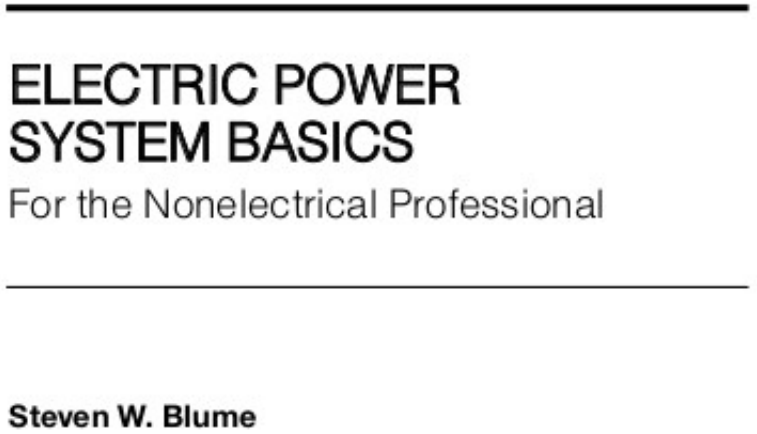
ETM521

Lecture 1 - Power System Overview

Barış Sanlı

Resources


ELECTRIC POWER
SYSTEM BASICS
For the Nonelectrical Professional
Steven W. Blume
IEEE PRESS SERIES ON POWER ENGINEERING
Mohamed E. El-Hawary, Series Editor
IEEE
IEEE PRESS
1807 WILEY 2007
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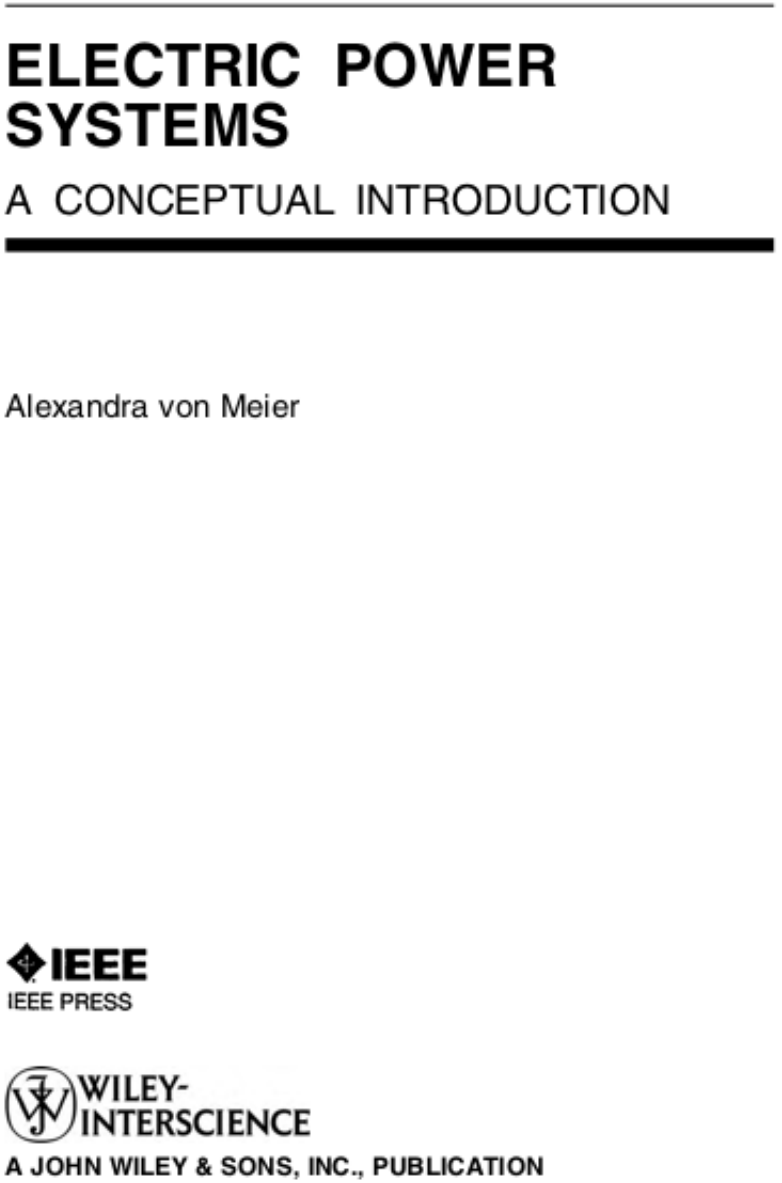
ELECTRIC POWER
SYSTEMS
A CONCEPTUAL INTRODUCTION
Alexandra von Meier
IEEE
IEEE PRESS
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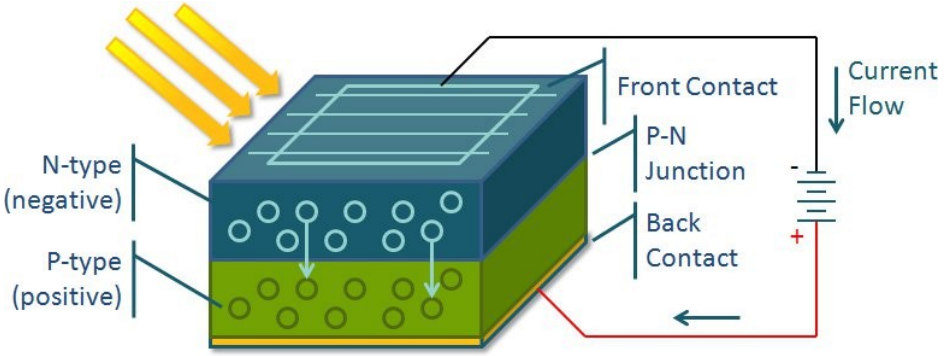
Electricity

- Energy carrier
  - Not an energy source, but proxy
- What is moving?
  - Pulse... not electrons
- Behaves like light
  - Can you store light? Why not?

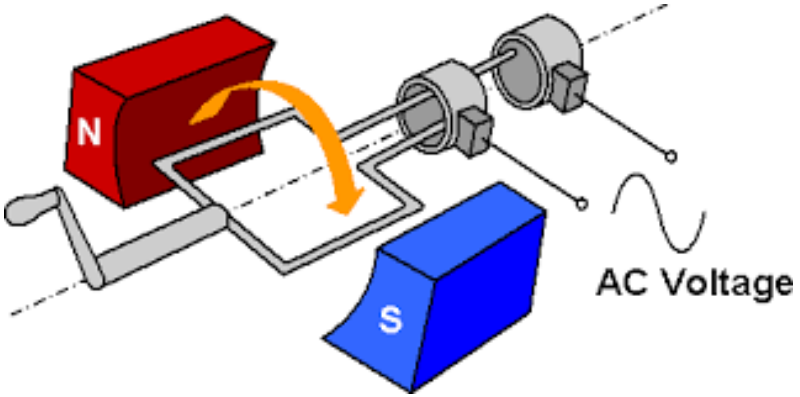
Ways to generate electricity

- Electron in balance
  - Excess- deficit
- Static
- Chemical (historical)
- Mechanic (contemporary)
- Physics – semi conductor/ quantum

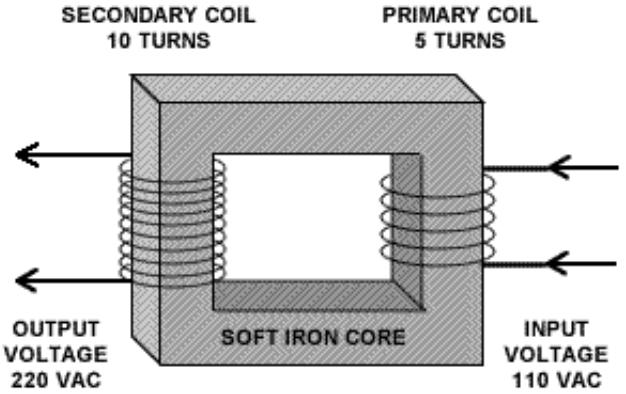


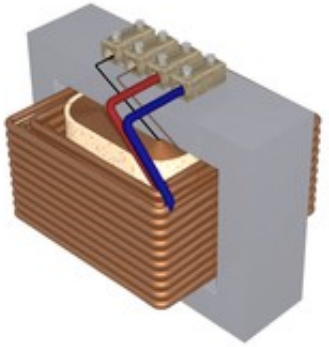
Magnetism

- Generation



- Transformer





Physics of Electricity

- Benjamin Franklin late 1700s
  - Charge -> “positive” or “negative”
- Electric current -> the ability of electrons to travel
- Charges spread out
  - A local accumulation or deficit of electrons causes a “discomfort” or “tension”
  - Discomfort level is potential-tension
- A charge move to a more “comfortable” location by producing heat in wire

Potential

- There has to be a “reference” location -> ground
- Potential represents a measure of how comfortable or uncomfortable it would be for any charge to reside at that location
- One volt -> One joule/coulomb
- The wire is “12kV” means wire to ground

Conductivity

- Imagine electrons moving a little to side like people, giving its neighbor a repulsive “shoulder” in metrobus
- Metals are important
- But air can ionize -> plasma (salt, wet air)
- Superconduction

Current

- Current is the flow rate of charge
- If
  - Voltage is a measure of “how badly the stuff wants to get there”
  - Current is a measure of “how much stuff is actually going”
- Amperes “amps”, I ,flow rate of charge
- General sense “positive” flow is current
- What is travelling is “pulse” or “signal” of current

Ohm’s Law

- V = IR
- Resistance
  - Matter properties * length / cross-section
  - Resistance of copper wire increases as it heats up
- Higher flow (current) higher friction (heat & loss)

Other

- Electric circuit
  - Pathway to recycle charge to “less comfortable” position
  - Closed /open circuit
- Voltage Drop
  - Current and resistance determines voltage drop
- Electric Shock
  - Current that causes biological damage
  - “keep one hand in pocket”
- Resistive heating
  - Result of “friction”... undesireable in transmission
  - Thermal expansion & sagging

Resistive heating

- $P = I * V$
- $V = I*R$
- $P = I* I* R = I^2*R$
- Resistive heating -> square of current
- More sensitive to current changes
- For a required P, choose I and V
  - Either increase cross-section or decrease length
  - Edison system limited to be only a few miles

Field

- Electric/Magnetic Field
  - Like gravity
- Electric Field (+/-)
  - Affects charge, radial
- Magnetism (N-S)
  - Divide magnet till atoms, still N-S
- 1820 Oersted observed compass needle moved by current through a nearby wire
- Magnetic field must be changing in order to have any effect
- Force exerted on charge is EMF
- Electromagnetic force acts on electrons-> accelerate
- “Induced current” induced by changing magnetic field

Kirchhoff’s Law

- German physicist Gustav Robert Kirchhoff
- KVL
- KCL

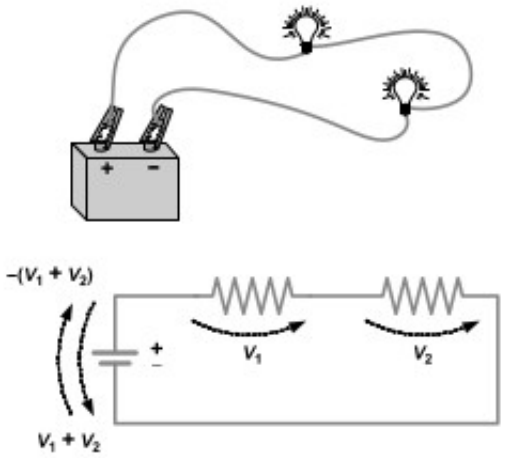


Figure 2.4 Kirchhoff's voltage law.

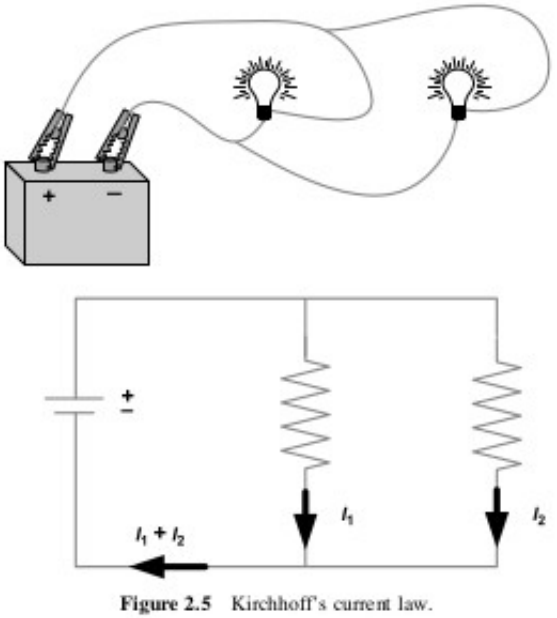


Figure 2.5 Kirchhoff's current law.

- Ex : LED strip has 50 LED’s plugged to 240 V

Magnetic Circuits

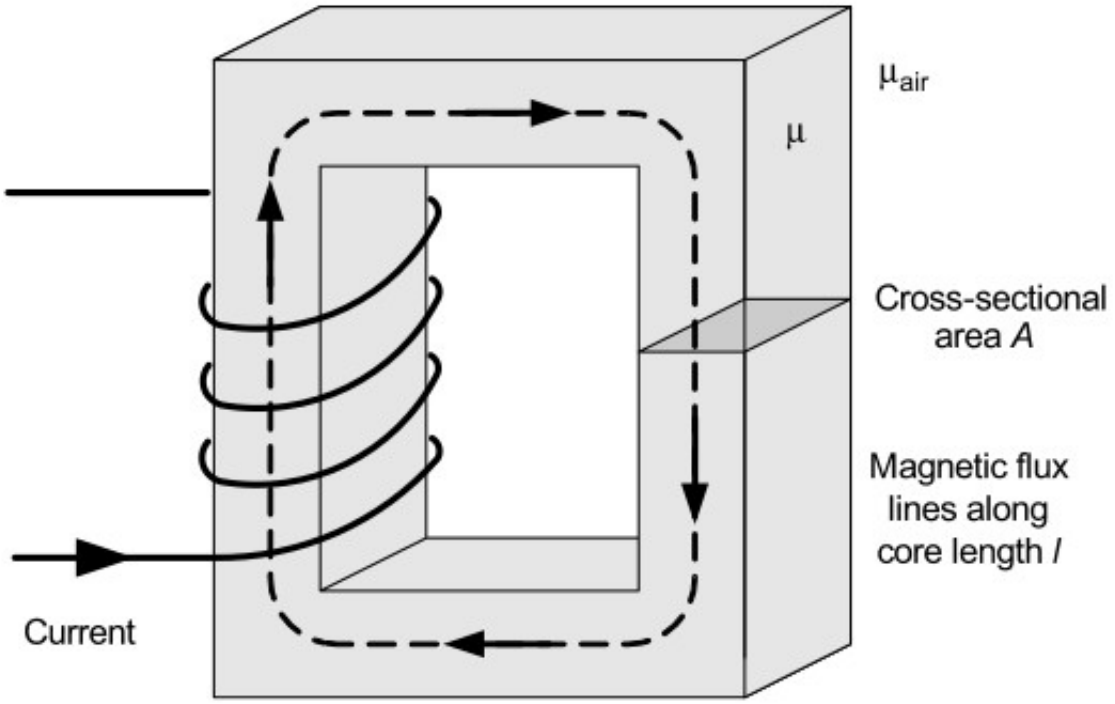


Figure 2.7 A magnetic circuit.

DC and AC

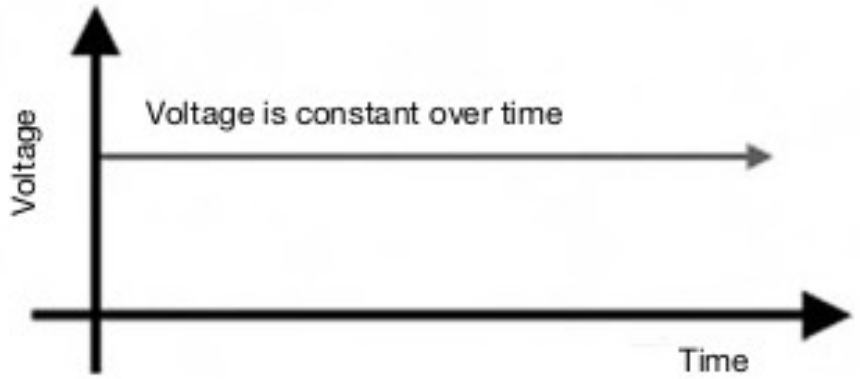


Figure 1-4. Direct current (dc voltage).

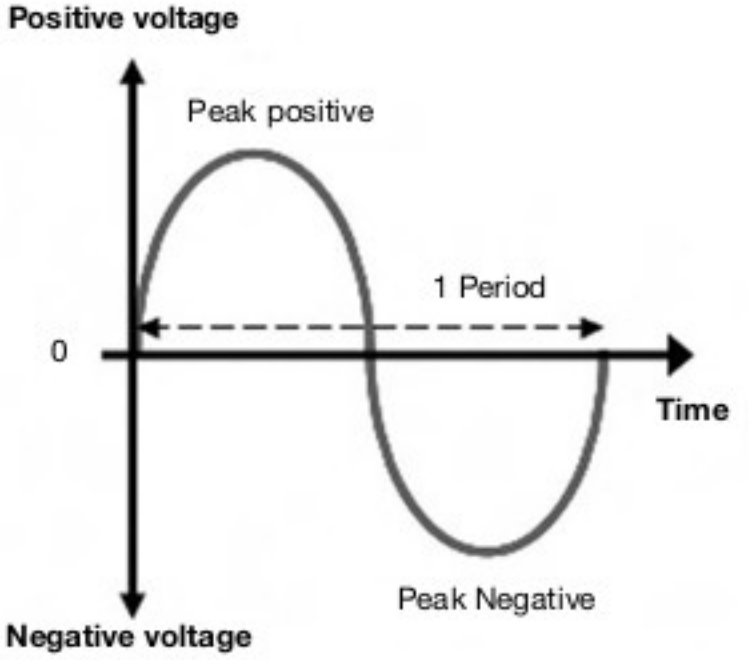


Figure 1-5. Alternating current (ac voltage).

AC Power

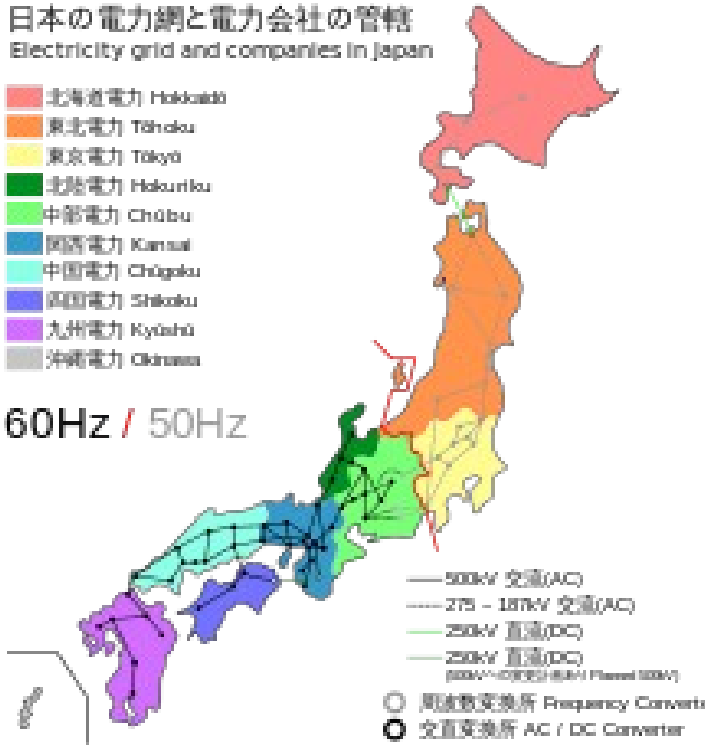
- AC frequency 50 Herts -> 50 times/second
- Main reason is it allows
  - Raising and lowering the voltage by means of transformers
  - In DC it is more expensive
  - But safety of high voltage AC
- Transformers introduced in 1880s,
- DC – AC battle, by mid 1890s resolved

Early frequency

- Different across 25 Hz to 133 1/3 cycles
- For generators
  - Lower freq -> fewer magnetic poles
- For transmission
  - Lower freq->line’s resistance(!) increases with f
- For loads
  - Higher freq-> less flickering

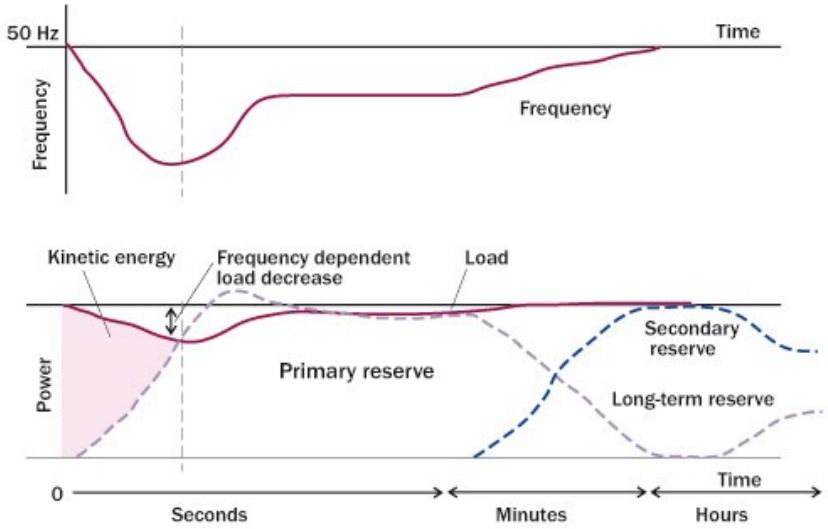
Modern electricity system

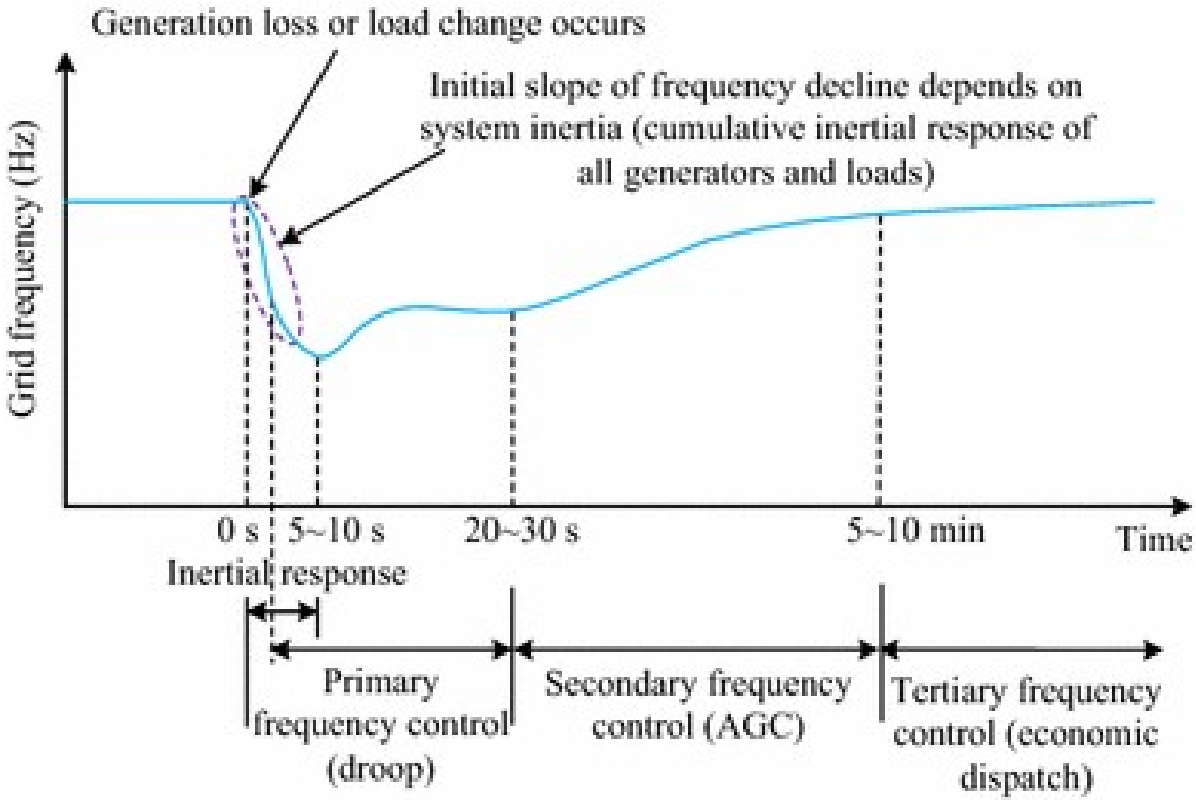
- Edison DC-110 Volt
- Tesla 240 V – 60 hertz
- Westinghouse arc lights 60 hertz
- Germany AEG, 50 Hertz, 120 V
- Europe 120 V till 1950s then 220 V
- UK converted to both 220 V and 50 hertz



https://www.quora.com/Electrical-Engineering-Why-is-Indias-frequency-maintained-in-50-Hz-only

Frequency





https://link.springer.com/article/10.1007/s40565-017-0315-y

Math

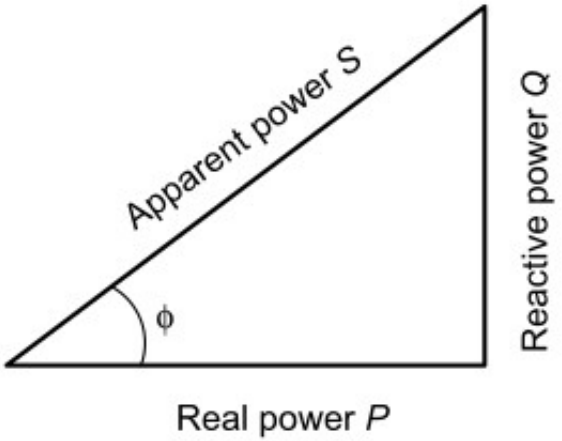
- A sinusoidal function
  - Amplitude, freq, phase
  - Freq: number of complete oscillations per unit time
  - Phase: Starting point of sinusoid
- RMS value
  - DC equivalent of sinusoid

Reactance (to freq)

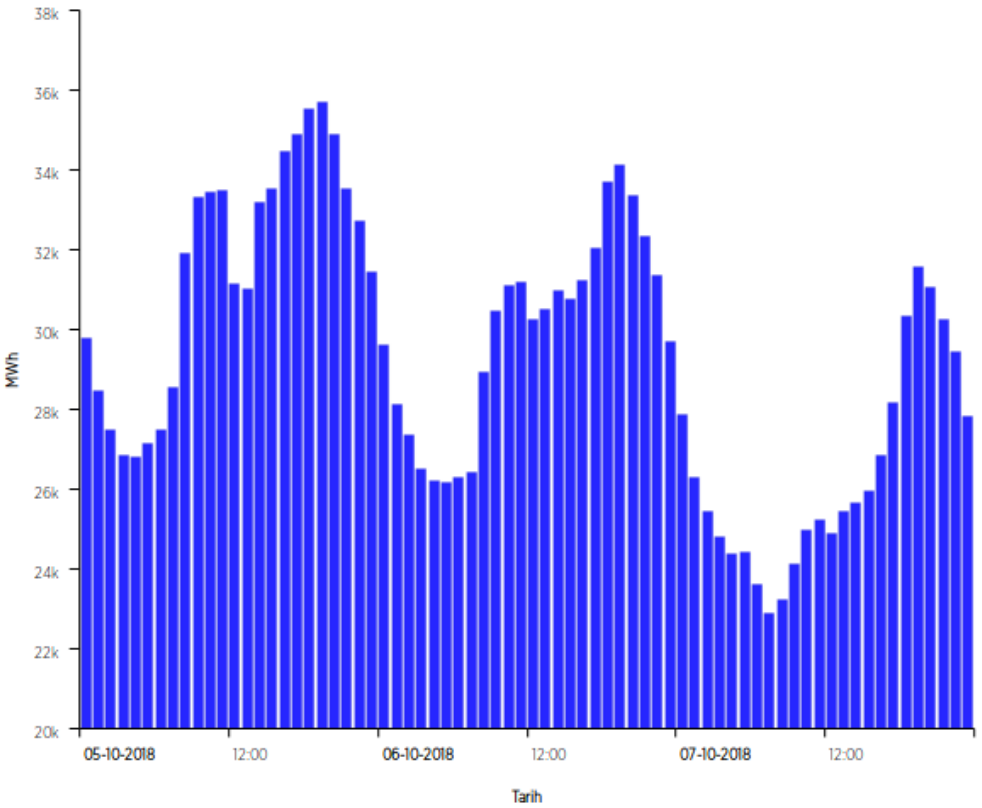
- Reactance property fo a device to influence the relative timing of an alternating voltage and current
- Inductance- L- (voltage leads V=max, I = 0)
  - Changing magnetic field induces an opposing current
  - Magnetic field increases and decreases during different parts of the cycle, it stores and releases energy. Energy no dissipated but exchanged (between magnetic field and the rest of circuit)
- Capacitance- C- (current leads I max, V = 0)
  - Current flow across a capacitor is proportional to rate of change of electric field
- Impedance Z= R +jX

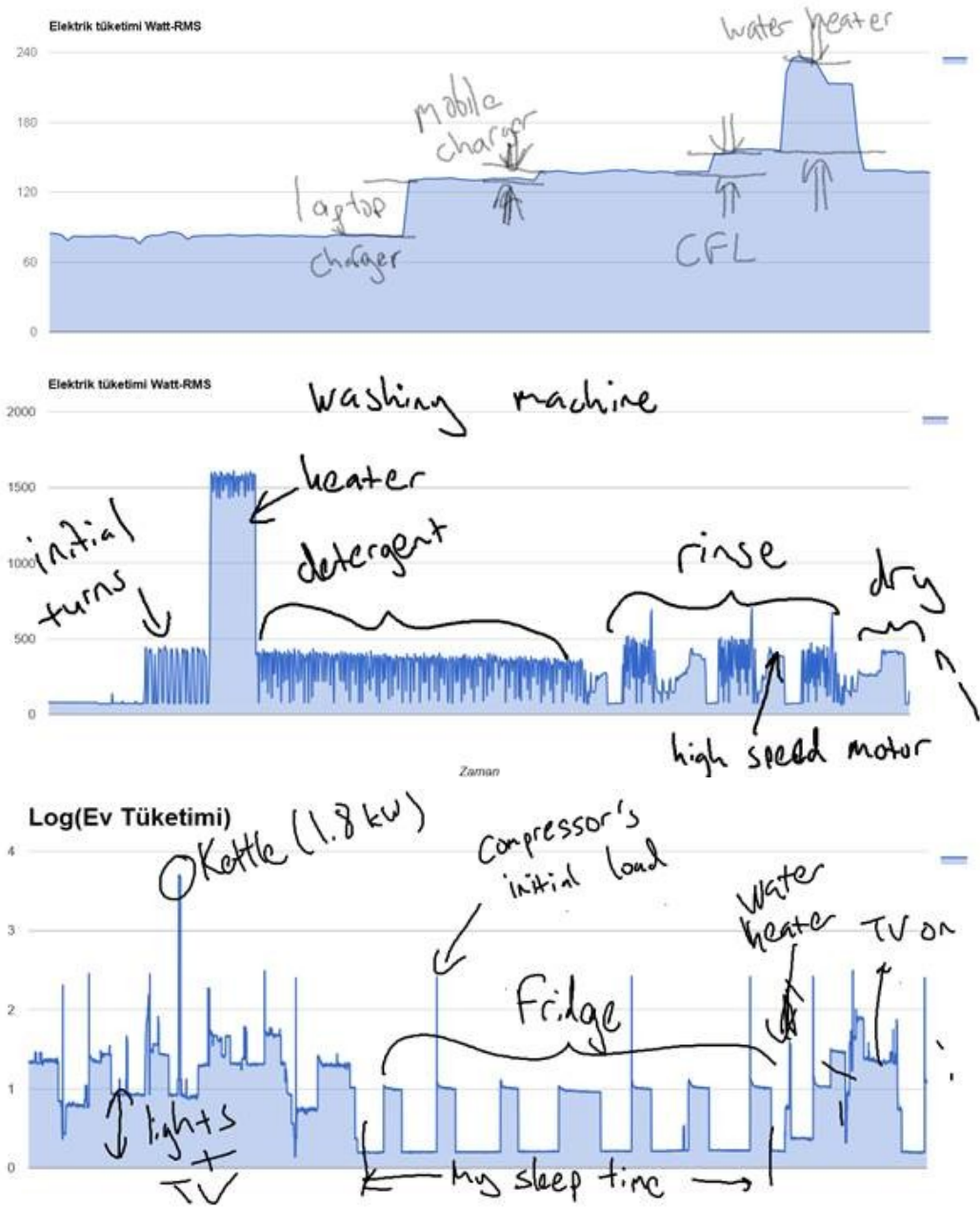
Power & Loads

- Power is a measure of energy per unit time
- P= I^2R, “dissipated”-> converted to heat
- Line drop : few % of line voltage
- Real power, active power, P (MW)
- Apparent power, S (kVA,MVA)
- Reactive power, Q (VAR)
- Power factor
  - Desirable 0.8-0.9
- Inductive loads consume reactive energy
- Capacitive loads supply reactive energy
- Most loads and lines -> inductive



Load





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Power Factor

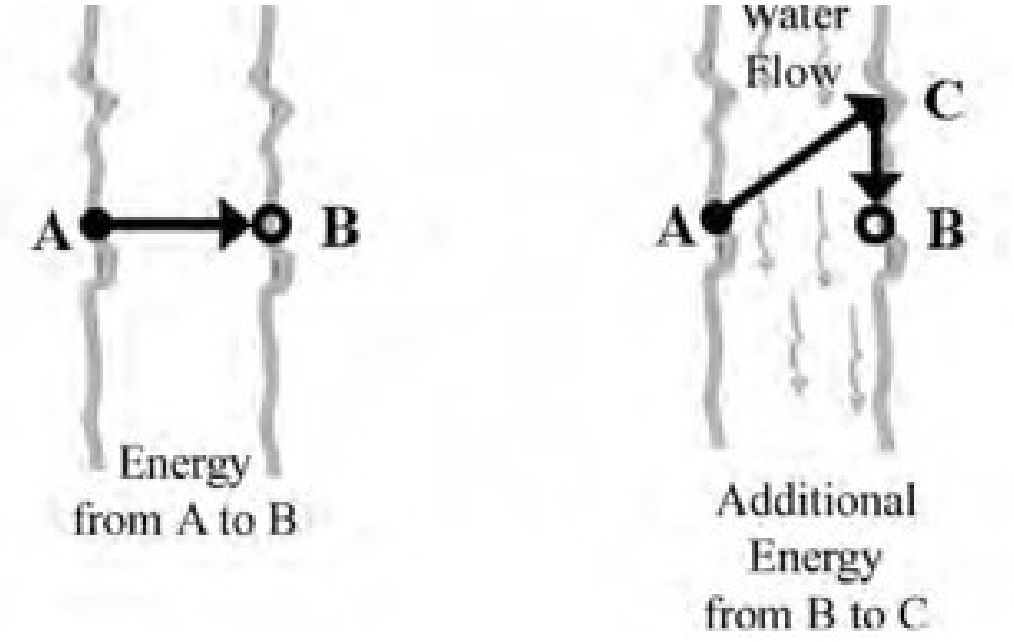
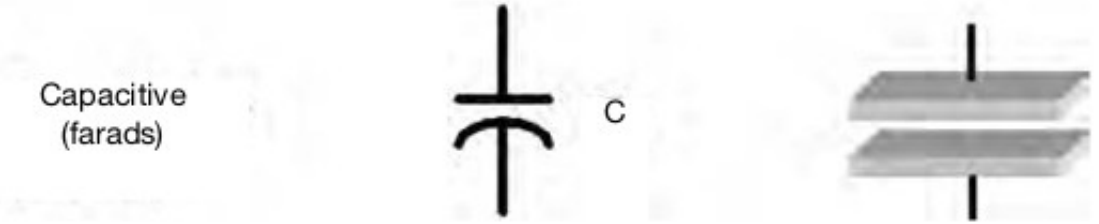


Figure 6-5 Power factor

3 types of loads

- Resistive
- Inductive
- Capacitive



Reactive Power

- “The cholesterol of power lines”
- With capacitors “VAR compensation”, near load
- Planning and scheduling reactive power generat.
- Fluorescent lamps
  - Ballasts 0.6 electronic, 0.5 for magnetic

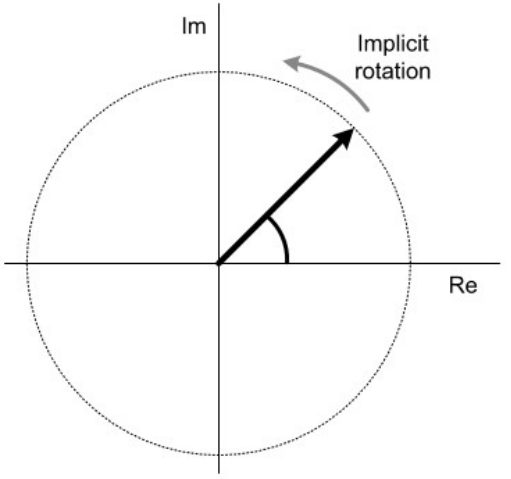


Figure 3.13 A phasor.

Generator

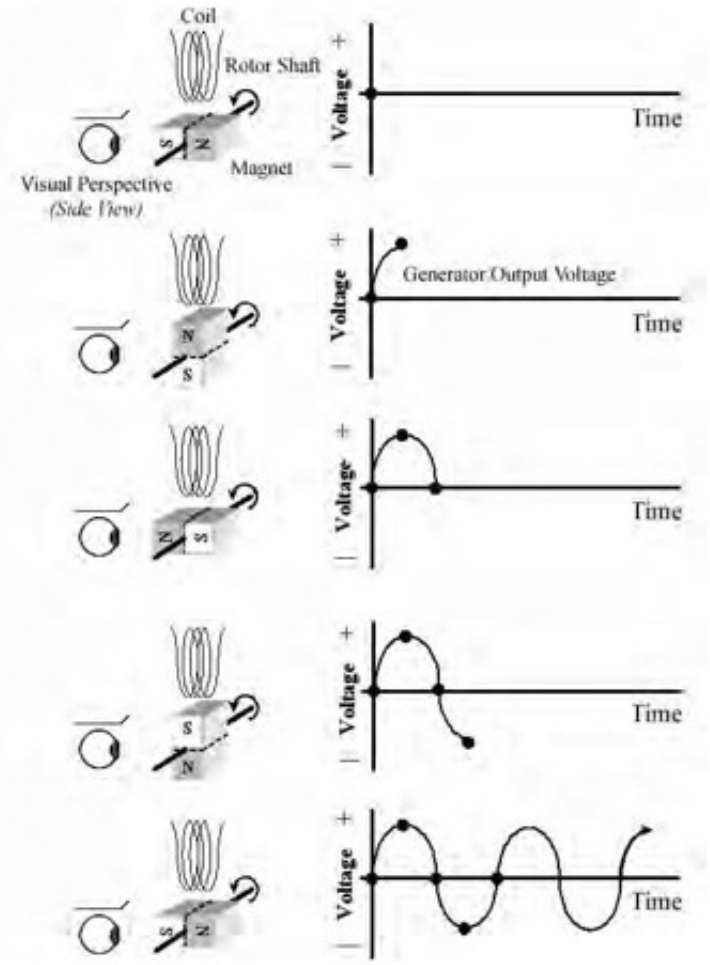


Figure 2-1. Magnetic sine wave.

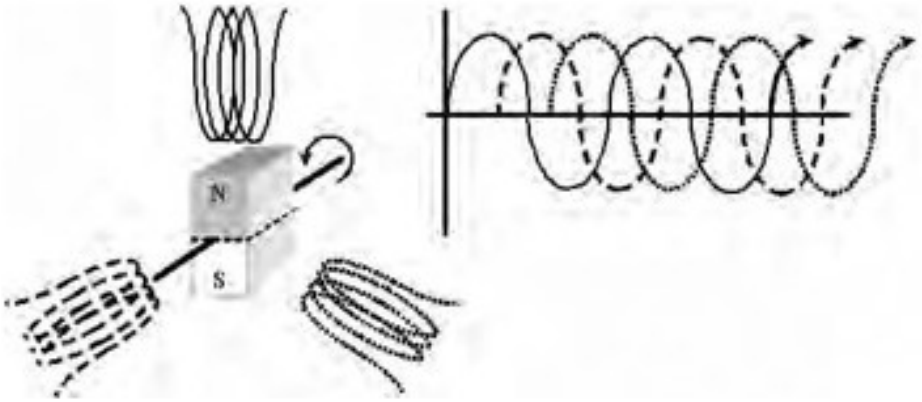


Figure 2-2. Three-phase voltage production.

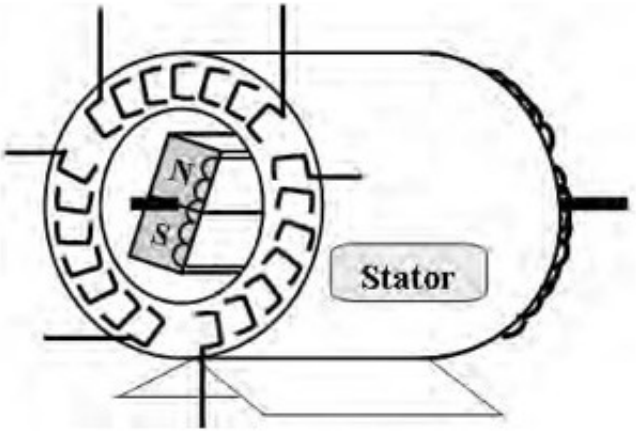


Figure 2-3. Three-phase generator—stator.

Electromagnet Generator

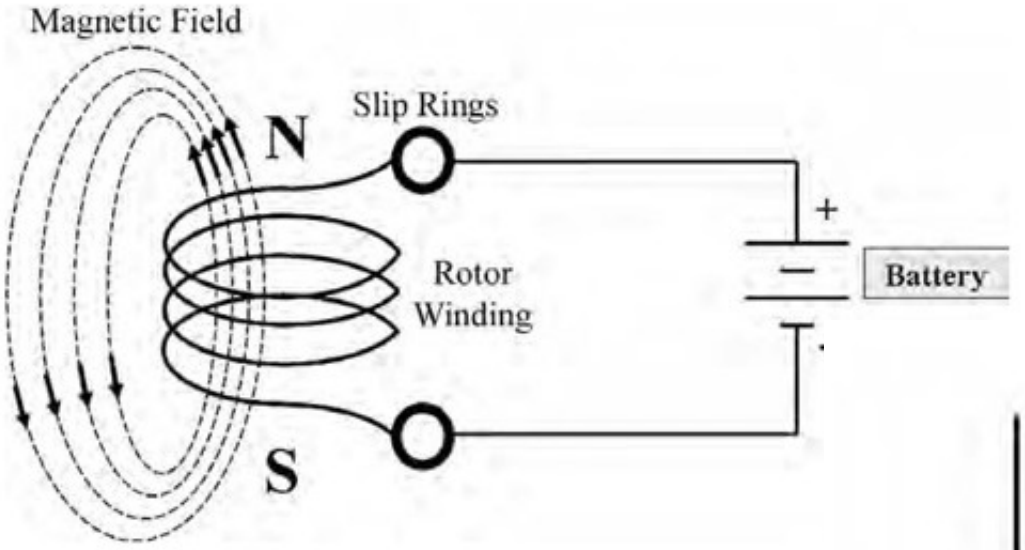


Figure 2-4. Electromagnet and slip rings.

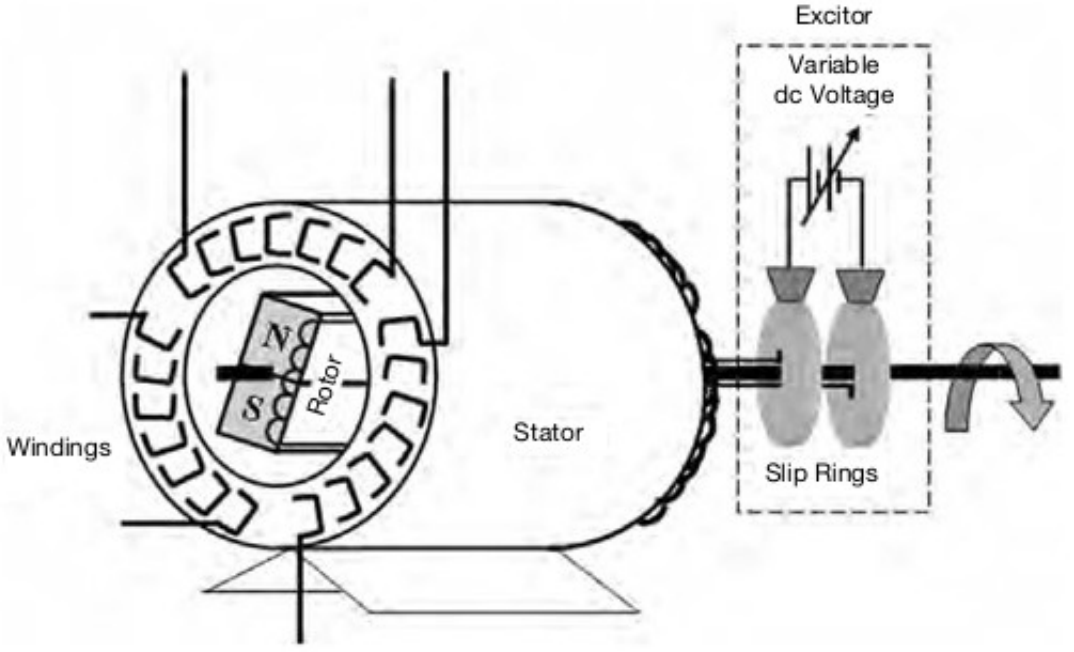
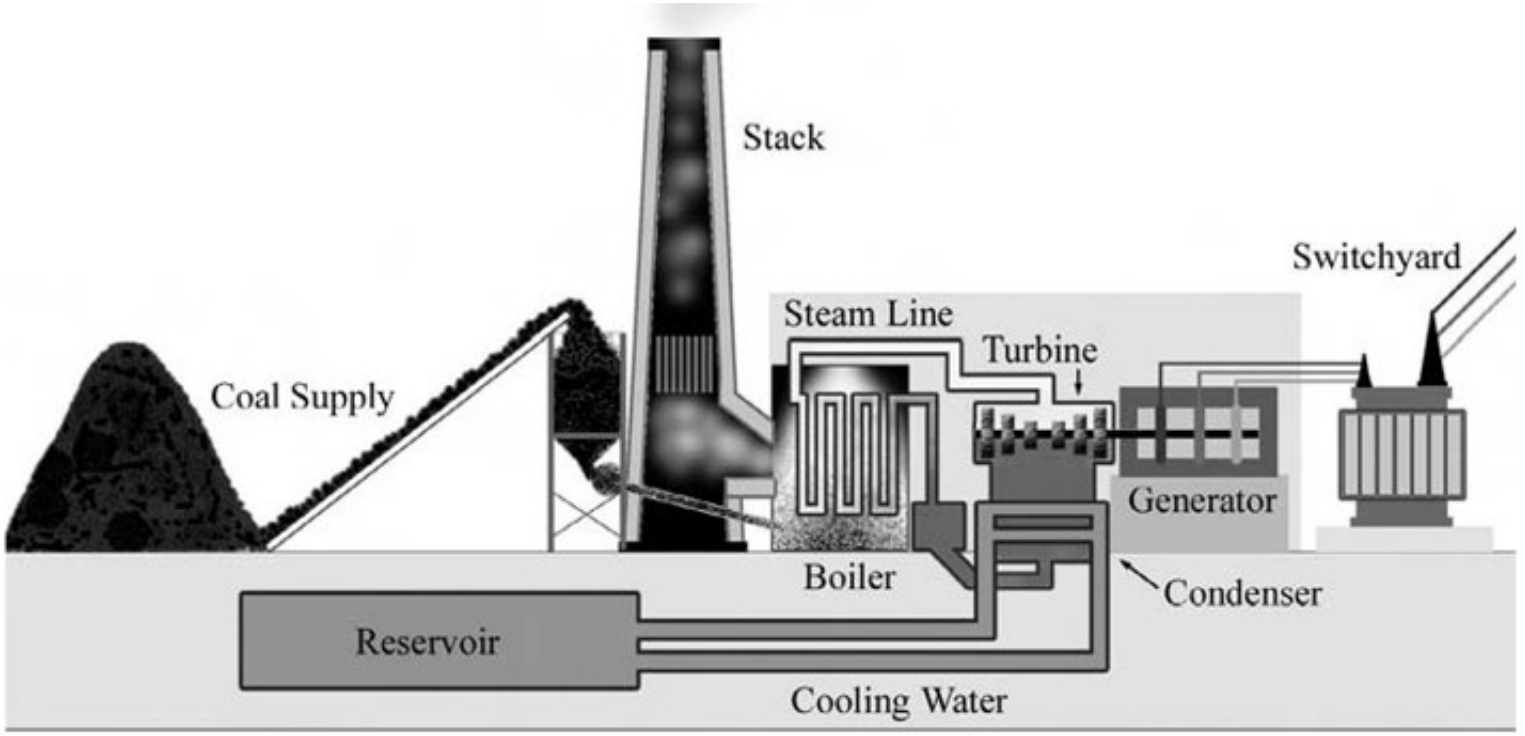


Figure 2-5. Three-phase voltage generator components.

Prime Movers - Coal



Prime movers - Nuclear

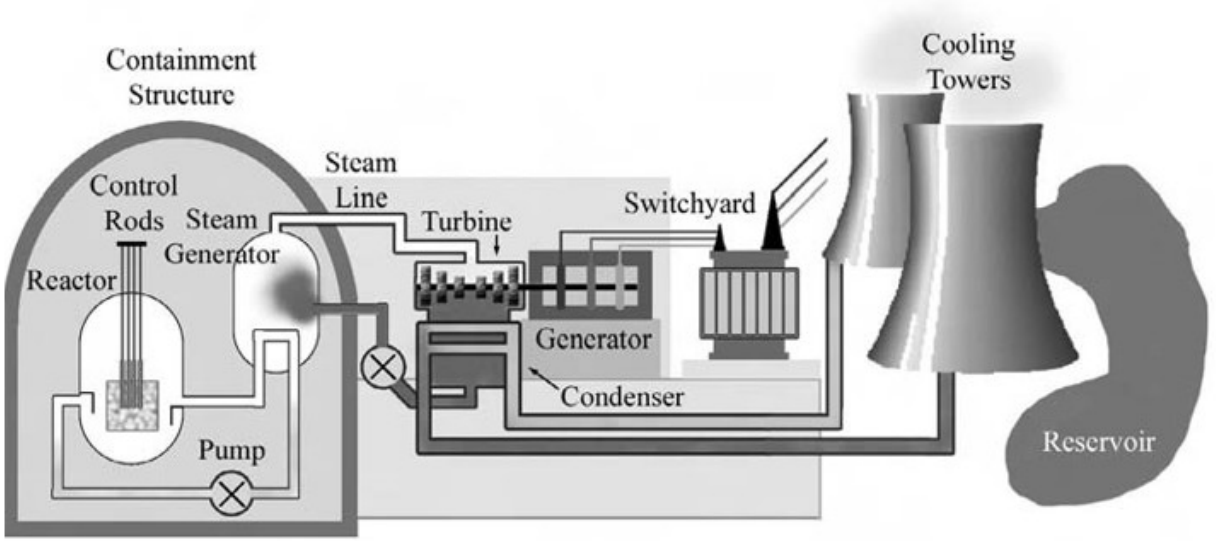


Figure 2-13. Pressurized water reactor.

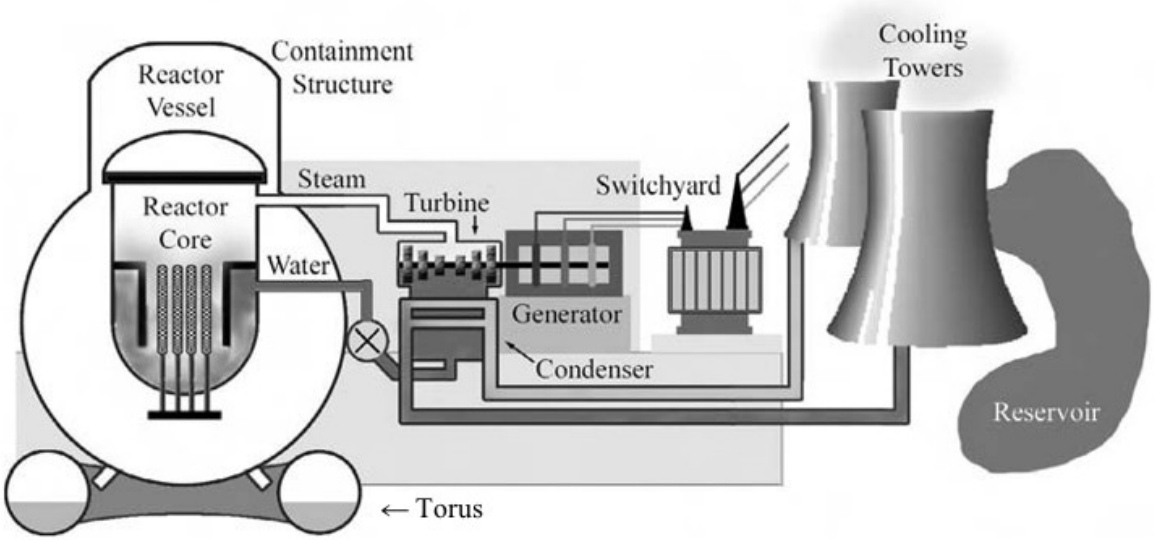
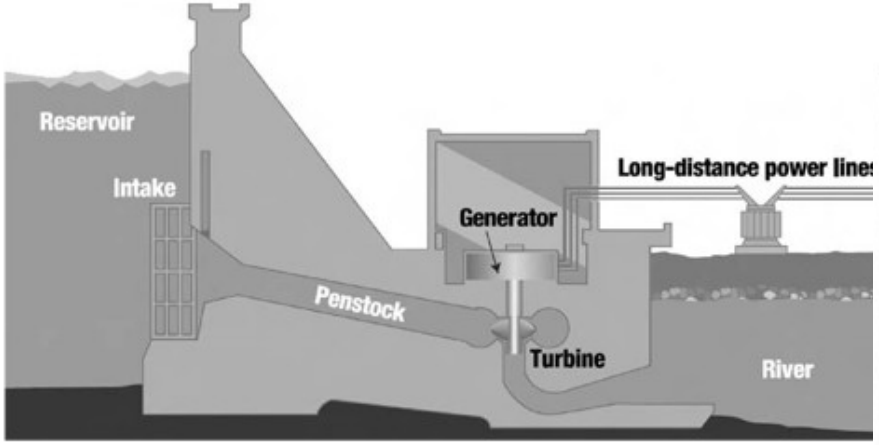
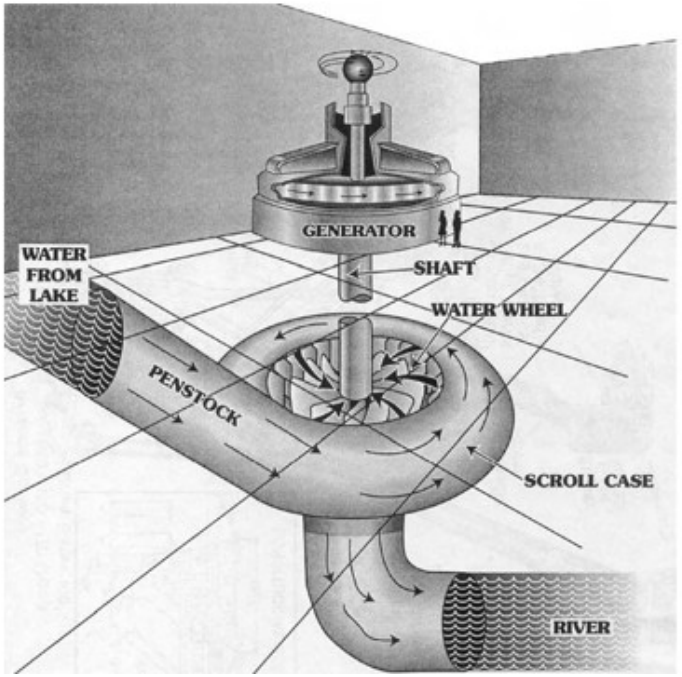


Figure 2-14. Boiling water reactor.

Prime Movers - Hydro

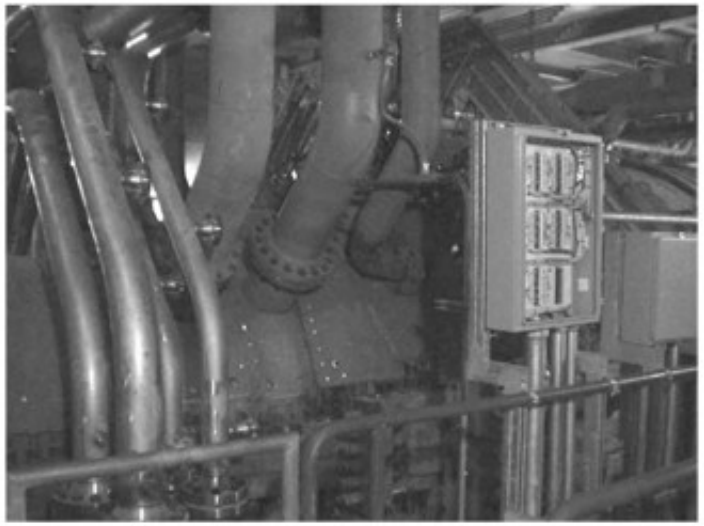


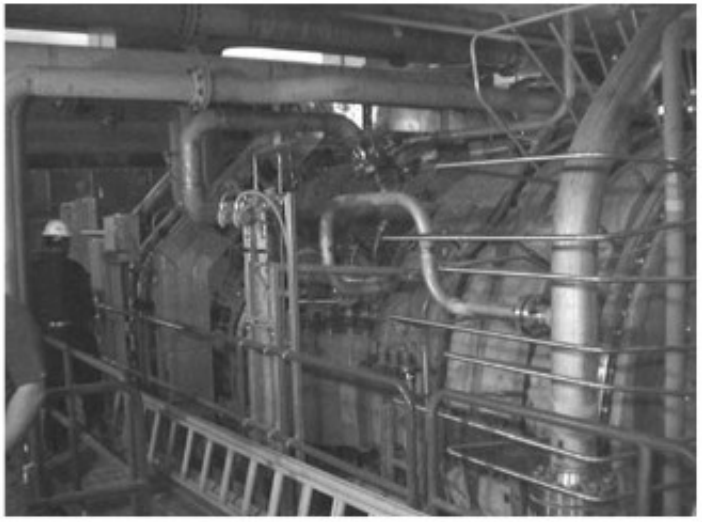


PM – Pumped Storage

Figure 2-19. Pumped storage power plant.

PM - CCGT





PM - Wind

PM – Direct Solar

Figure 2-23. Direct Solar Photovoltaic. *Source:* Fotosearch.

Generators

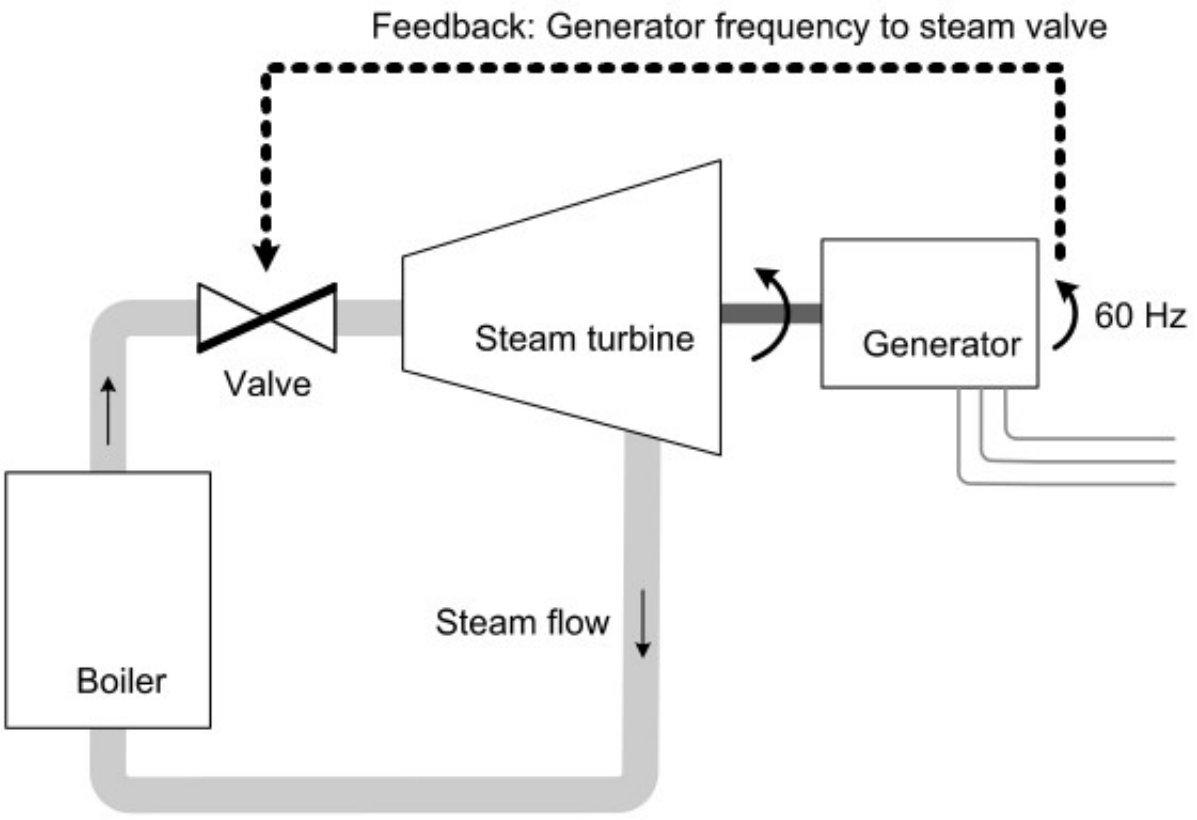


Figure 4.10 Controlling generator output with the governor valve.

Solid State wave form

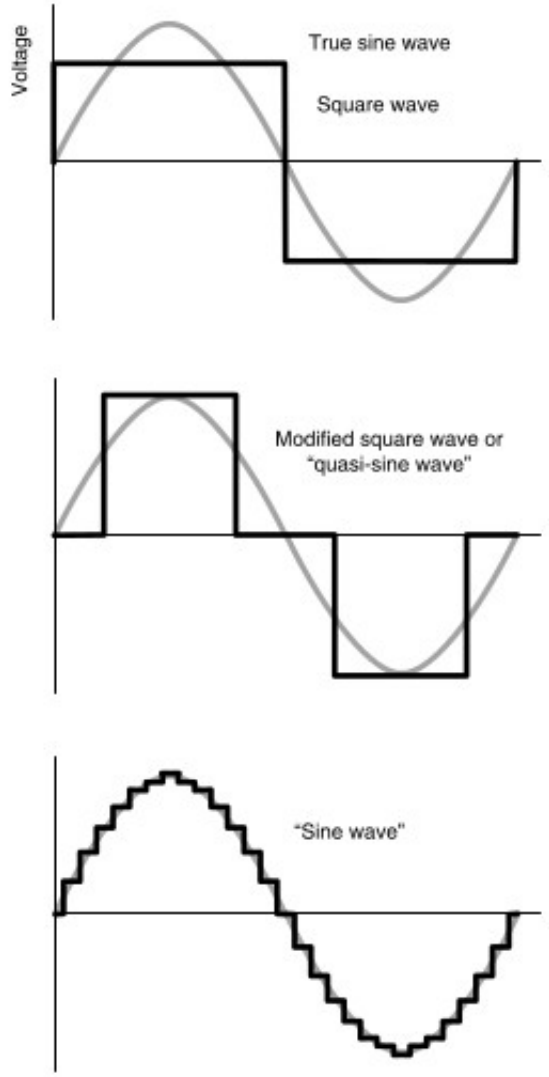


Figure 4.25 Inverter waveforms.

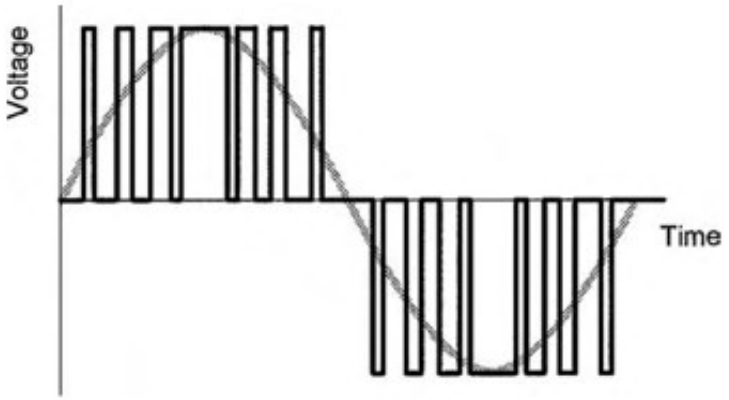
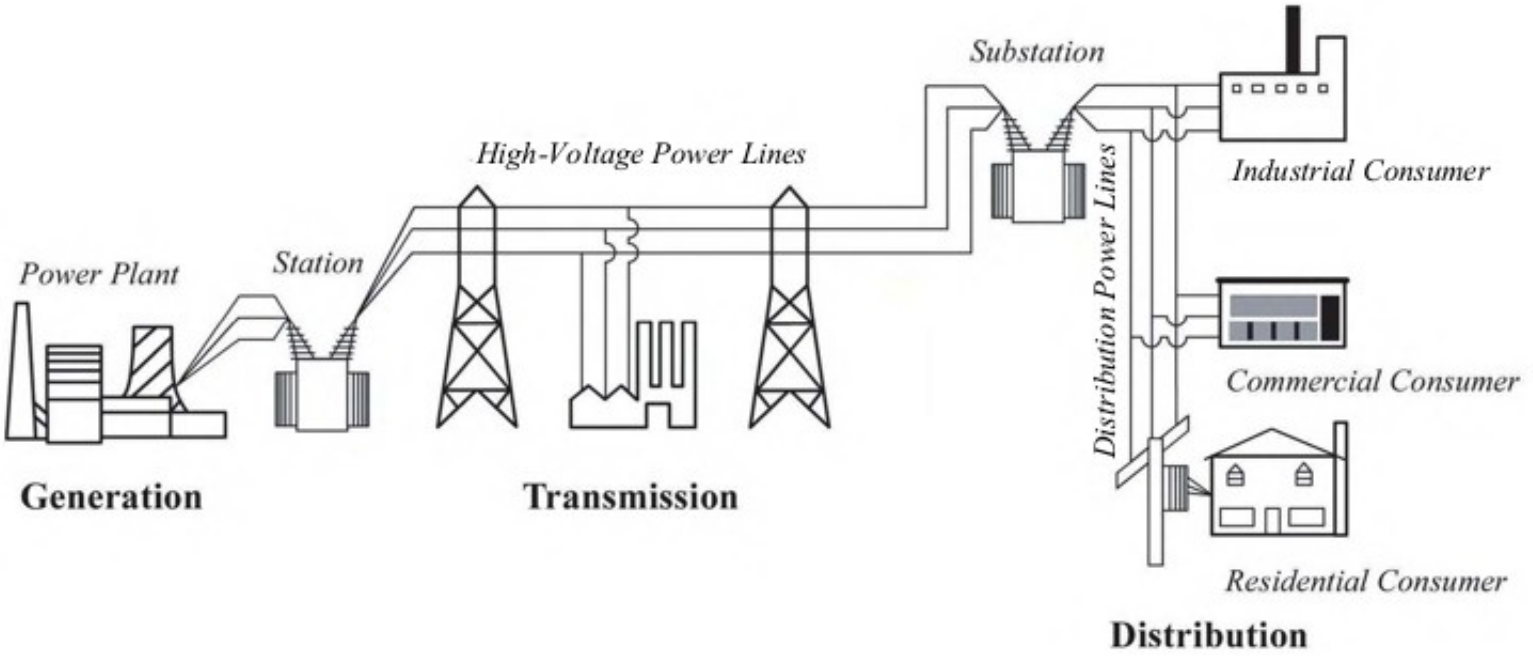


Figure 4.26 Pulse-width modulation

System Overview



Carrying electricity

- USB cables
  - 2.0 max 5 meter
  - 3.0 max 3 meter
- Voltage drop across line
  - Cable
  - Current
- Higher voltage less loss

Voltage Drop at 500mA

AWG	15cm	50cm	1m	2m	3m	5m
20	0.064997	0.076655	0.09331	0.12662	0.15993	0.22655
22	0.067944	0.08648	0.11296	0.16592	0.21888	0.3248
24	0.072633	0.10211	0.14422	0.22844	0.31266	0.4811
26	0.080085	0.12695	0.1939	0.3278	0.4617	0.7295
28	0.091935	0.16645	0.2729	0.4858	0.6987	1.1245

Voltage Drop at 1000mA

AWG	15cm	50cm	1m	2m	3m	5m
20	0.129993	0.15331	0.18662	0.25324	0.31986	0.4531
22	0.135888	0.17296	0.22592	0.33184	0.43776	0.6496
24	0.145266	0.20422	0.28844	0.45688	0.62532	0.9622
26	0.16017	0.2539	0.3878	0.6556	0.9234	1.459
28	0.18387	0.3329	0.5458	0.9716	1.3974	2.249

Voltage Drop at 2000mA

AWG	15cm	50cm	1m	2m	3m	5m
20	0.259986	0.30662	0.37324	0.50648	0.63972	0.9062
22	0.271776	0.34592	0.45184	0.66368	0.87552	1.2992
24	0.290532	0.40844	0.57688	0.91376	1.25064	1.9244
26	0.32034	0.5078	0.7756	1.3112	1.8468	2.918
28	0.36774	0.6658	1.0916	1.9432	2.7948	4.498

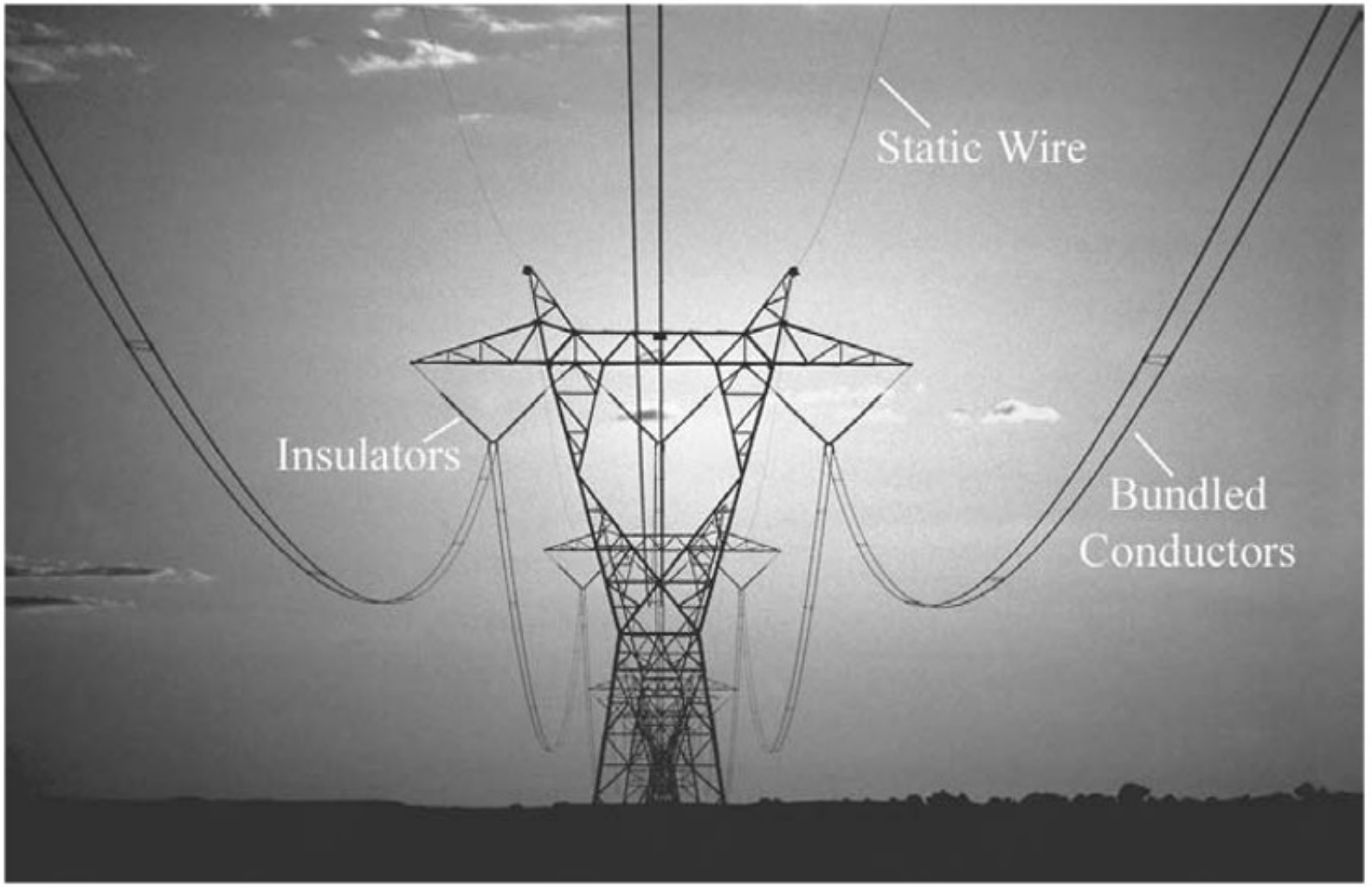
Voltage Drop at 2400mA

AWG	15cm	50cm	1m	2m	3m	5m
20	0.311983	0.367944	0.447888	0.607776	0.767664	1.08744
22	0.326131	0.415104	0.542208	0.796416	1.050624	1.55904
24	0.348638	0.490128	0.692256	1.096512	1.500768	2.30928
26	0.384408	0.60936	0.93072	1.57344	2.21616	3.5016
28	0.441288	0.79896	1.30992	2.33184	3.35376	5.3976

<=0.25v >0.25v >0.5v by goughlui.com

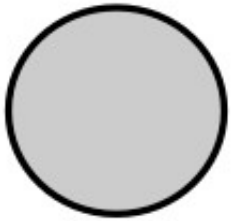
https://goughlui.com/2014/10/01/usb-cable-resistance-why-your-phonetablet-might-be-charging-slow/

Transmission Lines

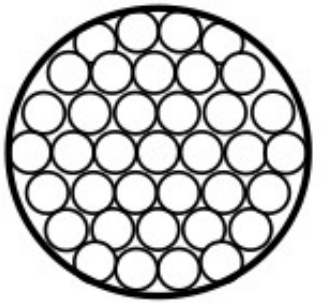


Conductor Types

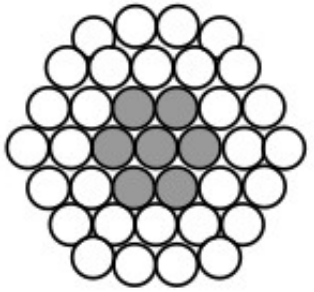
- Solid



- Stranded

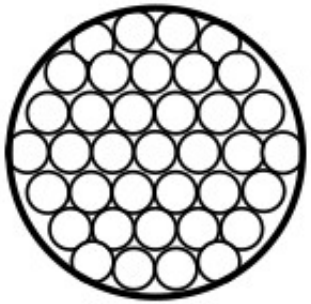


- Alu. Conductor, Steel Reinforced



Conductor Size

- American Standard Wire Gauge (AWG)
  - Reverse order
    - Number smaller -> conductor bigger
- Circular Mills (> AWG 4/0)



= 1 circular mil

= 1/1000 of an inch

Table 3-1. Typical ACSR conductor sizes

Cross section (inches)	Size, (AWG or cmils)	Size, copper equivalent	Ratio (Al to steel)	Diameter (inches)	Current (amps), (75°C rise)
0.250	4	6	7/1	0.250	140
0.325	2	4	6/1	0.316	180
0.398	1/0	2	6/1	0.398	230
0.447	2/0	1	6/1	0.447	270
0.502	3/0	1/0	6/1	0.502	300
0.563	4/0	2/0	6/1	0.563	340
0.642	266,000	3/0	18/1	0.609	460
0.783	397,000	250,000	26/7	0.783	590
1.092	795,000	500,000	26/7	1.093	900
1.345	1,272,000	800,000	54/19	1.382	1,200

Transmission Voltage

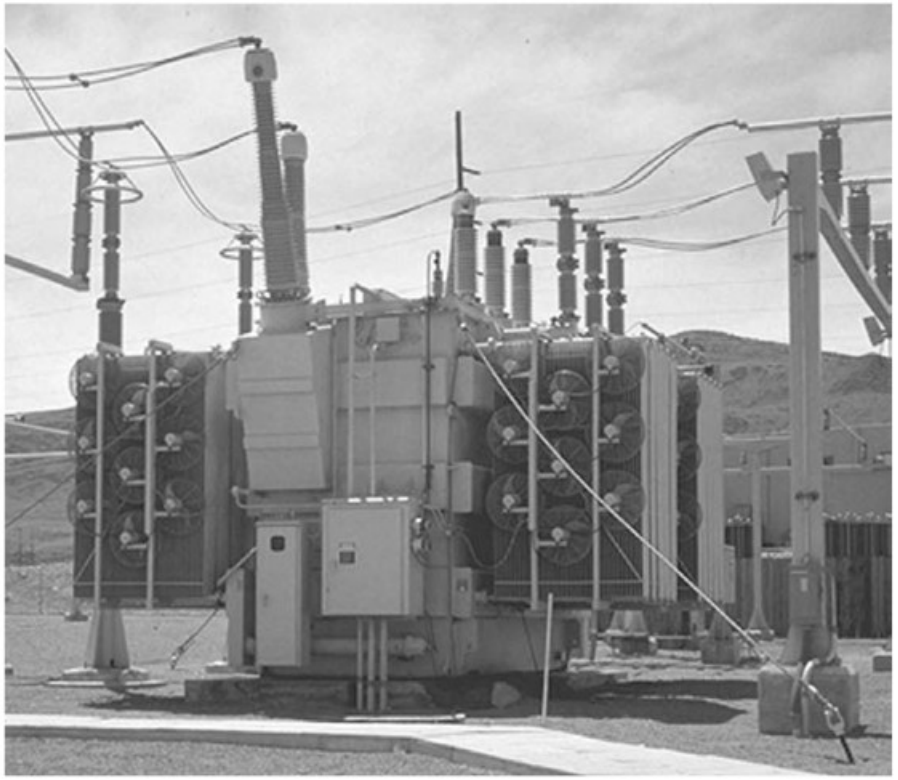
Voltage class	Voltage category	System voltage
69,000		Subtransmission
115,000		
138,000		
161,000		Transmission
230,000	Extra high voltage (EHV)	
345,000		
500,000		
765,000		
Above 1,000,000	Ultra high voltage (UHV)	

Substations

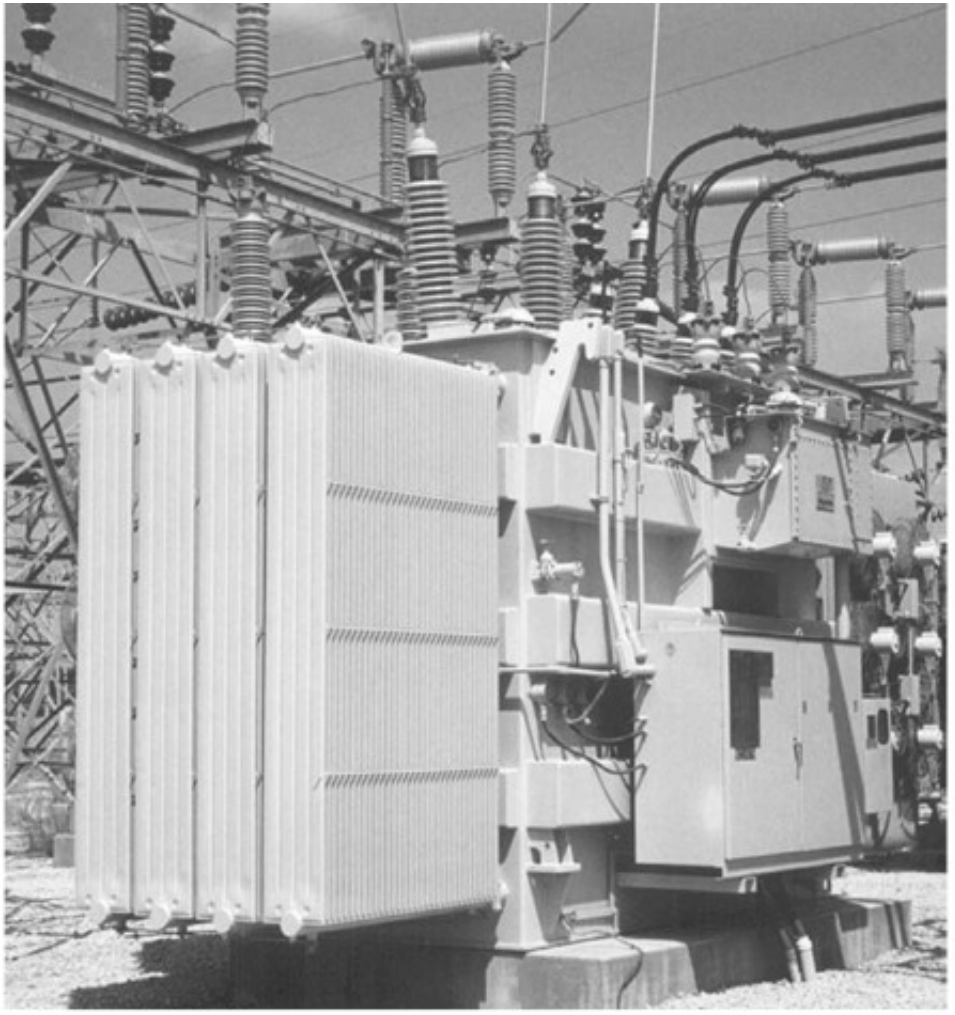
Substations

- Transformers
- Regulators
- Circuit breakers and reclosers
- Air disconnect switches
- Lightning Arresters
- Electrical buses
- Capacitor banks
- Reactors
- Static VAR compensators
- Control building
- Preventative maintenance

Transformers



Step down



Distribution

Inside and connections

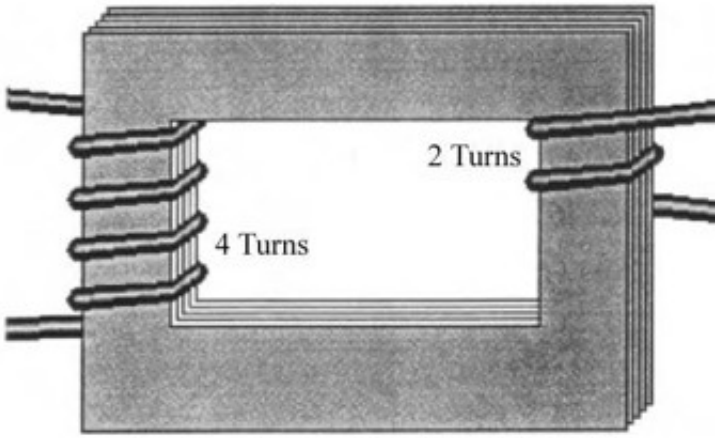
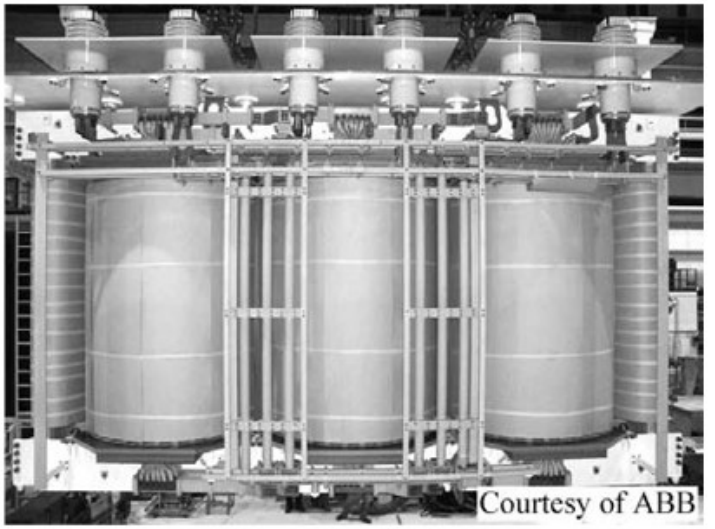


Figure 4-4. Transformer windings. Courtesy of Alliant Energy.



Transformer core and coils

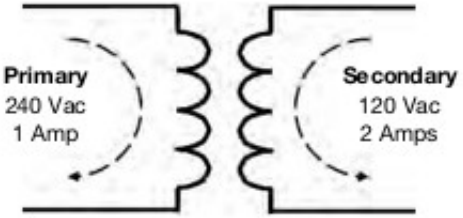
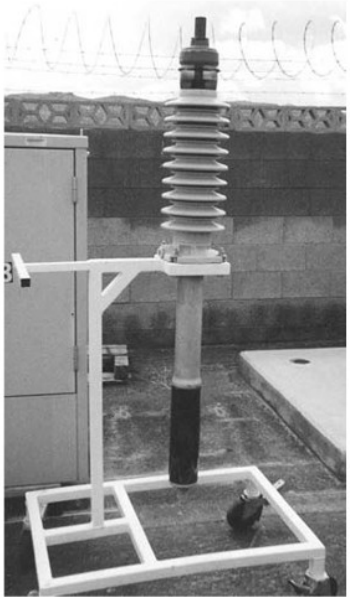


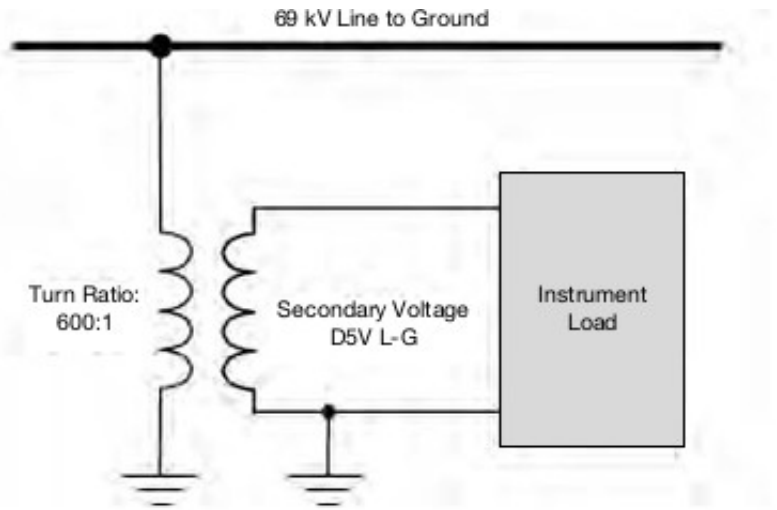
Figure 4-5. Transformer turn ratio.

Bushing

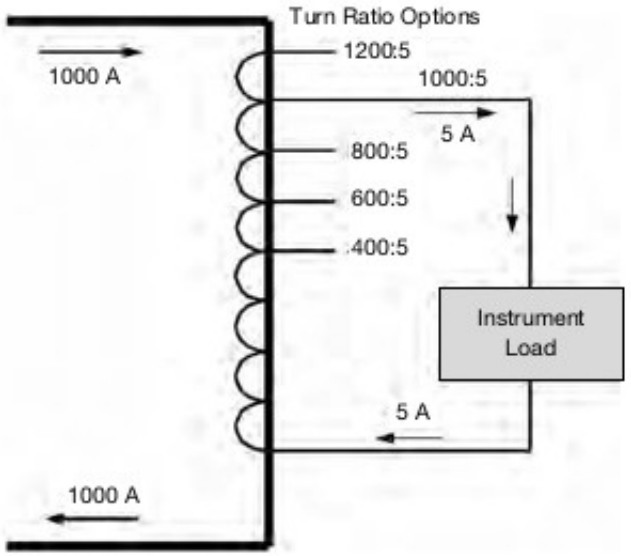


PT and CT

- Potential Transformers
  - Metering, protective relaying and sys monitoring

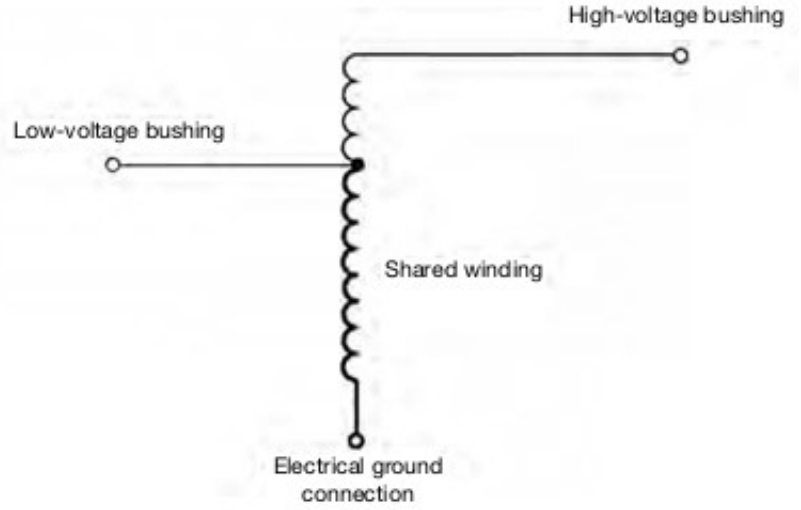


- Current Transformers



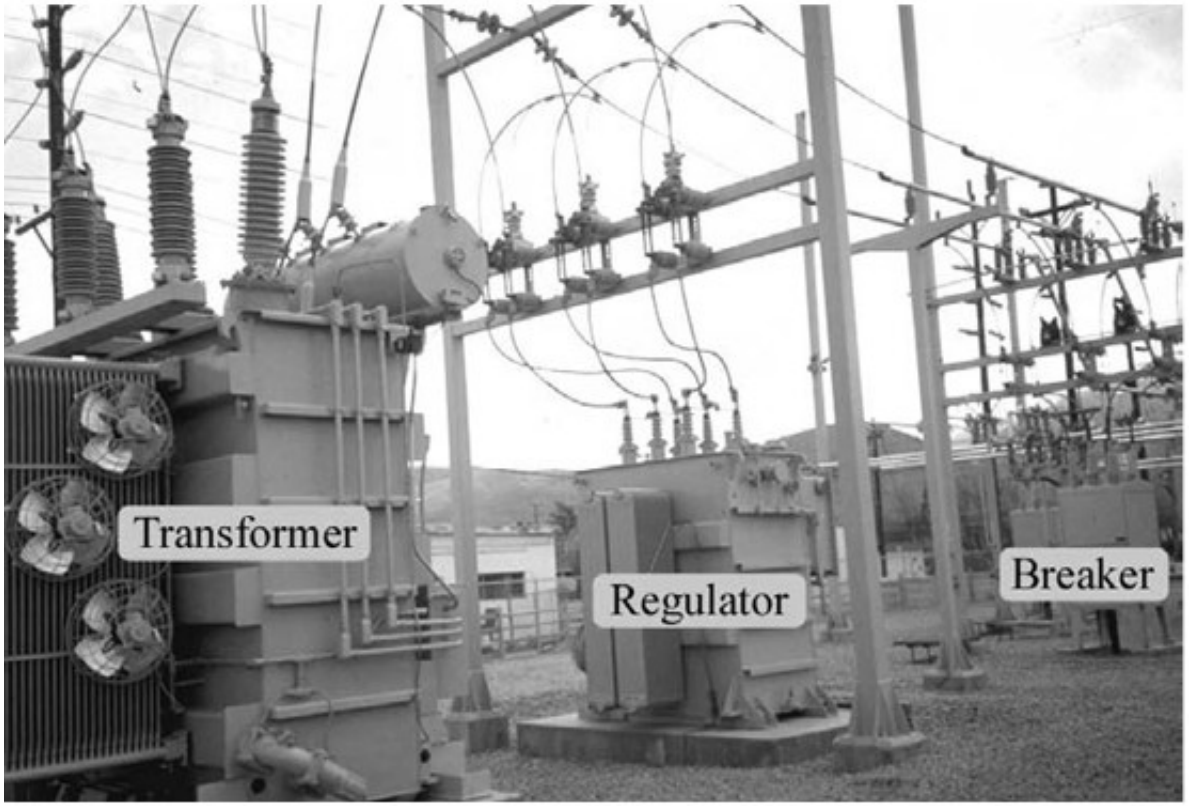
Autotransformers

- Specially constructed variations of regular two winding transformers. They share a winding..
- Both windings on the common core
- Works best with small turns (5:1)
  - 500kV-230kV.... 345 kV to 120kV

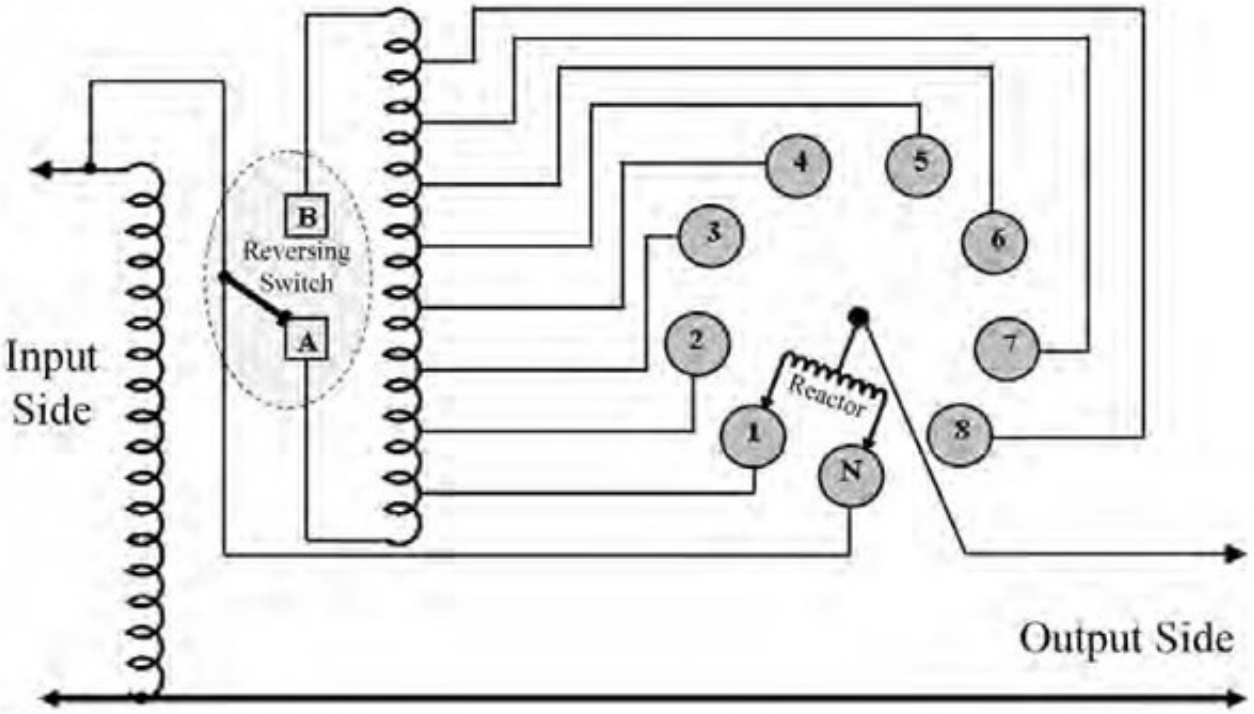


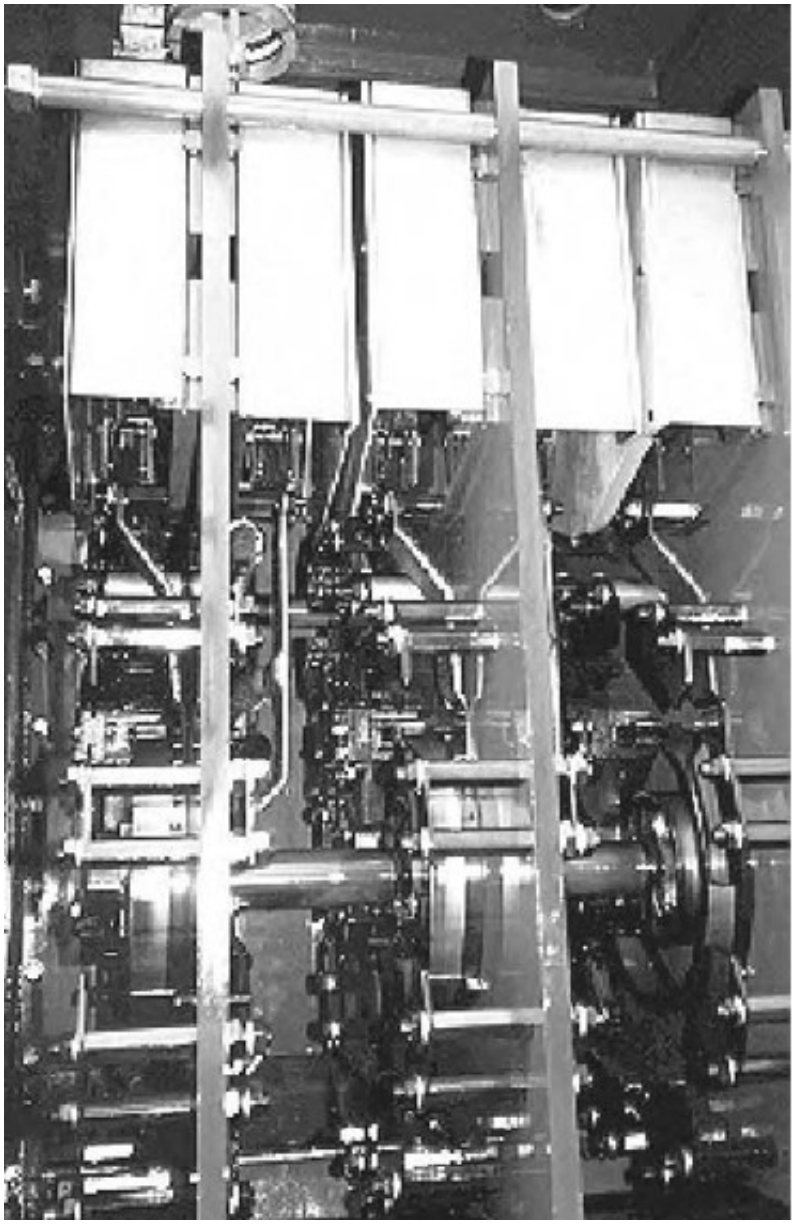
Regulators

- Steady-regulated voltage (Ex: 240 Vac regulated to +-5%)
- First costumer should not exceed 252 V, last customer should not be less that 222 V)
- Load tap changer



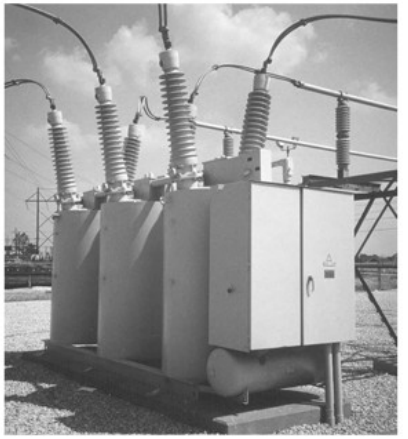
Load tap changer

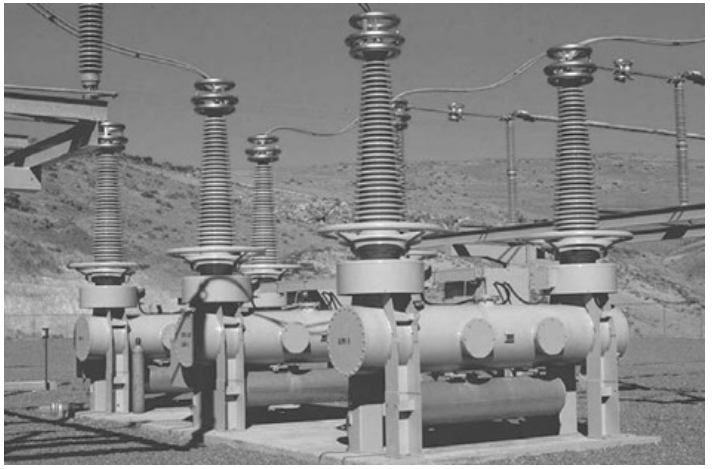


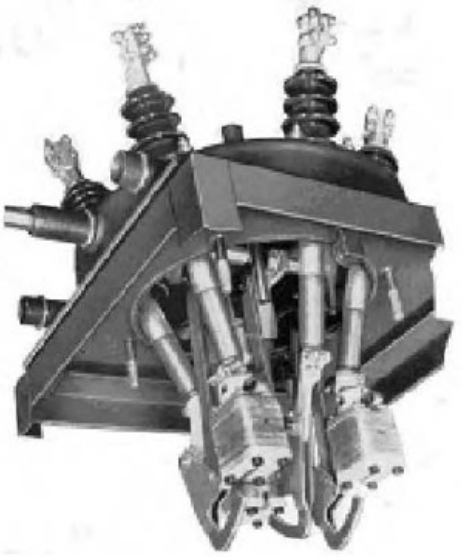


Circuit breakers

- Oil (OCB)
- Gas (SF6 – sulfur hexafluoride) (GCB)
- Vacuum
- Air

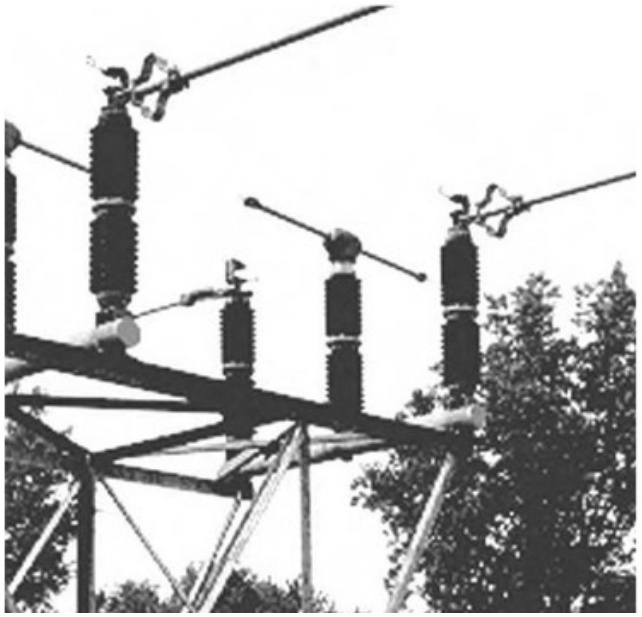






Breaks (Disconnect Switches)

- Vertical break
- Horizontal break
- Gang operated(3 phase)

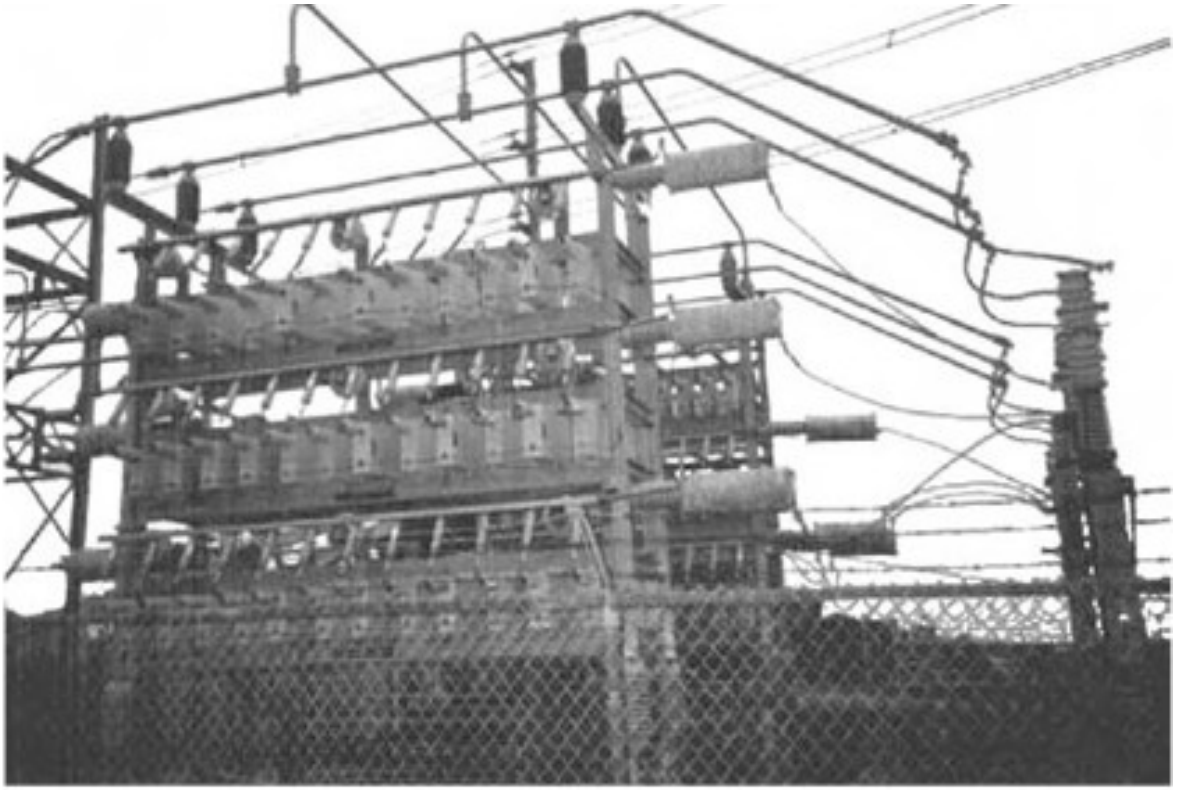


Electrical Bus

- Electrical bus connects equipment together

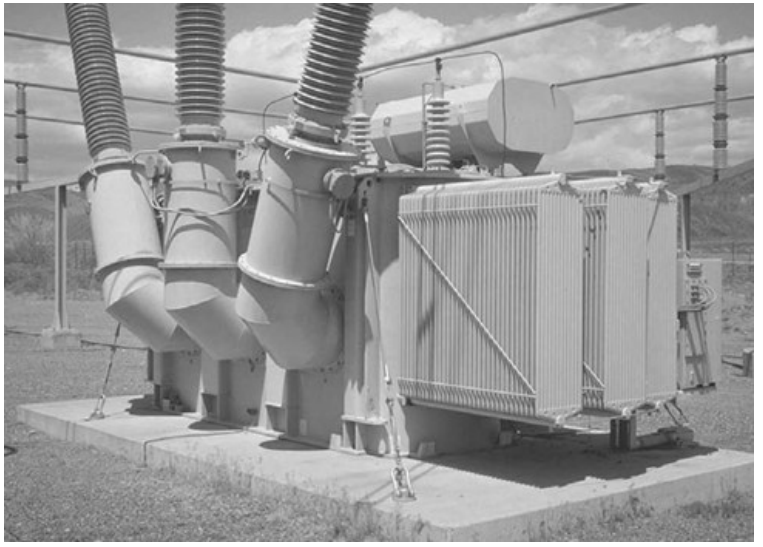
Capacitor Banks

- Online continuously or turned on/off to meet dynamic reactive requirements



Reactors

- Another name for a high voltage-inductor (one winding transformer)
  - Absorbing surplus VAR (reactive power) or line charging: capacitance effect of long lines
  - Connected in series to reduce fault current in distribution lines



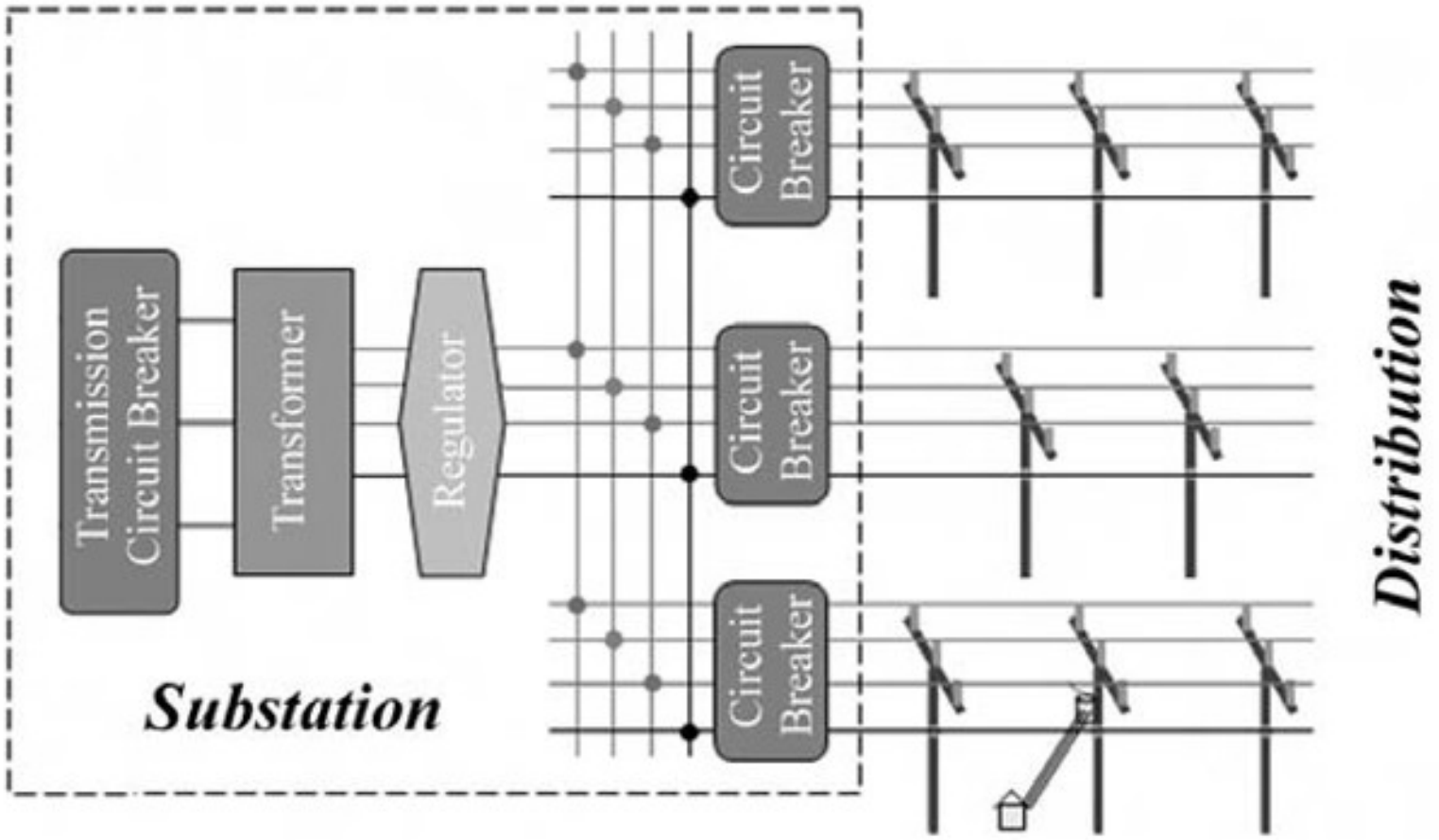
Static VAR Compensator (SVC)

- To control power flow, improve stability, reduce system losses
- Several capacitors +inductors+electronic switching
- When voltage low, SVC generates reactive power(capacitive)
- When voltage high, SVC absorbs reactive power (inductive)

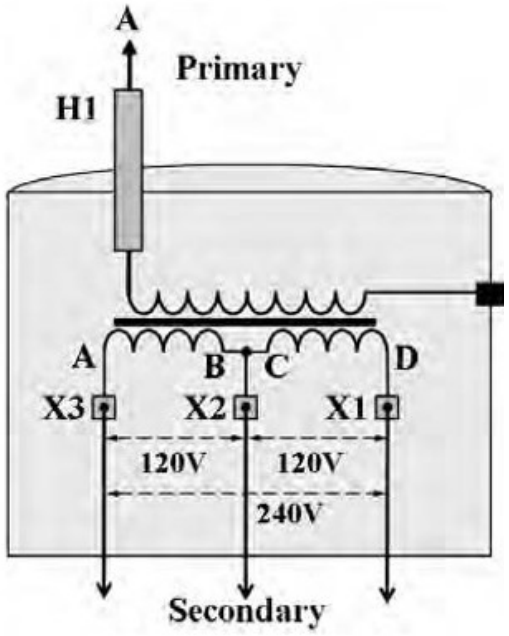
Distribution Voltages

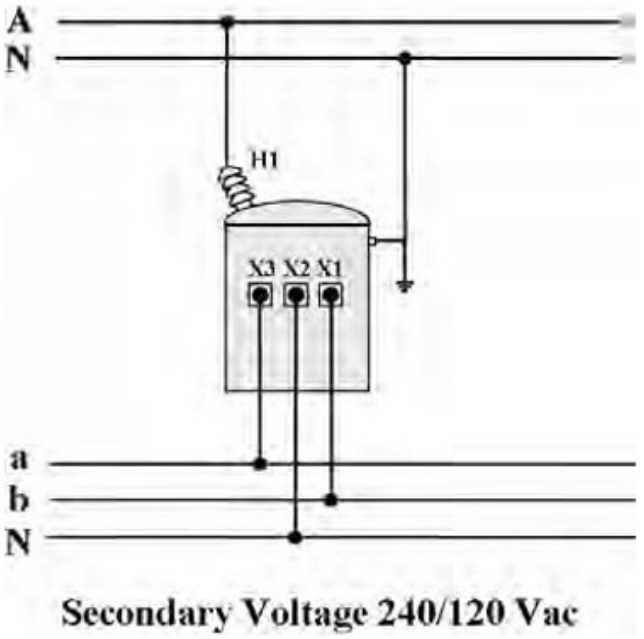
System voltage	Voltage class	Nominal voltage (kV)	Voltage category
Secondary	Under 600	0.120/0.240/0.208 0.277/0.480	Low voltage (LV)
Distribution	601–7200	2.4–4.16	Medium voltage (MV)
	15,000	12.5–14.4	High voltage (HV)
	25,000	24.9	
Distribution or subtransmission	34,500	34.5	

Distribution feeders



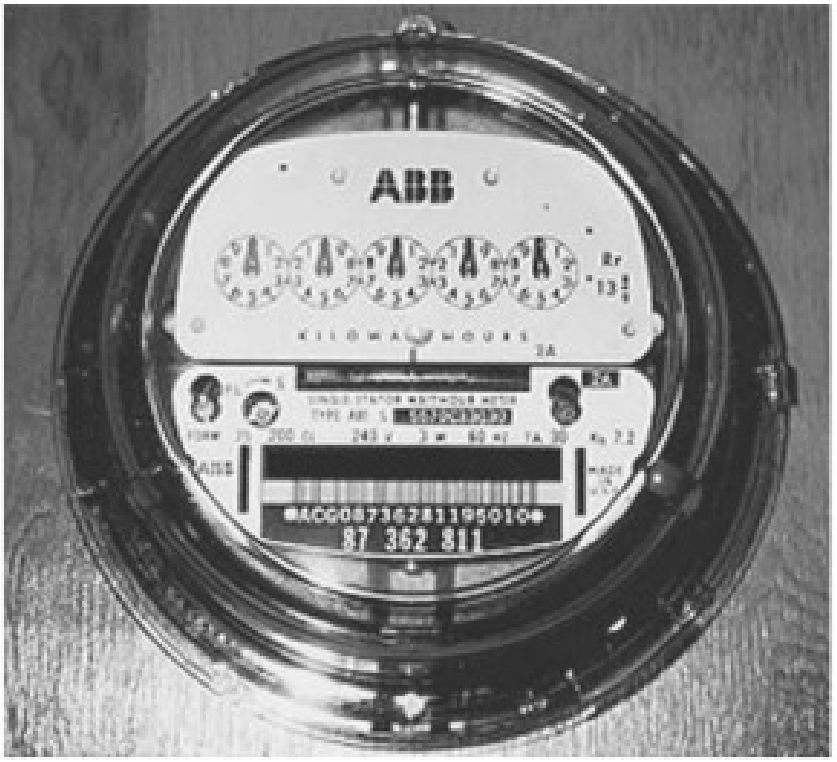
Three phase Distribution Transformers





One bushing transformer

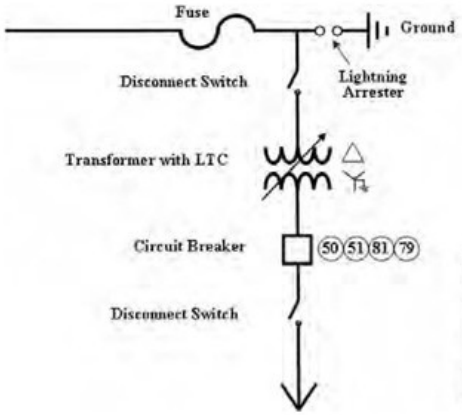
Metering



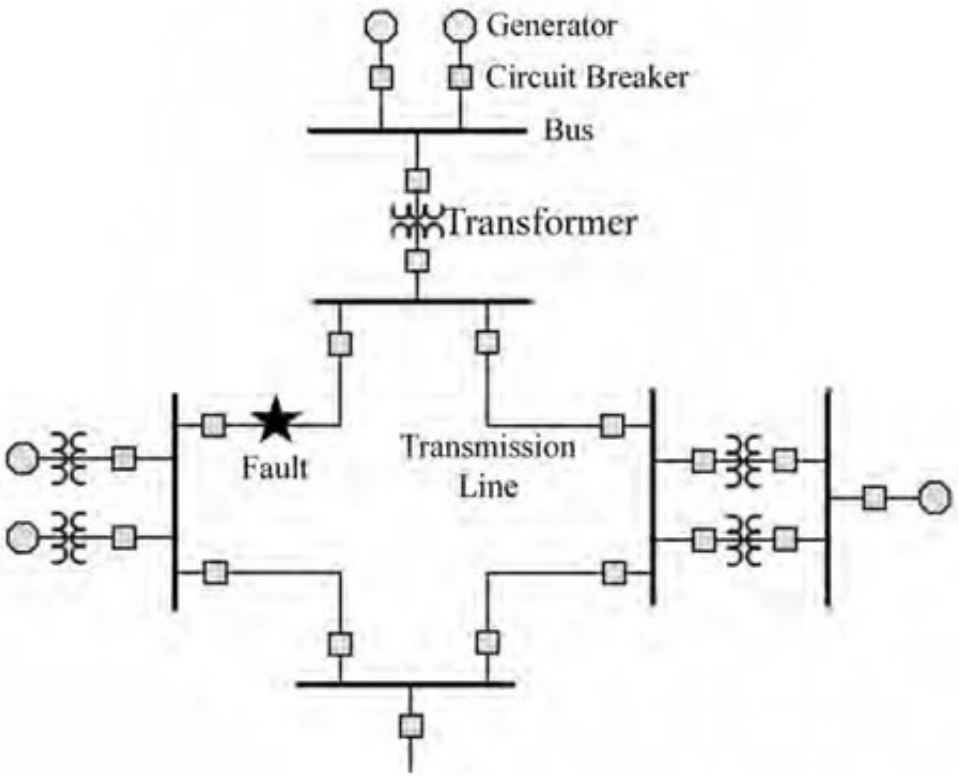
Electromechanical

Solid state

One line diagram



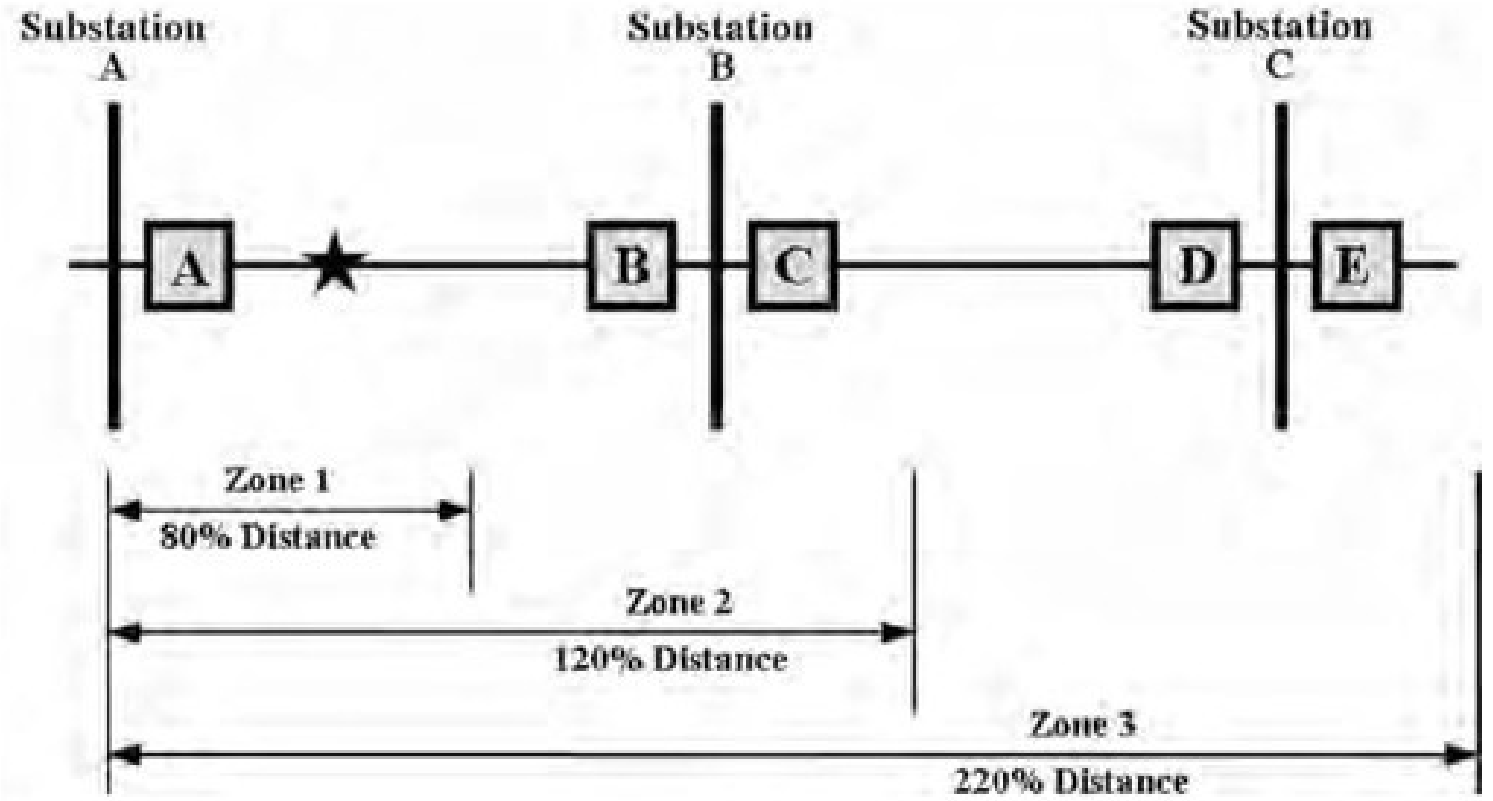
50	Instantaneous Overcurrent Relay
51	AC Time Overcurrent Relay
79	AC Reclosing Relay
81	Frequency Relay



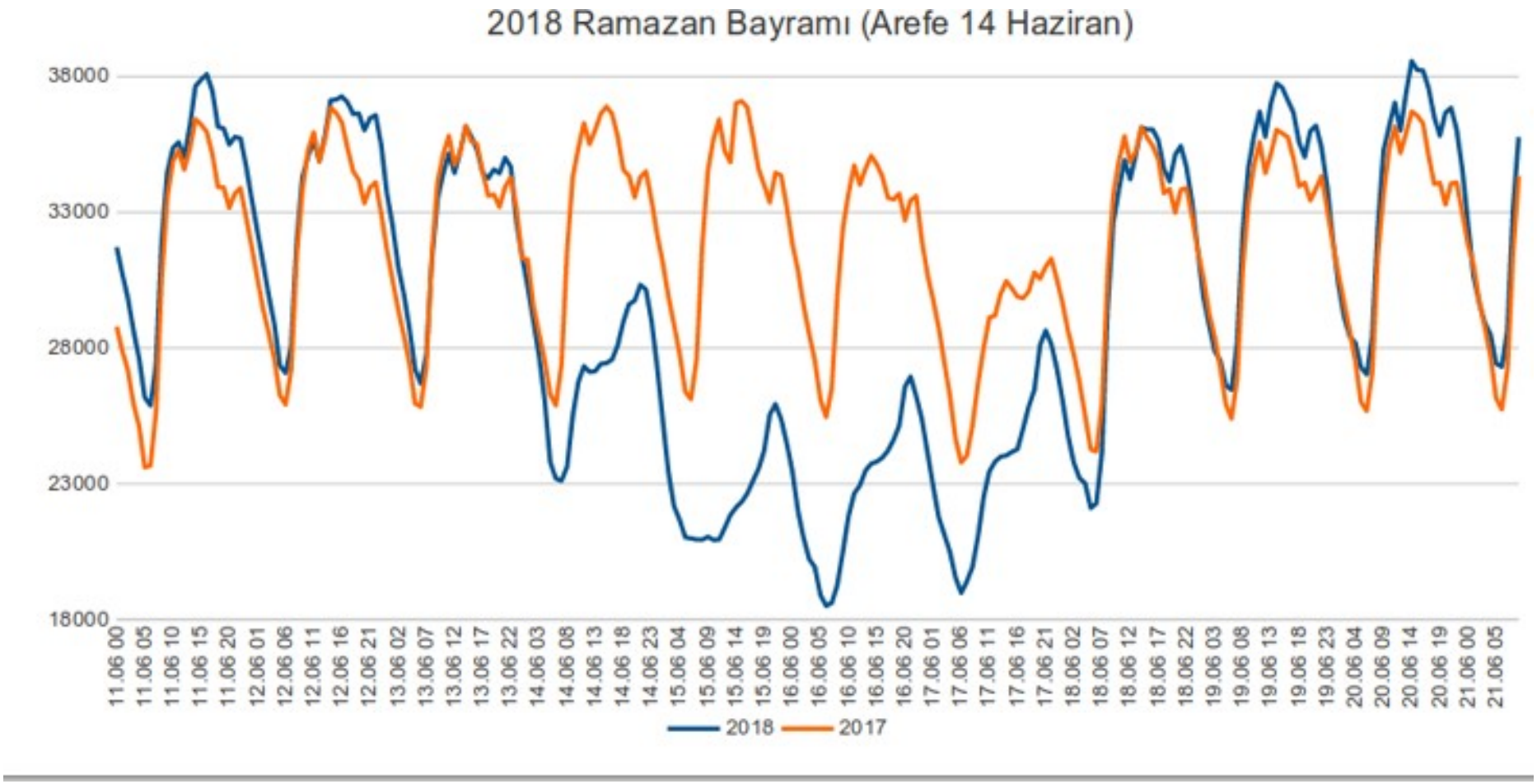
Underfrequency Relays

- Load shed relays
  - @ 49.8 Hz shed a minimum 10% of a load
  - @ 49.5 Hz shed a minimum 10% of a load
  - @ 49.2 Hz shed a minimum 10% of a load

Zone or Distance Relays



Load


2018 Ramazan Bayramı (Arefe 14 Haziran)
38000
33000
28000
23000
18000
11.06 00
11.06 05
11.06 10
11.06 15
11.06 20
12.06 01
12.06 06
12.06 11
12.06 16
12.06 21
13.06 02
13.06 07
13.06 12
13.06 17
13.06 22
14.06 03
14.06 08
14.06 13
14.06 18
14.06 23
15.06 04
15.06 09
15.06 14
15.06 19
16.06 00
16.06 05
16.06 10
16.06 15
16.06 20
17.06 01
17.06 06
17.06 11
17.06 16
17.06 21
18.06 02
18.06 07
18.06 12
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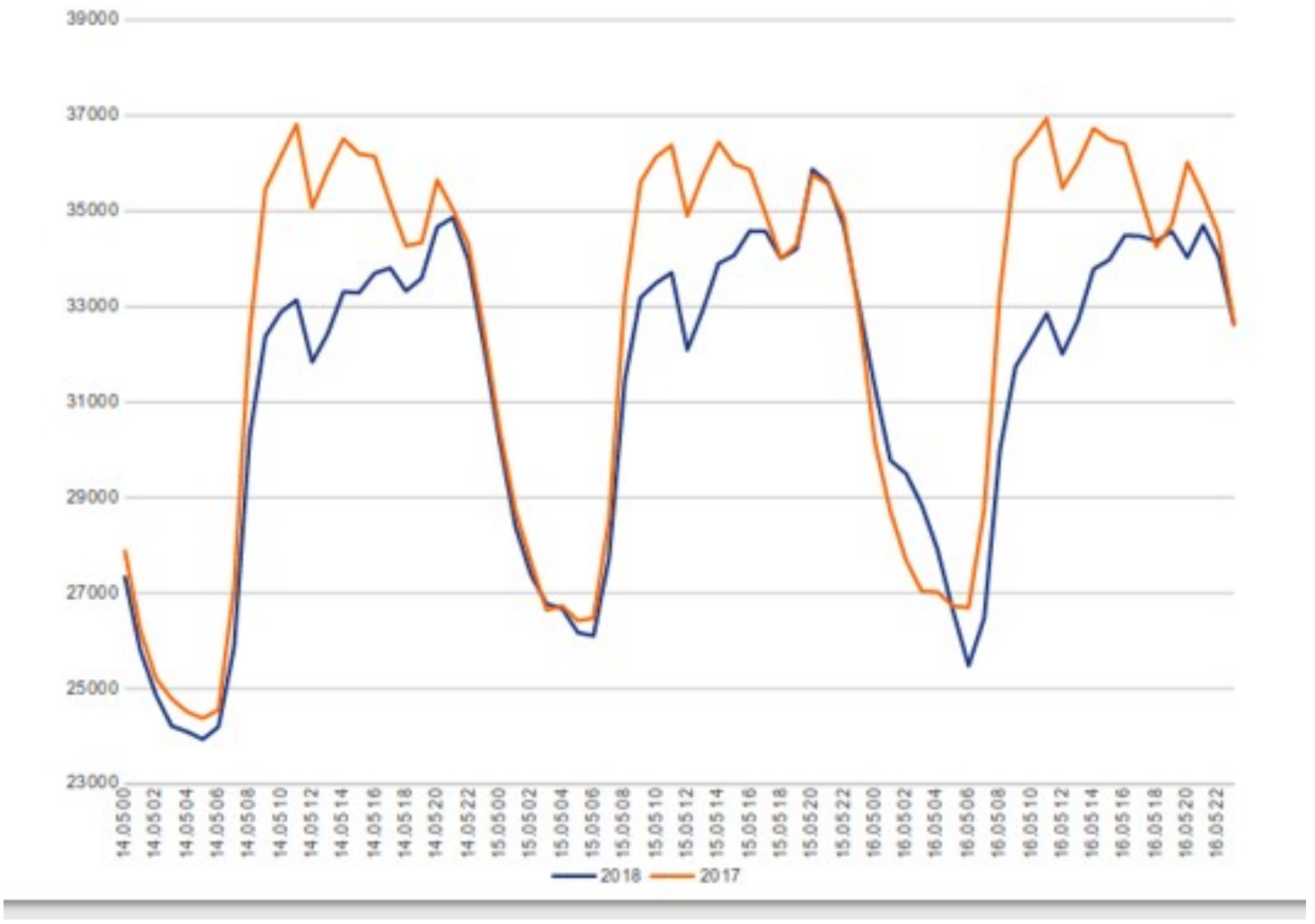
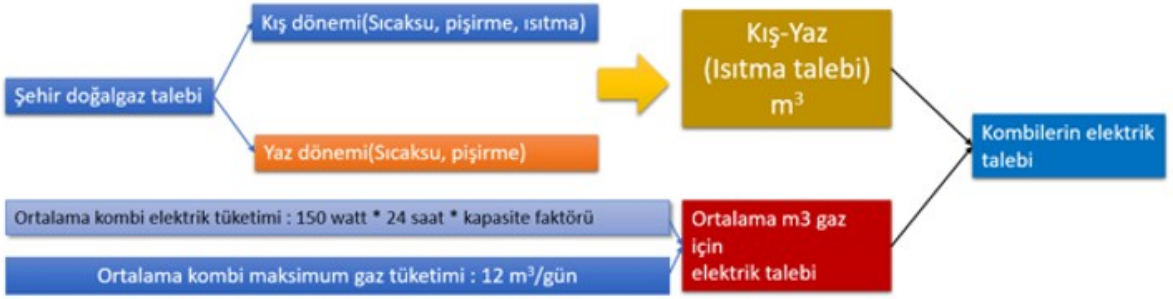
18.06 22
19.06 03
19.06 08
19.06 13
19.06 18
19.06 23
20.06 04
20.06 09
20.06 14
20.06 19
21.06 00
21.06 05
2018
2017

Load – First days of Ramadan



Q3 – Electricity in heating

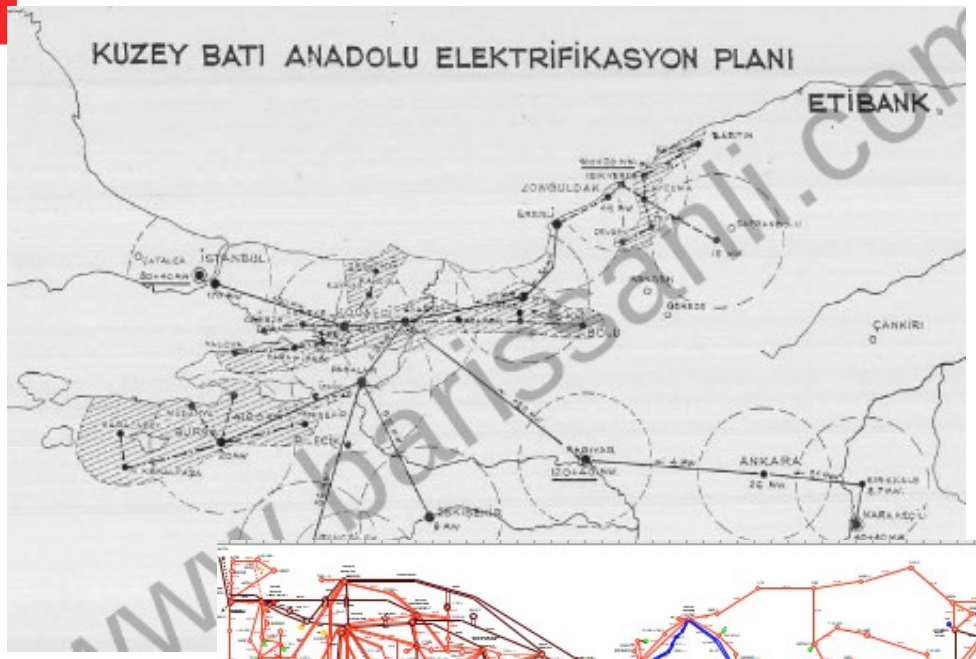


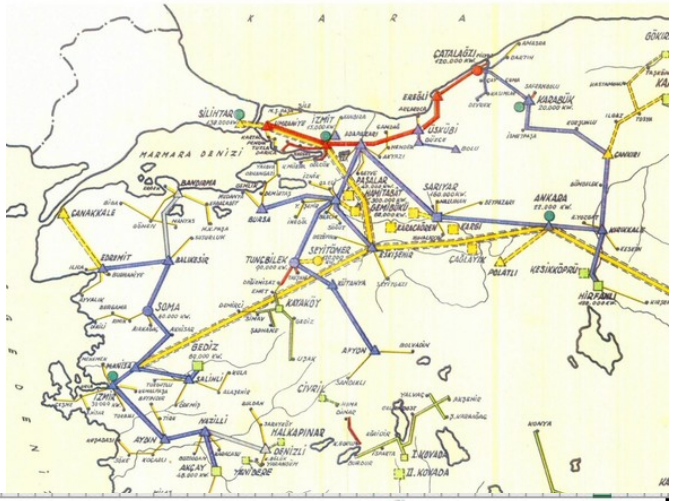
Grafik - Günlük elektrik talebi içinde ısıtma ve içindeki elektrik talebi (Y ekser

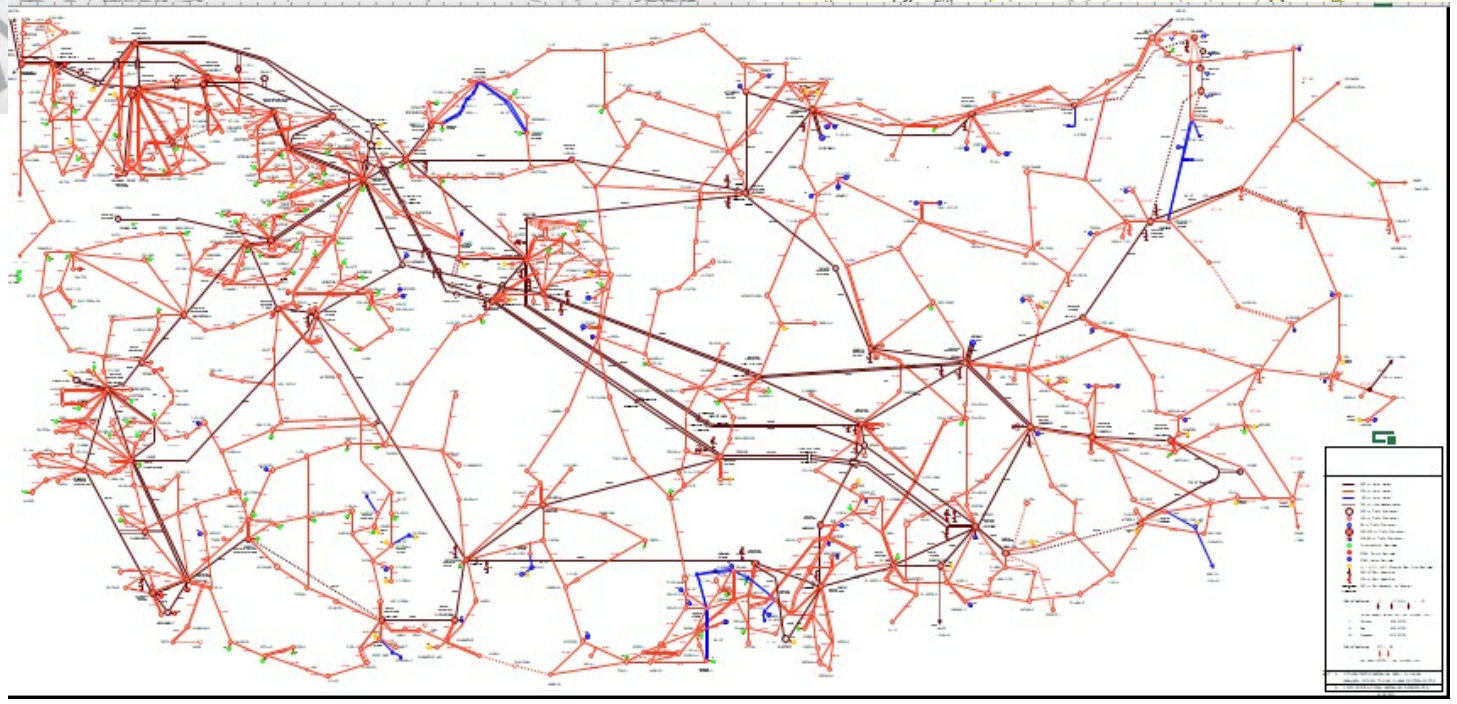
How Turkey uses its energy

	mtep(milyon ton eşdeğer petrol)	Kömür	Petrol	Doğalgaz	Yenilenebilir	Elektrik	Toplam
ARZ	Üretim	15	3	0	17	0	35
	İthalat	24	51	38	0	1	113
	İhracat+İhrakiye	0	11	1	0	0	12
	Enerji Arzı	38	42	38	17	0	136
DÖNÜŞÜM	Dönüşümde Tüketilen	-23	-1	-16	-11	19	-32
	Elektriğe dönüşüm	-22	-1	-15	-12	24	-26
	Rafineri	0	2	-1	-0	-0	1
	İçtüketim & Kayıp	-1	-3	-0	0	-4	-8
TÜKETİM	Nihai Tüketim	16	41	22	6	20	105
	Sanayi	10	4	9	1	9	33
	Ulaştırma	0	26	0	0	0	27
	Konut	2	0	10	3	4	20
	Ticarethane	4	1	3	1	6	14
	Tarım	0	3	0	1	1	4
	Enerji dışı(hammade)	0	6	1	0	0	7

Interconnected Grid







https://electronicsystematic.blogspot.com/2018/02/turkiye-enterkonnekte-sebeke-sistemi.html

How system is balanced

- Voltage and frequency
  - Voltage → reactive
  - Frequency → generation
- Day ahead planning
- Reserve and security margins
- Flexibility is important
- Real time management

Thank you

- For more info

  www.barissanli.com