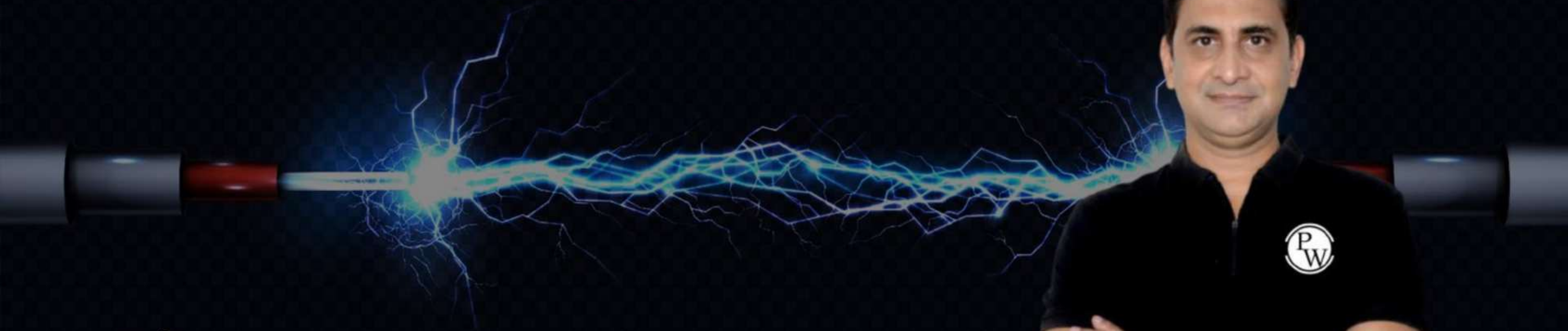


Electrical Engineering

Power System



Lecture No.-1

Voltage Control



By- Ajay Gupta Sir



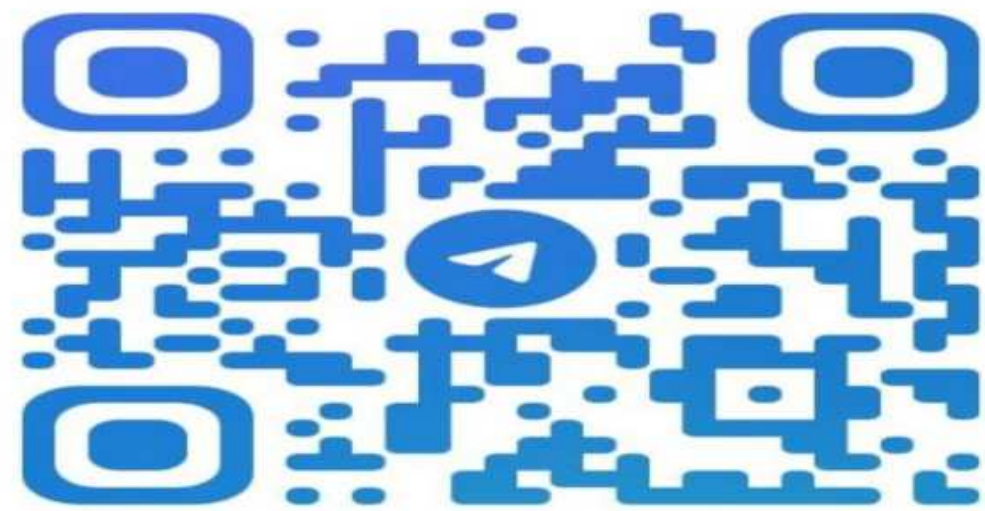
Recap Of previous class

- ✓ 1. Interference with transmission line
- ✓ 2. Electromagnetic Induction
- ✓ 3. Electrostatic Induction
- ✓ 4. Questions



Topics to be Covered

- ✓ 1. What is voltage control
- ✓ 2. Source and sink of reactive power
- ✓ 3. Shunt Capacitor
- ✓ 4. Shunt Reactor



@AJAYGUPTASIRPW

VOLTAGE CONTROL

- As all the equipment in power system are designed to operate satisfactorily, when voltage level on system is rated or within $\pm 5\%$ of range.
- Even if sending end voltage is fixed. The receiving end voltage keep on changing as per load & its pf.
- Voltage variation will be more if,
 - (i) Load is large
 - (ii) pf is low.

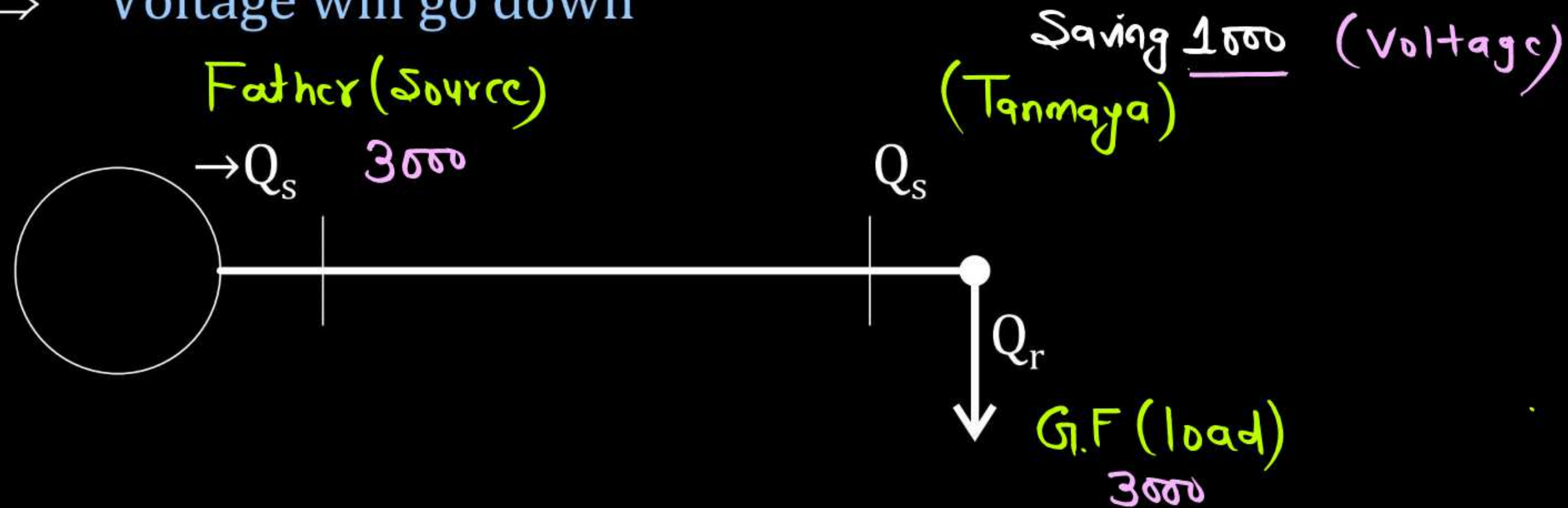
Voltage variation at any node depend upon reactive power generated & reactive power consumed at that node.

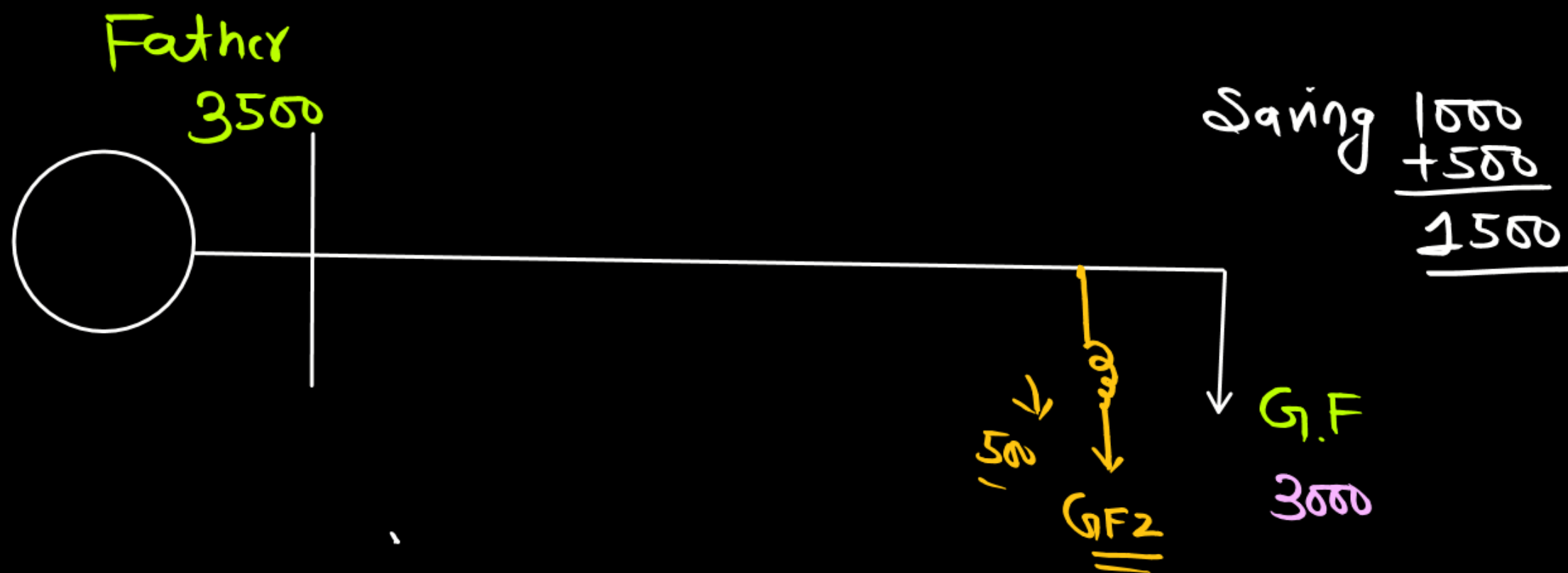
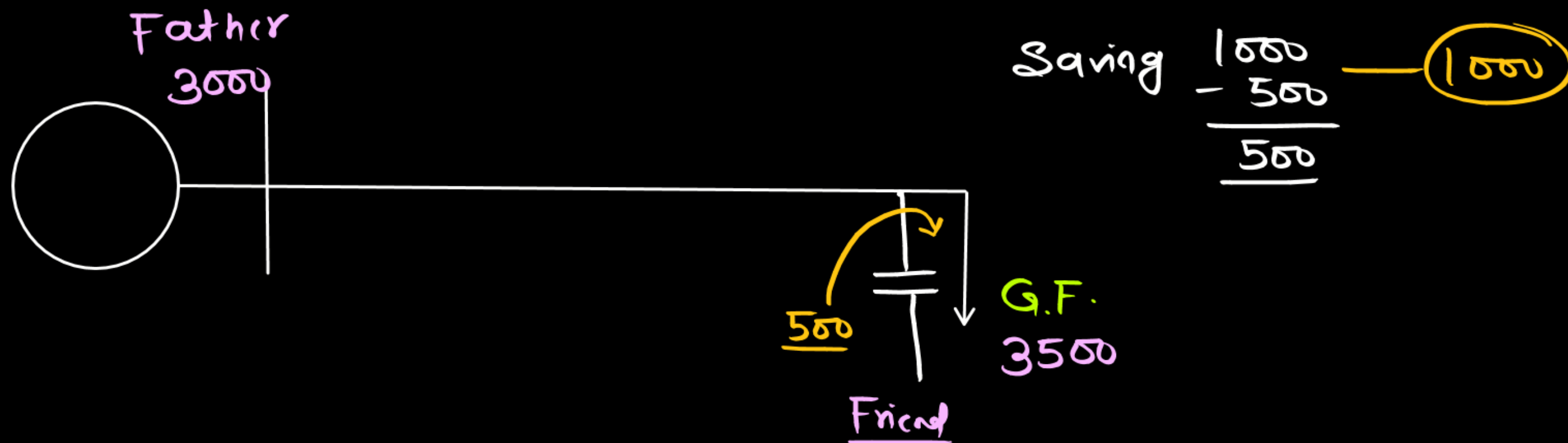
➤ If reactive power generated > Reactive Power consumption.

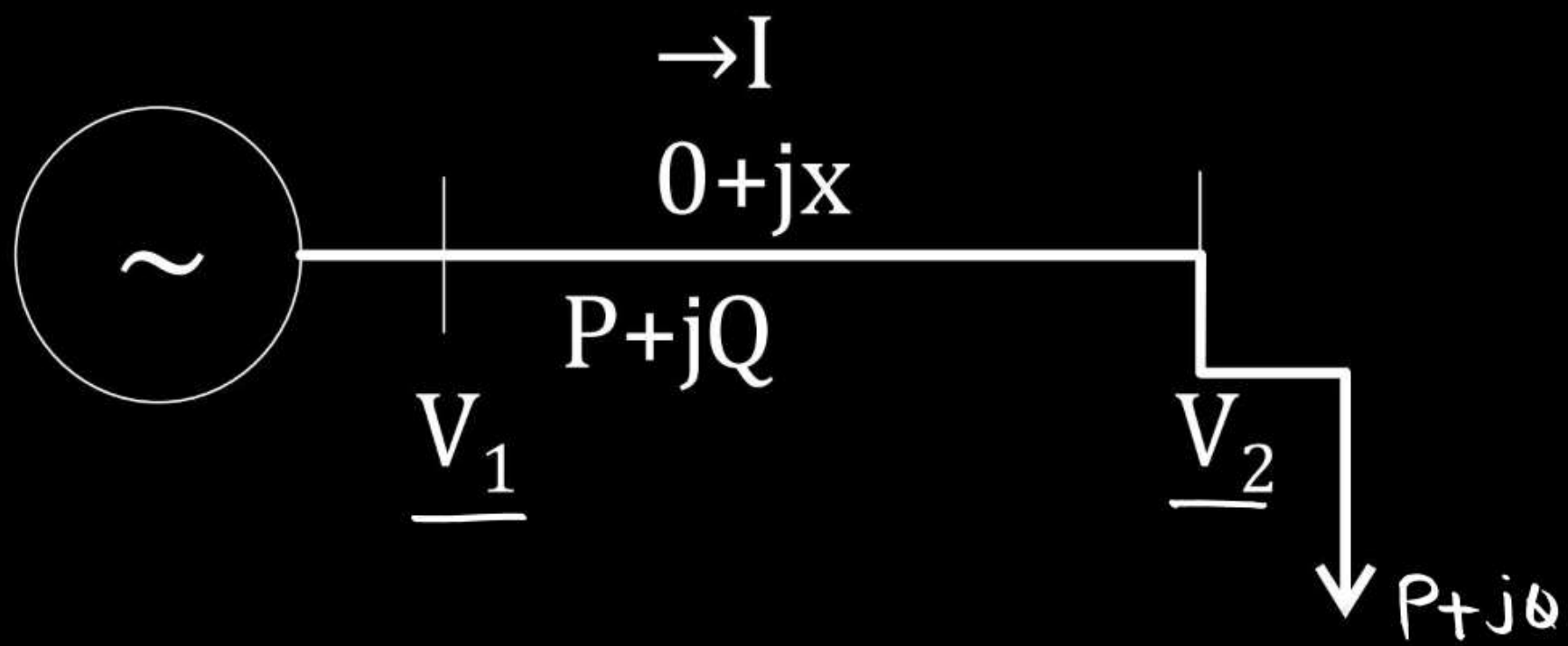
⇒ Voltage will go up.

➤ If reactive power generated < reactive power consumption.

⇒ Voltage will go down







$$\rightarrow P + jQ = \underline{V}_1 I^*$$

$$P - jQ = \underline{V}_1^* I$$

$$I = \frac{P - jQ}{\underline{V}_1^*}$$

if V_1 is a reference $V_1 = V_1 \angle 0$
 $V_1^* = V_1 \angle 0 = V_1$

$$I = \frac{P - jQ}{V_1}$$

$$\rightarrow V_2 = V_1 - I(jx)$$

$$V_2 = V_1 - \left(\frac{P - jQ}{V_1} \right) (jx)$$

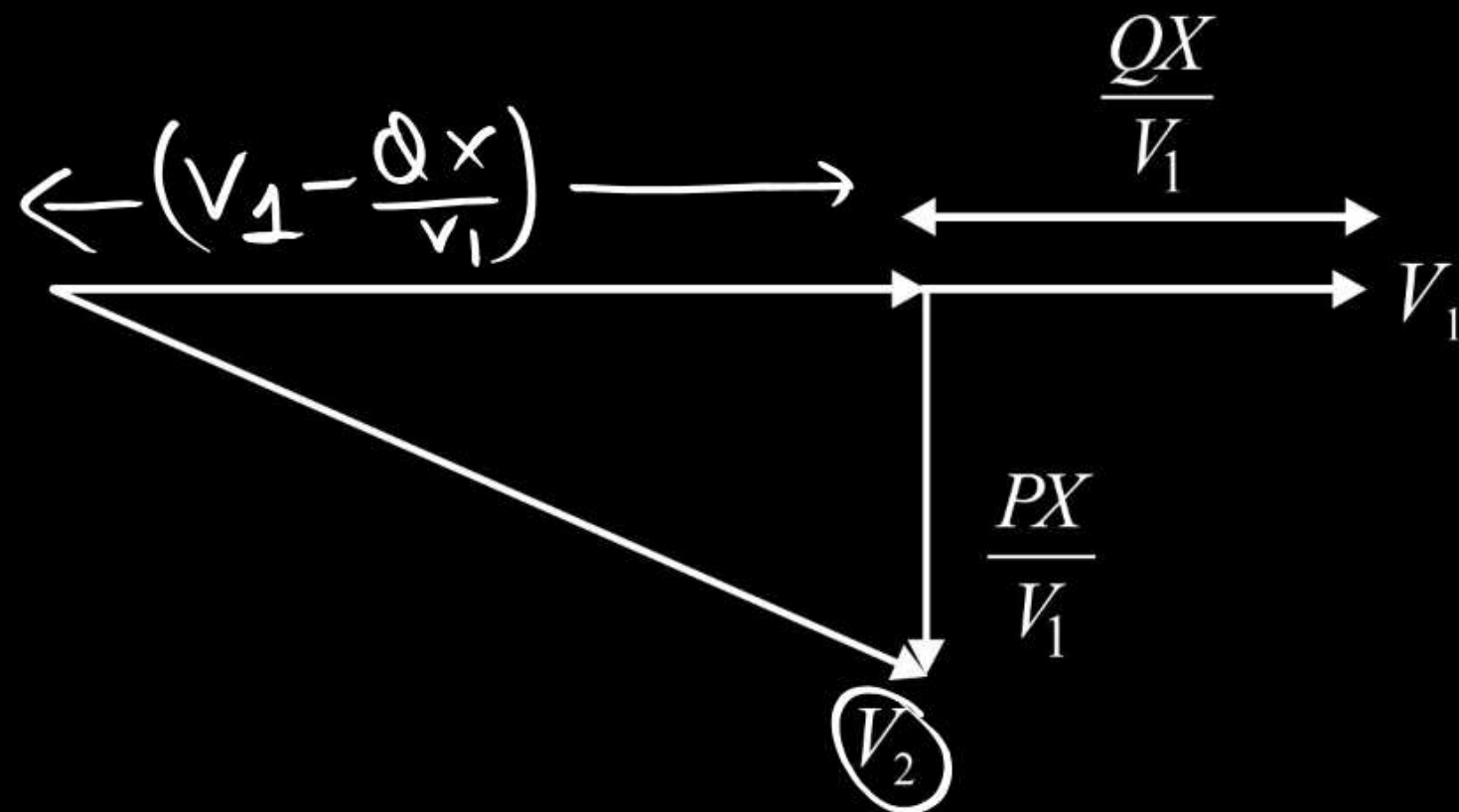
$$V_2 = \left(V_1 - \frac{Qx}{V_1} \right) - j \frac{Px}{V_1}$$



$$V_2 = \left(V_1 - \frac{QX}{V_1} \right) - j \frac{PX}{V_1}$$

25 3

$$\underline{V_2} \approx \underline{V_1} - \frac{QX}{V_1}$$

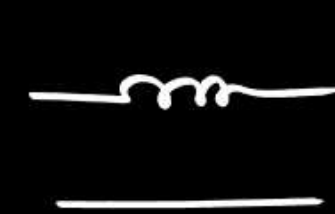


V_2 is not affected much due to P , as its component is normal to V_1 .
So if we neglect this component

$$V_2 = V_1 - \frac{QX}{V_1}$$

V_1 = Sending end voltage
 V_2 = Receiving end voltage

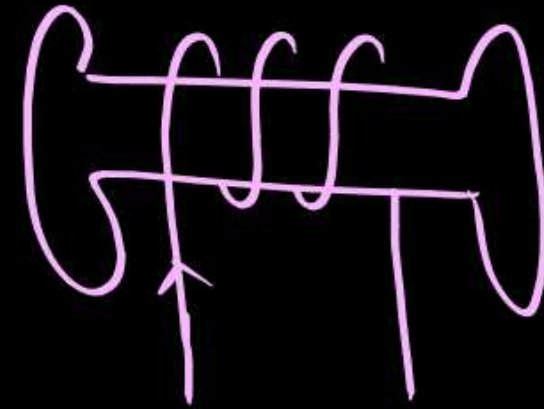
Source & Sink of Reactive Power



Equipment	Source	Sink	Neither Source Nor Sink
Alternator	✓ (Over excited)	✓ (Under excited)	✓ (Normally Excited)
Transformer	×	✓	
Inductor (TL) Reactor	×	✓	
Capacitor (TL)	✓	×	
Resistor	×	×	✓
Induction Motor	×	✓	×
Synchronous Motor	✓ (Over excited)	✓ (Under excited)	✓ (Normally excited)
Induction generator	×	✓	×

- Voltage control can be control by
 - (i) **Internal control** → by changing the field excitation of alternator, V_1 can be change, which change the V_2 .

$$\underline{V_2} = \underline{V_1} - \frac{Q \uparrow X}{V_1}$$

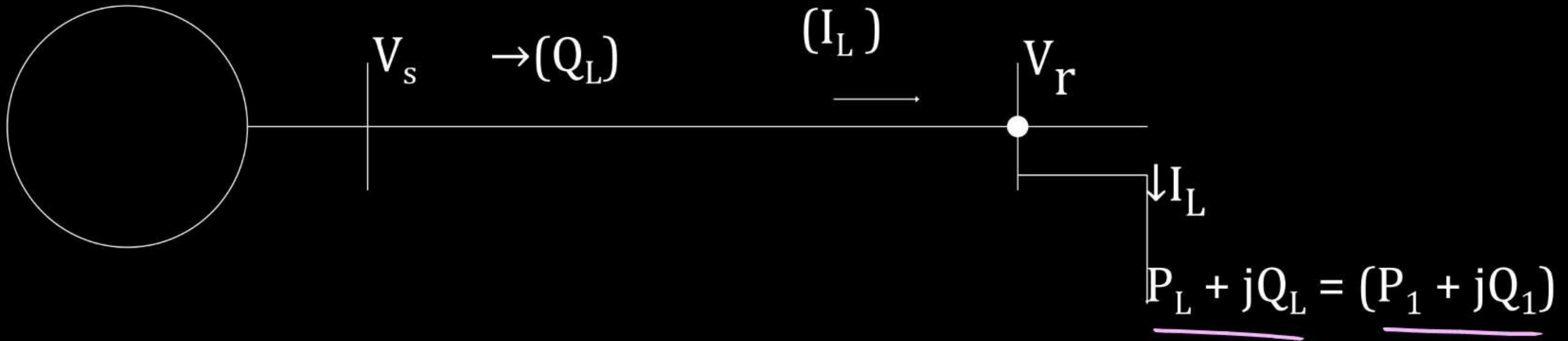


- Excitation below certain limit → stability problem
- Excitation above certain limit → over heating of rotor. ✓

(ii) **External control** → In this method , the sending end voltage is unchanged, But by varying reactive power , receiving end voltage is controlled. For that we connect some external equipment which is called compensator.

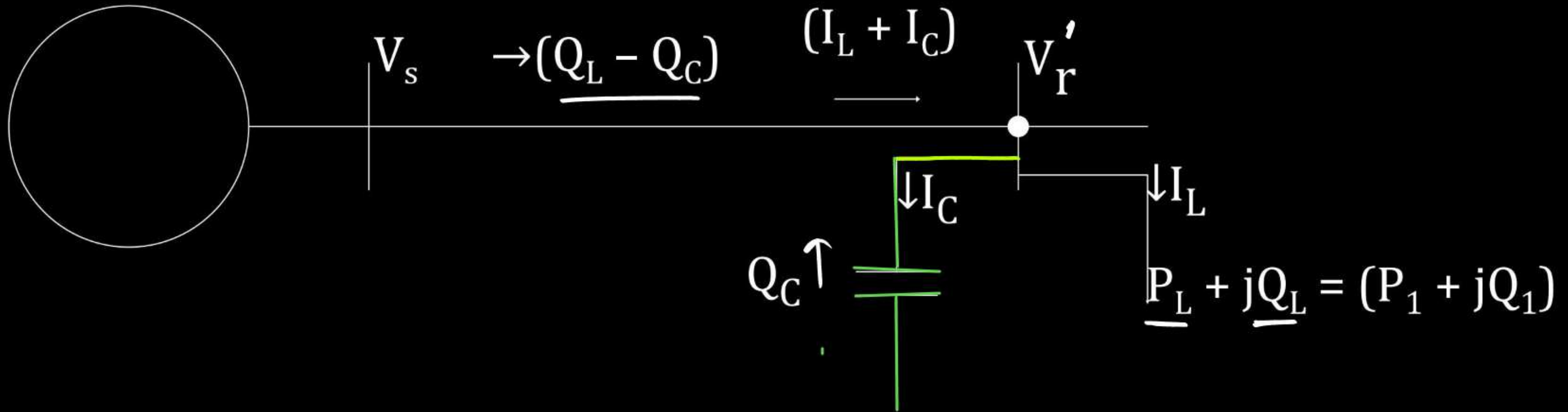
- If this equipment are connected in parallel, it is called shunt compensator.
- If this equipment are connected in series, it is called series compensator.

Without Compensator:



- It is used across any inductive load to supply reactive power required by load
- It is connected directly to bus bar or tertiary winding of transformer.

Shunt Capacitor :



- It is used across any inductive load to supply reactive power required by load
- It is connected directly to bus bar or tertiary winding of transformer.

➤ Without shunt capacitor

$$V_r = V_s - \frac{Q_L X}{V_s} \quad \dots(1)$$

➤ With shunt capacitor

$$V_r' = V_s - \frac{(Q_L - Q_C)X}{V_s} \quad \dots(2)$$

$$V_r' = V_s - \frac{Q_L X}{V_s} + \frac{Q_C X}{V_s}$$

$$V_r' = V_r + \frac{Q_C X}{V_s}$$

$$V_r' > V_r$$

➤ So, increment of voltage

$$V_y' - V_y = \frac{Q_c X}{V_s}$$

$$\Delta V = \frac{Q_c X}{V_s}$$

So, for increment of ΔV voltage, the shunt capacitor rating.

$$Q_c = \frac{\Delta V V_s}{X} = \frac{\Delta V V_s}{X}$$

Shunt capacitor is used to increase the voltage.



◆ It also improve the pf



➤ Voltage drop = $|V_s| - |V_r|$
 $= I_r R \cos \phi + I_r X \sin \phi$

if $R \approx 0$

here, $IR \cos \phi = 0$

then, Voltage drop = $I_r X \sin \phi \propto I_r \sin \phi$

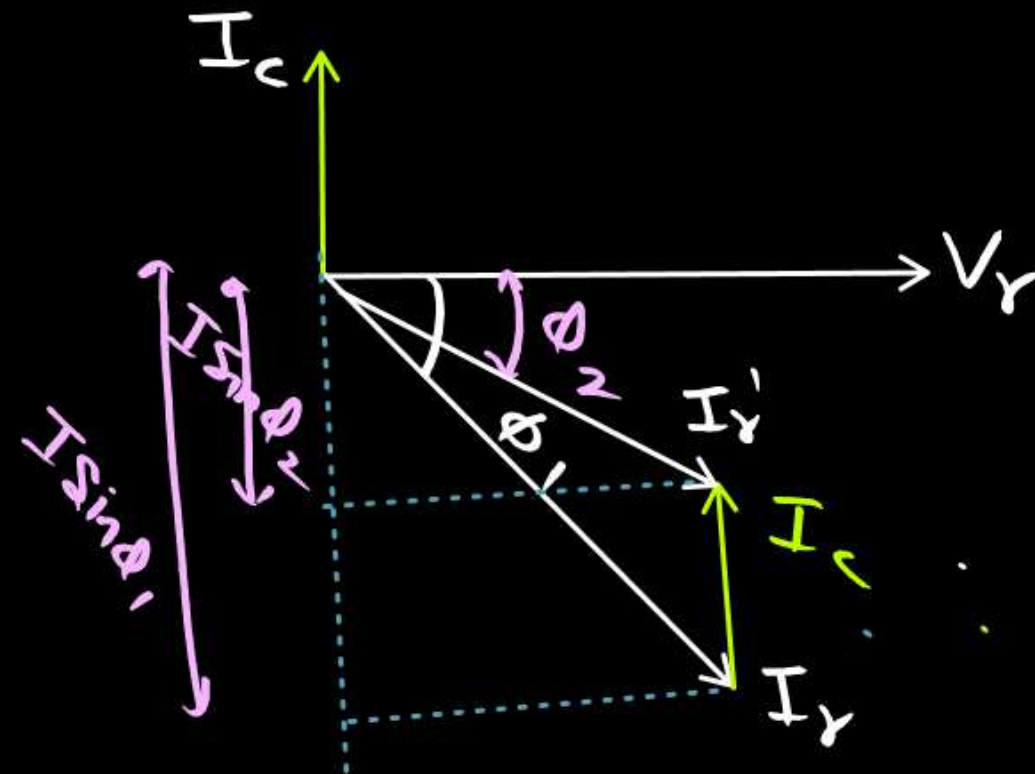
Voltage drop $\downarrow = X(I \sin \phi) \downarrow$

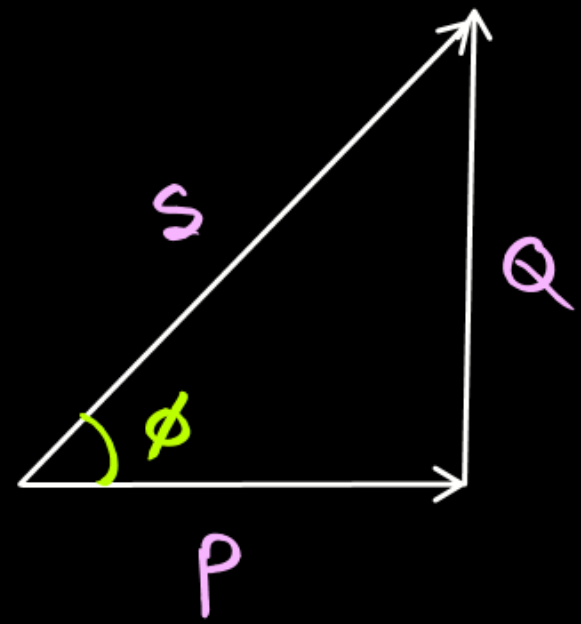
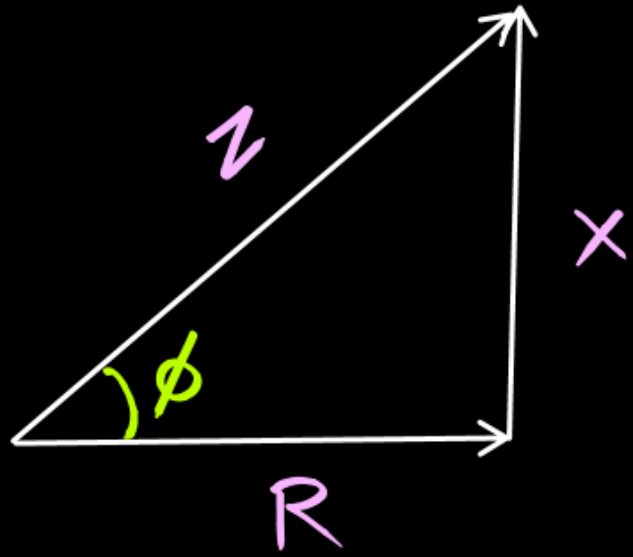
➤ So, voltage drop is reduced, so receiving end voltage is increased.

$\phi_2 < \phi_1$

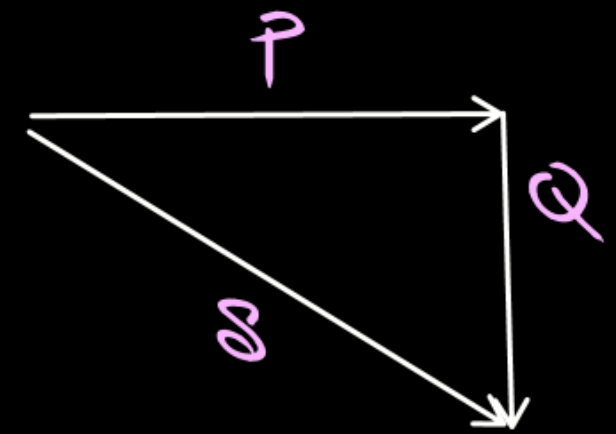
$\cos \phi_2 > \cos \phi_1$

$(P_t)_2 > (P_t)_1$



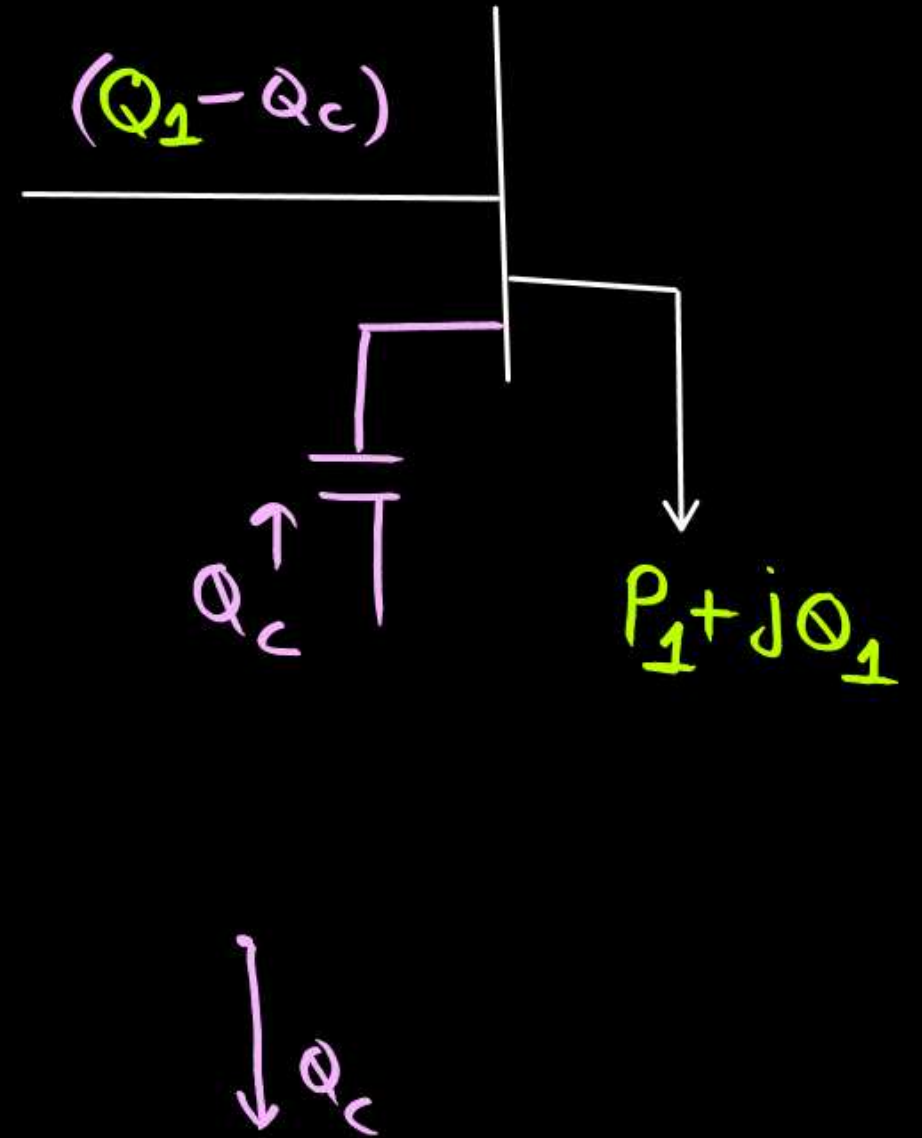
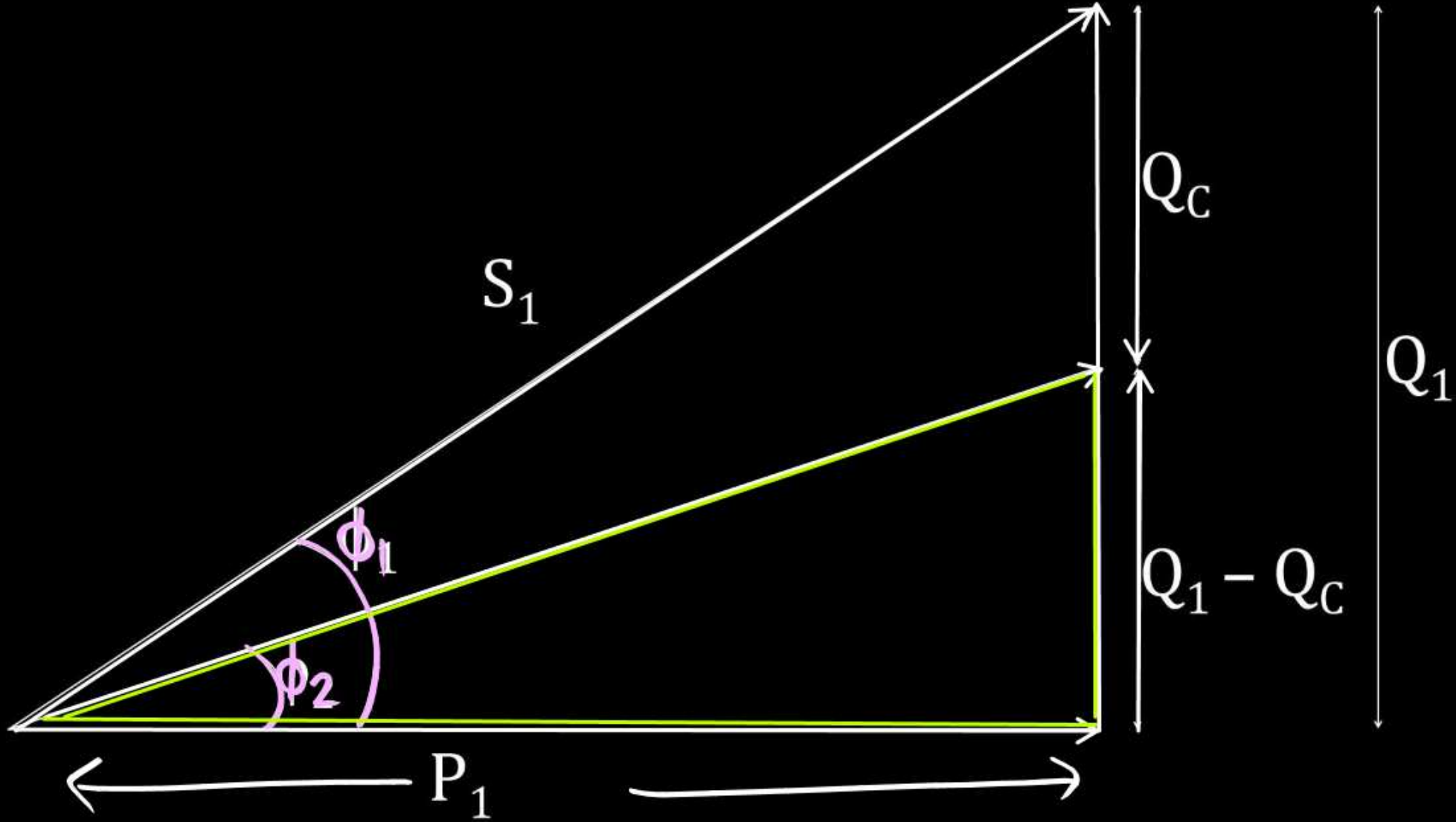


R-L load



R-C load

➤ The capacitor Rating for power factor Improvement:



Initially power drawn by load = $P_1 + jQ_1$

The power draw by capacitor = $0 - jQ_c$

Net power : $P_1 + j(Q_1 - Q_c)$

Initially pf angle, $\tan \phi_1 = \frac{Q_1}{P_1} \Rightarrow Q_1 = P_1 \tan \phi_1$

pf angle after shunt compensator,

$$\tan \phi_2 = \frac{Q_1 - Q_c}{P_1} \Rightarrow Q_1 - Q_c = P_1 \tan \phi_2$$

$$Q_1 = P_1 \tan \phi_1 \quad \dots(1)$$

$$Q_1 - Q_c = P_1 \tan \phi_2 \quad \dots(2)$$

$$P_1 \tan \phi_1 - Q_c = P_1 \tan \phi_2$$

$$Q_c = P_1 \tan \phi_1 - P_1 \tan \phi_2$$

Rating of shunt capacitor to improve pf angle from ϕ_1 to ϕ_2 .

$$Q_c = P_1 [\tan \phi_1 - \tan \phi_2]$$

$$3 \frac{V_{ph}^2}{X_c} = P_1 [\tan \phi_1 - \tan \phi_2]$$

$$3 \omega C_{ph} V_{ph}^2 = P_1 [\tan \phi_1 - \tan \phi_2]$$

$$C_{ph} = \frac{P [\tan \phi_1 - \tan \phi_2]}{3 \omega V_{r(ph)}^2}$$

P = total active power

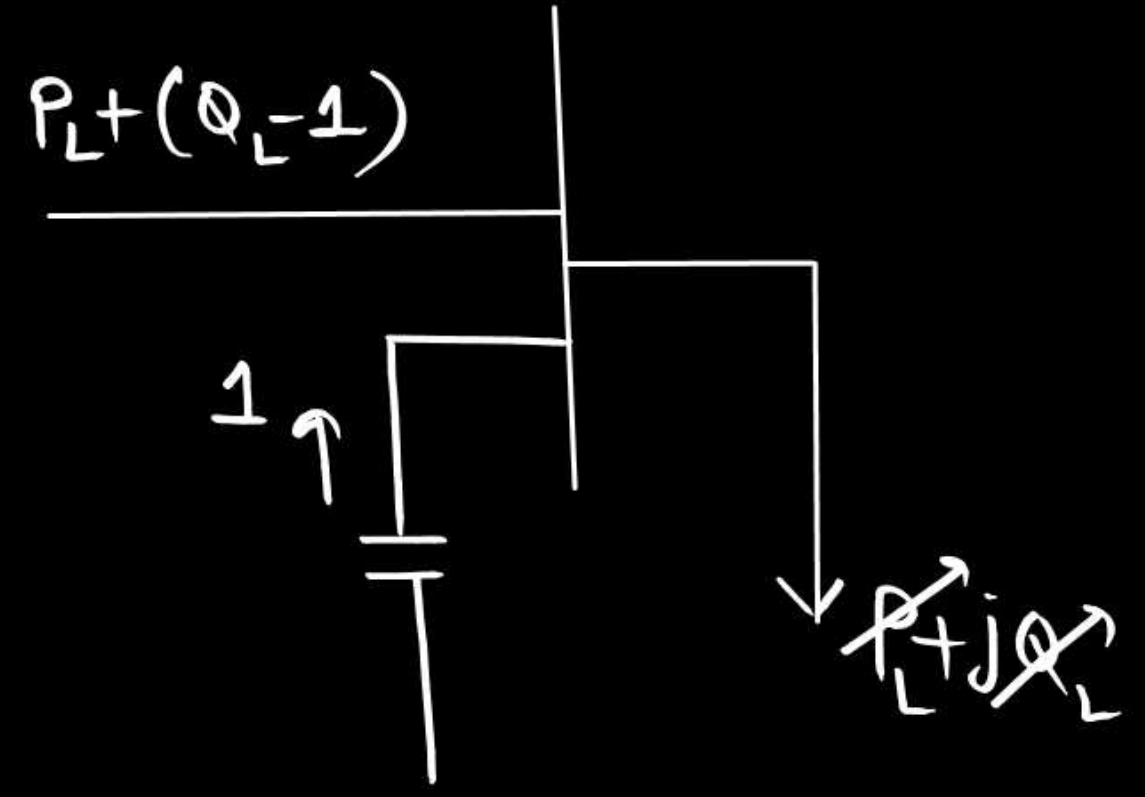
Q.



A load is supplied by a 230 V, 50 Hz source. The active power P and the reactive power Q consumed by the load are such that $1 \text{ kW} \leq P \leq 2 \text{ kW}$ and $1 \text{ kVAR} \leq Q \leq \underline{2} \text{ kVAR}$. A capacitor connected across the load for power factor correction generates 1 kVAR reactive power. The worst-case power factor after power factor correction is.

- A 0.447 lag
- B 0.707 lag
- C 0.894 lag
- D 1

P.f ↓ = $\cos \phi = \text{Min}$
 $\phi = \text{Max}^m$
 $\tan \phi = \text{Max}^m$



$$\tan \phi = \frac{Q_L - 1}{P_L} = \text{Max}$$

$$= \frac{(Q_L)_{\max} - 1}{(P_L)_{\min}}$$

$$= \frac{2 - 1}{1}$$

$$\tan \phi = 1$$

$$\phi = 45$$

$$\cos \phi = 0.707$$

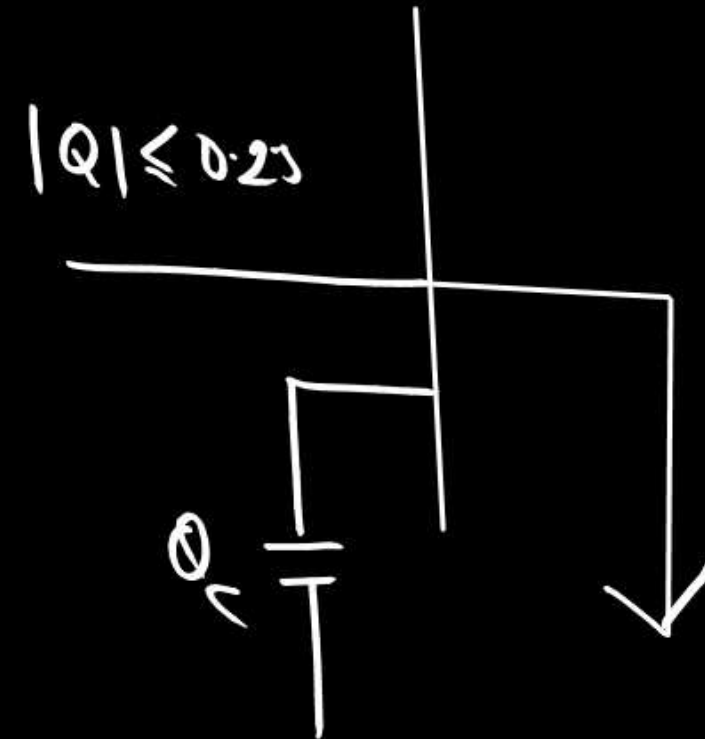
NAT

The complex power consumed by a constant voltage load is given by $(P_1 + jQ_1)$, where $1\text{ kW} \leq P_1 \leq 1.5\text{ kW}$ and $0.5\text{ kVAR} \leq Q_1 \leq 1\text{ kVAR}$. A compensating shunt capacitor is chosen such that $|Q| \leq 0.25\text{ kVAR}$, where Q is the net reactive power consumed by the capacitor load combination. The reactive power (in kVAR) supplied by the capacitor is _____

[GATE-2014-EE (Set-3) 2M]

$$|Q| \leq 0.25$$

$$-0.25 < Q < 0.25 \quad (\text{Total})$$



Load $0.5 \leq Q_1 \leq 1$

load + Capacitor

$$0.5 - Q_c \leq \underline{Q_1 - Q_c} < 1 - Q_c$$

$$\begin{cases} 0.5 - Q_c \leq Q \leq \underline{1 - Q_c} \text{ (Total)} \\ -0.25 \leq Q \leq \underline{0.25} \end{cases}$$

$$0.5 - Q_c = -0.25$$

$$\textcircled{Q_c = 0.75}$$

$$1 - Q_c = 0.25$$

$$\underline{Q_c = 0.75}$$

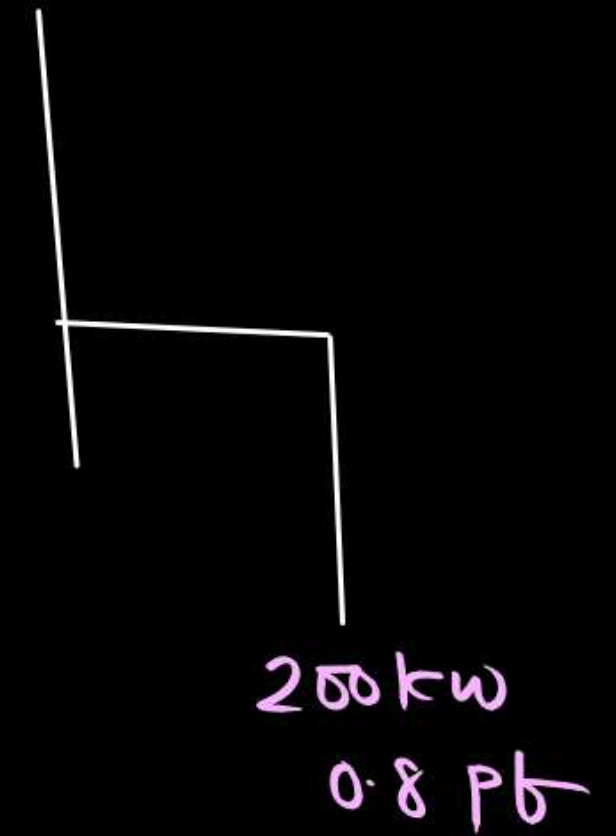
Q.



A 3 Phase 11 kV, 50 Hz 200 kW load has pf of 0.8 lag. A delta connected 3 Phase capacitor is used to improve pf to unity. The capacitance per phase of capacitor in μF is

- A 3.948
- B 1.316
- C 0.439
- D 11.844

$$\begin{aligned}\cos \phi_1 &= 0.8 \\ \phi_1 &= 36.87^\circ \\ \cos \phi_2 &= 1 \\ \phi_2 &= 0\end{aligned}$$

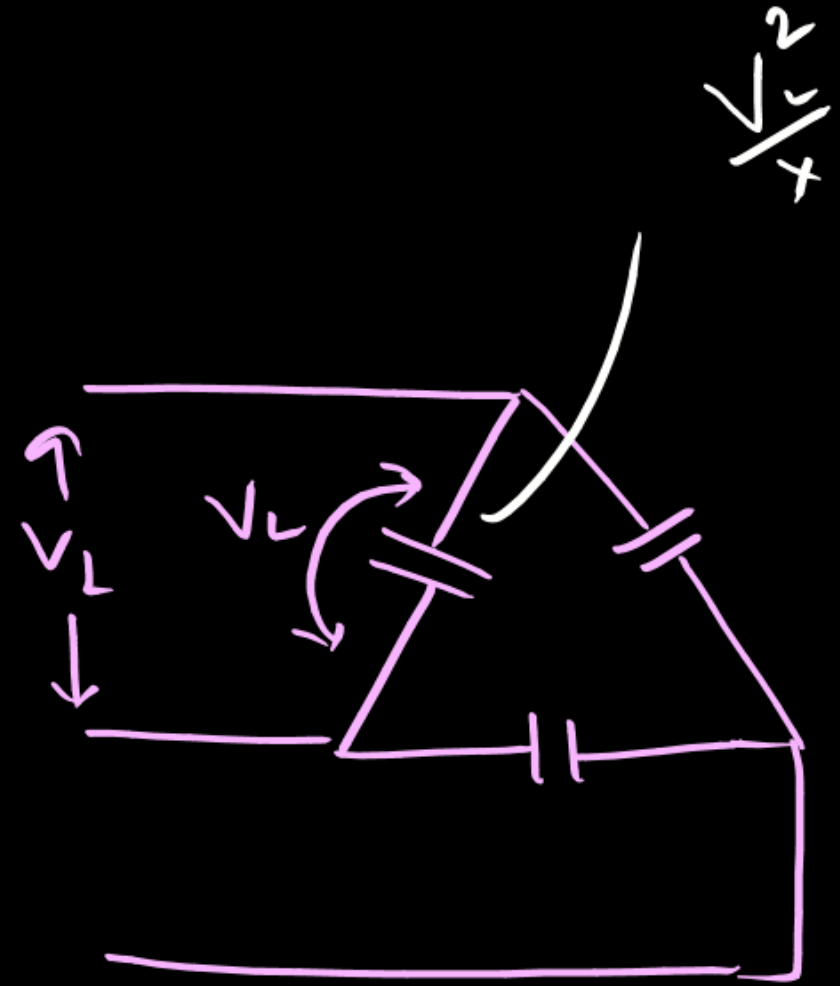


$$Q_c = P [\tan \phi_1 - \tan \phi_2]$$

$$Q_c = 250 \times 10^3 [\tan 36.87 - \tan 0]$$

$$\underline{Q_c = 150 \times 10^3 \text{ VAR}}$$

$$\text{Per phase} = \frac{150 \times 10^3}{3} = 50 \times 10^3$$



$$\frac{V_L^2}{X_C} = 50 \times 10^3$$

$$(V_{Ph} = V_L)$$

$$\frac{(11000)^2}{1} (2\pi \cdot 50) C = 50 \times 10^3$$

$$C = \frac{50 \times 10^3}{100\pi \times 121 \times 10^6}$$

$$C = \underline{1.315 \mu F}$$

Q.



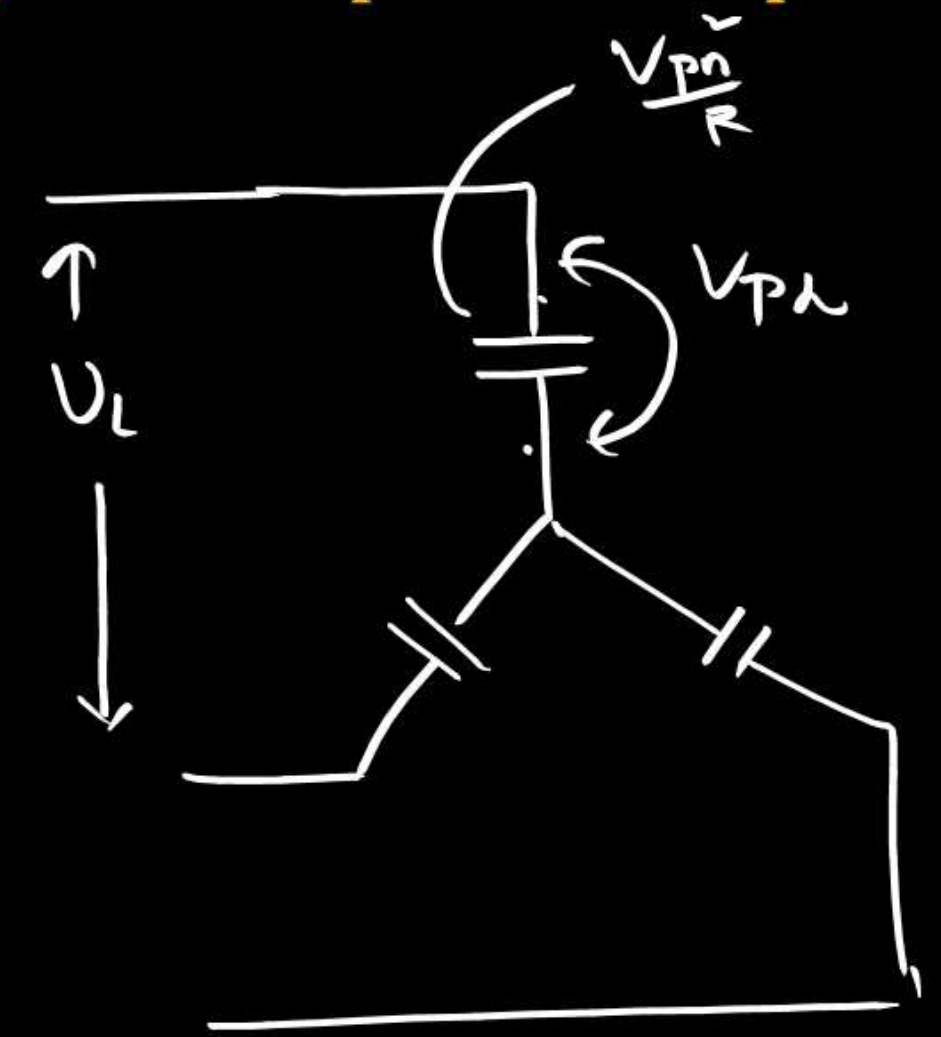
A 3 Phase 11 kV, 50 Hz ^{Y Conn} 200 kW load has pf of 0.8 lag. A star connected 3 Phase capacitor is used to improve pf to unity. The capacitance per phase of capacitor in μF is

- A 3.948
- B 1.316
- C 0.439
- D 11.844

$$\frac{V_{ph}^2}{X_c} = 50 \times 10^3$$

$$\left(\frac{11000}{\sqrt{3}} \right)^2 \omega C = 50 \times 10^3$$

$$C = \frac{50 \times 10^3 \times 3}{(11000)^2 \times (2\pi \cdot 50)} = 3.945$$



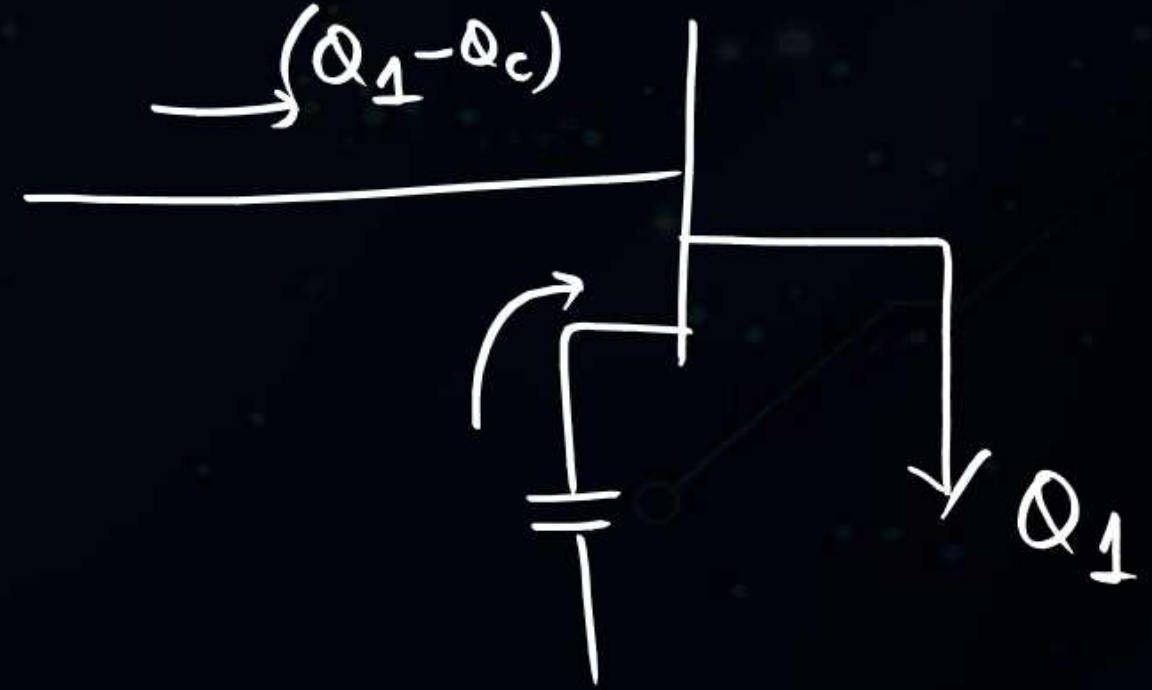


2 Minutes Summary

$$\rightarrow \underline{Q} = \underline{P} [\tan \phi_1 - \tan \phi_2]$$

$\rightarrow$ Voltage control method

$\rightarrow$ Shunt capacitor.



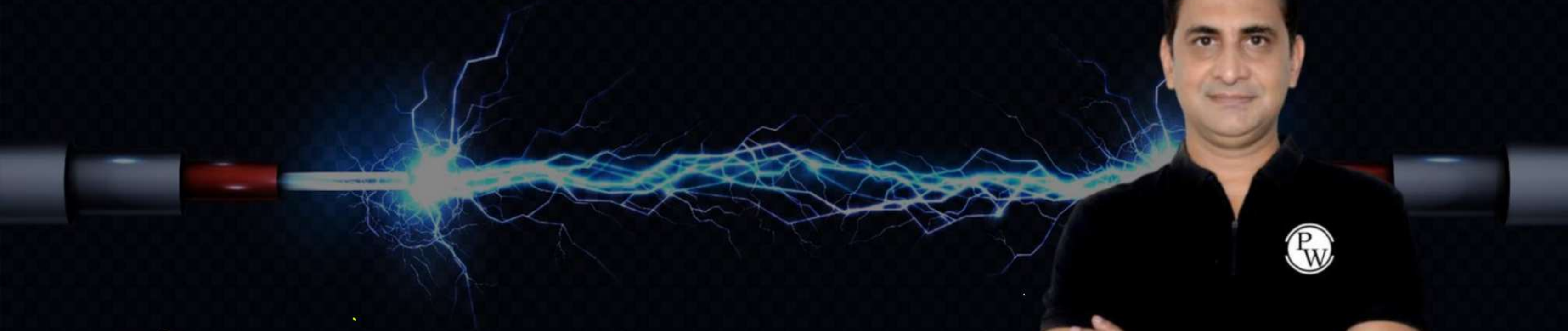
Thank you

GW
Soldiers !



Electrical Engineering

Power System



Lecture No.-2

Voltage Control



By- Ajay Gupta Sir



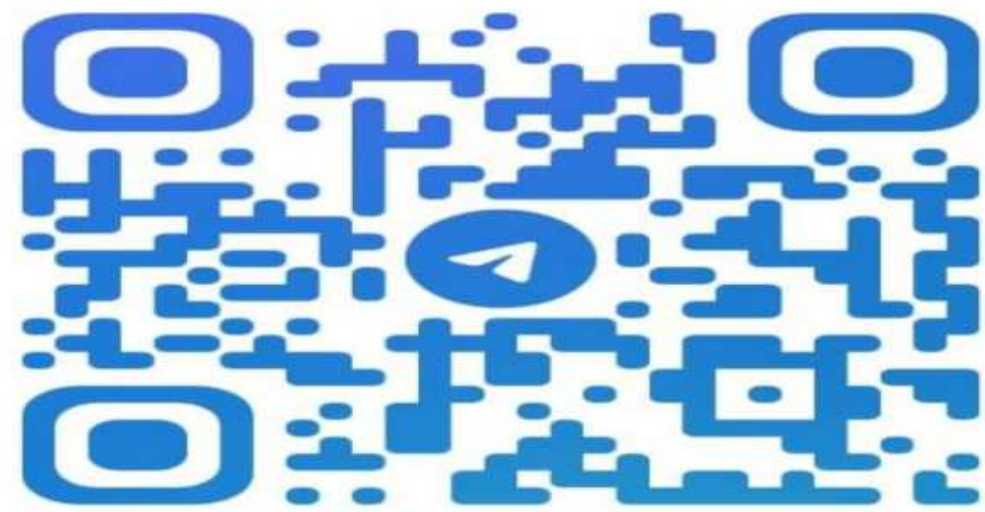
Recap Of previous class

- ✓ 1. What is voltage control
- ✓ 2. Source and sink of reactive power
- ✓ 3. Shunt Capacitor
- ✓ 4. Shunt Reactor



Topics to be Covered

- ✓ 1. Shunt reactor
- ✓ 2. Ferranti effect remover
- ✓ 3. Questions



@AJAYGUPTASIRPW

Q.



A 3 Phase 11 kV, 50 Hz 200 kW load has pf of 0.8 lag. A star connected 3 Phase capacitor is used to improve pf to unity. The capacitance per phase of capacitor in μF is

A

B

C

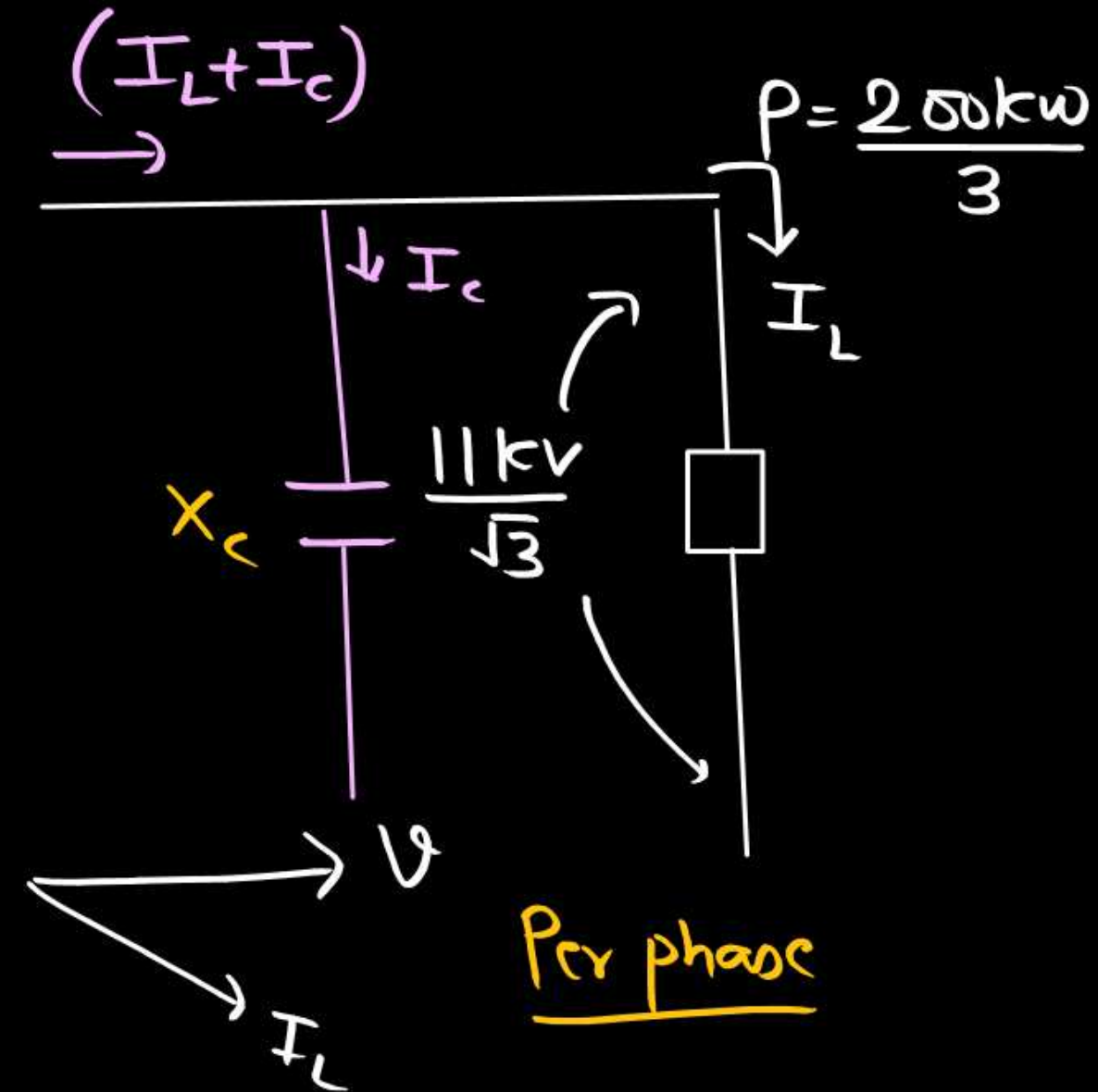
D

$$P = V_{Ph} I_{Ph} \cos \phi$$

$$\frac{200 \text{ kW}}{\sqrt{3}} = \frac{11 \text{ kV}}{\sqrt{3}} \times I \times 0.8$$

$$I = \frac{200}{\sqrt{3} \times 11 \times 0.8} = 13.12$$

$$I_L = 13.12 \angle -\cos^{-1} 0.8 = 13.12 \angle -36.87^\circ$$



$I_L + I_c$ should be in phase of V .

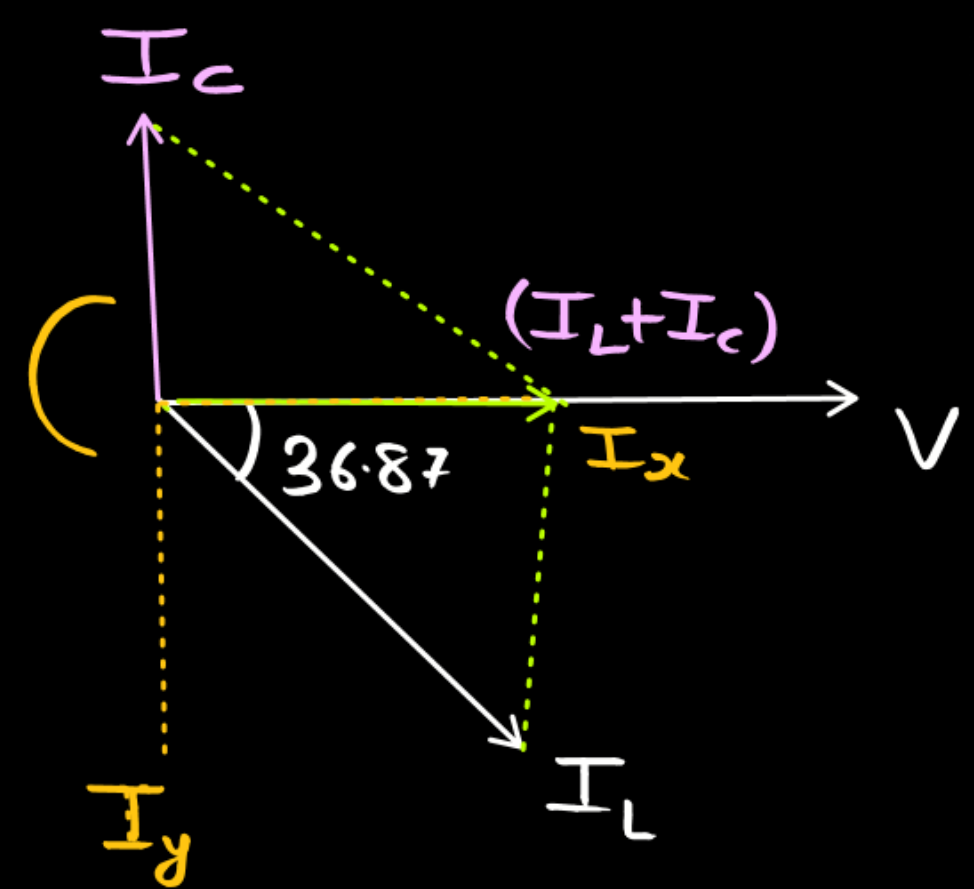
$$(\cancel{I_x} + I_y) + I_c = \cancel{I_x}$$

$$I_y = -I_c$$

$$I_L \sin 36.87 = I_c$$

$$13.12 \sin 36.87 = I_c$$

$$I_c = 7.872$$



$$X_c = \frac{V_{ph}}{I_c} = \frac{11000}{\sqrt{3} \times 7.872} = 0.806 \times 10^3$$

$$\frac{1}{\omega C_{ph}} = 0.806 \times 10^3$$

$$\frac{1}{100\pi C_{ph}} = 0.806 \times 10^3$$

$$C_{ph} = \frac{1}{100\pi \times 0.806 \times 10^3}$$

$$C_{ph} = 3.94 \times 10^{-6} \text{ F}$$

Q.

At an industrial sub-station with a 4 MW load, a capacitor of 2 MVAR is installed to maintain the load power factor at 0.97 lag. If the capacitor bank is out of service, the load power factor will be



- A** 0.8 lag
- B** 0.75 lag
- C** 0.9 lag
- D** 0.85 lag

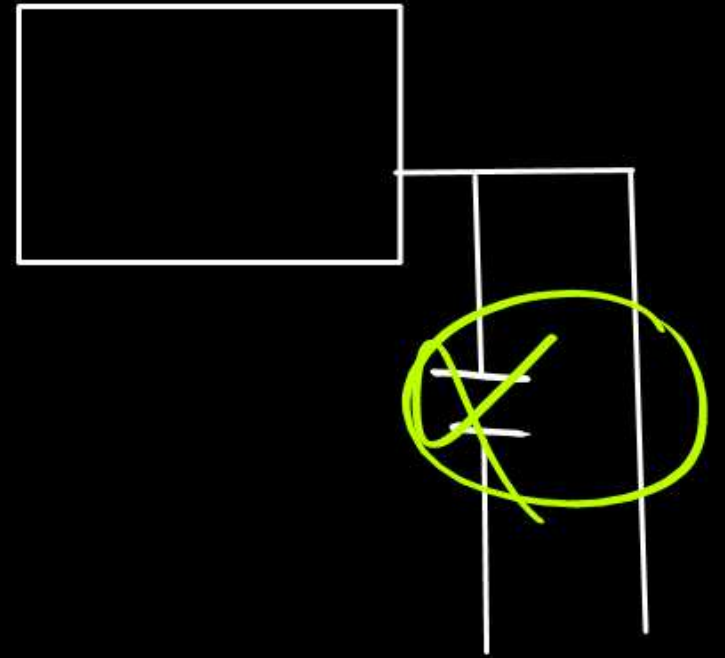
$$\phi_2 = \cos^{-1}(0.97) = \underline{14.07}$$

$$\cos \phi_1 = ?$$

$$Q_c = P [\tan \phi_1 - \tan \phi_2]$$

$$2 \times 10^6 = 4 \times 10^6 [\tan \phi_1 - \tan 14.07]$$

$$0.5 = \tan \phi_1 - 0.25$$



$$\tan \phi_1 = 0.75$$

$$\phi_1 = 36.87$$

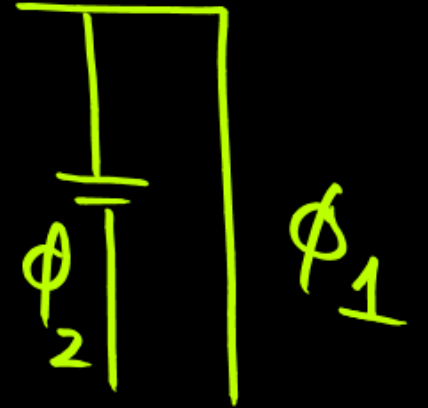
$$\cos \phi_1 = \cos 36.87 = 0.8$$

We want to improve P.f from $\cos \phi_1$ to $\cos \phi_2$

$$Q_c = P [\tan \phi_1 - \tan \phi_2]$$

ϕ_1 = P.f angle without capacitor

ϕ_2 = P.f angle with capacitor



Q.

A balanced delta connected load of $(8 + j6) \Omega$ per phase is connected to a 400 V, 50 Hz, 3-phase supply lines. If the input power factor is to be improved to 0.9 by connecting a bank of star connected capacitors the required kVAR of the bank is



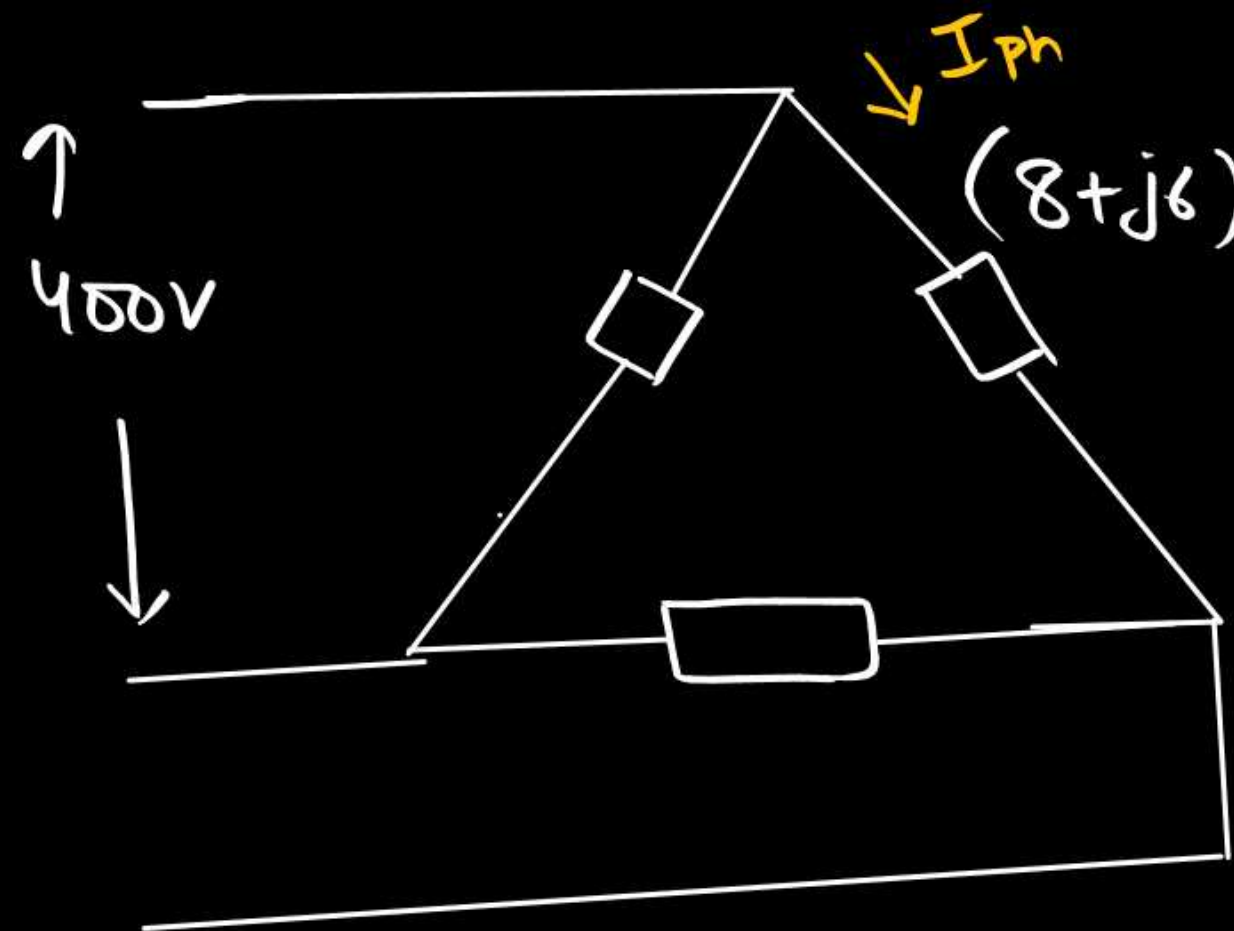
$$I_{ph} = \frac{400 \angle 0^\circ}{8 + j6} = \frac{400}{10 \angle +36.86^\circ}$$

$$I_{ph} = 40 \angle -36.87^\circ$$

$\downarrow$
 ϕ_1

$$\begin{aligned} \text{Per phase } P &= I_{ph}^2 (8) \\ &= (40)^2 (8) \end{aligned}$$

$$P = 12800$$



$$\text{Total} = 38400$$

$$\phi_1 = \cos 36.87 = 0.8$$

$$\phi_2 = \cos^{-1}(0.9) = 25.84$$

$$\underline{Q} = \underline{P} [\tan \phi_1 - \tan \phi_2]$$

$$Q = 38400 [\tan 36.87 - \tan 25.84]$$

$$Q = 1020373 \text{ VAR}$$

$$10.2 \text{ kVAR}$$

Q.

A 400 V, 50 Hz, three phase balanced source supplies power to a star connected load whose rating is $12\sqrt{3}$ KVA, 0.8 pf (lag). The rating (in KVAR) of the delta connected (capacitive) reactive power bank necessary to bring the pf to unity is



(a) 28.78

(b) 21.60

(c) 16.60

(d) 12.47

$$P = \underline{VI} \cos \phi$$

$$P = 12\sqrt{3} \times 0.8$$

$$P = 16.62 \text{ kW}$$

$$\phi_1 = \cos^{-1}(0.8) = 36.87$$

$$\phi_2 = \cos^{-1}(1)$$

$$\phi_2 = 0$$

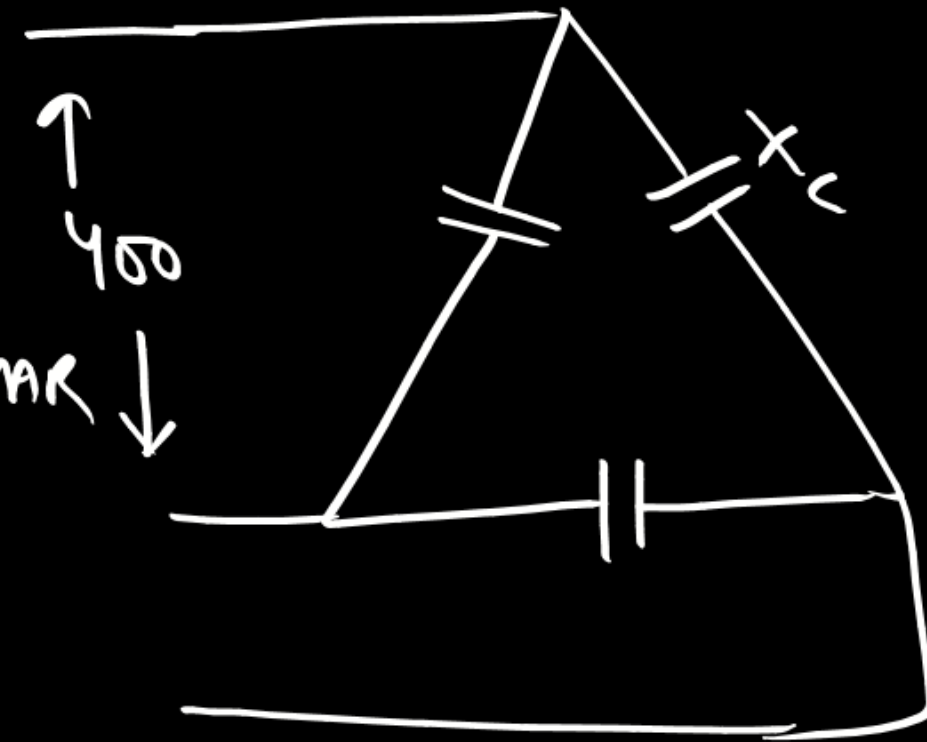
$$Q = P [\tan \phi_1 - \tan \phi_2]$$

$$= 16.62 [\tan 36.87 - \tan 0]$$

$$Q = 12.46 \text{ kVAR}$$

(11) find out per phase capacitor

$$\begin{aligned} \text{Per phase Reactive power} &= \frac{12.46}{3} \\ &= 4.153 \text{ kVAR} \end{aligned}$$



$$\frac{V_L^2}{X_C} = 4.153 \times 10^3$$

$$\frac{(400)^2}{X_C} = 4.153 \times 10^3$$

$$X_C = 38.526$$

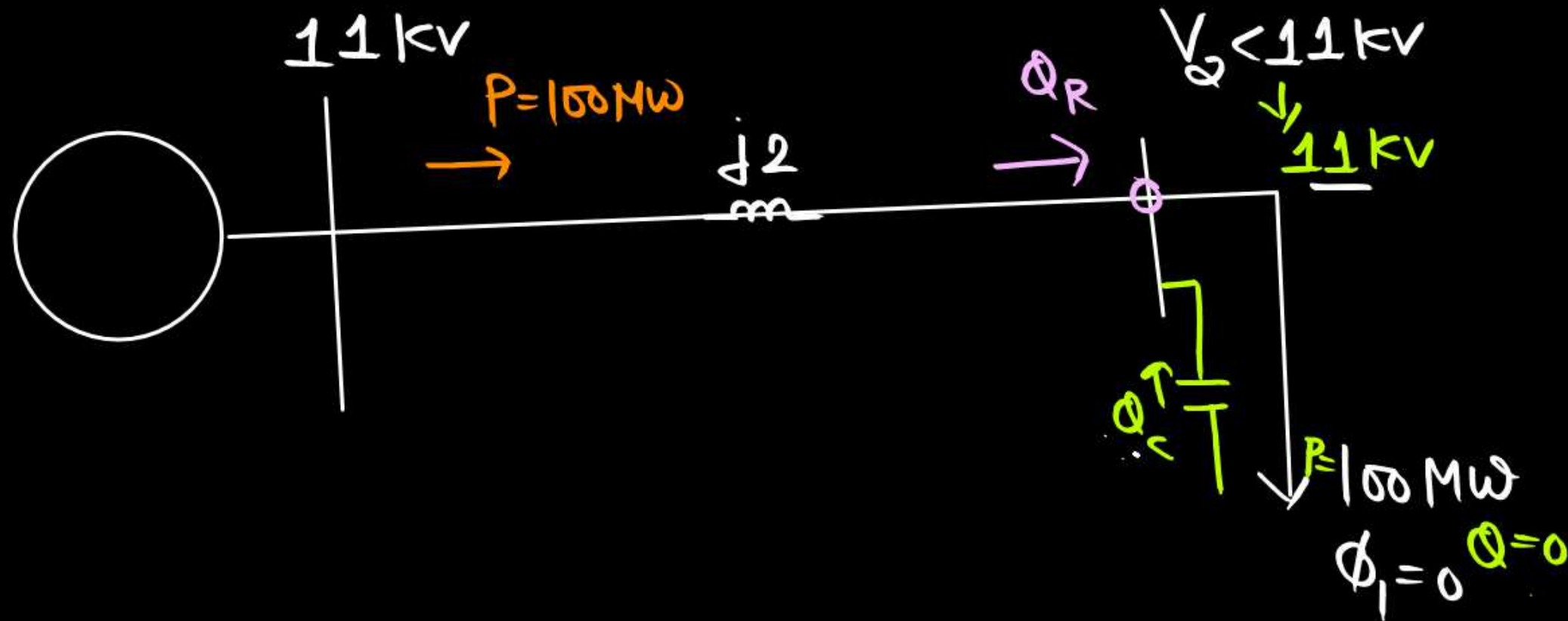
$$\frac{1}{\omega C} = 38.526$$

$$C = \frac{1}{100\pi \times 38.526} = 8.26 \times 10^{-5}$$
$$= \underline{82.6 \times 10^{-6}}$$

Q.



A 3-phase 11-kV generator feeds power to a constant power unit power factor load of 100 MW through a 3-phase transmission line. The line-to-line voltage at the terminals of the machine is maintained constant at 11 kV. The per unit positive sequence impedance of the line based on 100 MVA and 11 kV is $j0.2$. The line to line voltage at the load terminals is measured to be less than 11 kV. The total reactive power to be injected at the terminals of the load to increase the line-to-line voltage at the load terminals to 11 kV is



$$P_r = P_s = 100 \times 10^6 = \frac{V_s V_r}{X} \sin \delta$$

$$100 \times 10^6 = \frac{11 \times 10^3 \times 11 \times 10^3}{0.242} \sin \delta$$

$$\sin \delta = 0.2$$

$$\delta = 11.53^\circ$$

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

$$Q_R = \frac{11 \times 10^3 \times 11 \times 10^3}{0.242} \cos 11.53 - \frac{(11 \times 10^3)^2}{0.242} = -10.1 \times 10^6 \\ = -10.1 \text{ MVAR}$$

$$Z_B = \frac{KV^2}{MVA} = \frac{(11)^2}{100} = 1.21$$

$$X(\text{Actual}) = X_{p.u} \times Z_B$$

$$= 0.2 \times 1.21$$

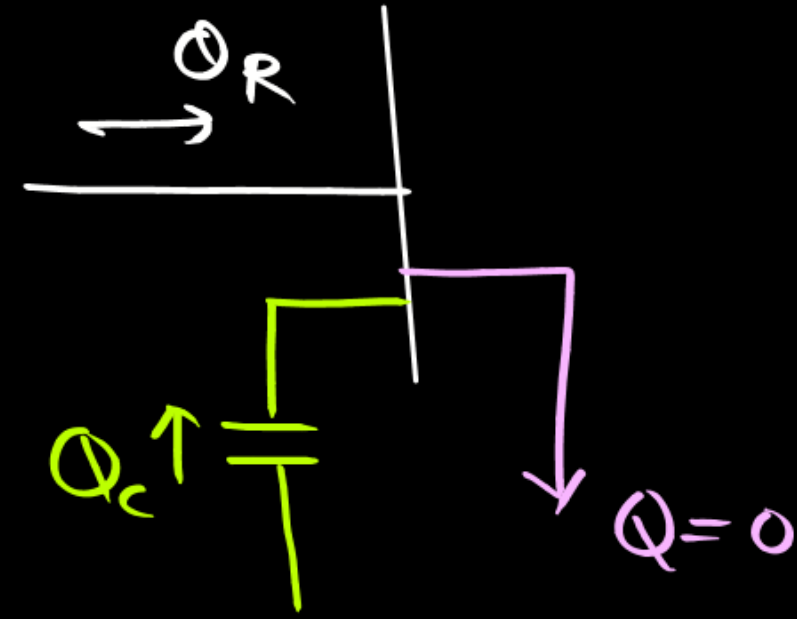
$$= 0.242 \Omega$$

$$Q_R + Q_C = 0$$

$$Q_C = -Q_R$$

$$Q_C = -(-10.1)$$

$$Q_C = 10.1$$



Q.

At an industrial sub-station with a 6 MW load, a capacitor of 2.5 MVAR is installed to maintain the load power factor at 0.90 lagging. If the capacitor goes out of service, the load power factor becomes



- (a) ~~0.85~~
- (b) ~~1.00~~
- (c) ~~0.80 lag~~
- (d) ~~0.90 lag~~

With Capacitor $\cos \phi_2 = 0.90$
 $\phi_2 = 25.84$

Without Capacitor $\cos \phi_1 = ?$

$$Q = P [\tan \phi_1 - \tan \phi_2]$$

$$2.5 = 6 [\tan \phi_1 - \tan 25.84]$$

$$0.416 = [\tan \phi_1 - 0.484]$$

$$\tan \phi_1 = 0.416 + 0.484$$

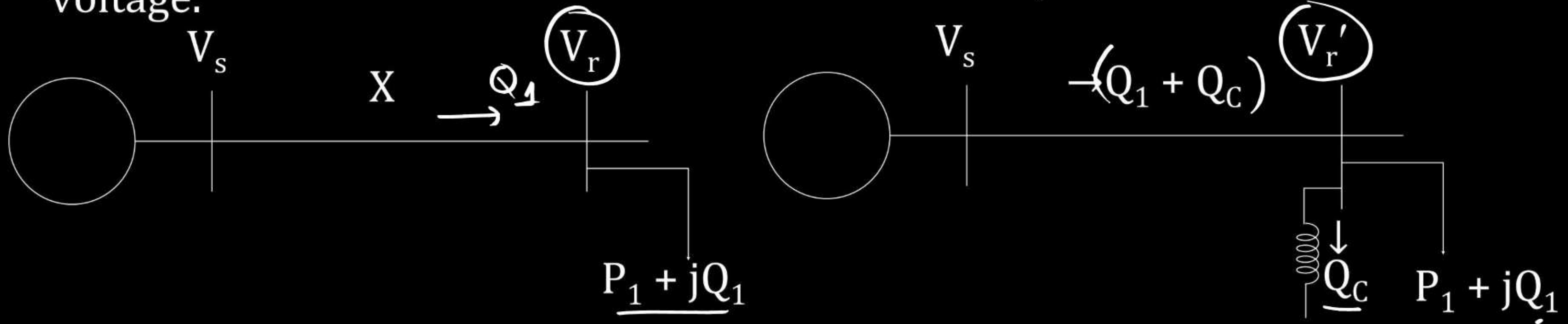
$$\tan \phi_1 = 0.9$$

$$\phi_1 = 41.98$$

$$\cos \phi_1 = \underline{0.743}$$

Shunt Reactor

It is connected across capacitive load or lightly loaded line to reduce the voltage.



Without reactor

$$\underline{V_r} = V_s - \frac{Q_1 X}{V_s}$$

...(1)

With reactor

$$V_r' = V_s - \frac{(Q_1 + Q_c) X}{V_s} = \overbrace{V_s - \frac{Q_1 X}{V_s}} - \frac{Q_c X}{V_s} \quad \text{---(11)}$$

$$V_r' = V_r - \frac{Q_c X}{V_s}$$

$$V_r - V_r' = \frac{Q_c X}{V_s}$$

$$\underline{\underline{V_r' < V_r}}$$

- So reactor will reduce the voltage
The decrement of voltage.

$$\Delta V = \frac{Q_c X}{V_s}$$

Q_c = Reactive power consumed by Compensator
(Reactor)

- So, rating of shunt reactor for decrement of ΔV voltage

$$\sqrt{Q_c} = \frac{\Delta V V_s}{X}$$

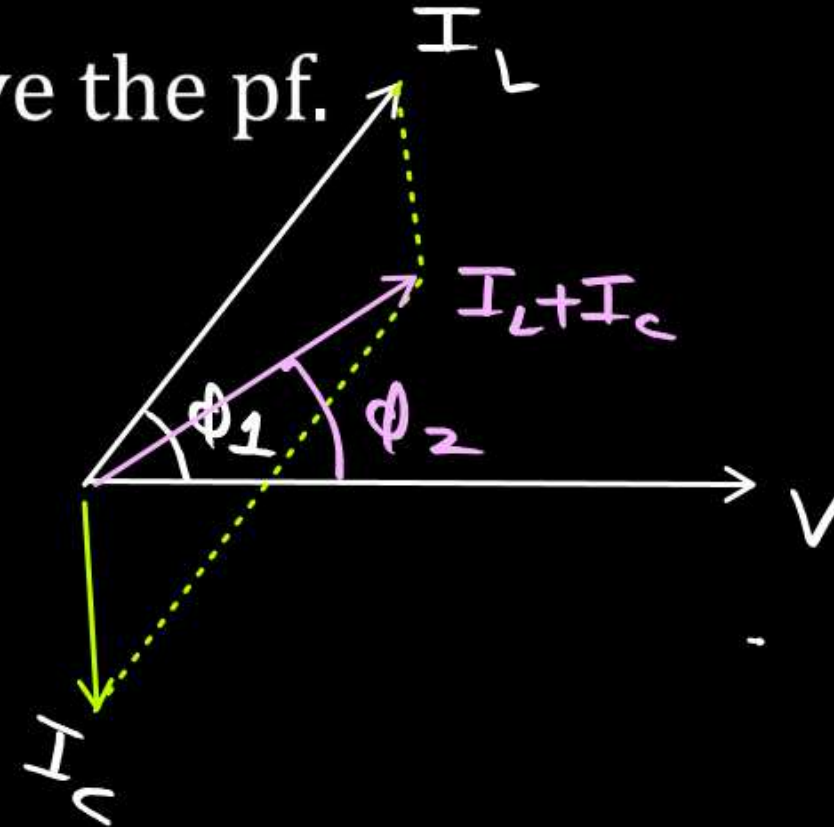
Q_c - Reactive power consumed by shunt reactor (compensator)

- For capacitive nature of load, it also improve the pf.
(leading)

$$\phi_2 < \phi_1$$

$$\cos \phi_2 > \cos \phi_1$$

$$(pf)_2 > (pf)_1$$



Note : But practically leading load does not exist, so it is not used for pf improvement.

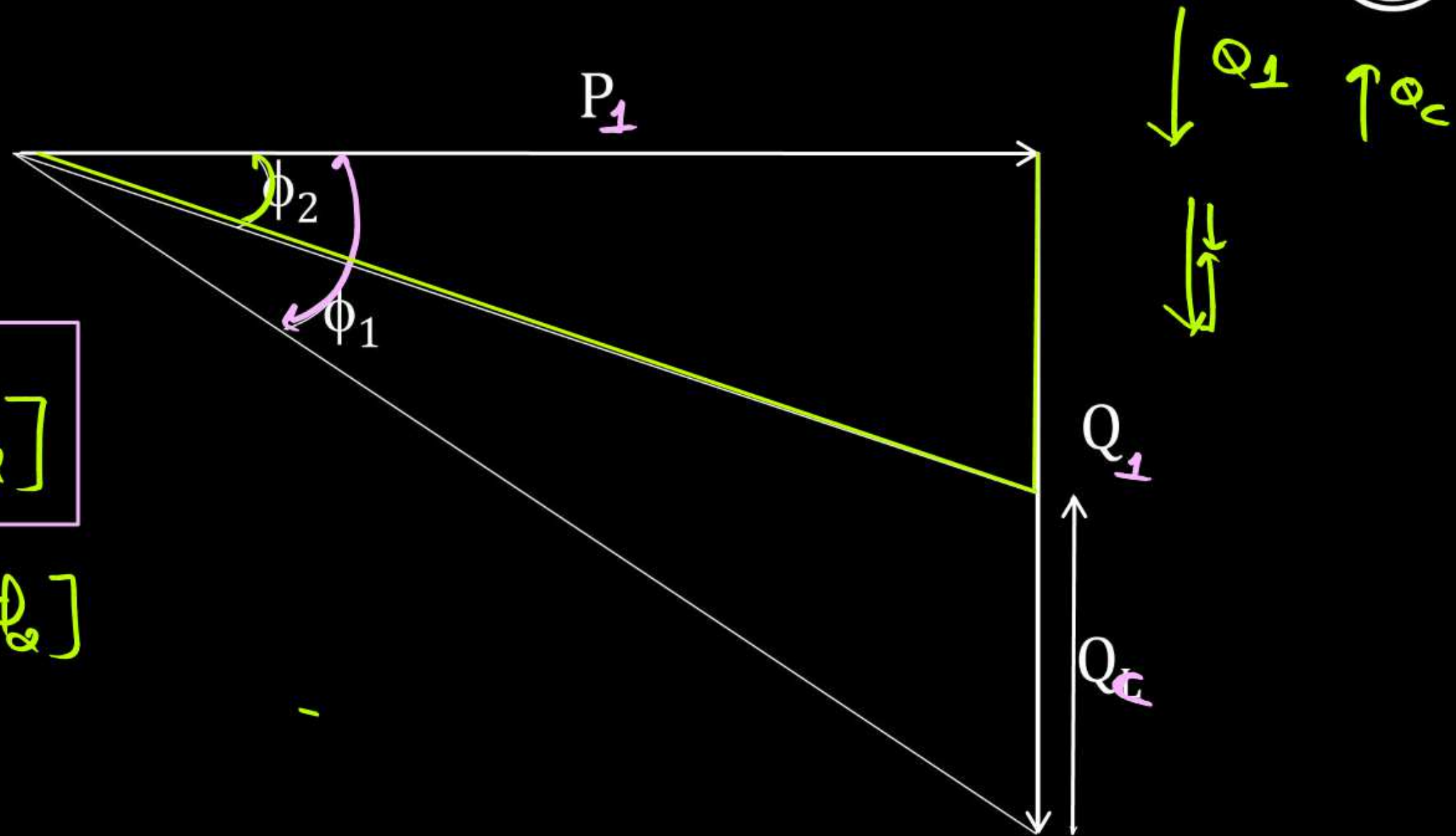
➤ As previously done

$$Q_c = P [\tan \phi_1 - \tan \phi_2]$$

$$\frac{3V^2}{X_L} = P [\tan \phi_1 - \tan \phi_2]$$

$$\frac{3V^2}{\omega L_{ph}} = P [\tan \phi_1 - \tan \phi_2]$$

$$L_{ph} = \frac{3V^2}{\omega P [\tan \phi_1 - \tan \phi_2]}$$



In real, reactor is used to limit the Ferranti effect of line rather than pf control. So, it is treated as a voltage control.

Ferranti Effect Control:

Without shunt reactor..

$$V_s = AV_r + BI_r$$

at no load $I_r = 0$, $V_r = V_{r0}$

$$V_s = AV_{r0}$$

$$V_{r0} = \frac{V_s}{A}$$

$$A < 1$$

$$V_{r0} > V_s$$

$$\frac{I_r = 0}{V_r = V_{r0}}$$

➤ With shunt reactor

$$V_R = I_R X_L \Rightarrow I_R = \frac{V_R}{jX_L}$$

$$V_S = AV_R + BI_R$$

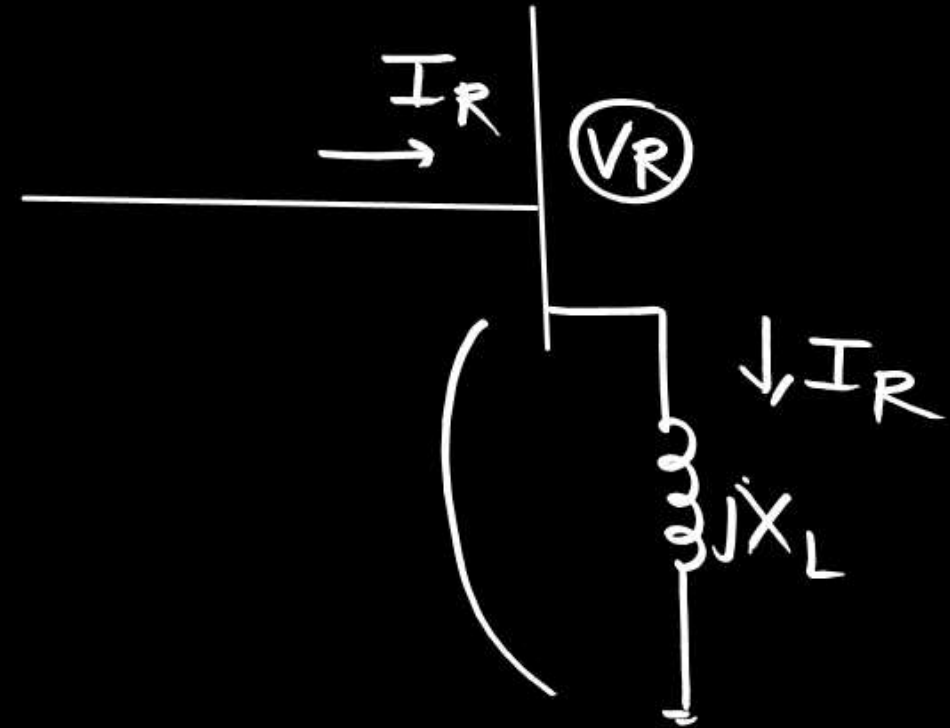
$$V_S = AV_R + B \frac{V_R}{jX_L}$$

$$V_S = V_R \left[A + \frac{B}{jX_L} \right]$$

if we want $V_S = V_R$

➤ To remove Ferranti effect,

$$\left[A + \frac{B}{jX_L} = 1 \right]$$



^{Normally:}
for short line, $\angle A = \alpha = 0$ $\angle \beta = 90 = j$

$$|A| + \frac{|B|}{X_L} = 1 \Rightarrow |A| + \frac{|B|}{x_L} = 1$$

$$\frac{|B|}{X_L} = 1 - |A|$$

$X_L = \frac{|B|}{1 - |A|}$

 $\rightarrow$ to Make $V_r = V_s$.



$$A = 1 = |A| \angle \alpha$$

$$|A| = 1, \alpha = 0$$

$$B = Z = |Z| \angle \theta = x \angle 90$$

$$|B| = x \quad \beta = 90 = j$$

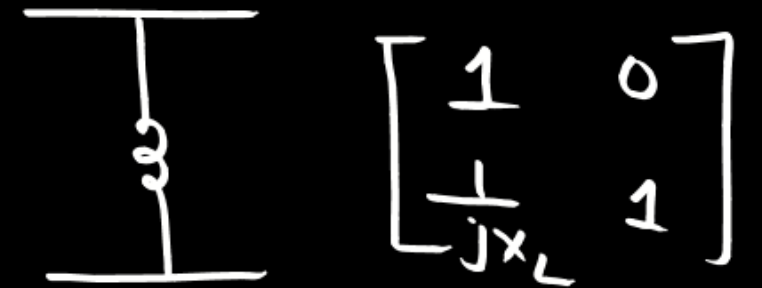
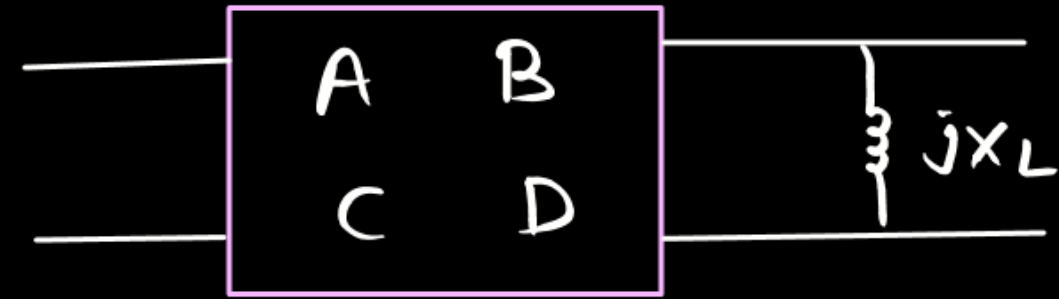


II Method

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_{\text{Overall}} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} 1 & 0 \\ \frac{1}{jX_L} & 1 \end{bmatrix}$$

$$= \begin{bmatrix} A + \frac{B}{jX_L} & B \\ C + \frac{D}{jX_L} & D \end{bmatrix}$$

$$A_{\text{Overall}} = A + \frac{B}{jX_L}$$



$$V_{x0} = \frac{V_s}{A} \quad \text{To Make } V_s = V_{x0} \Rightarrow A = 1$$

$$A + \frac{B}{jX_L} = 1$$

Q.



A shunt reactor of 100 MVAR is operated at 98% of its rated voltage and at 90% of its rated frequency. The reactive power absorbed by the reactor is

- A 98 MVAR
- B 104.02 MVAR
- C 96.04 MVAR
- ☒ D None

$$Q = \frac{V^2}{X} = \frac{V^2}{\omega L} = \frac{V^2}{2\pi f L} \propto \frac{V^2}{f}$$

$$\frac{Q_1}{Q_2} = \frac{V_1^2}{f_1} \times \frac{f_2}{V_2^2}$$

$$\frac{100}{Q_2} = \frac{V_1}{(0.98V_1)^2} \times \left(\frac{0.9f_1}{f_1} \right)$$

$$\frac{100}{Q_2} = 0.937 \quad Q_2 = \frac{100}{0.937} = 106.72$$



2 Minutes Summary

→ Shunt Reactor

→ Question.

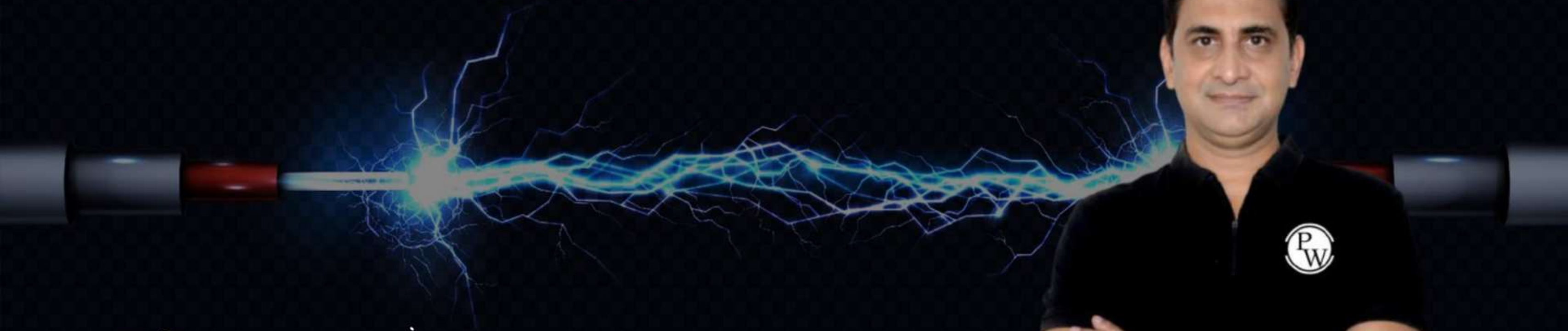
Thank you

GW
Soldiers !



Electrical Engineering

Power System



Lecture No.-3

Voltage Control

By- Ajay Gupta Sir



Recap Of previous class

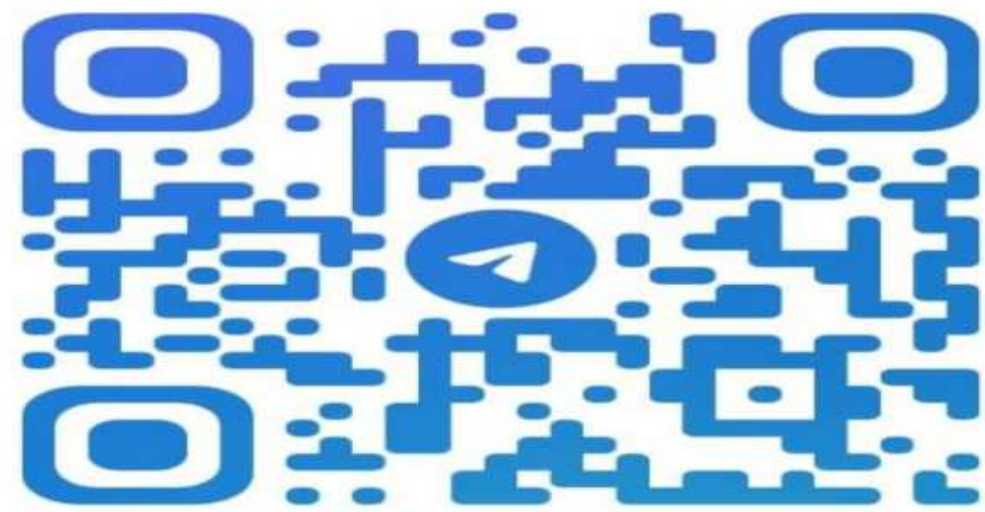
1. Shunt compensator

2. Question



Topics to be Covered

1. Series capacitor
2. Sub synchronous resonance
3. Synchronous Condensor



@AJAYGUPTASIRPW

Q.



The ABCD parameters of a 3-phase overhead transmission line are $A = D = 0.9 \angle 0^\circ$, $B = 200 \angle 90^\circ \Omega$ and $C = 0.95 \times 10^{-3} \angle 90^\circ \text{ S}$. At no-load condition a shunt inductive reactor is connected at the receiving end of the line to limit the receiving-end voltage to be equal to the sending-end voltage. The ohmic value of the reactor is

- A** $\infty \Omega$
- B** ☒ 2000Ω
- C** 105.26Ω
- D** 1052.6Ω

$$X_L = \frac{|B|}{1 - |A|} = \frac{200}{1 - 0.9} = \frac{200}{0.1} = 2000$$

MCQ



The inductance and capacitance of a 400 kV, 3 – ϕ , 50 Hz lossless transmission line are 1.6 mH/km/phase and 10 nF/km/phase respectively. The sending end voltage is maintained at 400 kV. To maintain a voltage of 400 kV at the receiving end, when the line is delivering 300 MW load, the shunt compensation required is

[GATE-2016-EE (Set-2) 1M]

- ☐ A capacitive
- ☐ B inductive
- ☐ C resistive
- ☐ D zero

$$Z_s = \sqrt{\frac{L}{C}} = \sqrt{\frac{1.6 \times 10^{-3}}{10 \times 10^{-9}}} = 400 \Omega$$

$$QIL = \frac{V_L^2}{Z_s} = \frac{(400 \times 10^3)^2}{400} = 400 \times 10^6 = 400 \text{ MW}$$

Actual loading (300 MW) < SIL (400 MW)

So line is lightly loaded. So ferranti effect occur which make $V_r > V_s$.

So we have to reduce $V_r \Rightarrow$ Shunt Reactor

Q.



A load draws 100 kvar at 0.7 p.f. lagging from a 3-phase, 11 kV supply. It is desired to raise the p.f. to 0.95 lagging using shunt capacitors. Calculate the rating of the capacitor required. (KVAR)

$$\text{For load } \tan \phi = \frac{Q}{P}$$

$$\phi = \cos^{-1} 0.7$$

$$\phi = 45.57$$

$$\tan 45.57 = \frac{100}{P}$$

$$P = 98.03 \text{ kW (load power)}$$

$$\phi_2 = \cos^{-1} 0.95 = 18.19$$

$$Q = P[\tan \phi_1 - \tan \phi_2]$$

$$Q = 98.03 [\tan 45.57 - \tan 18.19]$$

$$Q = 67.78 \text{ kVAR}$$

$$\approx \underline{68}$$

MCQ



Shunt reactors are sometimes used in high voltage transmission systems to

[GATE-2014-EE (Set-2) 1M]

- A** limit the short circuit current through the line.
- B** compensate for the series reactance of the line under heavily loaded condition.
- C** limit over voltages at the load side under lightly loaded condition.
- D** compensate for the voltage drop in the line under heavily loaded condition.

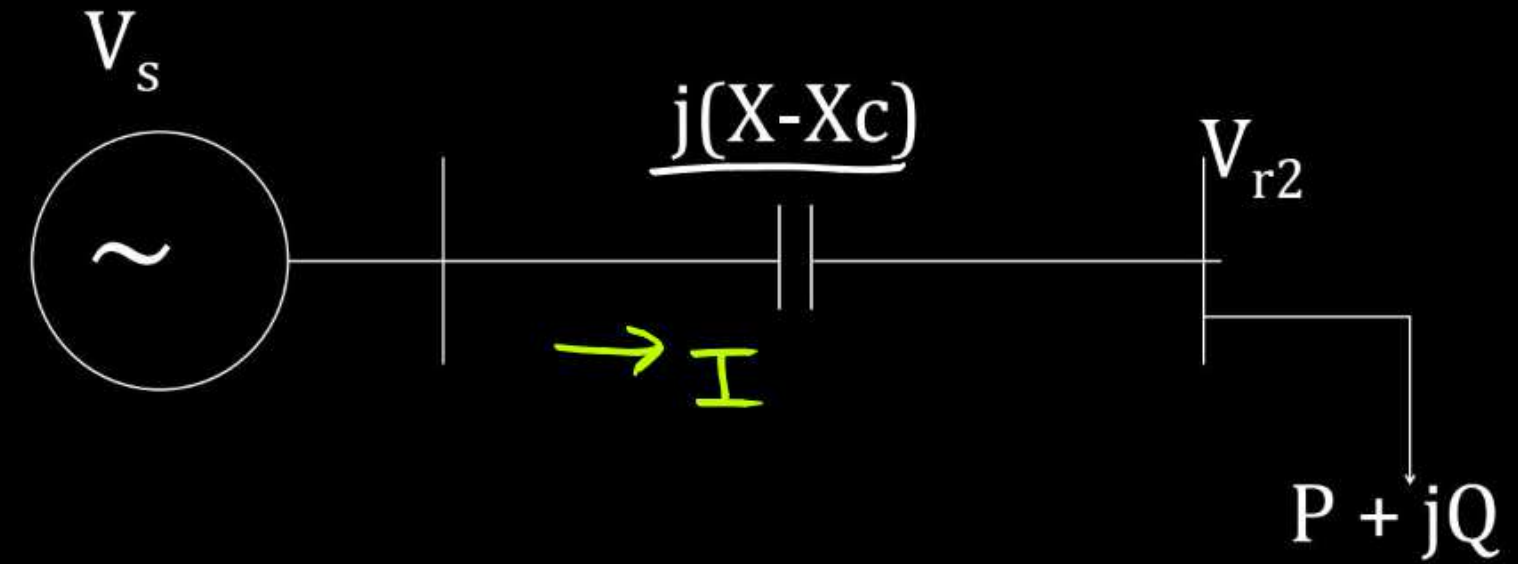
Series Compensator:

Series capacitor:



Series Compensator →

Series Capacitor →



jX = Reactance of transmission line $-jX_c$ = reactance of capacitor.

- If we connect series capacitor, it reduce the inductive reactance of T.L., so voltage drop is reduced.

Without Series Capacitor

$$|V_s| - |V_{r1}| = |I| R \cos \phi_r + |I| X \sin \phi_r \quad \text{if } R \ll X$$

$$|V_s| - |V_{r1}| = I X \sin \phi_r \quad \dots(1)$$

With series capacitor

$$|V_s| - |V_{r2}| = I(X - X_c) \sin \phi_r \quad \dots(2)$$

Subtracting equation (2) from equation (1)

$$|V_{r2}| - |V_{r1}| = I X_c \sin \phi_r \quad (V_{r2} > V_{r1})$$

So, change in voltage

$$\Delta V = I X_c \sin \phi_r \Rightarrow I X_c = \frac{\Delta V}{\sin \phi_r}$$

- So, series capacitor is also called voltage booster.
- So, rating of series capacitor to change the voltage ΔV

$$Q_c = 3I^2 X_c$$

$$= 3I(X_c I)$$

$$Q_c = 3 \frac{\Delta V}{\sin \phi} \cdot I$$

- Degree of series compensator = $\frac{X_c}{X} \times 100\%$

Comparison between series and shunt capacitor:

- If voltage to increase by ΔV , so rating of shunt capacitor required

$$Q_{Sh} = \frac{V_s \Delta V}{X} \text{ per phase.}$$

For same amount of voltage boost up, the rating of series capacitor

$$Q_{Se} = \frac{\Delta V I}{\sin \phi} \text{ per phase.}$$

$$\frac{Q_{Sh}}{Q_{Se}} = \frac{V_s \cancel{\Delta V}}{X} \cdot \frac{\cancel{\sin \phi}}{\cancel{\Delta V} I} = \frac{V_s}{I} \cdot \frac{\sin \phi}{X}$$

$$\frac{Q_{sh}}{Q_{se}} = \frac{Z_B \sin \phi}{X}$$

$$\frac{Q_{sh}}{Q_{se}} = \frac{\sin \phi}{X_{p.u.}} = \frac{0.6}{0.1}$$

$$Q_{sh} = 6 Q_{se}$$

$$\frac{V_s}{I} = Z_B$$

$$\frac{X}{Z_B} = X_{p.u.}$$

Normally $\cos \phi = 0.8$

$$\sin \phi = \sqrt{1 - \cos^2 \phi} = 0.6$$

$$X_{p.u.} = 0.1 \text{ p.u.}$$

➤ 1/ So, for same voltage boost up, the rating of shunt capacitor is more than rating of series capacitor. P
W

➤ But at high current, series capacitor may be damaged. So, it should be protected, which will increase cost of protection system.

➤ For shunt capacitor,

$$\text{Voltage drop} = \underline{IX} \sin \phi_r$$

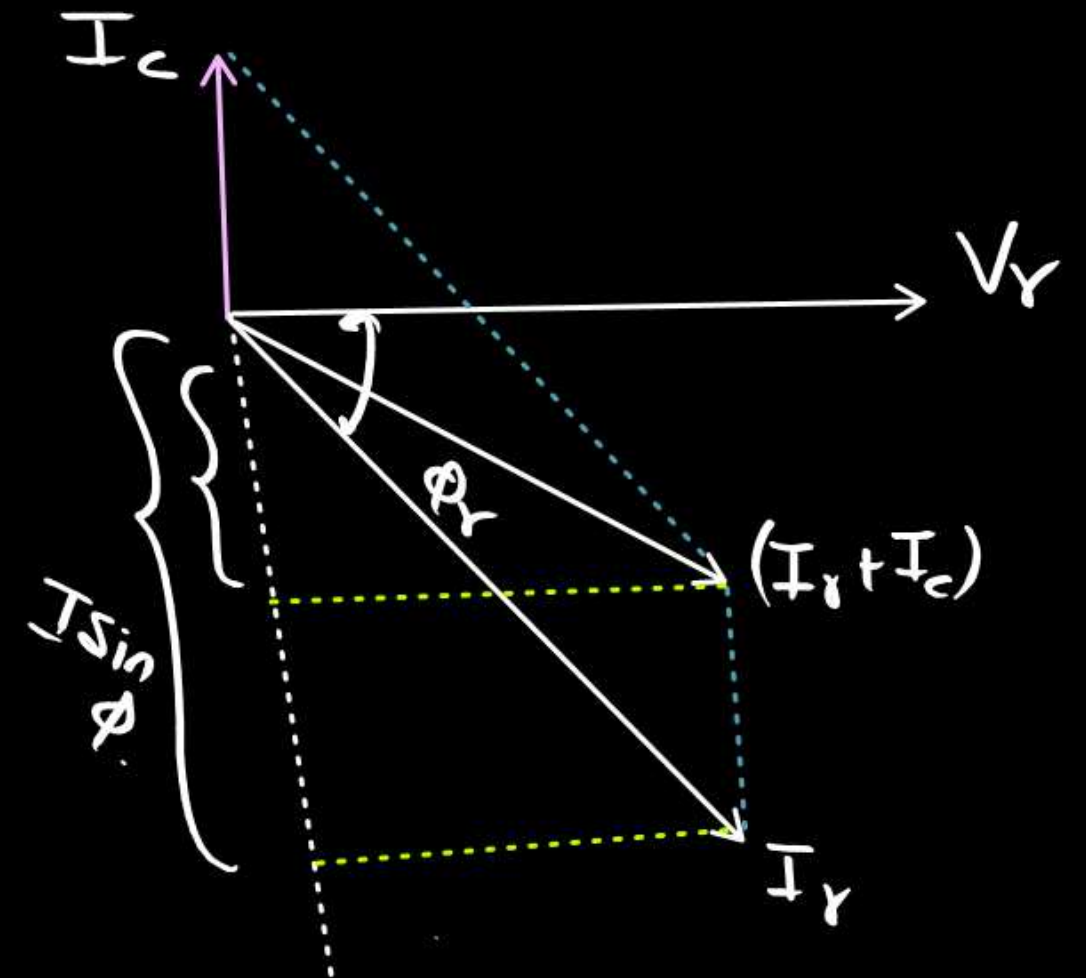
$$X \propto \text{length}$$

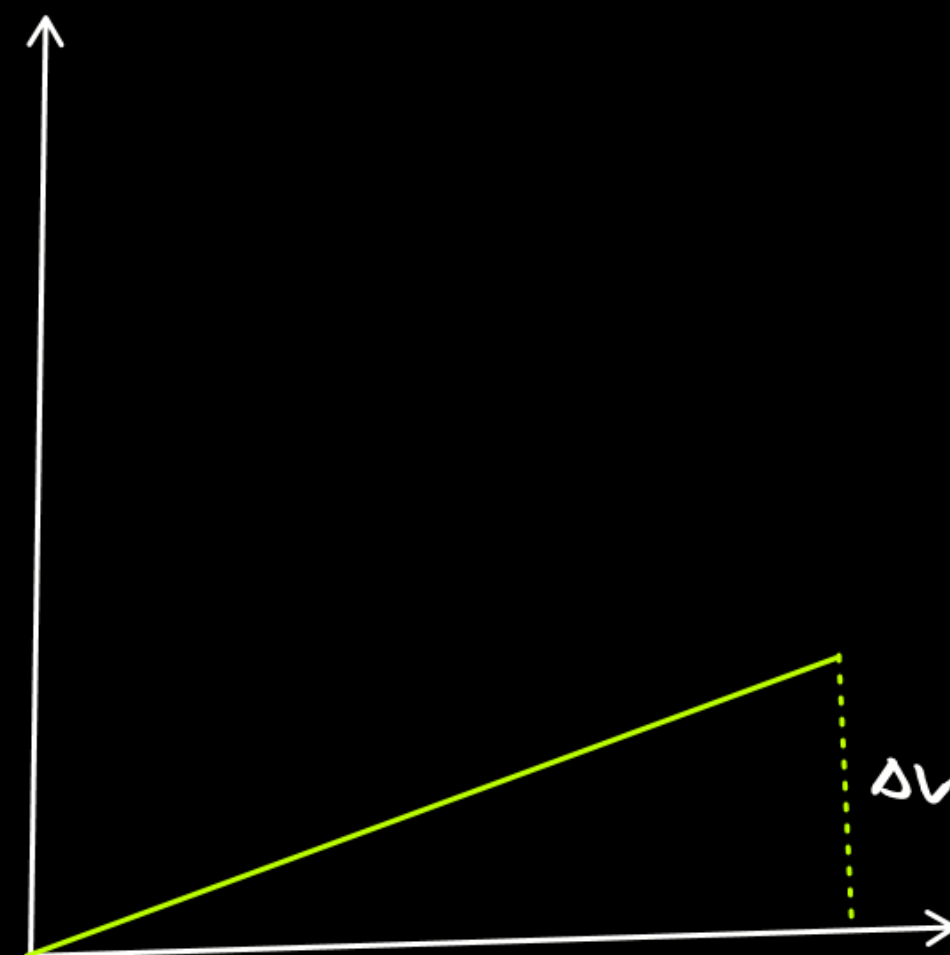
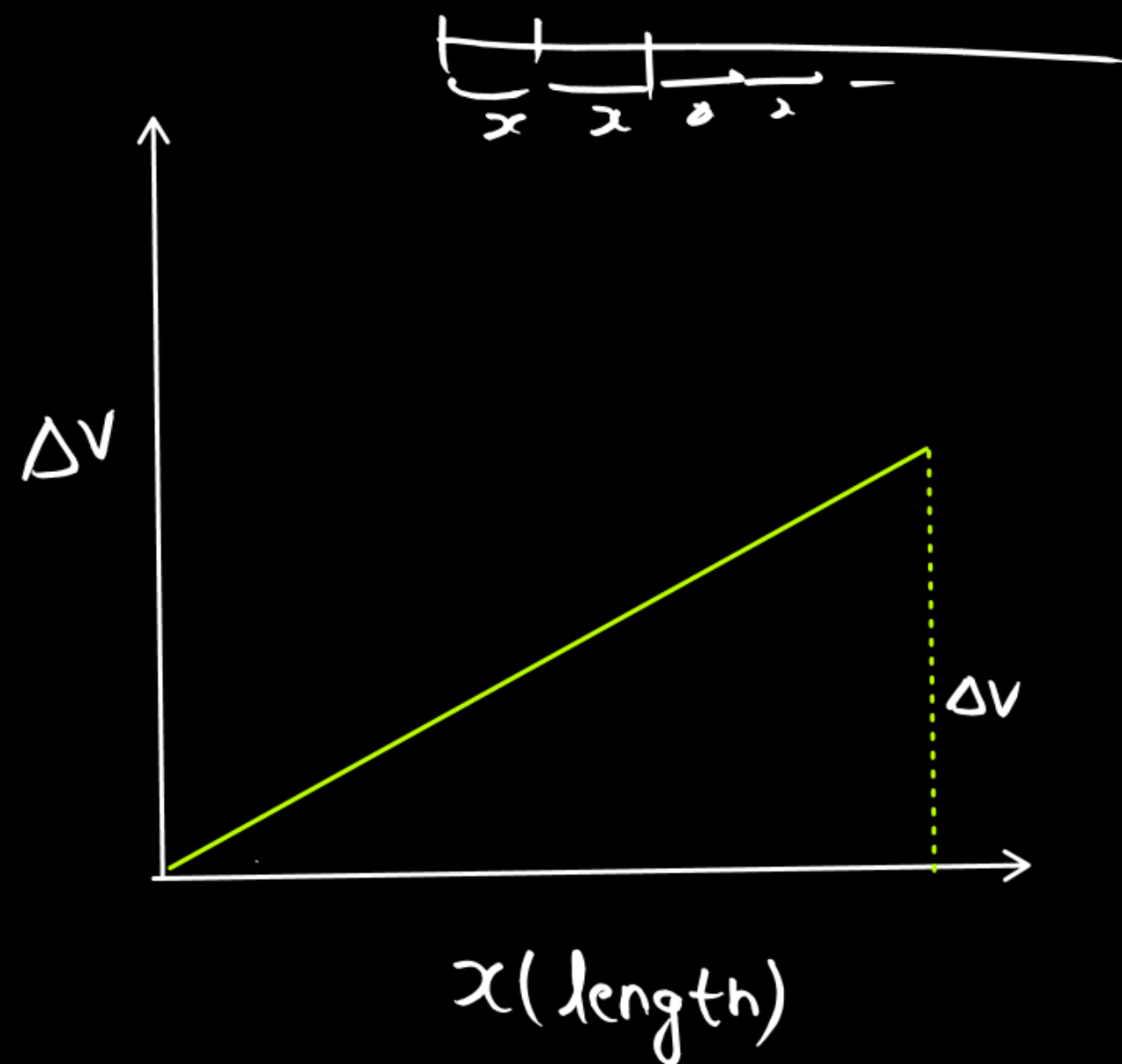
$$\Delta V = I (\text{length}) \cdot \sin \phi$$

$$\frac{\Delta V}{\text{length}} = I \sin \phi$$

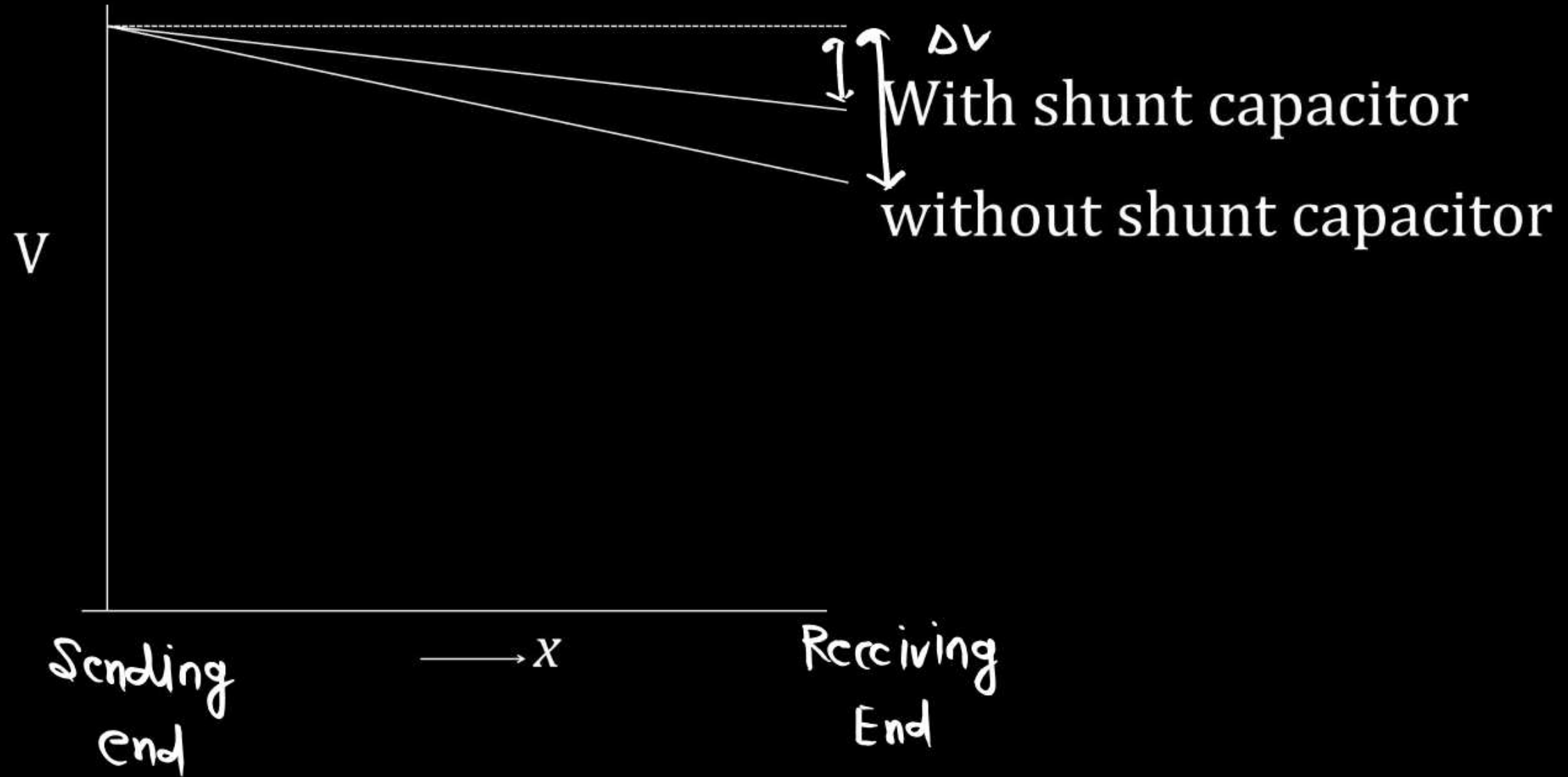
Since $I \sin \phi$ reduce, when apply shunt capacitor.

$$L = m + 1 \text{ km}$$

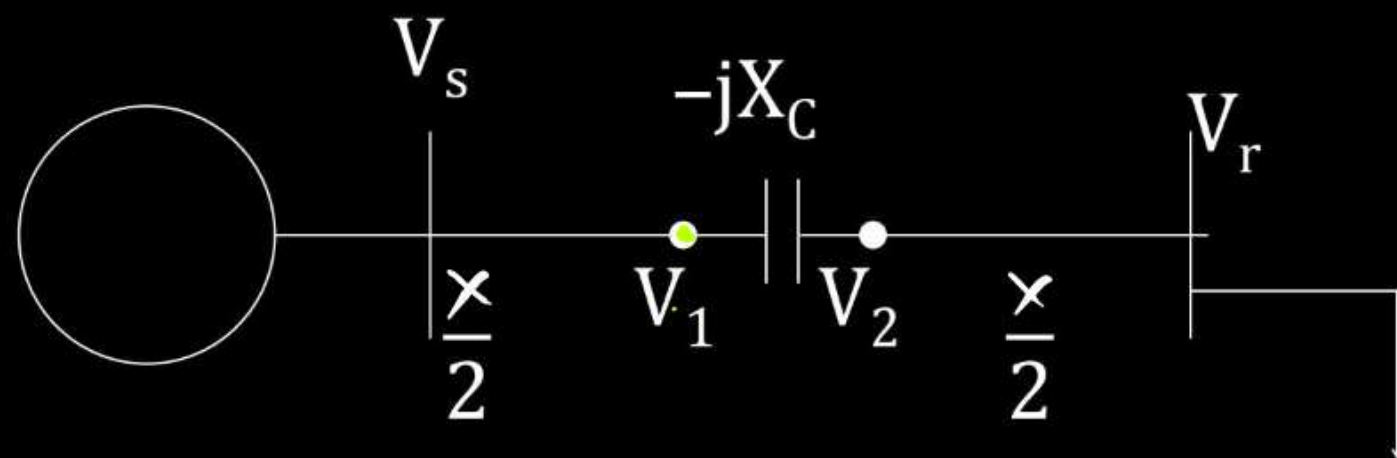




- So, by use of shunt capacitor, $I \sin \phi$ is reduce, so slope of line is also reduce. 



➤ Incase of series capacitor

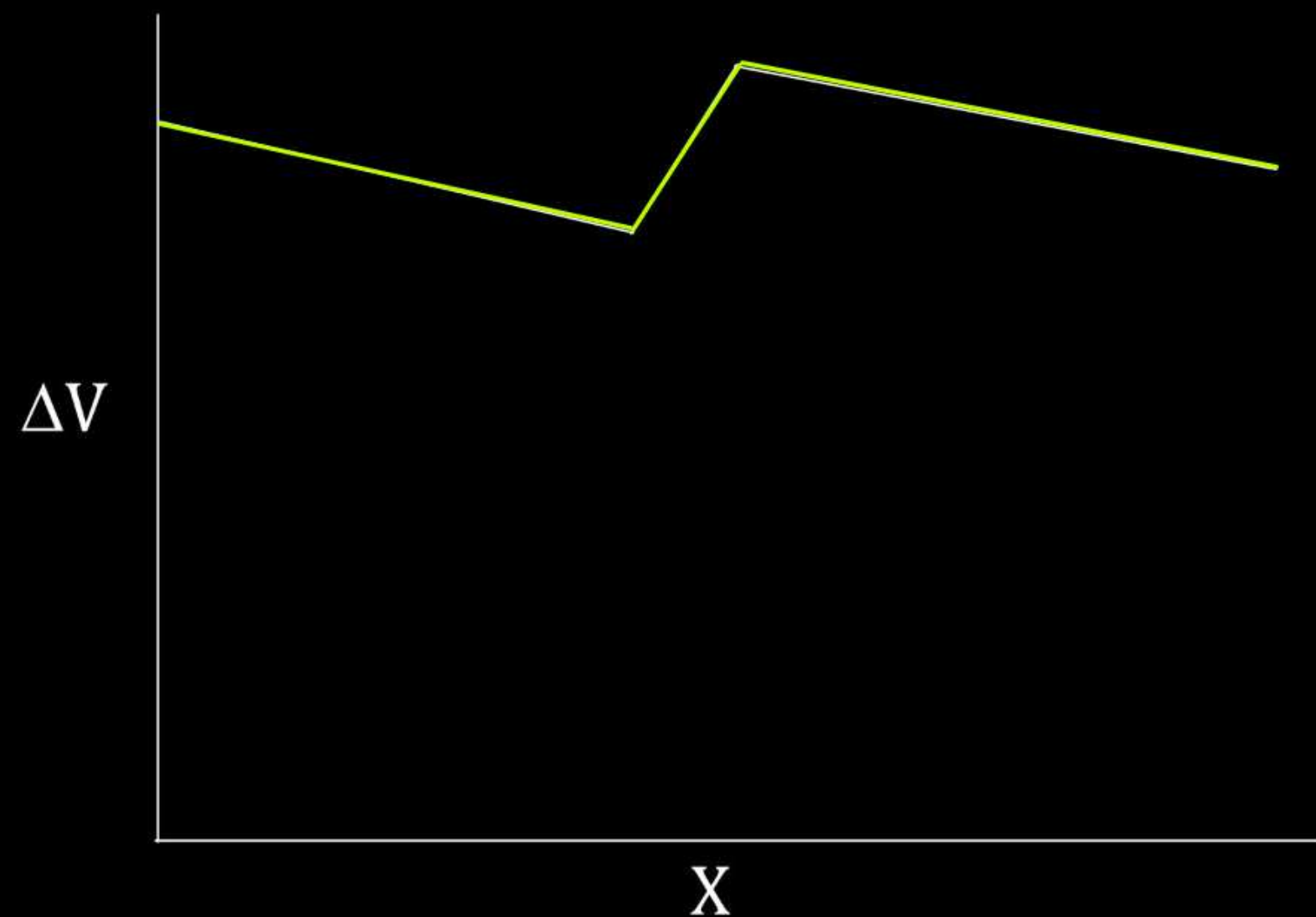


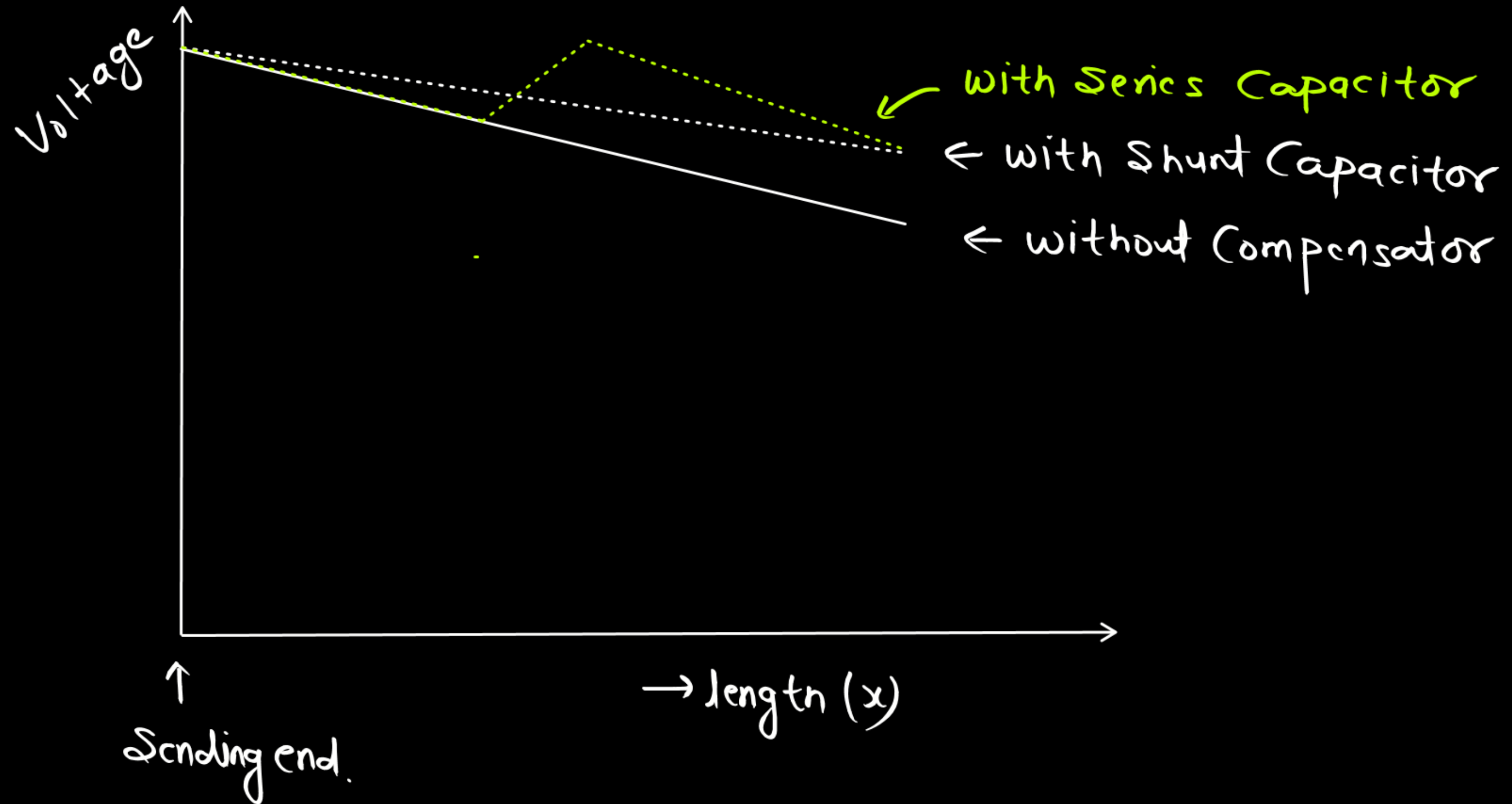
$$\rightarrow V_1 = V_s - I \left(\frac{X}{2} \right) \sin \phi_r$$

$$\rightarrow V_2 = V_1 - I (-X_c) \sin \phi_r$$

$$V_2 = V_1 + I X_c \sin \phi_r$$

$$\rightarrow V_r = V_2 - I \left(\frac{X}{2} \right) \sin \phi_r$$





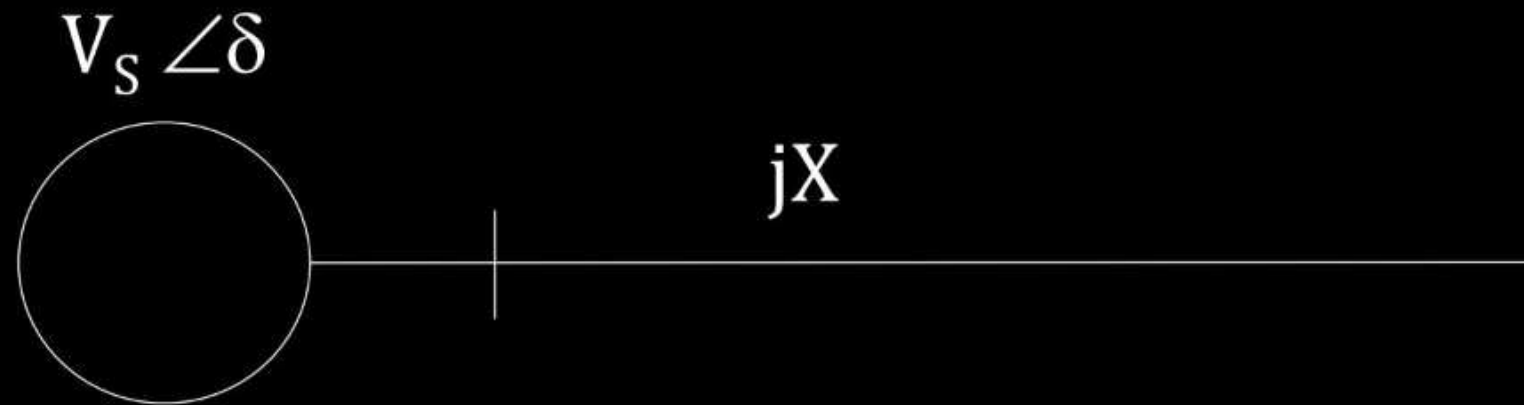
27 So change in Voltage is more uniform with Shunt Capacitor than Series capacitor.

(3) Series capacitor also improve steady state stability limit

$$\text{Before capacitor} = \frac{|V_s| |V_r|}{X}$$

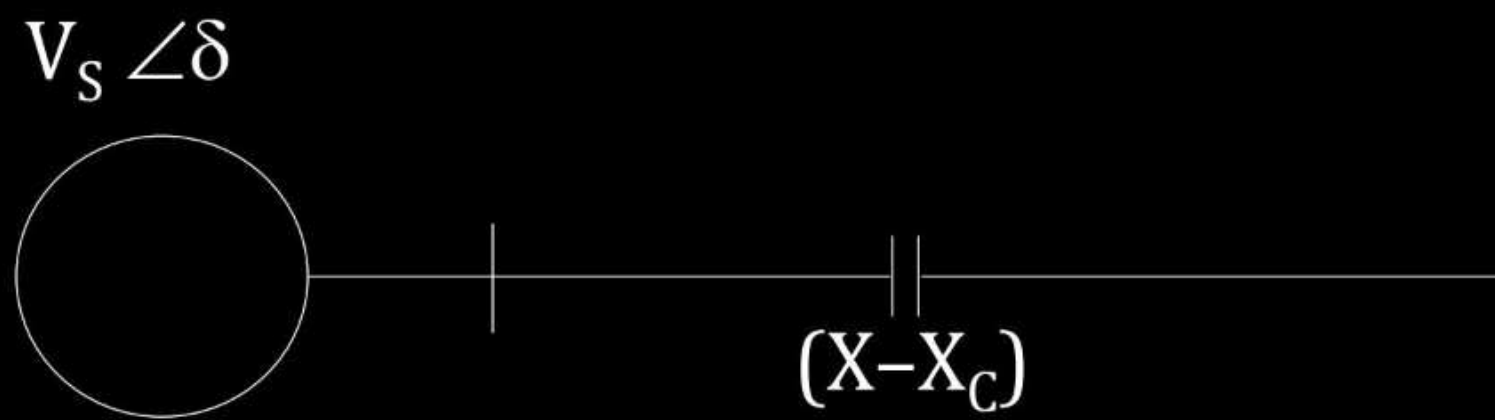
$$\text{After capacitor} = \frac{|V_s| |V_r|}{(X - X_c)}$$

(4) It increase magnitude of fault current.



Before series capacitor.

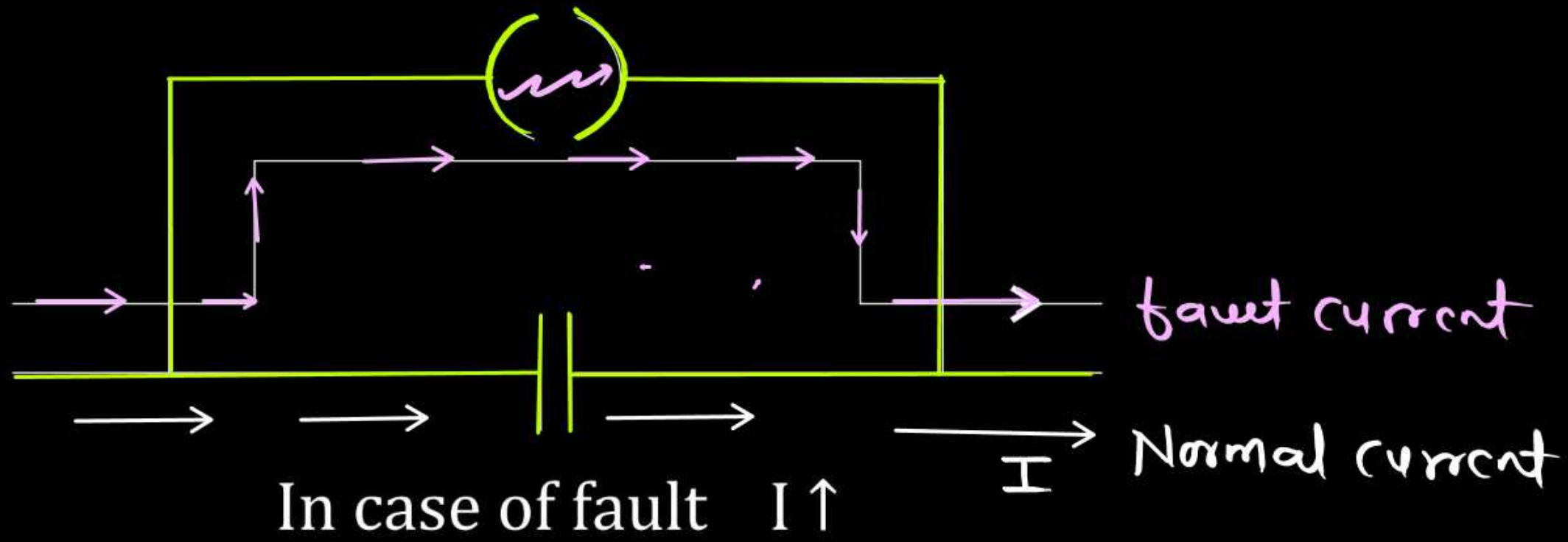
$$|I_f| = \frac{V_s}{X}$$



Fault current after series capacitor

$$|I_f| = \frac{V_s}{(X - X_c)}$$

- To protect the capacitor from this high current sphere gap (spark gap) is used.



$$\downarrow$$

$$IX_C \uparrow$$

$$\downarrow$$

So voltage across sphere gap is also increase



If this voltage $>$ break down voltage of air.



The air will be ionized.



So, current will start flowing through sphere gap.



So, capacitor will not be damaged.

Sub synchronous Resonance



The mechanical part of alternator has 2nd order mechanical system, which has its own natural frequency of oscillation.



When we apply series capacitor, LC series circuit will be formed. This also has its own natural frequency of oscillation.

$$\downarrow \omega_{osc} = \frac{1}{\sqrt{LC}}$$



When both frequency match, the resonance will occur. So energy is exchange between two system. This exchange of energy results in torsional stress on the turbine generator shaft that can lead to severe damage. In extreme cases, the shaft can actually fracture. Which may damage the mechanical part of alternator.

$$\omega_{osc} = \frac{1}{\sqrt{LC}} \times \frac{\omega}{\omega} = \frac{\omega}{\sqrt{\omega L} \sqrt{\omega C}}$$

$$X = \omega L$$

$$X_c = \frac{1}{\omega C}$$

$$\omega_{osc} = \omega \sqrt{\frac{X_c}{X}}$$

$$\sqrt{\frac{X_c}{X}} = \sqrt{\frac{1}{\omega C} \cdot \omega L}$$

$$\omega_{osc} = \omega \sqrt{K_{se}}$$

generally $K_{se} < 1$

$\omega_{osc} < \omega.$

$$\frac{j\omega_0}{m} - j\omega_0$$

Shunt Capacitor		Series Capacitor	
1.	Voltage boost up is evenly distributed ✓ 	1.	There is a sudden change of voltage. 
2.	It also improve P.F. ✓	2.	It hardly change the P.F. ✓
3.	If does not change stability of system ✓	3.	It improves the stability of system. ✓
4.	For same voltage boost up rating of shunt capacitor is high ✓	4.	For same voltage boost up rating of series capacitor is low. ✓
5.	It does not change fault current	5.	It increases the magnitude of fault current.

$$I_f \propto \frac{1}{X_L}$$

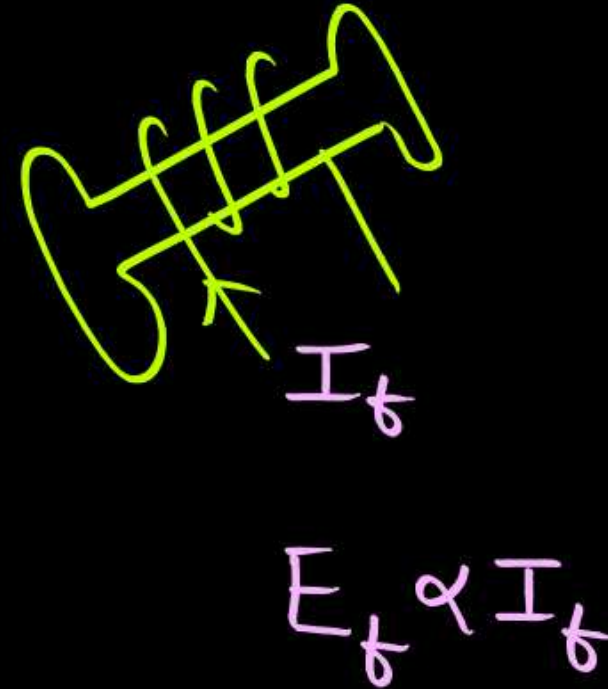
Synchronous Condenser(capacitor)/Synchronous Coil(Inductor) :



- It is a dynamic voltage control device
- It is a synchronous motor without any mechanical load.

Over excited $\Rightarrow$ Capacitor

Under-excited $\Rightarrow$ Inductor



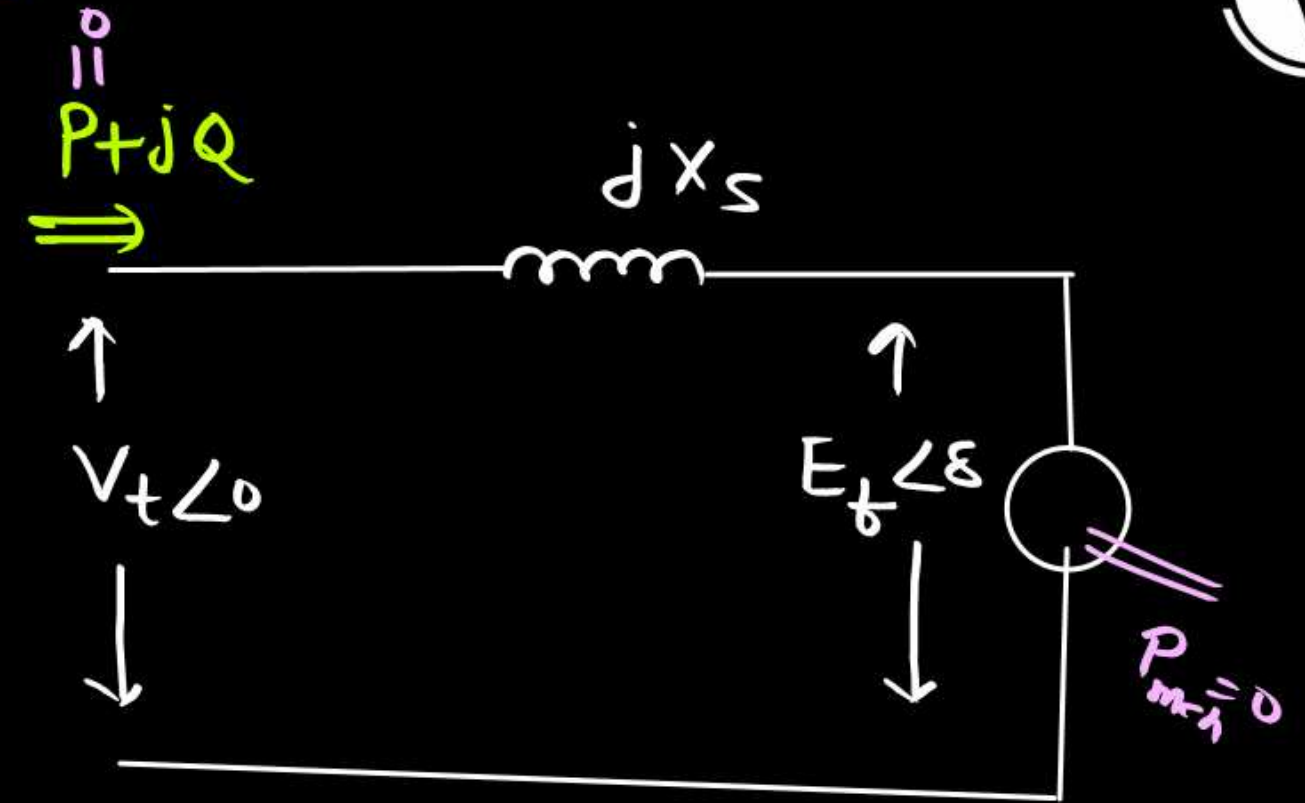
Synchronous Condenser/Synchronous Coil :



$$P = \frac{|V_t| |E_f|}{X_s} \sin \delta = 0$$

$$\sin \delta = 0$$

$$\delta = 0$$



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

$$Q = \frac{|V_t|^2}{|X_s|} - \frac{|V_t||E_t|}{|X_s|} \cos \theta$$

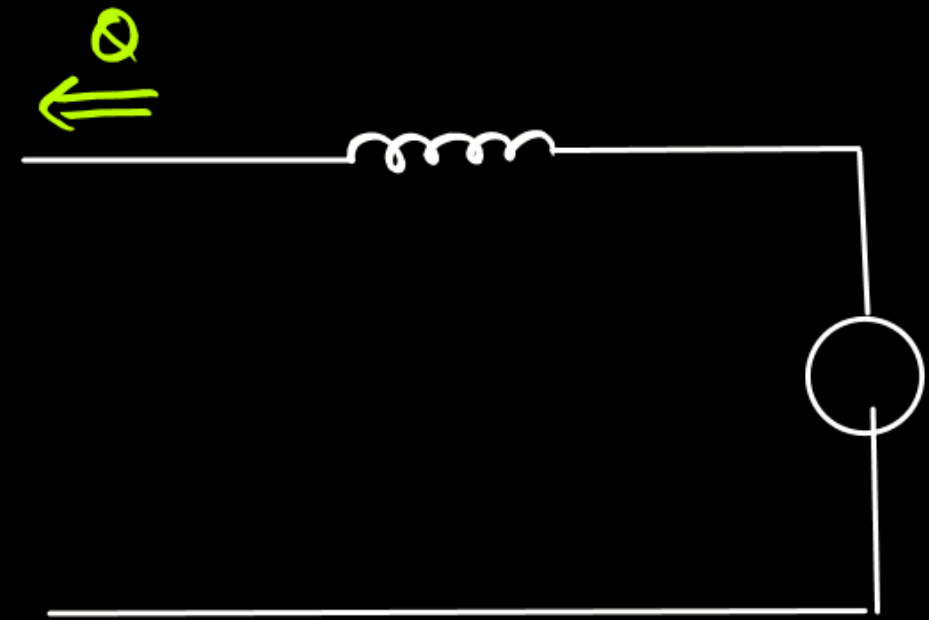
$$Q = \frac{|V_t|}{X_s} [|V_t| - |E_t|]$$

Case I

if $|E_f| > |V_t| \Rightarrow$ over excited.

$$Q = \ominus ve$$

So it is delivering reactive power
it act like a capacitor.



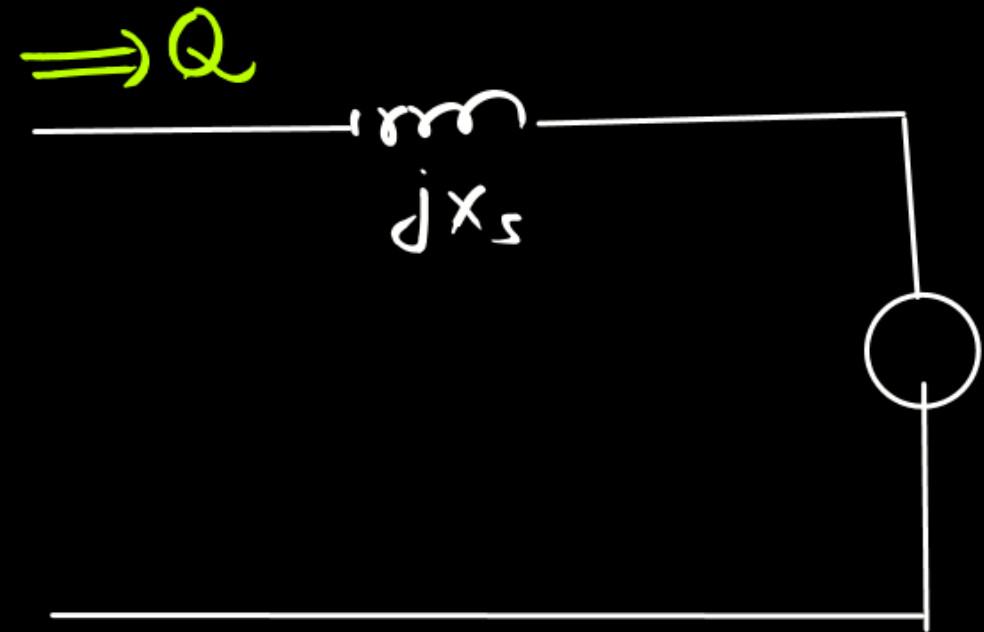
Case-II

$$\text{if } |E_f| < |V_t|$$

$$Q = (+) V_c$$

So it take reactive power.

it act like inductor.



#Q. ✓ Assertion (A): It is not necessarily desirable to compensate by a series capacitance for all the line reactance.

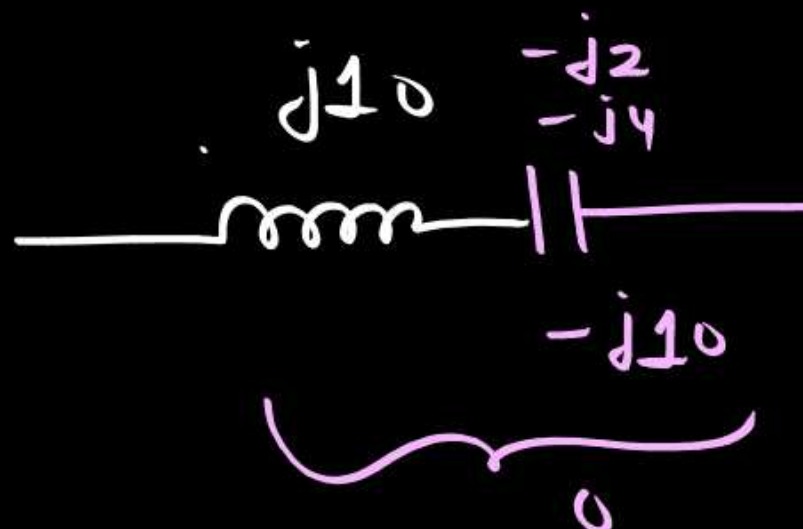
✓ Reason (R): Power can be transformed only if reactance is present. [ESE-2011]

A ✓ Both A and R are individually true and R is the correct explanation of A

B Both A and R are individually true but R is not the correct explanation of A

C A is true but R is false

D A is false but R is true



#Q. A shunt capacitor used for reactive power compensation is operated at 98% of its rated frequency and 95% of its rated voltage. The reactive power supplied by this capacitor (as compared to its rated capacity) is [ESE-2015]

- A** 7.9% lower
- B** 11.5% lower
- C** 11.5% higher
- D** 7.9% higher

$$Q = \frac{V^2}{X_c} = V^2 \omega C = V^2 (2\pi f C)$$

$$Q_1 \propto V^2 f$$

$$Q_2 \propto (0.95V)^2 (0.98f_1)$$

$$Q \propto 0.884 V^2 f$$

#Q. Which one of the following statements is correct regarding shunt/series capacitor? [ESE-2024]

- A** Shunt capacitor improves the power factor whereas series capacitor improves the stability of transmission line.
- B** Series capacitor improves the power factor whereas shunt capacitor improves the stability of transmission line.
- C** Shunt capacitor improves both the power factor and the stability of transmission line.
- D** Series capacitor improves both the power factor and the stability of transmission line.

#Q. What is the percentage increase of busbar voltage required to compensate for the reactance drop when the feeder having a reactance of 5% carries a full load current at a p.f. 0.8 lagging? [ESE-2023]

$$\cos \phi = 0.8 \rightarrow \sin \phi = 0.6$$

A 3%

B 4%

C 1.5%

D 2%

$$|V_s| - |V_r| = IR \cos \phi + IX \sin \phi$$

$$= IX \sin \phi$$

$$= (1)(0.05)(0.6)$$

$$= 0.03$$

$$= \underline{3\%}$$



2 Minutes Summary

→ Series Capacitor

→ Series Capacitor v/s Shunt Capacitor

→ Sub synchronous reactance

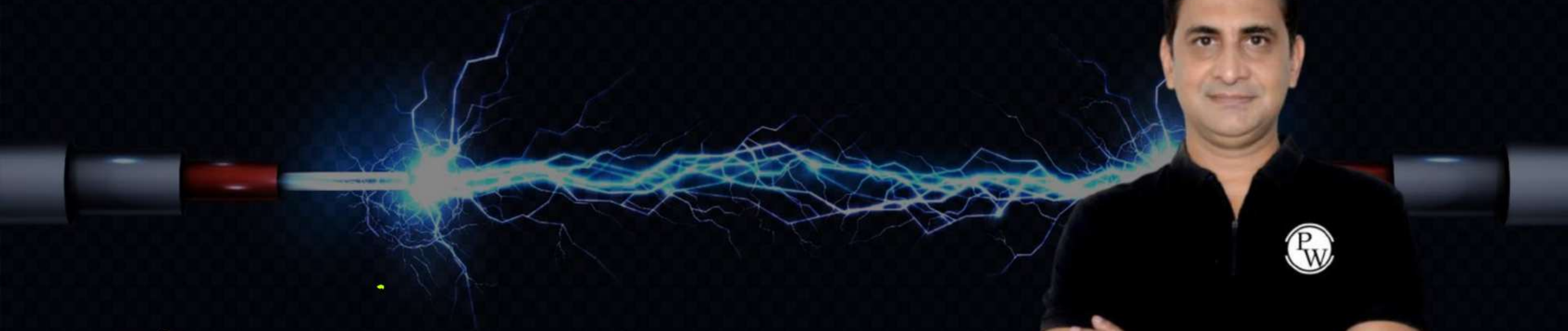
Thank you

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Electrical Engineering

Power System



Lecture No.-4

Voltage Control

By- Ajay Gupta Sir



Recap Of previous class



1. Series capacitor



2. Sub synchronous resonance

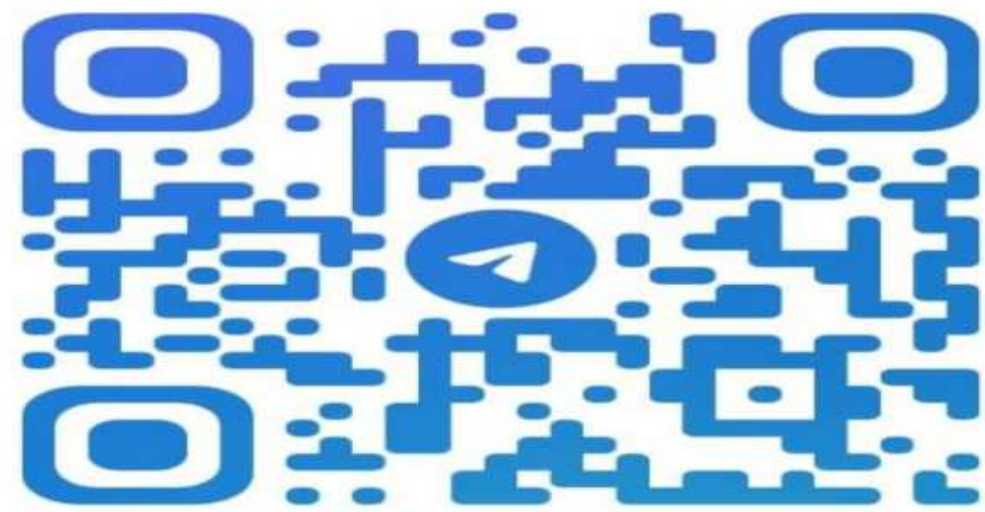


3. Synchronous condensor



Topics to be Covered

- ✓ 1. Modification of SIL
- 2. Question



@AJAYGUPTASIRPW

1. Over excited $I_f \uparrow \rightarrow \phi_f \uparrow \rightarrow E_f \uparrow = \sqrt{2} \pi f V \phi_f \uparrow$

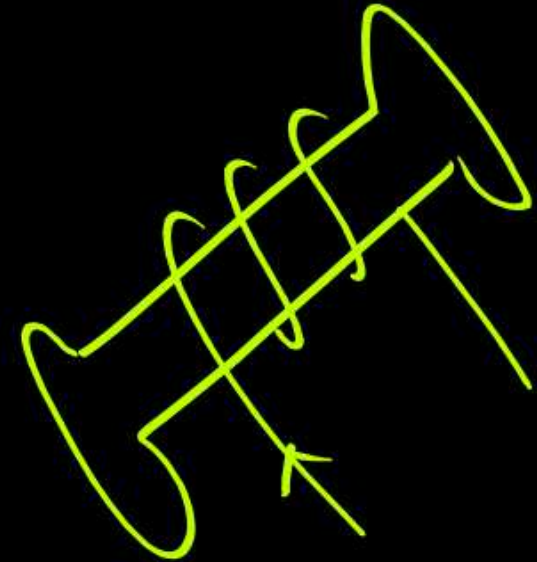
$$E_f > V_t \Rightarrow Q = -Ve.$$

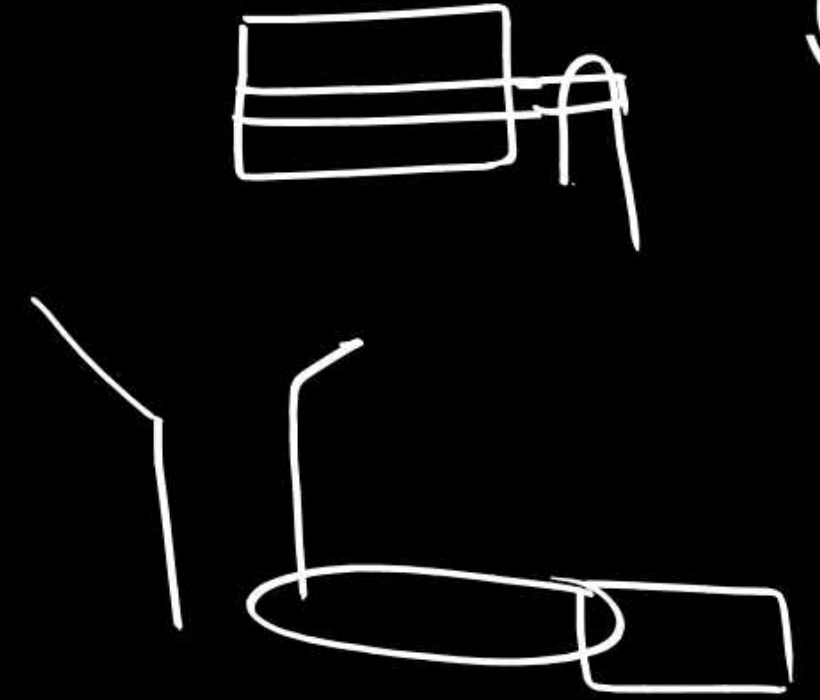
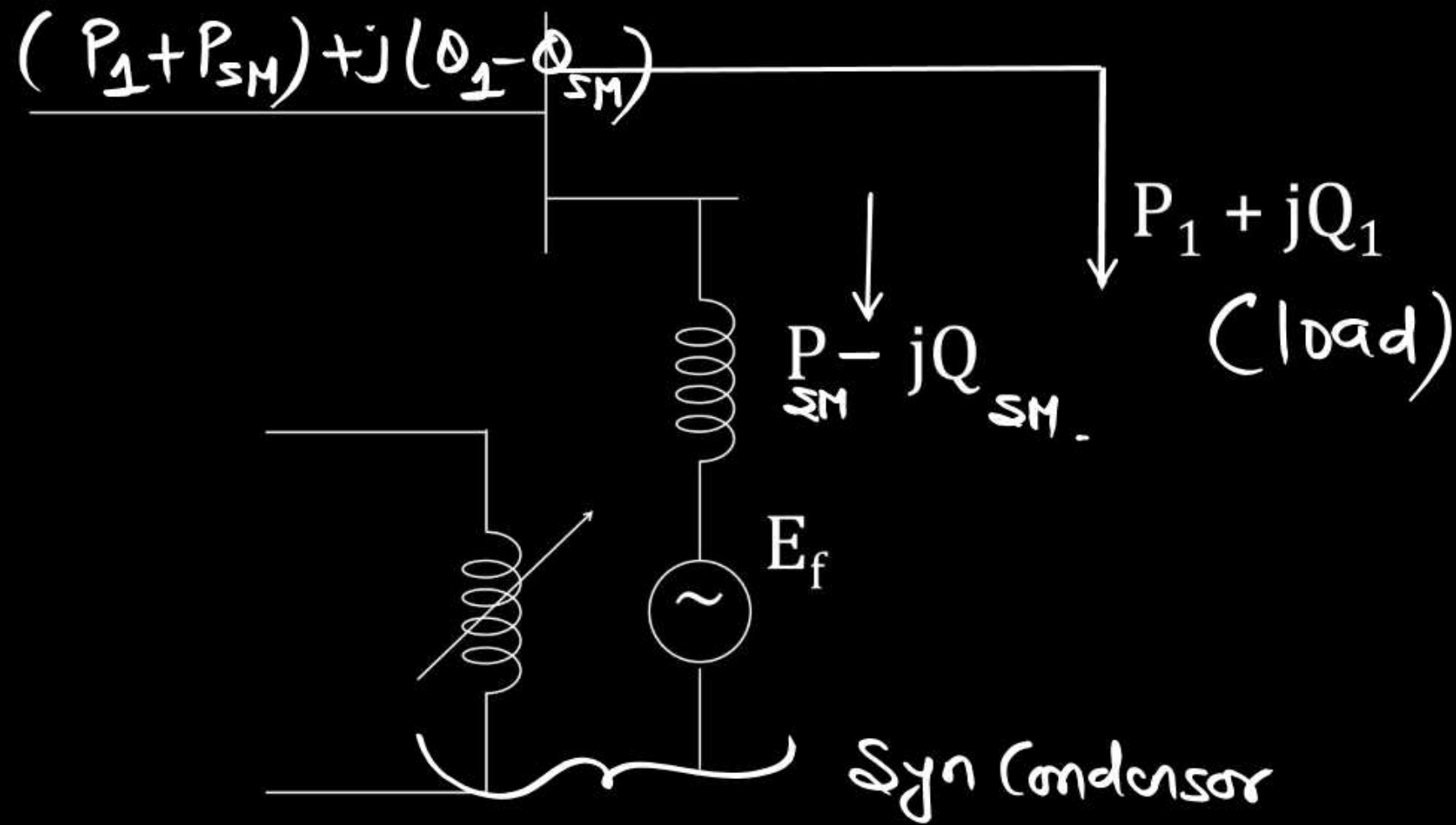
It gives the reactive power (It is a synchronous condenser)

(ii) Under excited $I_f \downarrow \rightarrow \phi_f \downarrow \rightarrow E_f \downarrow$

$$E_f < V_t \Rightarrow Q = +Ve$$

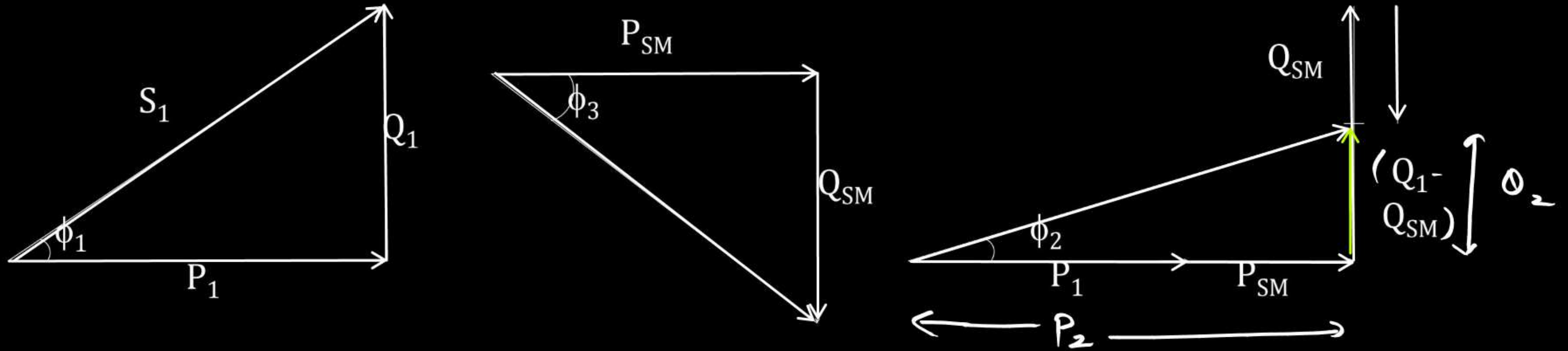
It takes reactive power (It is synchronous coil)





The synchronous condenser is same as synchronous motor except

- (i) It does not have shaft extensions
- (ii) The field core are large.



$\Phi_1 =$ Pf angle without condenser $\Phi_2 =$ Pf angle with condenser

- Some losses occur in synchronous condenser, so it also take small amount of active power from supply.

P.F. of synchronous condenser =
$$\frac{P_{SM}}{\sqrt{P_{SM}^2 + Q_{SM}^2}}$$

Without synchronous condenser reactive power by load $Q_1 = P_1 \tan \phi_1$

With synchronous condenser reaction power $Q_2 = P_2 \tan \phi_2$

$$Q_1 - Q_{SM} = (P_1 + P_{SM}) \tan \phi_2$$

$$P_1 \tan \phi_1 - Q_{SM} = (P_1 + P_{SM}) \tan \phi_2$$

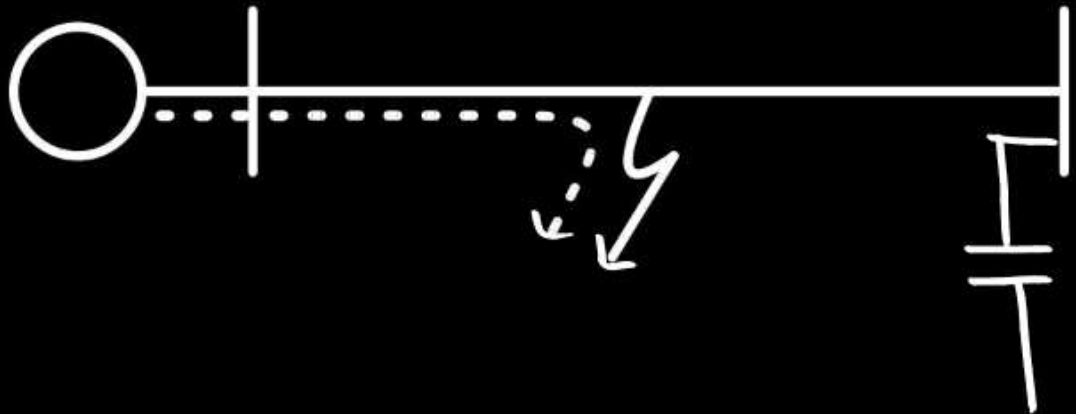
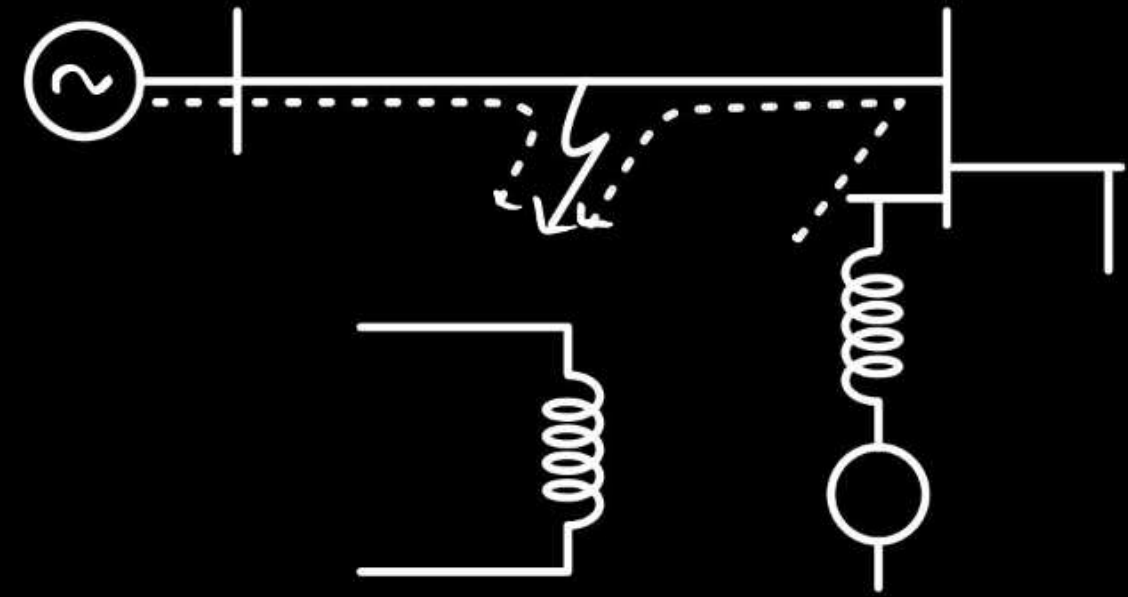
$$Q_{SM} = P_1 \tan \phi_1 - (P_1 + P_{SM}) \tan \phi_2$$

For a loss less syn condenser $P_{SM} = 0$

$$Q_{SM} = P_1 [\tan \phi_1 - \tan \phi_2]$$

Reactive power supplied by synchronous condenser for improvement of P.f. from $\cos \phi_1$ to $\cos \phi_2$.

- Synchronous condenser is mainly PF correction device rather than voltage control device.
- Small hydel Power plant can be run as a synchronous condenser during rainy season.
- Synchronous coil (underexcited) can be used as a Ferranti effect control device.

Shunt Capacitor 		Synchronous condenser 	
1.	The control of voltage (Reactive Power) is in steps	1.	The control of voltage (Reactive power is smooth)
2.	It does not consume any active power	2.	It consume some active power to feed the loss
3.	The cost is less	3.	The cost is high
4.	It does not change fault current 	5.	It increase the fault current 

5.	It does not effect the stability of system	5.	It may fall out of steps.
6.	It does not require starting medium	6.	It is to be started like syn machine.

Overexcited synchronous motor:

➤ In industry, we use synchronous motor in addition to I.M., it will

(i) Give the mechanical O/P power ✓

(ii) Give the reactive power ✓

(iii) It improve the P.F. ✓

$$P = \frac{|E_t| |V_t|}{X_s} \sin \delta \neq 0$$

$$\underline{\delta \neq 0}$$

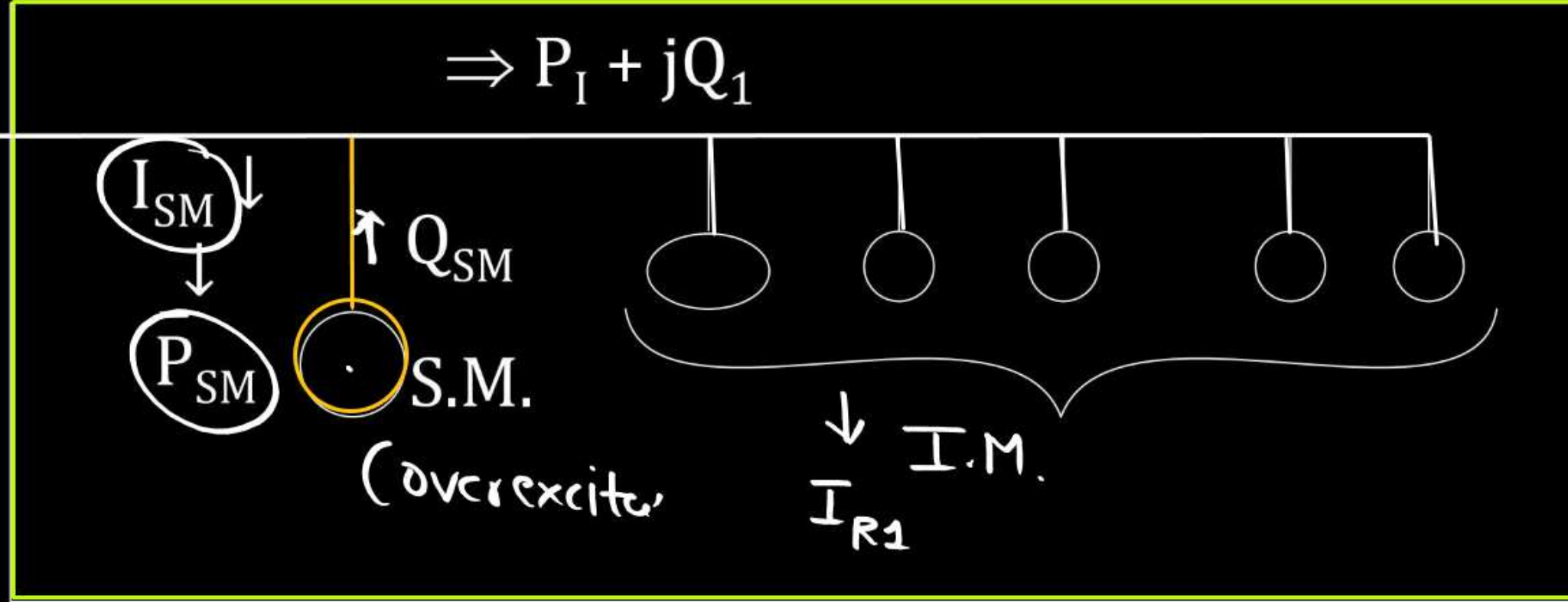
$$Q_{SM} = \frac{V_t}{X_t} [V_t - E_f \cos \delta], \quad P_{SM} = \frac{E_f V}{X} \sin \delta$$

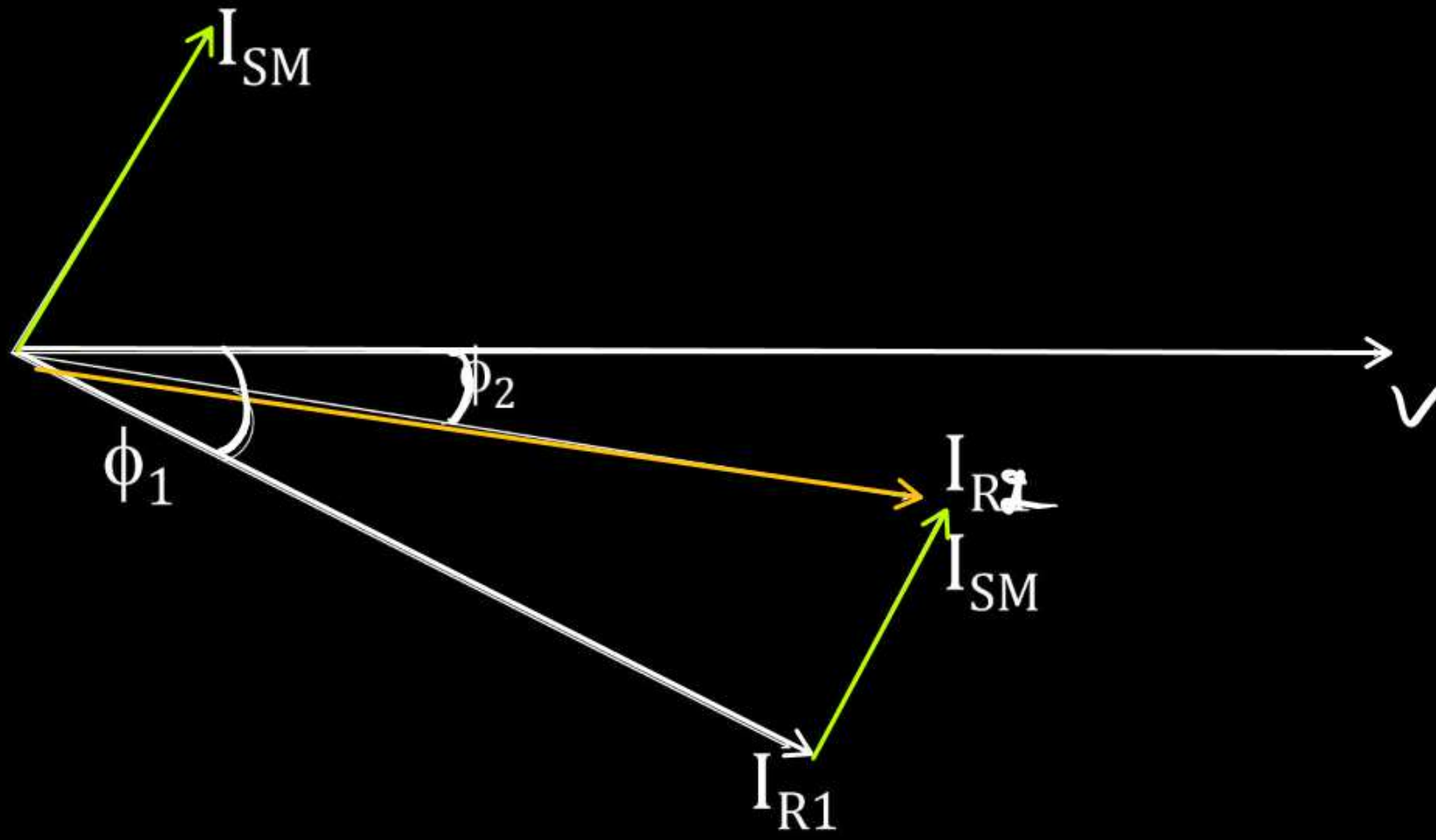


$\rightarrow I_{R1}$

$$(P_1 + P_{SM}) + j(Q_1 - Q_{SM})$$

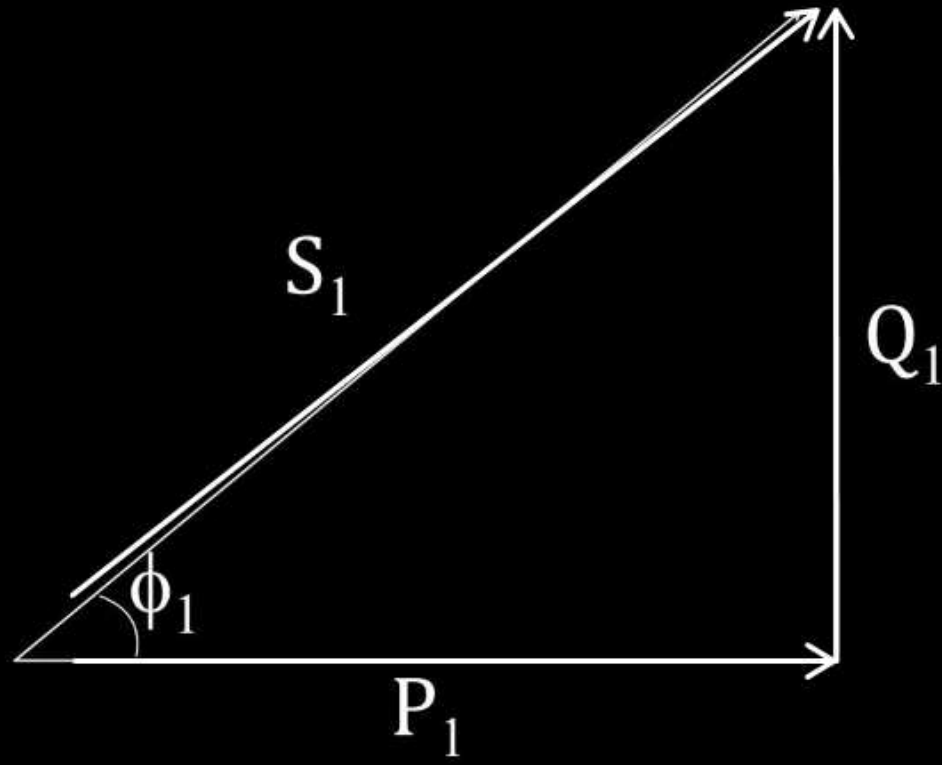
$$\Rightarrow P_I + jQ_I$$



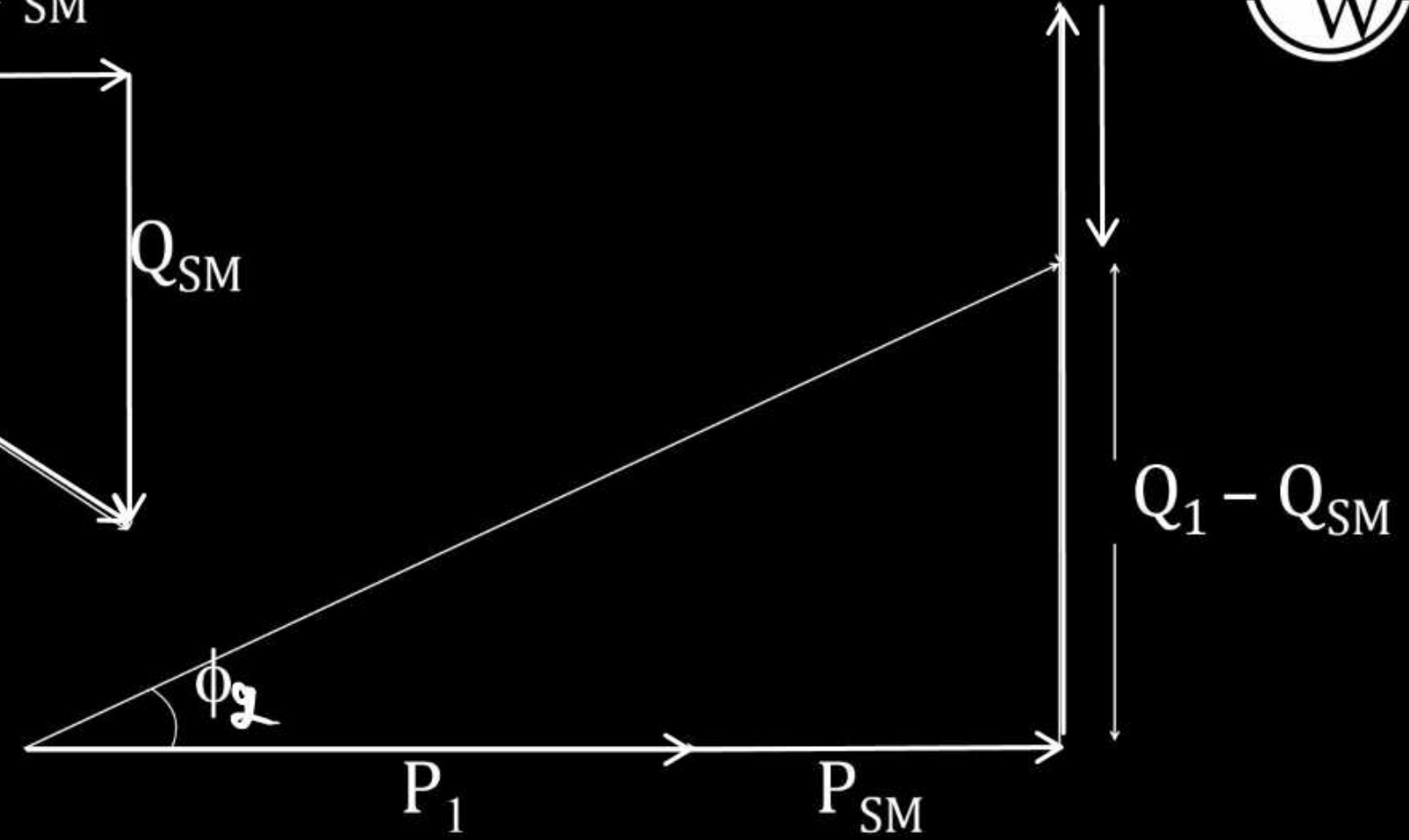
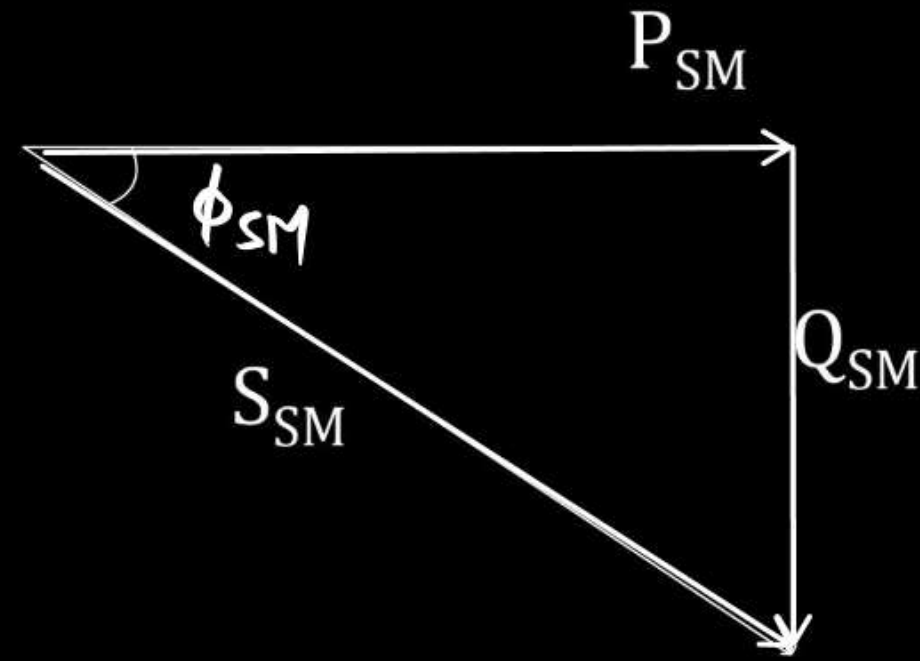


$$\phi_2 < \phi_1$$

$$\cos \phi_2 > \cos \phi_1$$



$$Q_1 = P_1 \tan \phi_1$$



$$Q_1 - Q_{SM} = (P_1 + P_{SM}) \tan \phi_2$$

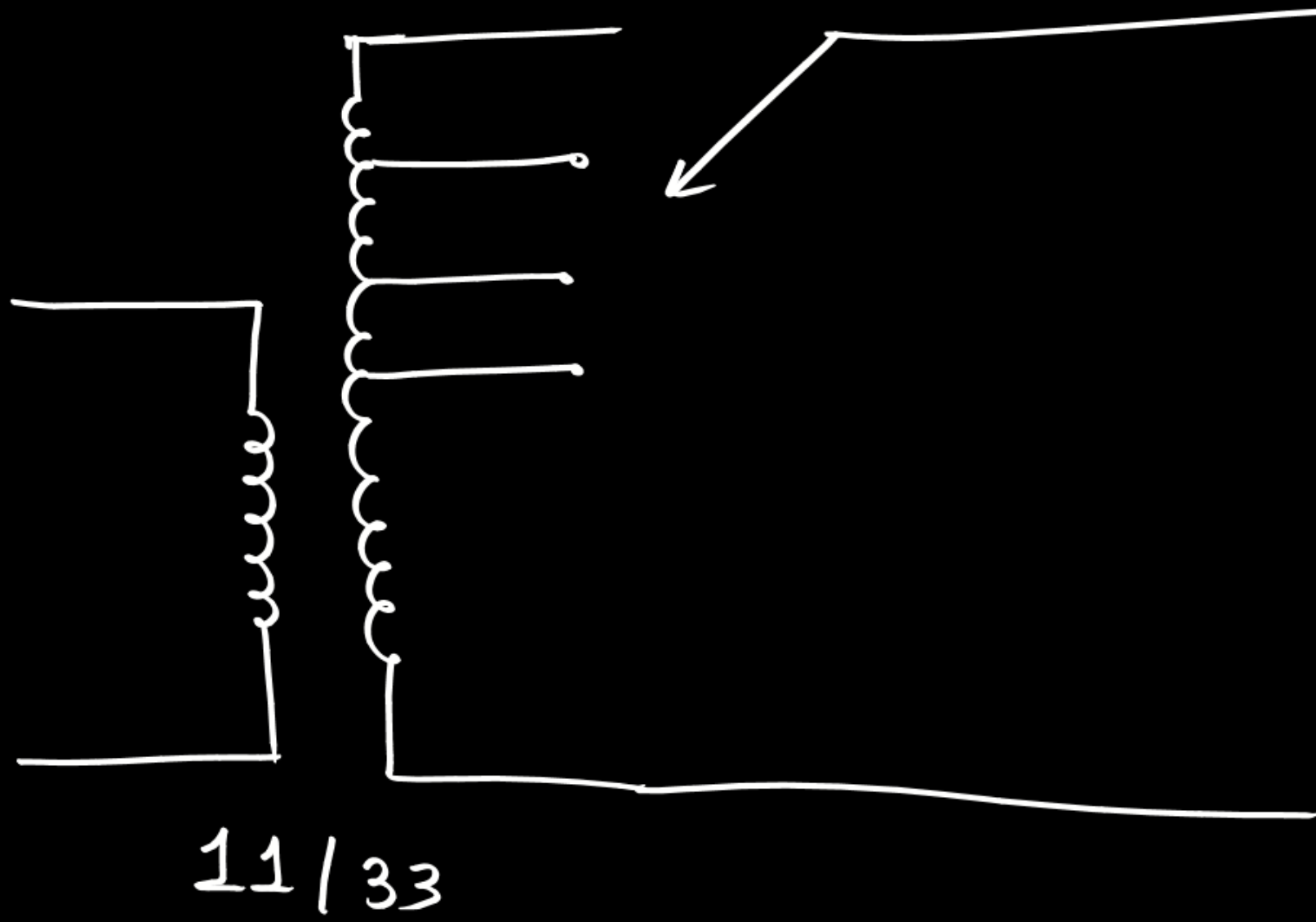
$$Q_{SM} = Q_1 - (P_1 + P_{SM}) \tan \phi_2$$

$$Q_{SM} = P_1 \tan \phi_1 - (P_1 + P_{SM}) \tan \phi_2$$

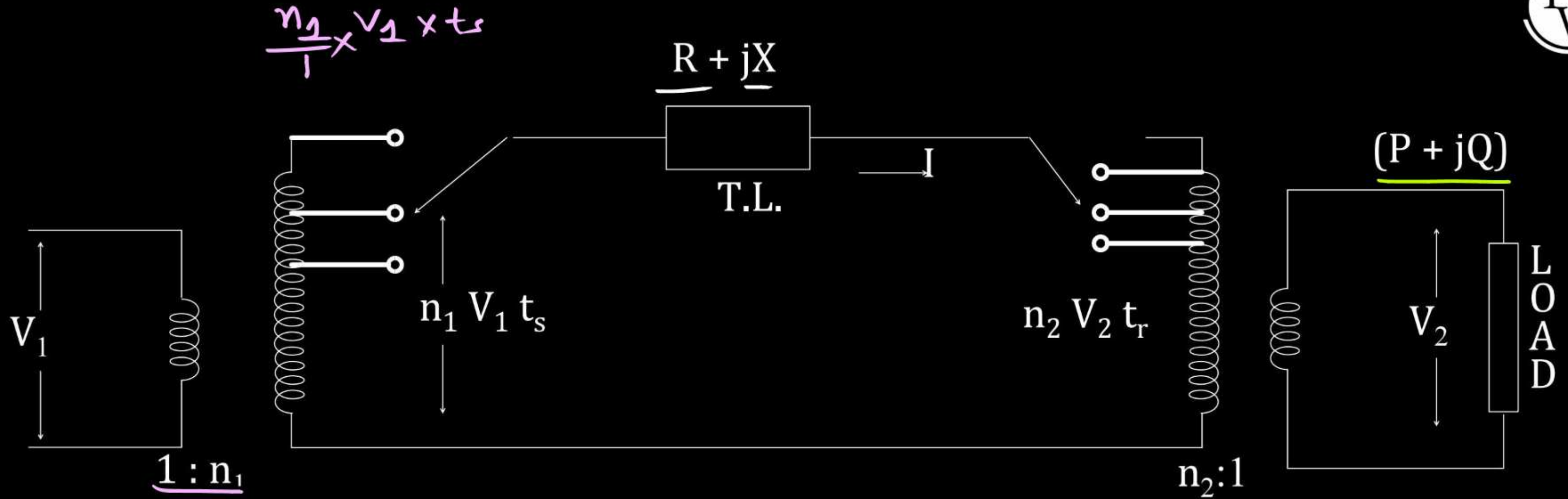
Tap changing Transformer:

- It control the voltage by changing number of turns. it do not control the reactive power
- If may be two type
 - (i) Off load tap changer
 - (ii) On load tap changer
- Generally, tap changing is done by using single phase → Motor.
- Generally, tap changer is placed at HV side.





$$V_2 = V_1 \frac{N_2}{N_1}$$



Nominal transformation ratio =

$$\frac{11 \times 33}{11} \times \frac{36}{33} = 36$$

$$V_1 \times \frac{n_1}{1} \times t_s$$

➤ 11/33 kV → Normal ratio (Nominal Ratio)

Suppose, we want to take 36 kV output by use of tap change 11/36

$$\text{Nominal transformation ratio} = \frac{36}{33} = 1.09$$

at sending end = t_s varied

receiving end = t_r

$$n_1 V_1 t_s = n_2 V_2 t_r + \underline{I} R \underline{\cos \phi_r} + \underline{I} X \underline{\sin \phi_r} \quad (1)$$

$$P = n_2 V_2 t_r I \cos \phi$$

$$I \cos \phi = \frac{P}{n_2 V_2 t_r}$$

$$Q = n_2 V_2 t_r I \sin \phi$$

$$I \sin \phi = \frac{Q}{n_2 V_2 t_r}$$

Put value of $I \cos \phi$ and $I \sin \phi$ in eqn(1)

$$\eta_1 V_1 t_s = \eta_2 V_2 t_r + \frac{RP}{\eta_2 V_2 t_r} + \frac{Qx}{\eta_2 V_2 t_r}$$

Generally $t_s t_r = 1 \Rightarrow t_r = 1/t_s$

$$\eta_1 V_1 t_s = \frac{\eta_2 V_2}{t_s} + \frac{RP t_s}{\eta_2 V_2} + \frac{Qx t_s}{\eta_2 V_2}$$

$$\eta_1 V_1 t_s^2 = \eta_2 V_2 + \frac{RP t_s^2}{\eta_2 V_2} + \frac{Qx t_s^2}{\eta_2 V_2}$$

$$\eta_1 t_s^2 = \eta_2 \frac{V_2}{V_1} + \frac{RP t_s^2}{\eta_2 V_1 V_2} + \frac{Qx t_s^2}{\eta_2 V_1 V_2}$$

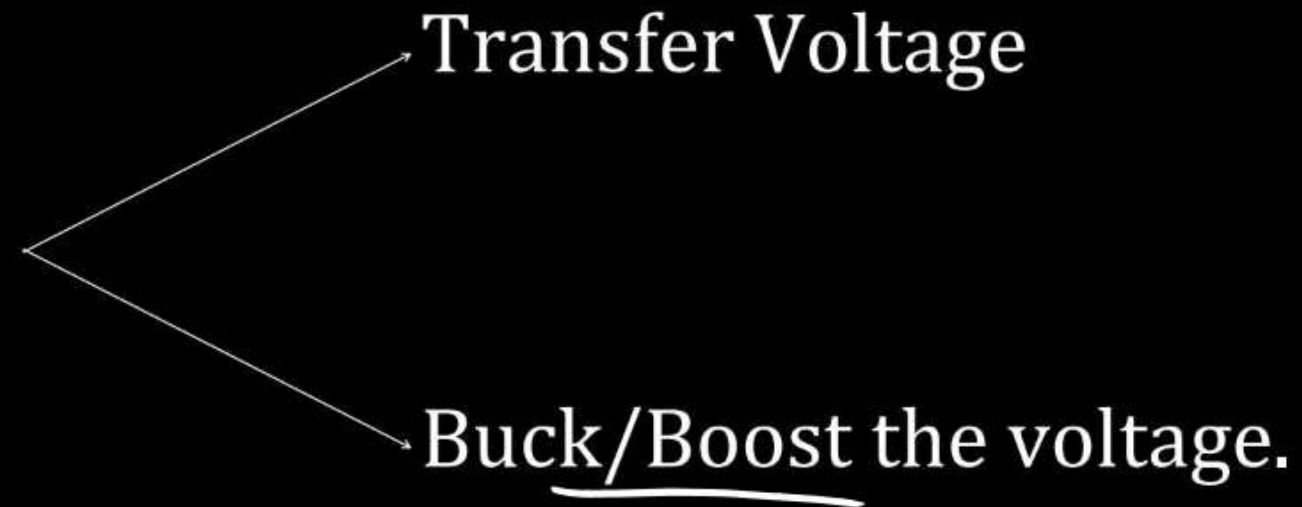
$$t_s^2 \left[n_1 - \frac{RP + XQ}{n_2 V_1 V_2} \right] = n_2 \frac{V_2}{V_1}$$

→ With load power ($P + jQ$) and V_1 & V_2 we can find out t_s and t_r .

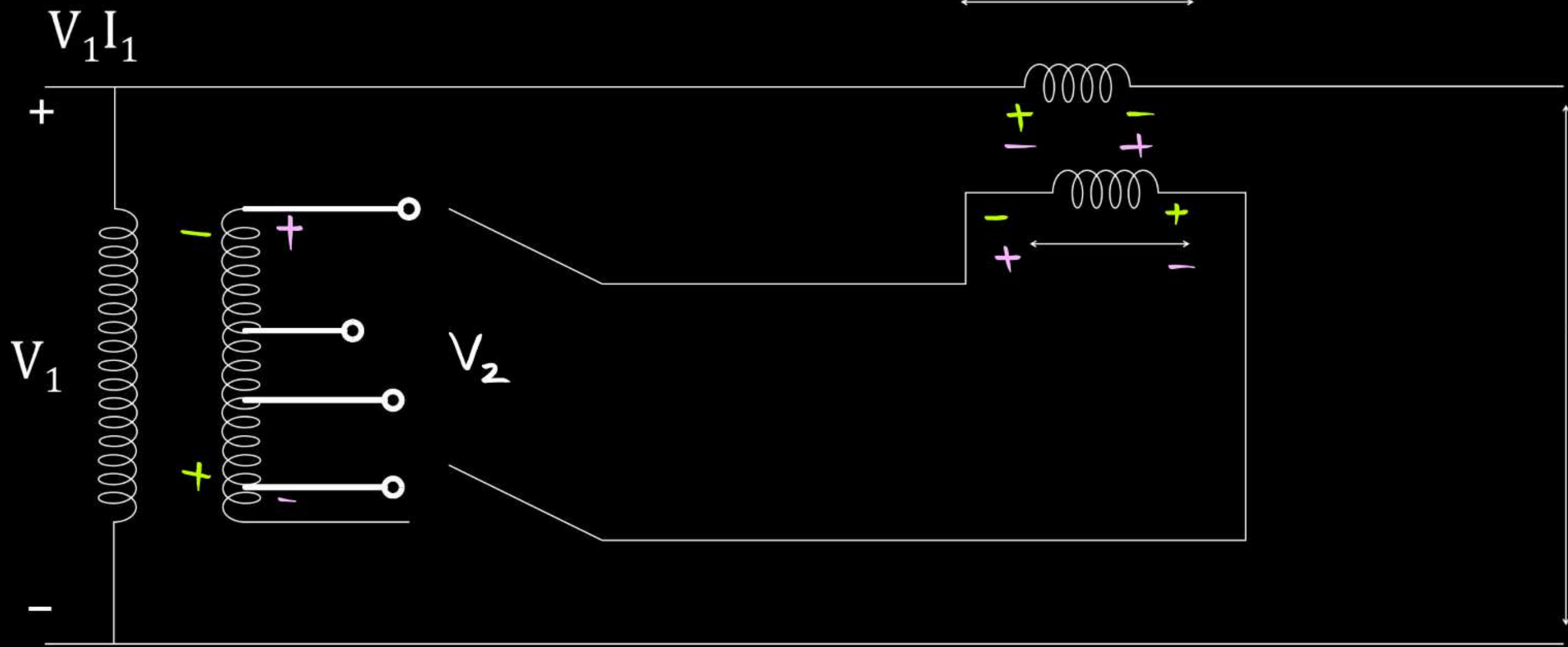
Booster Transformer



Normal tap changing
transformer



➤ But booster transformer do only second function.



$V_1 = 11$
 $10 \text{ to } 12 \text{ kv}$
 $V_2 = 1$

$\textcircled{\text{P}}$
 $\textcircled{\text{W}}$

$V_1 - V_2$
 $V_1 + V_2$

$V_2 = \frac{N_2}{N_1} V_1$

- It can be used at any intermediate position
- The rating of booster transformer is proportional to current & injected voltage, so its rating is approx. 10% of main transformer.
- Booster transformer is mainly used in distribution feeder, where cost of tap changing transformer is high.

$$Z = R + jX$$

$$Y = G + jB$$

Inductance

$$X = j\omega L$$

$$B = \frac{1}{j\omega L} = \frac{-j}{\omega L}$$

Capacitance

$$X = \frac{1}{j\omega C} = \frac{-j}{\omega C}$$

$$B = j\omega C$$

$$\text{Degree of Series Compensator} = \frac{X_c}{X_L}$$

C = Compensator

L = Line

$$\text{Degree of Shunt Compensator} = \frac{B_c}{B_L}$$

Modification of SIL with compensator →

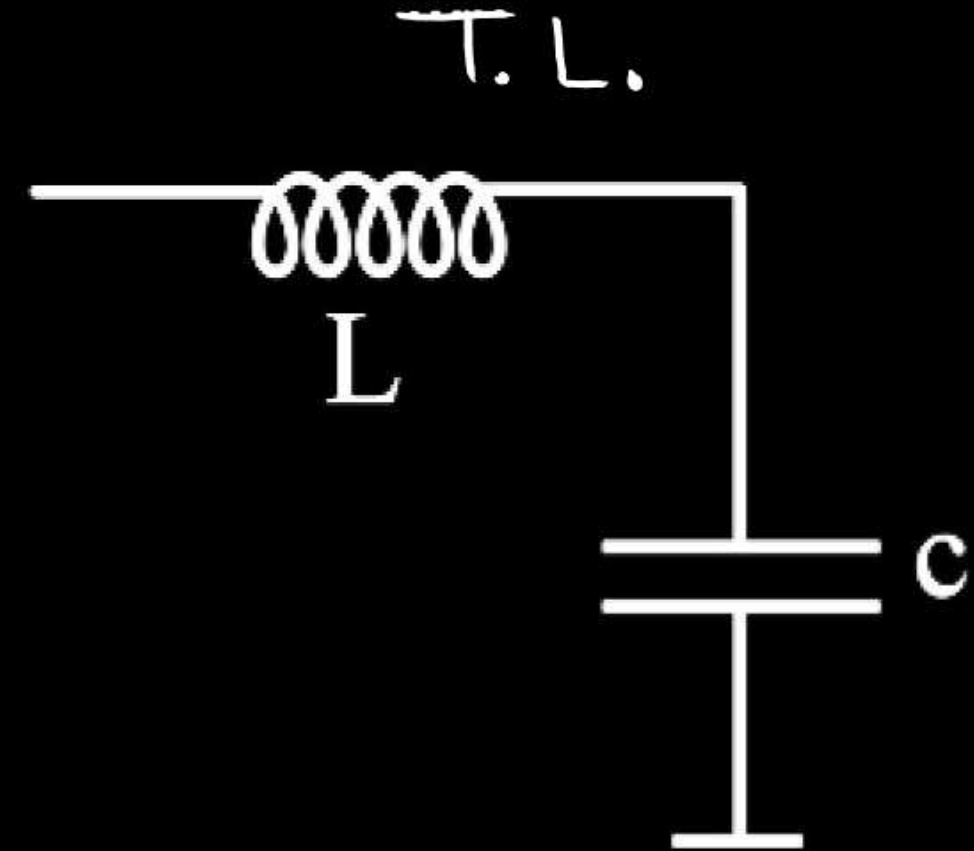
- Without any compensator

$$Z_s = \sqrt{\frac{L}{C}} = \sqrt{\frac{\omega L}{\omega C}} = \sqrt{\frac{X_L}{B_L}}$$

$$SIL = \frac{V^2}{Z_s}$$

X_L = line reactance

B_L = line susceptance



with shunt capacitor:

Total capacitance

$$C_T = C_L + C_c$$

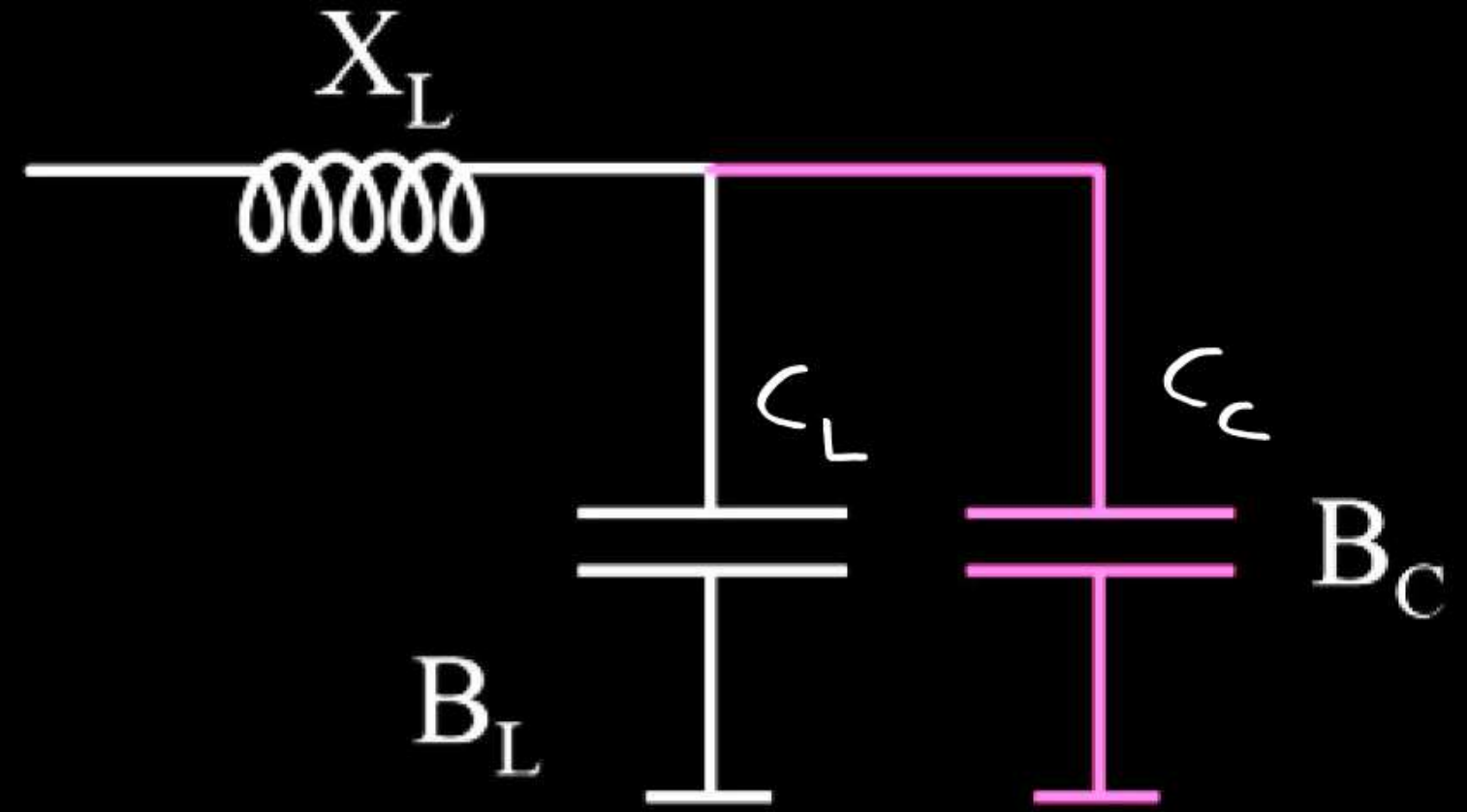
$$\omega C_T = \omega C_L + \omega C_c$$

$$B_T = B_L + B_c$$

Now surge impedance

$$Z'_s = \sqrt{\frac{X_L}{B_L + B_c}} = \sqrt{\frac{X_L}{B_L(1 + B_c/B_L)}}$$

$$Z'_s = \sqrt{\frac{X_L/B_L}{1 + B_c/B_L}} \Rightarrow Z'_s \sqrt{\frac{Z_s}{1 + B_c/B_L}} = \frac{Z_s}{\sqrt{1 + k_{sh}}}$$



Where $= \frac{B_C}{B_L} = \frac{C_C}{C_L} =$ degree of shunt compensator

$$\downarrow Z'_s = \frac{Z_s}{\sqrt{1 + k_{sh}}}$$

$$Z'_s < Z_s$$

$$SIL \uparrow = \frac{V^2}{Z'_s \downarrow}$$

→ So we can say that by shunt capacitor SIL of T.L. is Increased.



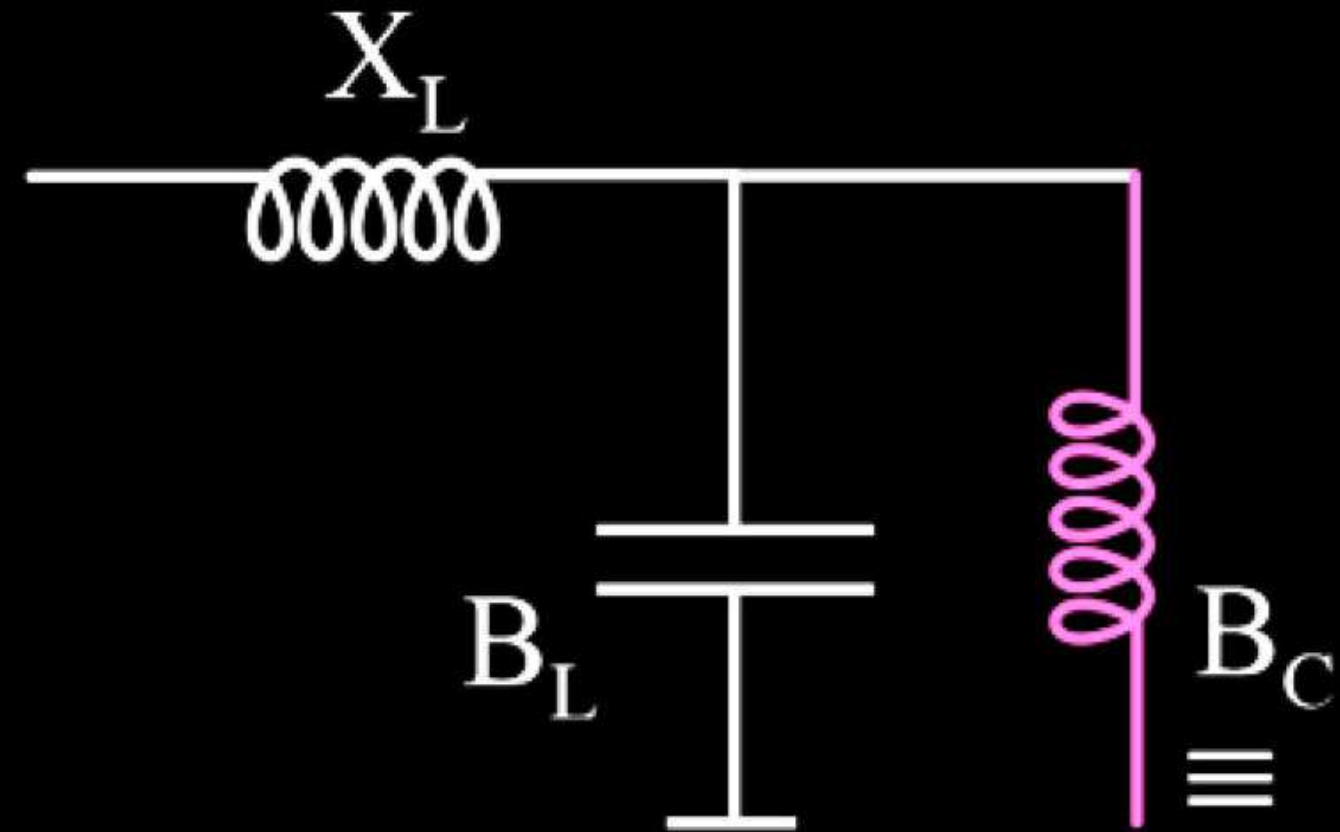
With shunt reactor:

$$j B_T = j B_L - j B_C$$

$$B_T = B_L - B_C$$

The susceptance of a inductor is negative

$$Z'_s = \sqrt{\frac{X_L}{B_L - B_C}} = \sqrt{\frac{X_L}{B_L \left(1 - \frac{B_C}{B_L}\right)}} = \sqrt{\frac{X_L |B_L}{1 - B_C |B_L}} = \frac{Z_s}{\sqrt{1 - \frac{B_C}{B_L}}} = \frac{Z_s}{\sqrt{1 - k_{sh}}}$$



$$\underline{Z'_s} = \frac{Z_s}{\sqrt{1 - k_{sh}}}$$

$$\underline{Z'_s} > \underline{Z_s}$$

$$SIL \downarrow = \frac{V^2}{\underline{Z'_s} \uparrow}$$

So we can say by shunt reactor SIL of line is reduce.

With series capacitor:-

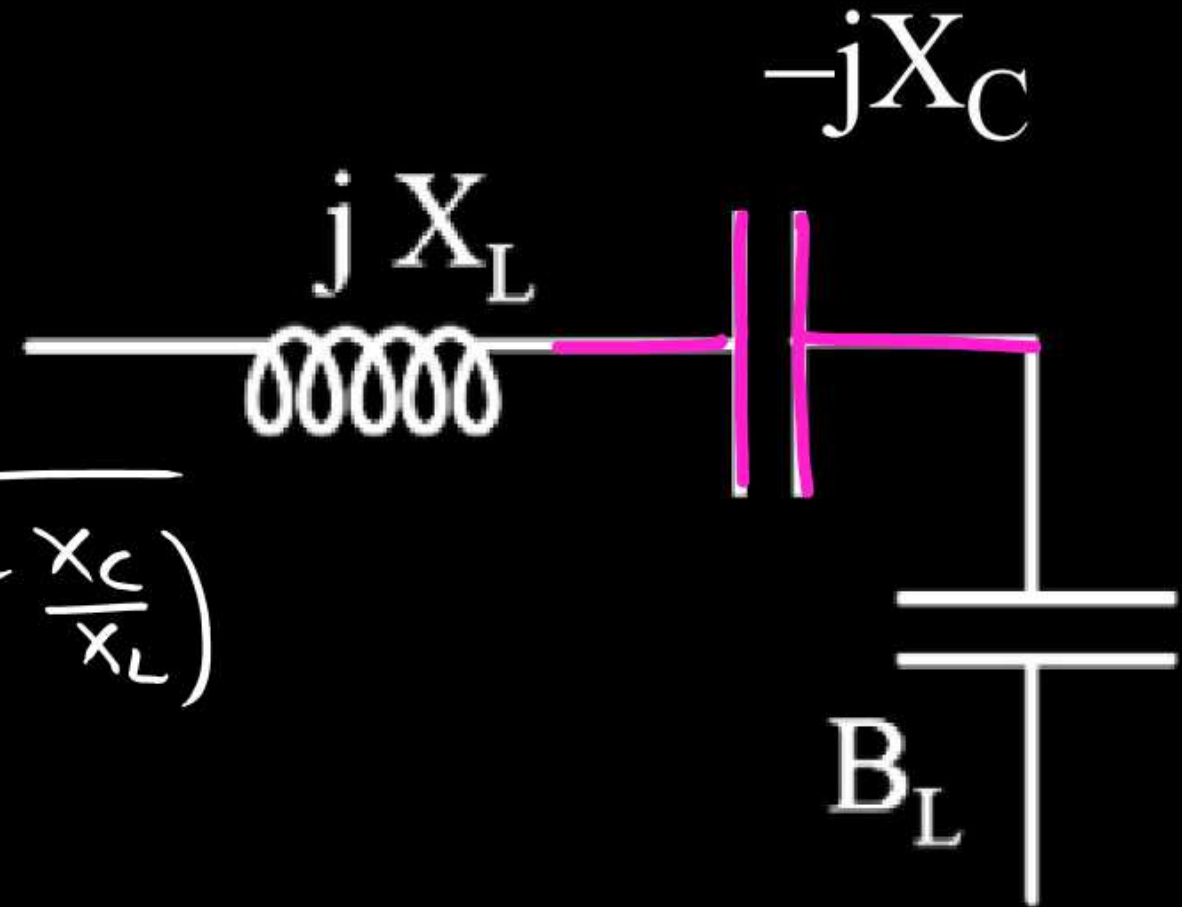
Total Series reactance

$$X_T = jX_L - jX_C = j(X_L - X_C)$$

$$Z'_s = \sqrt{\frac{X_L - X_C}{B_L}} = \sqrt{\frac{X_L \left(1 - \frac{X_C}{X_L}\right)}{B_L}} = \sqrt{\frac{X_L}{B_L}} \left(1 - \frac{X_C}{X_L}\right)$$

$$Z'_s = Z_s \sqrt{1 - k_{se}}$$

$$k_{se} = \frac{X_C}{X_L} = \text{degree of series compensator}$$



$$Z'_s = Z_s \sqrt{1 - k_{se}}$$

$$\underline{Z'_s < Z_s}$$

$$SIL \uparrow = \frac{V^2}{Z'_s}$$

So, we can say, series capacitor increase the SIL

With series reactor:

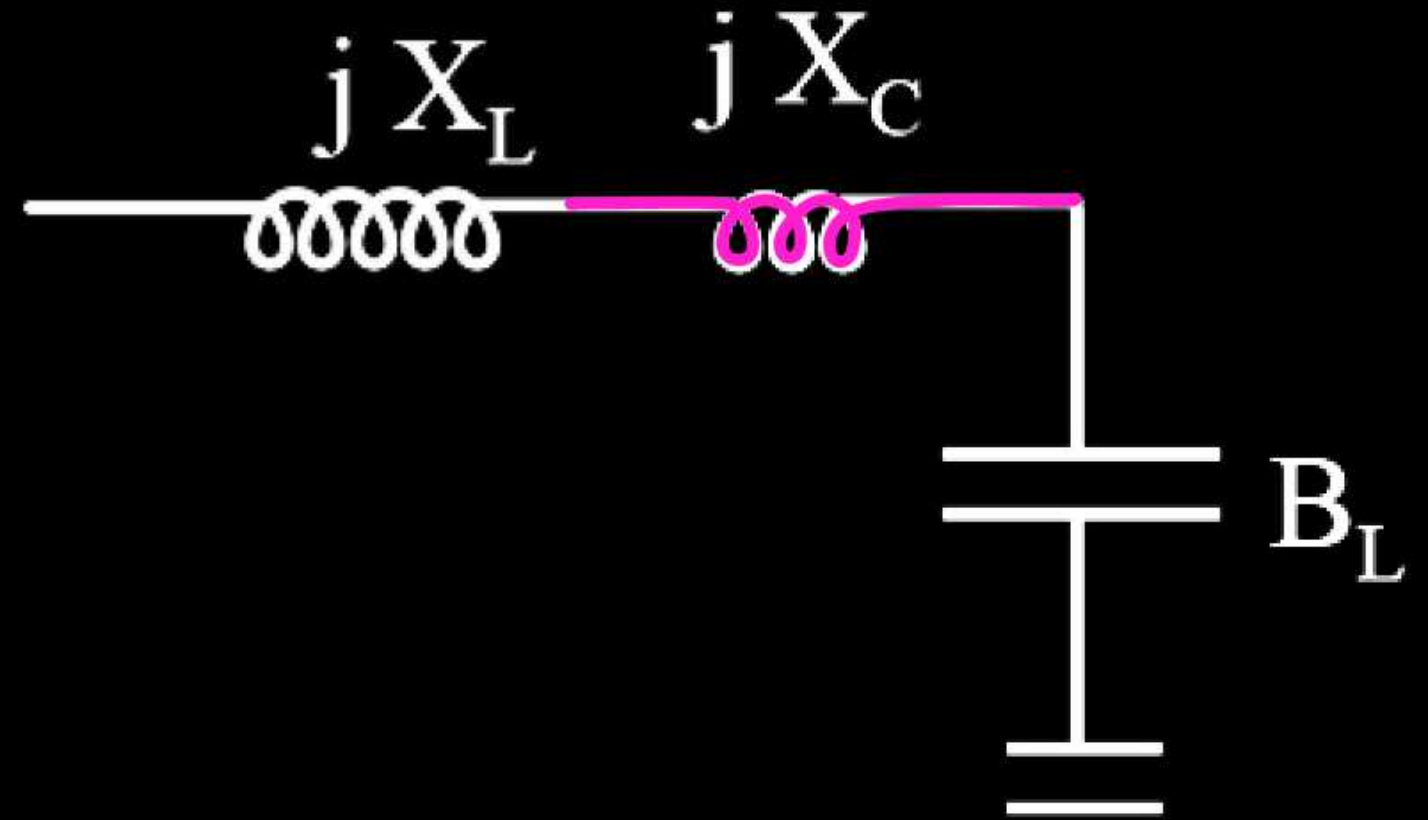
$$X_T = jX_L + jX_C = j(X_L + X_C)$$

$$Z'_s = \sqrt{\frac{X_L + X_C}{B_L}} = \sqrt{\frac{X_L(1 + X_C/X_L)}{B_L}}$$

$$Z'_s = \sqrt{\frac{X_L}{B_L}} \sqrt{1 + \frac{X_C}{X_L}}$$

$$Z'_s = Z_s \sqrt{1 + K_{se}}$$

$$SIL \downarrow = \frac{V^2}{Z'_s} \uparrow$$



So by series reactor SIL of line is decrease

Capacitor

Q. The combined effect of series and shunt compensation on transmission lines in terms of degree of series compensation (K_{se}), degree of shunt compensation (K_{sh}), and surge impedance of uncompensated line (Z_0) is given by which one of the following equation?

(A) $Z'_0 = Z_0 \sqrt{1-K_{se}} \times \sqrt{1-K_{sh}}$

(B) $Z'_0 = \left[\sqrt{1-K_{se}} \times \sqrt{1-K_{sh}} \right] / Z_0$

(C) $Z'_0 = Z_0 \sqrt{(1-K_{se}) / (1+K_{sh})}$

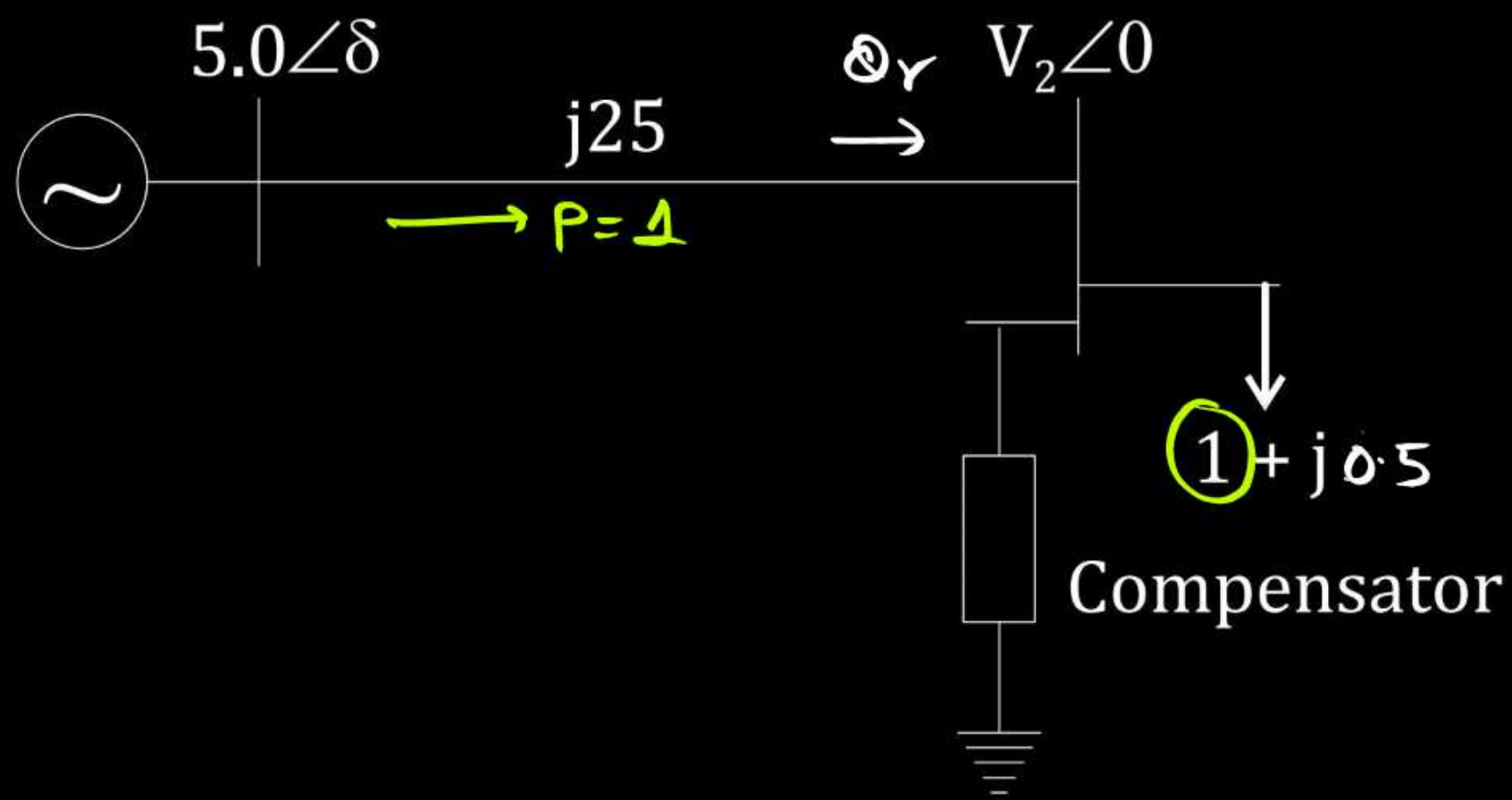
(D) $Z'_0 = Z_0 \sqrt{(1-K_{sh}) / (1-K_{se})}$

Series Capacitor = $Z_s \sqrt{1-K_{se}}$

Shunt Capacitor = $\frac{Z_s}{\sqrt{1+K_{sh}}}$

Both $\frac{Z_s \sqrt{1-K_{se}}}{\sqrt{1+K_{sh}}}$

Q.



Consider the given system to get the V_q equal to supply voltage in magnitude, the compensator required is ?

- A** A shunt capacitor of 1 VAR rating
- B** A shunt reactor of 1 VAR rating
- C** ✓ A shunt capacitor of 25 VAR rating
- D** A shunt reactor of 25 VAR rating

$$P = \frac{|V_s||V_r|}{X} \sin \delta$$

$$1 = \frac{(5)(5)}{25} \sin \delta$$

$$\sin \delta = 1$$

$$\delta = \pi/2$$

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

$$Q_r = \frac{(5)(5)}{(25)} \cos 90^\circ - \frac{(5)^2}{25}$$

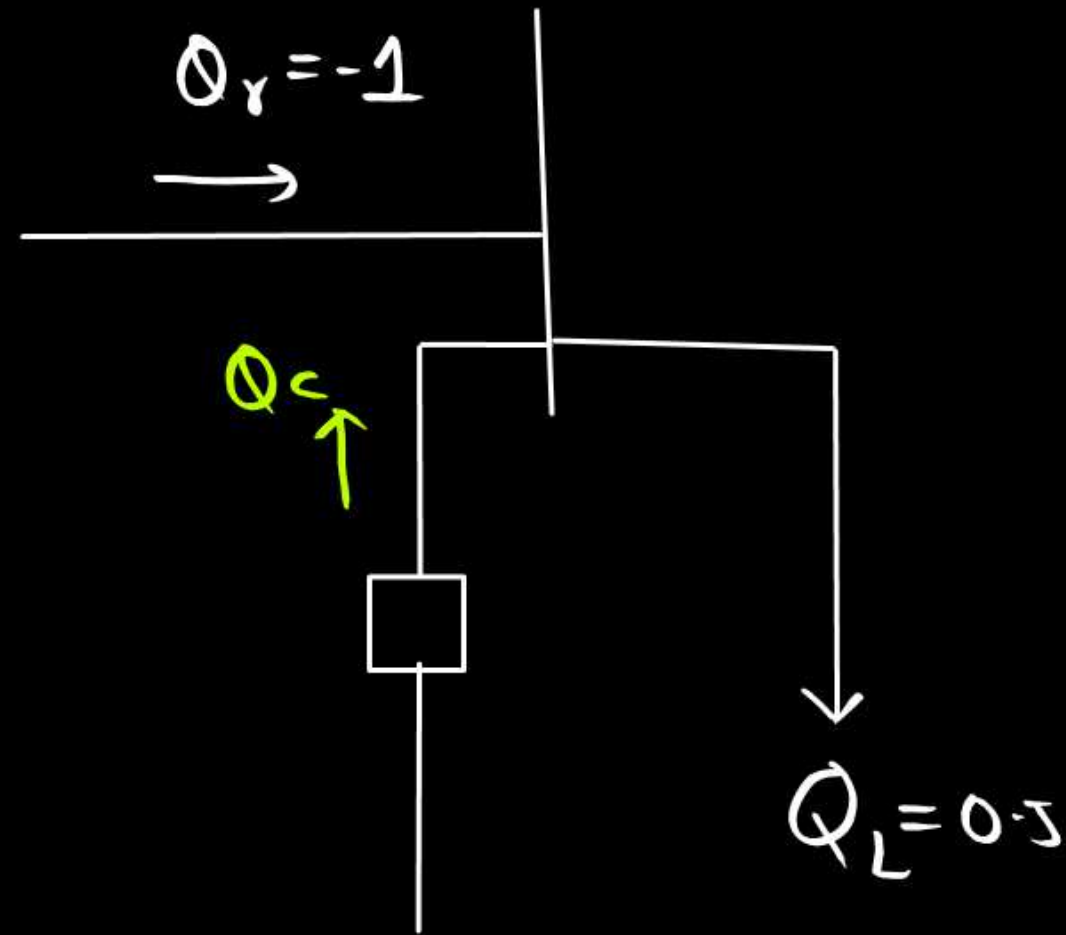
$$Q_r = -1$$

$$Q_c + Q_r = Q_L$$

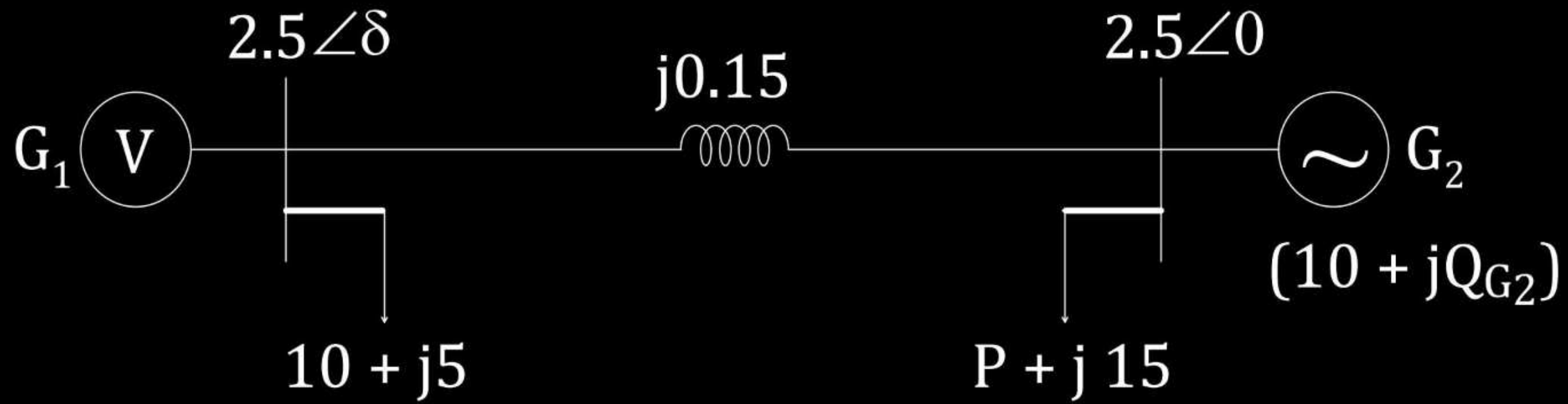
$$Q_c - 1 = 0.5$$

$$Q_c = \underline{\underline{1.5}}$$

it is giving reactive power (capacitor)



Q.



The reactive power supplied by generator G_2 is

- A** 27.75 VAR
- B** 39.82 VAR
- C** 32.12 VAR
- D** 13.82 VAR

#Q. If the loading of the line is less than the surge impedance loading, then which one of the following statements is correct? [ESE-2024]

Ferranti effect

V increases <

- A** ☒ The absorbed reactive power is greater than the generated reactive power and receiving-end voltage is greater than sending-end voltage.
- B** ☒ The absorbed reactive power is less than the generated reactive power and receiving-end voltage is greater than sending-end voltage. ($V_r > V_s$)
- C** The absorbed reactive power is greater than the generated reactive power and receiving-end voltage is less than sending-end voltage.
- D** The absorbed reactive power is less than the generated reactive power and receiving-end voltage is less than sending-end voltage.

#Q. Which one of the following is not a method of voltage control in power systems?
[ESE-2022]

- A** Booster transformer ✓
- B** Tap-changing transformer ✓
- C** Series ~~capacitor~~ ^{Inductor} ✗
- D** Shunt inductor ✓



2 Minutes Summary

- Effect on SIL by using Compensator
- Booster x-mcr
- tap changing x-mcr
- Overexcited syn Motor

Thank you

GW
Soldiers !



PRACTICE SHEET-1

EE

POWER SYSTEMS

Voltage Control

- Q 1** A string insulator has 5 units. The voltage across the bottom most unit is 25% of the total voltage. The string efficiency is :
 (A) 25% (B) 50%
 (C) 80 % (D) 75%
- Q 2** A 3-phase transmission line is supported by a 3-unit suspension insulator string. The voltage across the unit nearest to the line is 20 kV and that across the adjacent unit is 15 kV. The ratio of mutual to ground capacitance is :
 (A) 0.12 (B) 0.14
 (C) 0.16 (D) 0.18
- Q 3** A string of four insulators has a self-capacitance equal to 5 times pin to earth capacitance. The string efficiency is :
 (A) 62.12 % (B) 64.86 %
 (C) 72.12 % (D) 84.86 %
- Q 4** Two insulator discs of identical capacitance value C makes up a string for a 22 kV, 50 Hz, single phase overhead line insulation system. If the pin to earth capacitance is also C, then the string efficiency is ____%.
- Q 5** The corona loss on a particular system at 50Hz is 1kW/km per phase. The corona loss at 60Hz would be ____kW.
- Q 6** A 400-kV transmission line has following constant $A = 0.80 \angle 5^\circ$ $B = 180 \angle 70^\circ$
 Determine power at unity power factor that can be received, if voltage profile at each end is to be maintained at 400 kV.
 (A) 117.7 MW (B) 311 MW
 (C) 103.66 MW (D) 212.6 MW
- Q 7** A 200-kV transmission line having $A = 0.8 \angle 0^\circ = D$, $B = 100 \angle 90^\circ$, $C = 0.2 \times 10^{-6} \text{ } \Omega/\text{ph}$ is working under no load condition. The shunt reactor requires to compensate Ferranti effect at receiving end is.
 (A) 150 Ω
 (B) 500 Ω
 (C) 300 Ω
 (D) 250 Ω
- Q 8** A 400 km long transmission line has series impedance of $(0.5 + j1) \Omega/\text{km}$ and shunt admittance of $(0.01 + j5) \mu \text{ mho}/\text{km}$. The magnitude of characteristic impedance of transmission line will be_____
- Q 9** Corona is accompanied by:
 (A) Violet visible discharge
 (B) Hissing sound
 (C) Radio interference
 (D) All of these
- Q 10** Corona in DC supply is ____
 (A) Zero (B) Less than AC
 (C) Greater than AC (D) Cannot be calculated

Answer Key

Q1	C	Q6	B
Q2	D	Q7	B
Q3	B	Q8	472~473
Q4	75~75	Q9	D
Q5	1~1.16	Q10	B





Power Systems

Practice Sheet 01 Discussion Notes

Voltage control

By- Ajay Gupta Sir

Q.

A string insulator has 5 units. The voltage across the bottom most unit is 25% of the total voltage. The string efficiency is

A

25%

B

50%

C

80 %

D

75%

$$\eta = \frac{\text{Total voltage across string.}}{\text{No of unit} \times \text{Voltage of bottom most unit}}$$

$$\eta = \frac{100}{5 \times 25} = \frac{4}{5} = 0.8 = 80\%$$

Q.

A 3-phase transmission line is supported by a 3-unit suspension insulator string. The voltage across the unit nearest to the line is 20 kV and that across the adjacent unit is 15 kV. The ratio of mutual to ground capacitance is

A 0.12

B 0.14

C 0.16

D 0.18

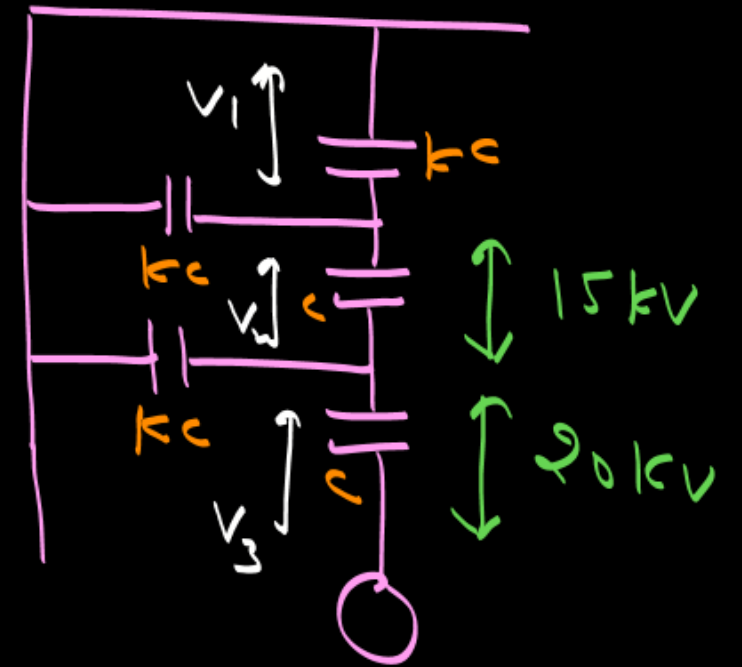
$$V_1 = V$$

$$V_2 = V(1+k)$$

$$V_3 = V(1+3k+k^2)$$

$$20 = V(1+3k+k^2)$$

$$15 = V(1+k)$$



$$\frac{\overset{4}{\cancel{20}}}{\underset{3}{\cancel{15}}} = \frac{1+3k+k^2}{1+k}$$

$$4+4k = 3+9k+3k^2$$

$$3k^2+5k-1=0$$

$$k = \frac{-5 \pm \sqrt{25+12}}{6} = \frac{-5 \pm 6.08}{6} = 0.18$$

Q.

A string of four insulators has a self-capacitance equal to 5 times pin to earth capacitance. The string efficiency is



$$k = \frac{1}{5} = 0.2$$

A 62.12 %**B** 64.86 % ✓**C** 72.12 %**D** 84.86 %

$$V_1 = V = V$$

$$V_2 = (1+k)V = 1.2V$$

$$V_3 = (1+3k+k^2)V = 1.64V$$

$$V_4 = (1+6k+5k^2+k^3)V = 2.408V$$

$$\eta = \frac{V + 1.2V + 1.64V + 2.408V}{2.408 \times 4} = 0.6486 = 64.86\%$$

Q.

Two insulator discs of identical capacitance value C makes up a string for a 22 kV, 50 Hz, single phase overhead line insulation system. If the pin to earth capacitance is also C , then the string efficiency is ____%.

$$K = \frac{C}{C} = 1$$

$$V_1 = V = V$$

$$V_2 = (1 + K)V = 2V$$

$$\eta = \frac{V + 2V}{2 \times (2V)} = \frac{3}{4} = 0.75 = 75\%$$

Q.

The corona loss on a particular system at 50Hz is 1kW/km per phase. The corona loss at 60Hz would be ____kW/ km/ Ph.

$$P_c \propto (f + 25)$$

$$\frac{P_{c1}}{P_{c2}} = \frac{(f_1 + 25)}{(f_2 + 25)}$$

$$\frac{1}{P_{c2}} = \frac{50 + 25}{60 + 25}$$

$$P_{c2} = \frac{85}{75} = 1.13 \text{ kW/km/phase}$$

Q. A 400-kV transmission line has following constant

$$A = 0.80 \angle 5^\circ \quad B = 180 \angle 70^\circ$$

Determine power at unity power factor that can be received, if voltage profile at each end is to be maintained at 400 kV

$$\text{if } V_S = V_R = 400 \text{ kV}$$

$$Q_R = 0 = \frac{|V_S||V_R|}{|B|} \sin(\beta - \delta) - \frac{|A||V_R|^2}{|B|} \sin(\beta - \alpha)$$

$$\frac{400 \times 400}{|B|} \sin(70 - \delta) = \frac{0.8 \times (400)^2}{|B|} \sin(5 - \delta)$$

$$\sin(70 - \delta) = 0.8 \sin(5 - \delta)$$

$$70 - \delta = 46.47 \Rightarrow \delta = 23.52$$

A 117.7 MW

B 311 MW

C 103.66 MW

D 212.6 MW

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

$$P = \frac{(400 \times 10^3)^2}{180} \cos(70 - 23.52) - \frac{0.80 \times (400 \times 10^3)^2}{180} \cos 65$$

$$= \frac{(400 \times 10^3)^2}{180} [0.6886 - 0.338]$$

$$= 311.65 \times 10^6 \text{ W}$$

$$= 311.65 \text{ MW}$$

Q.

A 200-kV transmission line having $A = 0.8 \angle 0^\circ = D$, $B = 100 \angle 90^\circ$, $C = 0.2 \times 10^{-6} \text{ S/ph}$ is working under no load condition. The shunt reactor requires to compensate Ferranti effect at receiving end is.

A 150 Ω

B 500 Ω

C 300 Ω

D 250 Ω

$$X_L = \frac{|B|}{1 - |A|}$$

$$= \frac{100}{1 - 0.8} = \frac{100}{0.2} = 500 \Omega$$

Q.

A 400 km long transmission line has series impedance of $(0.5 + j1) \Omega/\text{km}$ and shunt admittance of $(0.01 + j5) \mu\text{mho}/\text{km}$. The magnitude of characteristic impedance of transmission line will be _____ Ω

$$Z_c = \sqrt{\frac{Z}{y}} = \sqrt{\frac{(0.5 + j1)}{(0.01 + j5) \times 10^{-6}}} = \underline{472.8 \angle -13.2}$$

Q. Corona is accompanied by:

- A** Violet visible discharge
- B** Hissing sound
- C** Radio interference
- D** ✓ All of these

Q. Corona in DC supply is ____

- A** Zero
- B** Less than AC ✓
- C** Greater than AC
- D** Cannot be calculated

$$P_c \propto (t + 25)$$

Thank
you