EEP 225 Power Systems - Lecture 8 and 9 [1]

1 Main Parts of Power System

- **Generation station**
- **Primary transmission (transmission)**
- **Secondary transmission (sub transmission)**
- **Primary distribution**
- **Secondary distribution**

1.1 Generation Station

(6.6 kV, 11 kV, 15 kV, 33 kV)
Step up to 220 kV to reduce transmission losses.

1.2 Primary Transmission

220 kV - 3 phase 3 wire overhead systems.

1.3 Secondary Transmission

stepped down to 66 kV - 3 phase 3 wire underground to various substations

1.4 Primary Distribution

stepped down to 11 kV (or 20 kV) 3 phase 3 wire underground

1.5 Secondary Distribution

stepped down to 380 V - 3 phase 4 wire

2 Distribution System Components

- **Distribution substations**
- **Primary feeders**
- **Distribution transformers**
- **Low voltage distributions**
- **Service mains**

2.1 Distribution Substation

Reduces sub-transmission voltage 66 kV to 11 kV
A typical substation may include the components

- Power transformer
- Circuit breaker
- Disconnecting switches
- Bus bars
- Instrument transformers
- Lightning arrestors (Surge arrestors)
- Protective Relays
- Fuses

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2.1.1 Power Transformer

Step down from 66 kV to 11 kV

2.1.2 Circuit breaker

Can open and close the circuits in normal conditions (manually or by remote control) and fault condition (automatically).

2.1.3 Disconnecting Switch (Knife Switch)

To disconnect parts of the system for maintenance and repair
Designed to open at no load

2.1.4 Bus bar

Copper or aluminum bars to connect voltage lines directly

2.1.5 Instrument Transformer

To measure current → current transformer.
To measure voltage → potential transformer.
Their function is to o transfer current or voltage in the power lines to small values to measure

2.1.6 Lightning Arrestors (Surge Arrestors)

Protect against lightning by bypassing it to ground

2.1.7 Fuses and Arrays

Protect against short circuit and any other abnormal condition

2.2 Primary Feeders

A conductor connects the distribution sub-station to the area where power is to be distributed.
No tappings are taken from the feeder **Why?** so that current in it remains the same.
The most important thing in design is the **current carrying capacity**

2.3 Distribution Transformer

Connected to primary feeders and step down from 11 kV to 380 V

2.4 Distributors

A conductor to supply the consumers
Tappings are allowed, so the current through the distributor is not constant
Important thing in design is the **voltage drop** along the length
The size and length should be designed such that voltage supplied to the consumer is in the permissible limits ($\pm 5\%$)

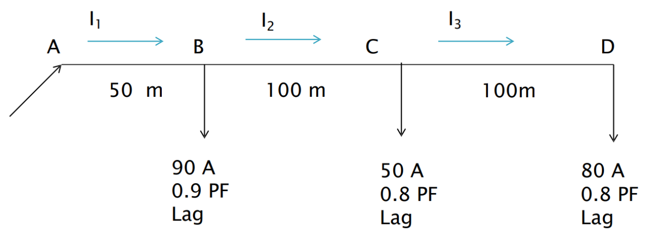
2.5 Services Mains

A small cable connects the distributor to the consumer terminals

3 Voltage Drop Calculations for Low Voltage Drop

Acceptable voltage deviation is $\pm 5\%$

$\boxed{1.\ \text{Q}}$ — For the low voltage 3 phase distributor shown, the voltage drop factor is 0.3 mV/A.m. find the approximate voltage factors are referred at point D. All power to the voltage at the beginning of the distributor.



A —
Note: to add current, we use vector addition not scalar addition (magnitude and angle)

$$0.8 \text{ lagging power factor} \rightarrow -\cos^{-1}(0.8) \rightarrow -36.87°$$

$$0.9 \text{ lagging power factor} \rightarrow -\cos^{-1}(0.9) \rightarrow -25.84°$$

$$I_D = 80\underline{/-36.87^\circ}\ \text{A}$$

$$I_C = 50\underline{/-36.87^\circ}\ \text{A}$$

$$I_B = 90\underline{/-25.84^\circ}\ \text{A}$$

$$I_3 = I_D = 80\underline{/-36.87^\circ}\ \text{A}$$

$$I_2 = I_C + I_D = 50\underline{/-36.87^\circ} + 80\underline{/-36.87^\circ} = 130\underline{/-36.87^\circ}\ \text{A}$$

$$I_1 = I_B + I_C + I_D = 130\underline{/-36.87^\circ} + 90\underline{/-25.84^\circ} = 219\underline{/-32.87^\circ}\ \text{A}$$

$$\text{Voltage drop} = \text{voltage drop factor} \times I \times \text{length}$$

$$V_{AB} = 0.3 \times 219 \times 50 = 3285\ \text{mV} = 3.285\ \text{V}$$

$$V_{BC} = 0.3 \times 130 \times 100 = 3900\ \text{mV} = 3.9\ \text{V}$$

$$V_{CD} = 0.3 \times 80 \times 100 = 2400\ \text{mV} = 2.4\ \text{V}$$

therefore

$$V_A = 220\ \text{V}$$

$$V_B = 220 - 3.285 = 216.715\ \text{V}$$

$$V_C = 216.715 - 3.9 = 212.815\ \text{V}$$

$$V_D = 212.815 - 2.4 = 210.415\ \text{V}$$

$$\therefore \text{Voltage drop ratio} = \frac{220 - 210.415}{220} = 4.36\%$$

Voltage drop is within the permissible limits

4 Voltage Adjustment

If the voltage drop is lower than the permissible limits, the voltage can be increased by a tap changer.

The tap changer connects primary of distribution transformer with different taps of the primary winding, which allows for small change (increase or decrease) of input voltage.

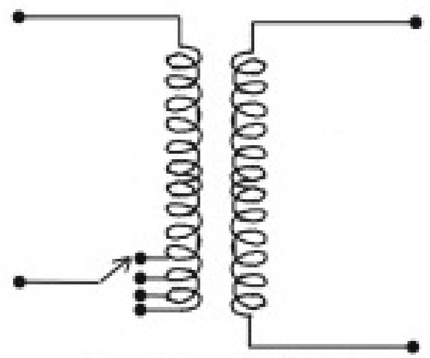


Figure 1: off load tap changer

5 Power Factor Improvement

Power factor is the cosine of the angle between voltage and current an an AC circuit

$$\text{Power factor} = \cos(\theta_V - \theta_I) = \cos(\phi)$$

If the circuits is inductive $\rightarrow$ I lags V $\rightarrow$ lagging power factor

If the circuits is capacitive $\rightarrow$ I leads V $\rightarrow$ leading power factor

Most of loads are inductive loads and have lagging power factor.

5.1 Power Triangle

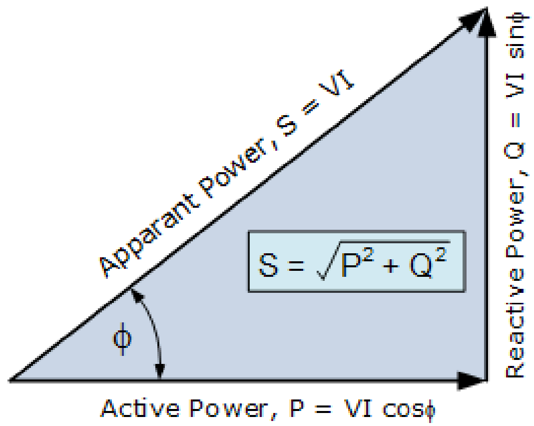


Figure 2: Power Triangle

$$\text{Power factor} = \cos(\phi) = \frac{P}{S}$$

$$\text{Reactive power}(Q) = P \times \tan(\phi)$$

5.2 Disadvantages of Low Power Factor

• For fixed power and voltage, load current is inversely proportional to the power factor, lower the power factor, higher is the load current and vice versa.
• High current leads to a need for conductors with more cross section are and more expensive
• Also leads to more copper losses resulting in poor efficiency
• Also leads to higher voltage drops resulting in poor (higher) voltage regulation
• Electrical machines are always rated in kVA

$$\text{kVA} = \frac{\text{kW}}{\cos(\phi)}$$

Lower the power factor the higher kW rating and so more expensive machines
• Reduced handling capacity of the system. The low power factor prevents the full utilization of the installed capacity

6 Power Factor Improvement Equipment

6.1 Static Capacitors

Connect capacitors in parallel with the load

6.1.1 Advantages

– Low losses.
– Little maintenance.
– Easily installed.
– Used under ordinary atmospheric conditions.
– Low capital and running cost.

6.1.2 Disadvantages

– Short service life from 8 to 10 years.
– Easily damaged if the voltage exceeds the rated value.
– Uneconomical repair when damaged.

6.2 Synchronous Condenser

An over excited synchronous motor running at no load behaves like a capacitor (has leading power factor)
It is mainly used by electric utilities and are rarely a practical solution in industrial plants.

6.2.1 Advantages

– By varying the excitation, we achieve step less control of the power factor.
– The motor windings have high thermal stability to short circuit currents.
– The faults can be removed easily.

6.2.2 Disadvantages

– High losses.
– Noisy.
– High maintenance cost.
– High cost comparing to the static capacitor of the same rating (except in sizes above 500 kVA).

7 Power System Protection

Protection system is used to detect and isolate the faulty section from the system automatically and as fast as possible.

7.1 Fault and Emergency Conditions

- **Short Circuit**
- **Over voltage during operation or caused by lightning or switching surges.**
- **Overloading**
- **Unbalanced operation**
- **Current or voltage waveforms distortion**

7.1.1 Short Circuit Current

Short circuits occurs when equipment insulation fails due to system over voltages caused by:

1. Lightning or switching surges
   (a) Flashover line-line (caused by wind)
   (b) Flashover to tree
2. Insulation contamination by dirt/salt
3. Mechanical failure
   (a) Cable insulation failure
4. Natural causes
   (a) Tower/pole or conductor falls
   (b) Objects fall on conductors

8 Function of System Protection

We need system protection to detect faults, isolate faulted components and restore them to protect them from damage and continue supplying for the rest of the system

9 Design Criteria and Characteristics

- **Reliability**
- **Selectivity**
Clearly discriminate between normal and abnormal system condition to avoid unnecessary, false trips.
- **Sensitivity**
Ability to distinguish the fault condition even if the different between fault and normal condition is small
- **Speed**
- **Economy**
- **Simplicity**

10 System Protection Components

- **Transducer/Instrument Transformer**
Provide low current and voltage suitable for the relays operation
- **Relay**
Discriminate between normal operating and fault conditions.
When current exceed a specified value relay will be operated and cause the trip coil of circuit breaker to be energized to open its contacts.
- **Circuit Breaker**
Open the line

10.1 Transducers

Also known as instrument transformer, used to reduce high voltage and current voltage to lower levels suitable to relays

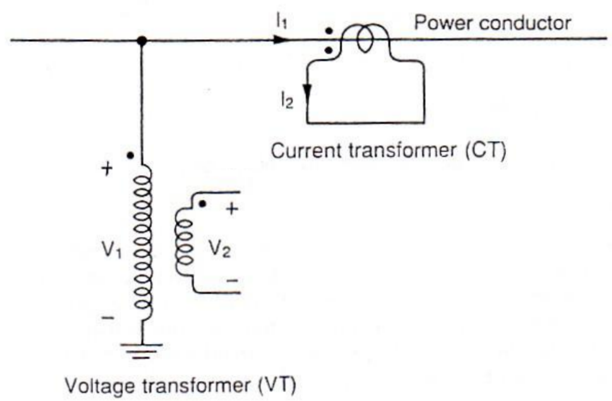


Figure 3

10.1.1 Voltage Transformer (VT)

- Very accurate
- Modeled as an ideal transformer
- Voltage transformer secondary is connected to voltage-sensing device with infinite impedance.

In HV and EHV, we use capacitor coupled voltage transformer (CVT), C_1 and C_2 are adjusted so that few kilo voltages is obtained across C_2, then stepped down by a transformer

10.1.2 Current Transformer (CT)

- The primary winding consist of a single turn which is the power conductor itself.
- Current transformer secondary is connected to a current-sensing device with approximately zero impedance.

10.2 Circuit Breakers and Relays

Circuit breaker ratings:

1. Rated Voltage

2. Rated frequency

3. Rated insulation voltage

4. Number of poles

5. Rated current

6. Rated breaking current: (The current that CB can safely break)

7. Rated making current: (The maximum current that can flow when CB is switched on)

8. Rated short-time current: (The current that CB can withstand for short period [from 1 to 3 sec]. It represents its thermal withstand capability)

• **Types of circuit breakers** :

Air circuit breaker	Up to 1 kV
Oil circuit breaker	3.3 kV to 22 kV
SF6 circuit breaker	3.3 kV to 800 kV
Vacuum circuit breaker	3.3 kV to 36 kV

11 Primary and Backup Protection

• **Primary protection** : protection provided by each zone to its element

• **Backup protection** : provided to operate in case primary protection fails

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