Voltage Control
Voltage variation and control

- When power is supplied through a transmission line, keeping the sending end voltage constant, the receiving end voltage varies in accordance with the changes in the magnitude and phase angle of the load. This is the most troublesome and widespread feature associated with the operation of the overhead transmission lines.

Basic methods of Voltage control

a) By varying the excitation of the generating plant
b) By varying the transformer ratio of the line transformer
c) By varying the amount of reactive power at the receiving end of the line

Ways of improving the line Regulation

Ignoring the effect of C, the line Regulation & Voltage drop along the line are numerically equal.

$$\Delta E = I(R\cos\phi_r + X\sin\phi_r)$$

and the %age Regulation

$$\Delta E_{\%age} = \frac{100 I}{E_r}(R\cos\phi_r + X\sin\phi_r)$$

$$= \frac{100 * P_r}{E_r^2}(R + X\tan\phi_r)$$

As

$P_r = I E_r \cos\phi_r$

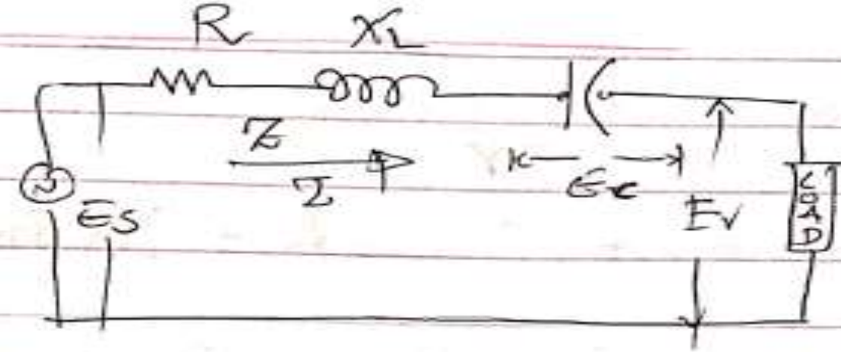
Regulation corresponding to a particular load power can be improved by

a) Increasing the Voltage
b) Reducing the resistance
c) Reducing the reactance
d) Improving the receiving end power factor

Reducing the Reactance of overhead Tx lines

a) Using double circuit lines
b) Using multiple conductors
c) Neutralizing part of the line reactance by mean of a series capacitor
d) Improving the receiving end power factor

Series Capacitor compensator

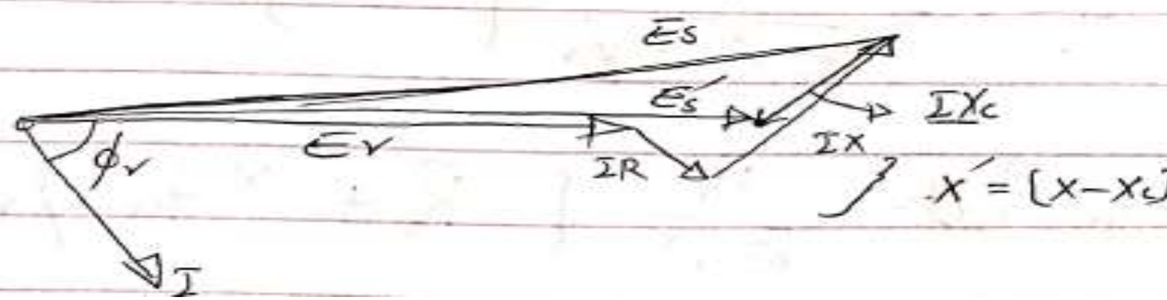


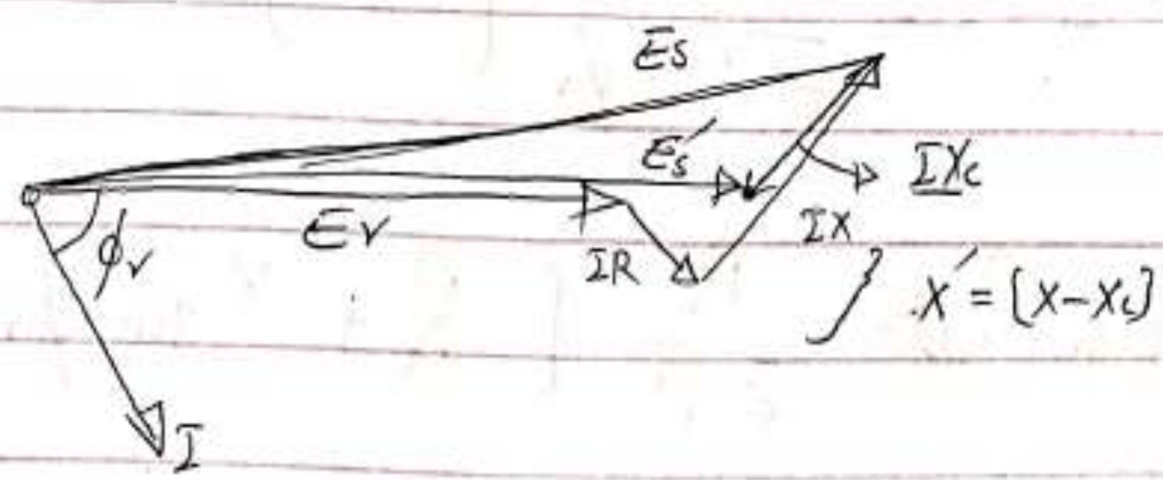
$$\Delta E = I\,[R\cos\phi_r + X\sin\phi_r]$$

when introduced $\underline{X_c}$ in series

$$\Delta E = I\,[R\cos\phi_r + (X - X_c)\sin\phi_r]$$

$$IX'$$





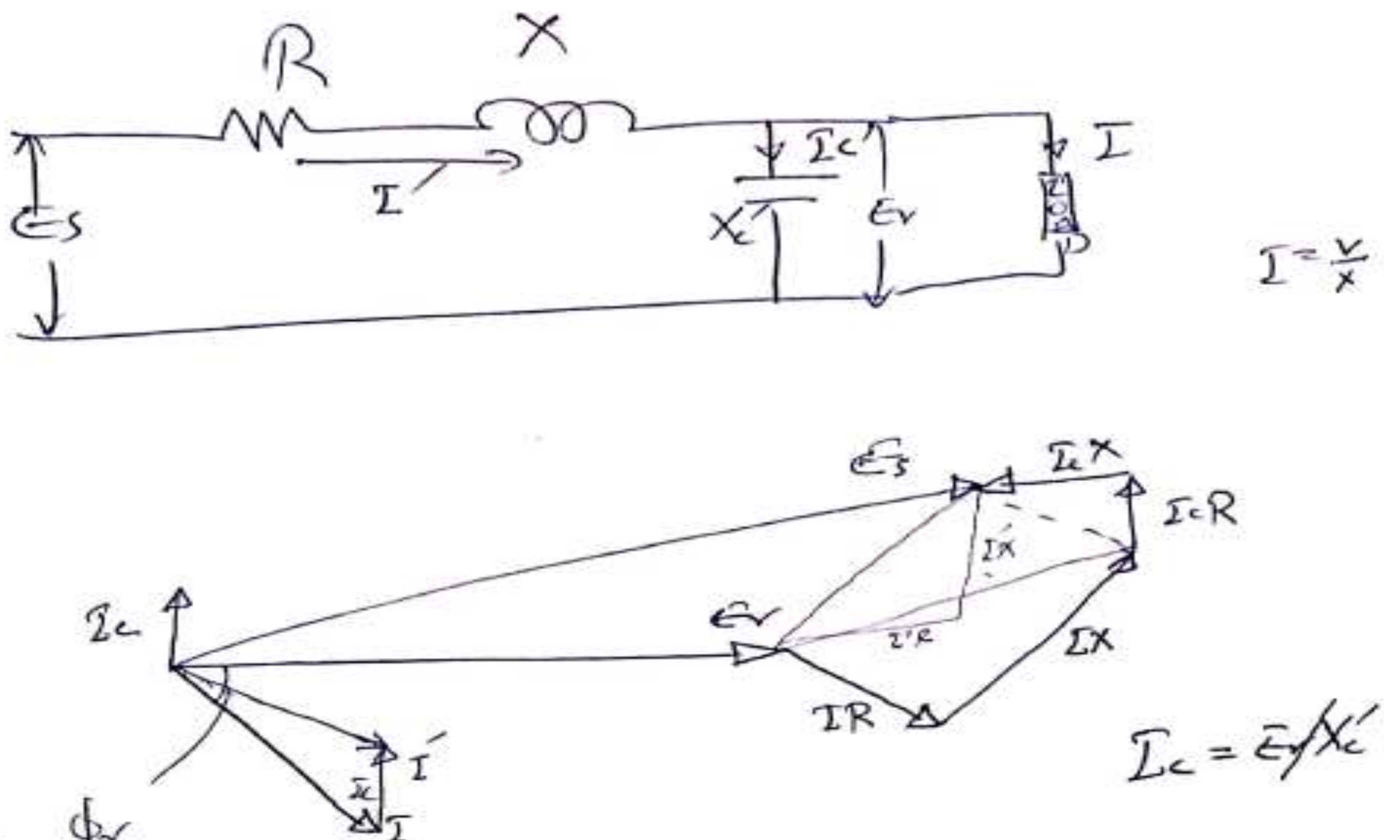
Voltage across the capacitor $E_c = I X_c$

the VAr rating of capacitor $Q_c = I \, I X_c = I^2 X_c$

The voltage boost

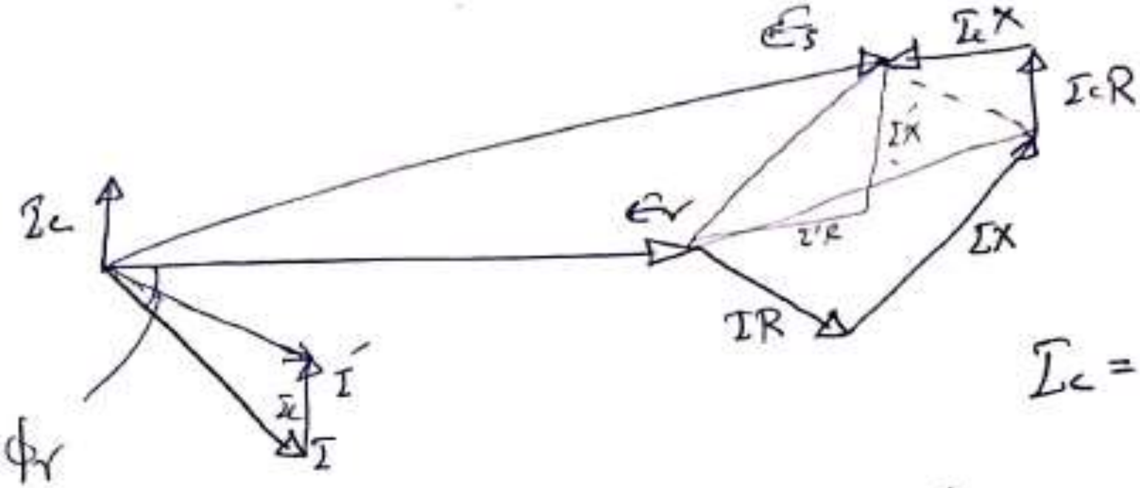
$$\Delta E_c = X_c I \sin \phi_r = \frac{Q_c}{I} \sin \phi_r$$

Improving power factor of the receiving end(Shunt compensation)



The voltage boost by capacitor

$$\Delta E_c' = I_c X = \frac{E_r X}{X_c'} = \frac{Q_c' X}{E_r}$$



$$I_c = E_r / X_c'$$

The Voltage Boost by capacitor

$$\Delta E_c' = I_c X = \frac{E_r X}{X_c'} = \frac{Q_c' X}{E_r}$$

where $Q_c' = \frac{E_r^2}{X_c'}$ is the VAr rating of the capacitors

Calculating percentage Regulation

$$\% \text{ Regulation} = \frac{E_s - E_r}{E_r} \times 100$$

$$E_s = E_r + (IR\cos\phi_r + IX\sin\phi_r)$$

$$\% \text{ Regulation} = \left\{\frac{IR\cos\phi_r + IX\sin\phi_r}{E_r}\right\} \times 100$$

$$\% \text{ of } R = \frac{I}{E_r}\{R\cos\phi_r + X\sin\phi_r\} \times 100$$

$$P_r = I_r E_r \cos\phi_r$$

$$I_r = \frac{P_r}{E_r \cos\phi_r}$$

$$= \frac{P_r}{E_r^2 \cos\phi_r}\{\ " \ \}$$

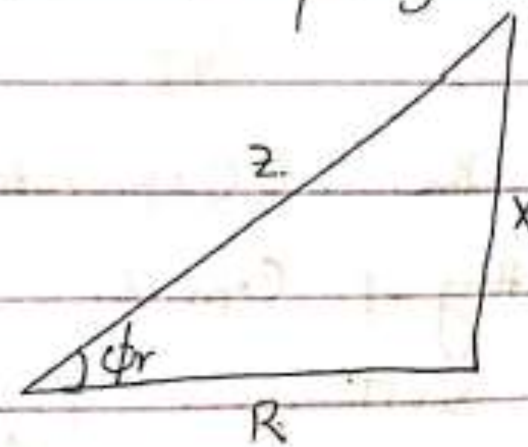
$$\% \text{ of Reglt} = \frac{P_r}{E_r^2}[R + X\tan\phi_r] \times 100$$

$$\%ge\ Reglt = \frac{P_r}{E_r^2}\left[R + X\tan\phi_r\right] \times 100$$

$E_r \uparrow$

$R \downarrow$

$X \downarrow$



$\cos$ ~~tan~~ $\phi_r = \frac{R}{Z}$

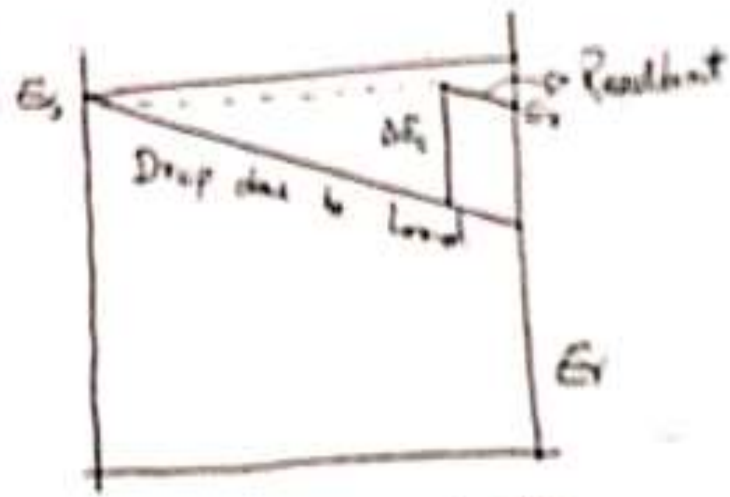
$\sin\phi_r = X/Z$

$\tan\phi_r = X/Z \div R/Z$

$\frac{X}{Z} \times Z/R = X/R$

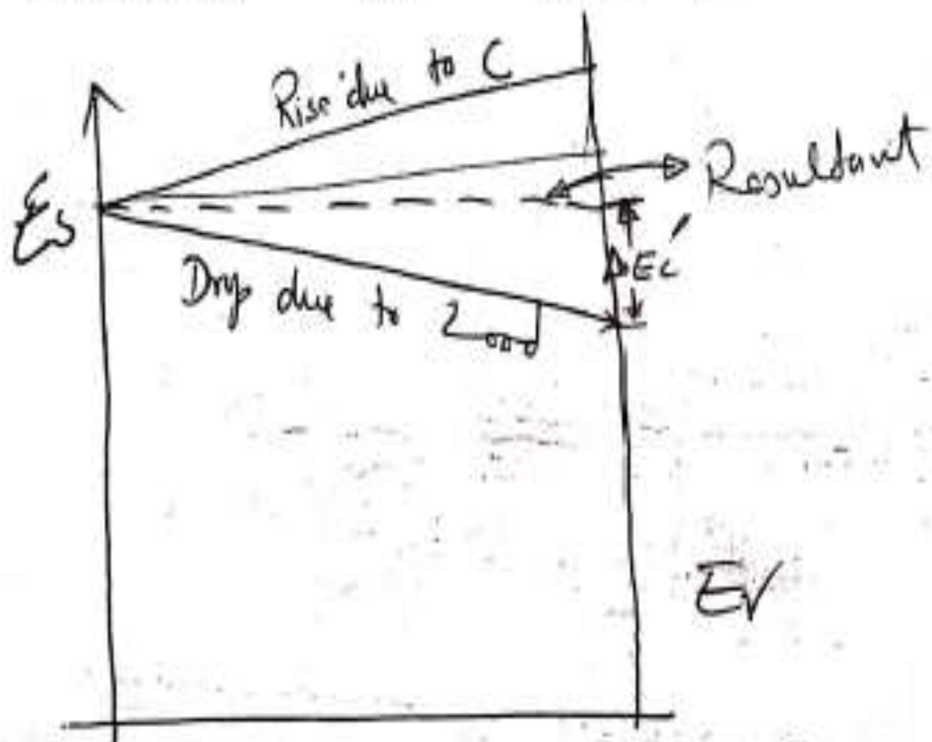
Comparison b/w series and parallel compensators

(a) In Series Capacitor the Voltage boost injected is Concentrated across the capacitor itself as shown below, and if the capacitor is installed at one end of the circuit the Voltage drop along the line itself is unaffected.



Series capacitor

On the other hand, the voltage boost produced by shunt capacitor is distributed along the line in exactly the same way as the voltage drop caused by the load. The voltage variation along the line is therefore reduced as shown below.



b) for Equality of Voltage boost with two techniques & applications then

$$\frac{Q_c' X}{E_r} = \frac{Q_c \sin \phi_r}{I}$$

(shunt) (Series)

$$Q_c' / Q_c = \frac{\sin \phi_r}{IX / E_r}$$

In a typical case if $\sin \phi_r = 0.6$, $IX/E_r = 0.1$

$0.6/0.1 = 6$

KVAr rating of a shunt capacitor has to be much greater than ~~in~~ ~~practice~~ that ~~of~~ a series capacitor for the same degree ~~of~~ boost.

On the other hand, the shunt capacitor provides all the benefits consequent on a higher power factor, whilst the series capacitor has little influence on a higher power factor.

(C) The Voltage boost due to series capacitor is directly proportional to the Load current, and changes automatically and instantaneously as the load changes. At zero load, the voltage boost is also zero. On the other hand, the voltage boost produced by the shunt capacitor is substantially constant, since it is dependent on the voltage and not on the load. There is therefore no improvement in the line regulation, since the same voltage rise in voltage is produced under both full_load and zero-load condition. At times of light load, this voltage rise may be very troublesome. This difficulty can be avoided by suitably grouping the capacitor units and providing switching equipment so that groups can be added or removed as the load changes. By having proper switching technique it can be at one and the same time a mean of controlling the receiving end voltage and a mean of neutralising the voltage variations along the line.