Power Transmission

- Economic choice of transmission voltage
- Conductor material
- Electrical Design of Overhead Lines
- Parameters of overhead transmission lines
  - ✓ Resistance
  - ✓ Inductance
  - ✓ Capacitance

References

1. POWER SYSTEM ANALYSIS BY HADI SADATT.
2. POWER SYSTEM ANALYSIS AND DESIGN BY GLOVER.
3. POWE SYSTEM ANALYSIS BY GRAINGER.
4. ELECTRICAL POWER SYSTEMS BY A.E. GUILE, W. PATERSON.
5. ELEMENTS OF POWER SYSTEM ANALYSIS BYWILLIAM STEVENSON.
6. ELECTRICAL POWER SYSTEMS BY WEEDY, B.M.
7. PRINCIPLES OF POWER SYSTEMS MEHTA.

Construction of electrical power systems

The Construction of electric power systems consists of the following main parts:

1- **Generating stations** (power station) : Bulk electric power is produced by special plants known as generating stations or power plants . This part divided in two section :

- ❖ Mechanical section – It is sources of mechanical energy as (Boiler, Turbine….) .
- ❖ Electrical section – as (Alternators, transformers, protection apparatus, controls system, and measuring instruments) .

2- **Transmission lines**: are the connecting links between the **power stations and the distribution system** and lead to other power systems over interconnections .There are two types:

- ❖ **Overhead transmission line.**
- ❖ **Underground cables.**

3- **Distribution systems**: It connects all the individual loads to the transmission line.

Power Transmission

There are two types of transmission system:

a- Overhead transmission line .

b- Underground cables.

Overhead transmission line

The overhead transmission line consists of conductors, insulators, support structures, and in most cases, shield wire (ground wire).

Economic choice of transmission voltage

$P1-phase = VI\cos\phi$ ....(1)

IF $\cos\phi$ constant

$$P^{\uparrow}_{1-phase} \propto V^{\uparrow} I^{\downarrow} \rightarrow \begin{cases} \rightarrow loss^{\downarrow}\ ,\ \eta^{\uparrow} \\ \rightarrow C.S.A\ of\ conductor \propto cost^{\downarrow} \\ \rightarrow Voltage\ regulation\ (V.R)^{\downarrow} \\ \rightarrow cost\ of\ transformers\ ,\ towers, \\ \quad insulators\ ,\ and\ switchgears^{\uparrow} \end{cases}$$

Cross-sectional area

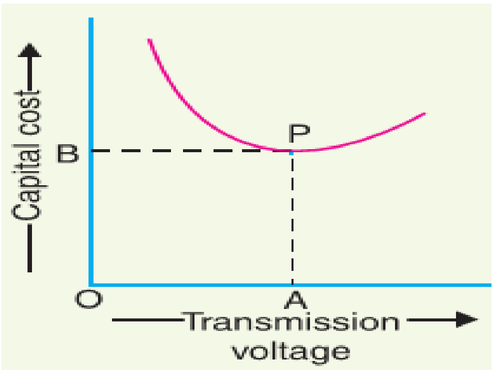
The transmission losses may be computed from the approximate formulas :

$$\left.\begin{aligned} P_{loss} &\approx R_l \frac{P_{tr}^2 + Q_{tr}^2}{|V_{tr}|^2} \qquad watt \\ Q_{loss} &\approx X_l \frac{P_{tr}^2 + Q_{tr}^2}{|V_{tr}|^2} \qquad \text{var} \end{aligned}\right] \ldots (2)$$

Where :

Rl - resistance of line
Xl : reactance of line
Ptr and Qtr :are active and reactive transmission power (power of load)

- The formulas informs that the *cost for lost energy* decreases with increased voltage level .
- However , the *fixed costs* of (towers , insulators transformers and switchgears) increase with voltage .
- There is optimum transmission voltage , beyond which there is nothing to be gained in the matter of economy. for every transmission line.
- The fig. blow shown that the total transmission costs will therefore be minimized at a certain voltage level. It is called ***economical transmission voltage***



The **empirical formula** to find the economical transmission voltage between lines in a 3-phase ac system is :

$$V = 5.5\sqrt{0.62\, l + \frac{3P}{150}} \qquad .....(3)$$

Where

V :line voltage in KV .
P : maximum KW per phase to be delivered to single circuit .

l : length of transmission line .

- The economical transmission voltage depends on length (or distance) of transmission line and power to be transmitted.
- With increase in distance of transmission line, the cost of equipments and apparatus increases which results in higher transmission voltage.
- If the power to be transmitted is large then large units of generating and transforming are required which reduces the cost per KW of terminal equipments.

Standard voltage levels

- Low voltage transmission (KV) : **11** , 22 , **33** , 66
- High voltage transmission (KV) :110 , **132** , 220 , 275 , 330
- Extra high voltage transmission (KV) : 380 , **400** , 500 ,750 , 1000
- 1100-1500 under research

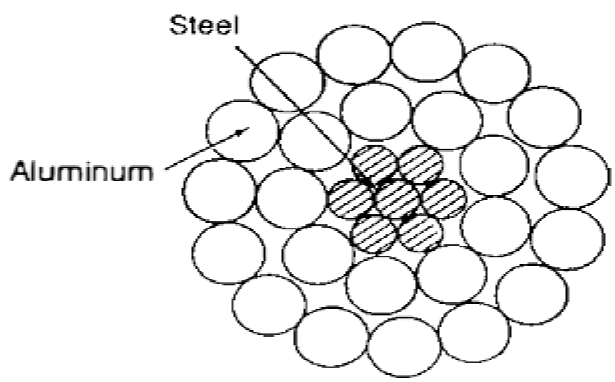
Conductor material

- Characteristics of material ;
  1- High electrical conductivity .
  2- High tensile strength .
  3- Low cost .
- **Better materials :**
  1- Copper (Cu): Conductivity and tensile strength of copper are high , but cost of material also high .
  2- Aluminum (AL) :
  a- conductivity of AL is 60% of that of Cu .
  b- Coefficient of expansion is high.
  c- Weak (low) tensile strength.
  d- Lower cost and lighter weight of an AL conductor compared with a Cu .
  e- For the same resistance , AL conductor has a large diameter than an Cu conductor , i.e low effect of **corona .**

Therefore aluminum has replaced copper as the most common conductor metal for overhead transmission .

Symbols identifying different types of AL conductors are as follows :
AAC : all- aluminum conductor .
AAAC : all- aluminum -alloy conductor .
ACAR : aluminum conductor alloy –reinforced .
ACSR : aluminum conductor , steel – reinforced .

The most common conductor types is ACSR , which consists of layers aluminum strands surrounding a central core of steel strands as shown in fig. below .Cross section of a steel reinforced conductor, 7 steel strands, and 24 aluminum strands.



ACSR consists of a central core of steel strands surrounded by layers of aluminum strands. ACA R has a central core of higher- strength aluminum surrounded by layers of electrical- conductor grade aluminum.

<u>Examples</u>:

- Conductor has Al. /St. of 18/1 indicating it has 18 strands of aluminum around 1 strand of steel.
- Conductor has Al. /St. of 26/7 indicating it has 26 strands of aluminum around 7 strands of steel.

<u>Number of aluminum layers</u>:

The strands are configured in a number of concentric layers equal to this number.

<u>Example</u>:

The conductor has Al./St. of 24/7. Its core will have 7 strands of steel (6 configured around 1) and 24 strands of aluminum (9 configured around the steel core, 15 configured around the 9).

A general formula for the total number of strands in concentrically stranded cables is

$$\textbf{Total No. of strands } (N_s) = 1 + 3n(n+1) \ldots\ldots\ldots(4)$$

$$\textbf{Or Total No. of strands } (N_s) = 3n^2+3n+1$$

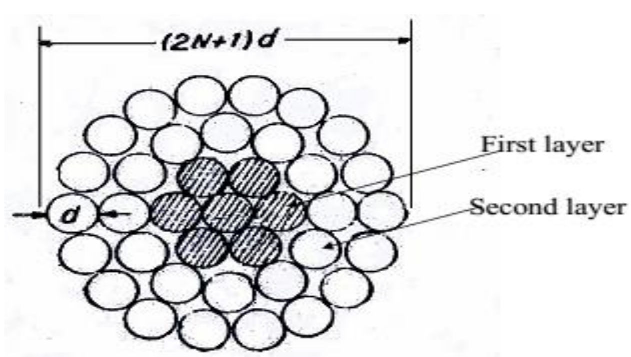
Where: n is the number of layers, including the single center strand. The above assumes equal diameters for all strands.

For example, for conductor , with n (2 aluminum layers), indication that the stranding is 18/1.

Stranded conductors usually have central wire (core) around which are successive layers of (6, 12, 18, 24) wires as shown in fig. below.
The equivalent diameter of stranded conductor is given by :

$$D = (1 + 2n)\,d \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Where ***d*** - is the diameter of the strand.



Example

Stranded conductor 19/2.9 mm. calculate the equivalent diameter of conductor.
Solution:

The diameter of one strand (*d*) = 2.9 mm No. of stranded in conductor (*Ns*) = 19 Therefore for No. of layer = 2 , distributed as follow : = [1 + 6 + 12]

core 1st layer 2nd layer

or can be calculated by eq. (4) as follow :

$$19 = 1 + 3n(n + 1)$$
$$18 = 3n^2 + 3n$$
$$n^2 + n - 6 = 0$$
$$(n+3)(n-2) = 0$$
$$\therefore \quad n = 2$$
$$D = (1 + 2n)d$$
$$= (1 + 2 \times 2) \times 2.9 = 14.5\ mm$$

Electrical Design of Overhead Lines

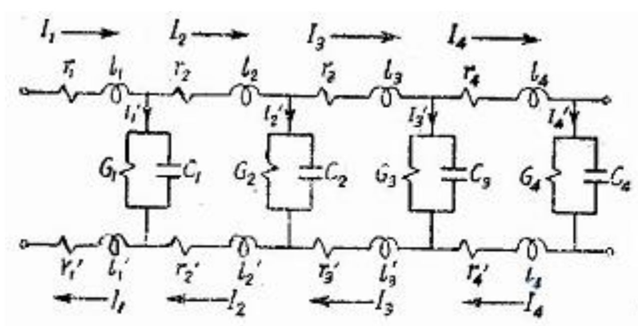
- A.C transmission line has resistance, inductance and capacitance uniformly distributed along its length. These are known as constants or parameters of the line.
- These Constants determine whether the efficiency and voltage regulation of the line will be good or poor.
- These constants is necessary in order to make the electrical design of a transmission line a technical success.

Parameters of overhead transmission lines

- Transmission lines (T.L) are basically circuits with distributed constants (parameters) :

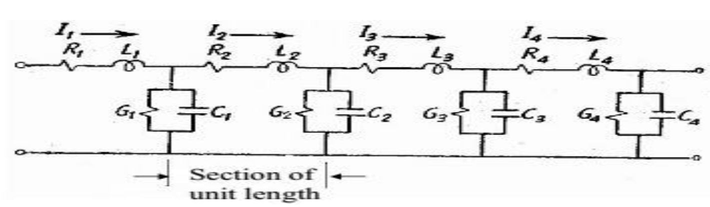
- ✓ series resistance , series inductance , shunt capacitance , and shunt conductance are distributed along the whole length of line ,as shown in below fig.
- ✓ Series resistance accounts for ohmic (I^2R) line losses.
- ✓ Series impedance, including resistance and inductive reactance, gives **rise to series – voltage drops** along the line.
- ✓ Shunt capacitance gives rise to **line – charging currents** .
- ✓ Shunt conductance accounts for (V^2G) line losses due to **leakage currents** between conductors or between conductors and ground over insulators ,

❖ Addition to corona losses. Shunt conductance of overhead lines is usually neglected.



The same current flows through the upper and lower part of each section the resistance and inductance of both can be combined and the equivalent circuit of below fig. is obtained. Thus:
$R1 = r1 + r1'$, $L1 = l1 + l1'$ …….*etc*.
Then if each section of the line is of equal length corresponding to unit length (say one meter) of the line we will have :

$R1 = R2 = R3 .... = R$ resistance per unit length of the line i.e. ohms/loop meter . Similarly,
$L1 = L2 = L3 ..... = L$ henrys/loop meter,
$G1 = G2 = G3..... = G$ mhos/loop meter, and
$C1 = C2 = C3 ...... = C$ farads/loop meter



Resistance of a Transmission Line

The resistance of transmission line conductors is the most important cause of power loss in a transmission line.

The resistance R of a line conductor having resistivity **ρ**, length **l** and area of cross section **a** is given by ;

$$R = \rho \frac{l}{a}$$

The variation of resistance of metallic conductors with temperature is practically linear over the normal range of operation.

Suppose R1 and R2 are the resistances of a conductor at t1ºC and t2ºC (t2 > t1) respectively.

If α1 is the temperature coefficient at t1°C, then,

$$R_2 = R_1 \; [1 + \alpha_1 \, (t_2 - t_1)]$$

Where

$$\alpha_1 = \frac{\alpha_0}{1 + \alpha_0 \, t_1}$$

α0 = temperature coefficient at 0º C.

❖ Comparison of SI and English units for calculating conductor resistance.

expressed in circular mils (cmil). One inch (2.54 cm) equals 1000 mils and 1 cmil equals $\pi/4$ sq mil. A circle with diameter D inches, or (D in.) (1000 mil/in.) = 1000 D mil = d mil, has an area

$$A = \left(\frac{\pi}{4} D^2 \text{ in.}^2\right)\left(1000 \frac{\text{mil}}{\text{in.}}\right)^2 = \frac{\pi}{4}(1000\ D)^2 = \frac{\pi}{4} d^2 \quad \text{sq mil}$$

or

$$A = \left(\frac{\pi}{4} d^2 \text{ sq mil}\right)\left(\frac{1 \text{ cmil}}{\pi/4 \text{ sq mil}}\right) = d^2 \quad \text{cmil} \qquad (4.2.2)$$

1000 cmil or 1 kcmil is equal to 0.506 mm^2, often approximated to 0.5 mm^2.

❖ **% Conductivity, resistivity, and temperature constant of conductor metals**

Material	% Conductivity	$\rho_{20°C}$ Resistivity at 20 °C $\Omega m \times 10^{-8}$	T Temperature Constant °C
Copper:			
Annealed	100%	1.72	234.5
Hard-drawn	97.3%	1.77	241.5
Aluminum			
Hard-drawn	61%	2.83	228.1
Brass	20–27%	6.4–8.4	480
Iron	17.2%	10	180
Silver	108%	1.59	243
Sodium	40%	4.3	207
Steel	2–14%	12–88	180–980