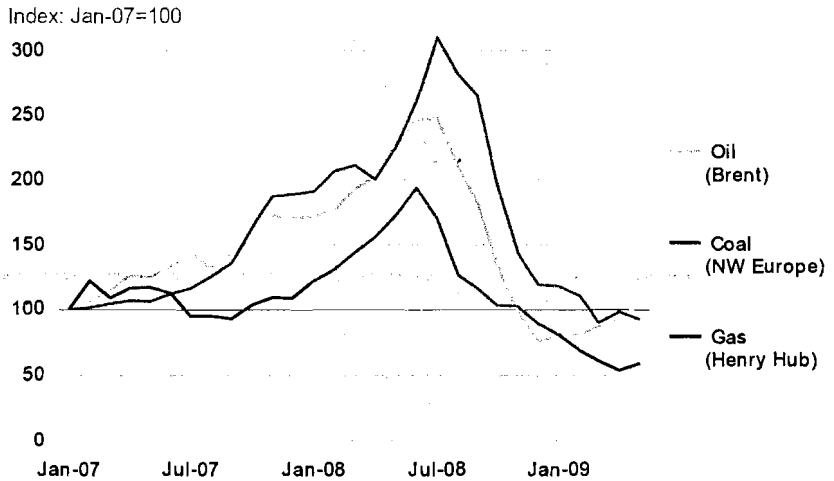
Energy Prices



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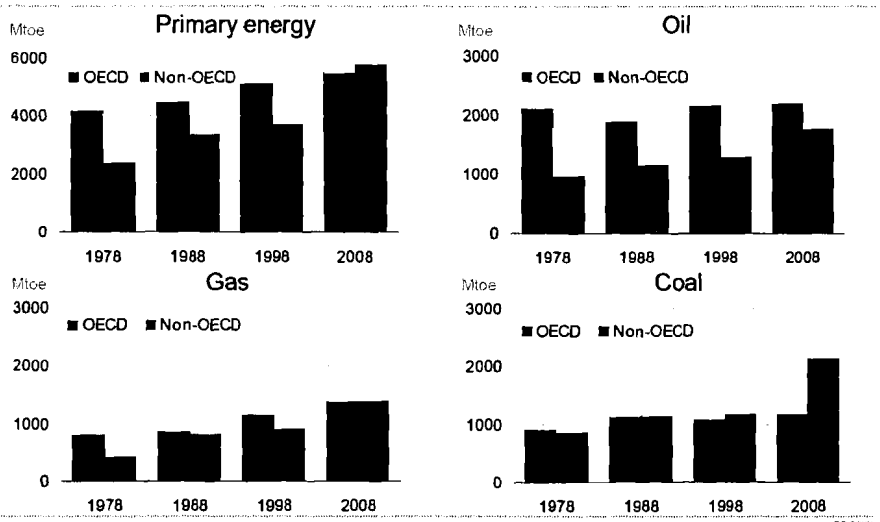
OECD and Non-OECD Energy Consumption



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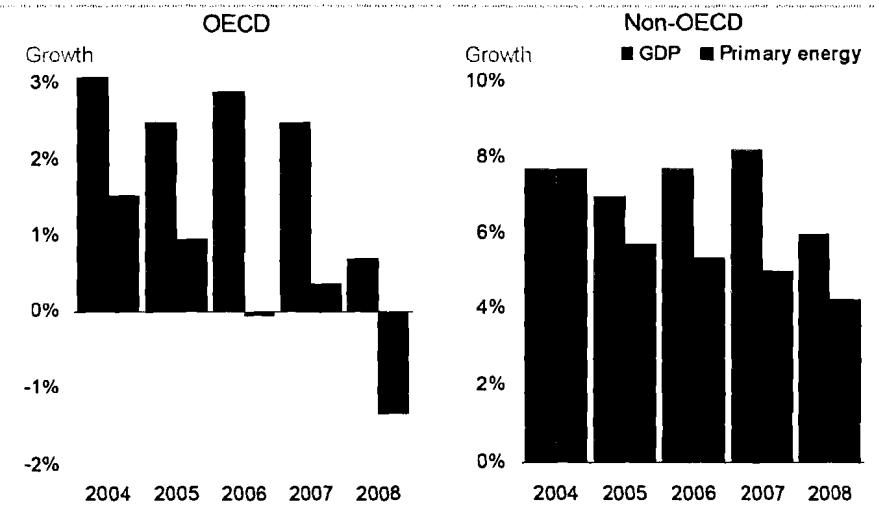
GDP and Primary Energy Growth



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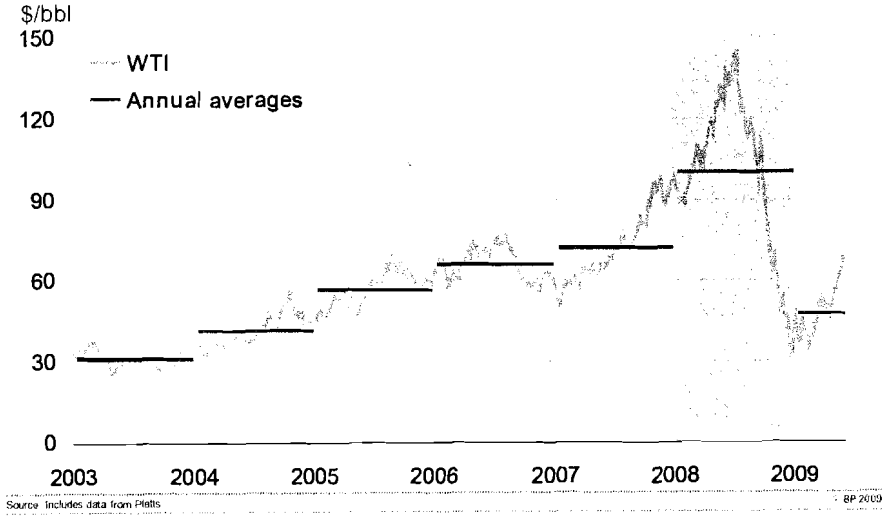
Crude Prices: What Happened?



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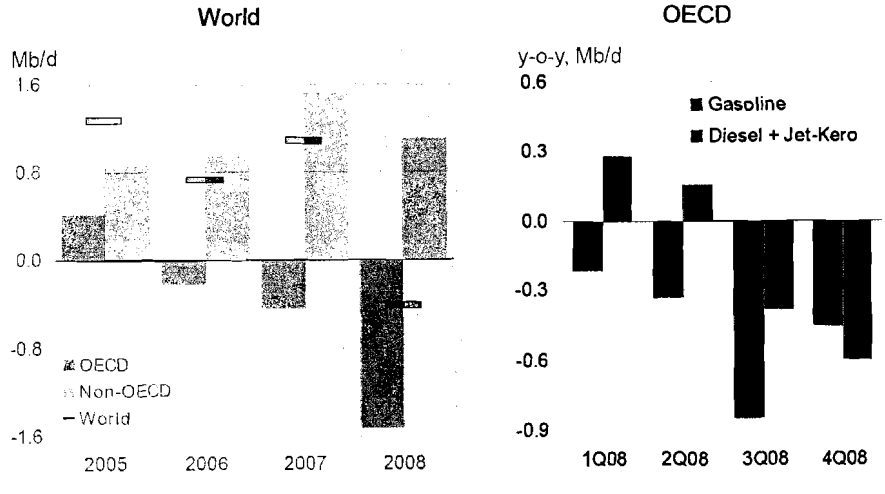
Oil Consumption Growth



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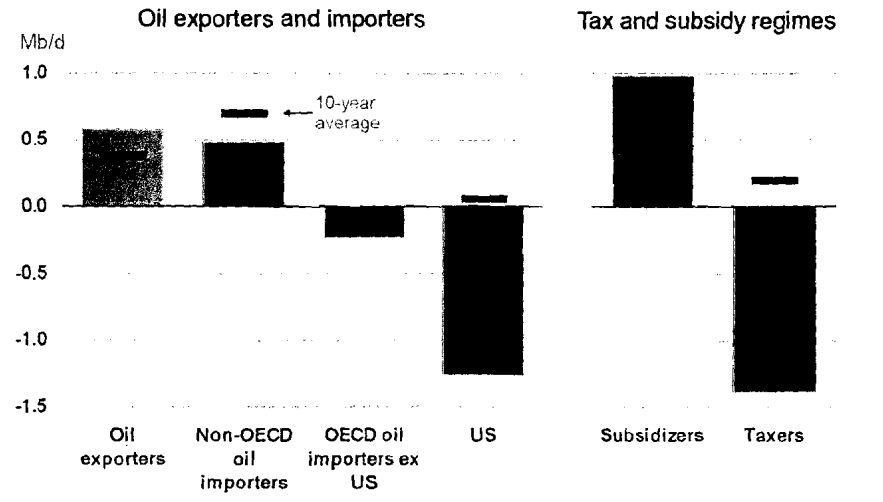
Oil Consumption Growth in 2008



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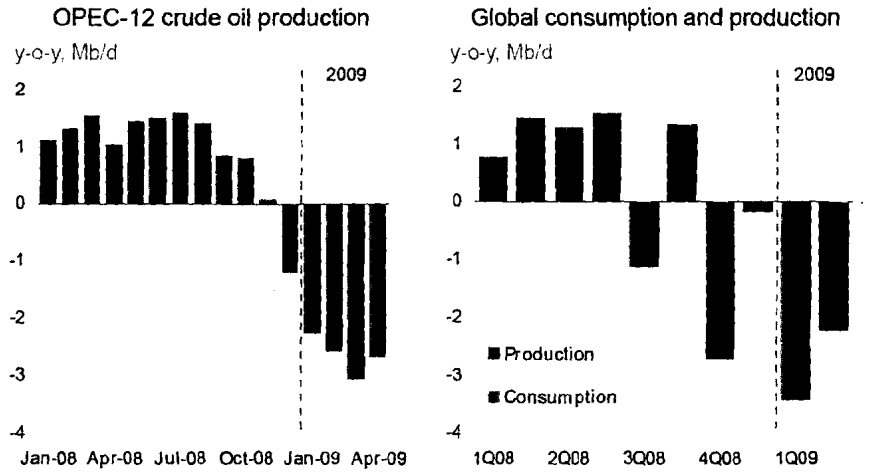
OPEC Adjusts to Falling Consumption



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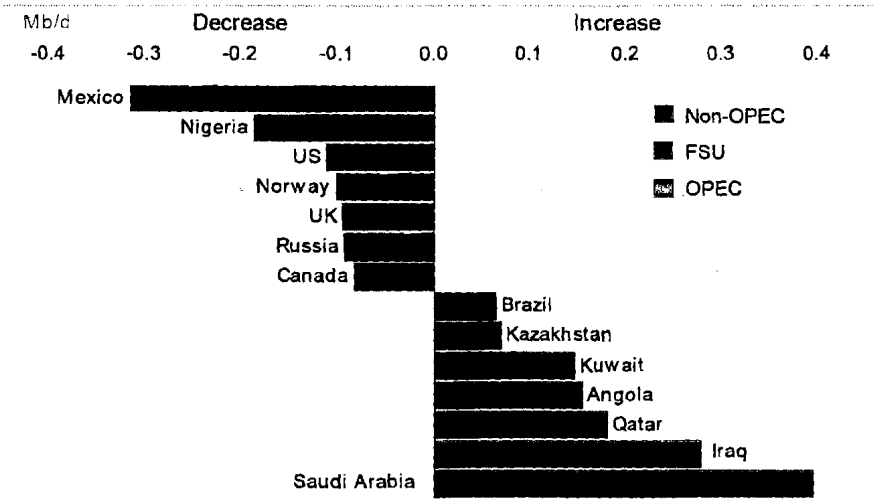
Main Oil Production Changes



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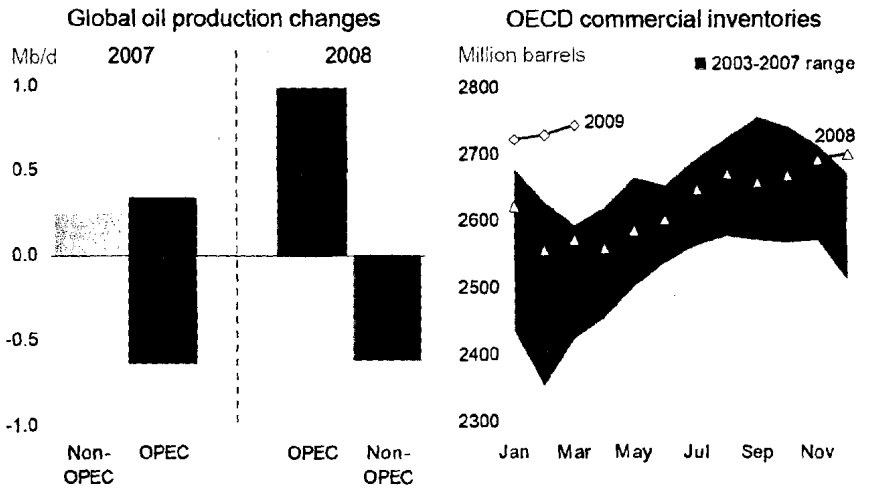
Changes in Production and Inventories



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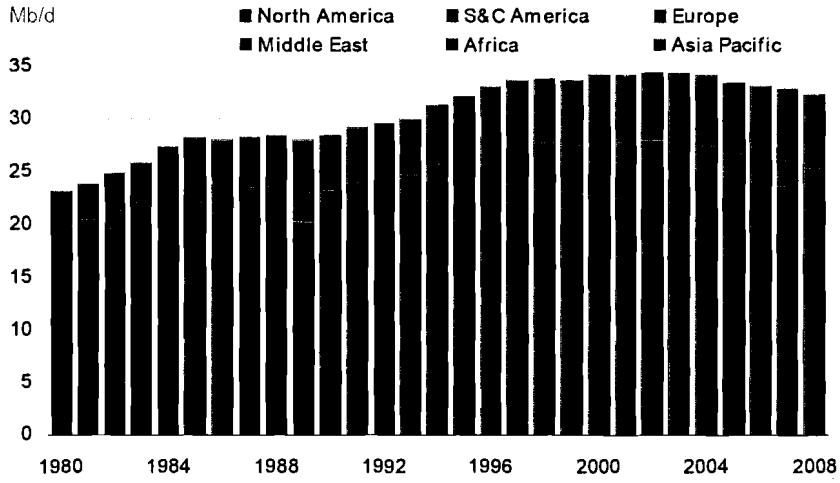
Non-OPEC ex FSU Oil Production



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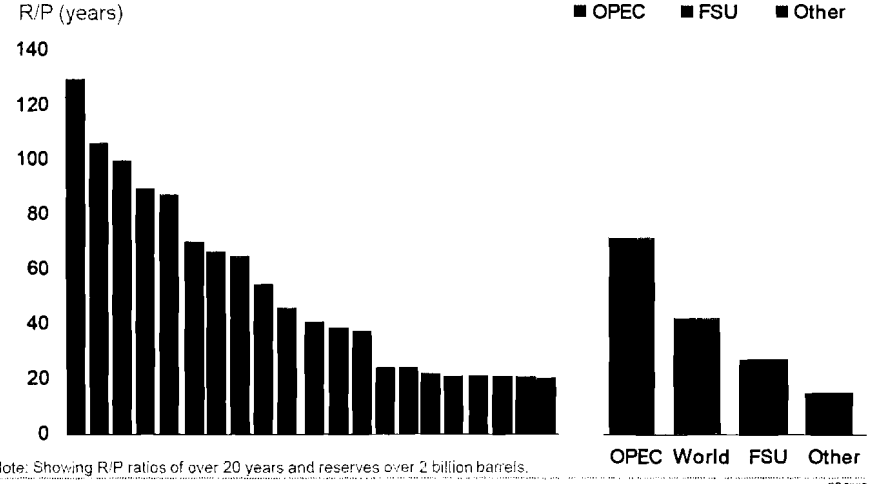
Reserves-to-Production Ratios



Note: Showing R/P ratios of over 20 years and reserves over 2 billion barrels.

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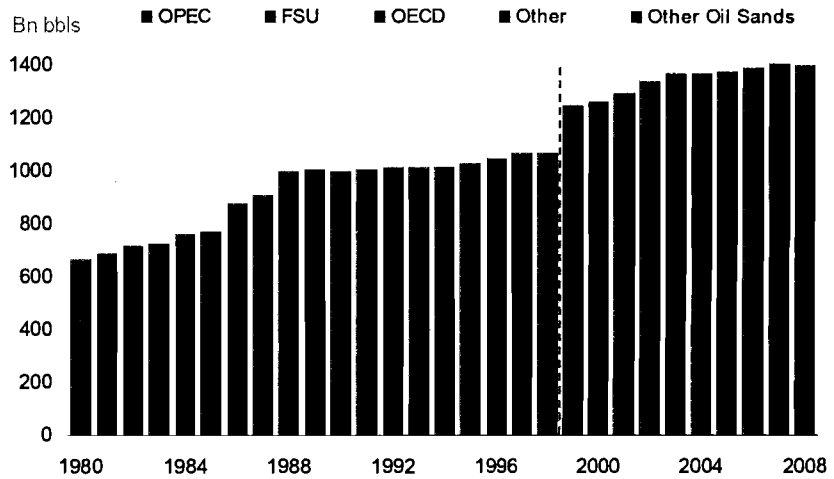
Global Oil Reserves



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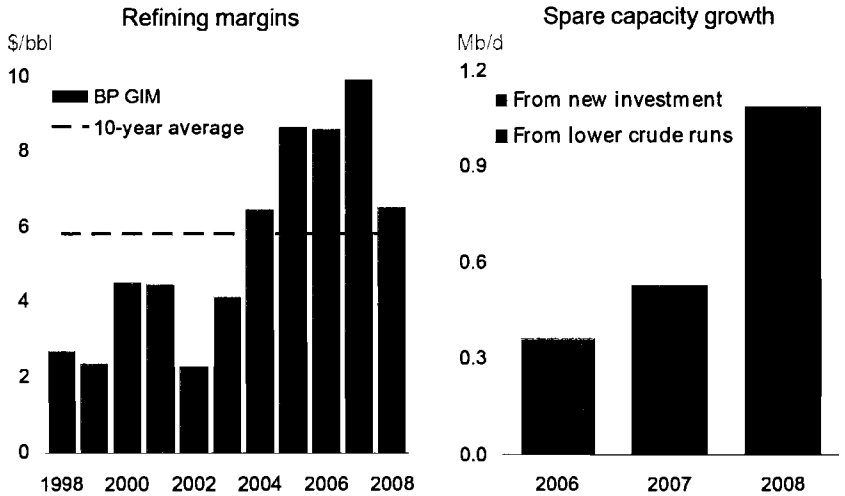
Refining Margins and Spare Capacity



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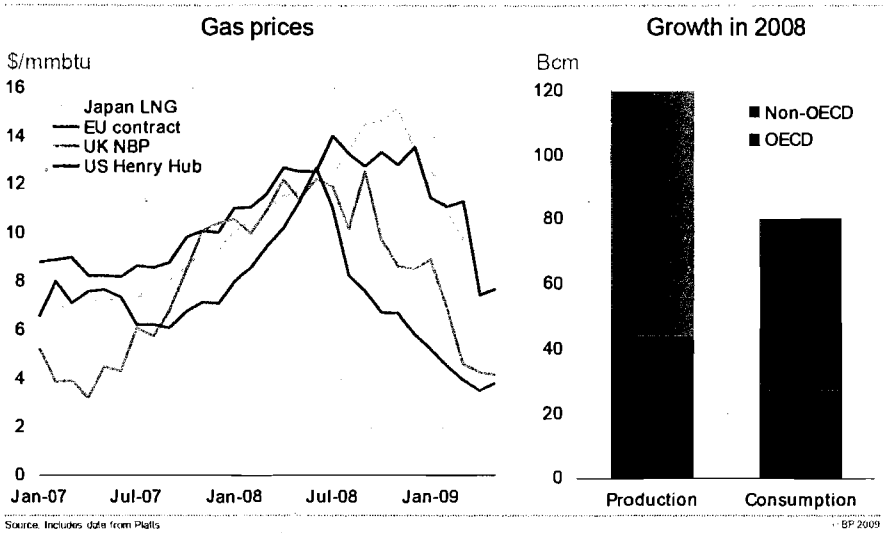
Natural Gas Market



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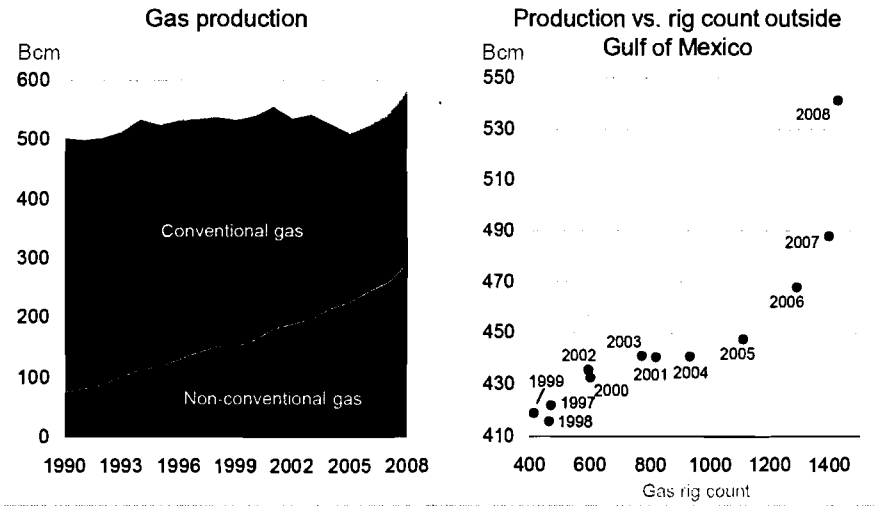
US Gas Production



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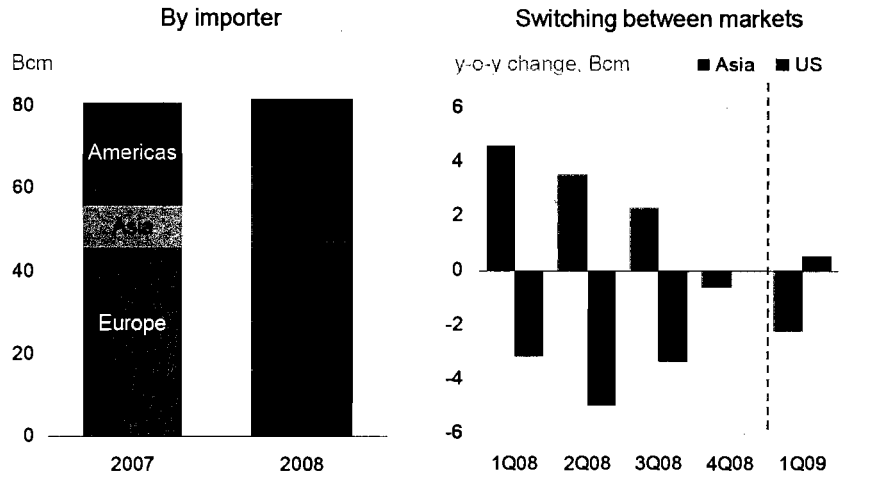
Atlantic Basin LNG*



* LNG from Algeria, Belgium, Egypt, Nigeria, Norway, Trinidad and Equatorial Guinea

Sources: Includes annual data from Cedigaz and quarterly figures from Waterborne LNG

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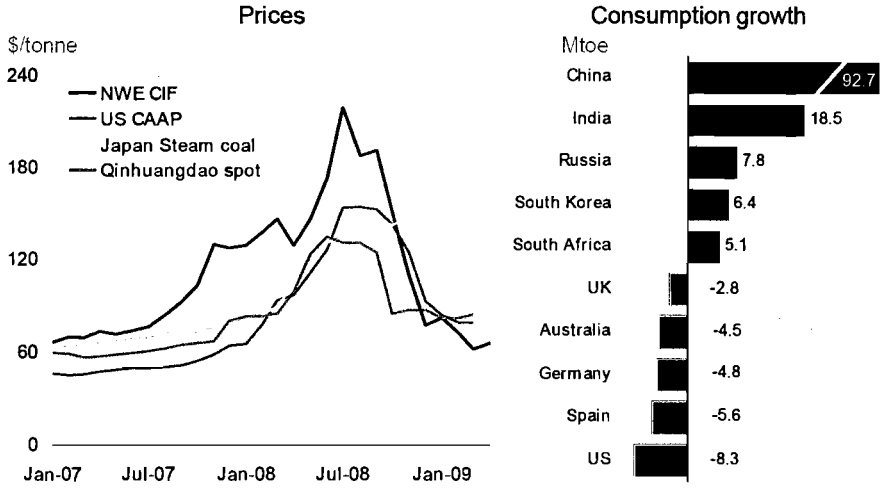
Coal Prices and Consumption Growth



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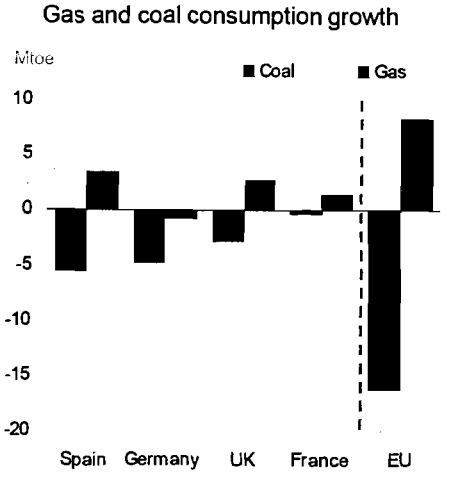
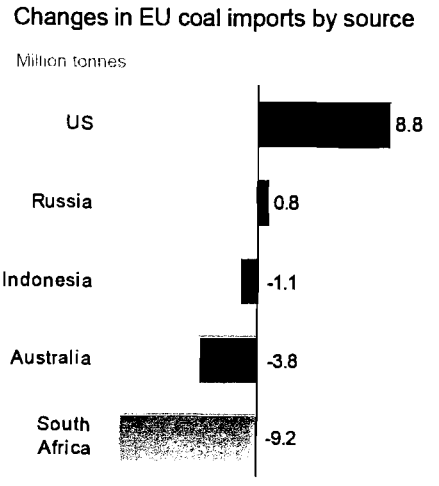
Coal in the European Union





Sources: Includes data from Eurostat

BP Statistical Review of World Energy June 2009

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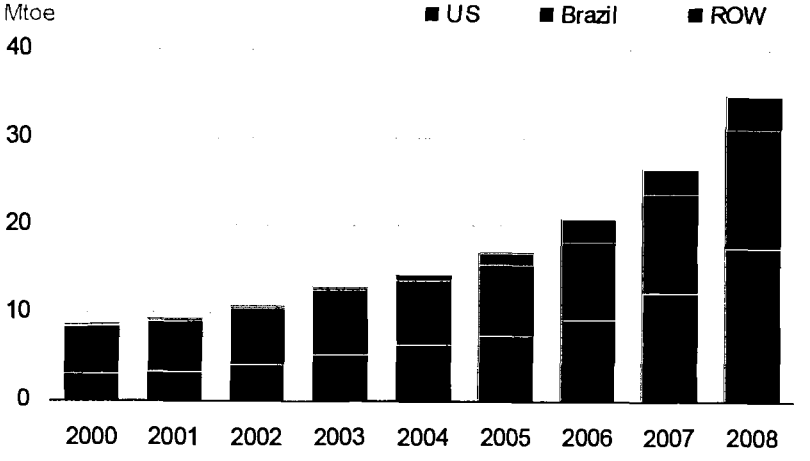
Global Ethanol Production



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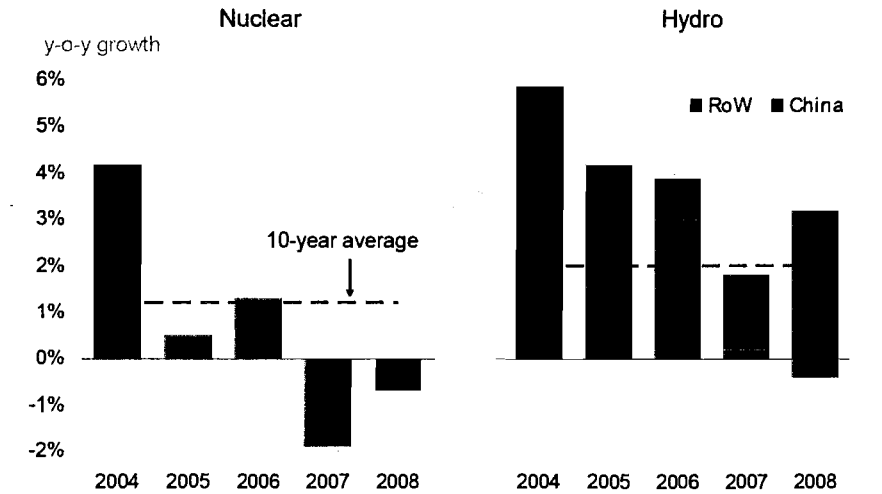
Nuclear and Hydroelectric Output



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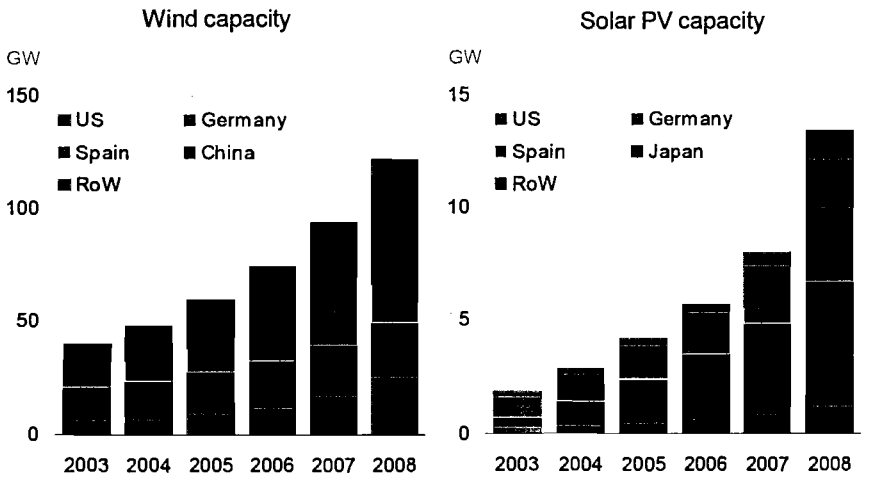
Renewable Energy



Sources. Includes data from BTM Consult, IEA, EPIA and EurObserver

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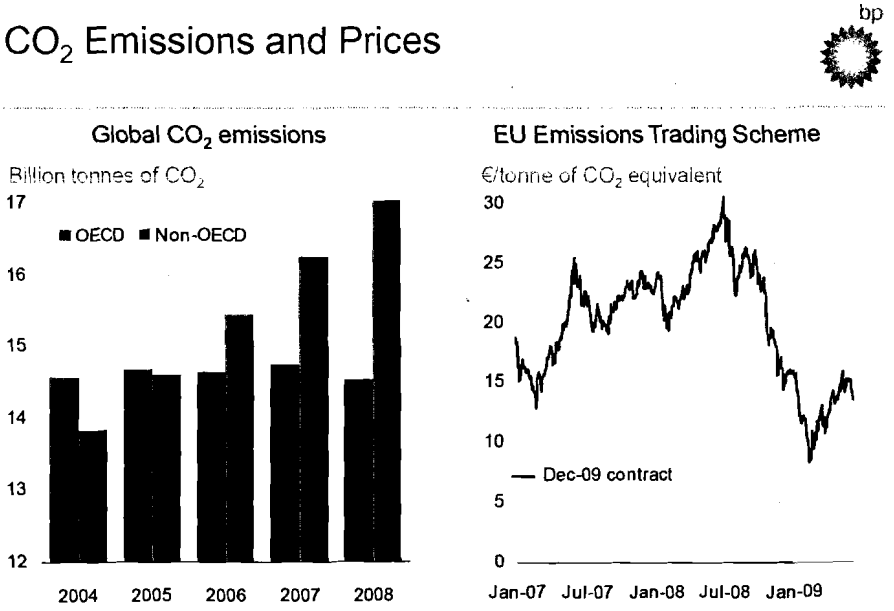
CO_2 Emissions and Prices



Source: Includes prices from European Climate Exchange

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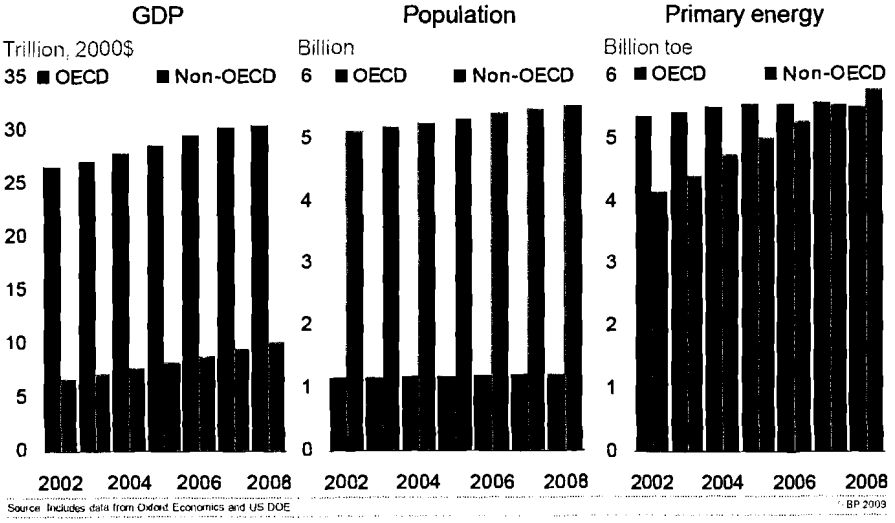
GDP, Population and Energy Consumption



Source: Includes data from Oxford Economics and US DOE

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Conclusion

- 2008: Rapid market adjustment
- Non-OECD: The future is here
- Volatility: Unavoidable in our industry?

EDISON ELECTRIC INSTITUTE

Public Policy Impacts on Business Decisions

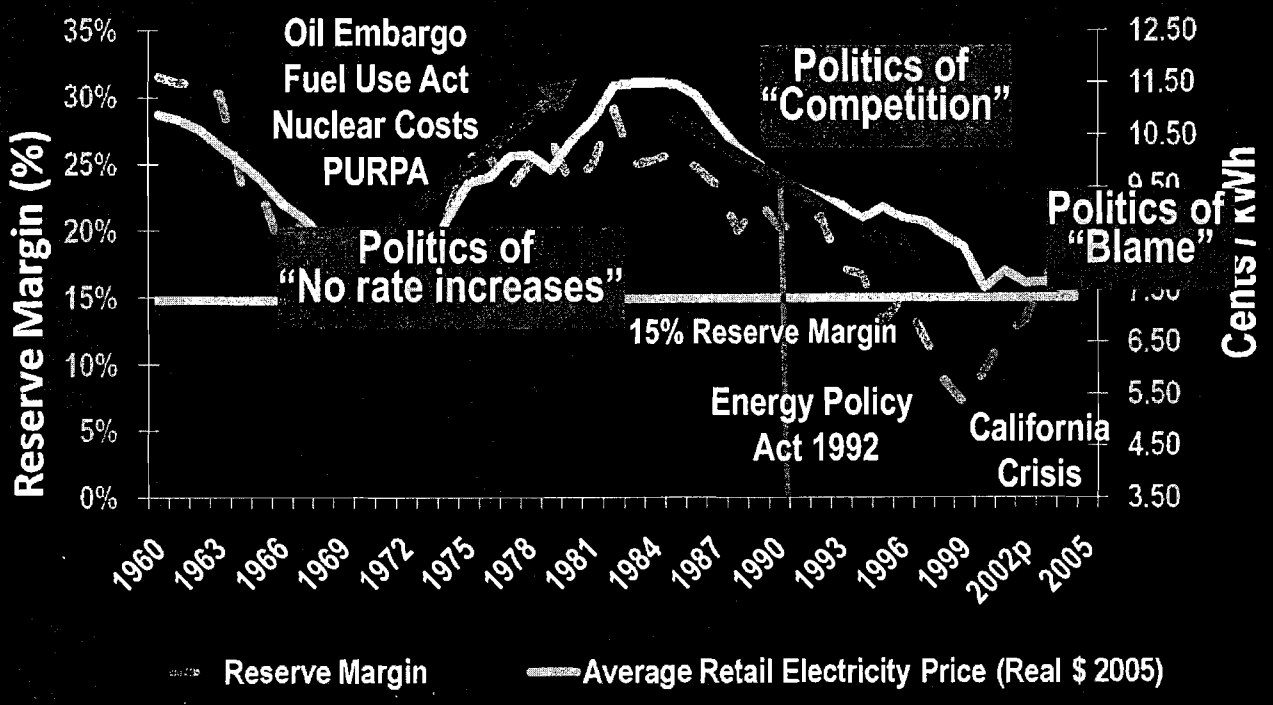
Michael Oldak

Sr. Dir. State Competitive & Regulatory Policies
Edison Electric Institute

Legislative Energy Horizon Institute
July 15, 2009

Inextricable Link

Public Policy Affected by Business Real Electricity Prices in the U.S.



Sources: North American Electric Reliability Council (NERC)
Energy Information Administration (EIA)

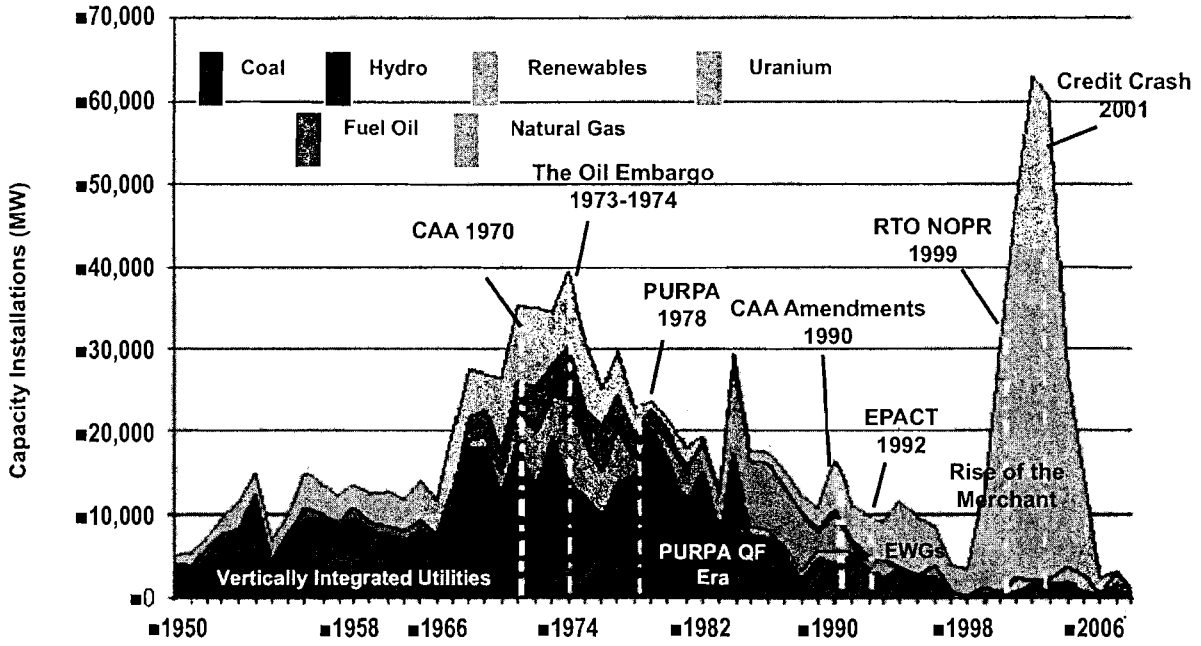
We've Been Here Before
It Ain't Pretty

- Ratemaking moves from finance and economics to politics
  - Regulators run on "No rate increase platforms"
  - Legislators start to "help" us
  - Scrutiny of Automatic Adjustment Clauses
  - Extend rate freezes
  - Perfect hindsight prudence reviews take center stage
  - Regulatory disallowances begin
  - Replace Governors, PUC chairs, and entire commissions

- Today's utility environment
  - Larger, more robust wholesale markets
  - Ability to control demand less expensive – Smart meters, AMI
  - Reserve margins critical

Generation Options – Affected By Public Policy

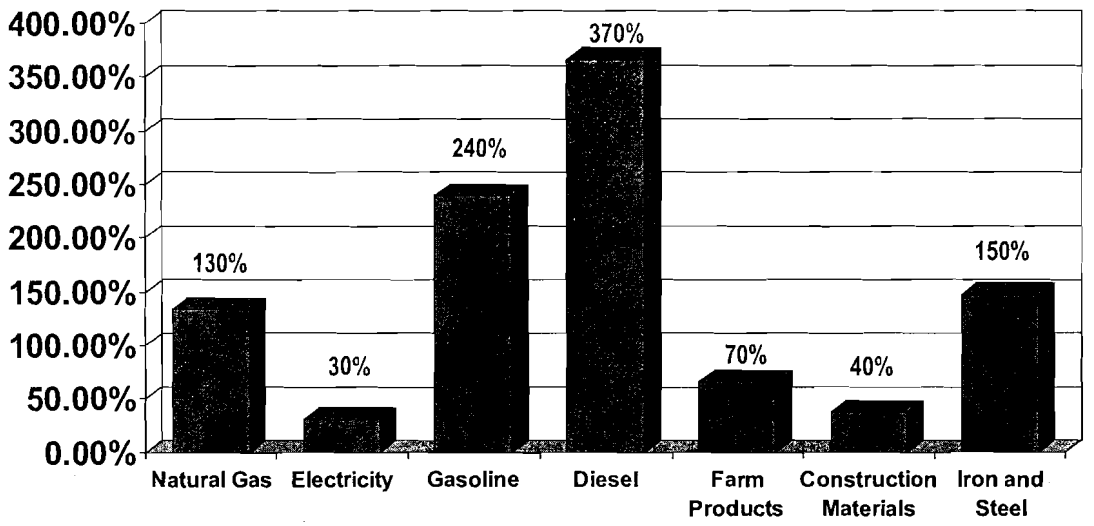
New Generation Capacity By Fuel Since 1950



Source: Henwood Energy Consulting

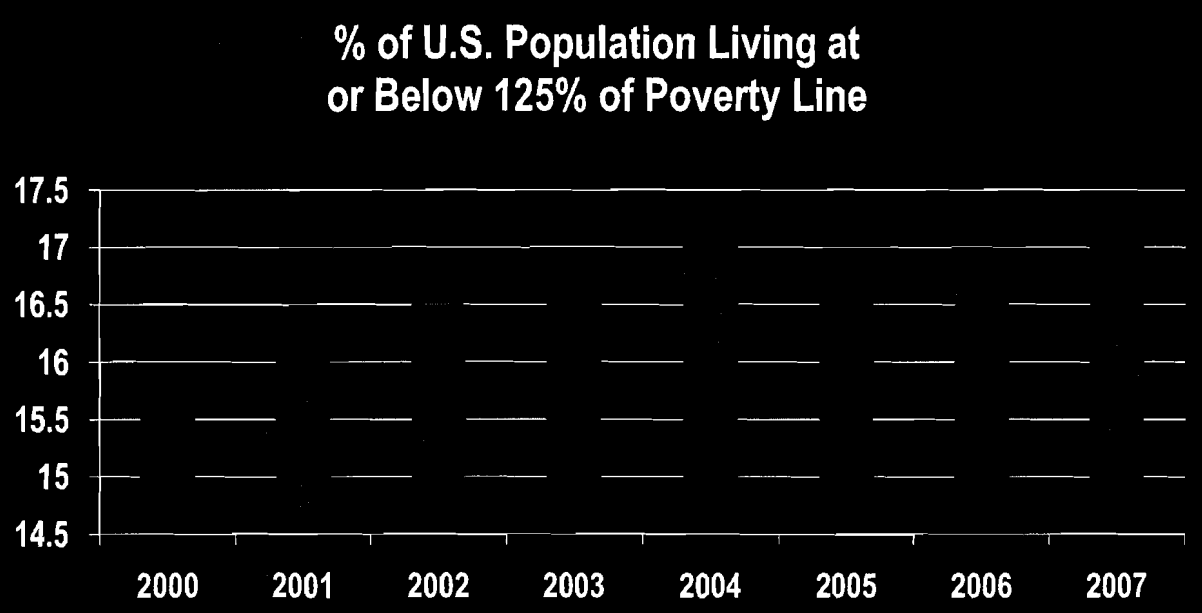
The State of Consumers

Energy, Food, and Raw Materials Prices Are Rising Dramatically



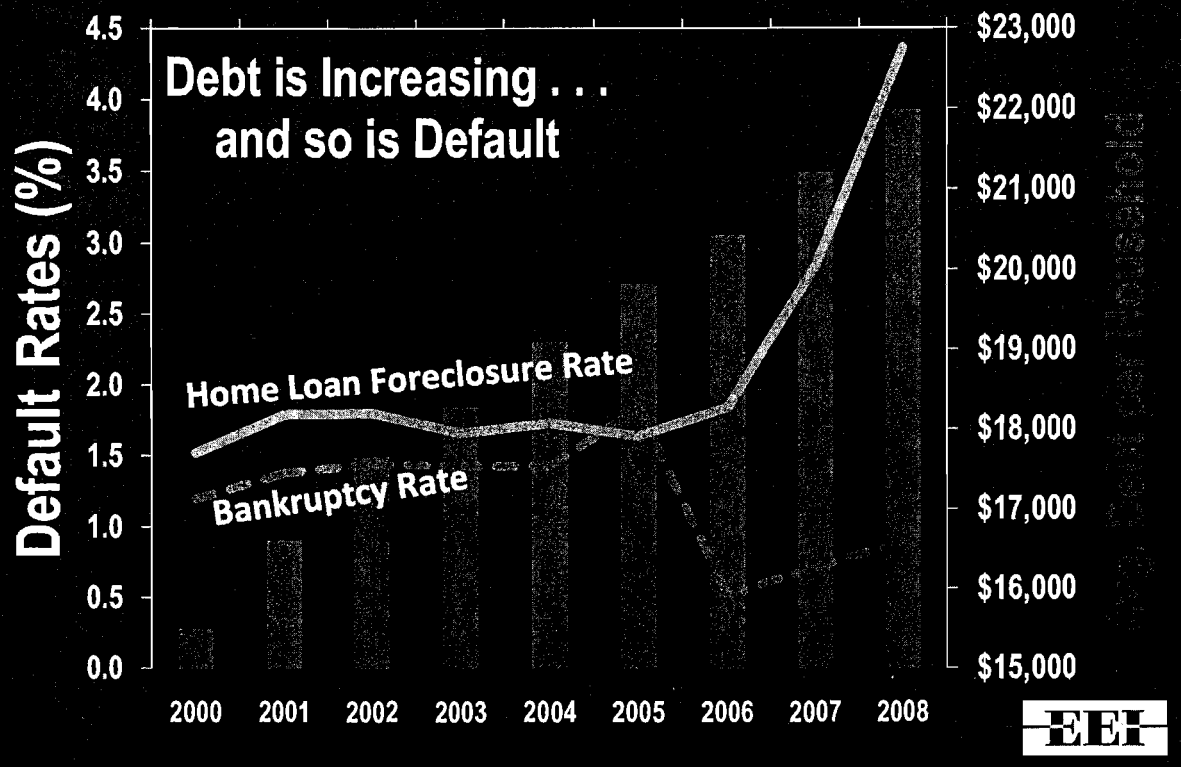
Source: Producer Price Index (Bureau of Labor Statistics, U.S. Department of Labor)

Recent Trends Indicate A Rise in Both Poverty ...



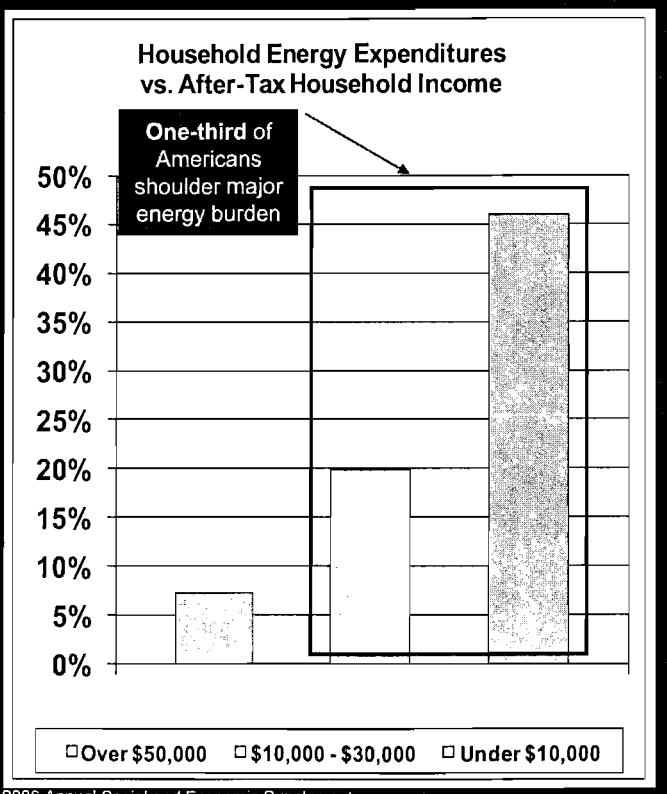
Source: U.S. Census

... and Consumer Debt



Increases in Energy Prices Hit Low- and Fixed-Income Households the Hardest

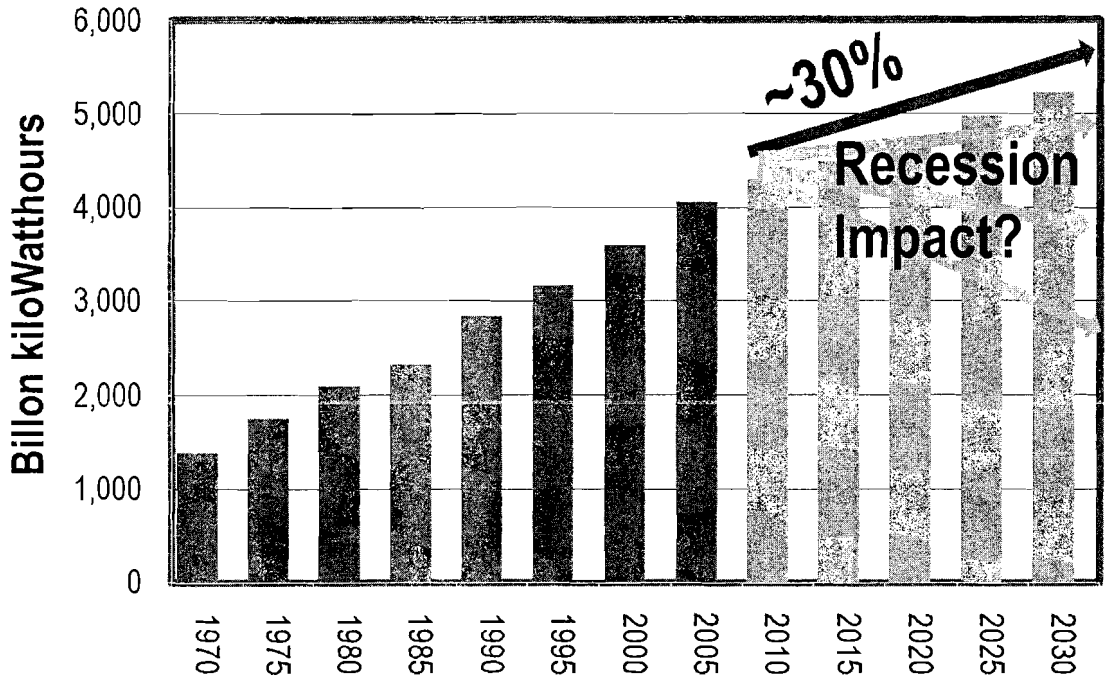
- **Income spent on energy for households earning**
  - >$50,000 / year - **7%** of income
  - $10,000 - $30,000 / year – **20%** of income (25% of households)
  - **<$10,000 / year - 46% of income** (8% of households)
- **Households earning < $30,000**
  - Mostly senior citizens, single parents, and minorities
  - Force hard decisions about what bills to pay ... housing, food, education, health care, and other necessities



Sources: Redefining Progress; U.S. Census Bureau, Current Population Survey, 2006 Annual Social and Economic Supplement

The State of the Business

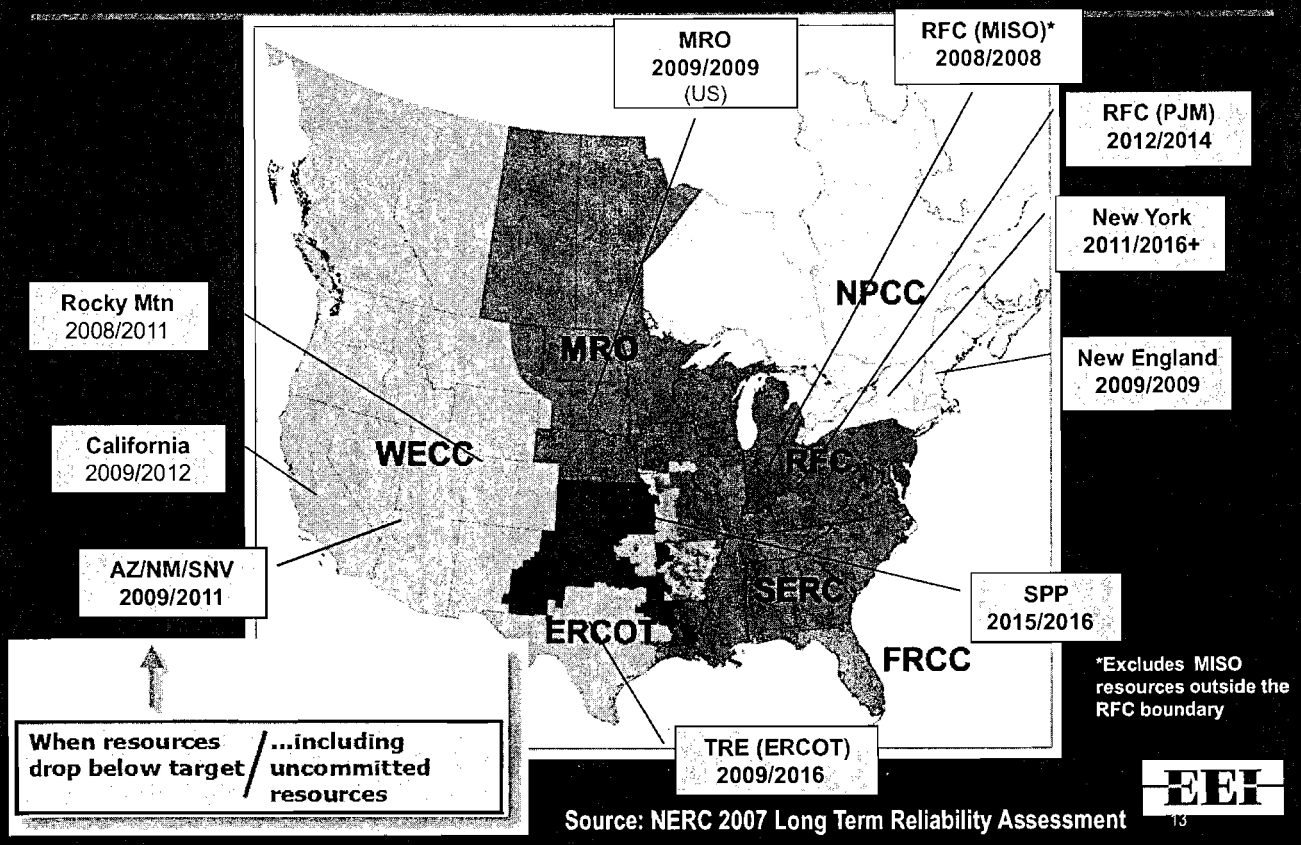
Demand Projected To Increase 30% by 2030



Sources: U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 2006* and *Annual Energy Outlook 2008 Early Release*

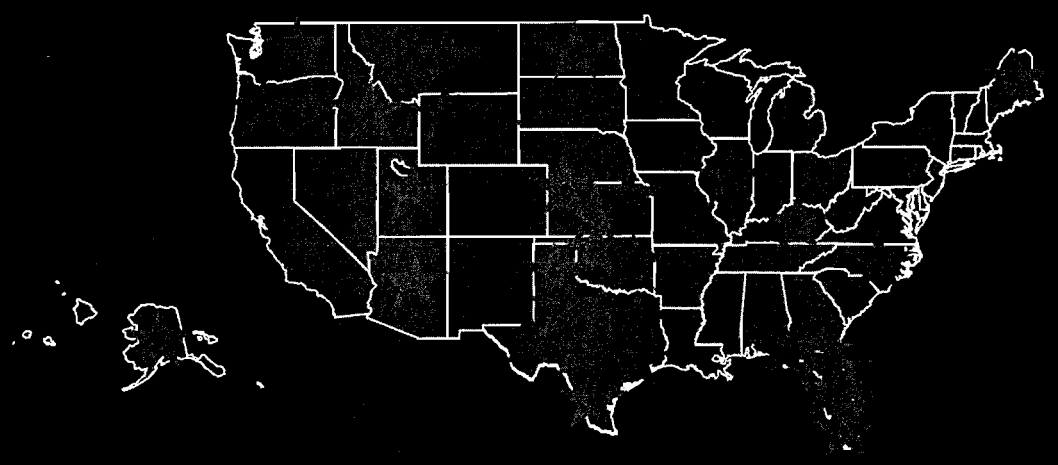
*Electricity demand projections based on expected growth between 2006-2030

Margins Projected to Fall Below Minimum Target Levels

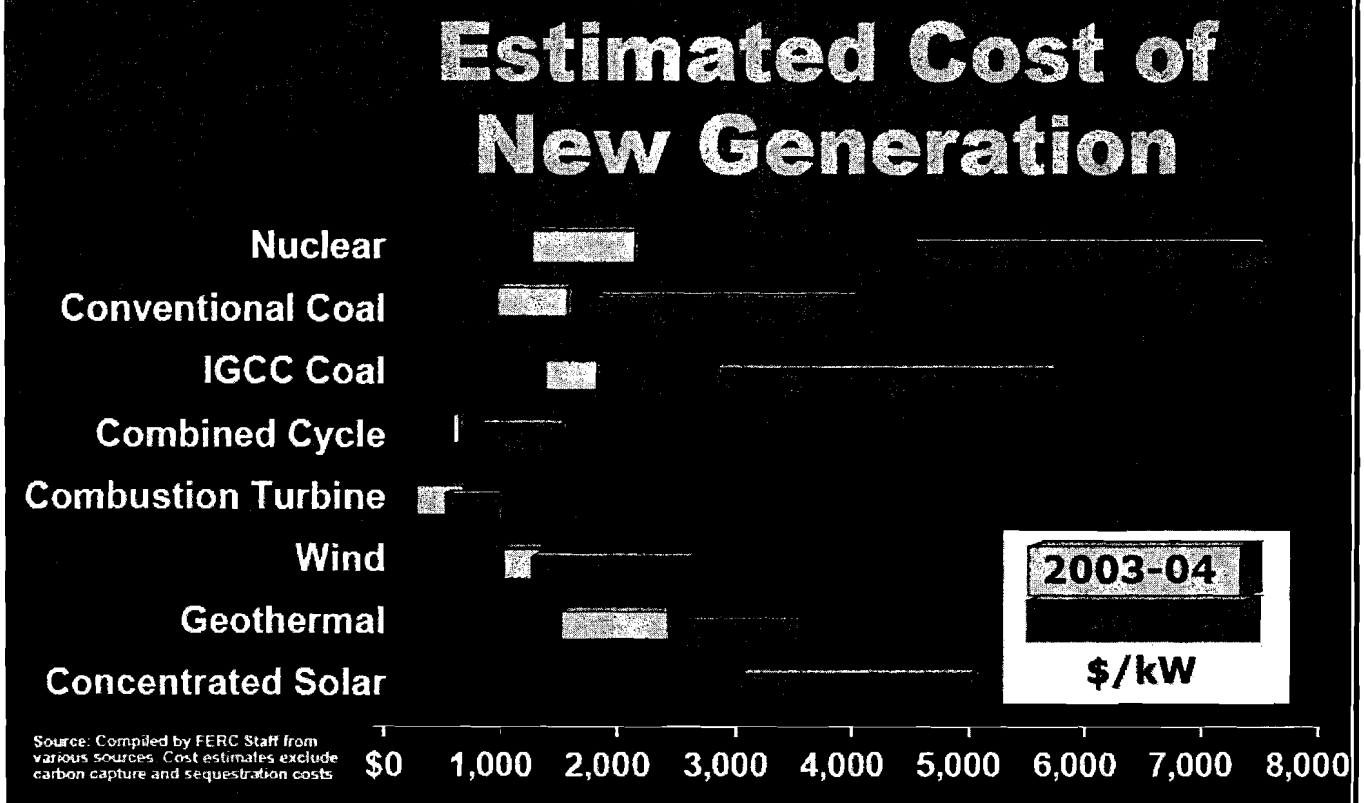


Source: NERC 2007 Long Term Reliability Assessment

Coal Plant Cancellations / Closings 2006 - 2007



Source: NRDC: *The Growing Trend Against Coal-Fired Power Plants; other publications*



Financial Crisis

Making Access to Financial Markets Difficult

EEI

Overview

- **Recession has dampened demand, but demand will rebound and grow into the future**
  - Commodity, equipment, and labor costs are down, making it an ideal time to build and prepare for future demand increases
- **Utility industry at the beginning of a major investment cycle**
  - Driven by new technology, demand growth, efficiency and environmental CAPEX
- **Addressing climate change and new priorities will be costly**
- **Wall Street Restructuring: access to capital markets and increasing cost of capital for needed utility investments**
  - As one of the most capital-intensive industries, reduced access to capital markets at higher costs, means that enhanced liquidity and financial flexibility is important

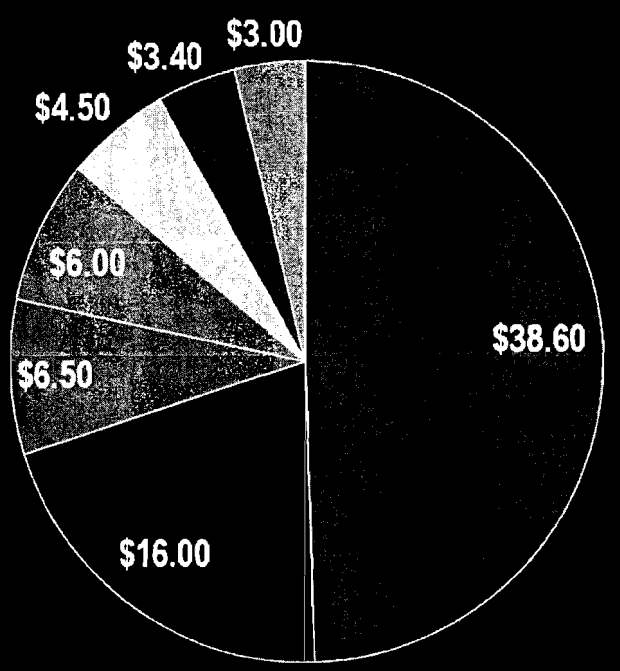
President Obama's Stimulus Vision

- **Immediate action to create good jobs in America**
  - Partner with America's automakers to help save jobs and ensure that the next generation of clean vehicles is built in the USA
- **A rapid, aggressive response to the financial crisis – using all the tools we have**
  - Fight for fair trade
  - Invest in a clean energy economy and create 5 million new green jobs
  - Create new job training programs for clean technologies
  - Boost the renewable energy sector and create new jobs
  - Invest in the sciences
  - Create a national network of public-private business incubators

President Obama's Stimulus Vision

- **Immediate relief for struggling families**
  - Funds to counteract high heating costs this winter – supplement LIHEAP
- **Direct, immediate assistance for homeowners, not a bailout for irresponsible mortgage lenders**
- **Electricity sector**
  - Energy efficiency
  - Smart Grid
  - Transmission
  - Electric Drive Transportation

ARRA Energy Stimulus Funding



(Billion)

- Energy Efficiency
- Renewables
- Federal Bonding Authority
- Loan Guarantee
- Transmission/Smart Grid
- Climate
- Electric Transportation

Total: $78 Billion

View Forward

President Obama's Energy / Environmental Views

Climate Change

80% reduction by 2050

Renewable Portfolio Standards

25% by 2025

Energy Efficiency

Overhaul of Federal Efficiency Codes

Smart Grid

Increased Government Support

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Questions We Must Answer

- **Climate Change**
  - How do you minimize compliance costs on low-income consumers?
  - What must U.S. climate change legislation and carbon management strategy include to ensure economic growth and energy security and avoid unfairness?
- **Energy Efficiency**
  - How significant of a role can energy efficiency play in the future?
  - How can customers benefit and actively participate in energy efficiency programs from the residential and commercial perspectives?
- **Renewable Technology**
  - How much can increased renewable capacity contribute going forward? How can renewables be utilized without substantially raising energy bills for low- and fixed-income households?

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Climate Change A Transformational Issue

- **Changing Regulatory Model (legislative initiatives)**
  - **Market / Environmental Initiatives**
    - Cap and Trade System
    - Renewable Portfolio Standards / Energy Efficiency Resource Standards
  - **New Federal / State Authorities**
    - Siting, planning, cost allocation
    - Market and environmental oversight
- **Changing Industry Business Model**
  - **Green / More Efficient Economy**
    - Alter power supply mix
    - Energy efficiency as a viable business
    - Embrace smart technologies – give customers information and tools
    - Support new technologies – storage, DG, Large scale renewables
    - Implement PHEV infrastructure
  - **A more reliable and secure grid**

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What Will It Take To Address Climate Change?

There Is No Silver Bullet!

- Renewables
- Energy Efficiency
- Clean Coal Technologies
- Carbon capture and storage
- Nuclear
- Plug-in hybrid electric vehicles

We need it all ...

but it will be costly!

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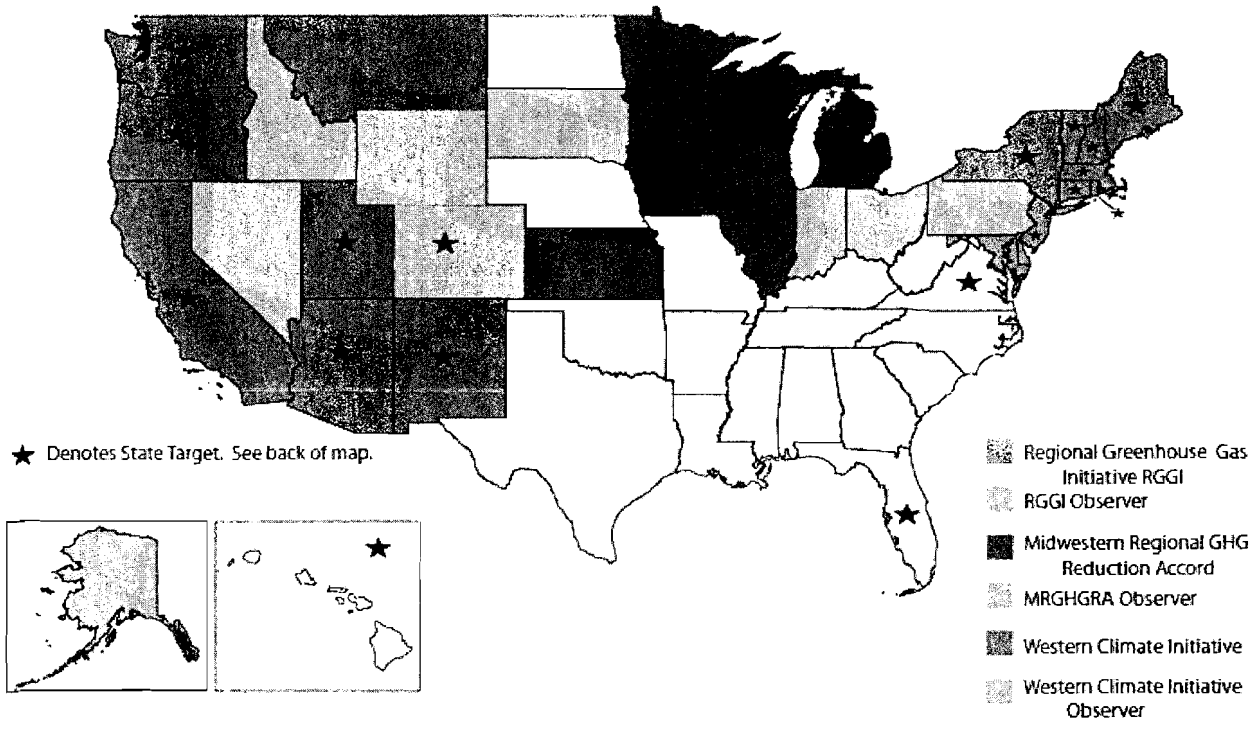
Regional GHG Programs & State GHG Targets



Edison Electric Institute, status as of December 9, 2008.

Key Climate Questions

- Targets and Timetables?
- Economy Wide?
- Cap-and-Trade or Tax?
- Mitigating Customer Impacts?
  - Auction and Dividend
  - Allocation to electric sector

Key Elements of H.R. 2454

- Economy-wide
- Targets and timetables – below 2005
  - 3% by 2012
  - 17% by 2020
  - 42% by 2030
  - 83% by 2050
- Combined Renewable Energy Standard (CRES) and Energy Efficiency Resource Standard (EERS)
  - **20% renewables by 2020** with **2.5¢ / kWh** alternative compliance payment
    - 75% must be met with renewables
    - Governor can petition to meet 40% with energy efficiency
    - Effectively allows RES at 12-18% and EERS of 2-8%
    - Alternative compliance payments stay within state

Key Elements of H.R. 2454

- **Cap and Trade - Auctions and Allowances**
  - Exclusively for the "benefit of customers"
  - **35% of allowances to electric sector until 2025 with 5 yr phase-out**
    - 30% to local distribution companies (LDCs)
      - 50% based on emissions, including purchased power
      - 50% based on retail sales
    - 5% to merchant coal generators and generators with long-term contracts (PPAs)
      - Up to 3.5% for merchant coal
      - PPAs get allowances equal to carbon costs

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Auctions vs. Allocation

- **Obama budget projects $646 billion in revenue by 2020 from 8 years of auctions:**
  - $120 billion to be spent on clean energy technologies
  - $83 billion returned to taxpayers through Making Work Pay tax credit.
  - Remainder devoted to ??
  - May be "additional net proceeds"

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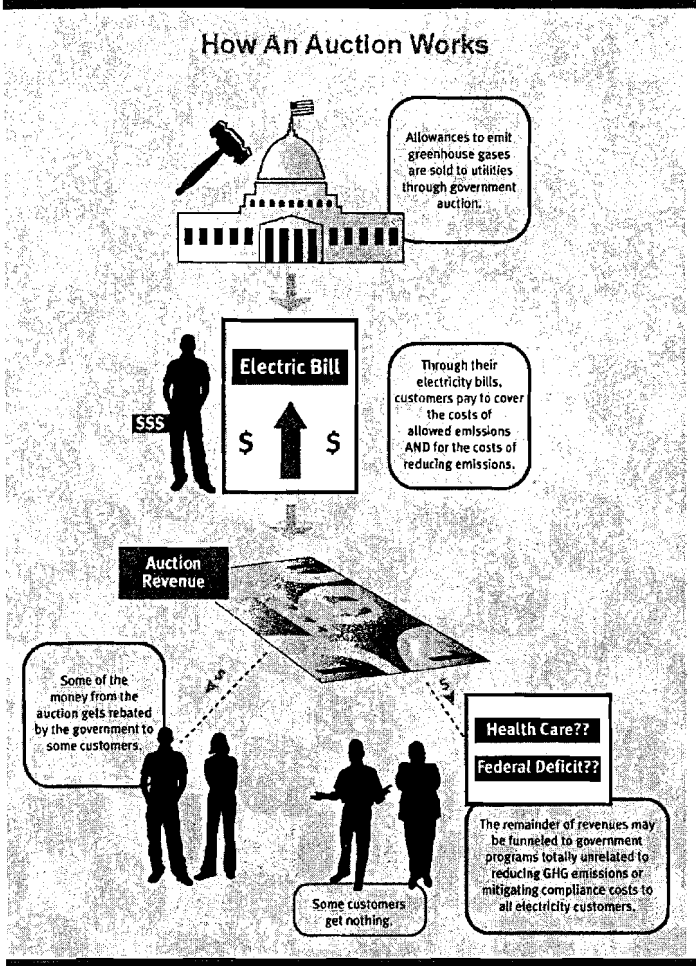
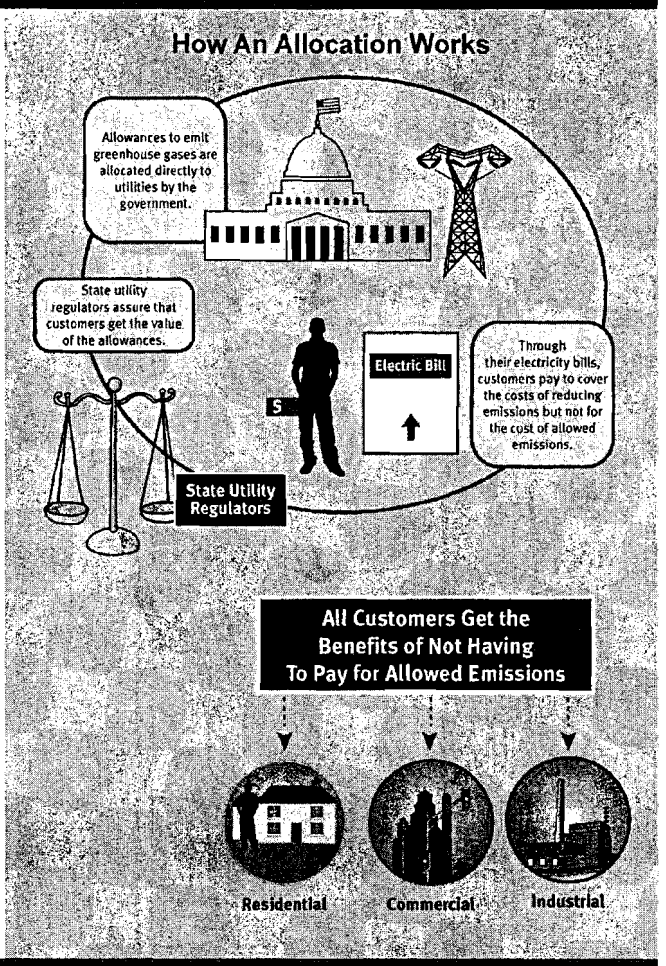




Financial Impacts of Climate Change

EPA

Household spending would drop by about $140 / year by 2020; gas prices would increase 33 cents / gallon by 2030

CRAI (for National Black Chamber of Commerce)

By 2015; $730 / year less in household purchasing power, electric rates would increase 7.3% by 2015; gas prices by 12 cents / gallon

Heritage Foundation

By 2035 electricity rates would increase by 90%, gas prices by 74%, household energy bills by $1500

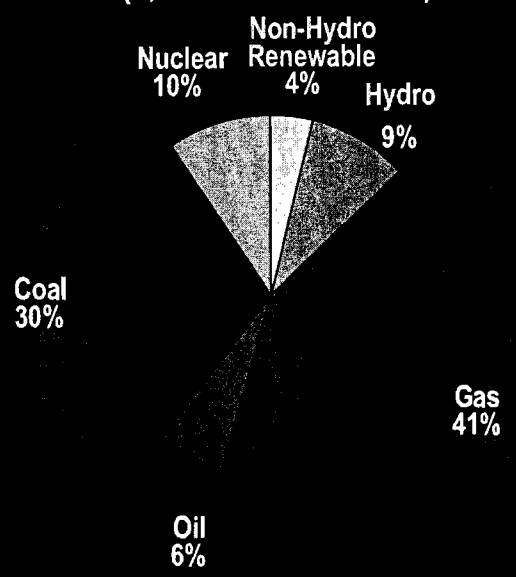
It's ALL About the Assumptions!

EEI

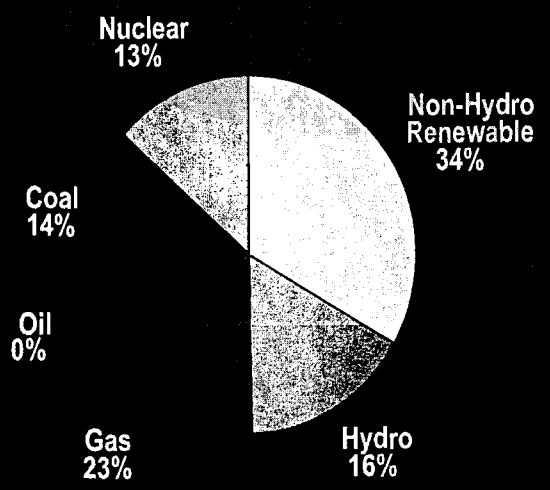
The Enhanced Role for Renewables

Planned Capacity Additions Reflect State RPS Requirements

US Generation Capacity in 2008
(1,061 GW in Service)



Planned Capacity Additions to 2020
(352 GW)

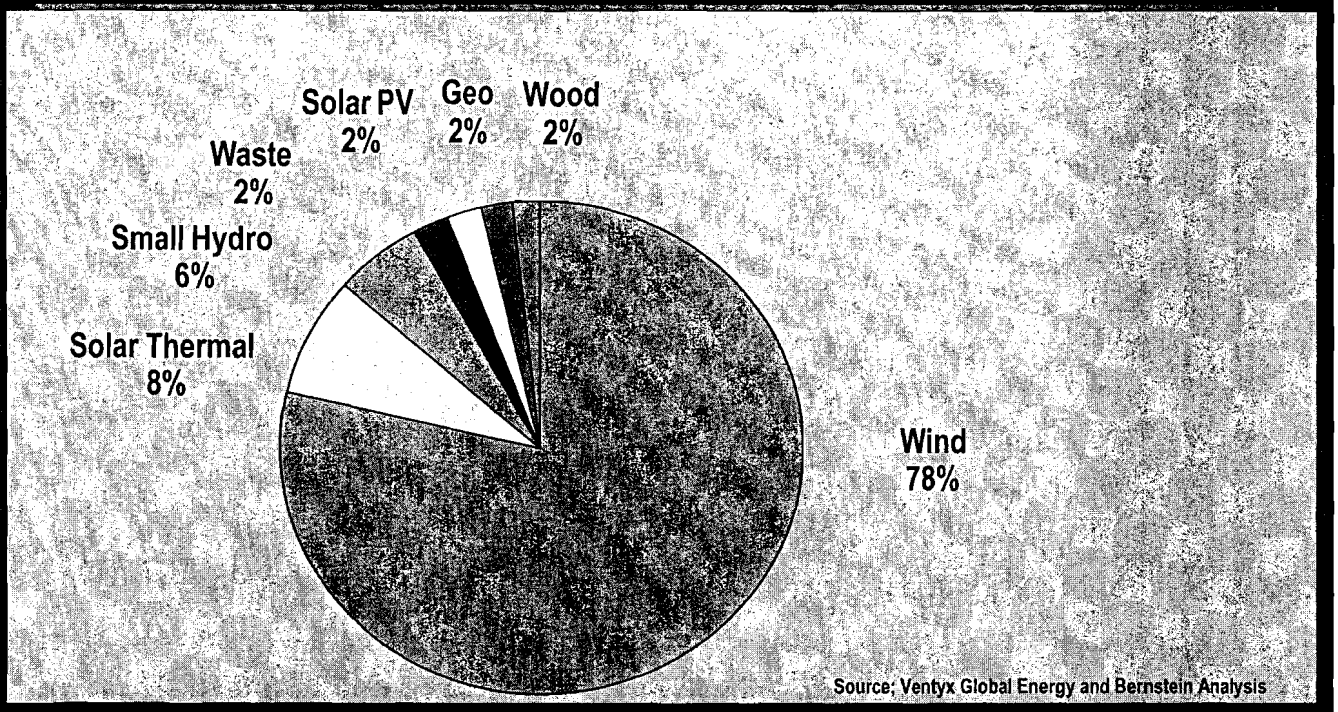


Source; Ventyx Global Energy and Bernstein Analysis

Non-hydro renewables make up 4% of US capacity today but 34% of planned capacity additions through 2020.

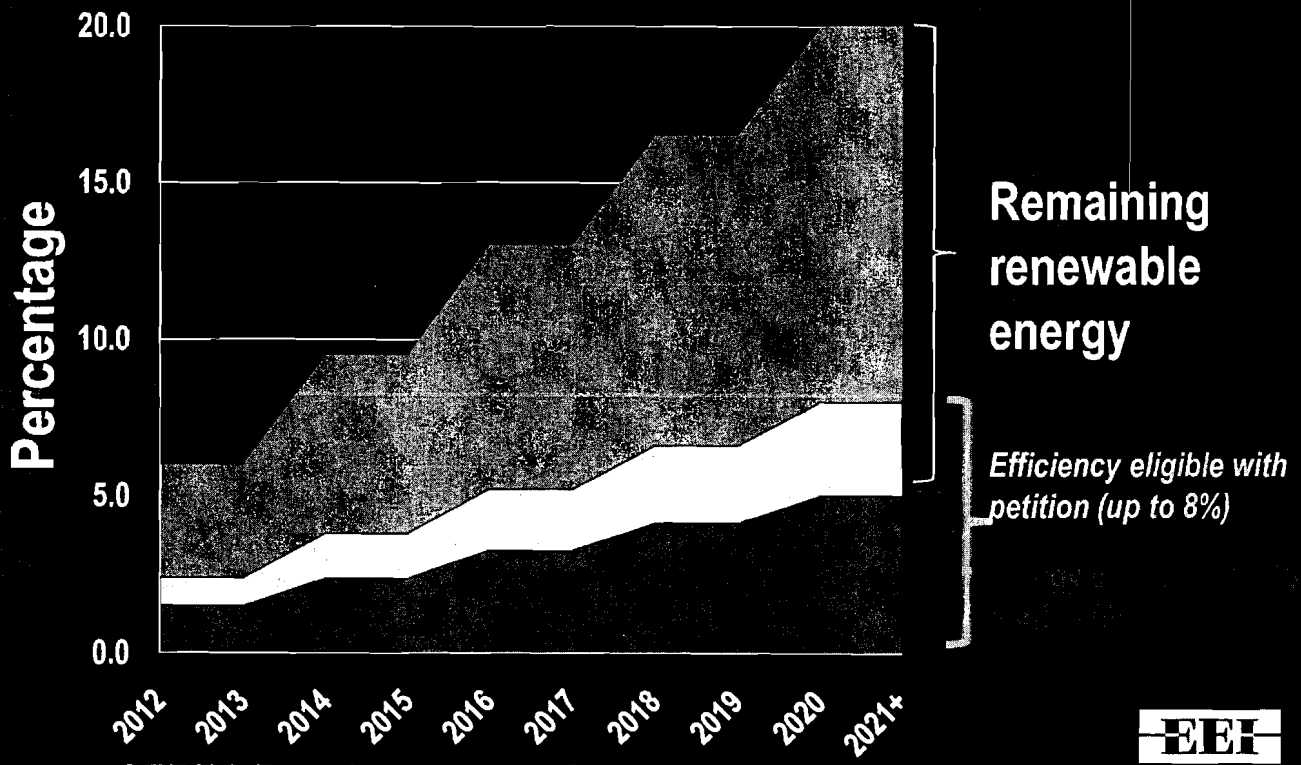
Source: Bernstein Research

Wind Dominates Proposed Renewable Capacity Additions Thru 2020



- Wind is 78% of planned renewable additions, solar thermal 8%, solar photovoltaic 2%
- Wind's off-peak capacity limits usefulness on power grids

Waxman-Markey CERES Requirements 20% by 2020



CERES Requirements as Percentage of Retail Sales

Electric Market Overview: Renewable Portfolio Standards

Federal Energy Regulatory Commission • Market Oversight @ FERC.gov

30 States* including D.C. have Renewable Energy Portfolio Standards (RPS)

ND: 10% by 2015
SD: 10% by 2015
NE: studying an RPS
KS: 20% by 2020
OK: Studying an RPS

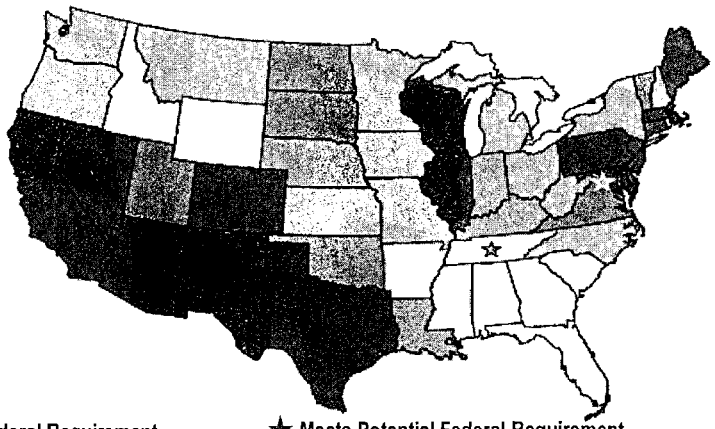
MN: 25% by 2025
IA: 105 MW
MO: 15% by 2021
WI: 10% by 2015
IL: 25% by 2025

MI: 10% MWh and 1,100 MW by 2015
IN: different bills pending
OH: 12.5% by 2025
WV: 25% by 2025
KY: Report recommends RPS

ME: 40% by 2017
NH: 23.8% by 2025
VT: 25% by 2025
MA: 15% by 2020
RI: 16% by end 2019
CT: 27% by 2020
NY: 25% by 2013
PA: 18% by 2020
NJ: 22.5% by 2020
DE: 20% by 2019
DC: 20% by 2020
MD: 20% by 2022
VA: 12% by 2022
NC: 12.5% by 2021
TVA: 50% by 2020

WA: 15% by 2020
OR: 25% by 2025
CA: 20% by 2010; Exec order: 33% by 2020
MT: 15% by 2015
NV: 25% by 2025
UT: 20% by 2025
CO: 20% by 2020
AZ: 15% by 2025
NM: 20% by 2020
TX: 5,880 MW by 2015

HI: 20% by 2020



Exceeds Potential Federal Requirement
Meets Potential Federal Requirement

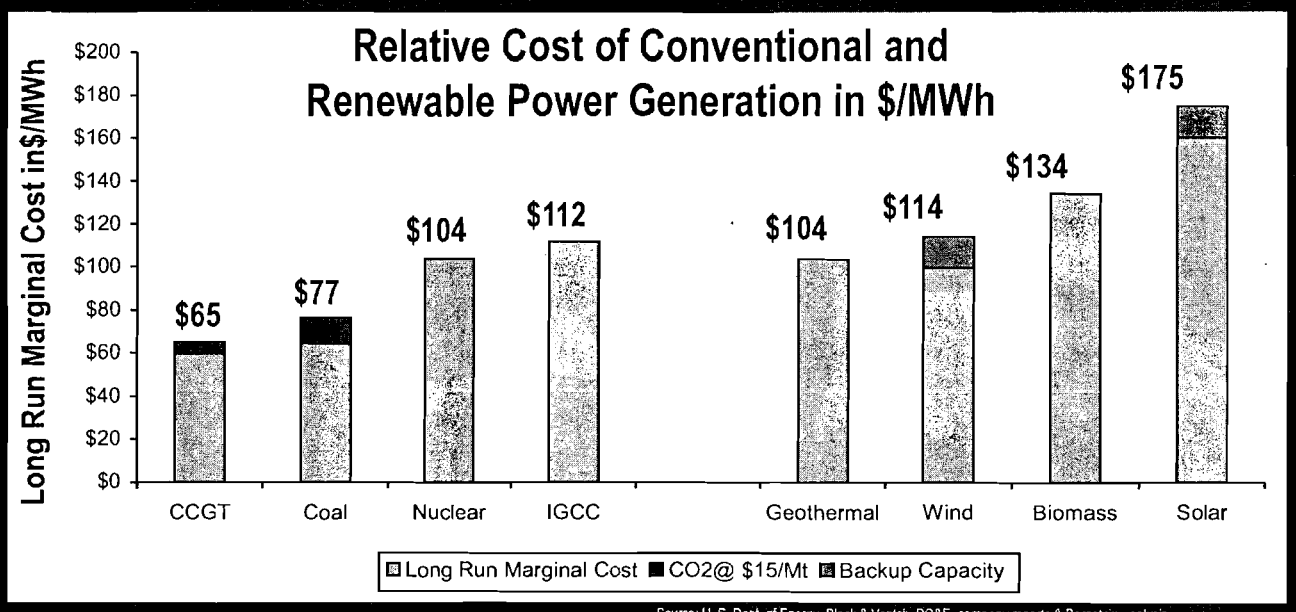
Updates at: http://www.ferc.gov/market-oversight/mkt-electric/overview/elec-ovr-rps.cdf

RPS
Accelerated or strengthened RPS
Voluntary standards or goals
Proposed RPS or studying RPS

Notes: *31 states if WV's Governor signs the Alternative & Renewable Energy Portfolio Act, passed 6/2/09. An RPS requires a percent of an electric provider's energy sales (MWh) or installed capacity (MW) to come from renewable resources. Most specify sales (MWh). Map percents are final years' targets. *TVA's goal is not state policy; it calls for 50% zero- or low-carbon generation by 2020. Alaska has no RPS.
Sources: Derived from data in: LBNL, *RPS in the U.S. through 2007* (4/08), PUCs, State legislative tracking services, Pew Center, and the Union of Concerned Scientists. Details, including timelines, are in the Database of State Incentives for Renewables and Energy Efficiency: http://www.dsireusa.org

Updated June 8, 2009

Renewables Are Expensive.... But So Is Conventional Power



Source: U. S. Dept. of Energy, Black & Veatch, PG&E, company reports & Bernstein analysis

- Assumes LR fossil fuel costs $7 / MMBtu gas and $65 / ton Appalachian coal (equal to $2.60 / MMBtu), conventional resources cost ~$60-$110 / MWh, excluding CO2, vs. $105-$135 for geothermal, wind and biomass.
- The increase in renewable generation required by state RPS is only 8% of supply.

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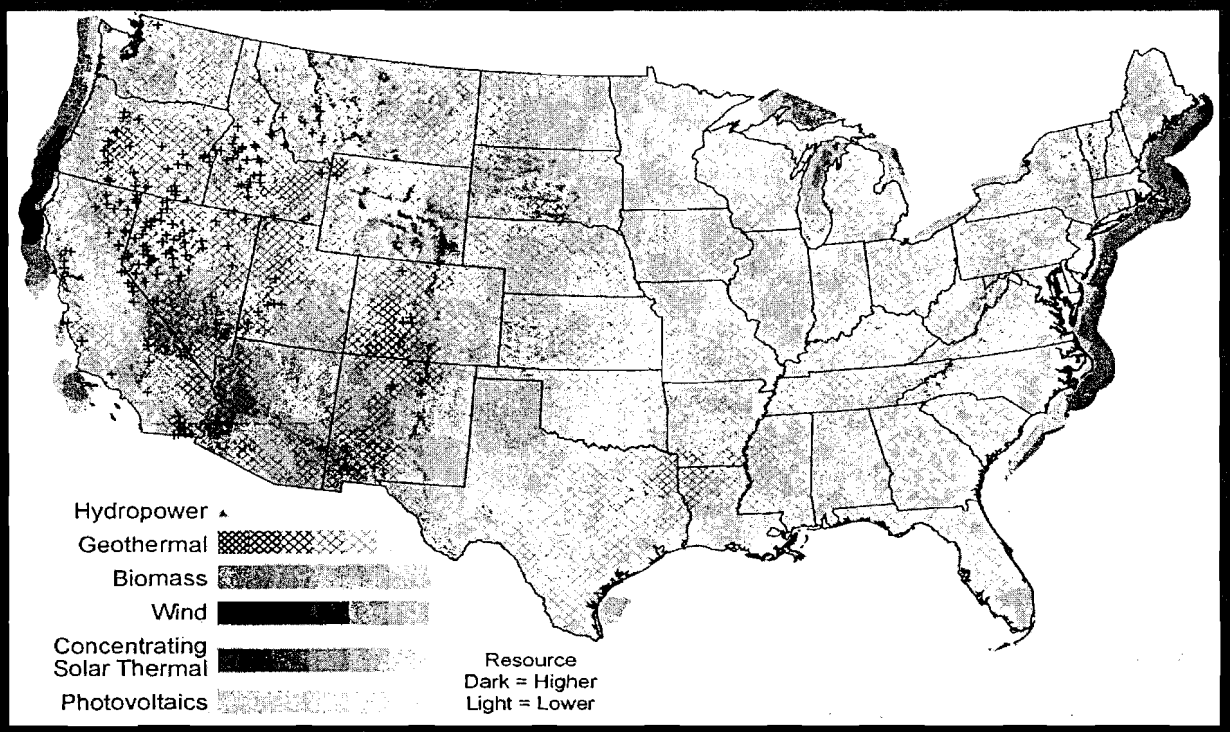
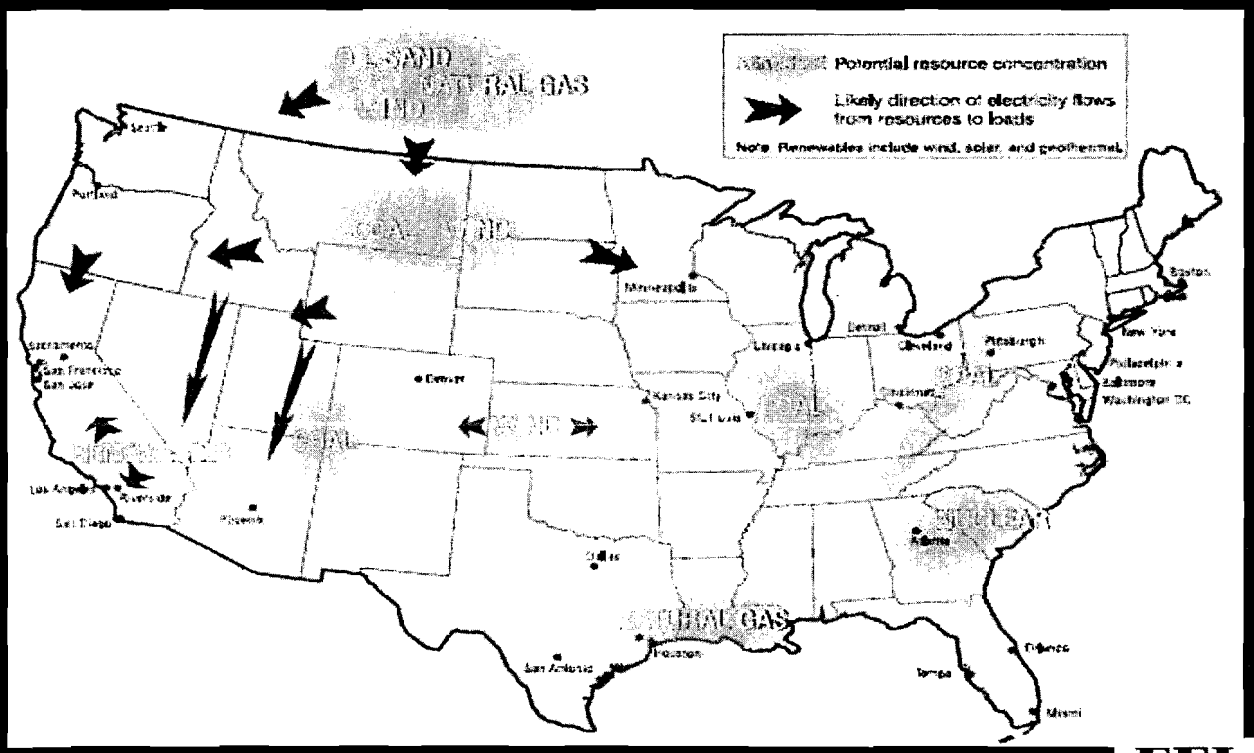
U.S. Renewable Resources

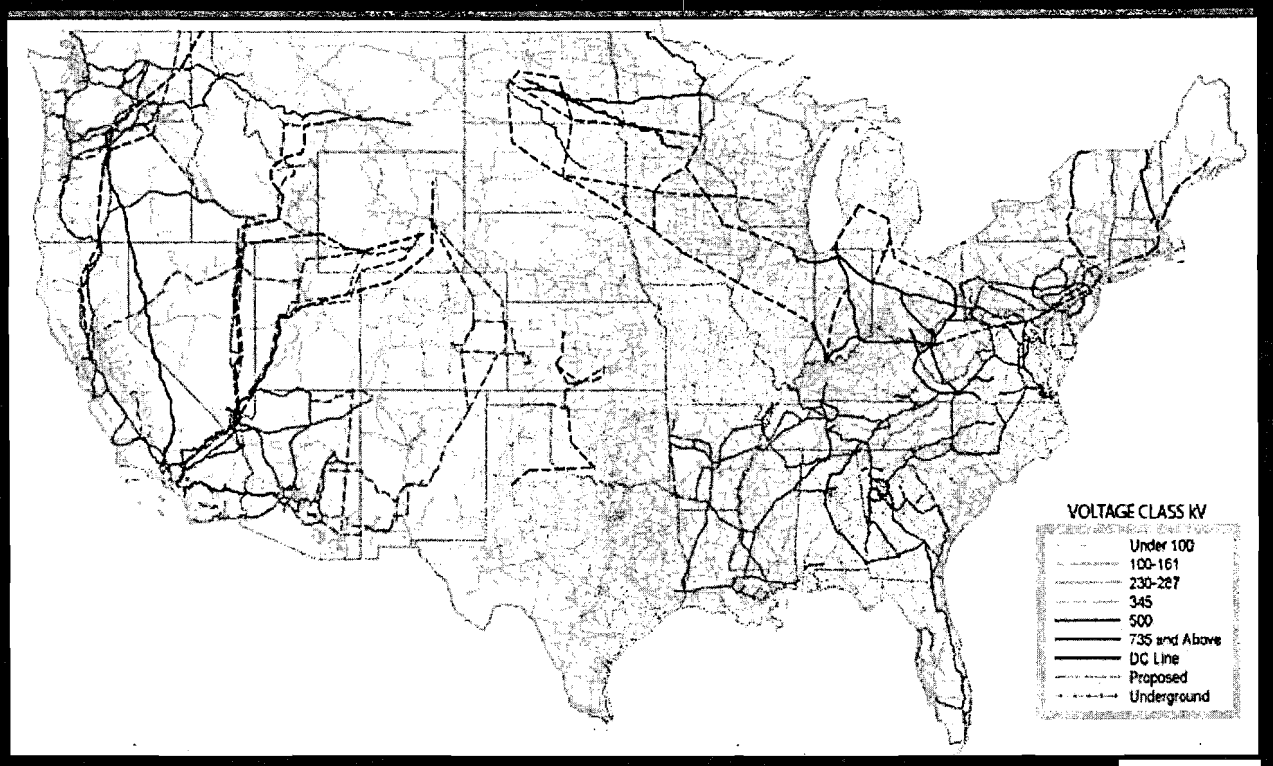


Source: National Renewable Energy Laboratory

Biggest Challenge ... Dramatically Increasing Transmission Congestion



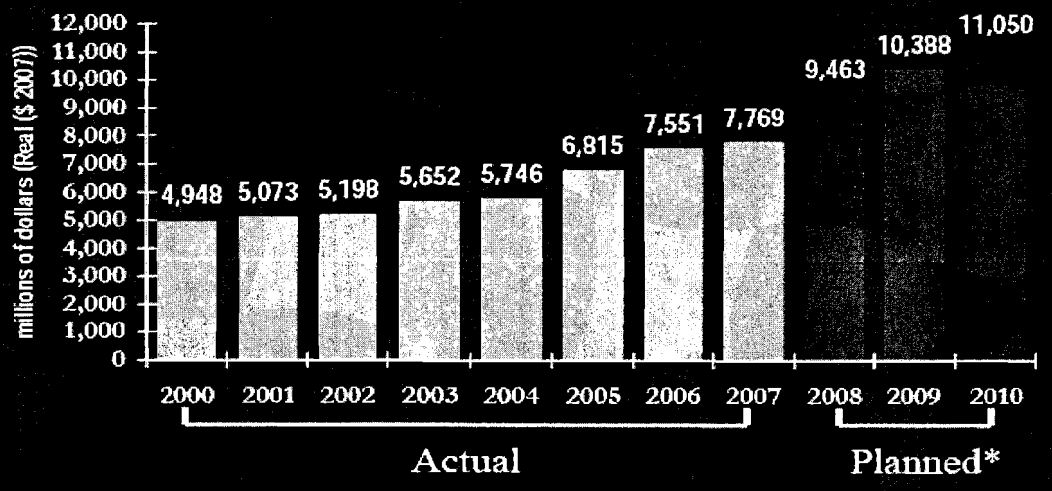
US Transmission Lines & Grid



Source: Produced by Edison Electric Institute. Data Source: Ventyx,Inc., The Velocity Suite 2009.

Actual and Planned Transmission Investment

Actual and Planned Transmission Investment by Investor-Owned Electric Utilities (2000-2010)



Note: Handy-Whitman Index of Public Utility Construction Costs used to adjust actual investment for inflation from year to year. Data represents both vertically integrated and stand-alone transmission companies. *Planned total industry expenditures are preliminary and estimated from 85% response rate to EEI's Electric Transmission Capital Budget & Forecast Survey. Actual expenditures from EEI's Annual Property & Plant Capital Investment Survey & Form 1s.

The Biggest Challenge for Interconnecting and Integrating Renewables is Transmission .....

- Planning
- Siting
- Cost Allocation

Renewables are Variable Resources!

Senate Transmission Provisions

Planning

- Develop national policy principles
- Roll up regional plans to interconnection-wide plan
- Modify plans, if necessary, to achieve policy objectives
- Applies to federal, state, municipal utilities, and cooperatives

Siting

- No renewable energy zones
- Backstop authority, with eminent domain, for high-priority national projects - 345 kV and above, renewable feeder lines 100 kV and above
- Applies if state fails to act in one year, denies, or imposes unreasonable conditions; must consult with states on state mitigation measures

Cost Allocation

- Due deference to methodologies broadly supported by affected states
- FERC must develop methodology
- Interconnection-wide cost allocation permissible; costs must be reasonably proportionate to measurable economic and reliability benefits

Lead Agency

- Department of Interior

Operational Challenges For Integrating Renewables

- **Higher RPS levels can create significant surplus energy**
  - Can't be used on grid or sold to others
  - Energy storage / off-peak electric vehicle charging can mitigate problem
  - At present these technologies can not significantly contribute to resource plans - smart grid will help enable these new technologies
- **Higher RPS levels will require higher planning reserve margins for system backup to maintain reliability**
  - More ancillary services req'd to maintain frequency and voltage levels
  - Generation and storage technologies required to meet system regulation, load following, and ramping requirements
  - Quick start and fast ramping technologies (peaking / storage) to manage generation variability and maintain reliability

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The New Role for Energy Efficiency

The Energy Efficiency Challenge

- **Average US household owns 24 consumer electronic products**
  - 2 DVRs use as much energy in 1 year as a refrigerator
  - Play Station and X-Box use more electricity than a PC
  - PCs and TVs now account for 10% of a home's electricity usage
  - 99% of these products must be plugged in or recharged
  - 42" Plasma TV uses more than twice as much as a standard 27" TV
- **More efficient use of energy could significantly reduce energy bills**
- **Need to educate <u>all</u> consumers about how to save energy and use it more efficiently**

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Intensified National Commitment To Energy Efficiency Is Needed

- **Aggressive campaign for technologies**
  - Smart buildings
  - Smart appliances
  - Smart electric meters and grid
  - Smart rates
- **Use of "smart technologies" and new rate designs can:**
  - Allow consumers to control their energy usage to save money
  - Avoid wasting energy
  - Control how and when appliances do their jobs
  - Help utilities efficiently operate their systems and maintain reliability
  - Help keep supply and demand in balance
  - Support more efficient use of generating resources
- **Commercializing plug-in hybrid electric vehicles**

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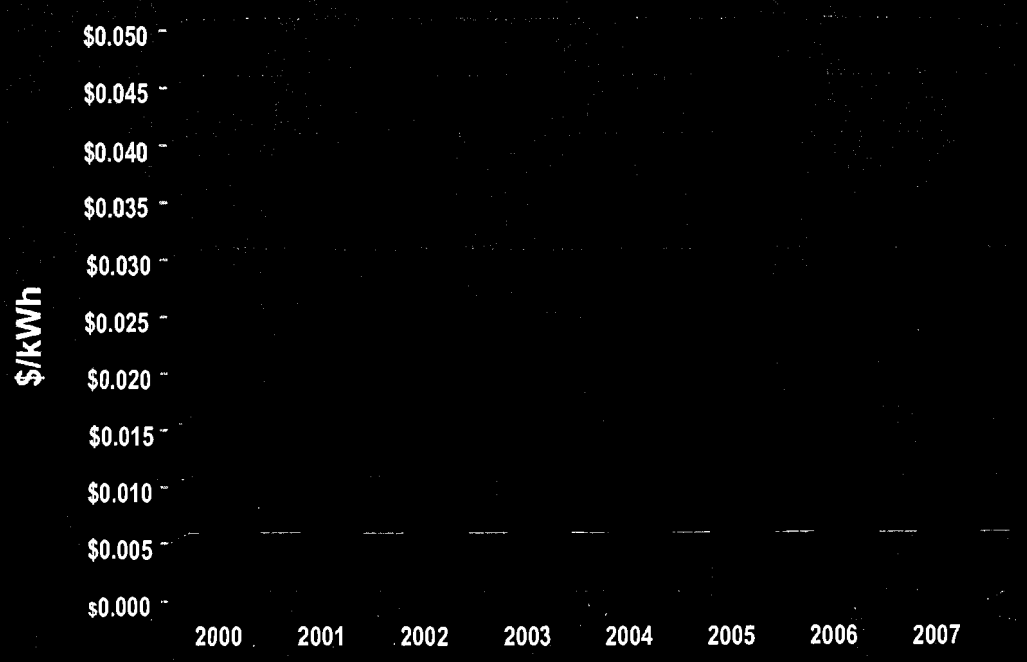
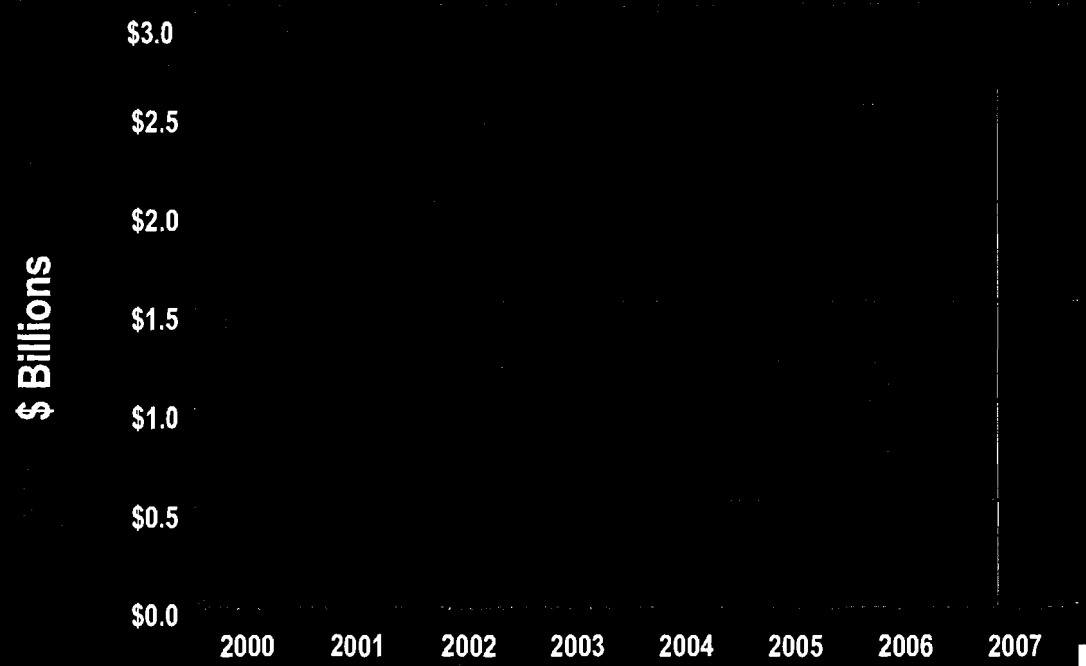
Energy Efficiency - Our 1st fuel
Ave. Cost ~$0.035 / kWh Saved

Total Utility EE Costs per kWh Saved



Source: The Edison Foundation – Institute of Electric Efficiency; **EIA Form 861**

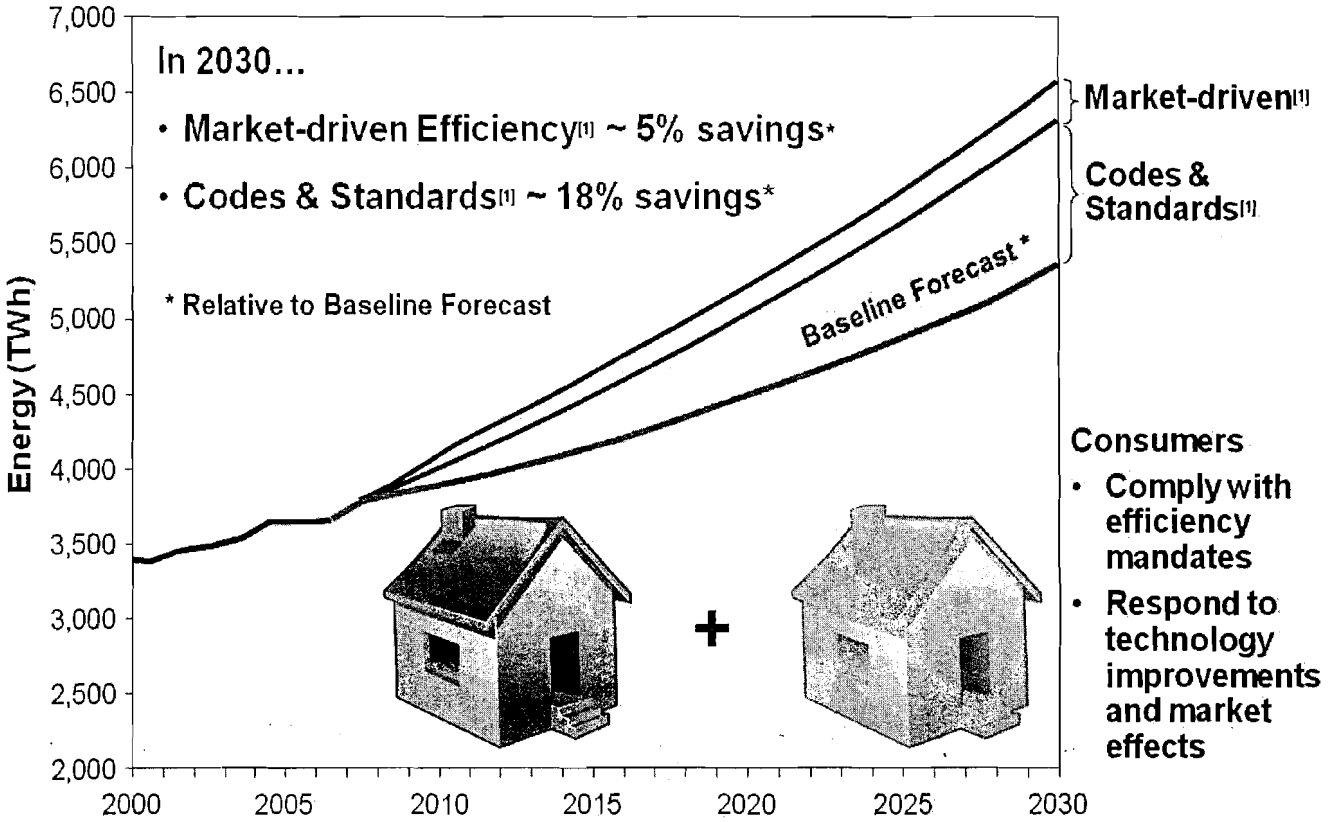
Total Utility Spending on Energy Eff. & Load Mgmt. *$2.5 Billion in 2007*



Source: The Edison Foundation – Institute of Electric Efficiency; EIA Form 861

Electricity Consumption...

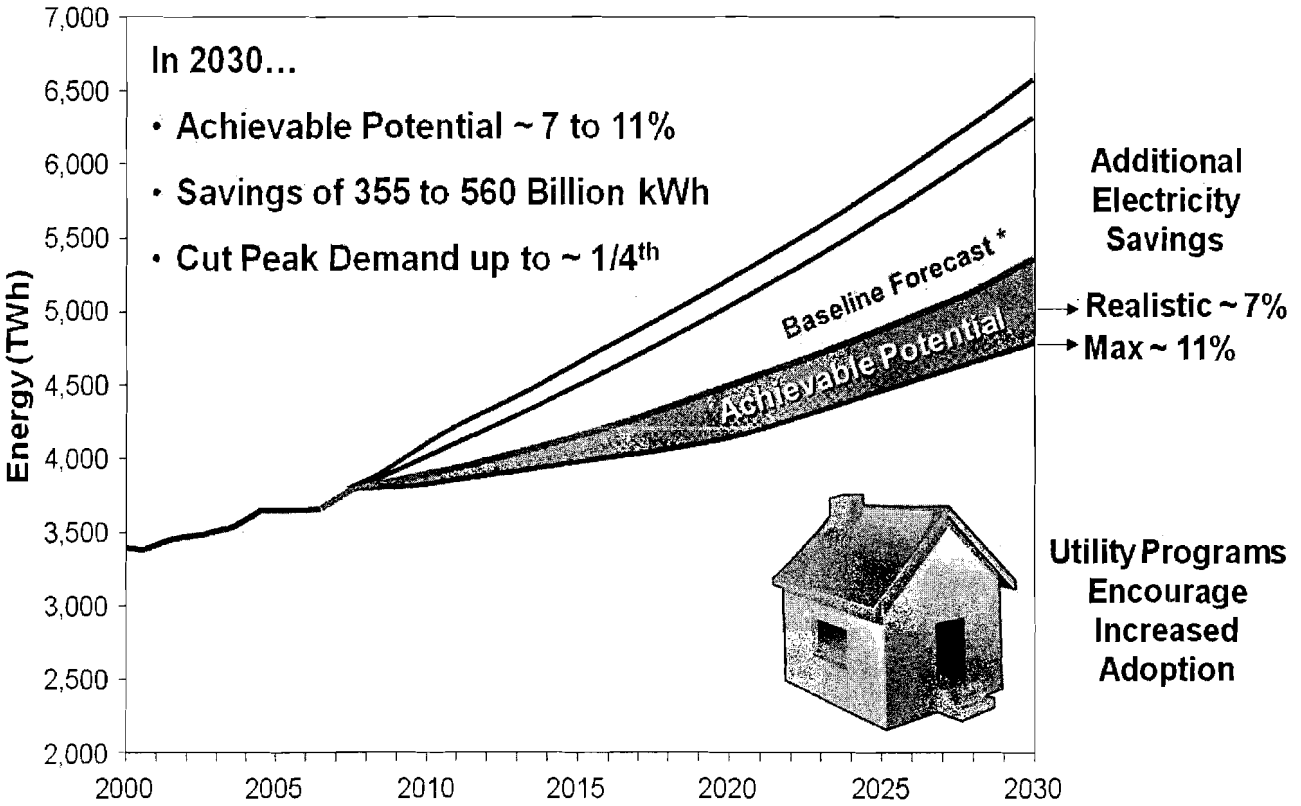
Impact of Codes & Standards and Market-Driven Efficiency



[1] Definitions on Slide 11 and 13 * Based on EIA Annual Energy Outlook 2007 (Residential, Commercial, and Industrial sectors)

Electricity Consumption...

Achievable Potential Electricity Savings

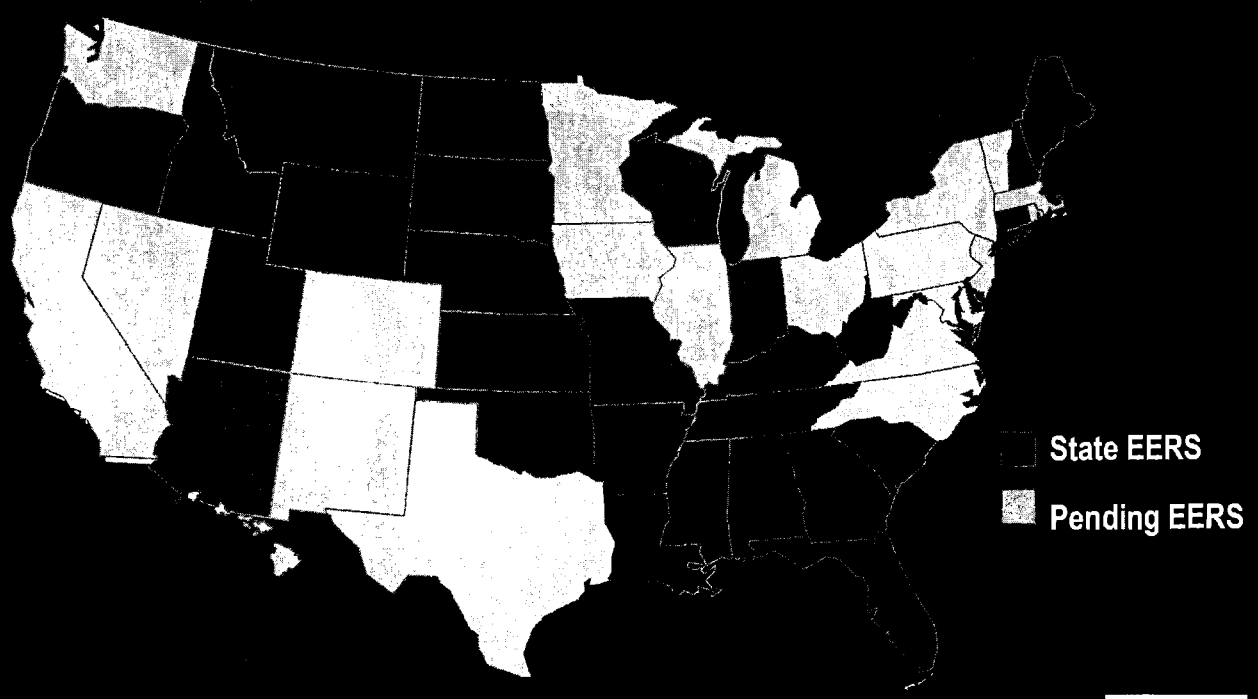


[1] Definitions on Slide 13 * Based on EIA Annual Energy Outlook 2007 (Residential, Commercial, and Industrial sectors)

State Energy Policies Support Energy Efficiency in the U.S.

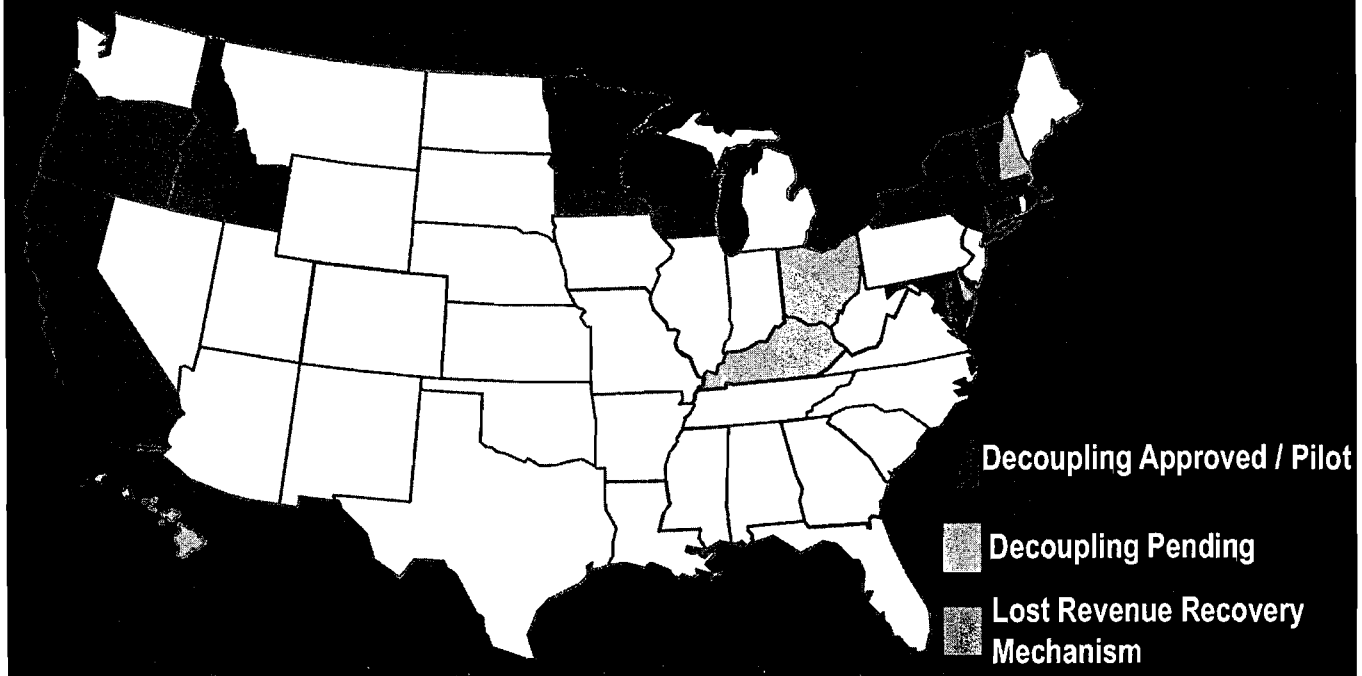
- EE savings represent ~1.8% of electricity sales
- Utilities recovery costs for EE program expenditures
  - Direct cost recovery
- Some states have lost revenue recovery or "decoupling"
  - Recovers lost revenue (lost margins) as a result of EE savings
- Many states now have performance incentives for "successful" EE investments
- About 19 states in U.S. have energy efficiency resource standards (EERS)
  - In some states, EE is part of RPS.

States with Energy Efficiency Resource Standards (EERS)



Source: ACEEE (March 2009)

States With Electric Utility Lost Revenue Recovery or Decoupling



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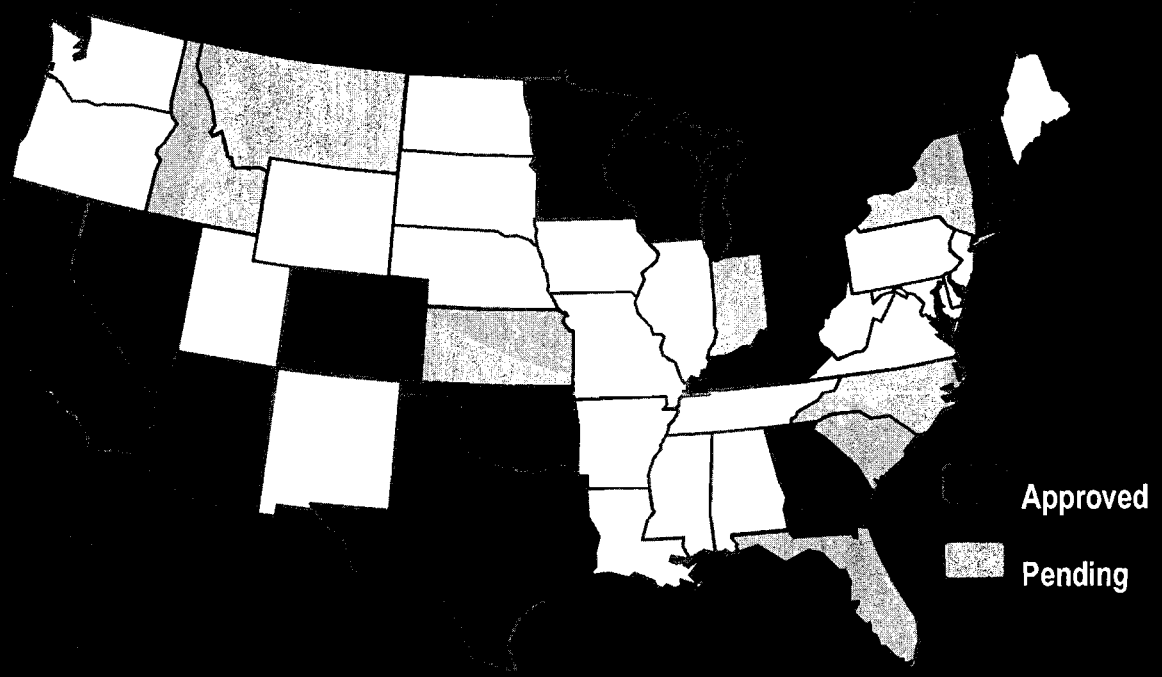
Performance Incentives for Energy Efficiency Programs



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What is the Smart Grid?

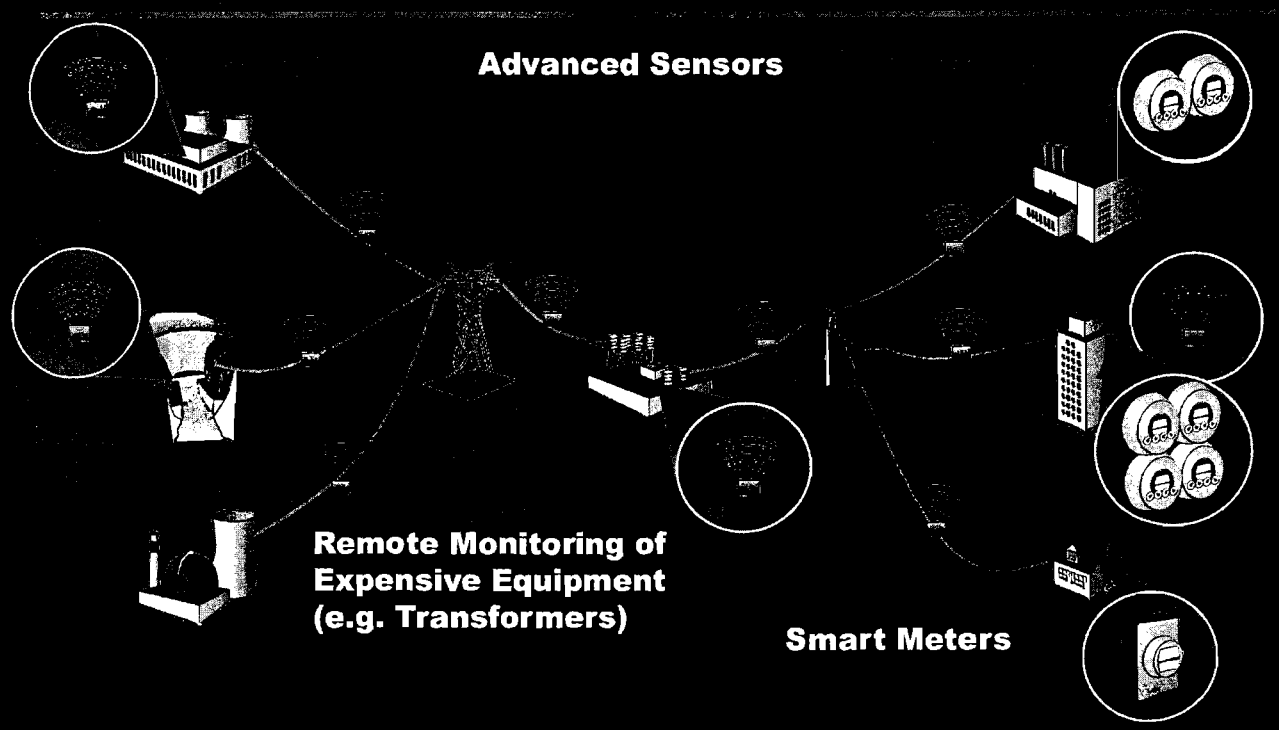
An advanced, telecommunication / electric grid with sensors and smart devices linking all aspects of the grid, from generator to consumer, and delivering enhanced operational capabilities that :

Provide CONSUMERS with the information and tools necessary to be responsive to electricity grid conditions (including price and reliability) through the use of electric devices and new services (from smart thermostats to PHEV)

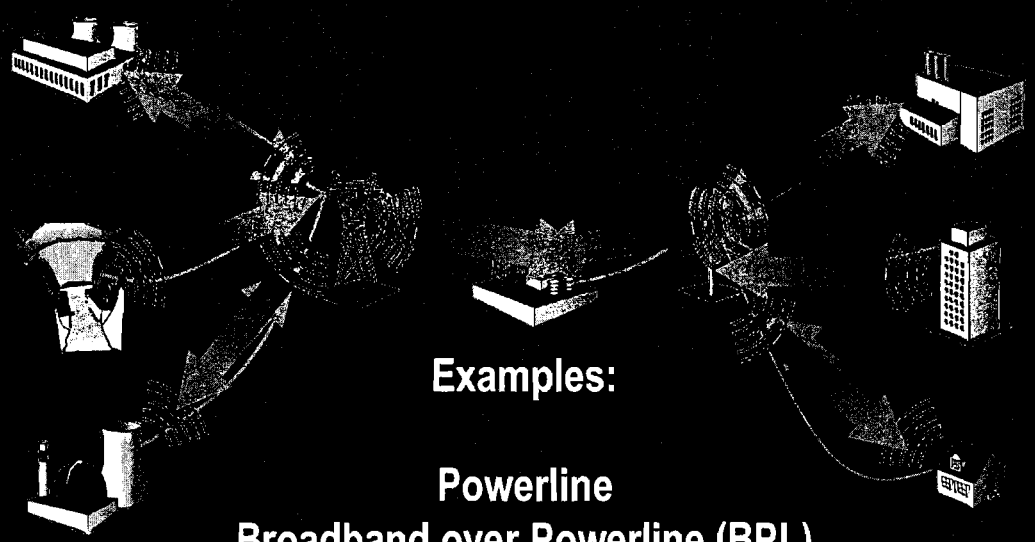
Ensure EFFICIENT use of the electric grid (optimizing current assets while integrating emerging technologies such as renewables and storage devices)

Enhance RELIABILITY (protecting the grid from cyber and natural attacks, increasing power quality and promoting early detection and self correcting grid "self-healing")

Smart Grid ...
Sensing and Measurement



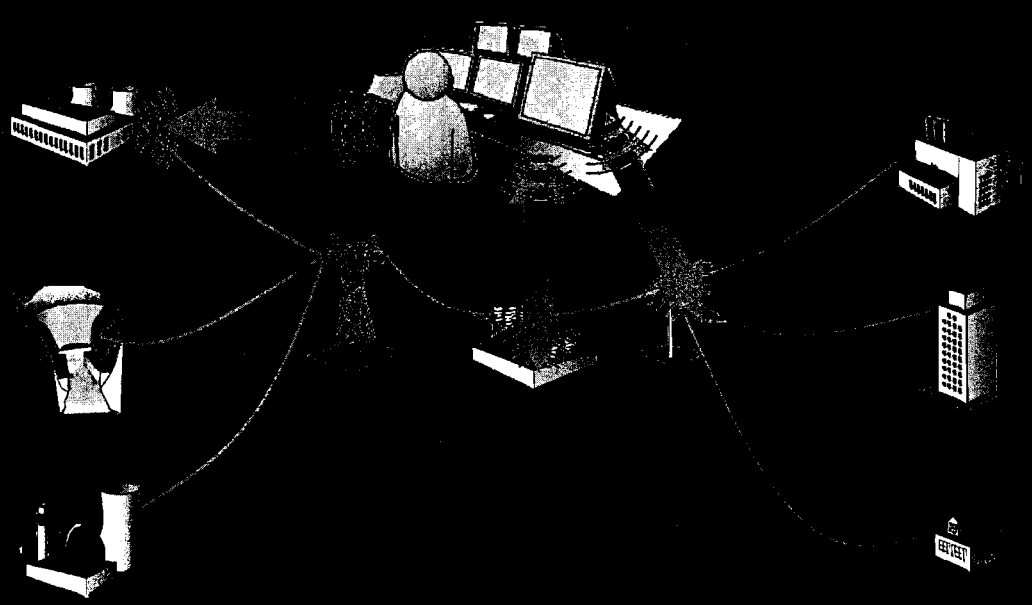
Smart Grid ...
Integrated Communications



Examples:

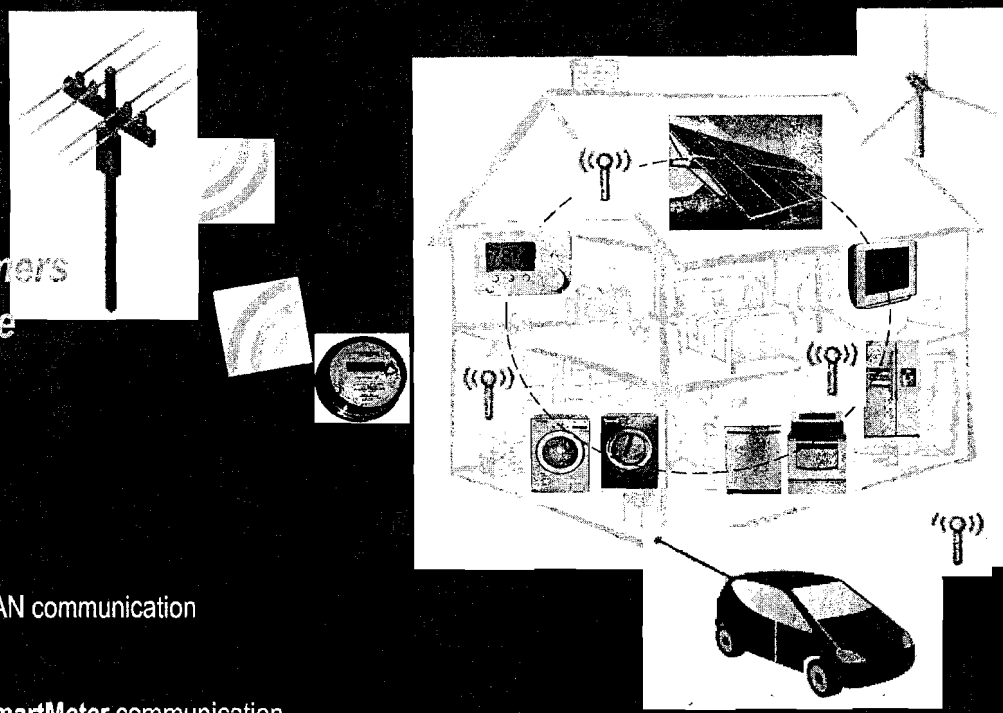
Powerline
Broadband over Powerline (BPL)
Cellular
Radio Frequency (RF)
Satellite

Smart Grid ...
Advanced Control



Smart Meters / Home Area Networks Will Take EE and DR to New Levels

Giving customers the tools and the know-how to be smarter energy consumers

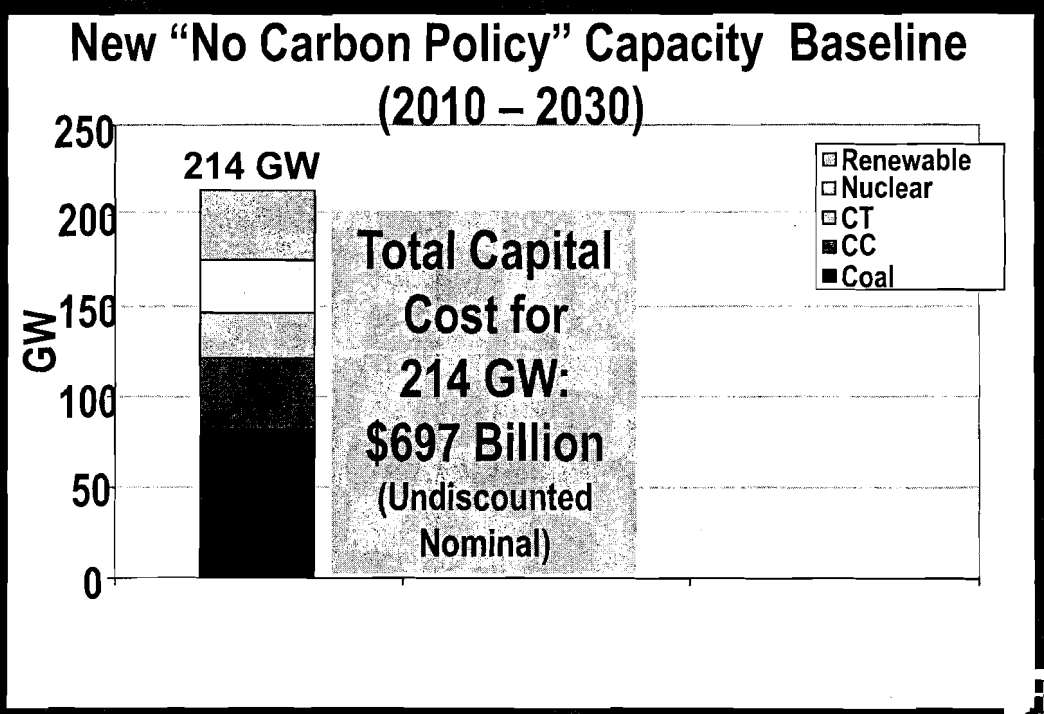


HAN communication

SmartMeter communication

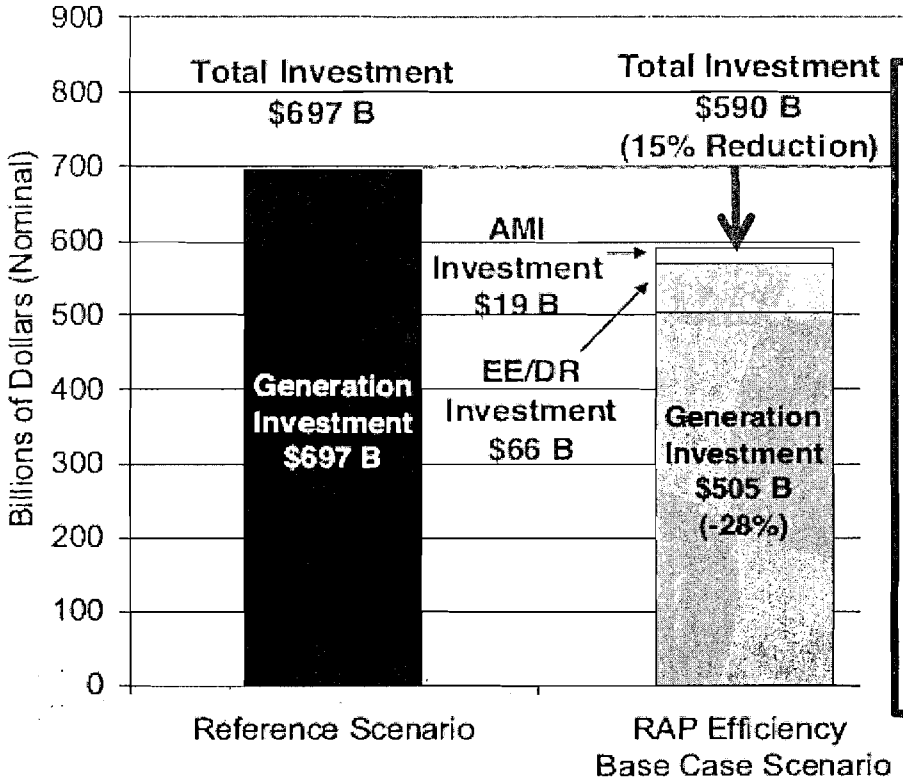
Major Impacts on Generation Investment

214 GW of new capacity needed if we do nothing



Prepared for the Edison Foundation by *The Brattle Group*

Potential Avoided Investment From EE / DR / AMI



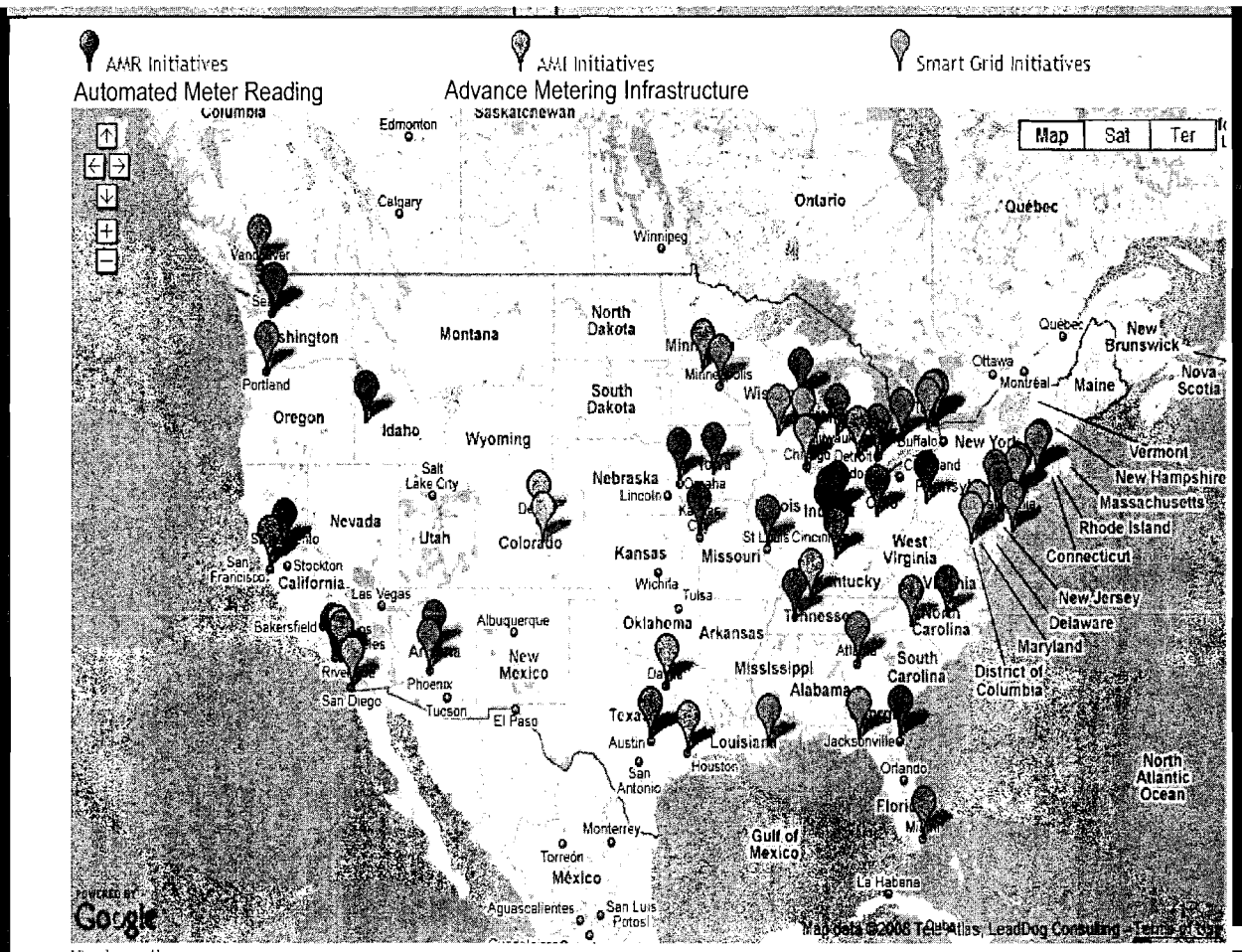
Realistically Achievable Potential

Reduces Total Investment -15% ($107 Billion)

Reduces Generation Investment - 28% ($192 Billion)

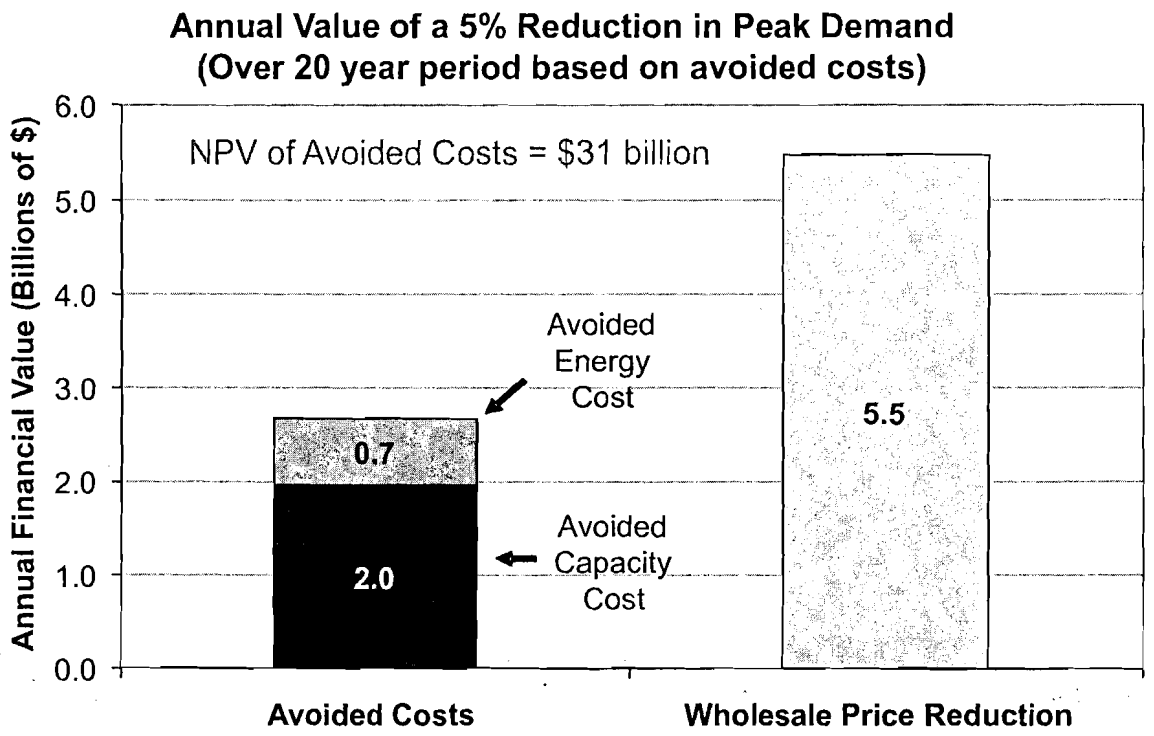
Reduces Total GW - 38%

Increased investment in AMI $19B EE/DR $66B

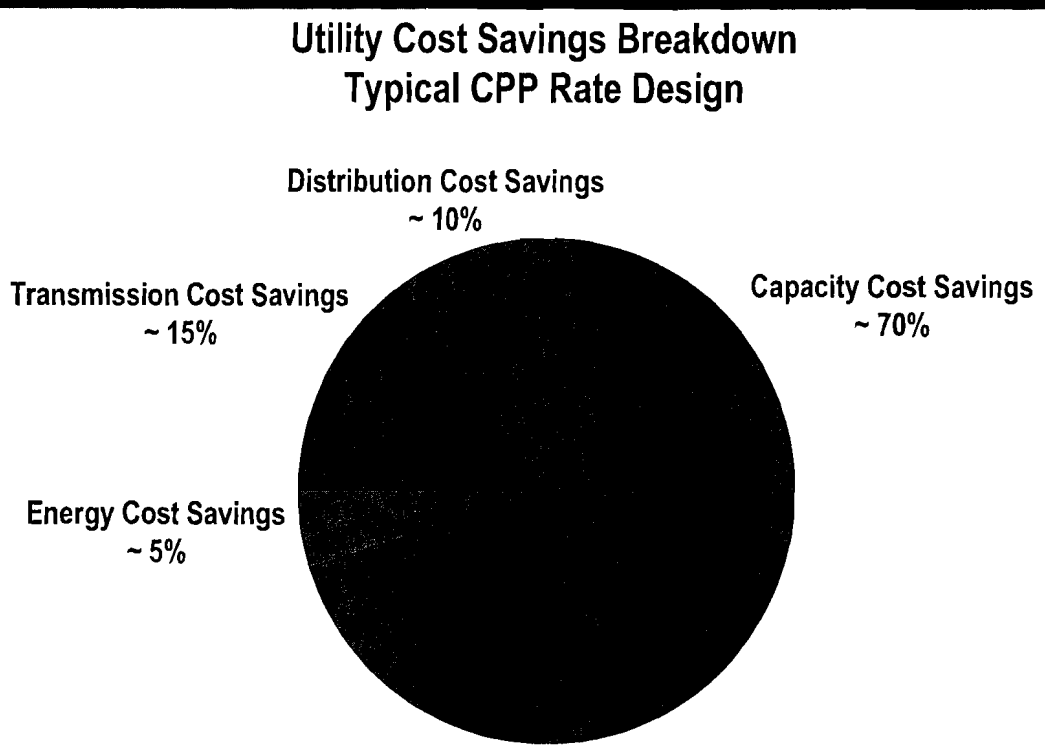


http://smartmeterpedia.synthasite.com/Enernex_Map.php

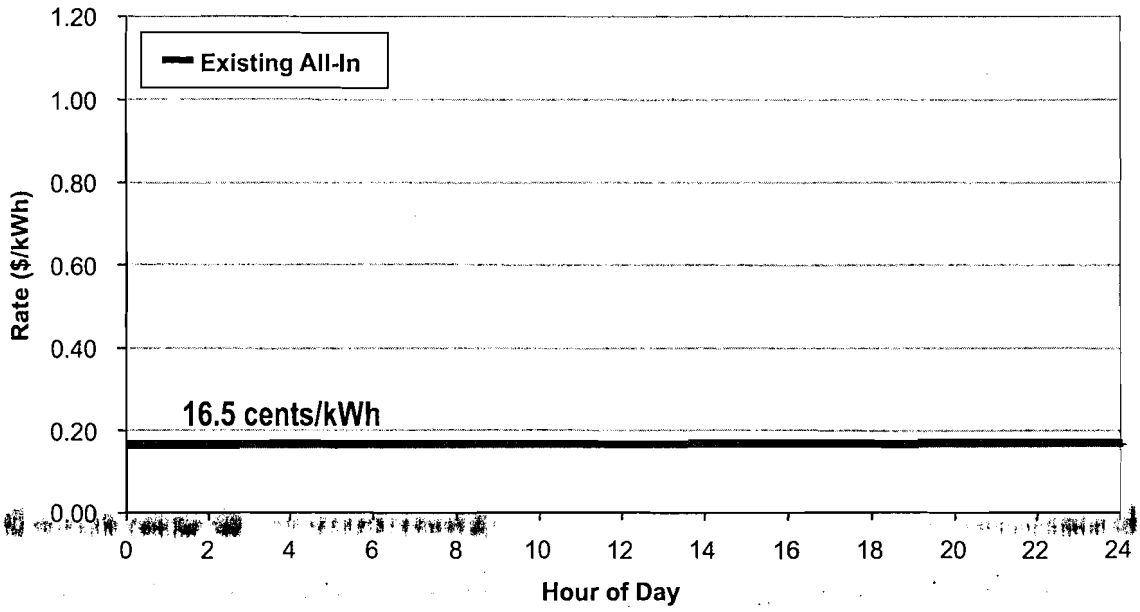
The Value
5% Peak Reduction Worth $31 Billion



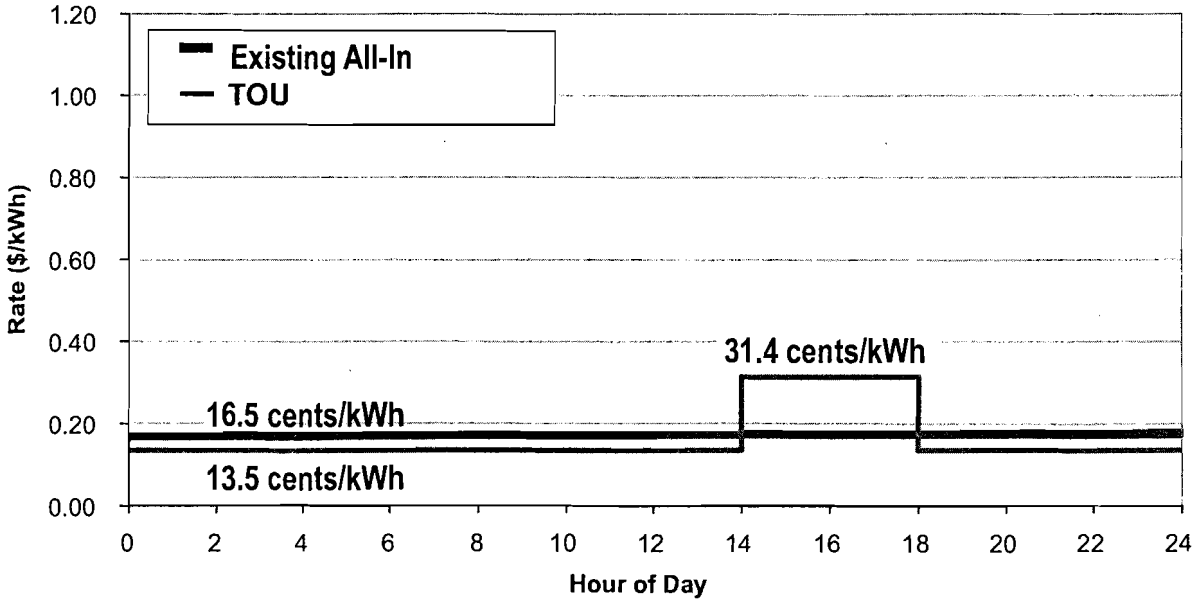
Avoided Generation Capacity Cost Typically Largest Portion Of Savings



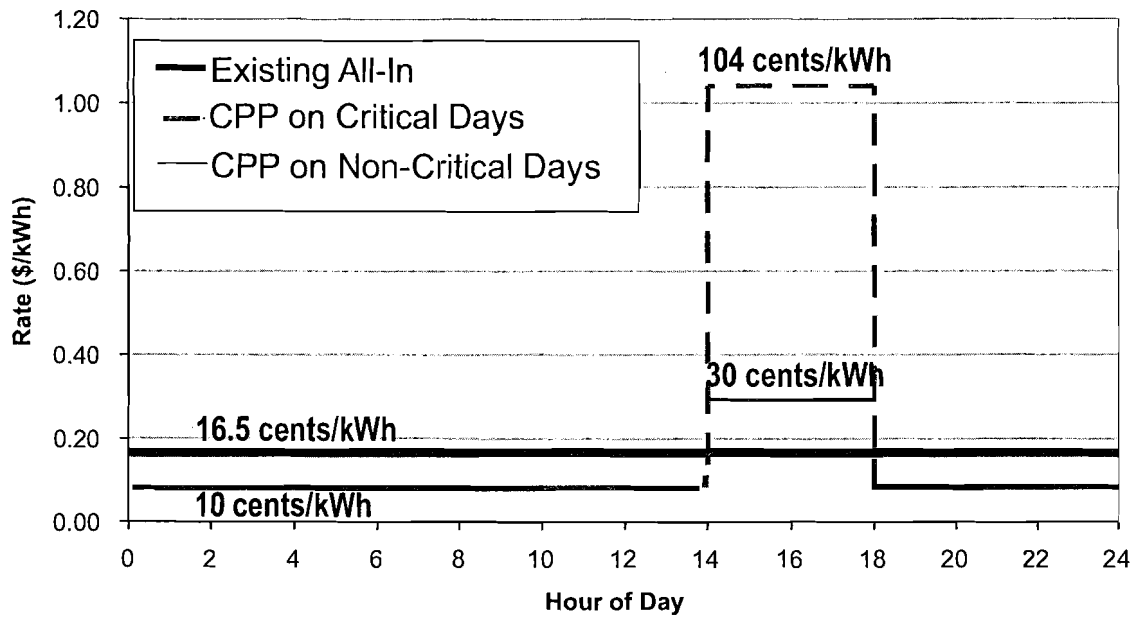
Flat Residential Rate



Weekday TOU Rate

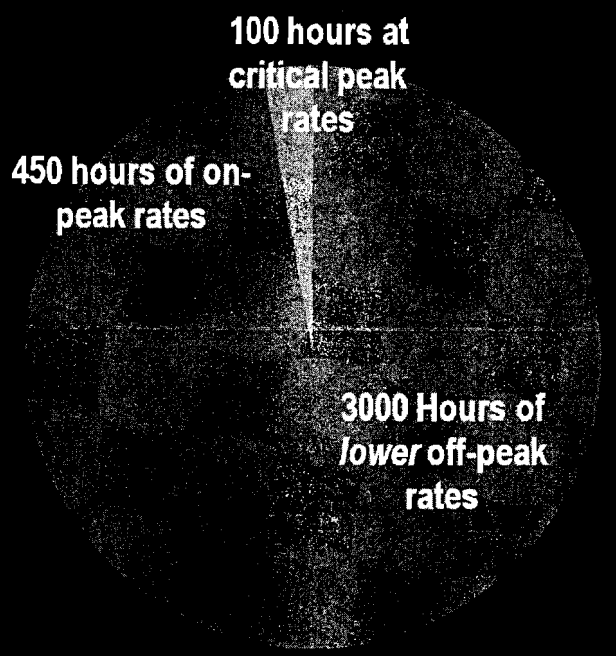


Critical Peak Pricing



Hours in Each Pricing Period

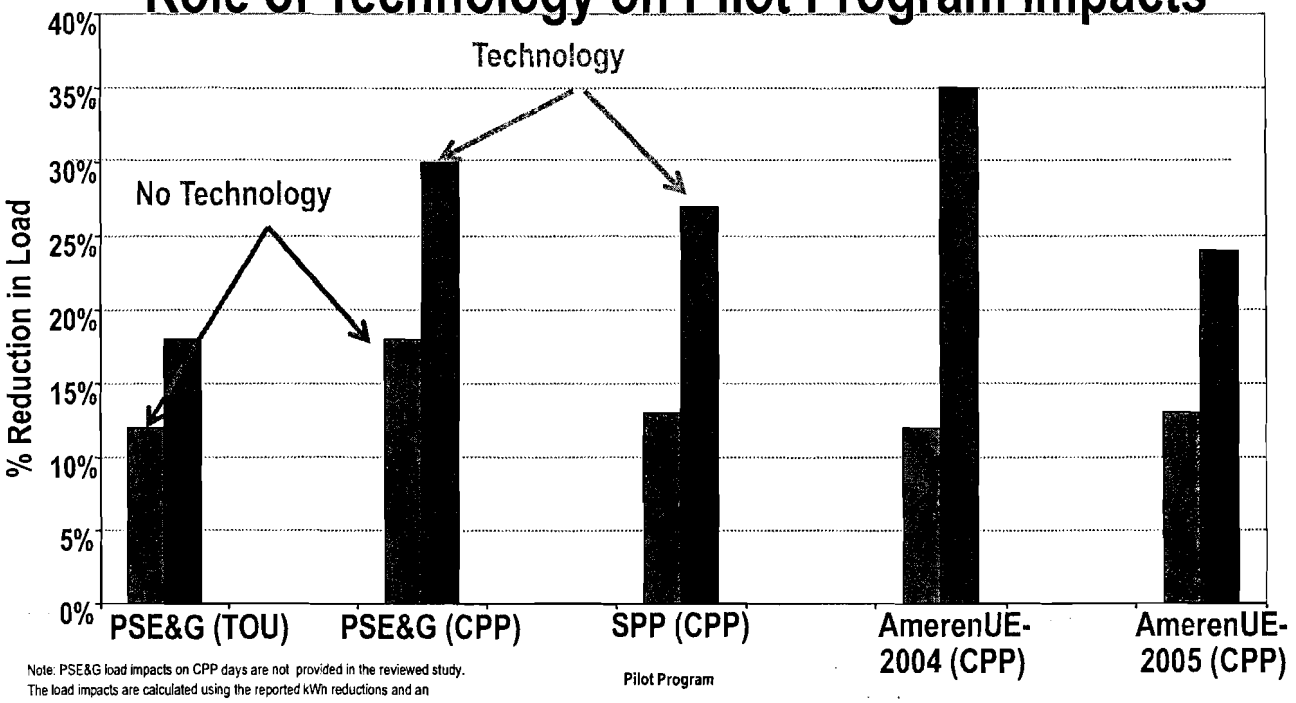
Summer Hours



Off-peak On-peak Critical peak

Enabling Technologies Magnify DR

Role of Technology on Pilot Program Impacts



Note: PSE&G load impacts on CPP days are not provided in the reviewed study. The load impacts are calculated using the reported kWh reductions and an estimate of consumption during peak on CPP days.

Customer Responses Create Savings

ESPP Bill Impacts

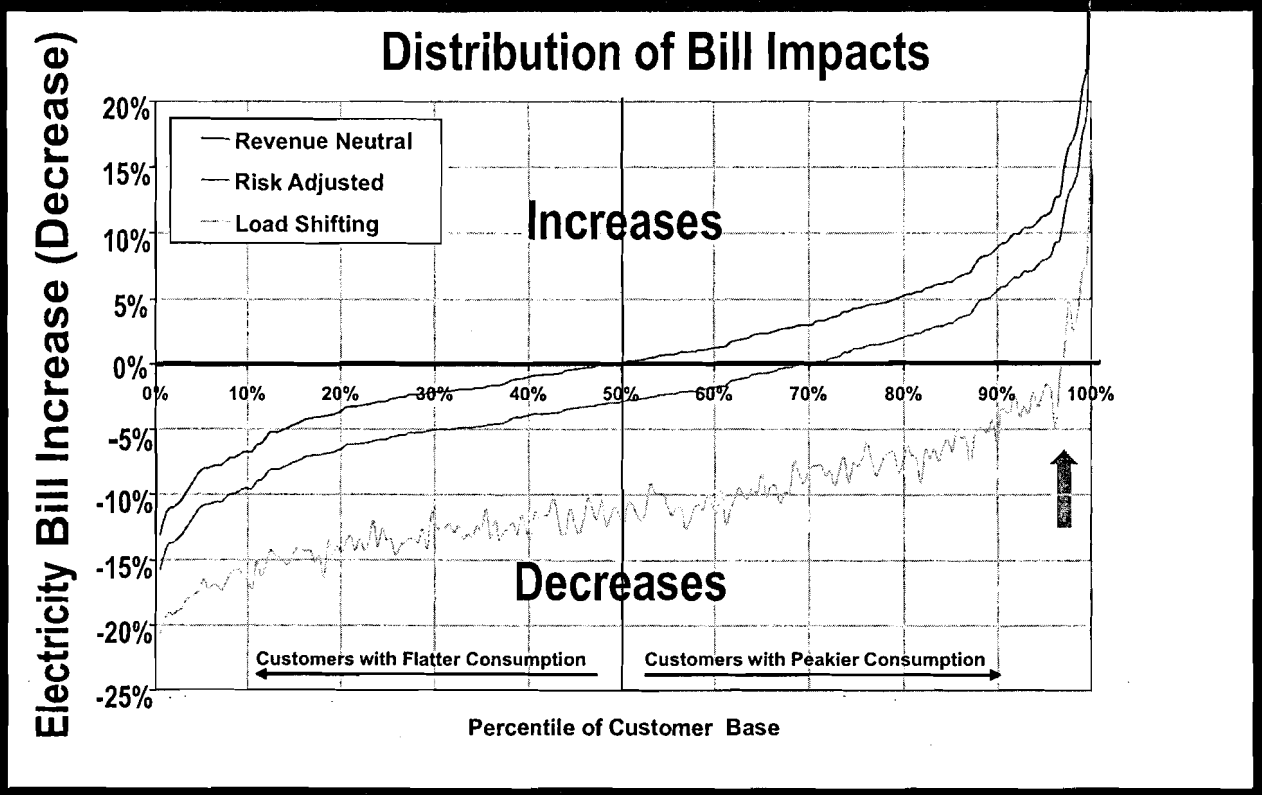
Year	Average Bill	Average Monthly kWh	Savings	Percent Renewing
2003	$51.10	630	20.1%	99%
2004	$56.99	648	11.3%	99%
2005	$77.82	758	-6.3%	87%
2006	$56.32	679	15.5%	N/A

Consistently high retention rate, even in 2005, despite a very hot summer, and high power prices driven by natural gas costs

(Does not include participants who moved during the year)

energy

With Demand Response, Dynamic Pricing Attractive To Over 95%



Pilots Reveal Both Consumer Bill Savings and Acceptability

- Peak reductions without technology ~15%
- Peak reductions with technology ~30%
- Acceptability 80-99% would continue

Benefits to Consumers

- Defer or avoid new expensive generation
- Utilities can wait for cleaner technologies
- Reduce or eliminate reliance upon hedging contracts
- Reduce purchase of generation during expensive critical peak periods
- Improved system operations, reliability, outage control

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New Opportunities

Opportunities - Green Jobs

- **Energy Independence and Security Act of 2007**
  - $125 million / year to create a worker training program, special focus on opportunities for low income people
- **American Reinvestment and Recovery Act (Stimulus Bill)**
  - Significant funding for a broad range of programs – including energy efficiency, renewables, climate change, smart grid
  - Workforce training
- **Renewables - Roof-top solar heating, water, energy**
  - Meeting the increasing state, federal and consumer requirements
- **Energy Efficiency**
  - Energy audits, retrofits, new technologies, green building standards
  - Efficiency management – data mining

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Opportunities - Green Jobs

- **Smart meters / smart grid**
  - Replacing legacy systems with new technologies
- **Demand response**
  - Provide consumers and utilities with new tools to manage demand
- **Plug-in Hybrid Electric Vehicles**
- **Need programs to develop and attract new talent**

The View Forward

- **Respond to comprehensive energy and climate legislation**
  - Preserve all options
  - Accelerate development of technologies
  - Mitigate the impact of rising costs on consumers
  - Ensure regulatory environment supports environmental initiatives
- **Develop a new regulatory model which ...**
  - Stimulates new investment
  - Provides timely cost recovery
  - Equitably transforms our society to a greener and more energy efficient economy

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