

SAARC Training Workshop 'Power System Studies for Synchronization of Multiple Systems'

Basic Elements of Power System

Day-1-D

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SAARC Energy Centre, Islamabad
www.saarcenergy.org



hassan@powerplannersint.com
www.powerplannersint.com

Basic Elements

- **Substation** is a point in a power system where transmission lines or distribution feeders are marshalled, to supply and control load.
- **Switchgear** is the general term for switching devices for use with generation, transmission, distribution and conversion of electric power.
- **Circuit breaker** is a mechanical switching device for making, carrying and breaking currents under normal and certain abnormal circuit conditions.
- **Isolator** is a mechanical switching device for opening (isolating) and closing a circuit off-load.

Basic Elements

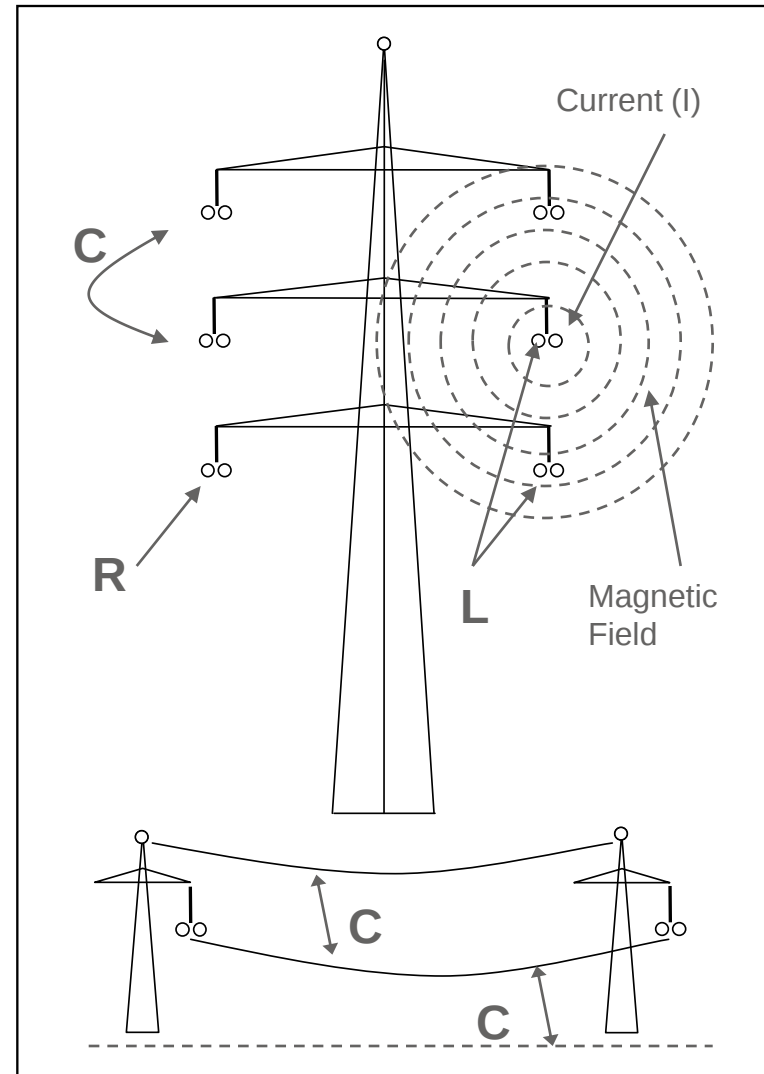
- **Busbar** in a substation, all circuits are marshalled, through circuit breakers, onto busbars.
- **Electric Cable** is a conductor for transmitting electric power, made up of two or more wires bound together and insulated.
- **Power Transformer** is used to step up or to step down AC voltage at constant frequency; the ratio of voltage in to voltage out is determined by the ratio of primary windings to secondary windings and by tap changers.
- **Reactive compensation** is a reactive component introduced to improve system stability, voltage regulation or power factor.

Elements of a Power System

- Busbars
- Overhead Lines
- Cables
- Transformers
- Generators
- Loads

Elements Overhead Lines

- Have resistance (R), inductance (L), and capacitance (C)
- We want to know the current (and power) that flows if we attach a voltage source (generator)
- We need to calculate and then model these electrical properties



Transmission Line Structures

- Overhead transmission lines are supported by towers that are typically built of steel
- Transmission line tower design is governed by many factors such as:
 - Voltage level
 - Conductor size
 - Minimum clearance

Transmission System Characteristics

- Transmission line shunt capacitance (charging) produces reactive power proportional to the square of the voltage
- Since transmission line reactive power varies over the load cycle, we can state:
 - Transmission line production = V^2B (relatively constant)
 - Transmission line consumption = I^2X (variable)
 - Line shunt susceptance, $B = \omega C$
 - Line series reactance, $X = \omega L$

Surge Impedance Loading (SIL)

- We are often interested in the loading where production equals consumption
- For a given length of line of reactance x and susceptance b , we set $V^2b = I^2x$, and solve for the surge impedance:

$$Z_0 = V/I = \sqrt{x/b} = \sqrt{L/C}$$

- Then surge impedance loading:

$$P_0 = V^2/Z_0$$

Transmission line parameters

- Most important parameters are:
 - Series resistance and reactance
 - Shunt susceptance
- Series resistance affects of:
 - Losses
 - Loadability (thermal and sag limits)
- Resistance can be ignored for high voltage lines

Transmission line parameters

- An equation for inductive reactance is:

$$x = \omega l = 2 \omega 10^{-4} \ln (GMD/GMR) \text{ } \Omega/\text{km}$$

Where:

- ω - power system radian frequency
- GMD – geometric mean distance between phases: $GMD = (d_{ab} + d_{ac} + d_{bc})^{1/3}$
- GMR – geometric mean radius (obtained from conductor tables), $GMR \cong 0.8r$ where r is the conductor radius

Transmission line parameters

- For bundled conductors (several subconductors per phase) with spacing s between adjacent subconductors, the equivalent GMR is:
 - $GMR_{equiv} = [n \times GMR[s/(2\sin\pi/n)]^{n-1}]^{1/n}$
- For two and three conductor bundles, the equivalent GMRs are:
 - Two conductor, $\sqrt{s \times GMR}$
 - Three conductor, $\sqrt[3]{s^2 \times GMR}$

Transmission line parameters

- Reducing the reactance by reduce the phase spacing (GMD) and/or increase the equivalent GMR
- GMR_{equiv} is reduced mainly by increasing the number of subconductors

Transmission line parameters

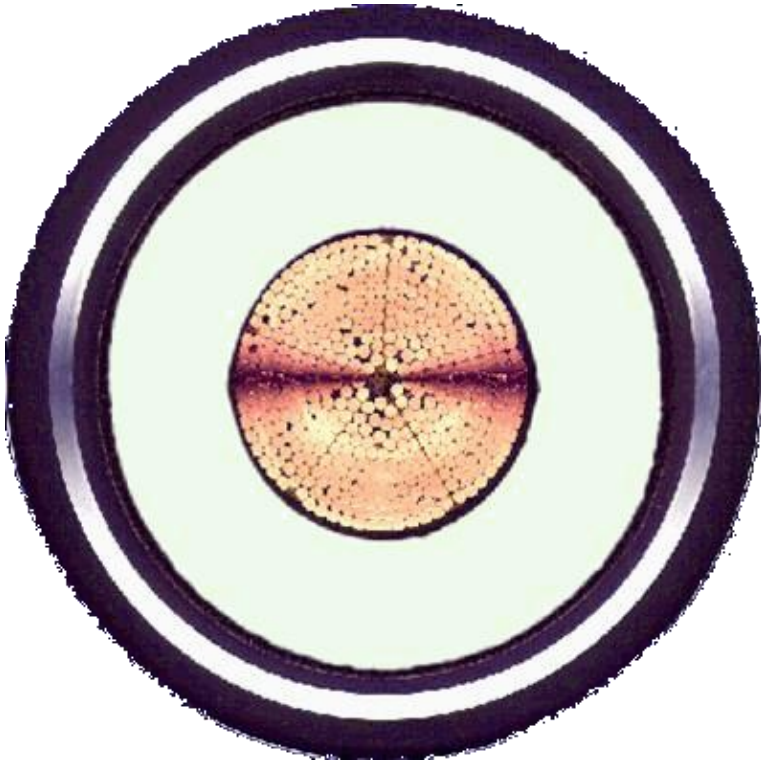
- A corresponding equation for shunt susceptance is:
 - $b = \omega c = \omega 10^{-6} / [18 \ln(\text{GMD}/r)] \text{ S/km}$
(siemens/km)
- For bundled conductors:
 - $r_{\text{equiv}} = [n \times r [s/(2\sin\pi/n)]^{n-1}]^{1/n}$
- The charging reactive power is:
 - $Q_{\text{chg}} = V^2 b$

Transmission line parameters

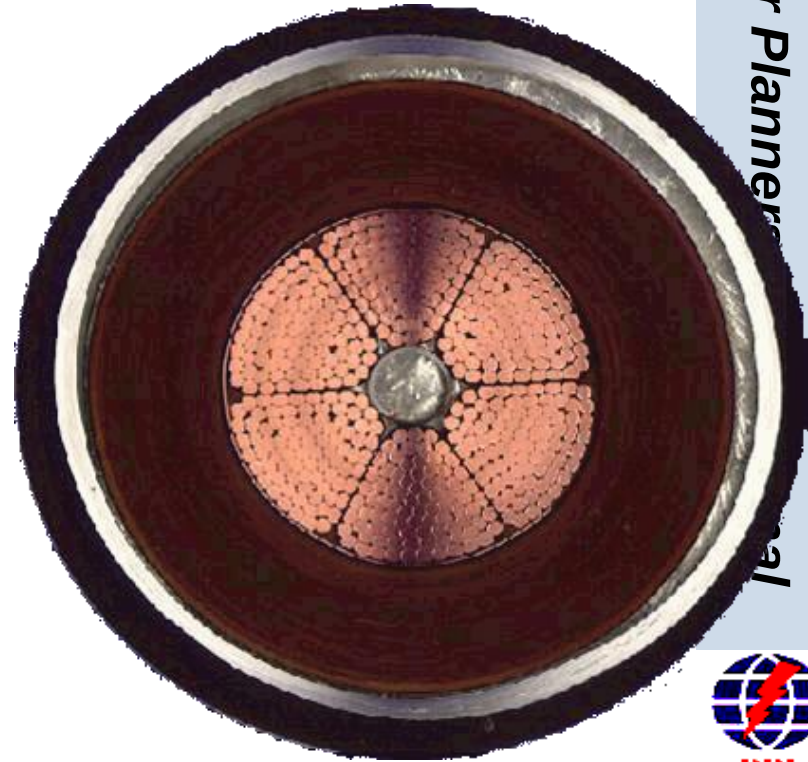
- Reduced phase spacing and bundled conductors reduce line inductance and reactance, and increase line capacitance and susceptance.
- This increases the surge impedance loading and effective transmission capability

Electric Cables

XLPE

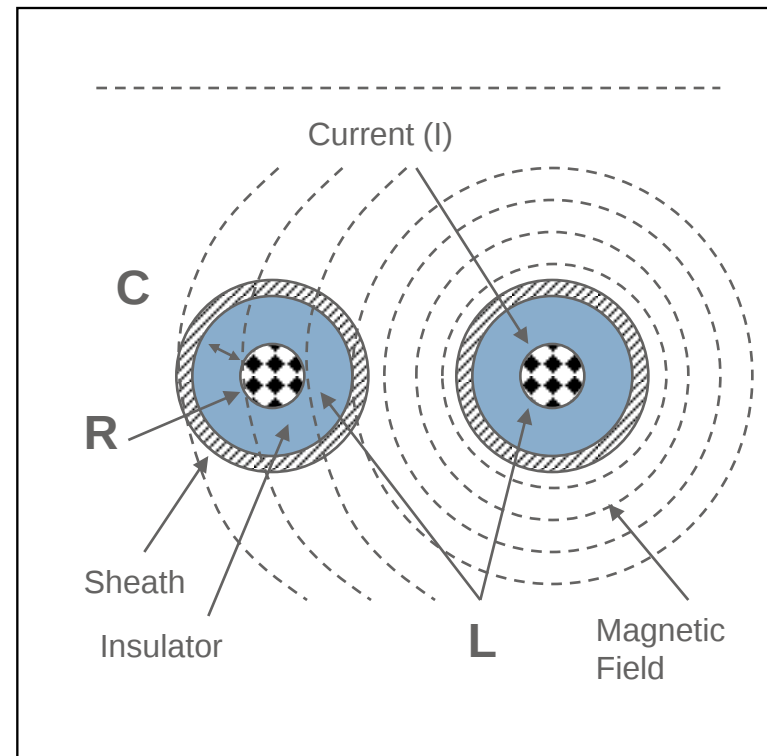


Paper with Oil



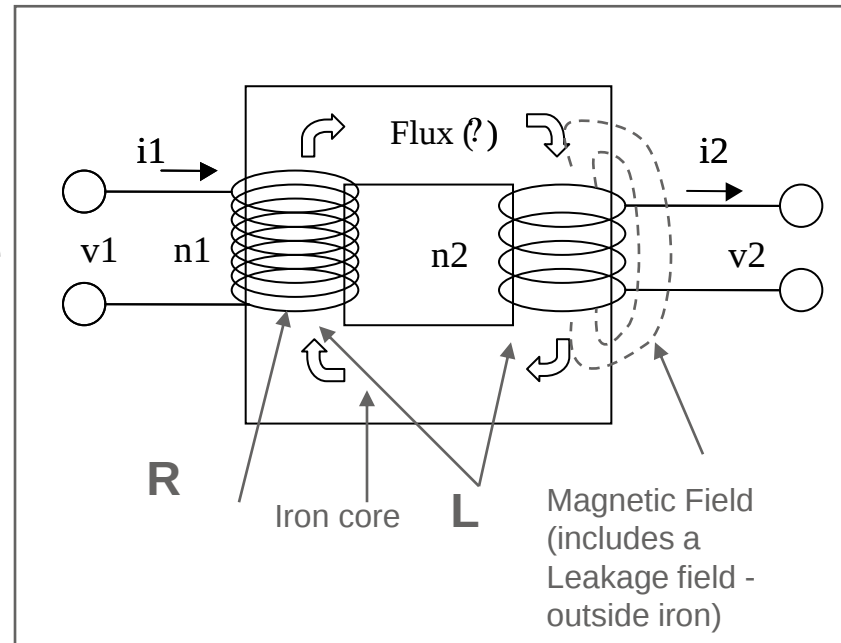
Elements Cables

- Also have resistance (R), inductance (L), and capacitance (C)
- Capacitance is high - as conductor and sheath are close together
- Inductance will depend on how the cables are buried
- Due to charging power, a key parameter of cables is the critical length
- Critical Length
- The length at which the charging power equals the cable thermal capacity
- For Extra High Voltage (EHV) cables, the critical length around 25 to 30km



Elements Transformers

- Have significant resistance (R), and inductance (L)
- Capacitance (C) is inter-turn (low voltage difference), and across the transformer bushings (high spacing)
- Total capacitance is small and usually ignored, except for high frequency analysis (e.g. lightning strikes)



Elements Transformers (cont.)

- There are two electrical circuits coupled via a magnetic circuit
- A simple analysis is that current flowing in circuit 1 generates flux in the transformer core which generates a voltage in circuit 2, which will create a current in circuit 2
- For the magnetic circuit, the ampere-turns balance must be maintained, so:

$$n_1 \times i_1 = n_2 \times i_2$$

(where 'n' is the number of turns in winding and 'i' is the current in winding)

- There is a flux in the transformer core that is the same for both windings so:

$$\frac{v_1}{v_2} = \frac{n_1}{n_2}$$

- We define a turns ratio (n) as equal to n_1/n_2 so we have:

$$v_2 = v_1/n \quad \text{and} \quad i_2 = n \times i_1$$

Elements Transformers (cont.)

- There is also a magnetic field created in the air around each winding. Some of this field (flux) associated with each winding does not link with the other winding
- These are the 'leakage' fluxes and represent the inductance presented to an external voltage source
- The flux that links both electrical circuits does not represent an impedance to electrical current passing through the transformer - this is the operating principle of the transformer
- The transformer also draws a current when there is no load connected to it, the magnetizing current. This is understood as the current required to sustain a magnetic field in the iron core of the transformer. The magnetizing current is usually small and often ignored
- There are also real power losses in the iron of the transformer which can be modelled as a Resistance in the magnetizing branch

Elements Generators

- The power is transferred through a magnetic field between a rotating rotor winding and a fixed stator winding.
- The rotor is a voltage source.
- The stator windings have resistance (R), and the generator has inductive reactance (X_D) - again primarily due to leakage fluxes that do not link the circuits on the rotor on stator.
- Capacitance (C) is usually small and ignored.
- Provide real power (and reactive power).

Elements Loads

- Typical substation load types

Induction motors	50-60%	Air conditioners, freezers, washing m/c, fan, pumps
Synchronous motors	10%	Industrial m/c
Lighting and Heating	20-30%	Water heating, electric heaters, filament lights

- Distribution losses ~ 10%
- Typical load power factor – between 0.8 and 0.95
- For steady state transmission planning, loads usually modelled as fixed MW and MVar
- For disturbed conditions in a power system, loads are modelled as dynamic loads