CMR
INSTITUTE OF
TECHNOLOGY

USN | | | | | | | | | |

Internal Assesment Test - III

Sub:	POWER SYSTEM OPERATION AND CONTROL							Code:	15EE81
Date:	14/ 05/ 2019	Duration:	90 mins	Max Marks:	50	Sem:	8th	Branch:	EEE

1. Three supply points A,B and C are connected to a common busbar M.Supply point A is maintained at a nominal 275 kv and is connected to M through a 275/132kv transformer (0.1 p.u. reactance) and a 132kv line of reactance 50Ω. Supply point B is nominally at 132kv and is connected to M through a 132kv line of 50Ω reactance. Supply point C is nominally at 275kv and is connected to M by a 275/132kv transformer (0.1 p.u. reactance) and a 132kv line of 50Ω reactance.
If at a particular system load, the line voltage of M falls below its nominal value by 5kv, calculate the magnitude of the reactive volt-ampere injection required at M to re-establish the original voltage.
The p.u. values are expressed on a 500 MVA base and resistance may be neglected throughout.

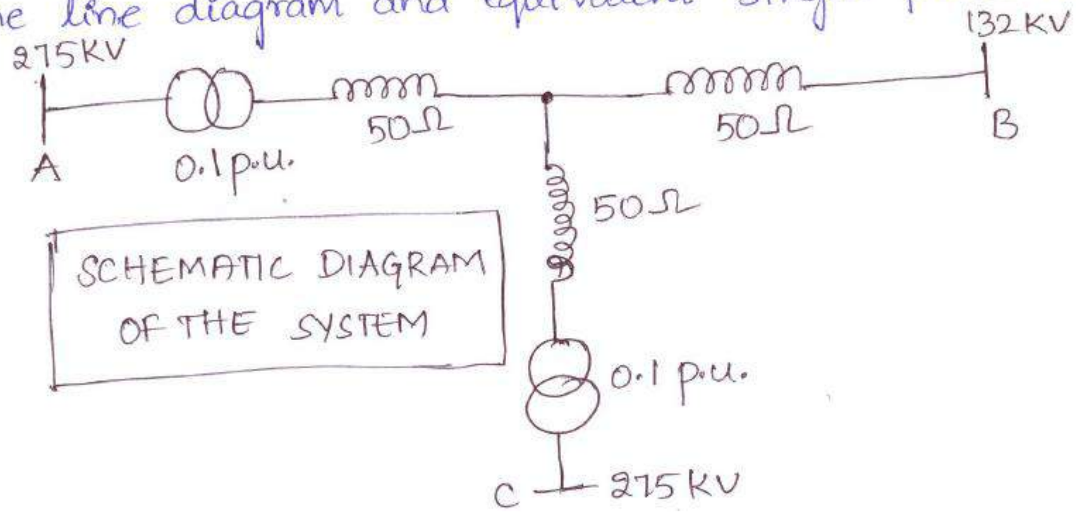
Base KV = 132 KV

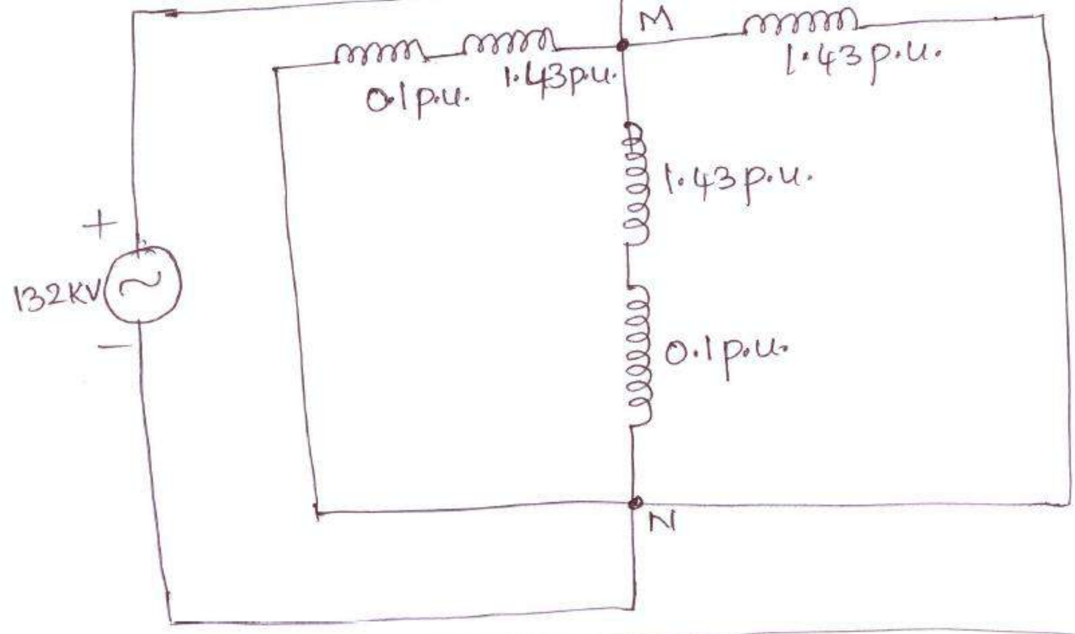
Base MVA = 500 MVA

$$\text{Base impedance} = \frac{(\text{Base kV})^2}{\text{Base MVA}} = 35\,\Omega$$

$$\therefore \text{The line reactances} = \frac{50}{35} = 1.43\ \text{p.u.}$$

The line diagram and equivalent single-phase circuit are:





EQUIVALENT SINGLE PHASE NETWORK.

Equivalent reactance from M to N = 0.5 p.u. 16

Hence the fault MVA at M = $\frac{500}{0.5}$ = 1000 MVA.

and the fault current = $\frac{100 * 10^6}{\sqrt{3} * 132000}$ = 4380.

we know that; $\frac{\partial Q_M}{\sqrt{3}\partial V_M}$ = three-phase short-circuit current.

where Q_M = Three-phase reactive power

V_M = phase voltage.

from $\frac{\partial Q_M}{\sqrt{3}\partial V_M}$ = 4380 A

$\frac{\partial Q_M}{\partial V_M}$ = 7.6 MVAr/KV

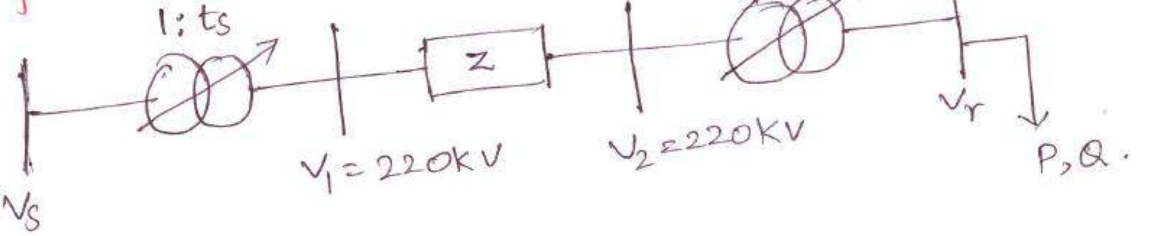
The natural voltage drop at M = 5 KV

$\therefore \boxed{\partial Q_M = 7.5 * 5 = 38 \text{ MVAr}}$

The reactive power to be injected.

2. A 220kv, line has tap changing transformer at both ends. The transformer at sending end has a nominal ratio of 11/220kv and that at receiving end 220/11kv. The line impedance is (20+j60) Ω and the load at the receiving end is 100 MVA, 0.8 p.f. (lag). If the product of two off-nominal setting is 1, find the tap setting to give 11kv at load bus

Sol:



$V_1 = V_2 = 220\,KV = 1\ p.u.$

$Z = (20 + j60)\,\Omega$ | Base MVA = 100 MVA $\quad \cos\phi \rightarrow \phi = 36.86^\circ$.

$|S| =$ Load MVA $= 100\,MVA,\ 0.8\ pf\ (lag)$

$P = |S|\cos\phi = 80\,MW$ | $Q = |S|\sin\phi = 60\,MVAR$.

$$S = P + jQ = (0.8 + j0.6)\ pu$$

$$\text{Base impedance} = \frac{(KV)^2}{MVA} = 484\,\Omega$$

$$t_s \cdot t_r = 1$$

$$R\,(pu) = \frac{20}{484} = 0.042$$

$$X\,(pu) = \frac{60}{484} = 0.124.$$

$$V_2 = \frac{1}{2}\left[V_1 t_s^2 + \sqrt{V_1^2 t_s^4 - 4t_s^2 (RP + QX)}\right]$$

$$2 = t_s^2 \pm \sqrt{t_s^4 - 0.432\,t_s^2}$$

$$(2 - t_s^2)^2 = t_s^4 - 0.432\,t_s^2$$

$$4 = t_s^2\,[4.432]$$

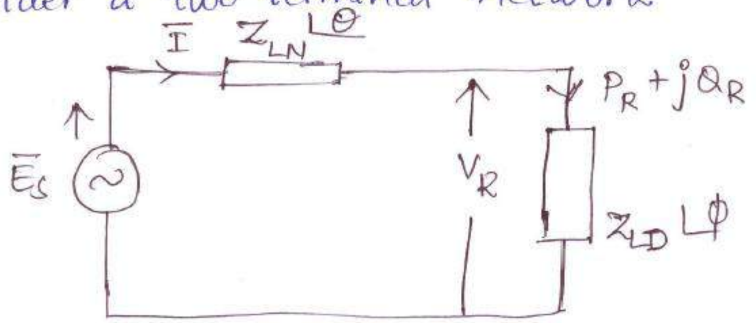
$$\boxed{t_s = 0.95} \quad \boxed{t_r = 1/t_s = 1.0526}$$

3. Explain voltage stability and voltage collapse

Voltage stability is the ability [top of line cut off] to maintain acceptable voltages at all buses in the system under normal conditions and after being subjected to a disturbance.

* A system enters a state of voltage instability when a disturbance increase in load demand or change in system condition causes a progressive and uncontrollable decline in voltage.
* The main factor causing instability is the inability of the power system to meet the demand of reactive power.

Consider a two terminal network. 18



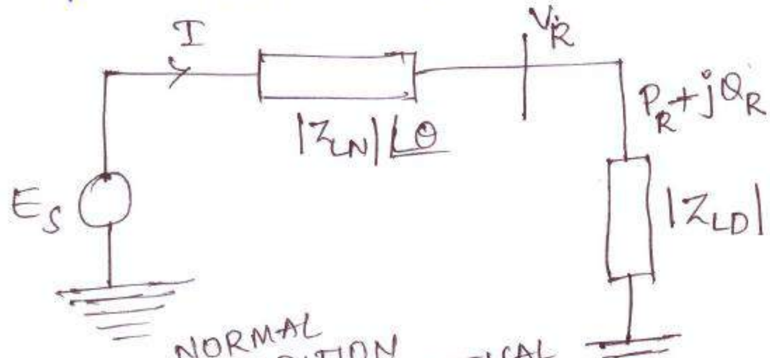
$$\bar{I} = \frac{\bar{E}_s}{Z_{LN} + Z_{LD}} \quad \text{--- (1)}$$

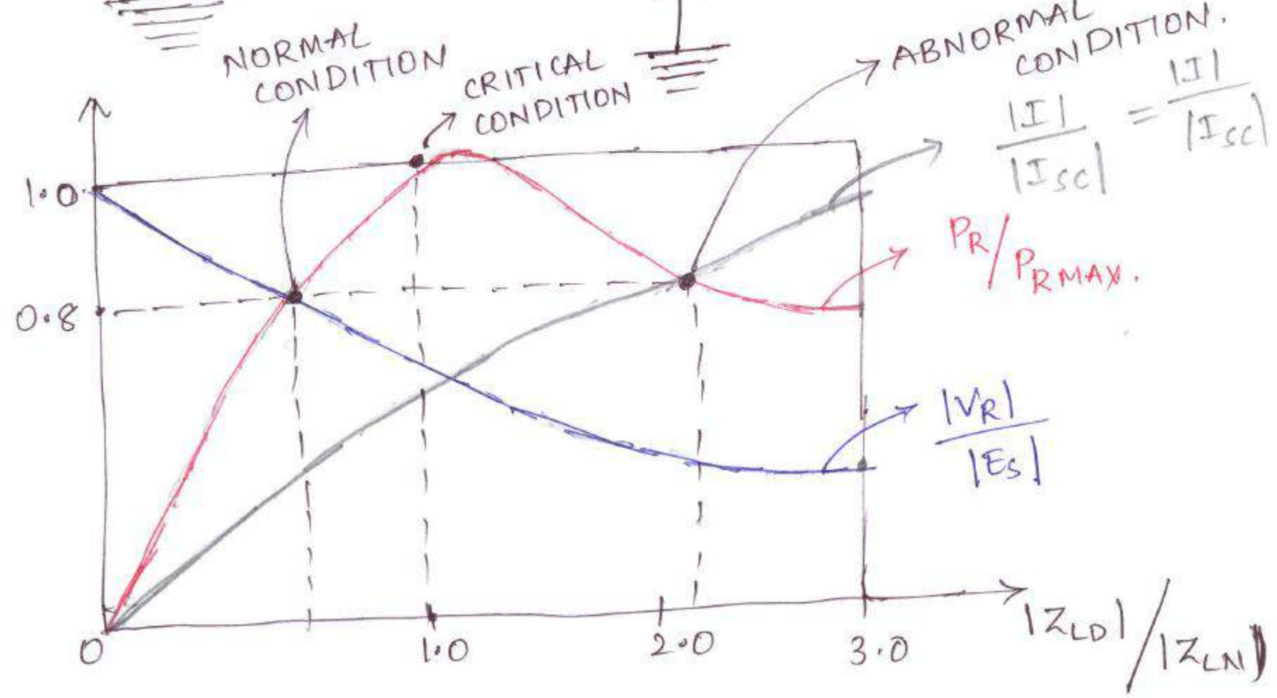
$$Z_{LN} = |Z_{LN}|\angle\theta = |Z_{LN}|\cos\theta + j|Z_{LN}|\sin\theta$$
$$Z_{LD} = |Z_{LD}|\angle\phi = |Z_{LD}|\cos\phi + j|Z_{LD}|\sin\phi$$
$$\bar{E}_s = |E_s|\angle 0^\circ$$

$$|I| = \frac{|E_S|}{\sqrt{\left(|Z_{LN}|\cos\theta + |Z_{LD}|\cos\phi\right)^2 + \left(|Z_{LN}|\sin\theta + |Z_{LD}|\sin\phi\right)^2}}$$

$$|V_R| = |Z_{LD}|\,|I| \quad \text{——— (2)}$$

$$P_R = |V_R|\,|I|\cos\phi \quad \text{——— (3).}$$

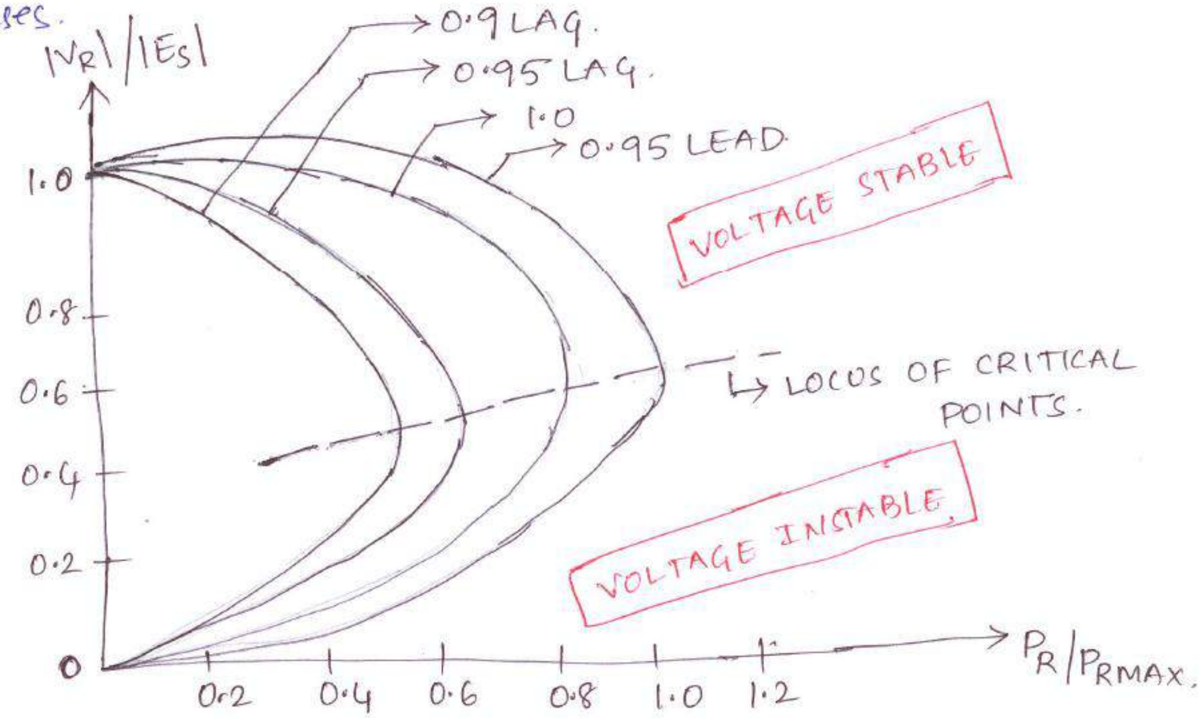




* As $|Z_{LD}|$ increases, the receiving end voltage (V_R) decreases.

* As $|Z_{LD}|$ increases, the current (I) increases. (19)

* As $|Z_{LD}|$ increases, the P_R increases and when $|Z_{LD}| = |Z_{LN}|$ $P_R \rightarrow P_{RMAX}$ (Maximum power transfer theorem) and then decreases.



VOLTAGE COLLAPSE:

Voltage collapse is the process by which the sequence of events accompanying the voltage instability leads to a low unacceptable voltage profile in a significant part of a power system.

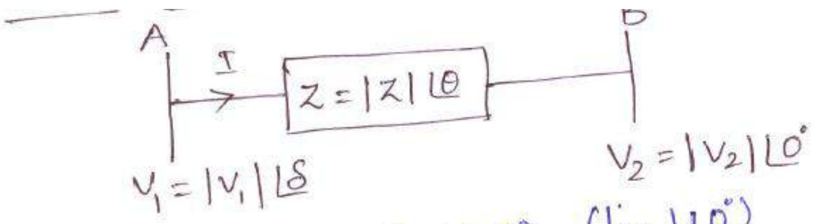
SCENARIO OF VOLTAGE COLLAPSE:

* Heavily loaded system
* Loss of heavily loaded line
* Reduction in voltage
* Operation of On-Load Tap Changer transformer
* Generators reaching field current limits.
* Reduced effectiveness of shunt compensators.

---

4. Show that real power flow between two nodes is determined by transmission angle δ,

And reactive power flow between two nodes is determined by scalar voltage difference between two nodes.



$$I = \frac{V_1 - V_2}{Z} = \frac{(|V_1| \angle \delta) - (|V_2| \angle 0^\circ)}{|Z| \angle \theta}$$

$$I = \frac{|V_1|}{|Z|} \angle \delta - \theta - \frac{|V_2|}{|Z|} \angle -\theta$$

$$\boxed{\begin{array}{l} \text{If } I = r \angle \theta \\ \quad I^* = r \angle -\theta \end{array}}$$

$$I^* = \frac{|V_1|}{|Z|} \angle \theta - \delta - \frac{|V_2|}{|Z|} \angle \theta$$

Complex power $S = V_2 I^* = (|V_2| \angle 0^\circ) \left[\frac{|V_1|}{|Z|} \angle \theta - \delta - \frac{|V_2|}{|Z|} \angle \theta \right]$

$$S = \frac{|V_1||V_2| \angle \theta - \delta}{|Z|} - \frac{|V_2|^2}{|Z|} \angle \theta$$

$$r \angle \theta = r \cos\theta + j r \sin\theta .$$

$$S = \left[\frac{|V_1||V_2|}{|Z|} \cos(\theta - \delta) + j \frac{|V_1||V_2|}{|Z|} \sin(\theta - \delta) \right] -$$

$$\left[\frac{|V_2|^2}{|Z|} \cos\theta + j \frac{|V_2|^2}{|Z|} \sin\theta \right]$$

$$S = P + jQ$$

$$P = \frac{|V_1||V_2|}{|Z|}\cos(\theta-\delta) - \frac{|V_2|^2}{|Z|}\cos\theta$$

$$Q = \frac{|V_1||V_2|}{|Z|}\sin(\theta-\delta) - \frac{|V_2|^2}{|Z|}\sin\theta$$

$\because$ For transmission line; $R << X_L$; $\tan^{-1}\left(\frac{X_L}{R}\right) = \theta \simeq 90^\circ$

$$\therefore P = \frac{|V_1||V_2|}{|Z|}\sin\delta$$ $\Rightarrow$ Real power flow between two nodes is determined by transmission angle (δ)

$$Q = \frac{|V_1||V_2|}{|Z|}\cos\delta - \frac{|V_2|^2}{|Z|}$$

$\because$ For small load angle;

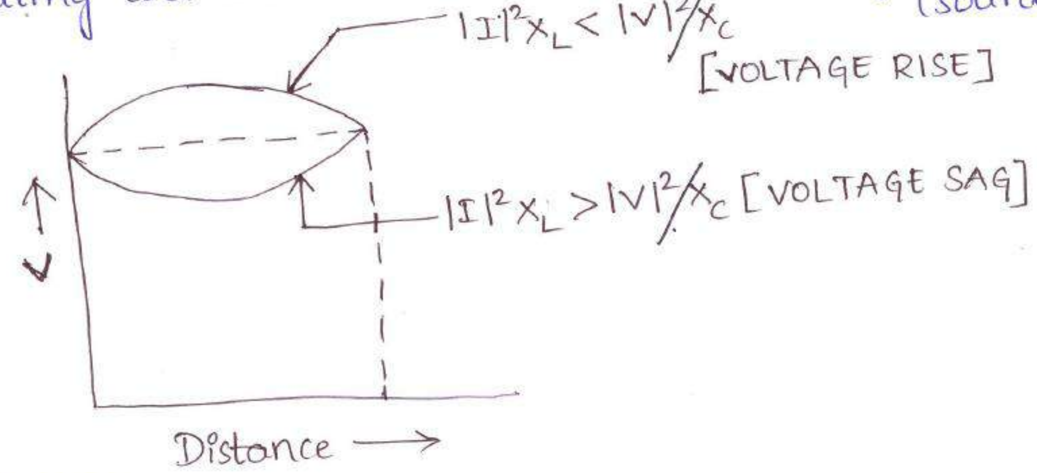
$$Q = \frac{|V_2|}{|Z|}\left[|V_1| - |V_2|\right]$$

$\hookrightarrow$ Thus Reactance power (Q) flow between two nodes is determined by scalar voltage difference between two nodes.

5. Discuss sources and sinks (Generation and Absorption) of reactive power.

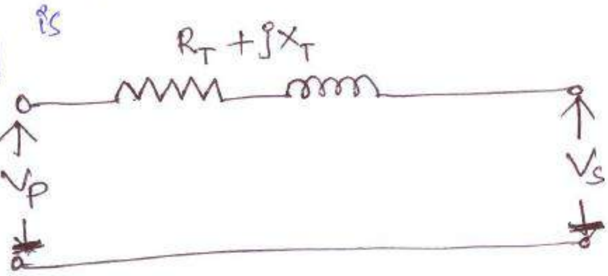
* TRANSMISSION LINES:

1. The loading condition in which the VARs absorbed are equal to VARs generated by the line is called surge impedance loading (SIL) and it is where the voltage throughout the length of line is same.
2. Normally the loading is greater than SIL and therefore, the condition $|I^2|X_L > |V|^2/X_C$ exists and the net effect of the line will be to absorb (sink) the reactive power (VARs).
3. Under light load conditions the effect of shunt capacitors is predominating and the line will work as VARs generator (source).



* TRANSFORMERS:

The equivalent circuit of a transformer for power frequency is



R_T = per unit resistance

X_T = per unit reactance.

By defination; Per unit reactance $(X_T) = \dfrac{\text{Actual Reactance } (X)}{\left(\frac{KV}{I}\right)}$

$$\text{Actual reactance}, X = X_T \cdot \left(\frac{KV}{I}\right)$$

$$I = \frac{KVA}{\sqrt{3}\ KV}$$

$$\therefore\ X = \frac{\sqrt{3}\, X_T \cdot KV^2 \cdot 1000}{KVA}$$

The reactive power absorbed by the transformer,

$$3I^2 X = \frac{3\,KVA^2}{3\,KV^2} \cdot \frac{\sqrt{3}\, X_T\, KV^2 \cdot 1000}{KVA}$$

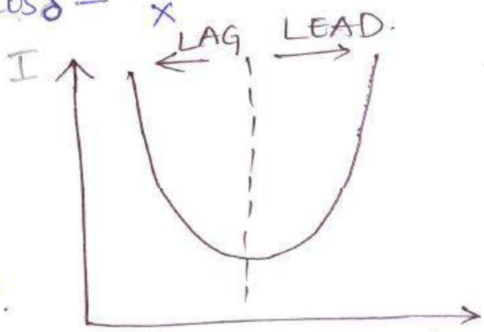
$$3I^2 X = \sqrt{3}\ KVA \cdot X_T \quad KVARS$$

Transformer always absorb reactive power.

* SYNCHRONOUS MACHINES :

It is known that power transmitted from a generator bus to an infinite bus-bar is given by

$$P = \frac{|E||V|}{X} \sin\delta \qquad \Big|\qquad Q = \frac{|V||E|}{X}\cos\delta - \frac{|V|^2}{X}$$



where, E = Generator voltage
V = Infinite bus bar voltage
X = Reactance of the unit
δ = Angle between E and V.

The above formula tells that if $|E|\cos\delta > |V|$, then $Q > 0$ and the generator produces reactive power i.e. it acts as a capacitor. Therefore, it can be said that an over-excited synchronous machine produces reactive power and acts as a shunt capacitor.

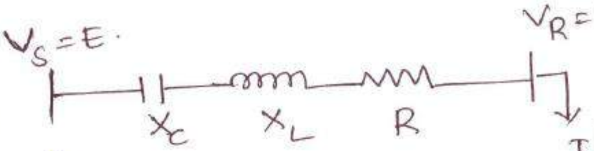
Similarly when $|E|\cos\delta < |V|$, $Q < 0$ and the machine consumes reactive power. Consequently an under-excited machine acts as a shunt coil.

* SHUNT CAPACITORS AND REACTORS:

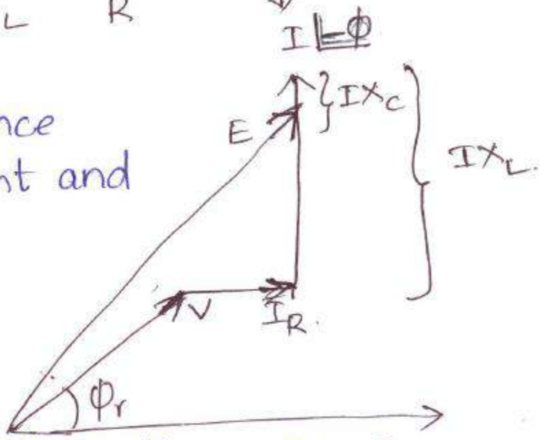
3

1. Shunt capacitors are used across an inductive load, to supply part of the reactive power (VARs) required by the load. Thereby the voltage across the load is maintained within certain desirable limits.
2. The shunt reactors are used across capacitive loads or lightly loaded lines to absorb some of the leadings VARs again to control the voltage across the load to within certain desirable limits.

* SERIES CAPACITORS:



If a static capacitor is connected in series with the line, it reduces the inductive reactance between the load and the supply point and the voltage drop is approximately



$$\boxed{IR\cos\phi_r + I(X_L - X_C)\sin\phi_r.}$$

It is clear from the vector diagram that the voltage drop produced by an inductive load can be reduced particularly when the line has a high X/R ratio.

*CABLES:

Cables are generators of reactive power owing to their high shunt capacitance.

6a. Derive the relation between voltage, active power and reactive power at a node.

We have seen that V at a node is a function of P & Q

$$\therefore \quad V = f(P, Q)$$

$$dv = \frac{\partial V}{\partial P} \cdot dp + \frac{\partial V}{\partial Q} \cdot dq \quad \text{— (5)}$$

We know that $\frac{\partial P}{\partial V} \frac{\partial V}{\partial P} = 1$ and $\frac{\partial Q}{\partial V} \cdot \frac{\partial V}{\partial Q} = 1$

Using in (5) $\longrightarrow$ $$dV = \frac{dP}{\partial P/\partial V} + \frac{dQ}{\partial Q/\partial V} \quad \text{—— (6)}$$

From (3) $\longrightarrow$ $$\Delta V = E - V = \frac{RP + XQ}{V}$$

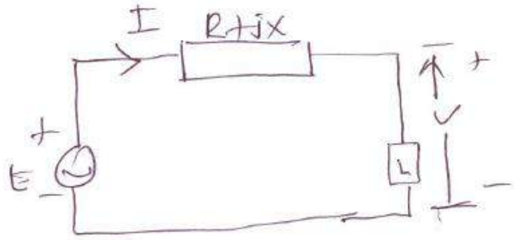
$$(E-V)V - RP - XQ = 0 \quad \text{— (7)}$$

$$\therefore \quad \frac{\partial P}{\partial V} = \frac{E-2V}{R} \quad \text{—— (8)}$$

$$\frac{\partial Q}{\partial V} = \frac{E-2V}{X} \quad \text{—— (9)}$$

(8), (9) in (6) $\longrightarrow$ $$\boxed{dV = \frac{dP \cdot R + dQ \cdot X}{E-2V}} \quad \text{—— (10)}$$

From (9) $\longrightarrow$ $$\frac{dQ}{\partial V} = \frac{E-2V}{X}$$



When the system is @ No-Load $V = E$,

$$\therefore \boxed{\left|\frac{\partial Q}{\partial V}\right| = \frac{E}{X}}$$

$\frac{E}{X}$ is nothing but the current when receiving end is short circuited and resistance neglected.

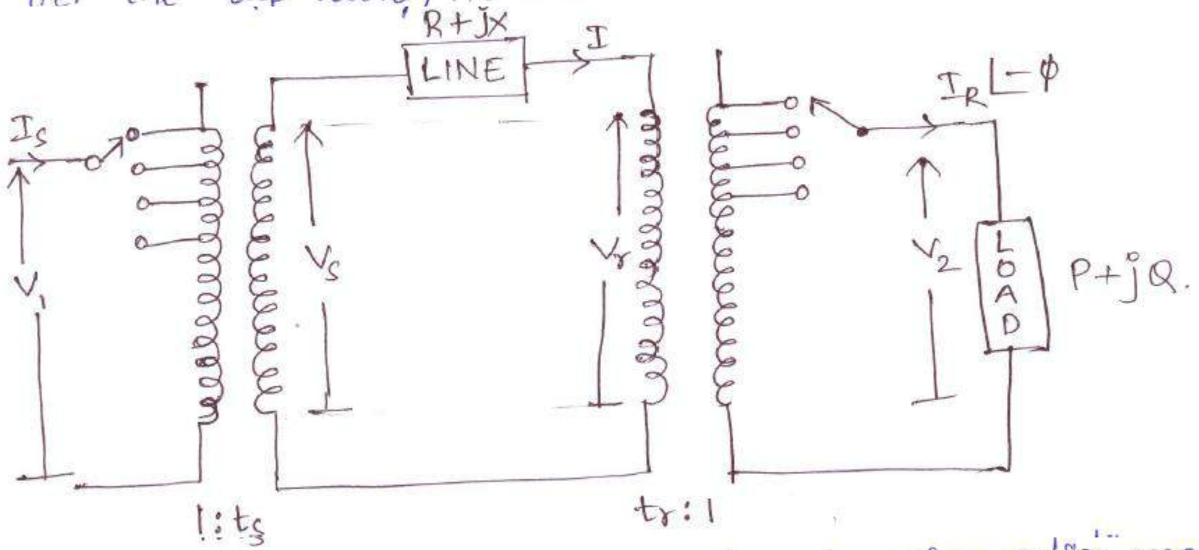
∴ We can say that the magnitude of $\left(\frac{\partial Q}{\partial V}\right)$ is equal to short circuit current, when $V = E$.

NOTE:— Even at loaded condition $E \simeq V$.

6b. Explain reactive power (voltage) control using tap changing transformer.

TAP-CHANGING TRANSFORMERS:

* By changing the transformation ratio of the tap-changing transformer, the voltage in the secondary circuit is varied and voltage control is obtained.
* Consider the operation of a radial transmission system with two tap-changing transformers, as shown in the equivalent single-phase circuit.
* Here t_s and t_r are fractions of the normal transformation ratios i.e. the tap ratio / nominal ratio.



* It is required to determine the tap-changing ratios required to completely compensate for the voltage drop in the line.
* The product $t_s t_r$ will be made unity.

Transfer all quantities to the load circuit. The line independence becomes; $(R+jX)/t_r^2$

$$\rightarrow \frac{V_1}{1} = \frac{V_s}{t_s} \longrightarrow V_s = V_1 \cdot t_s \rightarrow V_s = V_1 \cdot t_s$$

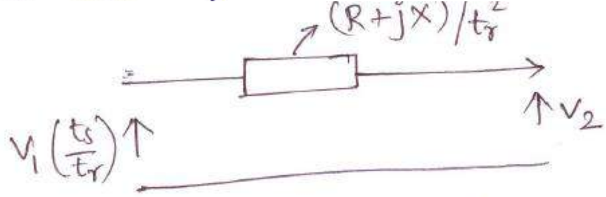
As the ~~imde~~ impedance has been transferred,

$$\rightarrow V_S = V_r = V_1 \cdot t_s \quad \text{Equating these two}$$

$$\rightarrow \frac{V_r}{t_r} = \frac{V_2}{1} \longrightarrow V_r = V_2 t_r \longrightarrow V_2 = V_1 t_s / t_r$$

$\therefore$ The input voltage to the load circuit becomes $V_1 t_s / t_r$ and the equivalent circuit is :

12



$\therefore$ The arithmatic voltage drop

$$\Longrightarrow \left[V_1 \frac{t_s}{t_r}\right] - V_2 = \frac{(RP + XQ)/t_r^2}{V_2} \; ; \text{ when } t_r = 1/t_s$$

$$t_s^2 V_1 V_2 - V_2^2 = (RP + XQ)\, t_s^2$$

$$V_2^2 - t_s^2 V_1 V_2 + (RP + XQ) t_s^2 = 0$$

$$ax^2 + bx + c = 0$$

$$\therefore \boxed{V_2 = \frac{1}{2}\left[V_1 t_s^2 \pm \sqrt{[V_1^2 t_s^4 - 4 t_s^2 (RP + QX)}\right]}$$

Hence if t_s is specified, there are two values of V_2 for a given V_1