~~Medium T.L.~~

Surge Impedance

Surge impedance (Z_o) of a line is defined as the square root of Z/Y

ie $Z_o = \sqrt{\frac{Z}{Y}}$

where $Z = R + jX \rightarrow$ Series impedance
$Y = G + jB \rightarrow$ shunt admittance

For a line having negligible resistance (ie when the conductors are of large c.s.) and having no shunt leakage (ie when value of G will be zero), $Z = \sqrt{L/C}$ which is a pure resistance. It has a value of 400 to 600 Ω for an overhead line & 40 to 60 Ω for an underground cable.

The surge impedance of a line may be measured in terms of Z_{oc} & Z_{sc} where these are impedances measured at the sending end with receiving end open-circuited & short circuited resp.

We know, for a T.L.,

When R.E is short circuited,

$V_R = 0$

$\therefore V_s = B \cdot I_R$

$I_s = D \cdot I_R$

$$\therefore Z_{sc} = \frac{V_s}{I_s} = B/D. \quad — (2)$$

Multiply (1) & (2),

$$\therefore Z_{oc} \cdot Z_{sc} = \frac{A}{C} \cdot \frac{B}{D}$$

As $A = D$ for a T-L;

$$Z_{oc} \cdot Z_{sc} = B/C$$

$$\left.\begin{aligned} B &= \sqrt{Z/Y} \cdot \sinh \sqrt{YZ} \\ C &= \sqrt{Y/Z} \sinh \sqrt{YZ} \end{aligned}\right\} \text{for a long T-L.}$$

$$\therefore \frac{B}{C} = Z/Y$$

But from definition of surge impedance,

$$\frac{Z}{Y} = Z_c^2$$

$$\therefore Z_{oc} \cdot Z_{sc} = Z_c^2$$

$$\therefore \boxed{Z_0 = \sqrt{Z_{oc} \cdot Z_{sc}}}$$

Surge impedance Loading (SIL)

SIL is a very imp. parameter in the study of power system as it is used in the prediction of max. loading capacity of T.L.s.

Before understanding SIL, we must know what is surge impedance (Z_c) or (Z_s)

We know that a long T.L. have distributed inductance & capacitance as its inherent property. When the line is charged, the capacitance component feeds reactive power to the line, while the inductance component absorbs the reactive power. If we take the balance of the two reactive powers, we get,

capacitive VAR = inductive VAR

Capacitive VARs $= V \cdot I = V \cdot \frac{V}{X_c} = \frac{V^2}{X_c}$

inductive VARs $= V \cdot I = I \cdot X_L \cdot I = I^2 X_L$

$$\therefore \frac{V^2}{X_c} = I^2 \cdot X_L$$

$$\therefore \frac{V}{I} = \sqrt{X_L X_C} = \sqrt{\frac{2\pi f L}{2\pi f C}}$$

$$\frac{V}{I} = \sqrt{\frac{L}{C}} = Z_c$$

This quantity having the dimensions of resistance (Ω) is called as surge impedance

It can be considered as a purely resistive load which when connected at the receiving end of the line, the reactive power generated by capacitive reactance will be completely absorbed by inductive reactance. It is nothing but the characteristic impedance (Z_c) of a lossless line.

The surge impedance of a line may be measured in terms of Z_{oc} & Z_{sc} where these are impedances measured at the sending end with receiving end open-circuited & short circuited resp.

We know that,

$$V_s = A \cdot V_R + B I_R$$

$$I_s = C \cdot V_R + D \cdot I_R$$

when there is O.C. at R.E, $I_R = 0$

$$\therefore V_s = A \cdot V_R$$

$$I_s = C \cdot V_R$$

$$\therefore Z_{oc} = \frac{V_s}{I_s} = A/C \quad \text{--- (1)}$$

When there is S.C. at R.E, $V_R = 0$

$$\therefore V_s = B \cdot I_R$$

$$I_s = D \cdot I_R$$

$$\therefore Z_{sc} = \frac{V_s}{I_s} = B/D \quad \text{--- (2)}$$

Multiply ~~A~~ ① & ②,

$$Z_{oc} \cdot Z_{sc} = \frac{A}{C} \cdot \frac{B}{D}$$

$$= \frac{B}{C} \quad \ldots \text{ as } A = D \text{ for T.L.}$$

$$\therefore Z_{oc} \cdot Z_{sc} = B/C$$

~~B~~ For a long T.L.,

$$B = \sqrt{Z/Y} \cdot \sinh \sqrt{YZ}$$

$$C = \sqrt{Y/Z} \sinh \sqrt{YZ}$$

$$\therefore \frac{B}{C} = Z/Y$$

But from definition of surge impedance,

$$\frac{Z}{Y} = Z_c^2$$

$$\therefore Z_{oc} \cdot Z_{sc} = Z_c^2$$

$$\therefore \boxed{Z_c = \sqrt{Z_{oc} \cdot Z_{sc}}} \longrightarrow \text{Surge impedance.}$$

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Now let's define SIL.

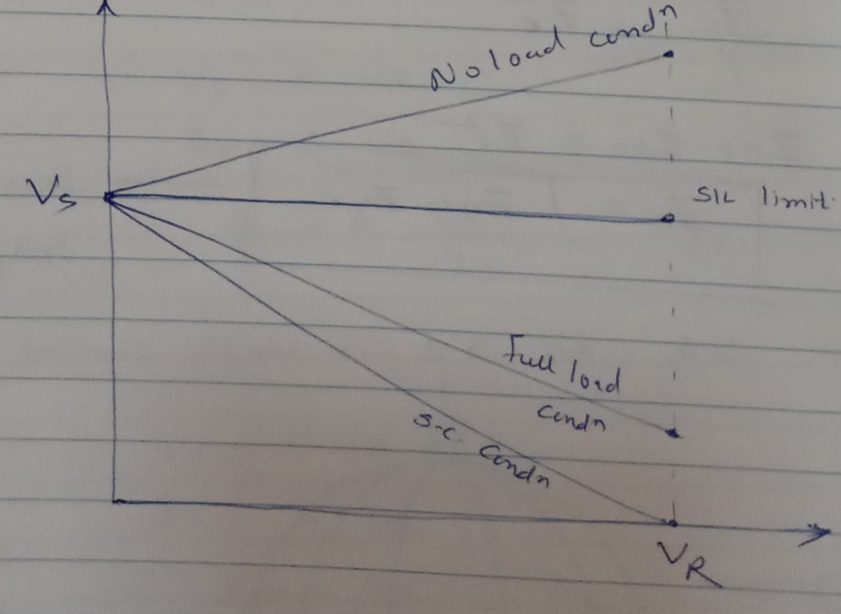
SIL is defined as the power delivered by a line to a purely resistive load equal in value to a surge impedance of that line.

The unit of SIL is watt.

When the line is terminated by surge impedance, the R.E. voltage is equal to S.E voltage and this case is called as flat voltage profile.

* imp. → surge impedance & hence SIL is independent of the length of the line. The value of surge impedance will be the same at all the points on the line & hence the voltage.

Voltage behavior of a long T.L. (without shunt reactor installed)



The power transmitted under SIL cond^n is,

$$P_R = \frac{V_R^2}{Z_c}$$

$Z_c \rightarrow$ surge impedance.

$P_R \rightarrow$ surge impedance loading.

↳ is also called as natural power of the line.

Above eq^n gives a limit to the max. power that can be delivered and is useful in the design of the T.L.

SIL can be used for the comparison of loads that can be carried on the lines at diff. voltages.

In order to increase the power transmitted through a long T.L., either value of RE voltage is to be increased or more than one T.L. can be run in parallel. But the 2nd method is costly.

∴ From above eq^n, in order to increase P_R, either V_R is to be increased or Z_0 is to be decreased.

Increase in V_R – now a days trend is for higher & higher voltages, so this is the most widely adopted method to increase the power limit.

<u>Decrease in Z_c</u> – Since spacing betn cond's cannot be decreased much, it being dependent

Z_c cannot be ~~vari~~ varied much.

$Z_c = \sqrt{L/C}$ for a lossless T-L. To decrease Z_c, either L is decreased using series capacitors or C is increased using shunt capacitors.

Surge Impedance Loading (SIL)

Surge impedance loading is defined as the load that can be delivered by the line having no resistance, the load being at unity p.f.

Surge impedance continued →

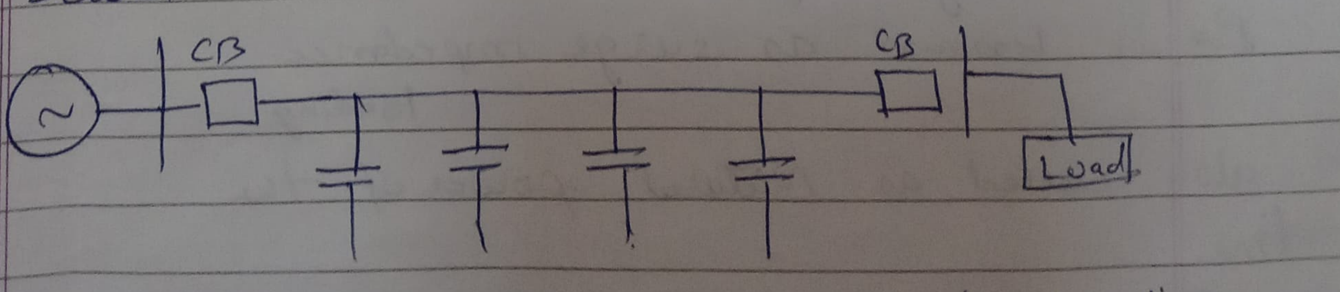
A long T.L. have distributed inductance & capacitance as its property. When the line is charged, the capacitance component feeds reactive power to the line while the inductance absorbs the reactive power.

At the balance of two reactive powers,

capacitive VAR = Inductive VAR

The load at which the inductive & capacitive VARs are equal & opposite, such load is called surge impedance load. In SIL, the voltage & current are in the same phase at all the points of the line.

Shunt capacitance charges the T.L. when the circuit breaker at the S.E is closed as shown below.

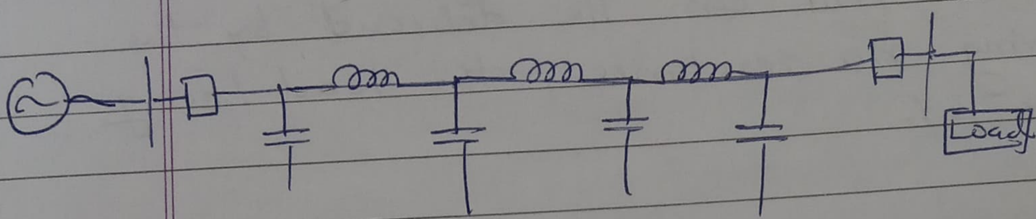


∴ Capacitive VARs generated in the line are,

$$= \frac{V^2}{X_c} = V^2 \omega C \quad \text{per ph.}$$

$$\left\{ V \cdot I = V \cdot \frac{V}{X_c} \right\}$$

The series inductance of the line consumes the electrical energy when the S.E. & R.E. terminals are closed



∴ Inductive VARs absorbed by the line,

$$= I^2 X_L = I^2 \omega L.$$

$$\left[P = V.I = I.R.I = I^2 R \right]$$

∴ capacitive VARs = Inductive VARs

$$\frac{V^2}{X_c} = I^2 X_L$$

$$\therefore \frac{V}{I} = \sqrt{X_L . X_c}$$

$$= \sqrt{\frac{L}{C}} = Z_0$$

The power transmitted under these conditions is,

$$P_R = \frac{V_R^2}{Z_0} \quad \left(\text{using } P = \frac{V^2}{R} \right)$$

* Z_0 is surge impedance
  P_R is known as surge impedance loading

also called as Natural power of the line.

Above eqn gives a limit to the max. power that can be delivered & is useful in the design of T.Ls.

SIL can be used for the comparison

of loads that can be carried on the lines at different voltages.

In order to increase the power transmitted through a long T.L., either value of R.E. Vltg. is to be increased or more than one T.L. can be run in parallel. But the 2nd method is costly. From the above eqn, in order to increase P_R, either V_R is to be increased or Z_o is to be decreased.

Increase in V_R – Now a days the trend is for higher & higher voltages, so this is the most widely adopted method to increase the power limit.

Decrease in Z_o – Since spacing betn conductors cannot be decreased much, it being dependent on the line voltages & corona, etc., the value of Z_o cannot be varied much. $Z_o = \sqrt{L/C}$ for a lossless T.L. To decrease Z_o, either L is decreased using series capacitors or C is increased using shunt capacitors.