Chapter-1
Introduction to High Voltage Engineering

Ravindra Arora
Professor (Retired)
Department of Electrical Engineering
Indian Institute of Technology Kanpur
Kanpur, Uttar Pradesh, India

Bharat Singh Rajpurohit
Associate Professor
School of Computing and Electrical Engineering
Indian Institute of Technology Mandi
Mandi, Himachal Pradesh, India

Learning Objectives

- High voltage in electric power system
- Importance of HV insulation design and testing
- Electric power grid system and its advantages
- Need for higher voltages
- Losses and efficiencies in high voltage installations
- Voltage levels of rated systems and power system frequencies
- Power consumption voltage levels
- Distinction between neutral and ground in power systems
- Electrical insulation and dielectric materials

High Voltage In Electric Power Systems

- Three area: generation, transmission, and distribution of power.
- It needs continuous regulation, control, and monitor to maintain balance between demand, the load, and the supply
- 200 MW capacities generate power is 11 kV
- For 500 and 650 MW machines it is at 22 kV level
- Pptimizing the electric field intensity in the generator conductors(to increase the voltage level)
- 1150 kV, being used in practice today in Russia
- Gas Insulated Transmission Lines (GITL) and Gas Insulated Sub-stations (GIS) enclosed in a metal clad system are built up to 1100 kV level in Japan

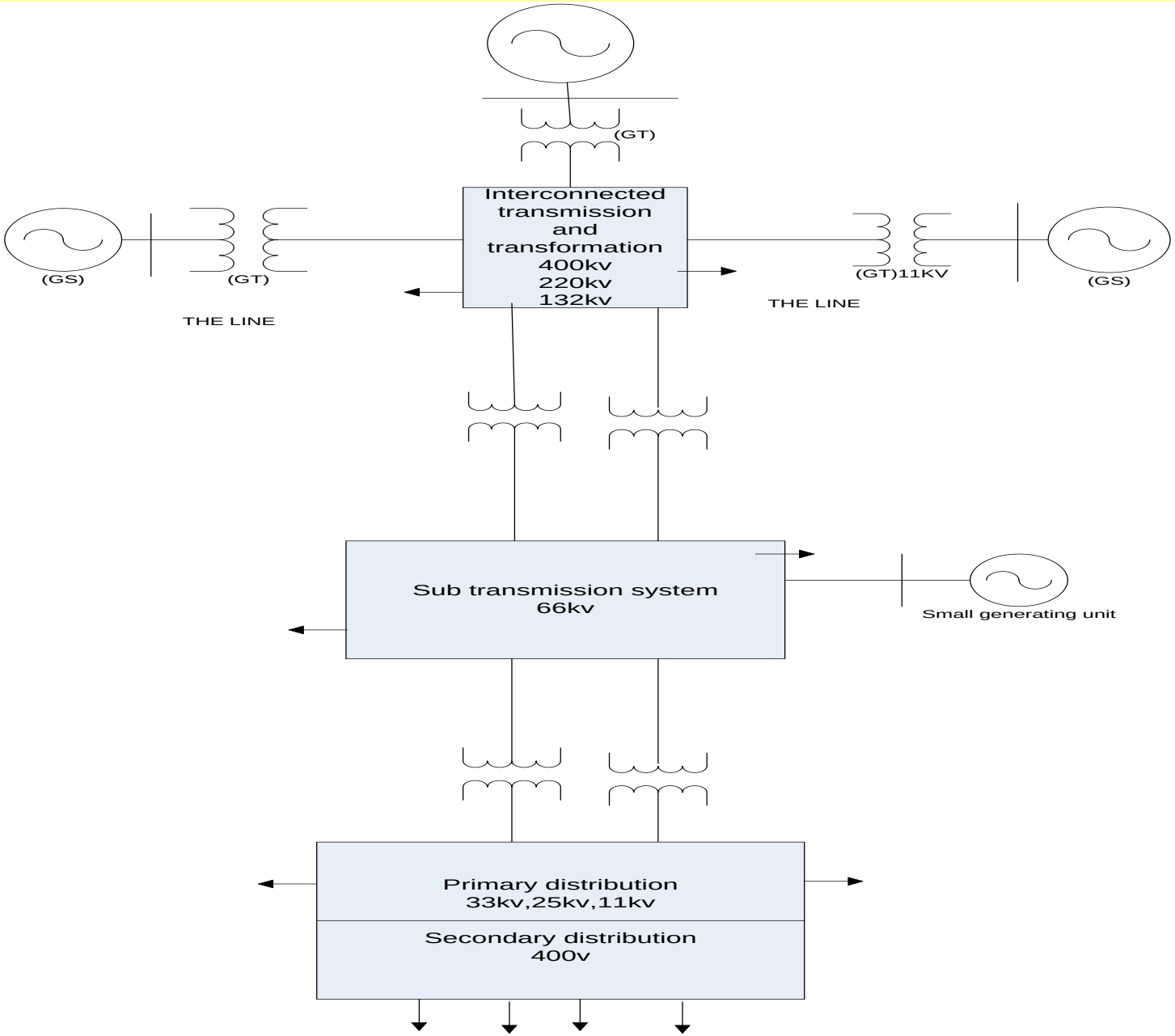
Importance of HV insulation Design &Testing

- Electricity- restless(to flow) in conductor and restful in insulation.
- Higher current needs more conductor size (Cross sectional area) to reduce resistance. But in higher voltage needs more insulation.
- Performance of insulating material depends on electrical, thermal, and mechanical stress.
- Electrical- stress control techniques- design- high voltage and ground electrode.
- HV Testing, type test, and knowledge about, gas, liquid and solid insulation materials.
- CPRI-Bengaluru- High Voltage test Facility

High Voltage Electric Power Grid System

- Inter-connected Power System Network- Power Grid
- The generating stations may be located at long distance from each other
- The transmission lines begin as well as terminate only at the sub-stations.
- Voltage level generated in India limited to 21.5 kV
- The present highest transmission voltage level in India is 800 kV ac and 1600 kV (±800 kV) dc.

Structure of Power System



Regional Grids

- 230 V single-phase or 400 V three-phase rated voltage
- State Electricity Power Grids- 5 regional Grids
- National Load Dispatch Centre (NLDC) at Delhi

Advantages of High Voltage Power Grid

- Secured and reliable power supply
- Smaller reserve capacity requirement
- Ability to install larger unit size
- Ease in meeting the peak load power demand

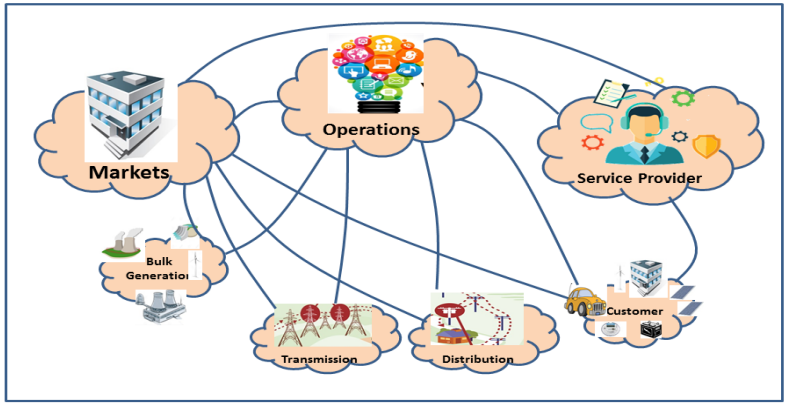


Fig: A schematic of Smart grid

Need For Higher Voltages on Power Systems

The power carried by the system,

$$P_{3\phi} = \sqrt{3} V_l I_l . \text{Cos } \Phi$$

the phase voltage, V_{ph}, (between phase and ground),

$$I_l = V_{ph} / Z_c = V_l / \sqrt{3}\, Z$$

Therefore,

$$P_{3\phi} = V_l^2 / Z_c . \text{Cos } \Phi$$

Ideal condition, $\text{Cos } \Phi = 1$

Impedance, 250 and 350 *ohm*.

- line current magnitudes – down
- $I^2 R$- it heats up the conductor

Equipment Efficiencies and Losses in Power Installations

- large generators, transformers and some motors- efficiency greater than 95 %.
- Theft of electrical power
- The efficiency of the fossil fuel and the thermal power generating stations within 40%
- Efficiency- Hydro-power is much higher

Levels of Voltage

- Low
- Medium
- High Voltage (115, 138, 161, 230 kV)
- Extra HV (345, 400, 500 kV)
- Ultra-high voltages (765, 1100 1200 kV)

Rated Voltages and Frequencies in Power Systems

Consumer level:

- 120 V, 230 V- single-phase, voltage is supplied between phase and neutral for house hold consumption.
- 230 V, 400 V, 3.3 kV, 6.6 kV, and 11 kV- are three-phase industrial consumer voltages. However, 3.3 kV and 6.6 kV are being phased out in order to rationalise the system.
- The railway traction at 25 kV- single-phase, stretch up to 40 km of track length that supplies power from 2x132 kV/25 kV substation transformers.

Rated Voltages and Frequencies in Power Systems(Continued..)

- **Generation level**:
- Three-phase synchronous generators 440 V, 3.3 kV, 6.6 kV (small generators), 11 kV (110 & 220 MW), 21.5 kV (500& 650 MW), 33 kV (1000 MW and above).
- **Distribution level:**
- 11 kV/400 V, 33 /11 kV, and 66/33 kV distribution transformers. (In Germany the rated distribution voltage levels are 400 V, 3.0 kV 6.0 kV, 10 kV, 30 kV and 60 kV).

Rated Voltages and Frequencies in Power Systems(Continued..)

Transmission with ac (HVAC):

- kV, 132 kV, 220 kV, 380 – 400 kV, 500 kV, 765– 800 kV, 1000 kV and 1150 kV.

Transmission with dc (HVDC):

- The dc single pole and bipolar lines at ± 100 kV, ± 500 kV, and ± 800 kV.
-

Frequency:

- 50 Hz is adopted in India and in most parts of the world.
- American continent, comprising Canada and USA, and in Latin American countries 60 Hz.

Advantages and Disadvantages of 120 vs 230 V Consumer Voltage

- USA- 120 V rated voltage (safer touch potential)

Disadvantages

- At 120 V double the magnitude of current is required to deliver the same amount of power as at 230 V.
- same magnitude of I^2R losses- required to limit the temperature rise of the conductor or that of the insulation, for example, up to 70° C for PVC insulation,
- The cross-sectional area of the cable conductor has to be increased four folds in this case.
- Thus the consumption of power at 120 V requires four times more copper dumped in the building walls as compared to a 230 V system. It is, therefore, an extremely expensive venture.
- Due to higher magnitude of currents, a high magnetic field prevails in the buildings, which is not good for health.

Neutral Vs. Ground In Electrical Installations

Neutral:

- 3-phase, three-wire system- All power system network at 11 kV
- $I_R + I_Y + I_B = 0$.

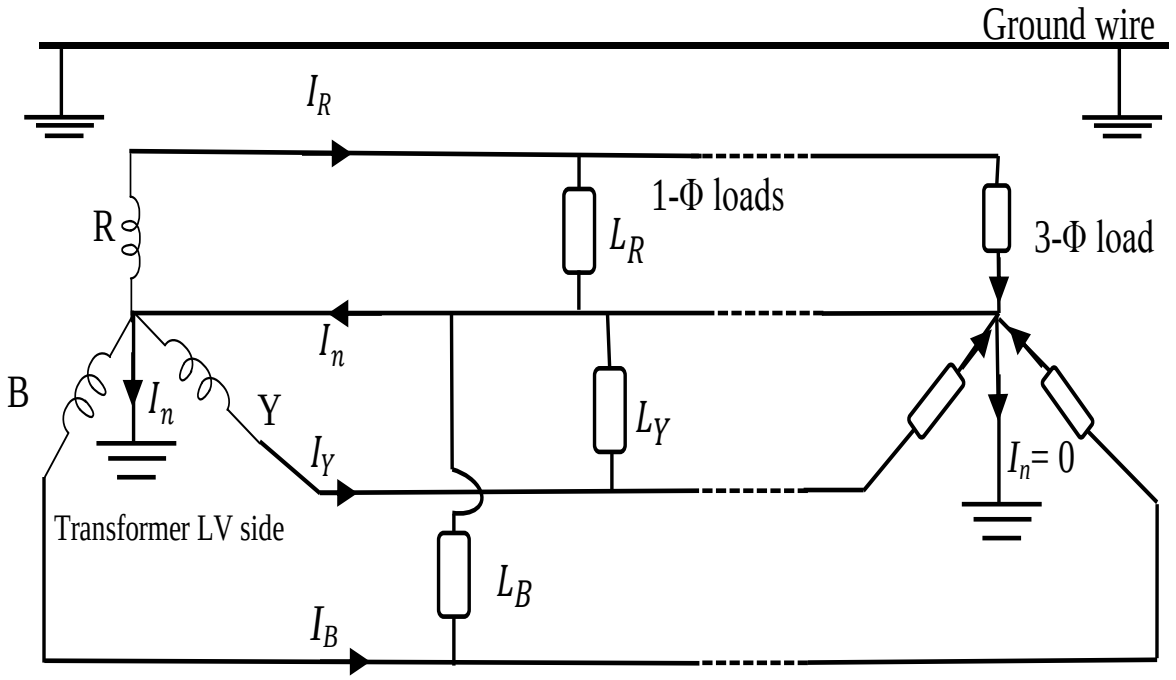


Fig: Three-phase five wire power distribution network for single and three phase loads

Neutral Vs. Ground In Electrical Installations (Continued..)

Ground

- It is a completely separate grounded (earthed) conductor.
- In a broad sense it can be said that the role of ground conductor in the power system is for protection.
- All transmission lines are provided at the top-most position a ‘ground conductor’ for protection from lightning. It is simply connected to the grounded towers, which keeps it at ground or zero potential. If the width of the arms of the transmission tower is very wide, there may be even two ground conductors required for the protection of all the live conductors from lightning.
- Being at the topmost position, the lightning strikes the ground conductor, which protects the phase wires below that are at lower height levels.

Electrical Insulation and Dielectrics

- **Gaseous Dielectrics:**
- Atmospheric air is the cheapest and most widely used dielectrics are Nitrogen , Sulphur hexafluoride SF_6(an electro-negative gas) and it's mixtures with CO_2 and N_2 . SF_6 is very widely applied for Gas Insulated Systems (GIS),
- Circuit Breakers and gas filled installations i.e. sub-stations and cables. It is being now applied for power transformers also

- **Vacuum as Dielectric :** Vacuum of the order of 10^{-5} Torr and lower provides an excellent electrical insulation. Vacuum technology developed and applied for circuit breakers in the last three decades is phenomenon .

Electrical Insulation and Dielectrics

Liquid Dielectrics:

Organic liquids, the mineral insulating oils and impregnating compounds, natural and synthetic, of required physical, chemical and electrical properties are used very widely in transformers, capacitors, cables and circuit breakers.

Solid Dielectrics:

- Very large in number.
- Most widely used are : XLPE, PVC, ceramics, glass, rubber, resins, reinforced plastics, polypropylene, impregnated paper, wood, cotton, mica, pressboards, Bakelite, Perspex, Ebonite, Teflon, etc.
- Introduction of nano materials are in offing.

Thank You
&
References

- Ravindra Arora and Bharat Singh Rajpurohit, "Fundamentals of High-Voltage Engineering" Wiley India, 2019.
- High Voltage and Electrical Insulation Engineering, By R. Arora, W. Mosch, IEEE Press, August 2011.
- High Voltage Insulation Engineering: Behaviour of Dielectrics ; Their Properties and Applications by R. Arora, W. Mosch, New Age International, 1995