classmate

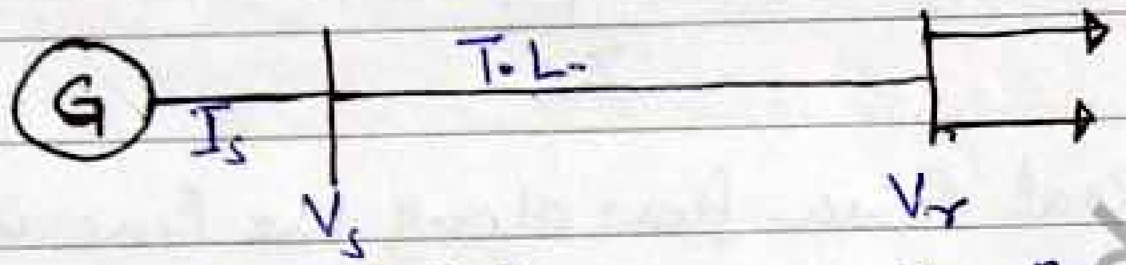
Date 28-05-14
Page 42

Lecture : 09

TRANSMISSION LINE STEADY STATE OPERATION

→ In transmission line, Steady State operation means how a line is going to perform when we want to transmit certain amount of power.

Steady State operation for two bus power system



$S_s = P_s + jQ_s$ $\qquad$ $S_r = P_r + jQ_r$

Power Flow on transmission line

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_r \\ I_r \end{bmatrix}$$

Solving this equation, we get:

$$I_r = \frac{1}{B} V_s - \frac{A}{B} V_r$$

$$I_s = \frac{D}{B} V_s - \frac{1}{B} V_r = \frac{A}{B} V_s - \frac{1}{B} V_r \quad [\text{bcoz } A = D]$$

Let

$$V_r = |V_r| \angle 0^\circ, \quad V_s = |V_s| \angle \delta$$

$$D = A = |A| \angle \alpha, \quad B = |B| \angle \beta.$$

$$\therefore \quad I_r = \frac{|V_s|}{|B|} \angle \delta - \beta - \frac{|A||V_r|}{|B|} \angle \alpha - \beta.$$

$$I_s = \frac{|A||V_s|}{|B|} \angle (\alpha + \delta - \beta) - \frac{|V_r|}{|B|} \angle -\beta$$

$$I_r^* = \frac{|V_s|}{|B|} \angle \beta - \delta - \frac{|A||V_r|}{|B|} \angle \beta - \alpha.$$

$$I_s^* = \frac{|A||V_s|}{|B|} \angle \beta - (\alpha + \delta) - \frac{|V_r|}{|B|} \angle \beta$$

Power ~~~~ received by Load $S_r = P_r + jQ_r = V_r I_r^*$.

$$\therefore \quad S_r = |V_r|\angle 0^\circ \left[\frac{|V_s|}{|B|}\angle\beta-\delta - \frac{|A||V_r|}{|B|}\angle(\beta-\alpha) \right]$$

$$\boxed{S_r = \frac{|V_s||V_r|}{|B|}\angle(\beta-\delta) - \frac{|A||V_r|^2}{|B|}\angle(\beta-\alpha)}$$

Similarly,
Power sends from the generator

$$\boxed{S_s = \frac{|A||V_s|^2}{|B|}\angle(\beta-\alpha) - \frac{|V_s||V_r|}{|B|}\angle(\beta+\delta)}.$$

we know $P = VI\cos\phi$, $Q = VI\sin\phi$.

$$\therefore \quad P_r = \frac{|V_s||V_r|}{|B|}\cos(\beta-\delta) - \frac{|A||V_r|^2}{|B|}\cos(\beta-\alpha).$$

$$Q_r = \frac{|V_s||V_r|}{|B|}\sin(\beta-\delta) - \frac{|A||V_r|^2}{|B|}\sin(\beta-\alpha).$$

Similarly, P_s & Q_s can be calculated.
if we have the system 220kV or 400kV then $|V_s| \simeq |V_r|$.

The Maximum power that can be received is when $\boxed{\beta = \delta}$.

P_r'

$$P_r'(max) = \frac{|V_s||V_r|}{|B|} - \frac{|A||V_r|^2}{|B|}\cos(\beta-\alpha)$$

$$Q_r'(max) = -\frac{|A||V_r|^2}{|B|}\sin(\beta-\alpha)$$

Conclusion: If the real power is maximum then the reactive power received at the Load end has to be -ve that means the power has to be transmitted for a Leading powerfactor Load.

For short line $A = D = 1\angle 0^\circ$, $B = Z\angle\theta^\circ$

$$\therefore P_r = \frac{|V_s||V_r|}{|Z|}\cos(\theta-\delta) - \frac{|V_r|^2}{|Z|}\cos\theta$$

$$Q_r = \frac{|V_s||V_r|}{|Z|}\sin(\theta-\delta) - \frac{|V_r|^2}{|Z|}\sin\theta$$

Similarly,

$$P_s = \frac{|V_s|^2}{|Z|}\cos\theta - \frac{|V_s||V_r|}{|Z|}\cos(\theta+\delta)$$

$$Q_s = \frac{|V_s|^2}{Z}\sin\theta - \frac{|V_s||V_r|}{|Z|}\sin(\theta+\delta)$$

For short transmission line $|Z| \simeq |X|$ & $\theta \simeq 90^\circ$ bcoz 'R' is negligible.

$$\therefore \boxed{P_r = \frac{|V_s||V_r|}{|X|}\sin\delta}$$

$$\boxed{Q_r = \frac{|V_s||V_r|}{|X|}\cos\delta - \frac{|V_r|^2}{X}}$$

As δ is very small ; $\cos\delta = 1$.

$$Q_r = \frac{|V_s||V_r|}{X} - \frac{|V_r|^2}{X}$$

$$\boxed{Q_r = \frac{|V_r|}{X}(|V_s| - |V_r|)}$$

~~Conclu~~ Conclusion:

→ For fixed value of V_s, V_r & X the real power depends on δ (the phase angle by which V_s Leads V_r) This δ is called power angle. When $\delta = 90^\circ$, P_r is maximum. For system stability δ has to kept below 90°. (normally 20°-30° bcoz any disturbance can make the system unstable if we work near to 90°).

★ Power can be transferred over line even when $|V_s| \leq |V_r|$. This is because of the phase difference b/w V_r & V_s causes the flow of power in the line. If δ is +ve then $|V_s| \geq |V_r|$
If δ is -ve then $|V_s| \leq |V_r|$.

In d.c. circuit, for power flow $|V_s| \geq |V_r|$. However in a.c. circuit power can flow when $|V_s| \geq |V_r|$ or $|V_s| \leq |V_r|$. Power system are operated with almost the same voltage magnitude (i.e. 1 p.u.) by using the method of voltage control.

★ The maximum real power transferred over the Line increases with increase in V_s and V_r. An increase in 100% in V_r & V_s increases the power ~~to~~ transfer to 400%. This is the reason for adopting high & extra high voltage transmission line.

→ Pmax depends on X which is directly proportional to the Line inductance. A decrease in L ↓ X and hence Pmax ↑. The Line inductance can be increased by bundled conductors. Another method of reducing Line inductance is by inserting Capacitance in series with the line. This method is known as Series compensation. The series capacitor are usually installed at the middle of the Line. If we connect a Capacitor in line, then total effective series reactance will get reduced.
→ generally done in order to increase the real power transfer capacity of the Line.

★ The reactive power transferred over the Line is $\propto (|V_s| - |V_r|)$ i.e. voltage drop along the line and is independent of power angle 'δ'. This means the voltage drop on the Line is due to the transfer of reactive power over the Line. To maintain a good voltage profile, reactive power control is necessary. This is done by means of Reactive power compensation of transmission Line.

VOLTAGE CONTROL

→ Reactive Power compensation equipment has the following effect:
1. Reduction in Current
2. Maintainance of voltage profile within ~~the~~ Limits
3. Reduction of Losses in the system. ($I \downarrow$ so, $I^2R \downarrow$)
4. Improvement in Powerfactor of Generator.

Why we need compensation?.
We need compensation mainly to see that the voltage profile of the Line is maintained as near the nominal value as possible.
Why it is so important?.

→ If we go at EHV, we need to insulate the Line from ground as well as from Line to Line which means we need to use insulator & which is very expensive.
Therefore, the voltage which is allowed to change is not more than ± 10% of nominal value. Therefore, it is necessary to control the voltage within these Limits.

→ If voltage drop ↑ then cost of insulation ↑. That's why compensation is done in order to maintain the voltage within a certain limit.

→ There are different ~~types of~~ way of doing compensation ~~used~~ to control voltage in transmission line:
1. Static compensation
2. Rotating compensation
3. Transformer.

Numerical: A 50Hz, 138kV, 3φ transmission line is 200km long. The distributed line parameter are

$R = 0.1\,\Omega/km$

$L = 1.2\,mH/km$

$C = 0.01\,\mu f/km$

$G = 0.$

The transmission line delivers 40MW at 132kV with 0.95 P.f. Lag. Find the sending end voltage & current, & also transmission line efficiency.

→ $Z = 0.1 + j\,0.377 = 0.39 \angle 75.14^\circ\ \Omega/km.$

$Y = j3.14\times10^{-6} = 3.14\times10^{-6}\angle 90^\circ$ mho/km.

from the above values,

$Z_c = \sqrt{z/y} = 352.42 \angle -7.43^\circ\ \Omega.$

$\gamma l = 200\sqrt{zy} = 0.2213\angle 82.57^\circ = 0.0286 + j0.2194$

Now,

$\sinh\gamma l = \dfrac{e^{\gamma l} - e^{-\gamma l}}{2} = 0.2195\angle 82.67^\circ$

$\cosh\gamma l = 0.975\angle 0.37^\circ$

Now, V_2 = Receiving end voltage $= \dfrac{132}{\sqrt{3}}\angle 0^\circ = 76.2\angle 0$ kV.

$P_{Load} = \dfrac{40}{3} = 13.33\,MW. = V_2 I_2 \cos\phi_2$ $[\cos\phi_2 = 0.95]$

$I_2 = \dfrac{13.33\times10^6}{76.2\times10^3\times0.95} = 184.1$

$I_2 = 184.1\angle -\cos^{-1}0.95 = 184.1\angle -18.195^\circ.$

Now, $V_1 = \cosh\gamma l\ V_2 + Z_c I_2 \sinh\gamma l = 82.96\angle 8.6^\circ$ kV.

$I_1 = I_2\cosh\gamma l + V_2/Z_c \sinh\gamma l = 179.46\angle 17.79^\circ$

Now, $P_{input} = Re(V_1 I_1^*) = 14.69\,MW.$

$\%\eta = \dfrac{13.33}{14.69}\times100 = 90.7\%.$

Numerical: A 3φ 132kV overhead Line delivers 60 MVA at 132kV and powerfactor 0.8 Lagging at its receiving end. The constant of the Lines are $A = 0.98 \angle 3^\circ$, $B = 100 \angle 75^\circ \Omega$/Phase.
Find (a) Sending end voltage & power angle.
(b) Sending end active & reactive power
(c) Line Losses & VAR absorbed by line.

(a) we have, $V_r = 132000/\sqrt{3} = 76210 \angle 0^\circ$

$$I_r = \frac{60 \times 10^6}{\sqrt{3} \times 132000 \times 0.8} = 262.43 \angle -36.87^\circ A$$

$$V_s = AV_r + B\bar{I}_r.$$
$$= 97.33 \times 10^3 \angle 11.92\ V.$$

Sending end Line voltage $= \sqrt{3} V_s = 168.58\ kV$.

Power angle $= \delta = 11.92^\circ$.

(b) $$S_s = |A||V_s|^2 |B|^{-1} \angle \beta - \alpha - |V_r||V_s||B|^{-1} \angle \beta + \delta.$$

$\beta = 75^\circ$, $\alpha = 3^\circ$, $|V_r| = 76210 \angle 0^\circ$, ~~$V_s = 168.58$~~
$|V_s| = 97.33 \times 10^3$ ~~$\angle 11.92$~~

$$\therefore\ S_s = 278.49 \angle 72^\circ - 222.53 \angle 86.92^\circ\ MVA$$

Sending end active power.

$$P_s = 278.49 \cos 72^\circ - 222.53 \cos 86.92^\circ = 74.10\ MW$$
$$Q_s = 42.65\ MVAR\ \text{Lagging}.$$

(c) Line Losses: $= P_s - P_r = 74.10 - 60 \times 0.8 = 26.10\ MW$.

MVAR absorbed by line $= Q_s - Q_r = 42.65 - 60 \times 0.6$
$= 6.65\ MVAR$.

End

FORMULAE

1. Inductance calculations for

(a) Solid cylindrical conductor $\lambda_{Total} = 2\times10^{-7} \ln D/r' \; [r' = re^{1/4}]$

(b) 3ϕ transmission line with

(i) Equilateral spacing $\longrightarrow \lambda = 2\times10^{-7} \ln D/r'$

(ii) Transposed line $\longrightarrow \lambda = 2\times10^{-7} \ln \frac{(D_{12} D_{23} D_{31})^{1/3}}{r'}$

(iii) Bundled conductor

$$\lambda = 2\times10^{-7} \ln \frac{D_{eq} \rightarrow \text{Mutual GMD}}{D_s \rightarrow \text{self GMD}}.$$

2. Capacitance calculation for

(a) 1ϕ Line $\longrightarrow$ $C_{xy} = \pi\varepsilon / \ln(D/r)$; $C_n = 2\pi\varepsilon / \ln(D/r)$

(b) 3ϕ Line with

(i) Equilateral spacing $C_{an} = 2\pi\varepsilon / \ln(D_{eq}/r)$

$$D_{eq} = \sqrt[3]{D_{ab} D_{bc} D_{ac}}$$

(ii) Bundled conductor $C_{an} = 2\pi\varepsilon / \ln(D_{eq}/D_s)$

$D_{eq} \rightarrow$ Mutual GMD
$D_s \rightarrow$ self GMD

3. Sending end Power

$$S_s = \frac{|A||V_s|}{|B|} \angle(\beta - \alpha) - \frac{|V_s||V_r|}{|B|} \angle(\beta + \delta)$$

4. Receiving End Power:

$$S_r = \frac{|V_s||V_r|}{|B|} \angle(\beta - \delta) - \frac{|A||V_r|^2}{|B|} \angle(\beta - \alpha)$$

$P_s = S_s \cos(\text{angle})$ $\quad P_r = S_r \cos(\text{angle})$

$Q_s = S_s \sin(\text{angle})$ $\quad Q_r = S_r \sin(\text{angle})$