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Power Distribution Systems

Lecture 1

Introduction to Distribution Systems

Simple Power System

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Electric power system is an interconnected network with components converting non-electrical energy continuously into the electrical form and transporting the electrical energy from generating source to the load/users.

Power system consists of three sub-systems;

- ***Generation*** – generating and/or sources of electrical energy
- ***Transmission*** – transporting electrical energy from it sources to load
- ***Distribution*** – distributing electrical energy from substations to end user/customers.

http://www.hydroquebec.com/learning/transport/construction-poste/index.html

Simple Power System

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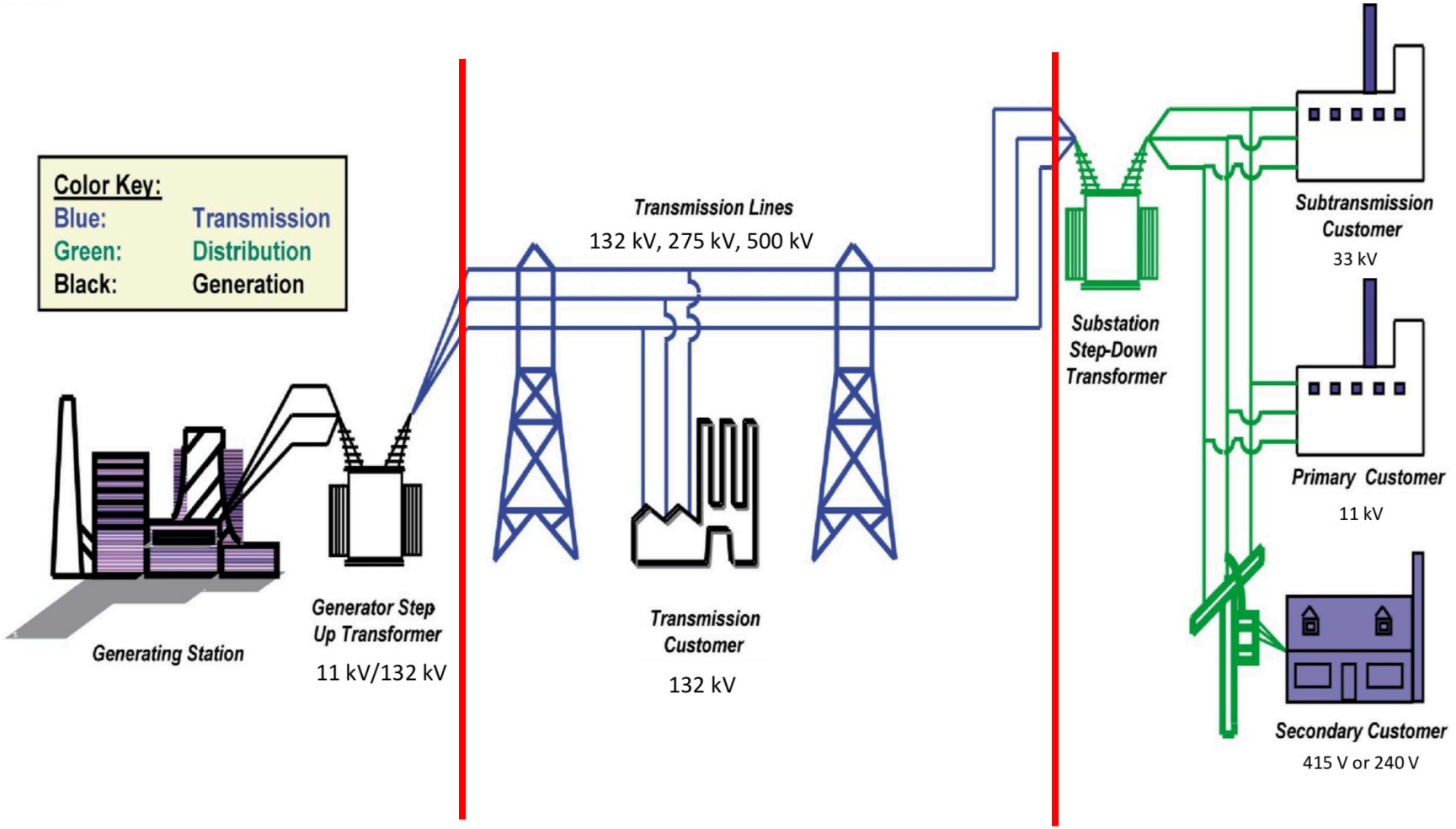
The Big Picture



Simple Power System

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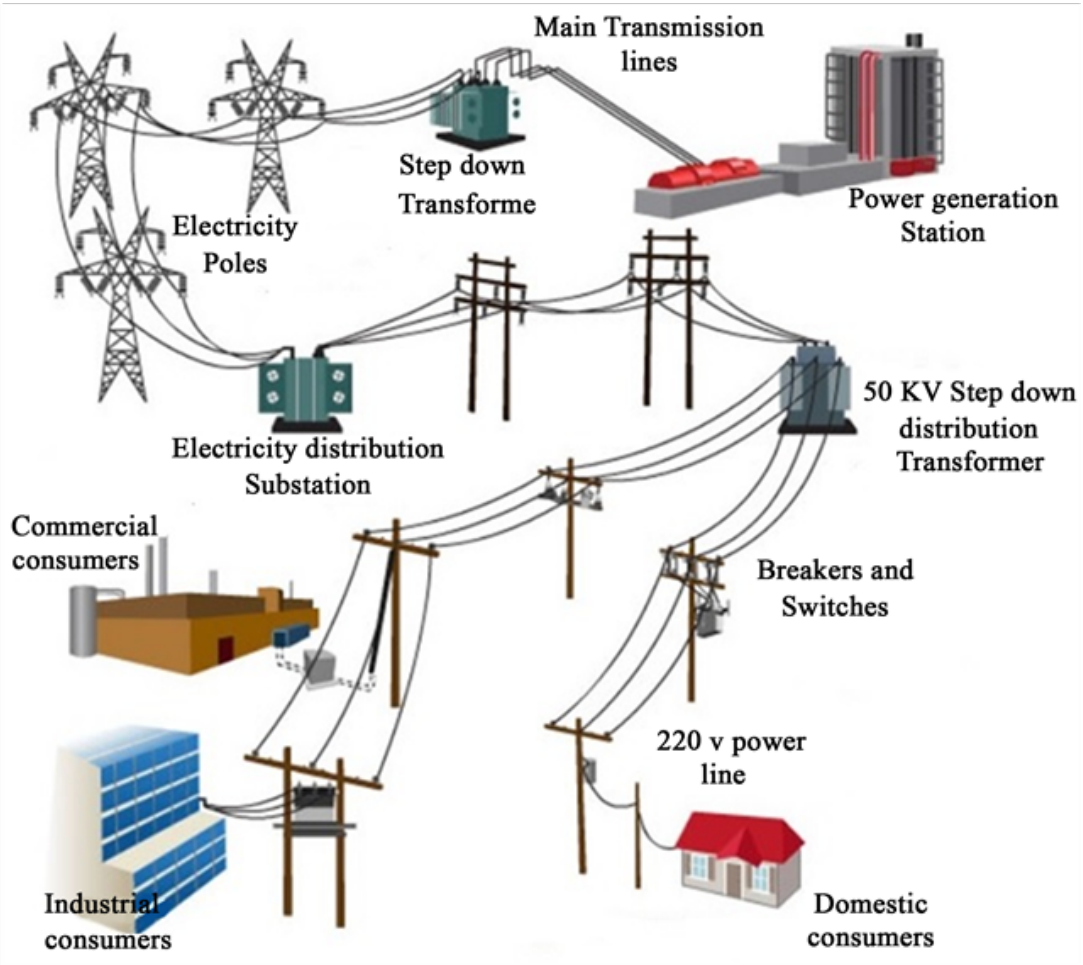
A Closer Look



Simple Power System

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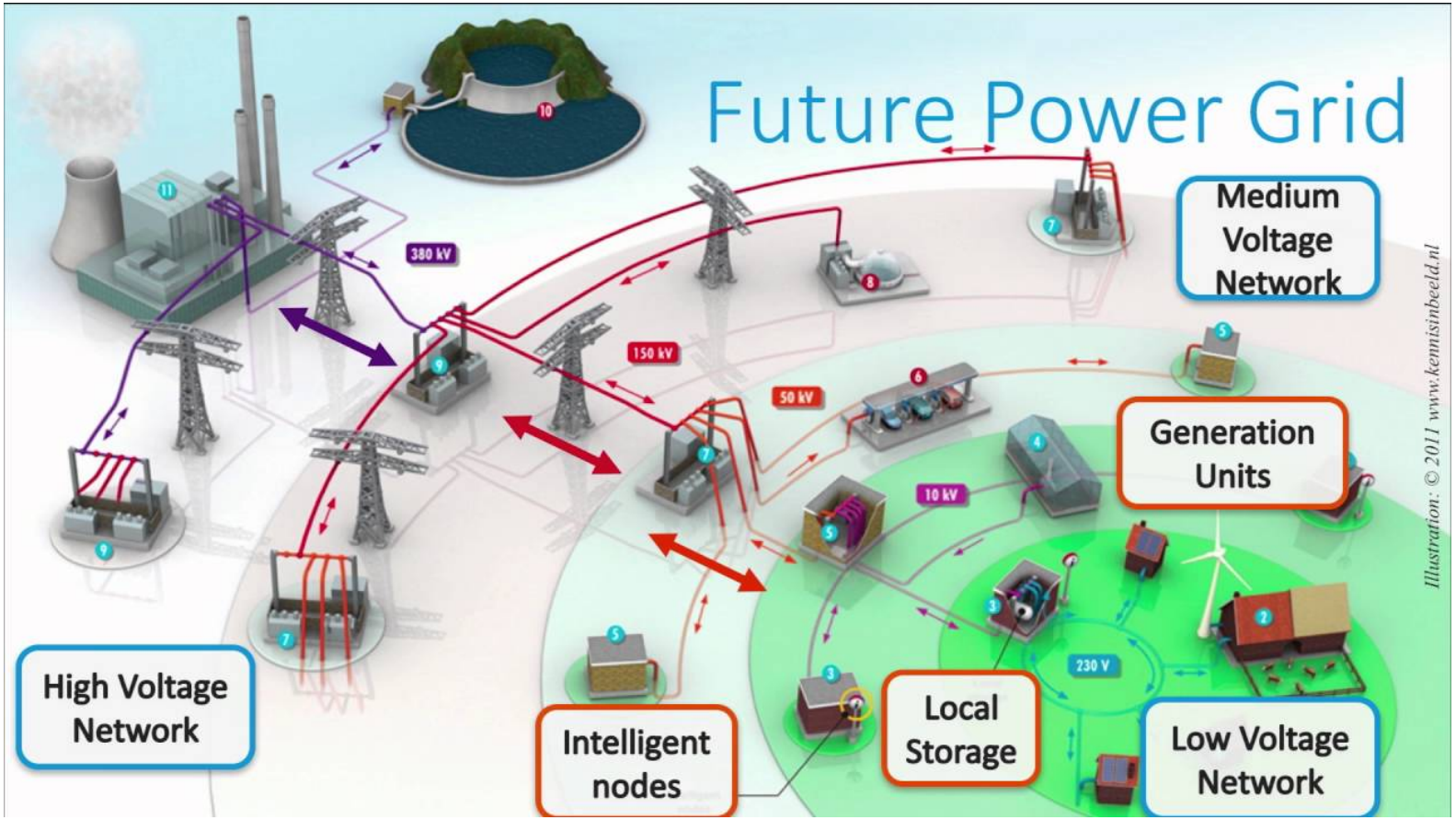
Next Generation Electric Power System



History of Electrical Power System

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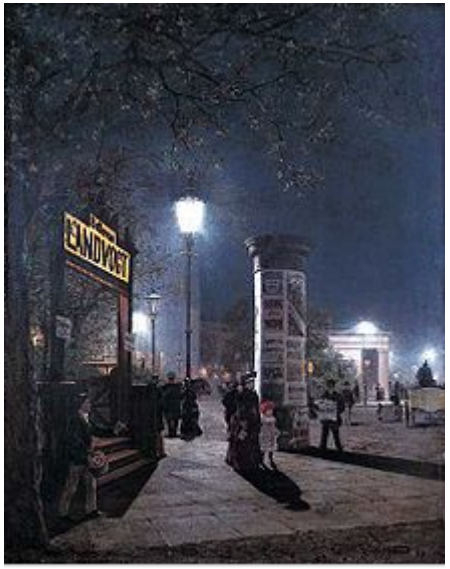
Early Electricity Delivery

- **Early 1880's :** Edison introduced Pearl Street dc system in Manhattan supplying only 59 customers within a one mile radius
- **1883 :** First 3-phase transmission line operating at 2.3 kV, 12 km in Sothern California
- **1896 :** AC lines deliver electricity from hydro generation at Niagara Falls to Buffalo, 32 km away



History of Electrical Power System

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Electricity in Turkiye

- **1902 :** Hydropower plant in Tarsus, only 2 kW
- **1914 :** Silahtaraga thermal power plant
- **By 1920's :** Installed power capacity is about 30 MW

Overview of Electrical Energy in Turkiye

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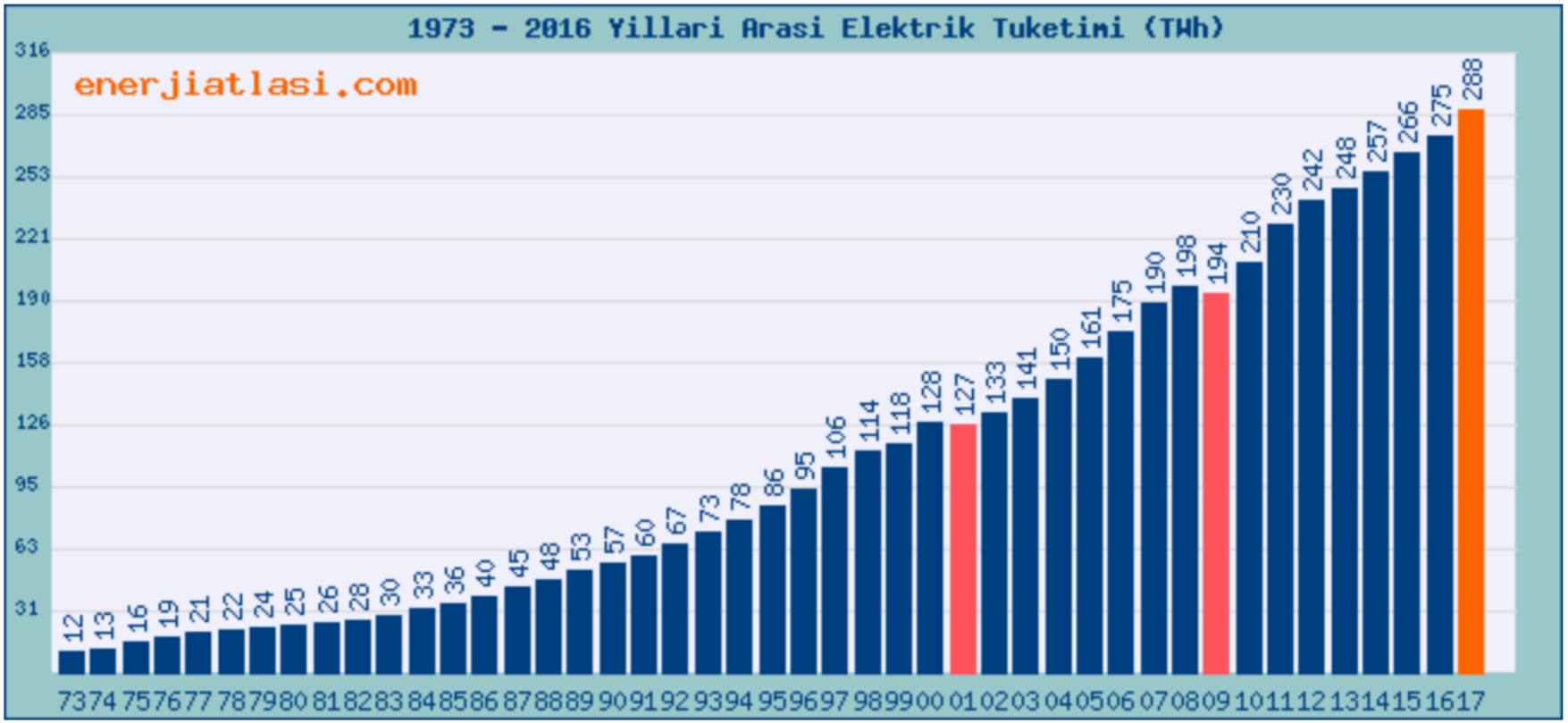
Energy consumption between 1970-2017 (TWh)



Overview of Electrical Energy in Turkiye

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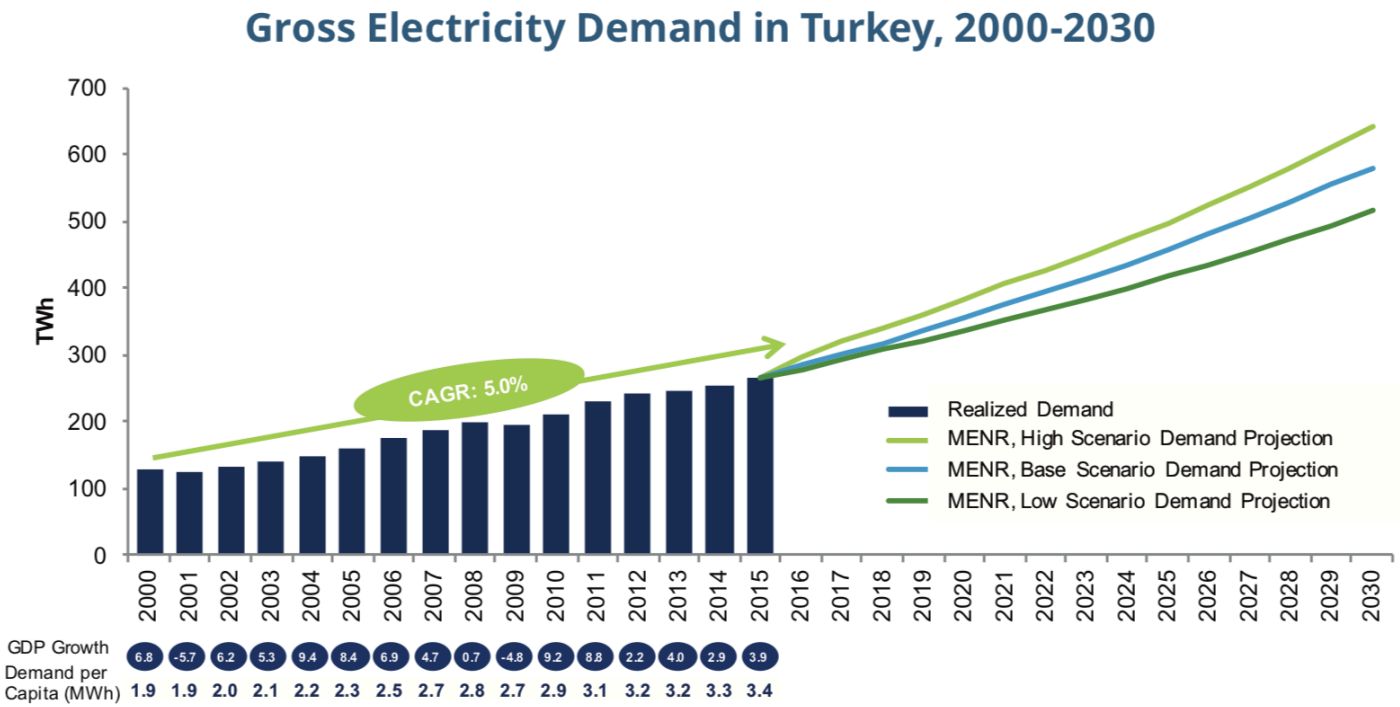
Electricity Demand



Source: TEİAŞ, MENR, TurkStat

Overview of Electrical Energy in Turkiye

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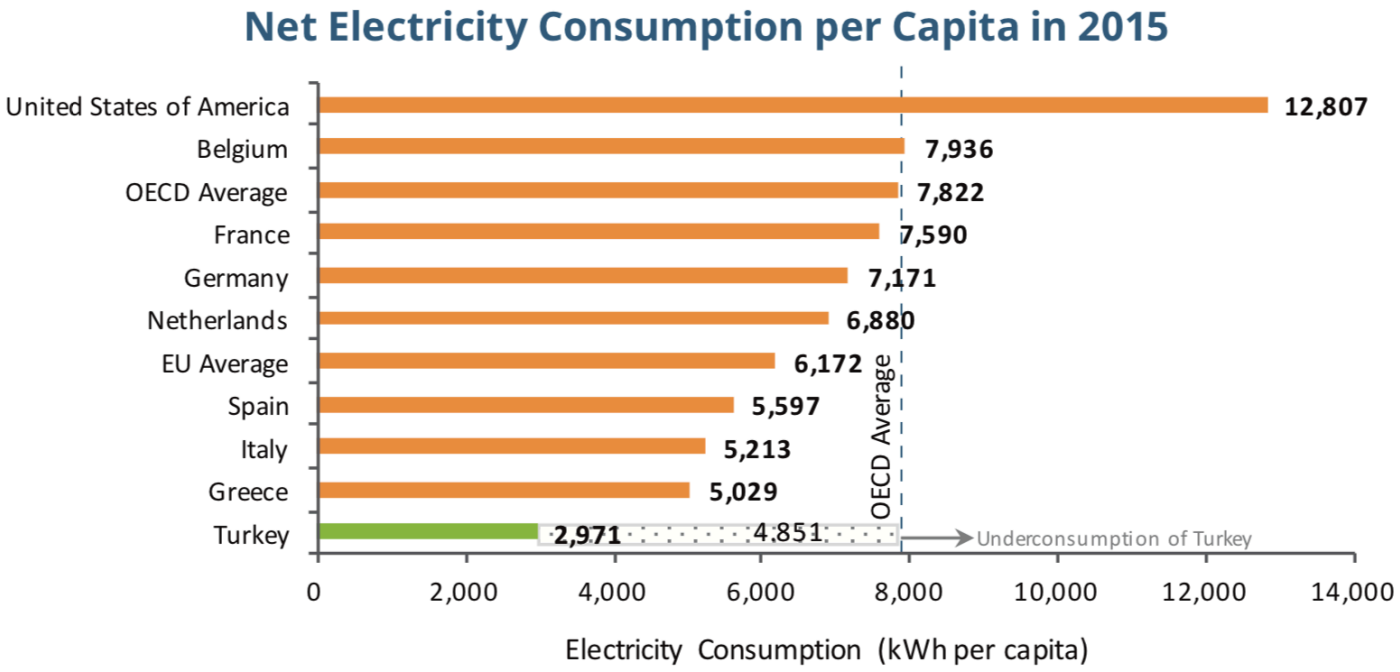
Electricity Consumption



Source: World Development Indicators

Overview of Electrical Energy in Turkiye

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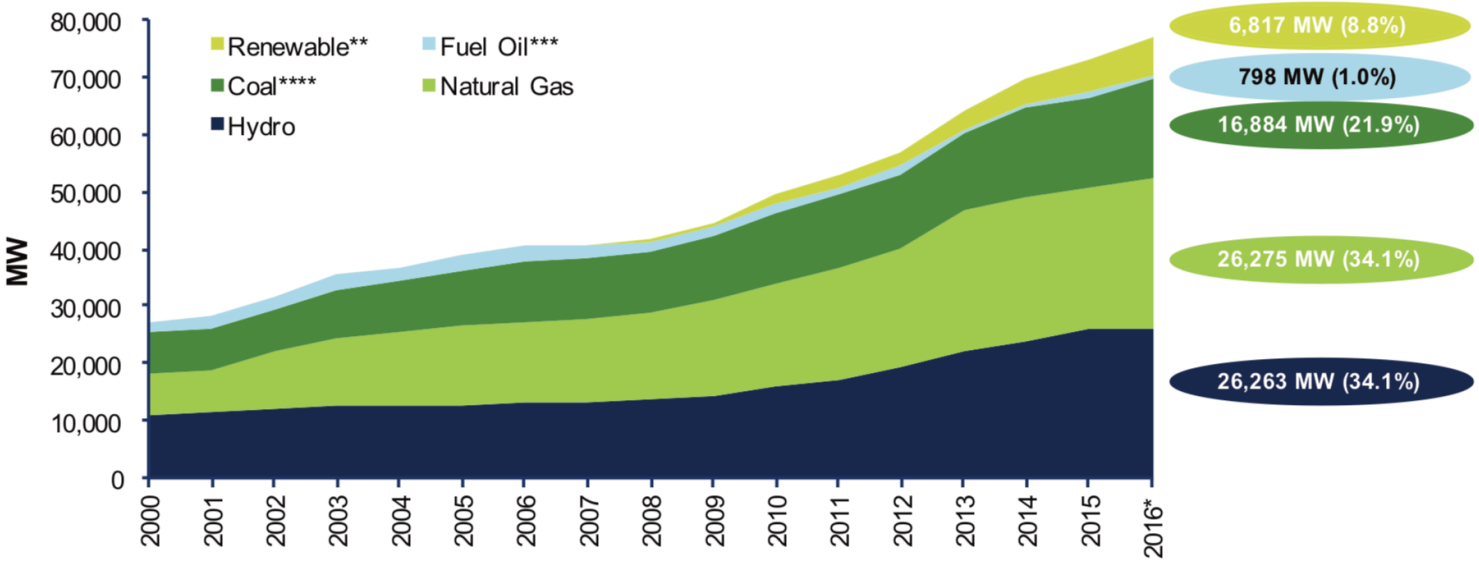
Installed Capacity

Historical Installed Capacity by Primary Energy Resources, 2000-2016*



*As the end of July 2016
** Includes Wind, Solar, Geothermal and Waste and other renewable power plants
*** Includes Diesel, Asphaltit and Naphta firing power plants
**** Includes all kinds of local and imported coal firing power plants
Source: TEİAŞ, Deloitte Analysis

Overview of Electrical Energy in Turkiye

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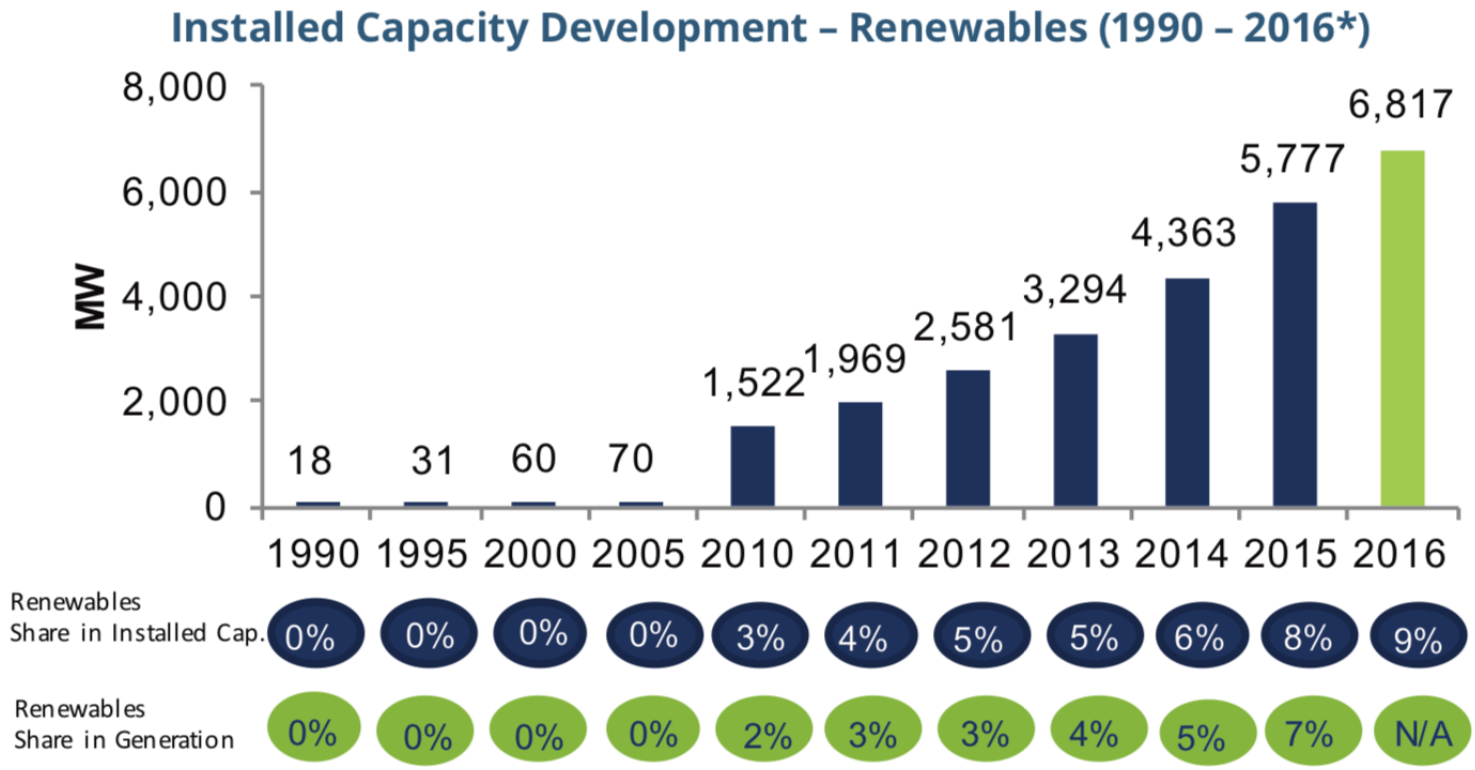
Renewable Energy Profile



Source: TEİAŞ
*As the end of July 2016

Overview of Electrical Energy in Turkiye

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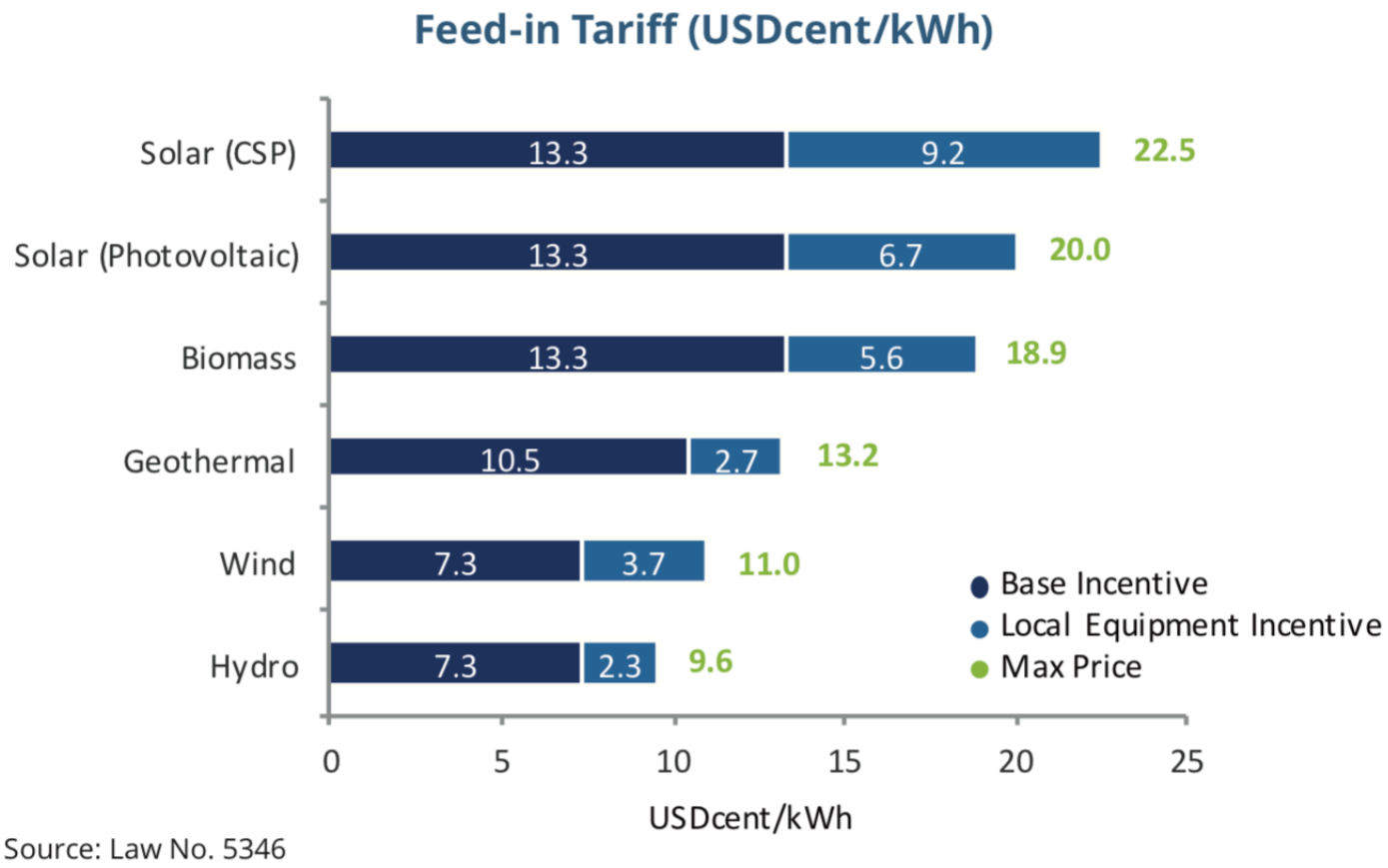
Renewable Energy Support



Source: Law No. 5346

Overview of Distribution Systems

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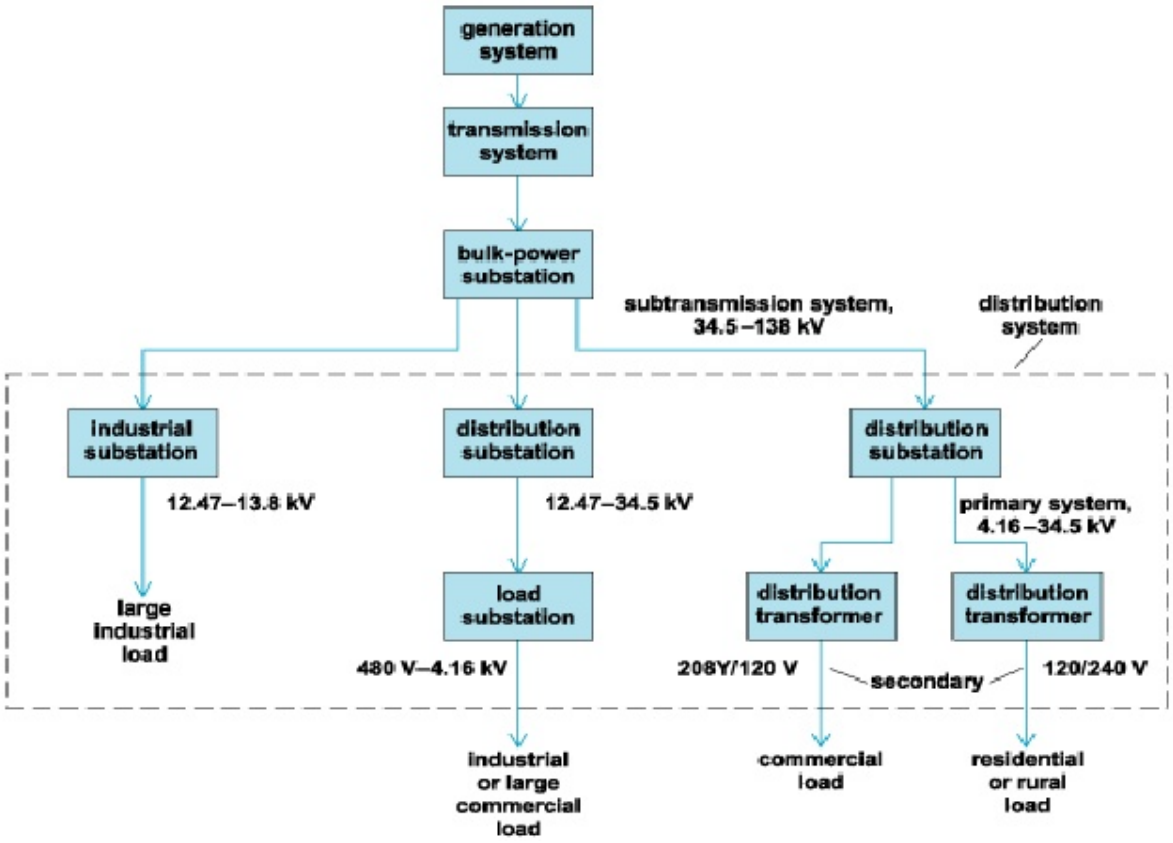
Distribution System Layot



Overview of Distribution Systems

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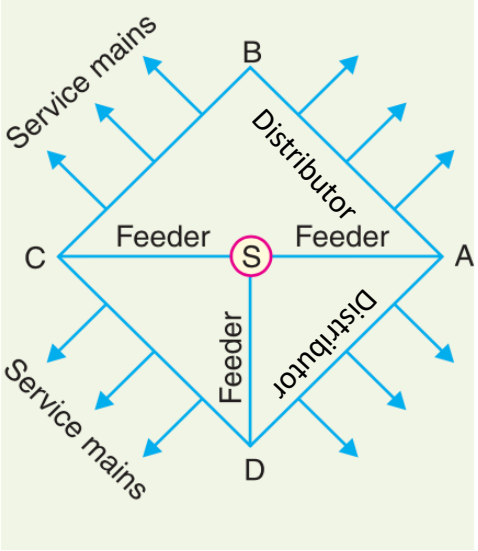
Distribution System

The part of power system which distributes electrical power for local use is known as "DISTRIBUTION SYSTEM"

This system is the electrical system between the substation fed by the transmission system and consumer meter.

Distribution line generally consist of

- Feeders
- Distributors
- Service mains



Overview of Distribution Systems

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Feeder

- A Feeder is conductor which connects the substation to the area where power is to be distributed
- Feeder are used to feed the electrical power from the generating station to the substation
- Generally, no tappings are taken from the feeder
- So the current in it remains the same
- throughout
- Main consideration in the design of feeder is the Current carrying capacity.

Overview of Distribution Systems

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Distributor

- A distributor is a conductor from which tapings are taken from pole mounted transformer to the consumer
- The current through a distributor is not constant because tapings are taken at various places along its length
- Voltage drop is main consideration
- Limit of variation is 5% of rated at consumer

Overview of Distribution Systems

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Service Mains

A service mains is a generally a small cable which connects the distributer to the consumer ‘s meter.
The connecting links between the distributor and the consumer terminals

Overview of Distribution Systems

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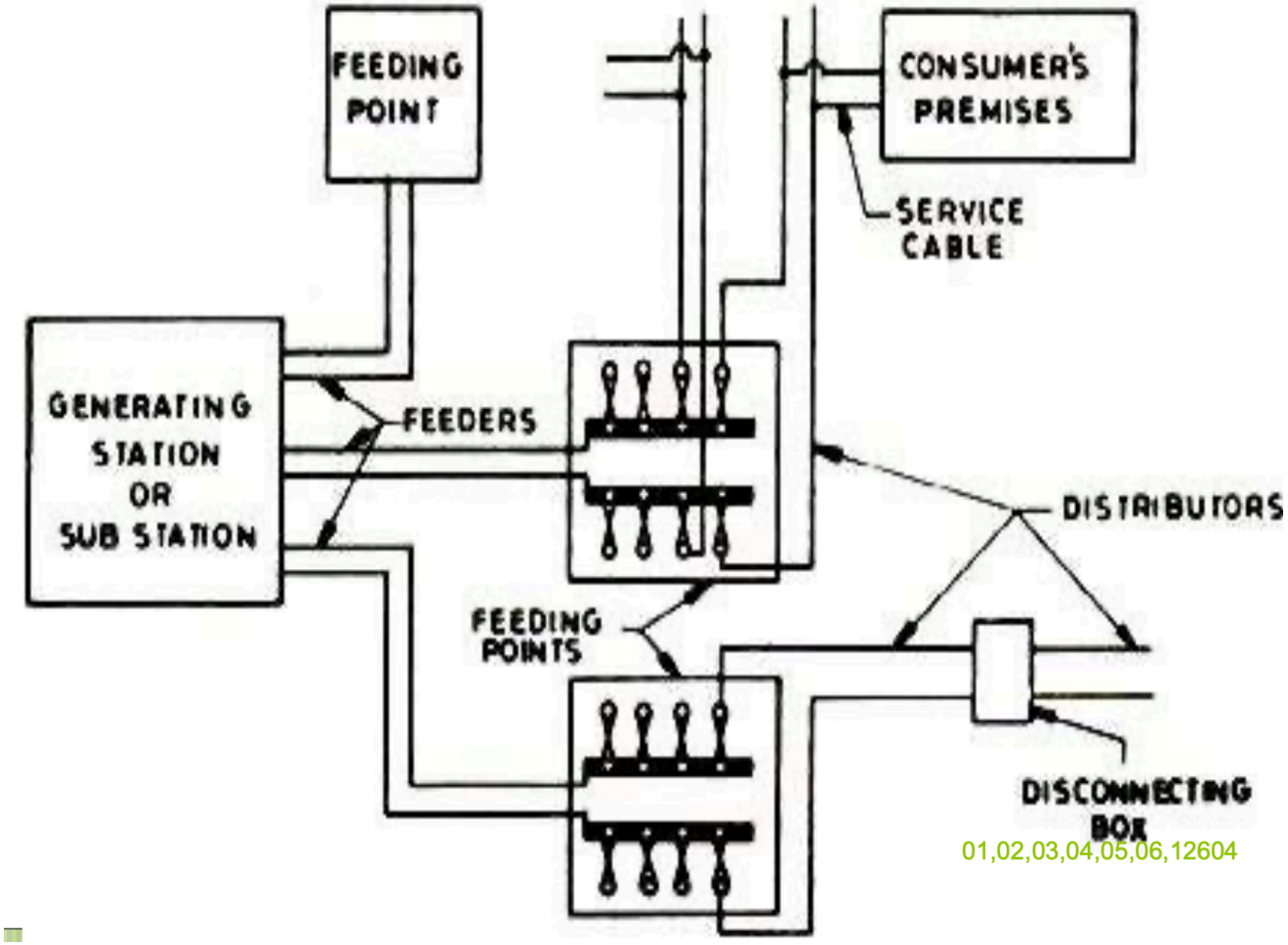
Typical Distribution System Diagram



Overview of Distribution Systems

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Typical Substation

Overview of Distribution Systems

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Classification of Distribution Systems

A distribution system may be classified according to ;

1. Type Of Current:
a) AC Distribution System
b) DC Distribution System

2. Type Of Construction:
a) Overhead System
b) Underground System

3. Type Of Service:
a) General Lighting & Power
b) Industrial Power
c) Railway
d) Streetlight etc

Overview of Distribution Systems

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Classification of Distribution Systems

4. Number Of Wires:
a) Two Wire
b) Three Wire
c) Four Wire

5. Scheme Of Connection:
a) Radial Distribution System
b) Ring or Loop Distribution System
c) Interconnected Distribution System

Overview of Distribution Systems

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AC Distribution System

AC distribution system is the electrical system between the step-down substation fed by the transmission system and the consumers' meters. The ac distribution system is classified into

a) primary distribution system
b) secondary distribution system.

Overview of Distribution Systems

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Primary Distribution System

- Voltages somewhat higher than general utilization and handles large blocks of electrical energy than the average low-voltage consumer uses.
- Commonly used primary distribution voltage 11KV, 6.6 KV,3.3 KV.
- Electric power from the generating station is transmitted at high voltage to the substation located in or near the city.
- At this substation, voltage is stepped down to 11 kV with the help of step-down transformer.
- Power is supplied to various substations for distribution or to big consumers at this voltage.
- This forms the high voltage distribution or primary distribution.

Overview of Distribution Systems

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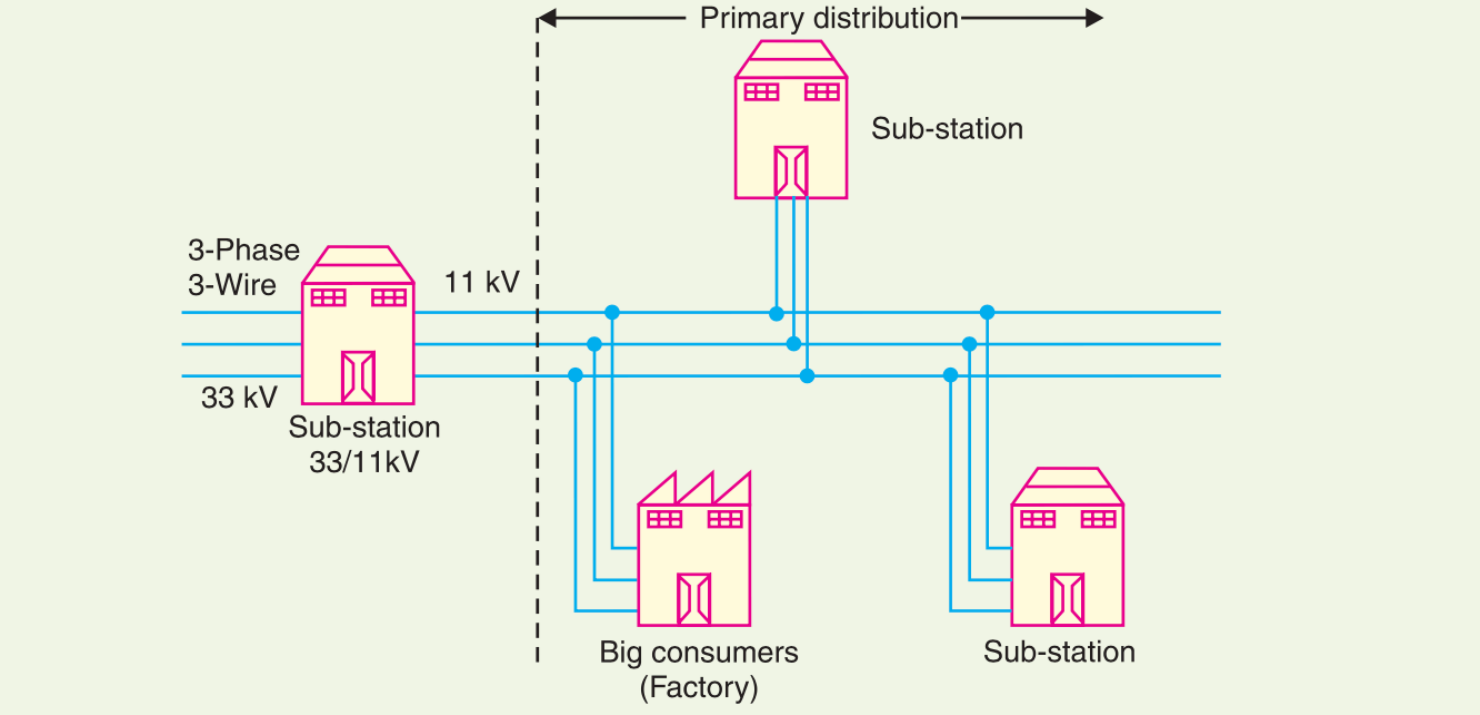
Primary Distribution System



Overview of Distribution Systems

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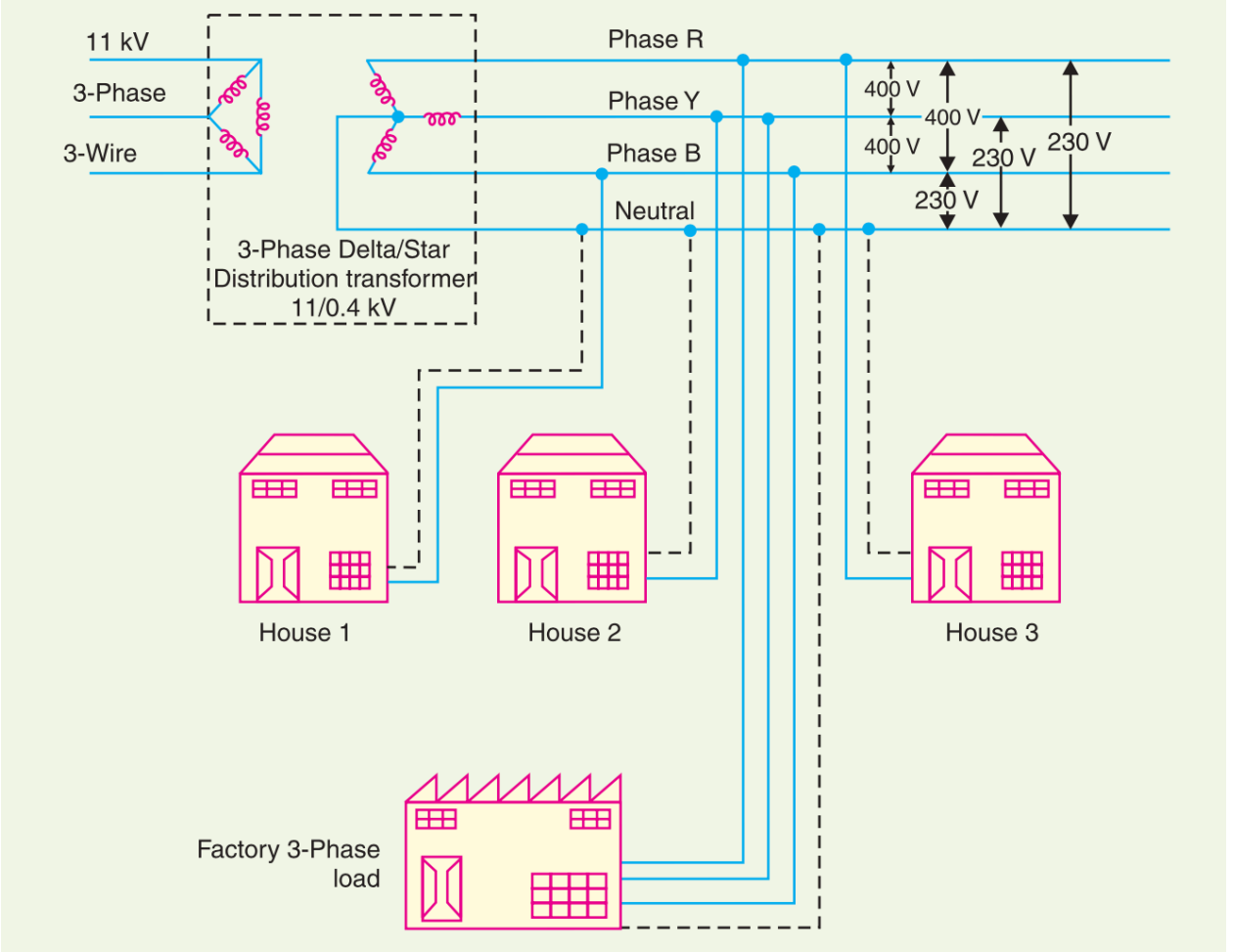
Secondary Distribution System

- It is that part of ac distribution system which includes the range of voltages at which the ultimate consumer utilizes the electrical energy delivered to him.
- The secondary distribution employs 400/230 V, 3-phase, 4-wire system.



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DC Distribution System

DC supply is required for the operation of variable speed machinery (i.e., dc motors), for electro-chemical work and for congested areas where storage battery reserves are necessary.

For this purpose, ac power is converted into dc power at the substation by using converting machinery e.g., mercury arc rectifiers, and motor-generator sets. The dc supply from the substation may be obtained in the form of

- 2-wire or
- 3-wire for distribution

Overview of Distribution Systems

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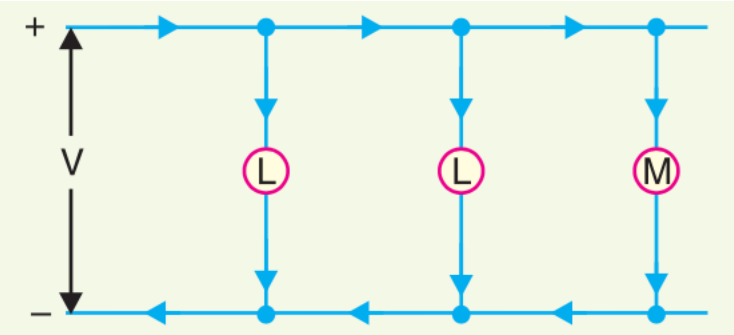
2-wire dc System

As the name implies, this system of distribution consists of two wires. One is the outgoing or positive wire and the other is the return or negative wire. The loads such as lamps, motors etc. are connected in parallel between the two wires.



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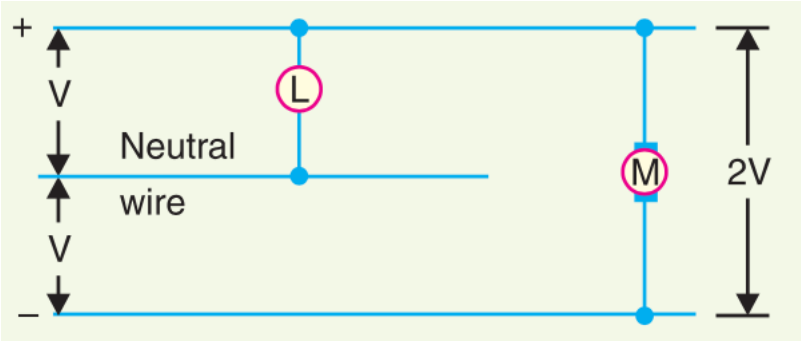
3-wire dc System

It consists of two outers and a middle or neutral wire which is earthed at the substation. The voltage between the outers is twice the voltage between either outer and neutral wire.

The principal advantage of this system is that it makes available two voltages at the consumer terminals *i.e.*, *V* between any outer and the neutral and 2V between the outers.

Loads requiring high voltage (*e.g.*, motors) are connected across the outers, whereas lamps and heating circuits requiring less voltage are connected between either outer and the neutral.



Overview of Distribution Systems

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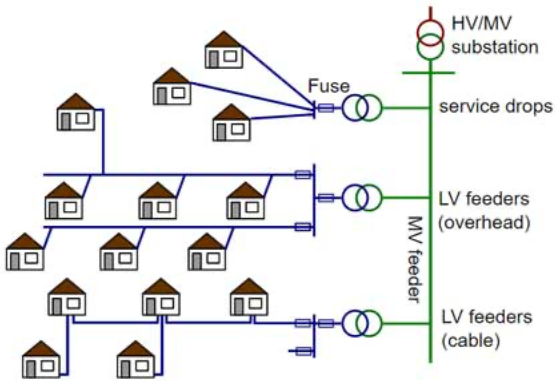
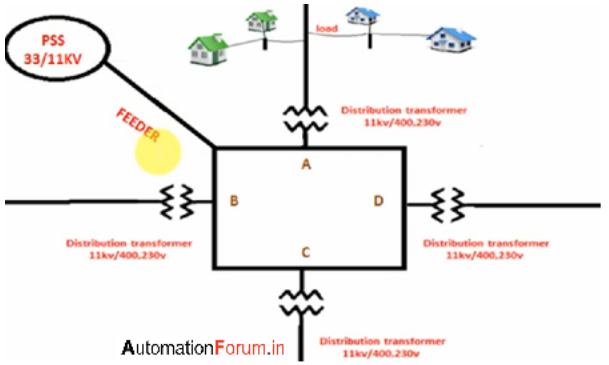
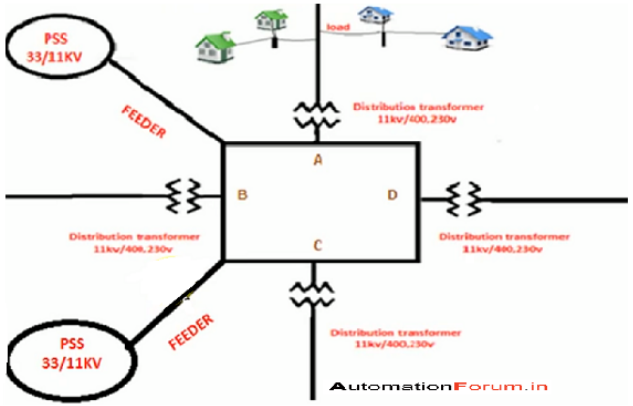
Connection schemes of distribution system

- Radial system
- Ring or loop system
- Interconnected system







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Radial Distribution System

Separate feeders radiate from a single substation and feed the distributors at one end only.
Only one path is connected between each customer and substation.
Electrical power flows along a single path.
If interrupted, results in complete loss of power to the customer

Advantages:

- Low cost .
- Simple planning.

Disadvantages :

- The radial system is employed only when power is generated at low voltage and the substation is located at the center of the load.
- Distributor nearer to feeding end is heavily loaded.
- Consumers at far end of feeder would be subjected to serious voltage fluctuations.

Overview of Distribution Systems

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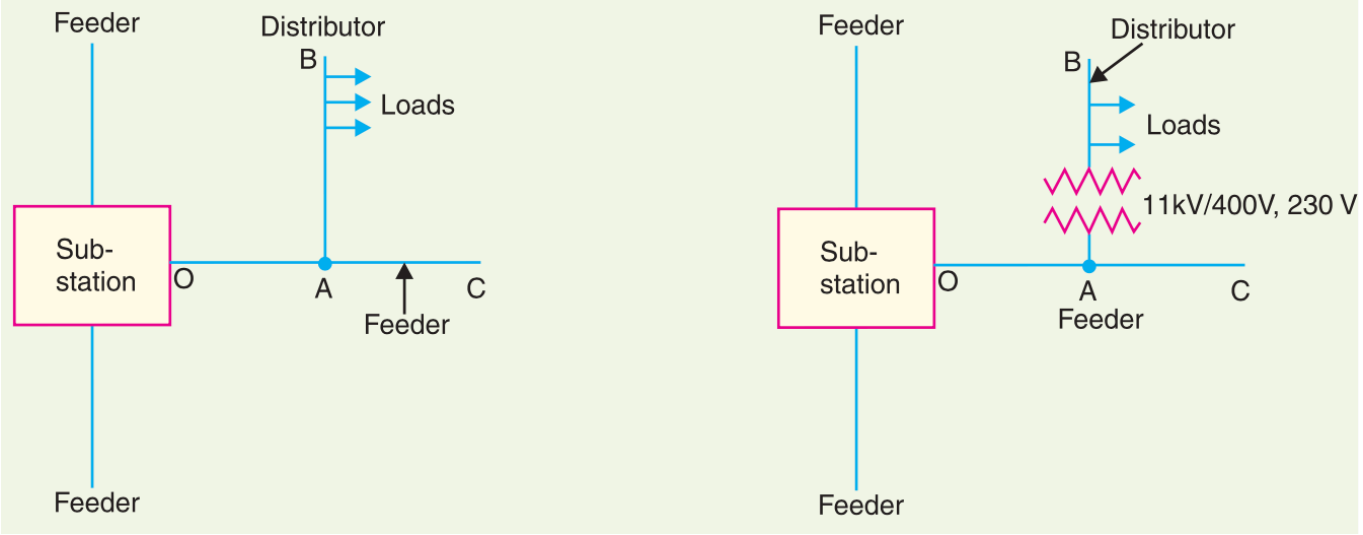
Radial Distribution System



DC Radial Distribution System

AC Radial Distribution System

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Ring or Loop Distribution System

It consists of two or more paths between power sources and the customer.
The loop circuit starts from the substation bus-bars, makes a loop through the area to be served, and returns to the substation

Advantages:

- Less conductor material is required.
- Less voltage fluctuations.
- More reliable.

Disadvantages :

- It is difficult to design as compared to the design of radial system.

Overview of Distribution Systems

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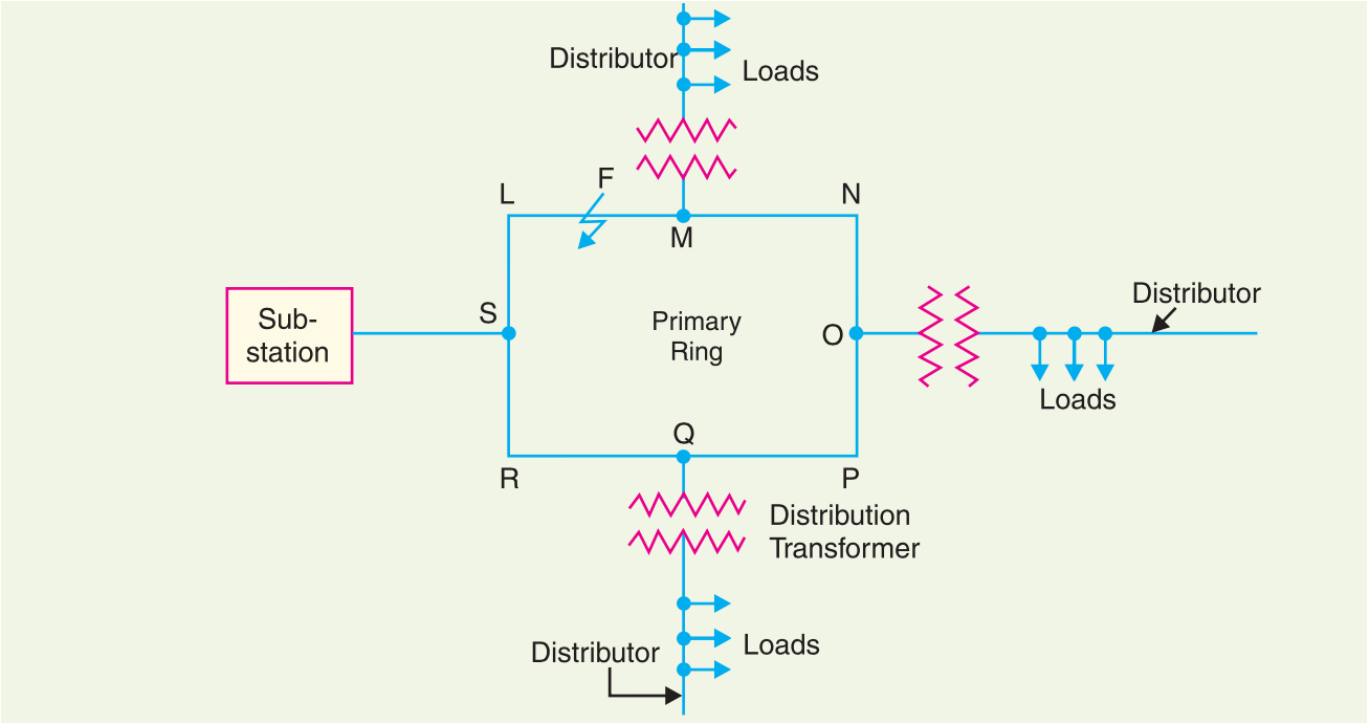
Ring or Loop Distribution System



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Interconnected Distribution System

It is supplied by a number of feeders.
Radial primary feeders can be tapped off from the interconnecting tie feeders.
They can also serve directly from the substation

Advantages:

- Increases the reliability of supply
- Losses are less
- Quality of service is improved

Disadvantages :

- Its initial cost is more.
- Difficult in planning, design and operation.

Overview of Distribution Systems

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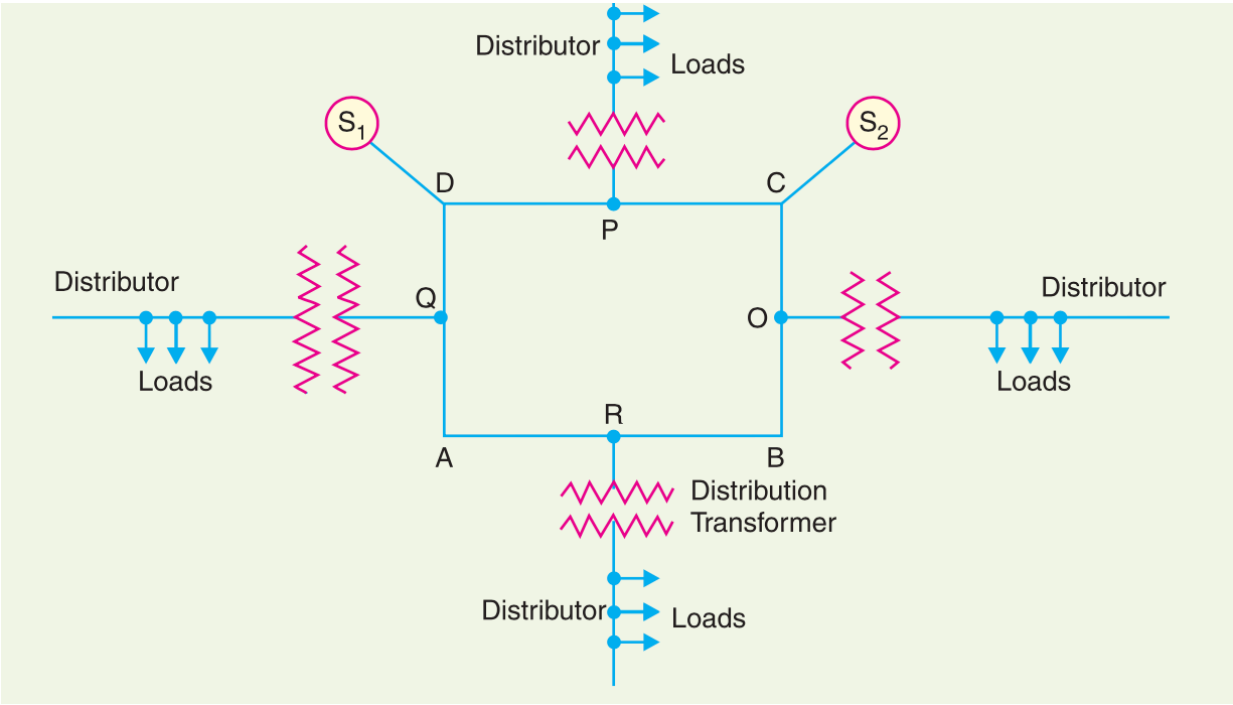
Interconnected Distribution System



Overview of Distribution Systems

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Distribution Substation Transformers

Rating of High Voltage Winding	34.5 to 230 kV
Rating of Low Voltage Winding	2.4 to 46 kV
MVA Rating (OA)	2.5 to 75 MVA
Transformer Impedance	5 to 12 %
Number of Transformers in Substation	1 to 4
Loading	OA, OA/FA, OA/FA/FOA, OA/FA/FA
High Side Protection	Circuit Switches, Circuit Breakers, Fuses
Relay Protection	Overcurrent, Differential, Under-Frequency
Feeder Protection	Circuit Breakers, Reclosers

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Distribution Substation Transformers

- Construction:
  Contain mineral oil for insulation and cooling Sealed and internal pressure is monitored
- Can have LTC and voltage regulator
- Ratings:
  - OA: passive cooling
  - FA: active cooling with fans only
  - FOA: active cooling with fans and oil circulation pump
- Nameplate transformer impedance usually given in % using OA rating as the MVA base

Overview of Distribution Systems

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Distribution Substation Transformers

Three phase 22.9kV Δ / 4.16kV Y, 12MVA OA, 16MVA FA1, 20MVA FA2, LTC on LV side

Overview of Distribution Systems

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Distribution Transformers

- Convert the primary distribution voltage (2.4 to 46kV) to secondary distribution voltage (<480V)
- Location:
  - pole mounted,
  - pad mounted,
  - inside buildings, or underground

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Distribution Transformers

Pole Mounted Transformers

- Liquid filled, 1 or 3 phase
- Small (eg., 25kVA)
- Different levels of protection, as required (eg., fuse cutout, surge arrester, circuit breakers).
- Typically the protection is attached to the outside of the transformer.

Overview of Distribution Systems

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Distribution Transformers

Pad Mounted Transformers

- Used for underground distribution
- Liquid filled or dry- type, 1 or 3 phase
- Medium sized (eg., 225kVA)

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Distribution Transformers

Pad Mounted Transformers

- Located in vaults, supplies power to secondary networks
- Liquid filled, 3 phase
- Large (300-2500kVA)

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Distribution Reliability

Goal: 1 interruption, max 2 hours in 1 year
Reliability indices:

System Average Interruption Frequency Index (SAIFI):

$$\text{SAIFI} = \frac{\Sigma \text{ Total Number of Customers Interrupted}}{\text{Total Number of Customers Served}}$$

System Average Interruption Duration Index (SAIDI):

$$\text{SAIDI} = \frac{\Sigma \text{ Customer Interruption Duration}}{\text{Total Number of Customers Served}}$$

Customer Average Interruption Duration Index (CAIDI):

$$\text{CAIDI} = \frac{\Sigma \text{ Customer Interruption Duration}}{\text{Total Number of Customers Interrupted}} = \frac{\text{SAIDI}}{\text{SAIFI}}$$

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Distribution Reliability

Average Service Availability Index (ASAI):

$$\text{ASAI} = \frac{\text{Customer Hours Service Availability}}{\text{Customer Hours Service Demands}}$$

Momentary interruptions not included
Prolonged interruptions (eg storm) treated differently
Typical values

- SAIFI: 1.1 interruptions/year
- SAIDI: 90 minutes/year
- CAIDI: 76 minutes/year
- ASAI: 99.982%