Omgamganapathai namaha

# Power Quality & FACTS

## unit - I

→ **what is power Quality :-** is defined as the fitness of electrical power Supplied to Consumers. However, there Can be different definitions based on different perspectives. Ex:- Manufacturers of electrical equipments define power Quality as those features of electrical power Supply which are needed for porper working of equipments.

power Supplies define power Quality in terms of reliabity. from the point of view of electrical Consumers "any power problem manifested in Voltage; Current or frequency deviation in failure or misoperation of Consumer equipment."

→ **Different types of power Quality disturbances:-**

- → Transients
- → Short duration Variation
- → Long duration Variation
- → Voltage Imbalance
- → wave form distortions
- → Voltage fluctuations
- → power frequency Variations.

Power Quality Problems in distribution System:-

→ Correcting Power Quality Problems requires an understanding of all power distribution System components and how a Problem in one Component Can Cause Problem in other Components.

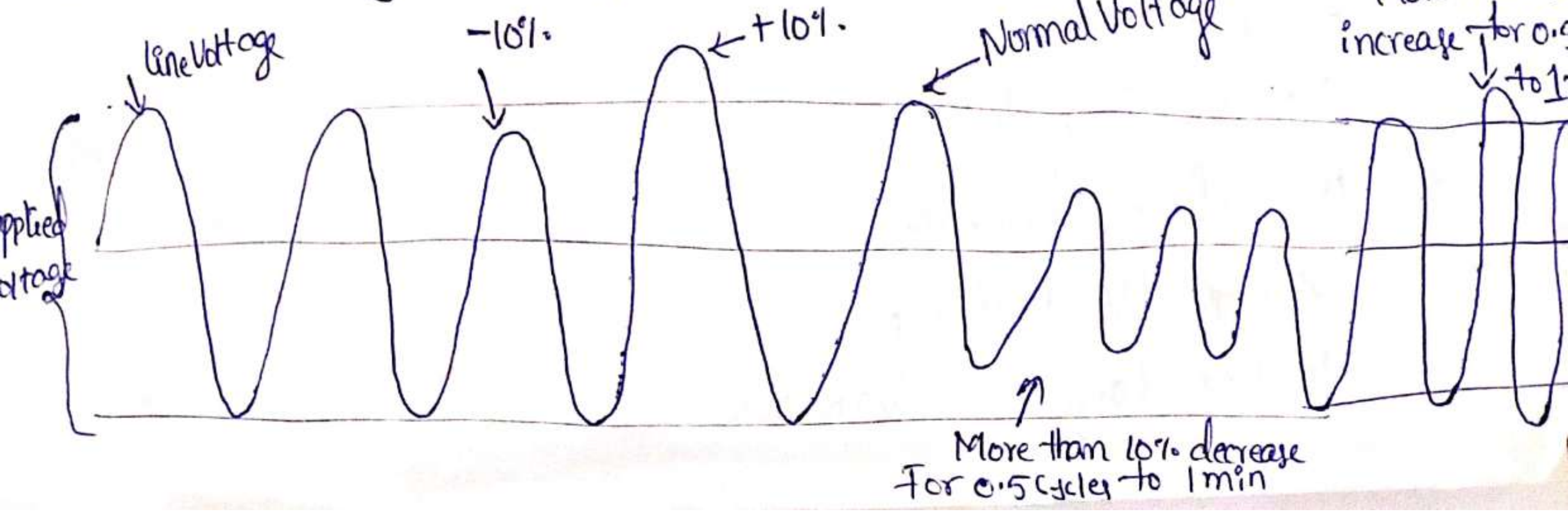
→ Distribution System Components include transformer, distribution lines, Switch boards, disconnectors, circuit breakers, fuses etc.

→ Electrical distribution System must be deliver quality power to loads, if the loads are to operate properly for their rated life-time and performance.

→ Quality power is power delivered to load that is within the load Specific Voltage, is Capable of delivering enough Current under any operating Condition, and includes minimal, not damaging changes.

→ Poor power Quality is power delivered to a load that includes excessive or damaging changes such as Voltage drops, Voltage unbalance, transients and harmonic distortion.

Power Quality Problems:-



## Power Quality:-

→ It is the ability of electrical grid or network to supply a clean and stable power to the consumers.

→ Electrical power quality mainly involves voltage, frequency and wave form.

**Power Quality = Voltage Quality**

⇒ Good power quality can be defined as:

→ Stedy supply voltage within prescribed range.

Ex:- 1-ph supply is for domestic consumers.

230V RMS, 50Hz & pure sinusoidal voltage.

→ Stedy AC frequency close to rated value.

Ex:- 48.5 to 50Hz.

→ Smooth voltage wave form.

## Power Quality Problems:-

→ Poor load power factor
→ Harmonic contents in load
→ Notching in load variation
→ DC off set in load voltage.
→ Unbalance of loads.
→ Supply voltage distortions
→ Voltage sag/swell
→ Voltage flicker.

## Different power Quality Terms:—

- → Transients:- short duration Problem due to Sudden change of state.
- → Short duration Voltage Variation
- → Long " " "
- → Voltage Imbalance or un balance
- → wave form distortions.
- → Voltage fluctuations.
- → Power freq Variations.

## Power Quality Problems and their Causes:—

(a)

| Broad Categories | Specific Categories | Method of Characterization | Typical Causes. |
| --- | --- | --- | --- |
| 1) Transients | Impulsive | Peak magnitude, rise time and duration. | Lightining Strokes, transformer energisation Capacitor Switching. |
| | Oscillatory | Peak magnitude, freq Components. | Line or Capacitor or load Switching. |
| 2.) Short duration Voltage Variation (up to 1 min) | Sag. | Magnitude, Duration | Ferroreasonant transformer, Single L-G faults. |
| | Swell | Magnitude, Duration. | " " " |
| | Interruption | Duration. | Temporary (self-cleaning) faults. |
| Long duration Voltage Variation. (More than 1 min) | under voltage. | Magnitude, Duration. | Switching on loads, Capacitor deenergisatio |
| | over voltage. | " " | Switching off loads (very large loads), Capacitor energisatio |
| | Sustained interuptions | Duration. | faults. |

| | | | |
|---|---|---|---|
| 4) Voltage Imbalance | | Symmetrical Components. | Single-phase loads, 1-phasing Condition. |
| 5) wave form distortion | Harmonics. | THD, Harmonic Spectrum. | Adjustable Speed drives, and other non-linear loads. |
| | Notching | THD, " | Powerelectronic converters. |
| | DC-offset | Volts, Amps. | Geo magnetic disturbances, half-wave rectification. |
| Voltage flicker. | | Frequency of occurence, modulating freq. | Arc-furnances, arc lamps. |

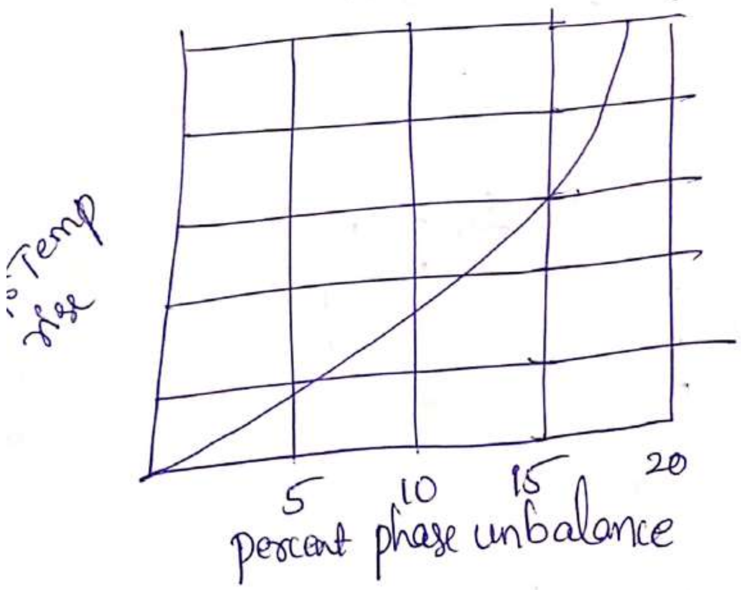
amngangarap...

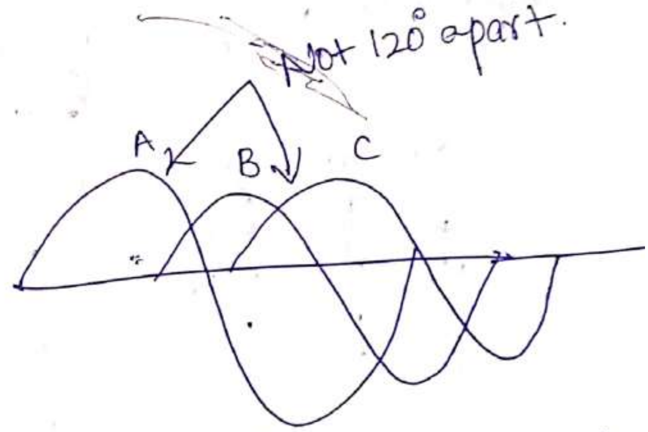
...se unbalance:- is the unbalance that occurs when power lines are out of phase.

phase unbalance of a 3-ϕ power system occurs when 1-ϕ loads are appalied, which causes one or two of the lines to carry more or less of the load. So this can be avoid by proper installation process.

A power Quality meter can be used to check phase unbalance of load on power lines. An unbalance begins to occur when additional 1-ϕ loads are added to the system. This unbalance causes the 3-ϕ lines to move out of phase so the lines are no longer 120° apart.

phase unbalance




phase unbalance causes 3-ϕ motors to run at tempara higher than listed ratings. The greater the phase unbalance the greater the temp rise. High Temp causes insulation breakdown and other related problems.

→A 3-ϕ motor operating in an unbalanced circuit causes cannot deliver its rated horse power

→ power Quality problems can damage electrical equipment and to unsafe operating conditions like

→ Improper phase seq of motor.

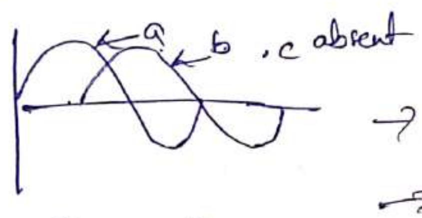
→ Voltage unbalance.

→ Voltage surges.

1-phasing:- is the operation of a motor is designed to operate on 3-ϕ but it is only operating on two phases bcz one phase is lost.

Single phasing occurs when one of the 3-lines leading to a 3-ϕ motor does not deliver voltage to the motor. Single phasing is the maximum condition of voltage imbalance in a distribution system.

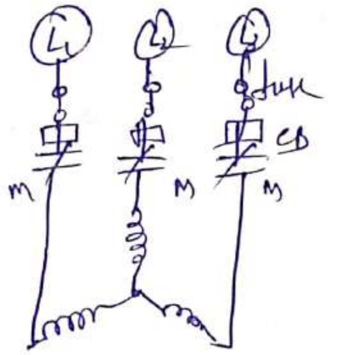
Motor wdg damage



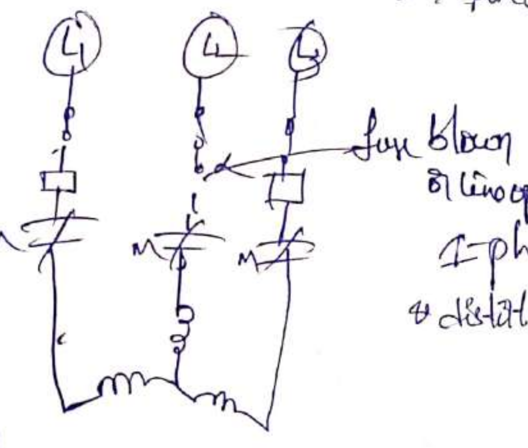

is reduced by using:-

→ properly sized dual element fuse and heaters.

→ An electronic phase loss monitor

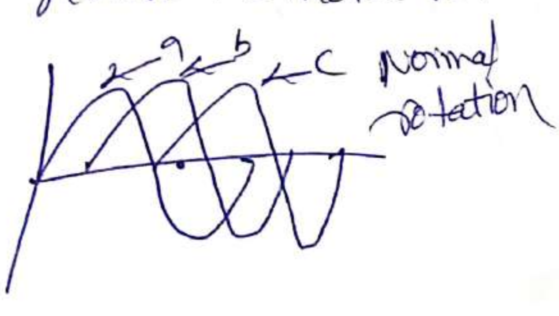



Normal motor operation (All 3 wdgs carry motor current)




1-phase causes severe burning & distortion to one or two wdgs

→ Improper phase seq:- means changing the sequence of any two phases (phase reversal) in a 3-ϕ motor ckt. Improper phase sequences change reverse the motor rotation. Improper phase seq can damage motor internal parts.




Currents unbalance

$L_1 = 58A$

$L_2 = 53A$

$L_3 = 57A.$

$$V_a = \frac{58+53+57}{3} = \frac{168}{3} = 56A.$$

$$I_d = 56-53 = 3$$

$$I_d = \frac{3}{56} \times 100 = 5.35\%$$

## Transients and Stedy State Variations in Voltage and frequency:-

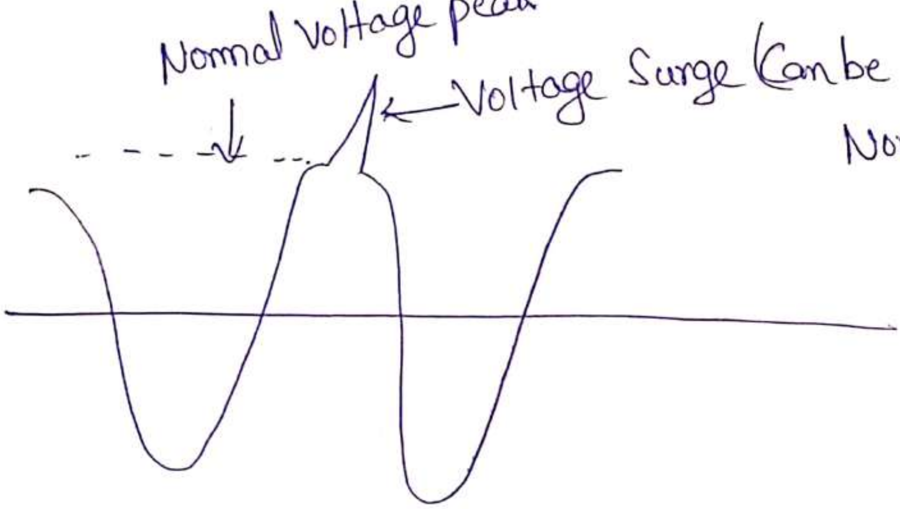
→ Transient over voltages in electrical transmission and distribution networks result from the unavoidable effect of lightning strike and network switching operations.

→ Response of an electrical n/w's to a sudden change in network conditions.

→ oscillation is an effect caused by a transient response of a system or circuit. It is a momentary event preceding the st. State during a sudden change of ckt.

So this Can be avoided by using proper lightining arrester, Surge arresters in distribution System.

→ Voltage Surges Can also occurs due to normal Switching & high power circuit, this Causes lessa damage to electrical equipments.




Normal Voltage Peak = Normal Rms Voltage X 1.4

Normal Rms = 230V

peak Voltage = 1.4 x 230 = 322 Volts.

$V_{RY} = 442V$ $V_{YB} = 474V$ $V_{BR} = 456V$.

Va = Add = 442 + 474 + 456 = 1372/3 = 457 V

find Voltage deviation 474 − 457 = 17V.
Vd =

Voltage unbalance = Vd/Va = ~~457~~

$= \frac{17}{457} \times 100 = 3.72\%$

2, 3, 10, 11
9, 11, 13, 14, 15

+5% -5%

Slightly decrease →

## DC Motor performance Characteristics

| | 10% Below Shunt | 10% Below Comp | 10% above Shunt | 10% above Comp |
|---|---|---|---|---|
| Start-Current | −15% | −15% | +15% | +15% |
| F.L Current | −5% | −6% | +5% | +6% |
| Motor torque | +12% | +12% | −8% | −8% |
| Motor eff | Decrease | | Increase | |
| Speed | Increase | | Decrease | |
| Temp rise | " | | " | |

**Voltage Surges:-** A Voltage Surge is a higher-than normal Vtg that temporarily exists on one or more power lines. Lightning is a major Cause of large Voltage Surges.

A lightning Surge on a power line Comes from direct lightning hit or induced Voltage. The lightning energy moves in both directions on the power line like rapidly moving wave.

A travelling Surge of lightning energy Causes a large Voltage rise in Short duration of time period. This Causes destroying the insulation and burning out of motor wdg.

# Voltage Variation characteristics

| Performance characteristics | 10% Above Rated voltage | 10% Below Rated Voltage |
| --- | --- | --- |
| → Starting current | +10% to +12% | −10% to −12% |
| → Full-load current | −7% | +11% |
| → Motor torque | +20% to +25% | −20% to −25% |
| → Motor efficiency | Little change → | |
| → Speed | +1% | −1.5% |
| → Temp rise | +3%°C to −4%°C | +6%C to +7%C |

A motor operates satisfactorily with a voltage variation of ±10% from the voltage rating listed on the nameplate.

<u>AC freq Variation</u>:— AC motors are rated for operation at specific frequencies. Motor performance is effected when freq varies from a motor's rated freq. A motor operates satisfactorily with a freq variation of ±5%.

| | 5% above Rated freq | 5% below rated freq. |
| --- | --- | --- |
| " | −5 to −6% | +5% to +6% |
| | −1% | +1% |
| | −10% | +11% |
| | Slightly increase → | |

**Long duration Voltage Variations:-** These are defined as the RMS Variations in the Supply Voltage at fundamental frequency for period more than 1min.

These are classified as.

**Over Voltage:-** An over voltage is a 10% increase in RMS Voltage for more than 1min.

**under Voltage:-** An under voltage is a 10% decrease in RMS Voltage for more than 1min.

**Sustained interruption:-** It happens when the Supply Voltage becomes zero for more than 1min.

**Voltage Imbalance: or Vtg unbalance.** In the Case of Voltage Imbalance, the Voltages & currents the three phases of the Supply are not equal in magnitude.

→ Voltages of three phases may not even be equally displaced.

→ The primary Cause of Voltage imbalance is the Single phase loads in three phase circuits and unequal line parameters.

→ These are restricted to within 5%

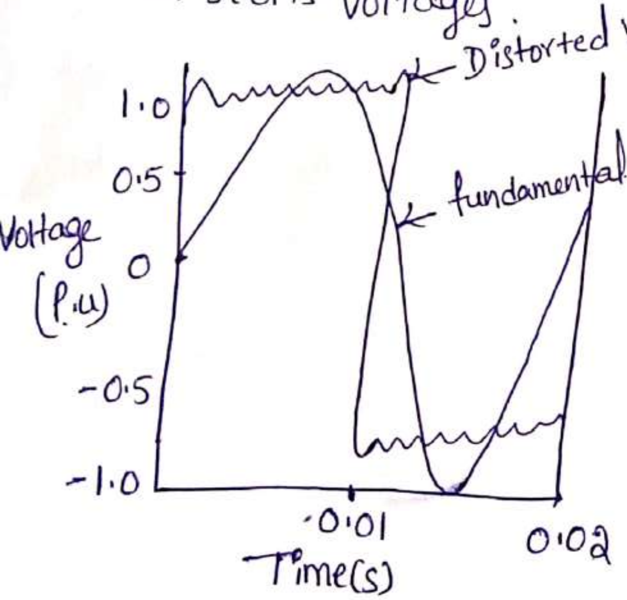

Max deviation of the Vtg or current, divided by the avg 3-φ Vtg or currents expressed in %.

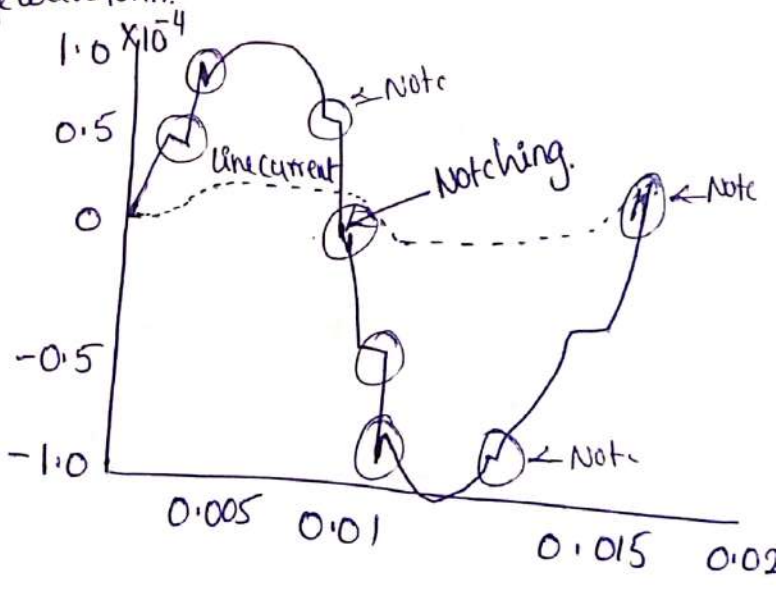
**Waveform Distortion:**– Steady state deviation in Voltage or Curr[ent] waveform an ideal Sine wave.

**Dc offset:**– The major Cause of dc offsets in power Systems are geomagnetic disturbance and half wave rectification.

**Harmonics:**– Power electronic loads like ups, adjustable speed drives etc. usually Causes harmonics. measure is (THD)

**Notching:**– It is a periodic Voltage distortion due to the operation of power electronic Converters when Current Commutates from one phase to other. During this period there is momentary short circuit b/w the two phases that distorts Voltages.




Voltage Distortion Limit

| Bus Voltage | P.u Voltage for n-th harmonic | Voltage (THD)% |
| --- | --- | --- |
| less than 69kV. | 3.0 | 5.0 |
| b/w 69 kV & 161 kV | 1.5 | 2.5 |

## Voltage fluctuations:-

→ These are systematic random variations in supply voltage.

→ A very rapid change in the supply voltage is called voltage flicker. This is caused by rapid variations in load current due to application of non-linear loads.

## Power frequency Variations:-

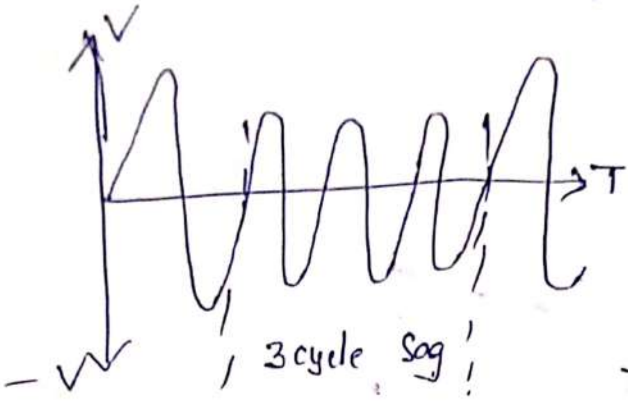
→ These variations are usually caused by rapid changes in the load connected to the system.

→ The maximum tolerable variation in supply frequency is often limited within ±0.5 Hz.

→ The frequency is directly related to the rotational speed of the generator.

Most common. PQ Prob.

Sag




→ Dip
→ Consumer loads.
→ either 1-φ or 3-φ
→ 3 to 30 cycles.
→ 0.1 to 0.9 pu.
→ 0.5 cycle to 1 min.
→ L-G, L-L & Symmetric

Swells

V & I b/w 1.1 & 1.8 P.U.

→ 0.5 to 1 min.

→ Single L-G faults. unfaulted phase, Capacitor banks etc.

Damage to sensitive equipments. unbalanced faults, transients, shutdown of large loads.

Interruption:- failure of equipment, Power sy faults, tree, cars, striking lines or poles, human errors

Consequences:- stopage of all equipments.

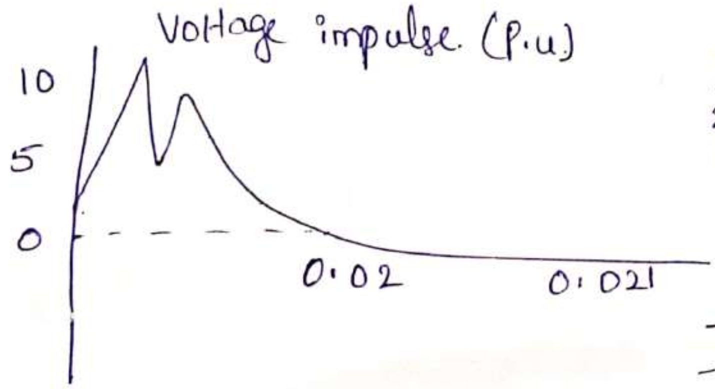
Transients :- A Transient is short duration problem due to sudden change of state.

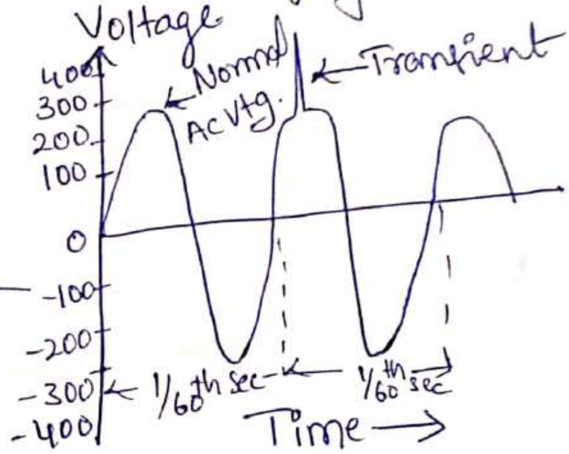
Classified in-to 2-types.

Ex:- Lightning strike & Switching operations.

① Impulsive transient :- is a sudden, non-power freq change in Voltage, Current etc. It is unipolar in nature.

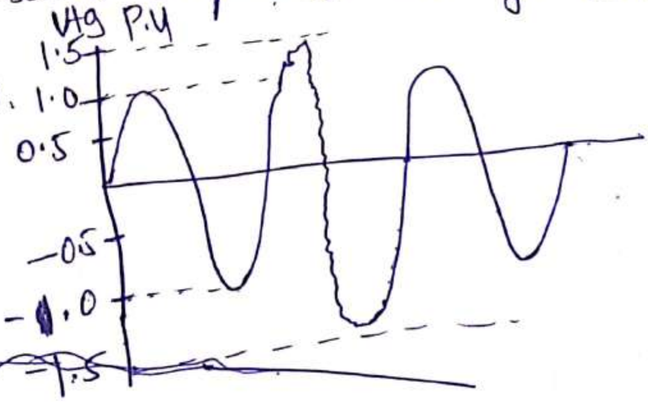
→ It has very fast rise time and decaying time.

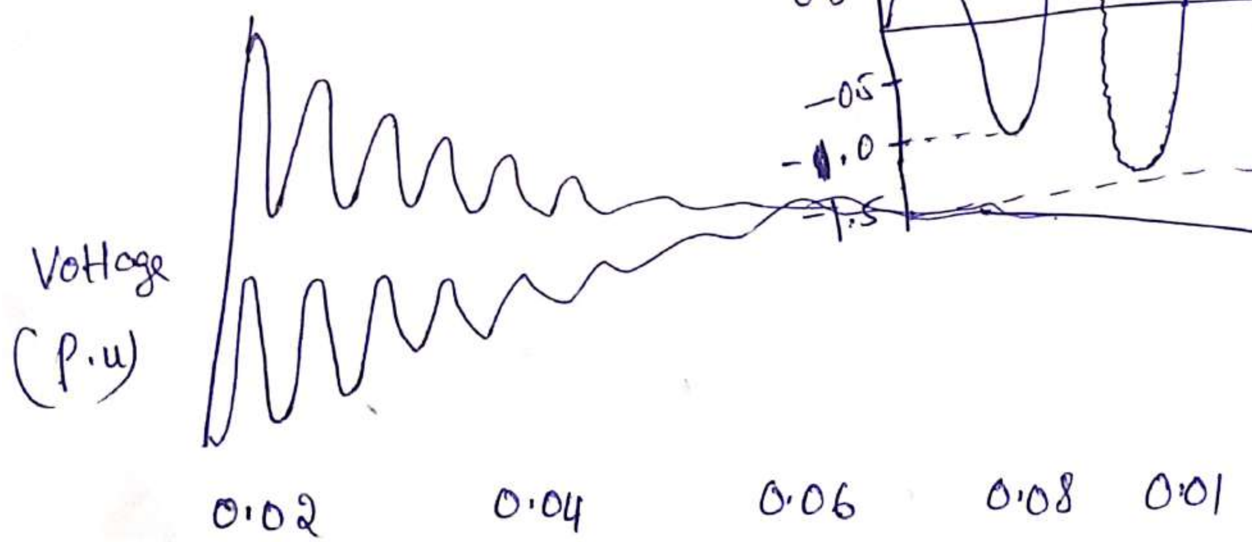



② Oscillatory transient :- It is a bi-polar in nature.

It has one or more sinusoidal components that get multiplied by a decaying term.



## Short duration Voltage Variation:- typically Sustain for a few cycles up to 1 min.

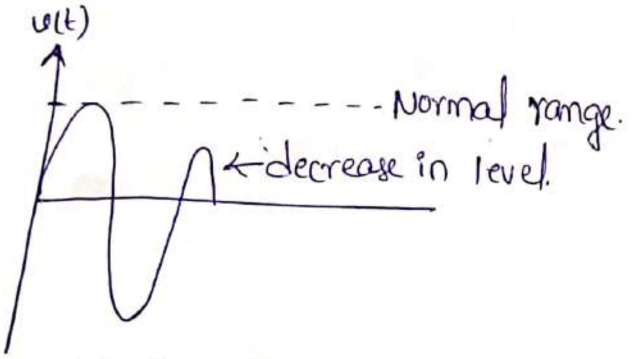
→ usually Such Variations are Caused by faults, energisation of large loads, and intermittent loose Connection in wiring.

Classified as

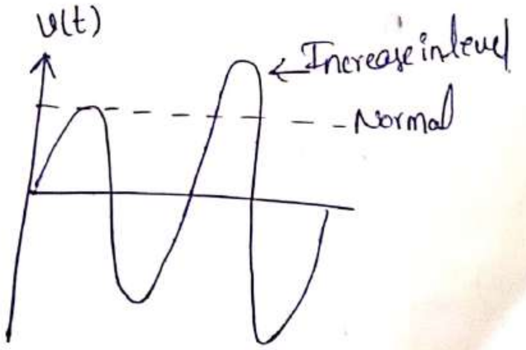
**Voltage Sag:-** It is defined as fundamental frequency decrease in Supply Voltage magnitude for a Short-duration (5 cycles to a min) 0.1 to 0.9 P.u in rms

**Voltage Swell:-** defined as increase of fundamental frequency Voltage magnitude for a Short duration.

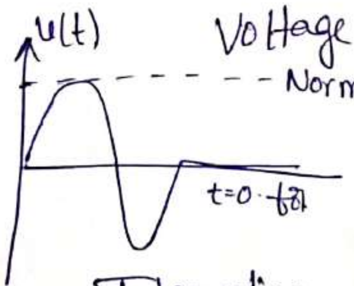
**Interruptions:-** It occurs when Supply Voltage (or load current) decreases to less than 0.1 per unit for a period of less than 1 min.




Voltage Sag.




Voltage Swell.




Interuption.

← The complete loss of Voltage on one or more phase Conductors for a time less than 1 min.

# UNIT- III

## static shunt compensators
## SVC & STATCOM.

### objectives of shunt compensation:-

→ The main function of reactive shunt compensator is to improve the steady - state transmittable power and voltage stability along the line.

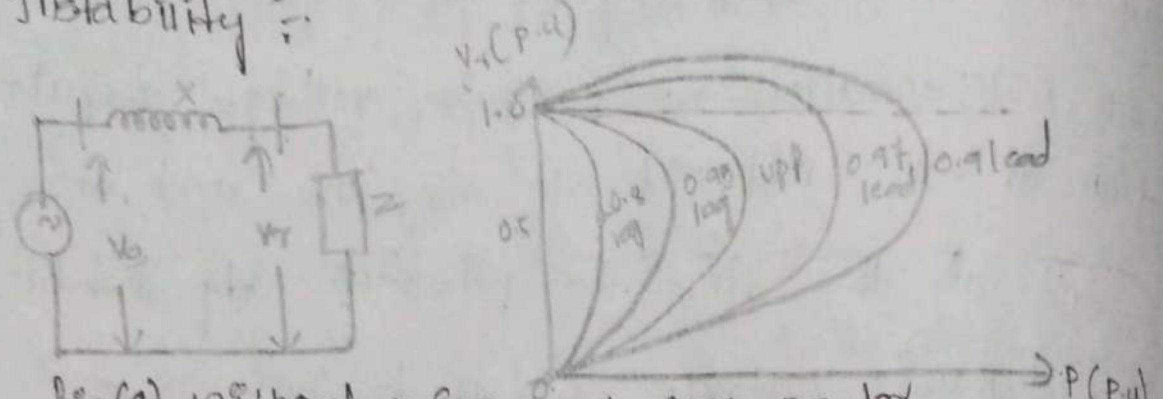
→ The purpose of reactive compensation is to change natural electrical characteristics of the transmission line and improve the line performance to meet the load demand.

→ shunt compensators are fixed or mechically switched reactors are used for minimise line over voltage under light load conditions, capacitor controllers is used to minimise voltage ~~under~~ levels under heavy load conditions.

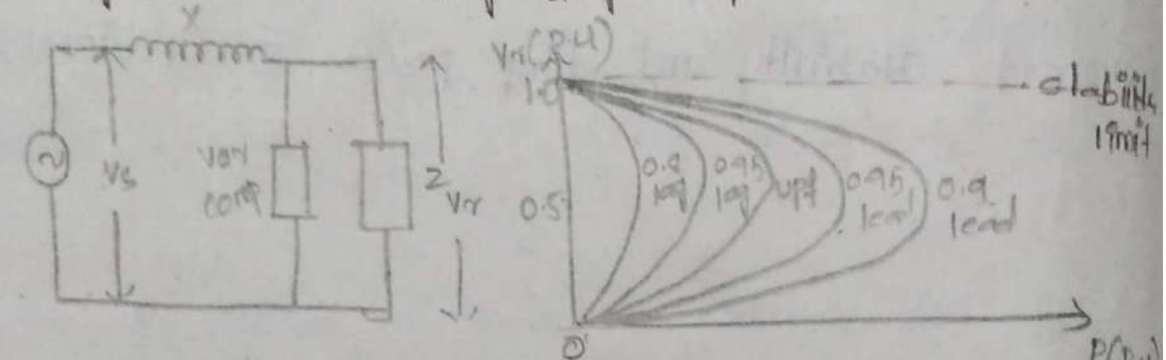
→ The main objective of shunt compensation is a tlln on system is to increase the transmittable power. This may improve steady-state transmission characteristics as well as stability of the system.

→ var compensation is used for voltage regulation at the mid point to the line and at the end of the line to prevent vtg instability, dynamic voltage control to improve transient stability and damp power oscillations.

End of line voltage support to prevent voltage instability :-




fig(a) without using any compensator




fig(b) with using compensator.

fig(1) shows without using any compensator, the.

* fig(1) shows sim.
with line reactance "X" and load impedance "Z"
The plot is drawn b/w terminal vtg and power at various load p.f ranging ~~front~~ from 0.8 lag to 0.9 lead.

→ "The nodes point at each plot given for a specific p.f represents vtg ~~m~~ instability.

→ WKT vtg stability limit decreases with inductive load and ↑ with capacitive load fig (b) shows unity using shunt reactive compensator of radial line is to be connected ll to the load

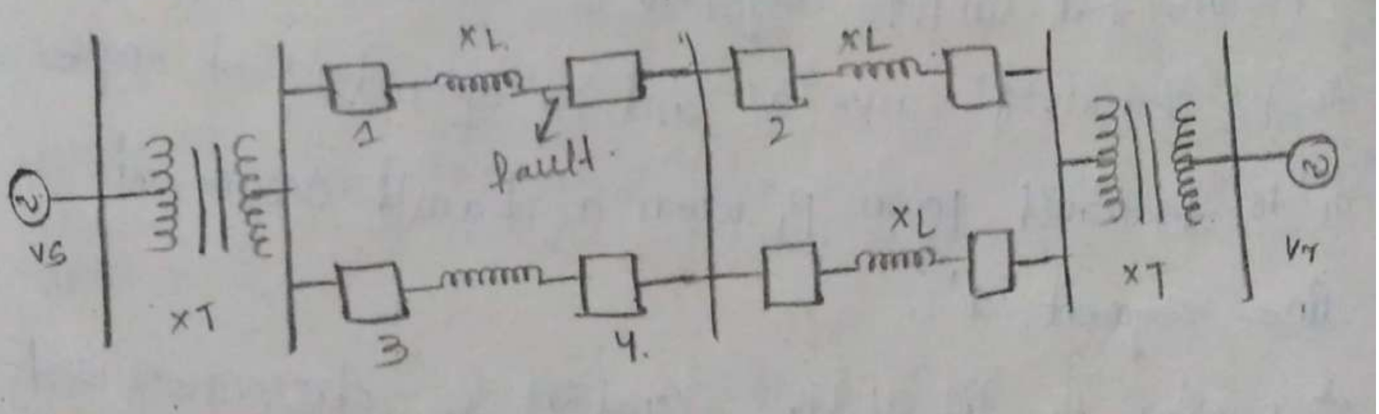
→ shunt reactive compensation can effectively increases the vtg stability limit by supplying reactive load. & resulting terminal vtg.

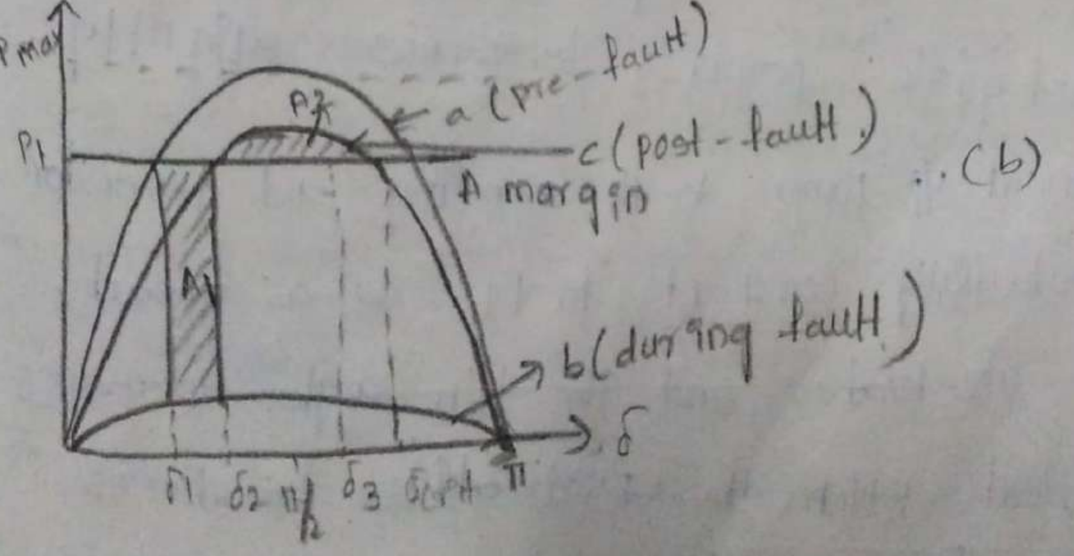
$V - V_r = 0$ shown in fig b.

→ Reactive shunt compensation is used in practically to regulate the voltage at a given bus against load variation.

→ Improvement of Transient stability :-

(a)




..(b)

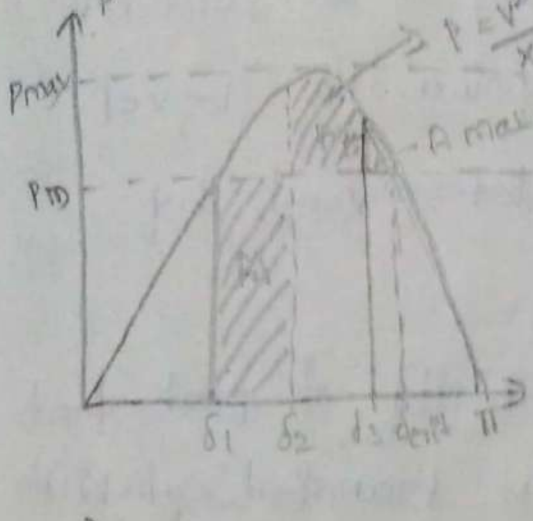
→ Illustration of the equal area criteria for transient stability of a two m/c, two-line power system

→ shunt compensation will be able to change the power flow in the system during and following disturbances is as to increase the transient stability limit and provide effective power oscillation damping.

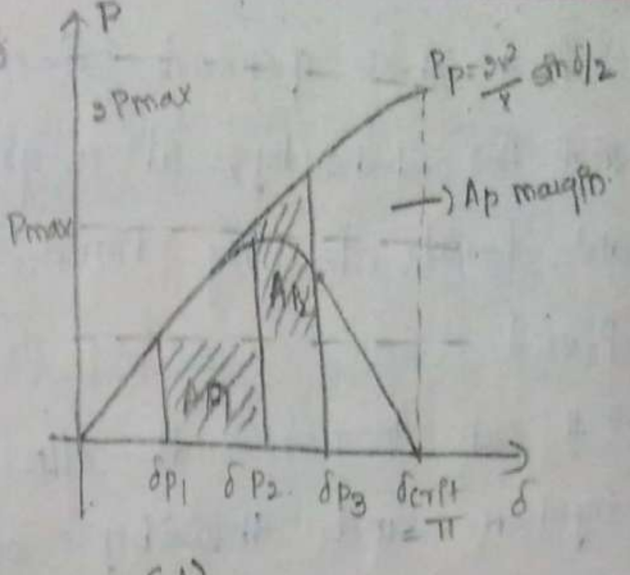
The potential effectiveness of shunt on transient stability improvement can be conveniently evaluated by the "equal area criteria".

→ Assume that complete system is characterised by the "p" versus "δ" curve "a" and is operating at angle $\delta_1$ to transmit power $P_1$ when a fault occurs at line segment "1".

→ During the fault the system is characterised by the "p" electric power decreases slightly while mechanical i/p power to the sending end generator remains substantially constant to $P_1$. as a result, the generator accelerates and the tlln angle increases from $\delta_1$ to $\delta_2$ at which the protective breakers disconnect the faulted line segment "1" and the sending end generator absorbs accelerating




(c)




(d).

energy represented by area A1

→ After fault clearing without line segment "1" the degraded system is characterized by P vs δ curve "c". At one angle δ on curve "c" the transmitted power exceeds the mechanical i/p power $P_1$ and the sending end generator starts to decelerate. forever angle δ further increase due to the kinetic energy stored in the m/c.

→ The max angle reached at $\delta_3 = \delta$ critical, beyond which the decelerating energy would not balance the accelerating energy and synchronism b/w the sending end and receiving end could not be restored.

The area "A margin" between $\delta_3$ & δ critical represent the transient stability margin of the system.

→ from above general discussion, it is evident that the stability, at a given power t/n level and fault clearing time is determined by P vs δ.

→ It can increase the t/n capability of post-fault system and thereby enhance transient stability

→ comparision of fig "c" & "d" shows increase in the transient stability to the ideal mid point compensation with not restricted var o/p can provide by effective segmentation of the t/n line. If uncompensated sys has transient stability margin, shunt comp sys has increase the transmittable without decreasing this margin.

→ 23/4/22. Methods of Controller VAR Generation

In this 2 types of controllers is there.

i) static VAR compensator.

ii) static VAR Generators

- Variable Impedance
  - TCR (Thyristor control Reactor)
  - TSR (T switch reactor)
  - FC-TCR (fixed capacitor - Thyristor control reactor).
- Variable Generators

i) SVG :-

whose o/p is varied so, has to maintain / control the specific parameters of the electrical power system.

→ It is a sufficiently functioning device it will draws a Reactive current from an Alternating power source.

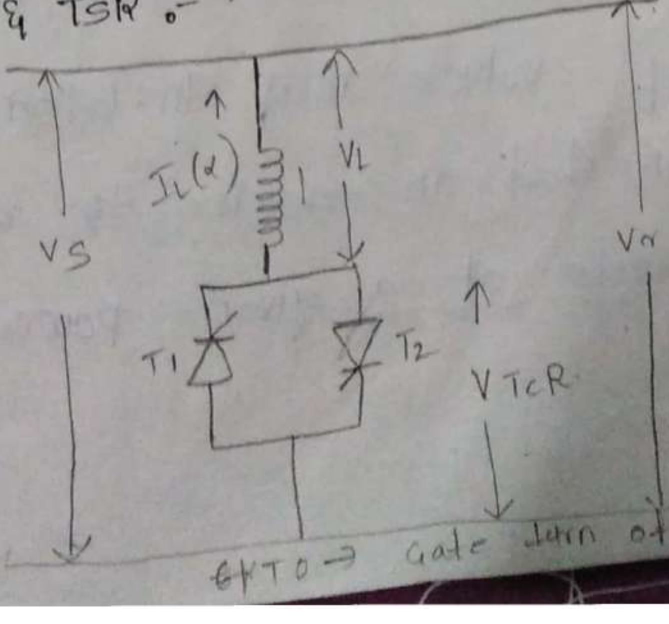
→ The control I/p of VAR Gen'r can be arbitrary (with in the operating range). Reactive current Impedance / power to the Reference the SVG delivers at it's o/p.

→ The SVG is used as power amplifier it faithfully produces the Required signal at the desired power levels.

Variable Impedance type.

static VAR. Generator :-

* TCR & TSR :-




* T1 → +ve half cycle

* T2 → -ve half cycle

The control range of thy is 90° to 180°

GTO → Gate turn off thyristors are used

→ Two thyristors are connected in the anti parallel ($T_1$ & $T_2$) GTO (Gate turnoff thyristor)

→ series connected with air cored Reactor is shown in fig.

→ $T_1$ will conducts during the +ve half cycle. & $T_2$ will conducts during the -ve half cycle.

→ The control Range of thyristors is 90° to 180°

→ fig ① shows single phase, thyristor controlled Reactor it consists of fixed air cored Reactor of Inductance (L). In a bidirectional thyristor valves (switches)

→ currently available thyristor are drawn vtg range 400V - 900V

→ conduction currents 3000 - 6000 Amps.

→ In Practically valves may thristors are 10 - 20 connected in series to require blocking vtg levels at a given power rating.

operation :-

→ Thyristor valve coming into the conduction by applying gate pulses to same polarity.

→ The valving automatically blocks after the AC current cross to 0, unless the gate signal is re applied.

→ It will operate on natural commutation (or) line commutation the current in the reacting can be controlled from max to zero by the method of thyristor. delay angle control.

→ the thyristor valve is delay with respective to the heat of applied vtg in each half cycle, at the duration of current control.

$$V_S = V_L + V_{TCR} \quad \text{——} (1)$$

$$V_S = V_L \quad \text{——} (2)$$

$V_{TCR}$ = There is no drop vtg

$$\therefore V_S = V_L = L \frac{di_L}{dt} \quad \text{——} (3)$$

$$V_S(t) = V \cos \omega t$$

$$i_L(t) = \frac{1}{L}\int_{\alpha}^{\omega t} V_s(t)\,dt$$

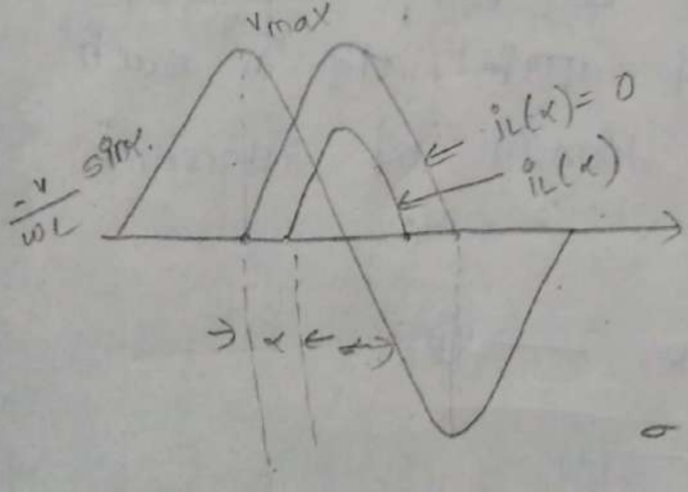
$$= \frac{1}{L}\int_{\alpha}^{\omega t} V\cos\omega(t)\,dt$$

$$= \frac{V}{L}\int_{\alpha}^{\omega t} \cos\omega t\,dt$$

$$= \frac{V}{L}\left[\frac{\sin\omega t}{\omega}\right]_{\alpha}^{\omega t}$$

$$i_L(t) = \frac{V}{\omega L}\left[\sin\omega t - \sin\alpha\right]$$

If current flowing inductor is ↑ses the absorption capacity of VAR ↑ses

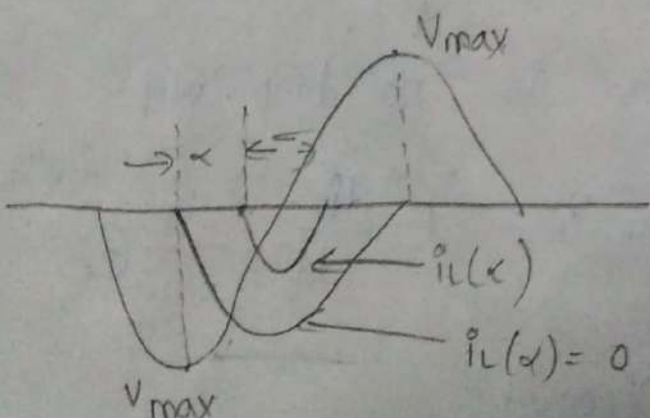



$\omega t\ \frac{V}{\omega L}\sin\alpha$

$\alpha \rightarrow$ firing angle

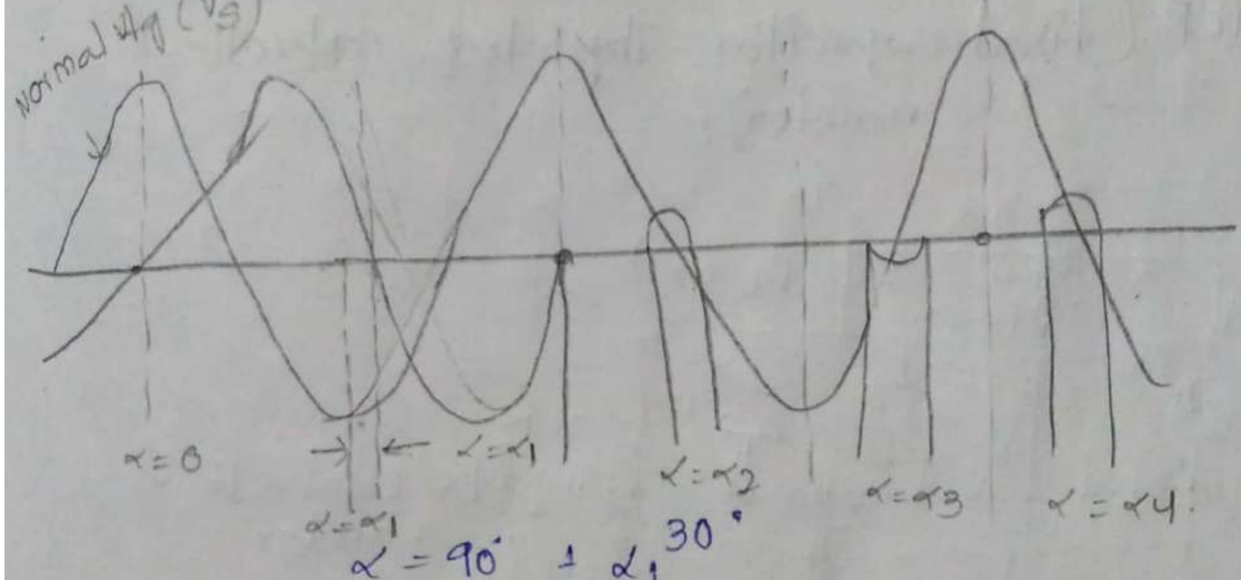
$\sigma \rightarrow$ conduction angle

$\sigma + 2\alpha \rightarrow$ +ve half cycle



Above fig shows delay angle firing angle controlled for +ve & -ve half cycles the method of current controlled during the +ve & -ve half cycles shown in above figure. when the vtg is max. at fig ($i$ max) at that current in the inductor $i_L(\alpha) = 0$ still not stop to absorb the reactive power.

It starts from $\alpha = 90^\circ$ to $180^\circ$ up to that period only inductor its stores the reactive power




$\alpha = 90^\circ + \alpha_1$ $30^\circ$

$\alpha = 90^\circ + \alpha_2$ $40^\circ$

$\alpha = 90^\circ + \alpha_3$ $50^\circ$

$\alpha = 90 + \alpha_4$ $60^\circ$

Positive half cycle $\rightarrow (\alpha \leq \omega t \leq \pi - \alpha)$

Negative half cycle $\rightarrow (\pi + \alpha \leq \omega t \leq 2\pi - \alpha)$

when ever $\alpha \to$ ↑ses from 0° to max value

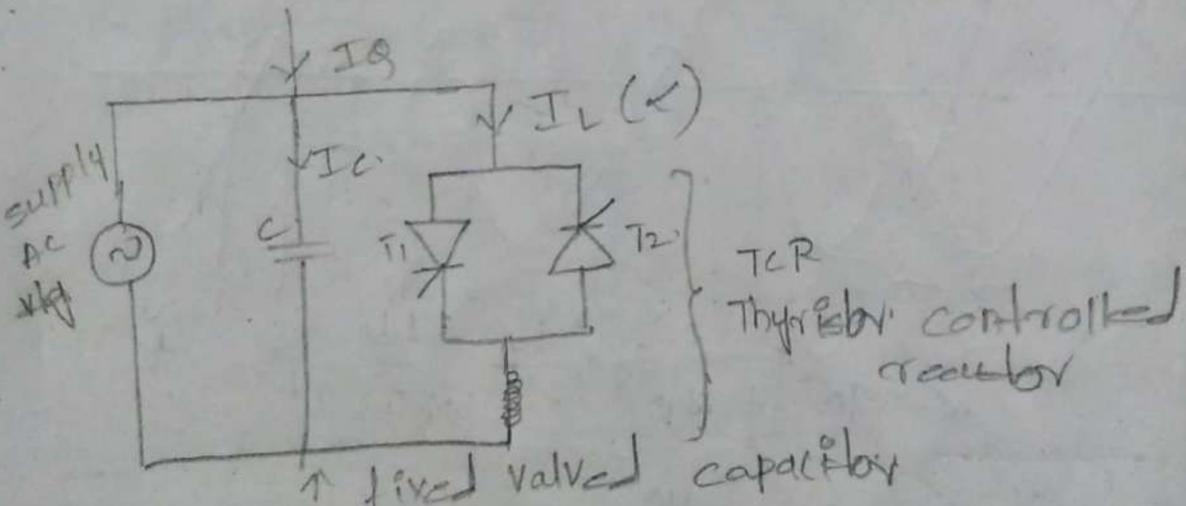
$\alpha = 0$ , $\alpha = \alpha_1$ , $\alpha = \alpha_2$ , $\alpha = \alpha_3$ , $\alpha = \alpha_4$

* By ↑ ses the '$\alpha$' the conduction angle ↓ ses and also current flowing inductor is ↓ses the amplitude

$$I_{CF}(\alpha) = \frac{V}{\omega L}\left(1 - \frac{2}{\pi}\ \frac{-1}{\pi}\ \sin 2\alpha\right) \quad (3)$$

31/5/22 from eqn $\frac{V}{\omega L}\left[\sin \omega t - \sin \alpha\right]$

**FC-TCR (fixed capacitor Thyristor controlled reactor).**




$$I_Q = I_C + I_{LF}(\alpha)$$

Above fig show's the fixed capacitor - TCR

* Above fig shows

(a) without using coupling T/f.

The current in the reactor by varing firing angle (α) α = 90° to 180°

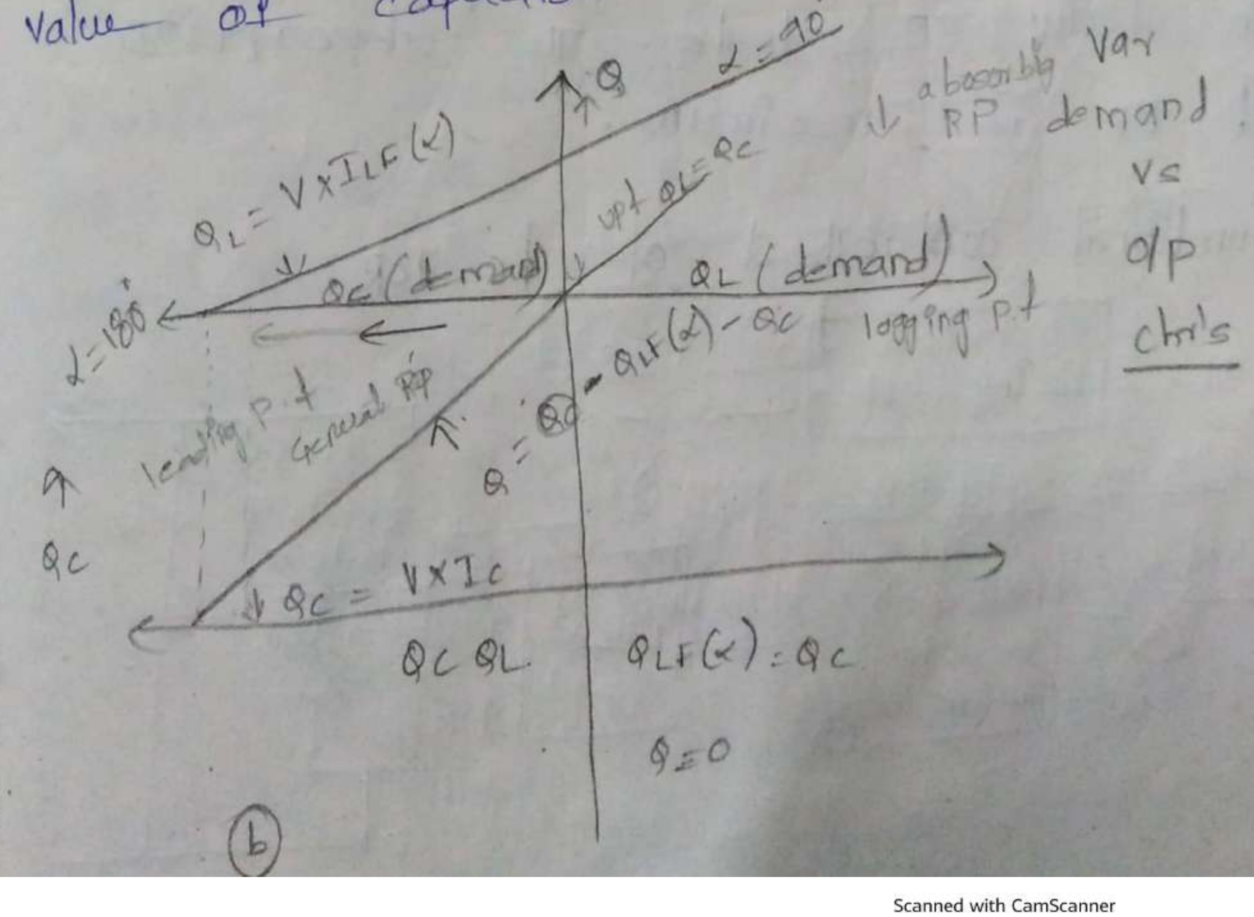
α = 90° TCR absorb's max reactive power

α = 180° fully on state.

when α = 180° There is no absorbtion of RP from bus. In this state TCR is in 'off' state.

→ The capacitor value is fixed. with the help of filter n/w to generate RP required but it provides a low impedance at selected frequencies

→ This FC-TCR consists of variable reactor (Ind) (controlled via delay angle α) and fixed value of capacitor.




(b)

fc "$Q_c$" oppose the variable var generation ($Q_L$). absorption to provide required total var o/p 'Q' = $Q_{LF}(\alpha) - Q_c$

1) when ever $\alpha = 180°$ TCR is fully off state in this cond'n. The capacitor only generate reactive power in to the bus

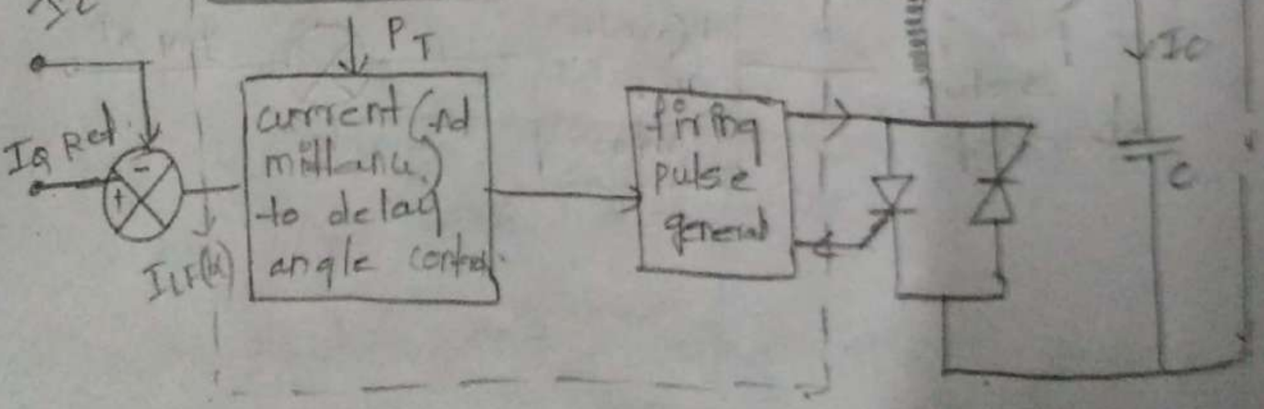
$\therefore$ $Q = 0 - Q_c$

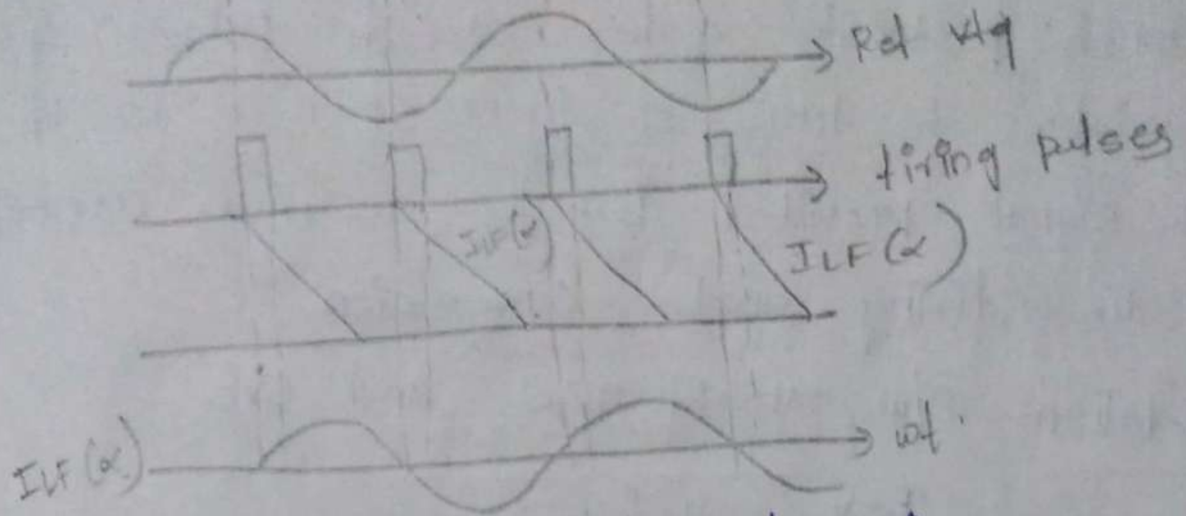
2) under the upf cond'n there is no absorption and gen of RP.

→ $Q_{LF}(\alpha) = Q_c$, The resultant $Q = 0$. There is no gen, no absortion of RP.

3) when ever $\alpha = 90°$ In this cond'n TCR is in fully on state. The absorption of RP is maximum.

Functional controlled of fc-TCR.






→ The control of Thyristor control in FC-TCR VAR generator need to provide 4 basic

1) synchronous timing :
This func is provided by phase Locked loop ckt, that turns in synchronism with AC sys vtg and gen timing pulses wrt to vtg.

2) Reactive current (or) (admittance) to firing angle conversion.

3) computation of reactor current $I_{LF}(\alpha)$ from total o/p current,

$$I_Q = I_C - I_{LF}(\alpha)$$

→ In this +ve → Inductive o/p current
-ve → capacitive o/p current.

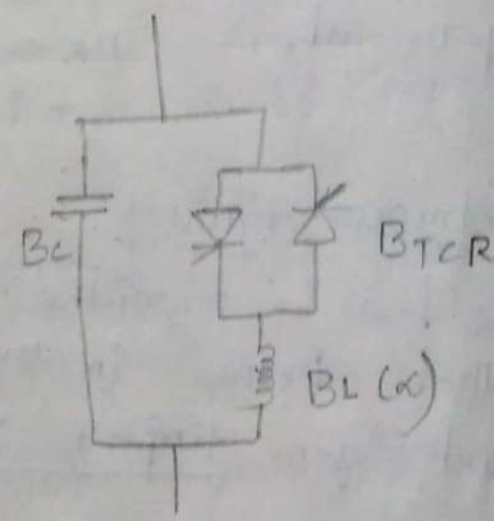
4) Thyristor pulse generation. This is done by the firing pulse generator.

→ which produces gate current pulses for thyristor to turn on in response to the o/p signal provided by the reactive current to the firing angle conversion.

Relation b/w susceptance and SVC

$$I_{SVC} = V \cdot j B_{SVC}$$

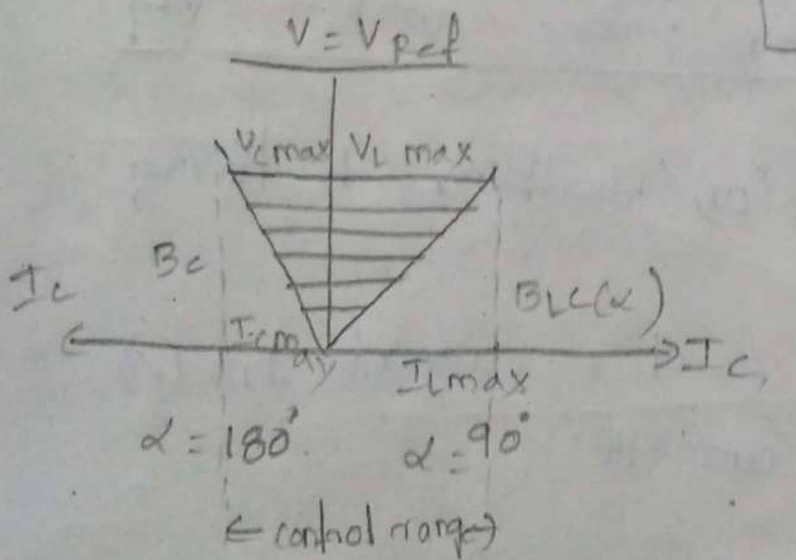
$$B_{SVC} = B_C + B_{TCR}$$




$$B_{TCR} = 0$$

$$\alpha = 180^\circ$$

$$B_{SVC} = B_C$$




V-I Chr's of FC-TCR.

$B_C$ → capacitive admittance.

$B_L$ → maximum inductive admittance

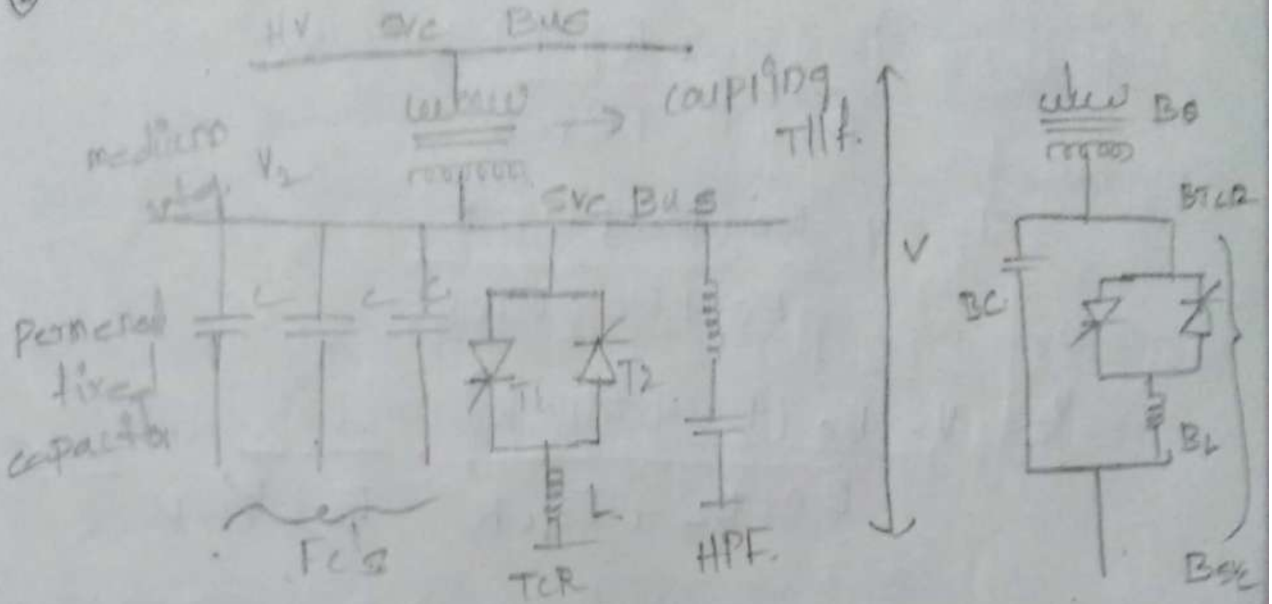
$I_{Lmax}$ → Inductive current limit

$I_{Cmax}$ → capacitive current limit.

$\alpha = 90^\circ$

$B_{TCR}$ = max

(b) Fc - TcR with coupling T/f.




$$\Rightarrow B_{SVC} = \frac{B_o (B_c + B_{TCR})}{B_o + B_c + B_{TCR}} \quad \text{--- (1)}$$

divide Nr & Dr with Bo

$$B_{SVC} = \frac{1}{1 + \frac{B_c + B_{TCR}}{B_o}} (B_c + B_{TCR}) \quad \text{--- (2)}$$

$B_{SVC} \rightarrow$ maximum of fc - TcR.

$\alpha = 180^\circ$

$B_{TCR} = 0$

$$B_{SVC\,max} = \frac{B_o B_c}{B_o + B_c} \quad \text{--- (3)}$$

$B_{SVC} \rightarrow$ minimum $\alpha = 90^\circ$

$$B_{SVC}\ \text{minimum} = \frac{B_o (B_c + B_{TCR})}{B_o + B_c + B_{TCR}} \quad \text{--- (4)}$$

$$V_2 = I_2 \cdot j \frac{1}{B_C + B_{TCR}}.$$

$$I_2 = V \cdot j B_{SVC}$$

$$B_{SVC} = \frac{B_O(B_C + B_{TCR})}{B_O + B_C + B_{TCR}}.$$

$$I_2 = V \cdot \frac{B_O(B_C + B_{TCR})}{B_O + B_C + B_{TCR}}$$

$$V_2 = V \cdot \frac{B_O(B_C + B_{TCR})}{B_O + B_C + B_{TCR}} \cdot \frac{1}{B_C + B_{TCR}} \quad — (5)$$

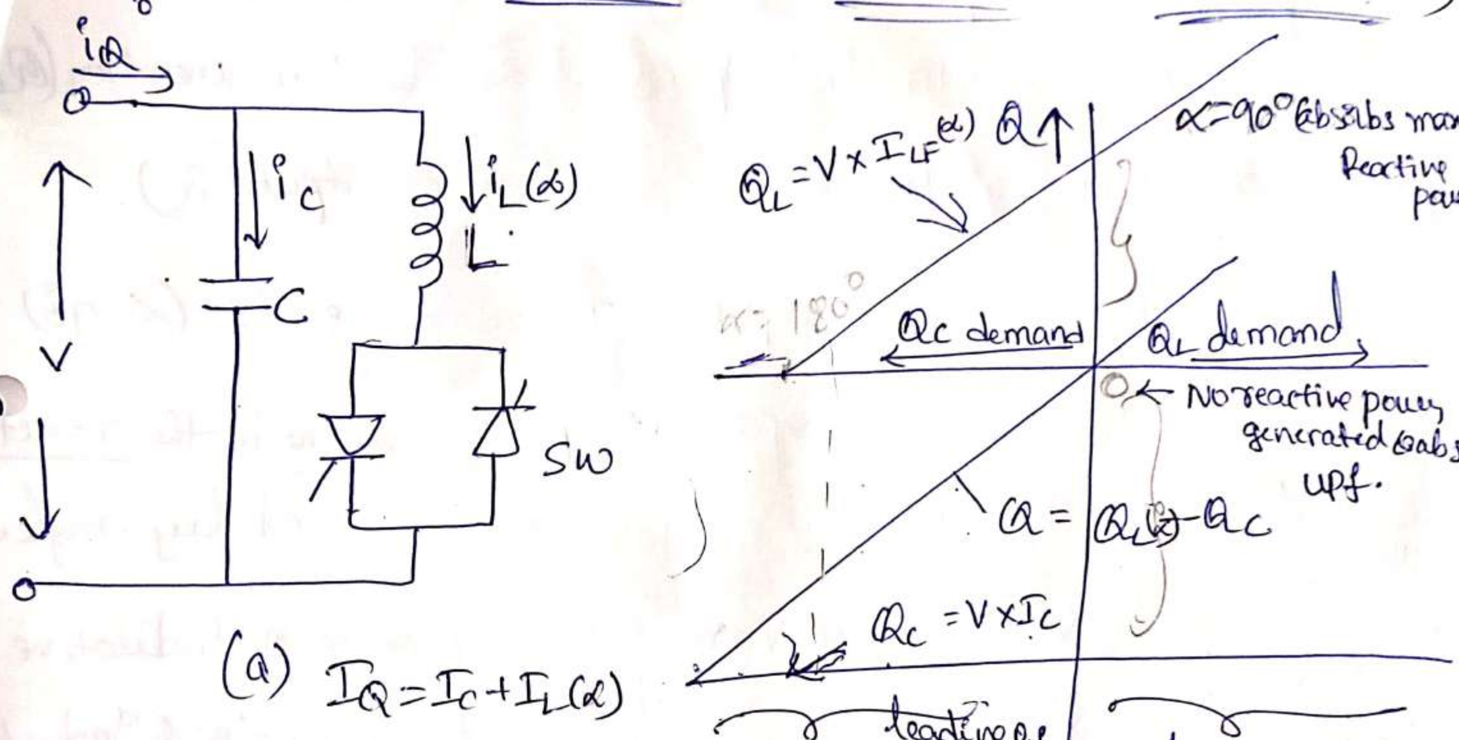
$$V_2 = V \cdot \frac{B_O}{B_O + B_C + B_{TCR}}.$$

when ever to design fc-TCR the coupling T/f of secondary wdg must be know.

UNIT- IV

# SVC and STATCOM

## Fixed Capacitor - Thyristor Controlled Reactor (FC-TCR)




(a) $I_Q = I_C + I_L(\alpha)$ (b)

Basic FC-TCR type static Var generator and its Var demand Versus Var output characteristics.

→ Above fig shows fixed capacitor thyristor controlled reactor (FC-TCR). The current in the reactor is varied by firing angle control.

→ The capacitor value is fixed with the help of filter network to generate reactive power required, but it provides a low impedance at selected frequencies.

→ This FC-TCR Consists Variable reactor (Inductor) (controlled by delay angle α) and fixed Valued Capacitor.

→ Var demand Vs output char shown in fig.

→ fixed Capacitor ($Q_C$) opposes the Variable Var generation ($Q_L$) absorption to provide req total Var output ($Q$).

→ At max Var output TC reactor is off ($\alpha = 90°$)

→ To decrease the Capacitive o/p, the Current in the reactor is increased by decreasing the delay angle α

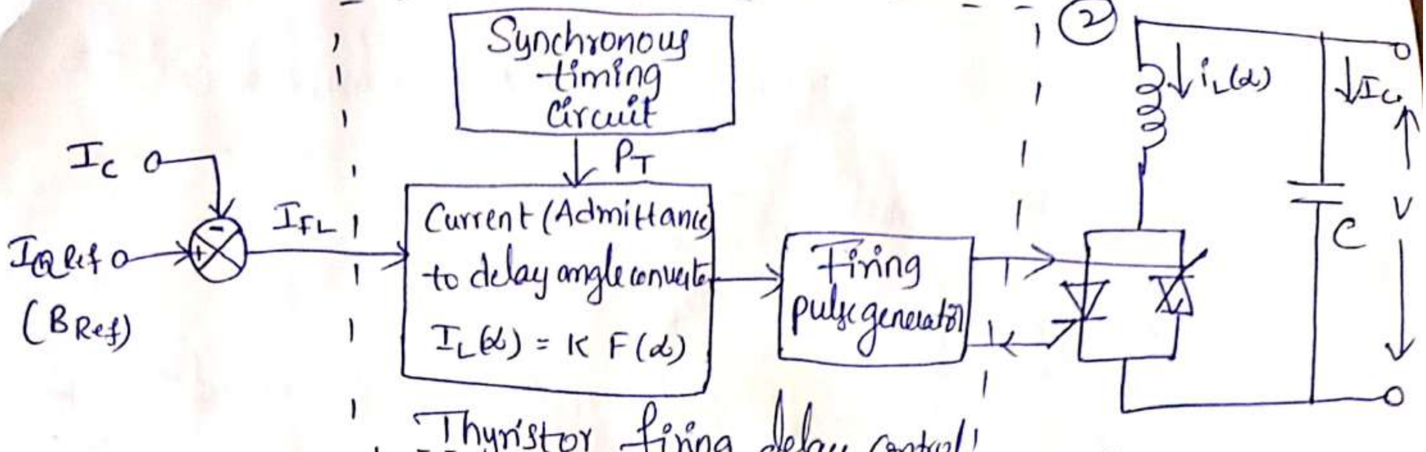
C↓ o/p I$_L$↑

→ At 'zero' o/p Var, the Capacitive & Inductive Currents becomes equal, and Capacitive & Inductive Vars Cancel out.

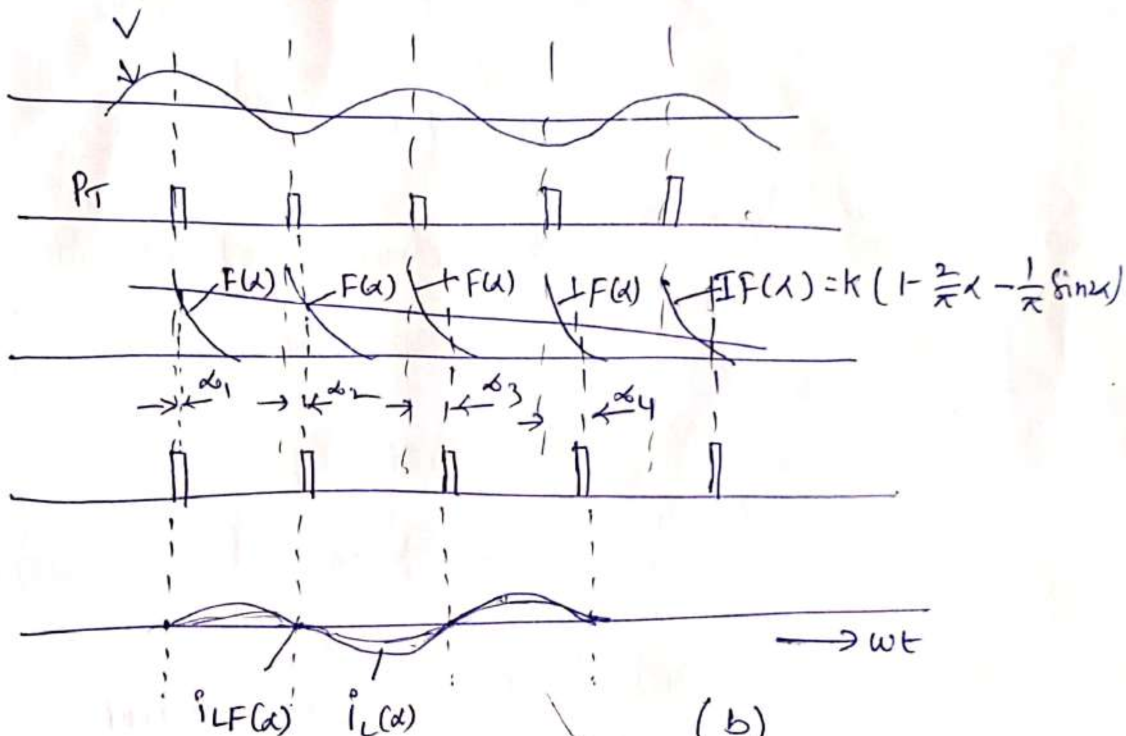
$Var_C = Var_L$ ='0' o/p

→ further decreasing the delay angle the Inductive Current becomes larger than the Capacitive Current, the resultant Var output is Inductive.

→ at zero delay angle, the thyristor-Controlled reactor Conducts current over the full 180° interval, results Inductive Var o/p is equal to diff b/w the var generated by the Capacitor & those absorbed by the fully Conducting reactor.




(a)




(b)

(a) Functional control scheme for the FC-TCR type static Var generator.
(b) waveforms.

→ The Control of the thyristor-Controlled reactor in FC-TCR type Var generator need to provide four basic functions.

1) is Synchronous timing :- This function is provided by phase locked loop ckt that runs in Synchronism with the ac System voltage and generates timing pulses cort voltage

→ Second function is reactive current (or admittance) to firing angle conversion.

→ 3rd function is Computation of reactor Current $I_{LF}$ from total output current $I_Q$.

i.e $I_Q = I_C - I_{QRef}$. Subtracting Capacitive Current.

+ve polarity means Inductive o/p current
-ve " " Capacitive o/p Current

→ 4th function is Thyristor firing pulse generation. This is done by the firing pulse generator.

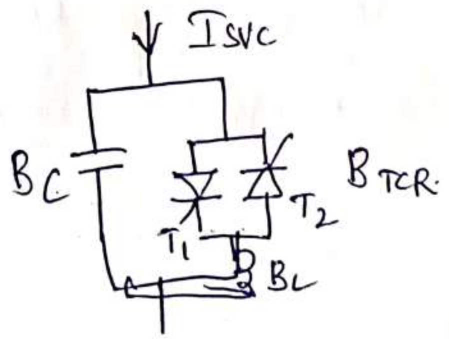
which produces the necessary gate current pulse for thyristor to turn on in response to the output signal provided by the reactive Current to firing angle Conversion.

→ Taking a block box view point of FC-TCR type var generator Can be Considered as a Controllable reactive admittance Connected to the ac system.

Relation b/w Susceptance and $I_{svc}$.

$I_{SVC} = V \cdot j B_{SVC}$.

where $B_{SVC} = B_C + B_{TCR}$

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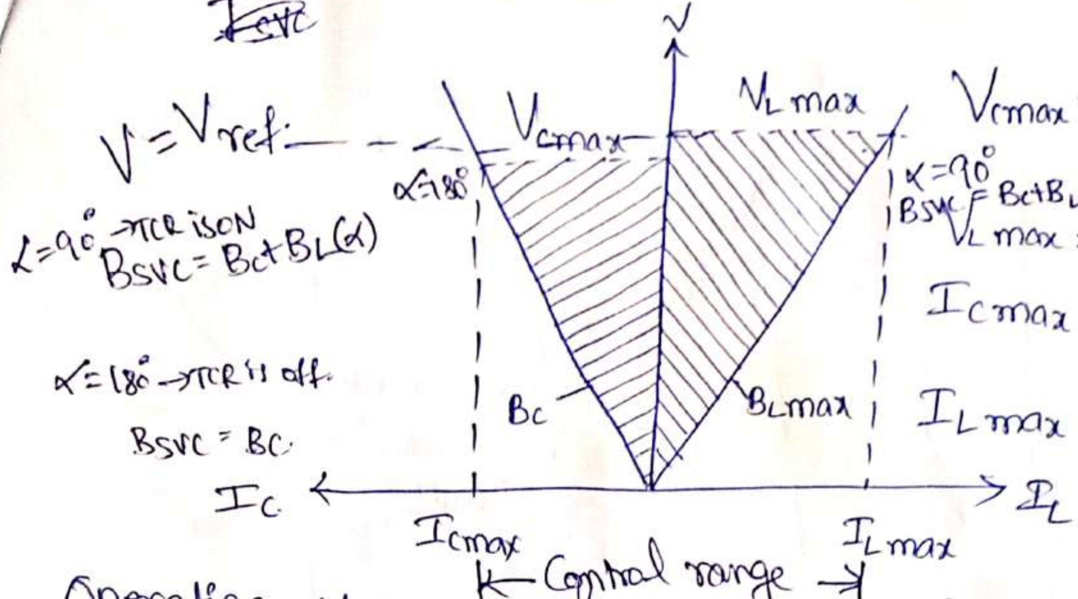



$V_{cmax}$ = Voltage limit for Capacitor

$V_{L max}$ = " " for TCR

$I_{cmax}$ = Capacitive current limit

$I_{L max}$ = Inductive Current limit

Operating V-I area of the FC-TCR type Var generator.

$B_{L max}$ = Max Inductive admittance

$B_c$ = admittance of Capacitor.

→ above V-I operating area of the FC-TCR Var generator is defined by maximum Capacity of Capacitive & Inductive admittance and Voltage, current ratings of Capacitor, Inductor & thyristor.

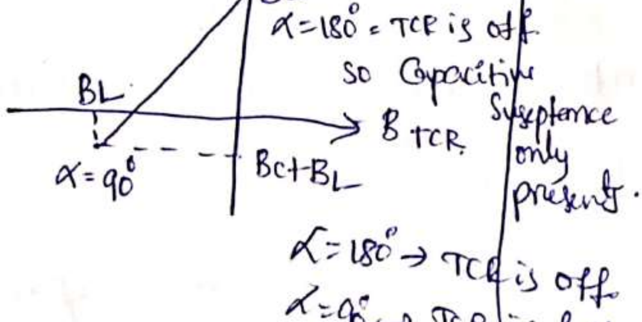
→ Transfer function of FC-TCR is $G(s) = ke^{-T_d s}$

(s) is Laplace transform operator

k is a gain Constant

Td firing delay angle (α)

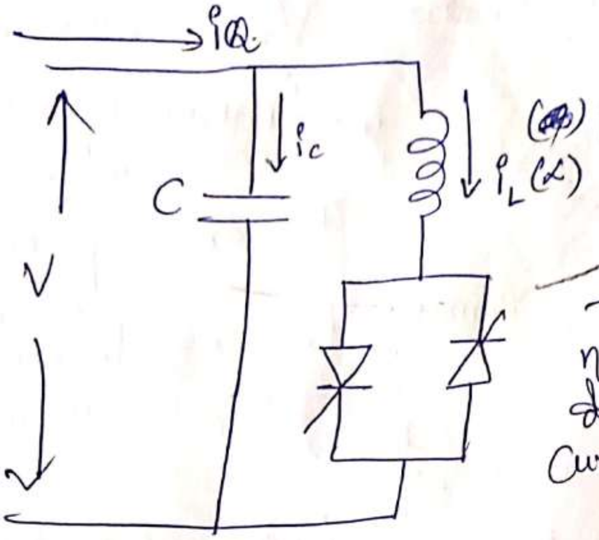
Relation b/w Bsvc and BTCR

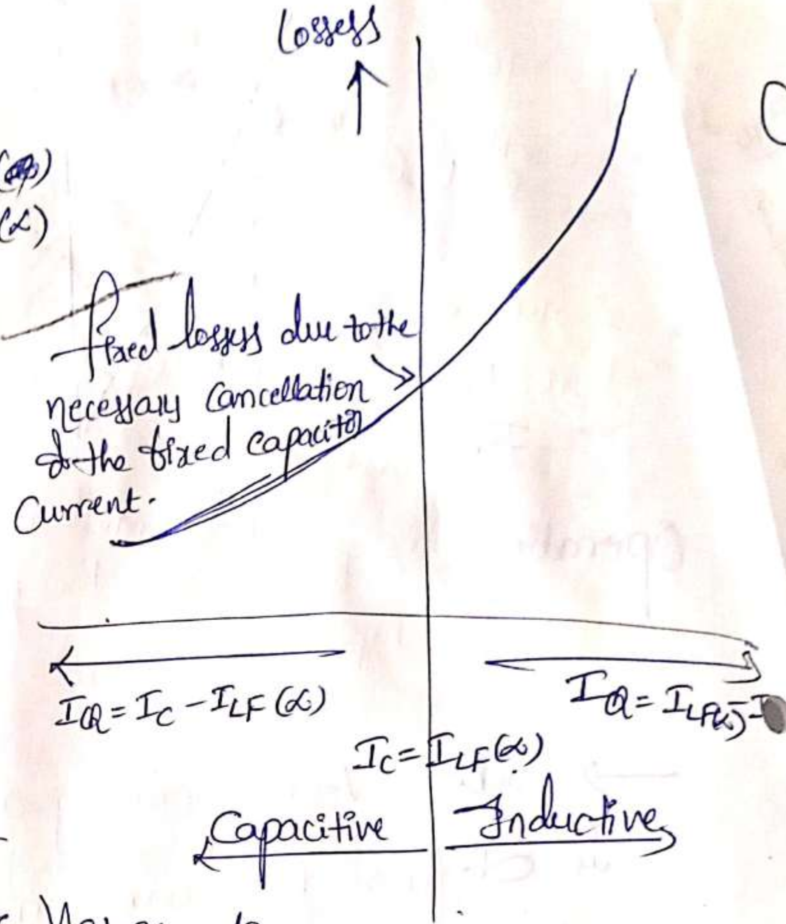



α=180° = TCR is off so Capacitive Susceptance only present.

α=180° → TCR is off.

α=90° → TCR is fully on ...




→ Loss Vs Var o/p char of FC-TCR type static Var generator.

In FC-TCR type Var generator, there are 3 major losses occurred ① The Capacitor losses (small)
② Reactor losses (these increase with square of current)
③ Thyristor losses (These are almost linear with current)

→ Thus total losses increases with increasing in current

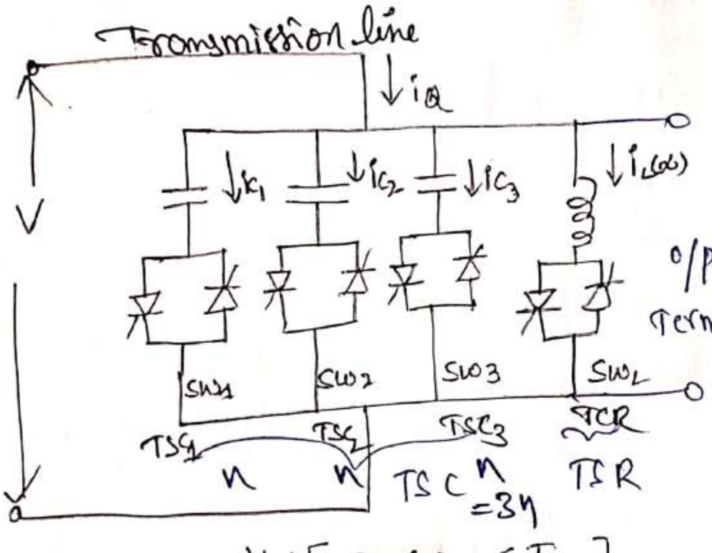
| $I_{Losses}$↑ I↑ |

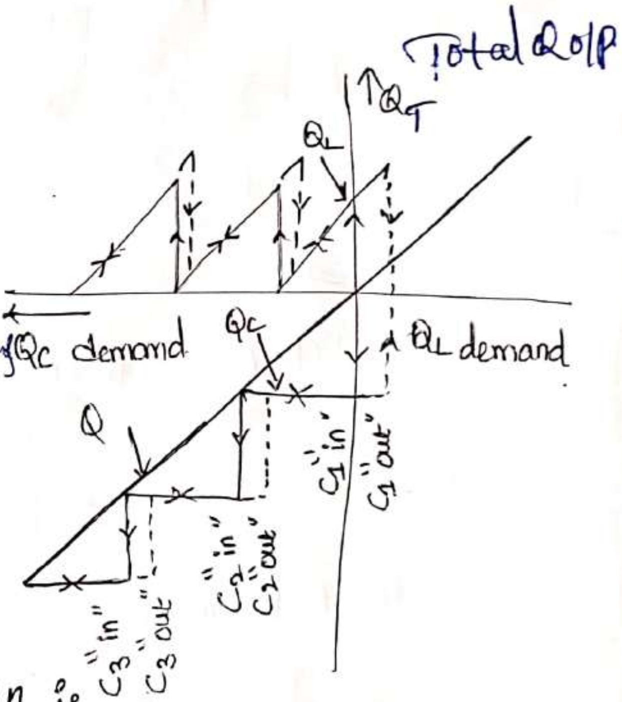
and decreases with decreasing the Capacitive Var output. Shown in fig (a).

→ Zero o/p is obtained by cancelling capacitive Vars with Inductive ($I_C = I_L$)

→ These loss char Curve is, advantageous when avg Capacitive Var o/p is relatively high this type is application req Industrial p.f Correction.
and disadvantageous when avg Var o/p is low,
u dynamic Compensation of Power transmission System.

## Thyristor-Switched Capacitor - Thyristor-Controlled Reactor (TSC-TCR) :-




$$Q = V \times \left[ I_{LF}(\alpha) - \Sigma I_{cn} \right]$$

→ The intention of TSC-TCR design is minimizing Stand by losses and increasing operating flexibility
↳ wastage of fuel losses

→ For a given Capacitive output range, it Consists of 'n' TSC branches and one TCR. The 'n' number of branches determines Operating Voltage level, maximum Var output, current rating of the thyristor Valves, bus work and installation cost. etc

Of Course, Inductive range also Can be expanded to any maximum rating by employing additional TCR branches.

operation:-

→ The total Capacitive output range is divided in to 'n' intervals. In the first Interval, the o/p of the Var generator is Controllable in the zero to $Q_{cmax}/n$ range, when $Q_{cmax}$ is the total rating provided by all TSC branches.

In this One Capacitor bank is Switched in (by firing, for example, thyristor Valve $Sw_1$,) and Simultaneously the current in the TCR is set by appropriate firing delay angle so that The Sum of the Var output of TSC (negative) and that of TCR (positive) equals the Capacitive output required.

→ In 2nd, 3rd .... & $n^{th}$ intervals, the output is Controlled in the $Q_{cmax}/n$ to $2Q_{cmax}/n$, $2Q_{cmax}/n$ to $3Q_{cmax}/n$ ---- and $(n-1)Q_{cmax}/n$ to $Q_{cmax}$ range by Switching in the 2nd, 3rd and $n^{th}$ Capacitor bank using the TCR to absorb the Surplus Capacitive vars.

Ex

$n=5$ $Q_{cmax} = 10$ MVAR.

Introduce 5 branches $2 \times 5 = 10$ MVAR $- 1$ TCR $= 9$ MVAR

our req is 9MVAR. ↓ absorbs surplus Capacitive var.

→ By being able to switch the capacitor banks in and out within one cycle of the appalied ac voltage, the maximum surplus capacitive var in the total output range can be restricted to that produced by one capacitor bank, and thus, theoritically, the TCR should have the same var rating as the TSC.

⇒ Var demand versus var output characteristics of the TSC-TCR type var generator is shown in fig (b).
The capacitive var output, $Q_T$ $Q_C$ is charged in step-like manner by the TSC, and the relatively small inductive var output of the TCR, $Q_L$, is used to cancel the surplus capacitive vars.

Ex:- Explained Hence theroticalley the TCR should have the same var rating as the TSC.

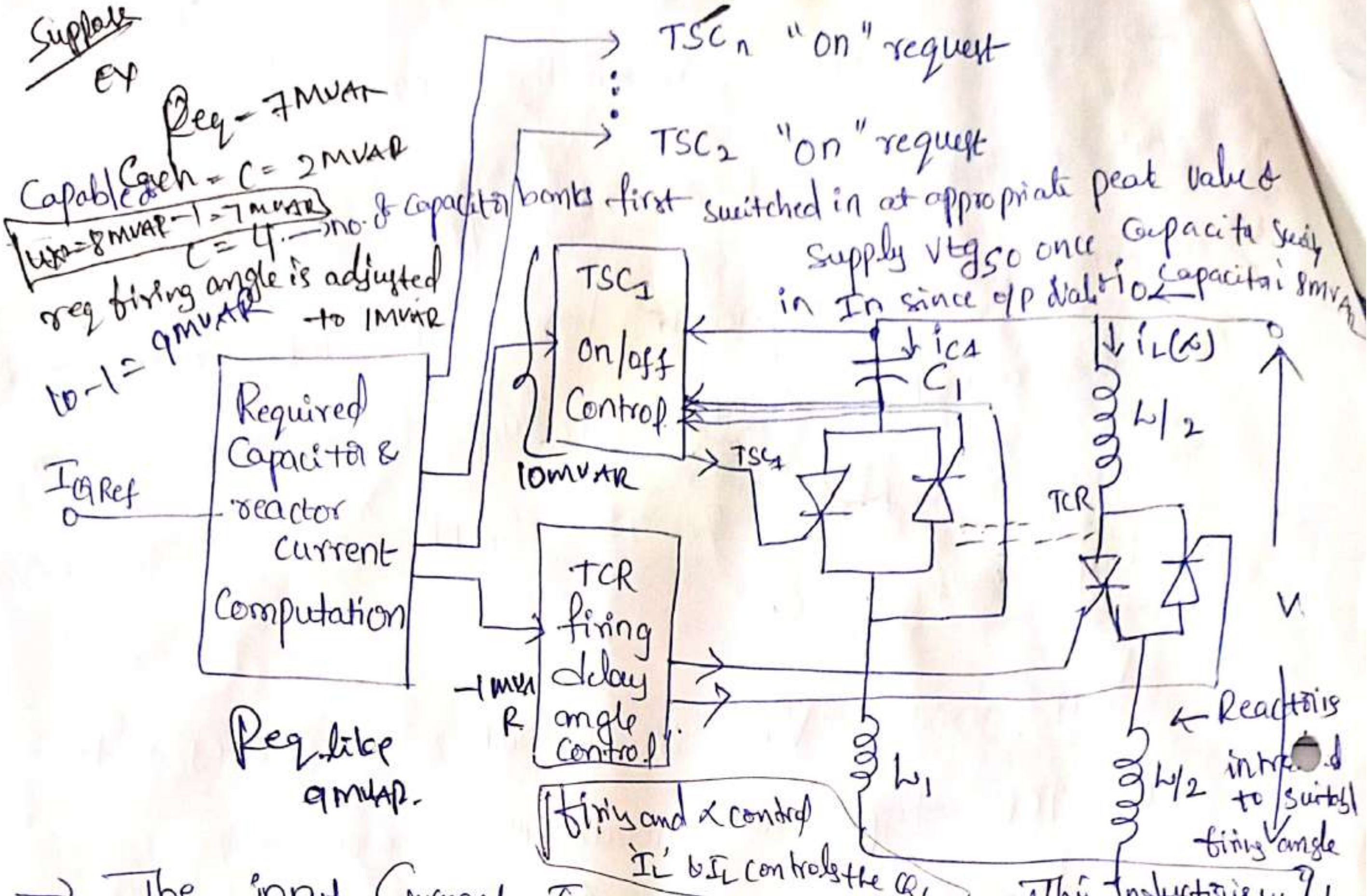
⇒ A functional control scheme of TSC-TCR shown bel

It provides 3 major functions-

→ 1) Determines the no. of TSC branches needed to be switched in to approximate the req capacitive output current and computes the amplitude of inductive current needed to cancel the surplus capacitive current.

→ 2) Controls the switching of the TSC branches in a "transient-free" manner.

→ 3). Varies the current in the TCR by firing delay angle control.




→ The input current $I_{QRef}$ represents the magnitude of the requested output current is divided by the amplitude $I_C$ of the current that a TSC branch would draw at the given amplitude V of the ac voltage. The result, gives the no. of capacitor banks needed.

1st function

→ The difference in magnitude b/w activated capacitor currents $\Sigma I_{cn}$ and the reference current $I_{QRef}$ giving the amplitude of $I_{LF}$ of fundamental reactor current req.

2nd function

→ basic logic for 2nd function (Switching for TSC branches) is shown in fig 5.24(a). This follows two simple rules for "transient-free" manner switching summary.

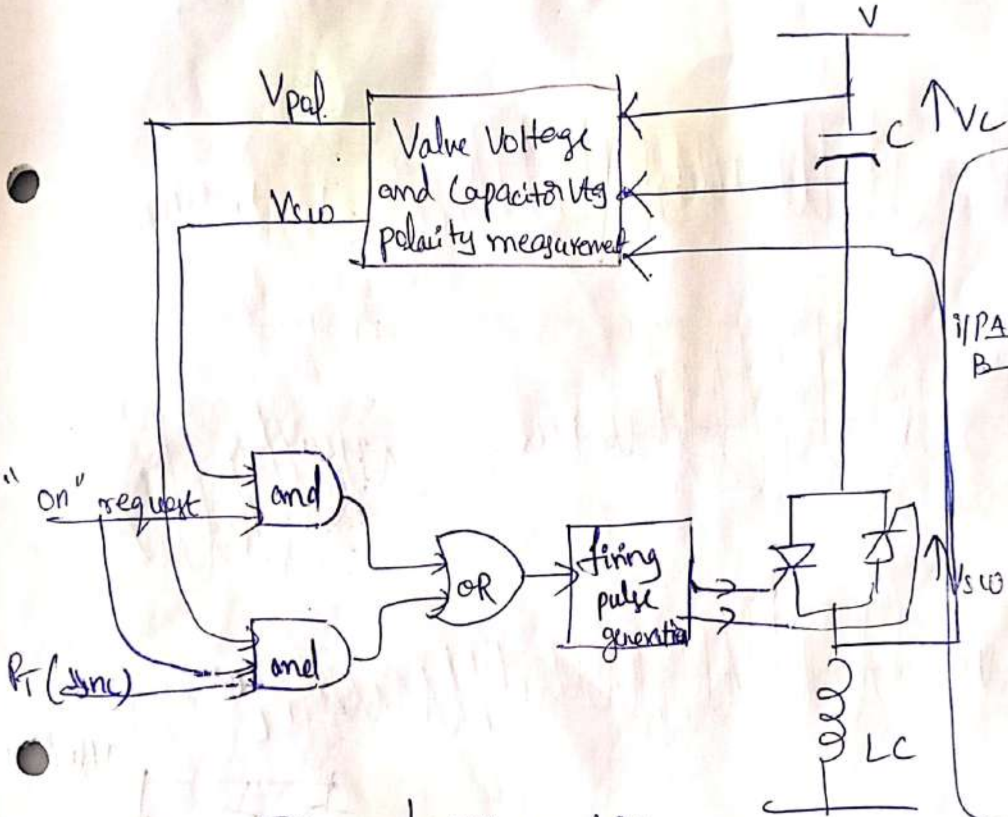
$V_s = V_c$ then i is transient free manner.

Supply vtg = Capacitor vtg.

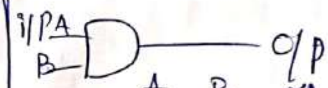
To Switch the Capacitor bank.

→ That is, either Switch the Capacitor bank when the Vtg across the thyristor Value becomes zero & when thyristor Valve Voltage is at a minimum.

→ The actual firing pulse generation for the thyristors in TSC Valve is Similar to that used for the TCR.




AND




| A | B | o/p |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 1 |

TSC turns on if:
"On" = 1 and $V_{sw} = 1$
or
"On" = 1 and $P_T = 1$ and $V_{pol} = 1$

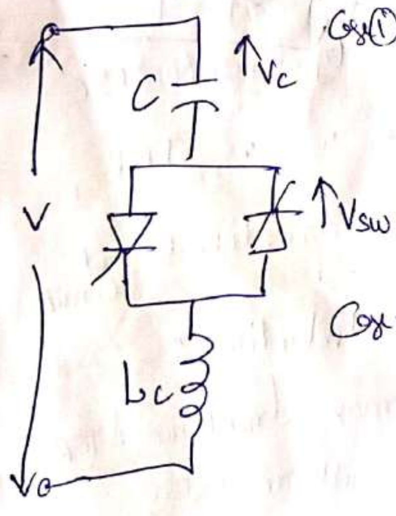
$V_{sw} = 1$ when $V_C = V$

$P_T = 1$ when $v = V$

$V_{pol} = 1$ when sign $v$ = Sign $V_C$

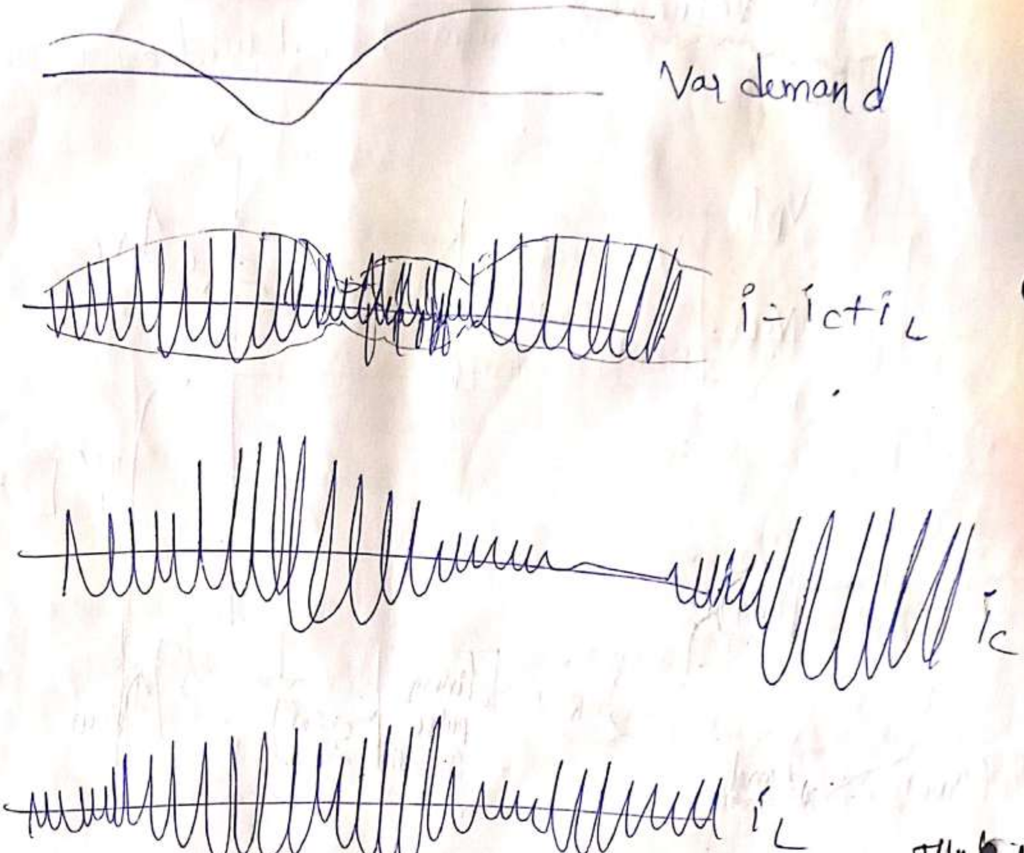
Case (i) - $V_C < V$ ← peak Vtg.
$V_C = V$ ← instantaneous ac vtg.
$V_{sw} = 0$

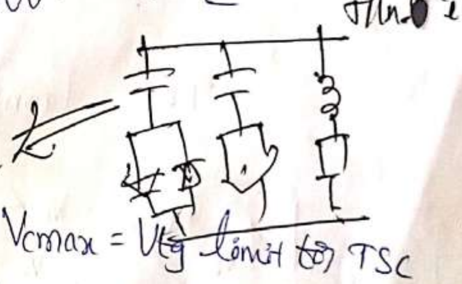
Case (ii) $V_C < V$
$\alpha = 0$
$V_{sw} = min$

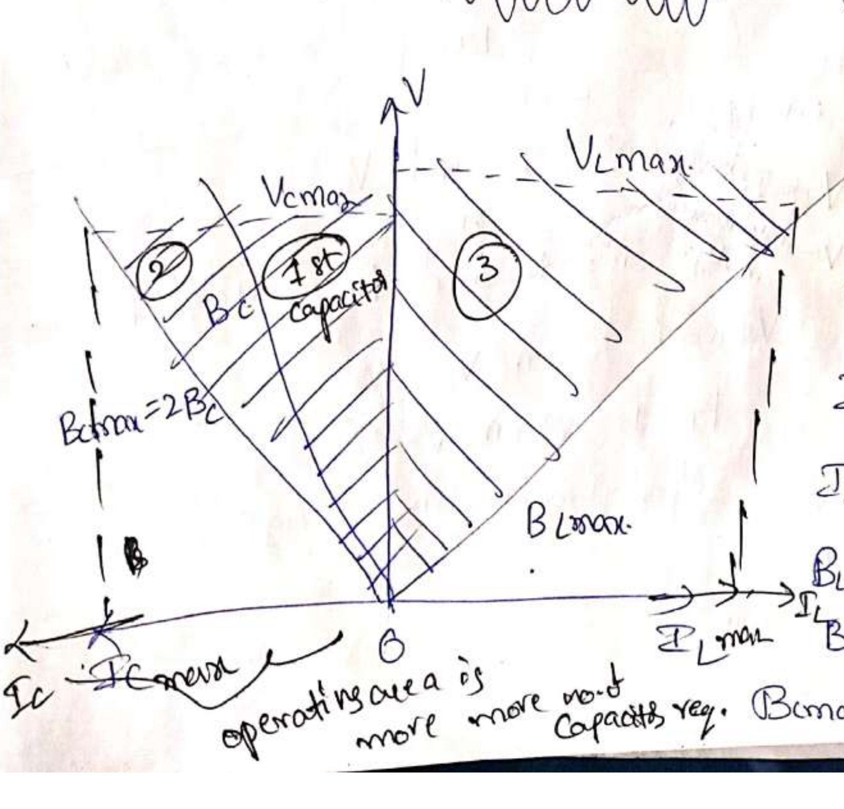


→ The third function (TCR firing delay angle control) is similar to FC-TCR. The operation of TSC-TCR type Var generator with 3 capacitor banks is shown below.

$I_{QRef} = I_{Q} = I_C + I_L$.






$V_{Cmax}$ = Vtg limit for TSC

$V_{Lmax}$ = " " TCR

$I_{Cmax}$ = Capacitive current limit

$I_{Lmax}$ = Inductive " "

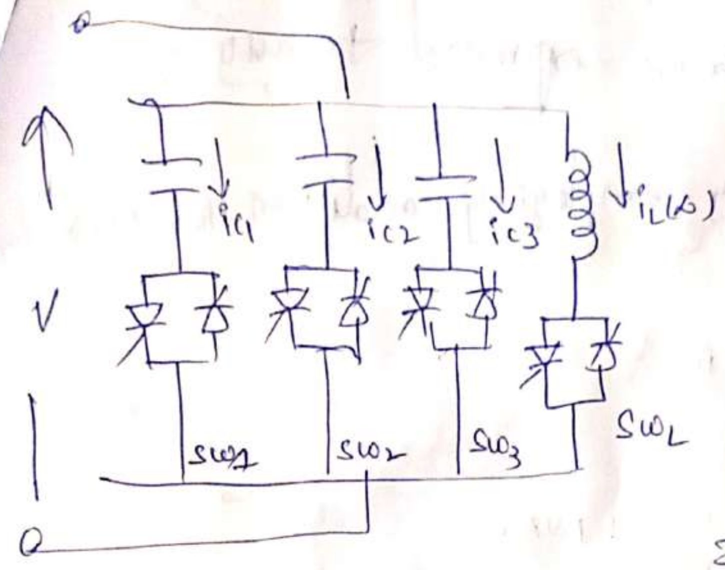
$B_{Lmax}$ = max admittance of TCR

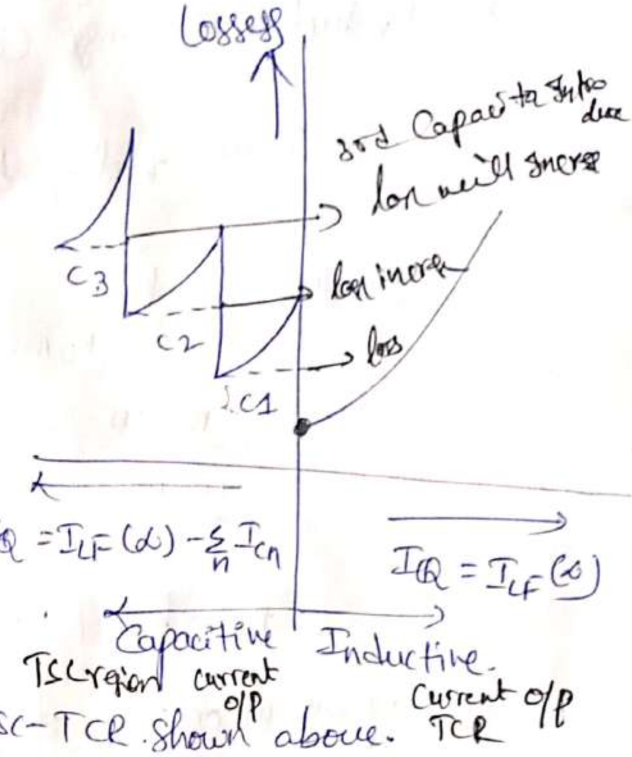
$B_C$ = admittance of TSC

$B_{Cmax}$ = max capacitive admittance

e)






loss vs o/p chag of TSC-TCR shown above.

At or slightly below zero var output, all capacitor banks are switched out, the TCR current is zero or negligibly small, and consequently, the losses are zero or almost zero.

→ as the capacitive output is increased, an increasing no. of TSC banks are switched in with the TCR absorbing the surplus capacitive vars.

→ ~~More over, losses of TCR vary from max to zero b/w~~ ~~Switching of TSC banks are added successive.~~

→ The main design intention is decreases the stand by losses

→ It consists of 'n' no. of TSC branches & one TCR.

→ 'n' no. of branches determines operating vtg.

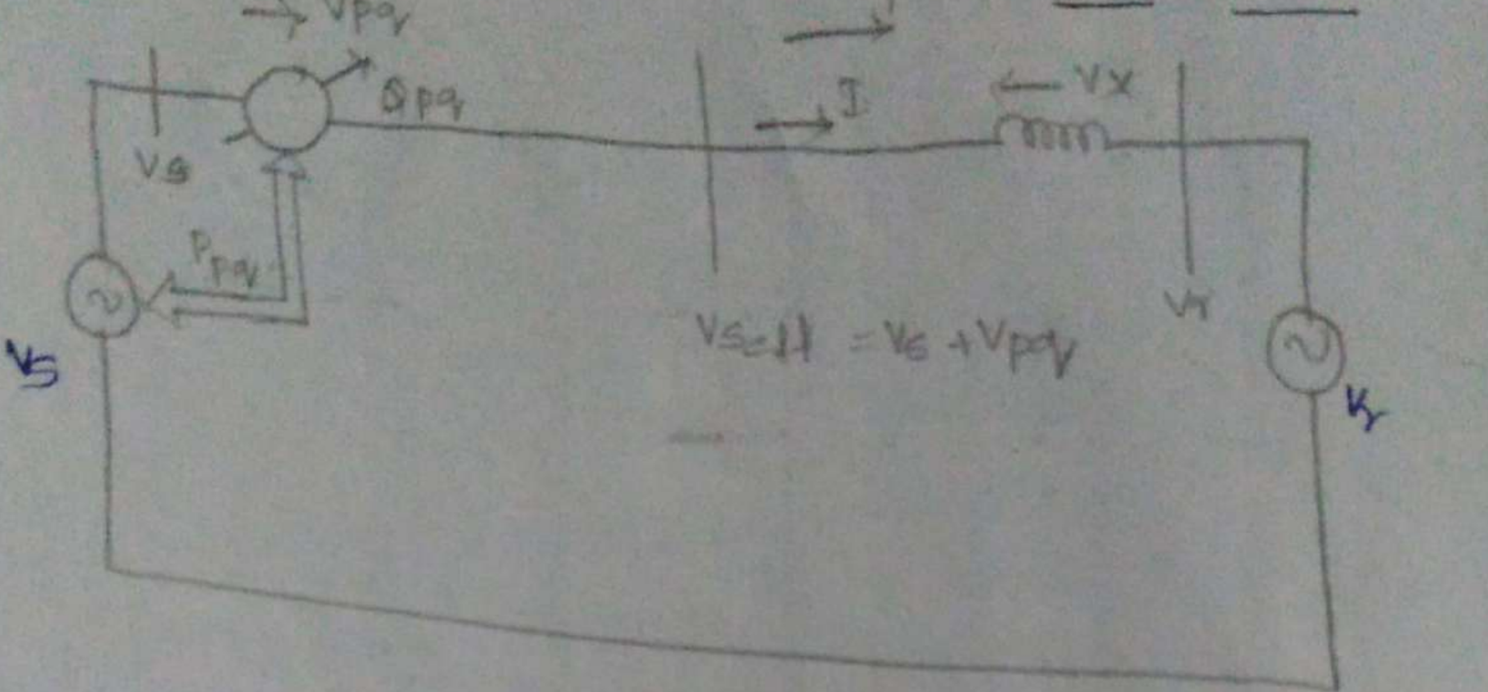
~~Suppose~~ → either connected in star or delta

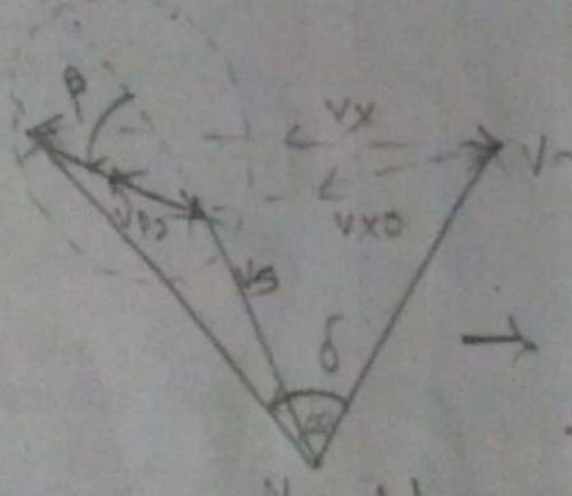
$$Q = V \times [\, I_{LF}(\alpha) - \sum I_{cn} \,]$$

Tot var o/p this scheme — $I_{LF}(\alpha)$ ↓ Inductive Curre; $\sum I_{cn}$ ↓ 'n' no. of capacitive currents.

UNIT-5

→ Unified power flow controller :- (UPFC) - 1991 UGi




→ Phasor diagram

→ To control active & Reactive power
↓
Real tym

Vpq → injected vtg.

## Introduction of UPFC:-

* The UPFC concept was introduced by Gyugyi in 1991

* UPFC was introduced for the real time control & dynamic compensation of AC t/m system

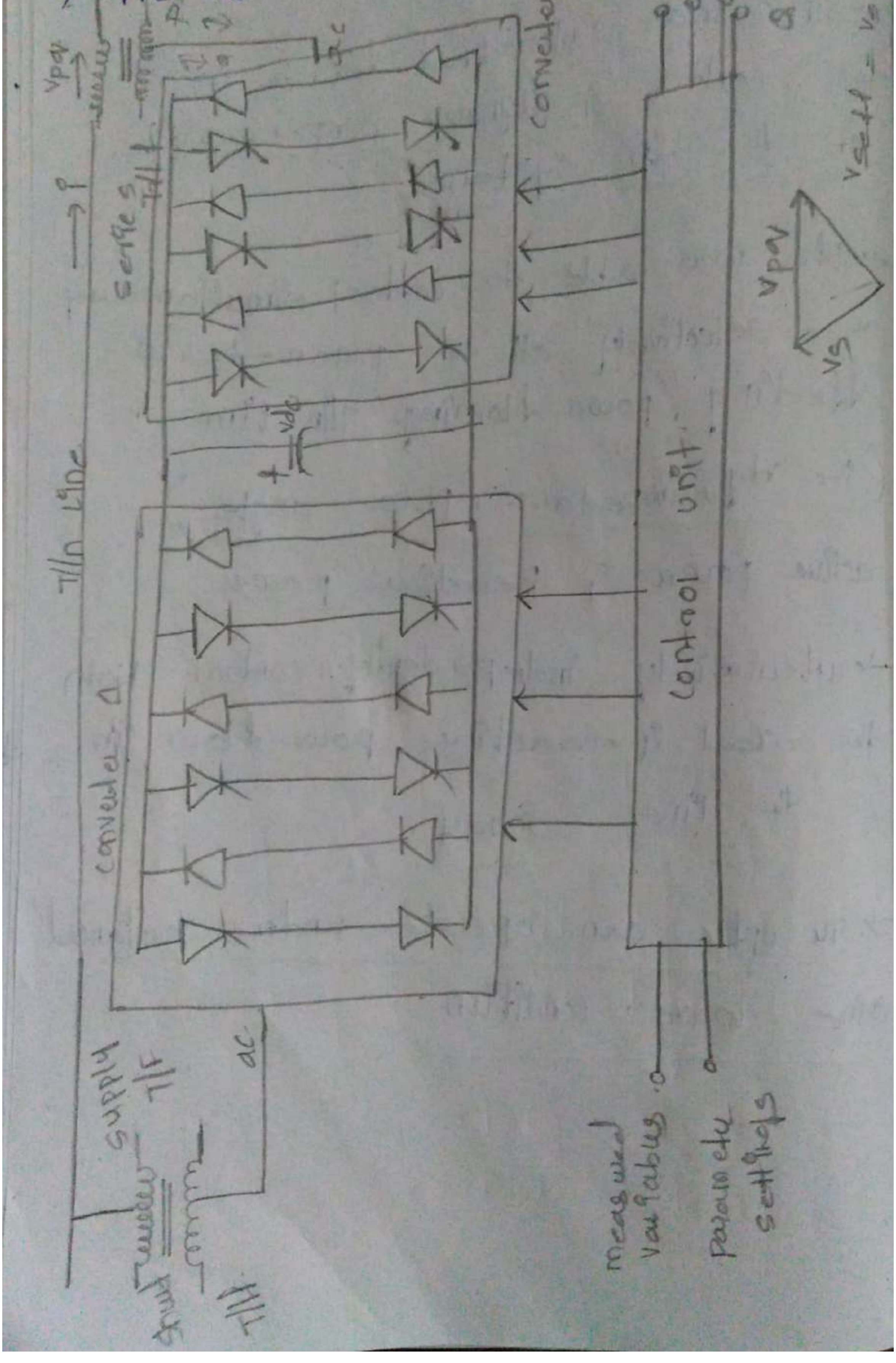
* UPFC was able to control simultaneously or selectively all the parameter's affecting power flowing. T/m Line (i.e vtg, impedance, phase angle), active power & Reactive power

* alternatively, independently control both the real & reactive power flow in the line. → 297

* The UPFC can operate under balanced sine wave condition.

→ **Basic operating principle**

1) UPFC is



→ fig ⑤ show's UPFC controller by 2 Back to Back vtg source converter

1) UPFC is a generalised synchronous vtg source (SVS). represented at the fundamental freq by vtg phasor $V_{pq}$

② It controllable magnitude $V_{pq}$

$V_{pq}. (0 \leq V_{pq} \leq V_{pq\,max})$

and angle $\rho \, (0 \leq \rho \leq 2\pi)$ 0 to 360°

In series with T/In line.

2) UPFC consist's of 2 voltage source converter's, converter-1 (STATCOM) and converter-2 (SSSC) with common DC link. $V_{dc}$ provided by dc storage capacitor.

→ fig shows Ideal ac to ac power converter in which the real power can freely flow in either direction b/w the ac terminals of the converter. and each converter can independently generate are absorb reactive power as its own ac o/p terminals.

→ Converter 2 provides main fun of upfc by injecting a vtg (VPq) and with controllable magnitude "Vpq" & angle "ρ" in series with the line via series (Injection T/f) T/f & this injection vtg acts like synchronous AC vtg source.

→ The tlln line current flows to this vtg source. results in reactive and the real power exchange b/w it and ac source.

→ The Reactive power exchange and the ac terminals i.e at the terminals of series injection T/f is generated internally by the converter.

→ The Real power exchange at the ac terminals is converted in to DC power which appear's at the dc link as a positive or Negative real power demand.

Basic operation of converter - 1

It is to supply and absorb the real power demand by converter - 2 at a common dc link, to support the real power exchange resulting from the series the vtg injection.

→ The dc link power demand of con - 2 is converted to back to ac by con - 1 and it coupled to the then line. with a shunt connected tlf

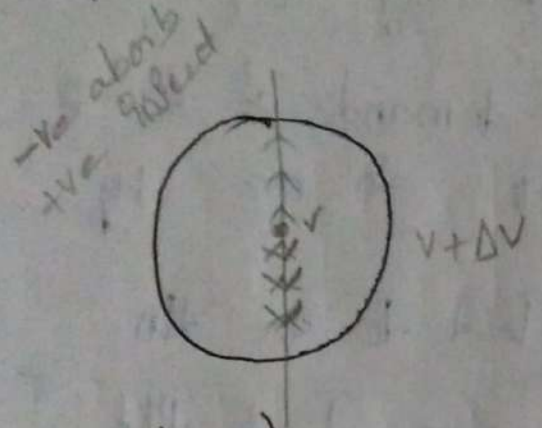
→ In addition to the real power 'p' of con - 2, con - 1 also generates or absorb controllable reactive power by providing shunt reactive compensation of line.

Note : There can be no reactive power flow to the upfc dc link.

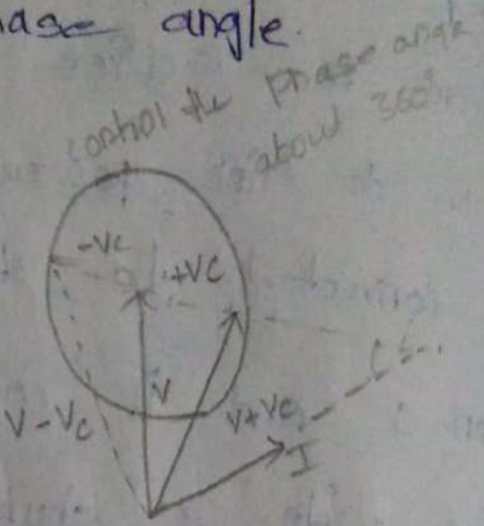
# Conventional Transmission control capabilities

control capabilities are mainly 4 type's

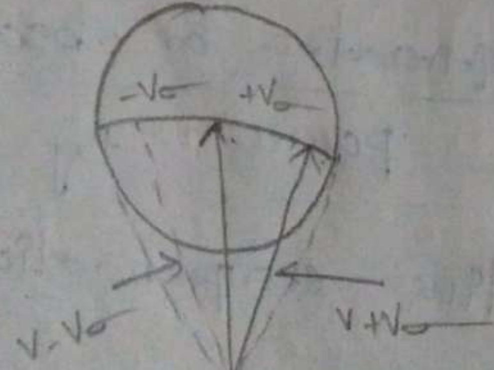
1) voltage regulation
2) line impedance compensation
3) phase shifting
4) simultaneous control of vtg, impedance and phase angle.



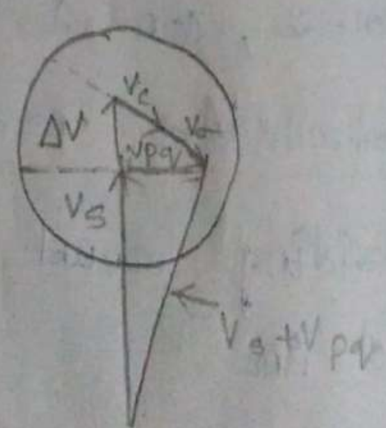

fig(1.)




fig(2)




fig(3)




fig(4.)

fig ① shows vtg regulation with continously variable inphase/ anti-phase vtg injection for vtg increment.

$$V_{pq} = V \pm \Delta V$$

+ This is obtain by tap changing T/f

+ fig ② shows Vpq is the injected in quadrature with line current "I". This is similar to series capacitive and inductive line compensation attain by SSSC.

+ The injected series compensating vtg can be kept constant. It is independent of line current variations

+ fig ③ shows phase angle regulation, where Vpq = V— is injected with an angular induction relation wrspt supply vtg that achieves design phase shift without any change in magnitude.

+ fig ④ shows multiple power flow control executed by simittaneously taminal vtg regulation (±ΔV) series capactive like compensation ($V_q$), phase shifting ($V_\sigma$)

$$V_{pq} = \Delta V + V_q + V_\sigma$$

$$P - jQ = \frac{V_s V_r}{X} \sin\delta \rightarrow V_{pq} = 0 \text{ --- (1) without any compensator}$$

$$P - jQ = V_r \left[\frac{V_s + V_{pq} - V_r}{X}\right]^* \sin\delta \Rightarrow \text{with upfc}$$

$V_{pq} \neq 0$

$$P - jQ = V_r \left[\frac{V_s - V_r}{X}\right]^* + \frac{V_r V_{pq}^*}{-jX}$$

Independent Real and Reactive power flow control.

$V_{pq}$ = injected compensating vltg

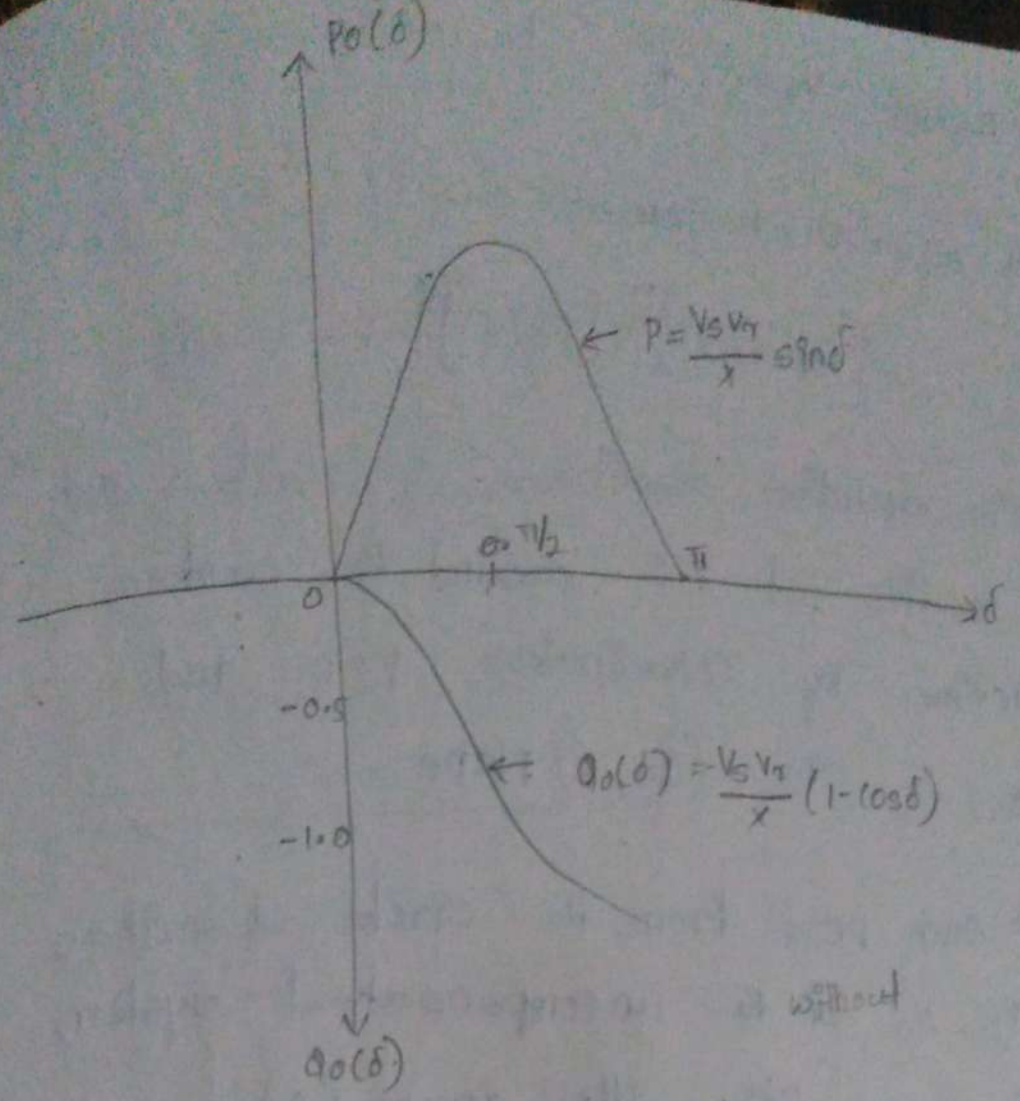
$$V_{pq} = 0 \text{ --- (1)}$$

There is no injected vltg.

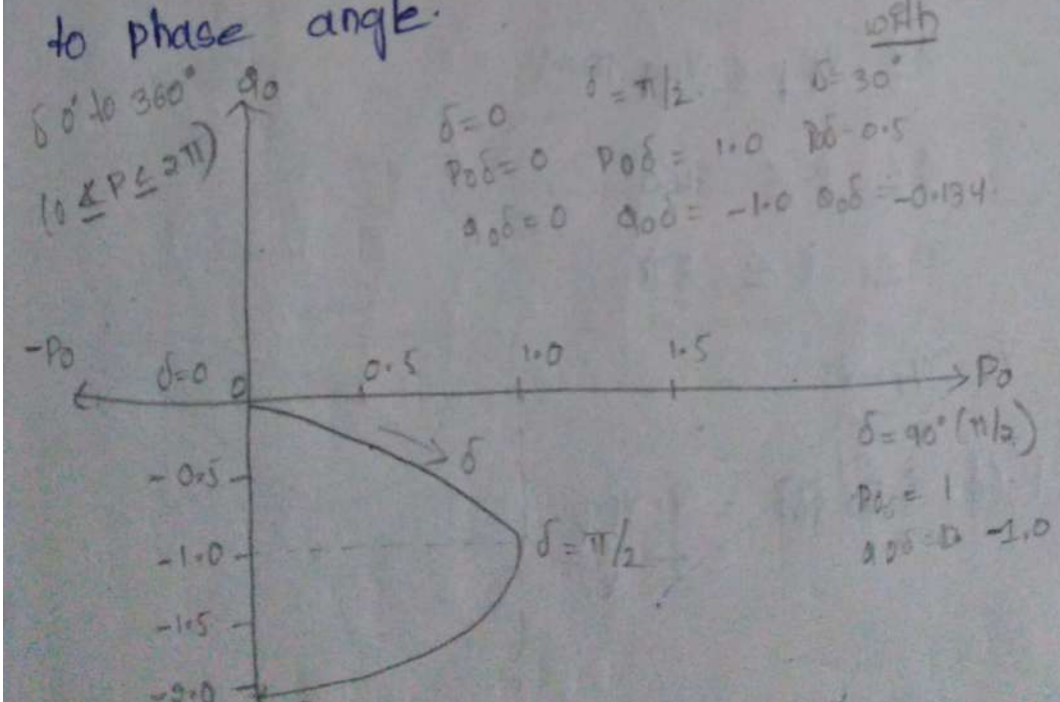
No compensator using.

$$P_0(\delta) = \frac{V_s V_r}{X} \sin\delta \text{ --- (2)}$$

$$Q_0(\delta) = \frac{-V_s V_r}{X}(1 - \cos\delta) \text{ --- (3)}$$




fig(1) shows the relation b/w Real power Po(δ), Reactive power with respect to phase angle.



→ Assume $\frac{V_s . V_r}{X} = 1$

The equation becomes.

$$\left[q_0(\delta)+1\right]^2+\left[P_0(\delta)\right]^2=1 \quad \text{---} (4)$$

This equation describes a circle with a radius of 1.0 around the centre define by coordinates $P=0$ and $Q_r=-1$ in $(Q_r, P)$ plane.

→ Each point from the circle describes $P_0, q_0$ of the uncompensated system at a specific T/n angle $(\delta)$

$\therefore V_{pq} \neq 0$

$$0 \leq V_{pq} \leq V_{pq\,max}$$

$$0 \leq \rho \leq 360°$$

$$0 \leq \rho \leq 2\pi$$

$$V_s = V_r = V$$

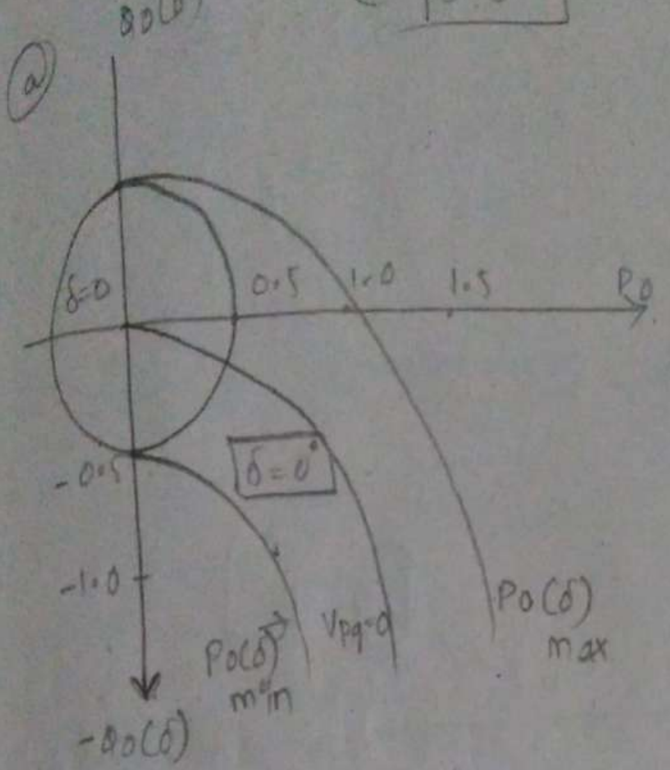
$$P_0(\delta) \;\&\; Q_0(\delta) = \frac{V_r V_{pq}}{X}$$

→ This is the radius of circle.

$$\left[P(\delta,P) - P_0(\delta)\right]^2 + \left[Q(\delta,P) - Q_0(\delta)\right]^2 = \left[\frac{V \cdot V_{pq\,max}}{X}\right]^2$$

Con

(a) @ $\delta = 0°$

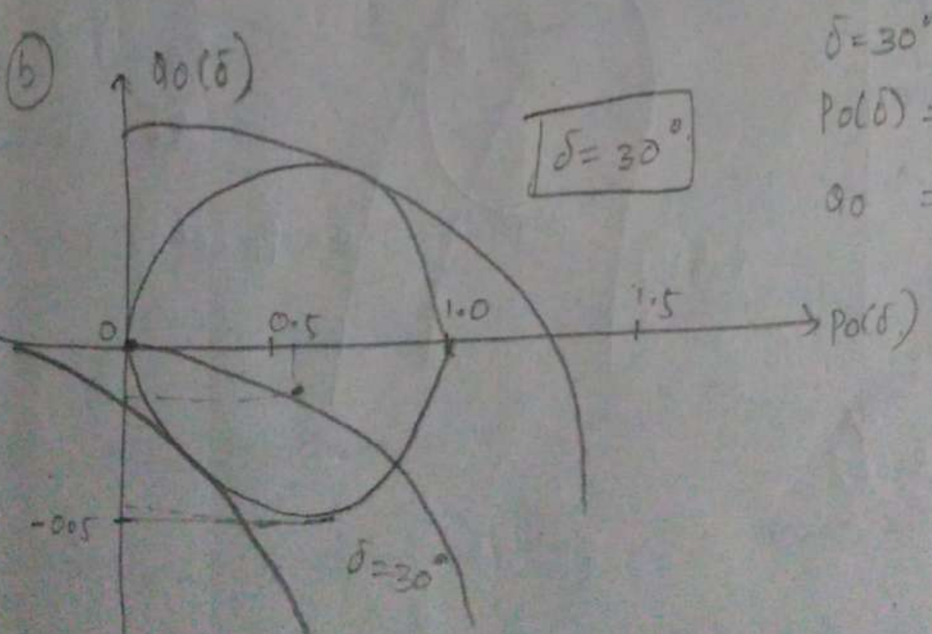



(b)

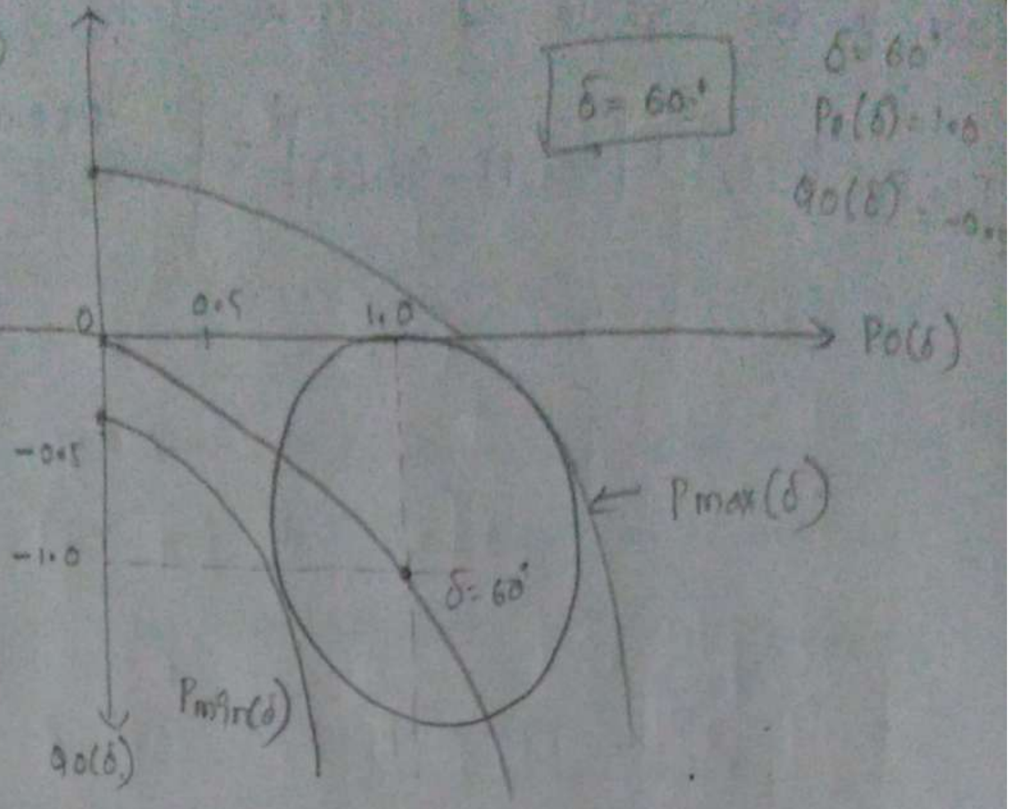
$\delta = 30°$

$P_0(\delta) = 0.5$

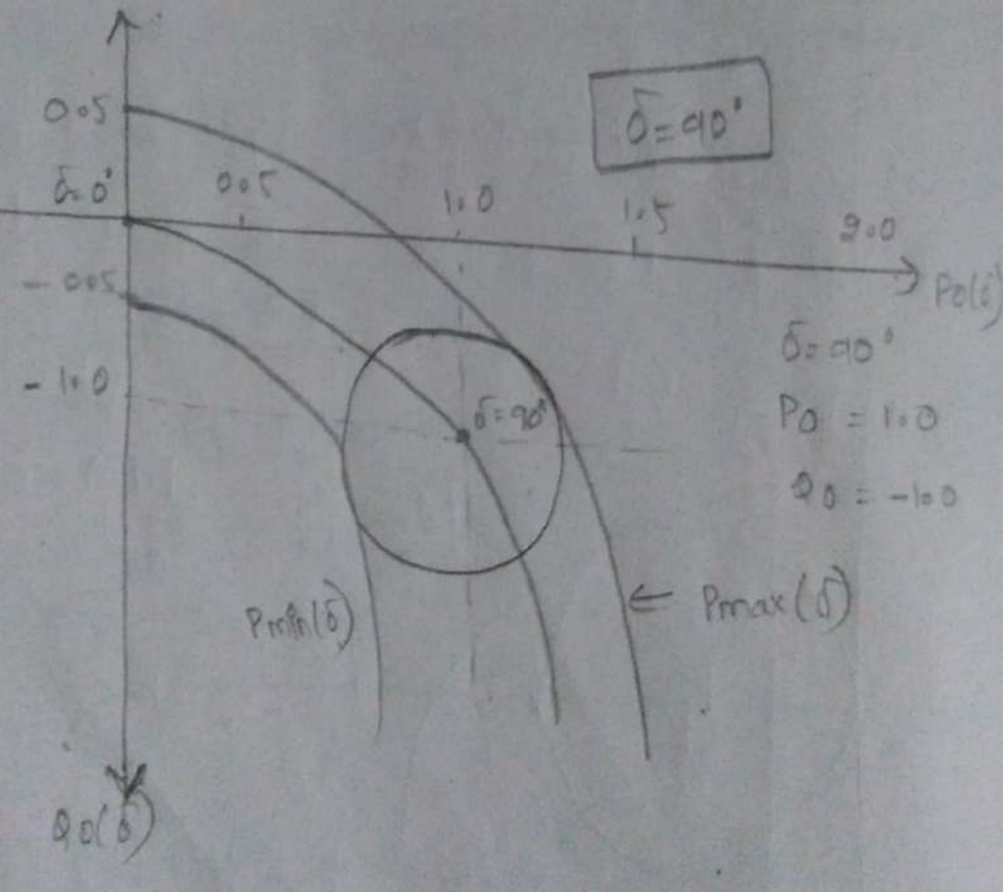
$Q_0 = -0.5$



(6)




(b)




Scanned with CamScanner

control region of the attainable power and Receiving & reactive power 'QR' with UPFC control with a tlln line,

→ $\delta$ = fig (a), 0°

$\delta$ = 30, fig (b)

$\delta$ = 60°, fig (c)

$\delta$ = 90°, fic (d) shown above.

→ In fig (a) illustrates, tlln angle = 0

$\delta = 0$

$V_{pq} = 0$

$P_0 = 0$

$Q_0 = 0$

that means the system is at stand still at the origin of $Q_r$, P coordinates

→ This circle around origin at the Qr, P, gives the corresponding values of Real power and Reactive power.

→ similar control chr's for real power 'P' & reactive power 'Q' can be absorbed at angles 0°, 30°, 60°, 90°, shown in fig ⓐ, b, c, d,

→ At any tlln angle 'δ' (0 to 360°), the transmitted power 'p' as well as reactive power 'Q' can be controlled freely by the upfc.

→ It is a unique capability to control the real & reactive power flow at any tlln angle.

# UNIT-II

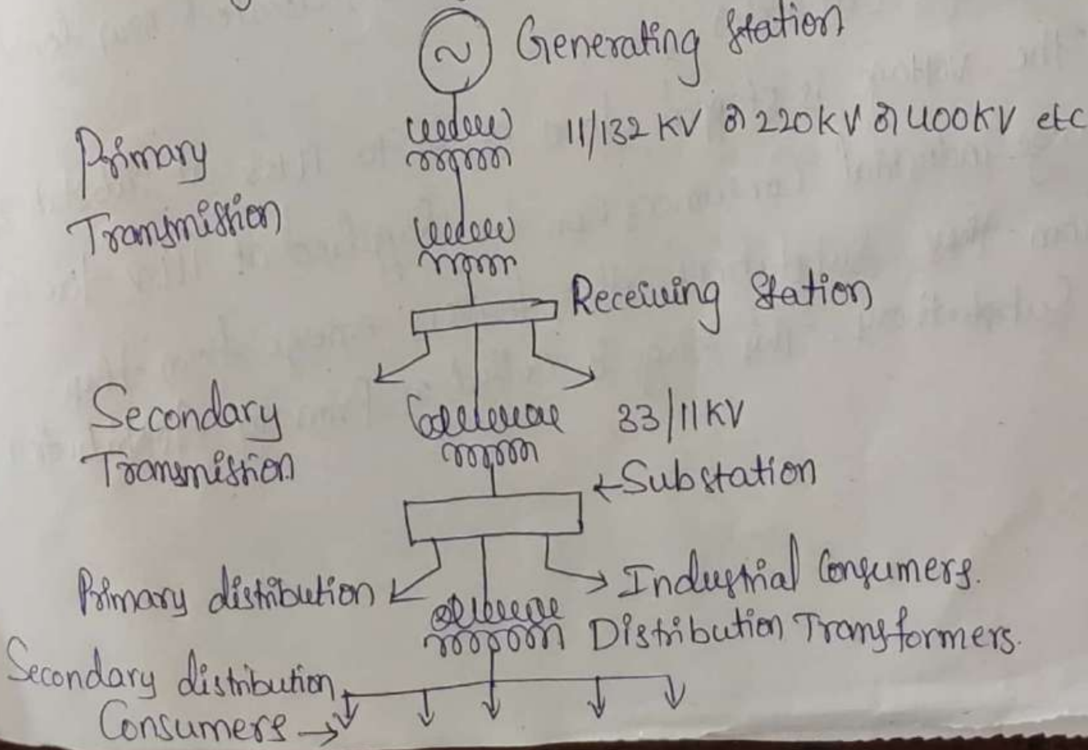
## Transmission lines and Series/shunt Reactive power Compensation.

**Basics of AC Transmission:-** Electrical energy is generated in TPS, HPS, NPS etc. This generated electrical energy is transmitted to the Consumers for utilisation.

Generally generating Stations is are usually situated away from the load Centres. The network that transmits and delivers power from Generating Station to the Consumers is Called Transmission System. This energy Can be transmitted in AC or DC form.

Traditionally, AC has been used for year now, but HVDC is rapidly gaining popularity.

Single line diagram



→ Electric power is commonly generated at 11kV in generating station in India and Europe. while in some cases, generating voltage might be higher or lower. Generating machines, to be used in power stations, are available between 6kV to 25kV from some big mfgs.

→ This generating voltage is is then stepped up to 132kV, 220kV, 400kV. or 765kV etc. Stepping up the voltage level depends upon the distance at which power is to be transmitted.

→ Longer the distance, higher will be the voltage level. Stepping up of voltage is to reduce the $I^2R$ losses in T/In lines. This stage is called primary transmission.

→ The voltage is the stepped down at receiving station to 33kV or 66kV. Secondary transmission lines emerge from this receiving station to connect substations located near load centres (cities etc).

→ The voltage is stepped down again to 11kV at substations. Large industrial consumers can be supplied at 11kV directly from these substations. Also, feeders emerge from these substations. This stage is called as Primary distribution.

→ feeders are either overhead lines or under ground cables which Carry power close to the load Points up to a couple of kilometers.

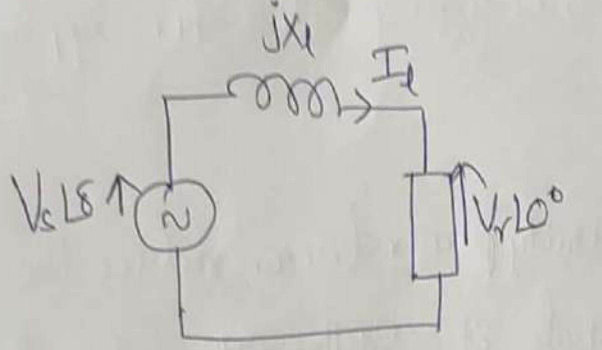
finally the Voltage is Stepped down to 415 volts by a Pole mounted distribution transformer

## Main Elements of a T/In lines:-

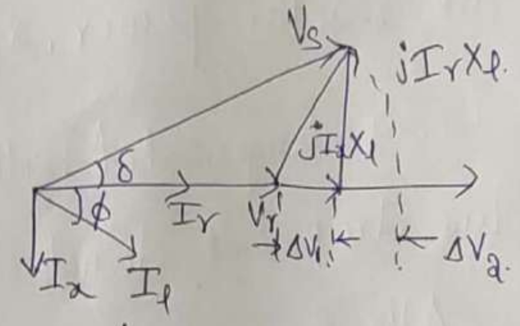
1) Conductors:- ACSR. , 3-ϕ 3wire, 3-ϕ 4wire
2) T/F's:- Step-up & Step-down
3) Line insulators:- To give mech support for the line Conductors
4) Support towers:- To support line Conductor.
5) prot devices - to Protect the T/In sys. and to ensure reliable operation. These includes ground wires, LA's CB's relays etc.
6) Vtg Regulators:- to keep the Vtg with in permissible limits at the receiving end.

# Analysis of uncompensated AC transmission lines:-

**Introduction:-** For simplicity assume the load is Inductive.




fig(a)




fig(b)

→ From the above fig, It is clear that between the sending and receiving end voltages and magnitude variation as well as a phase difference is created and the most significant part of the voltage drop in the line reactance is due to the reactive component of the load current and to keep the voltages in the network nearly at the rated value.

→ There are two compensation methods are.

1. Load Compensation
2. System Compensation.

## Load Compensation:-

→ It is possible to compensate for the reactive current of the load by adding a parallel capacitive load so that $I_c = I_x$ and the effective power factor to become unity.

→2). absence of $I_x$ eliminates the Voltage drop $\Delta V_1$ bringing $V_r$, Closer in magnitude to $V_s$, This Condition is Called load Compensation and actually by changing extra for Supplying the reactive power.

→3) Loads Compensated to the unity power factor reduce the line drop but do not eliminate it. Still exist a drop of $\Delta V_2$ from $jI_r X_l$.

## System Compensation:—

→ To regulate the receiving end voltage at the rated value a power utility may install a reactive power Compensator as shown in fig. and this Compensator draws a reactive Current to overcome both Components of the Voltage drop $\Delta V_1$ and $\Delta V_2$ as a Consequence of the load Current $I_l$ through the line reactance $X_l$.

→ To Compensate for $\Delta V_2$ (drop in the line) an additional Capacitive Current $\Delta I_c$ over and above $I_c$ that Compensates for $I_x$ is drawn by the Compensator.

→ when $\Delta I_c X_l = \Delta V_2$ the receiving end voltage $V_r$ equals the Sending end Voltage $V_s$. This method is employed by power utilities to ensure the quality of Supply to the Consumers.

## Load Compensation in power System:-

→ Load Compensation is the management of reactive power to improve power quality i.e Voltage and p.f profile.

→ Here the reactive power flow is controlled by installing Shunt Compensating devices (Capacitors/reactors) at the load end bringing about proper balance between generated and consumed reactive power.

→ This is most effective in improving the power transfer Capability of the System and its Voltage Stability. It is desirable both economically and technically to operate the System near unity power factor.

## Lossless Distributed parameter lines:-

→ Most power transmission lines are characterized by distributed parameters. Series Resistance, Series Inductance, Shunt Conductance and Shunt Capacitance all are distributed in per unit length depends upon Conductor size, Spacing, and Clearence above the ground, frequency and temparature of operation.

→ In addition these parameters depends on the bundling arrangement of the line Conductors and the Spacing b/w parallel lines.

UNIT- III

static shunt compensators
SVC & STATCOM.

objectives of shunt compensation:-

→ The main function of reactive shunt compensator is to improve the steady - state transmittable power and voltage stability along the line.

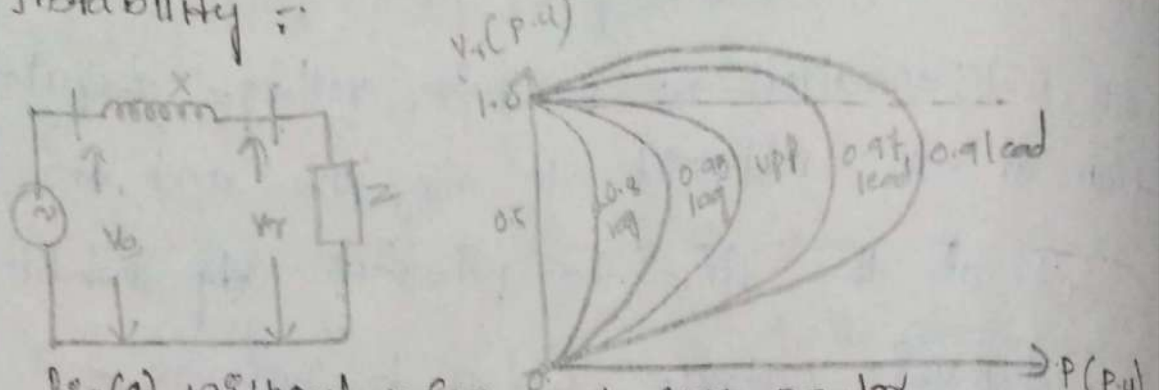
→ The purpose of reactive compensation is to change natural electrical characteristics of the transmission line and improve the line performance to meet the load demand.

→ shunt compensators are fixed or mechically switched reactors are used for minimise line over voltage under light load conditions, Capacitor controllers is used to minimise voltage ~~under~~ levels under heavy load conditions.

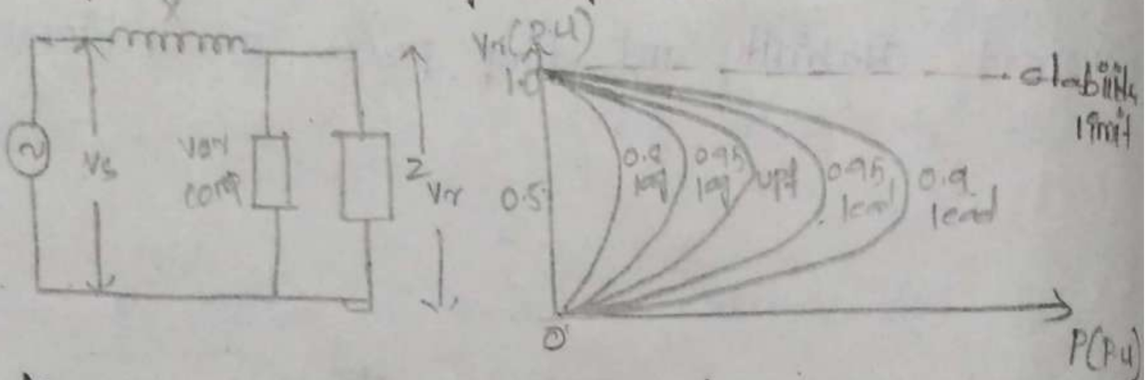
→ The main objective of shunt compensation is a tl/n on system is to increase the transmittable power. This may improve steady-state transmission characteristics as well as stability of the system.

→ var compensation is used for voltage regulation at the mid point to the line and at the end of the line to prevent vtg instability, dynamic voltage control to improve transient stability and damp power oscillations.

End of line voltage support to prevent voltage instability :-




fig(a) without using any compensator




fig(b) with using compensator.

fig(1) shows without using any compensator. the.

* fig(1) shows sim.
with line reactance "X" and load impedance "Z"
The plot is drawn b/w terminal vtg and power at various load p.f ranging ~~front~~ from 0.8 lag to 0.9 lead.

→ "The nodes point at each plot given for a specific p.f represents vtg ~~xx~~ instability.

→ WKT vtg stability limit decreases with inductive load and ↑ with capacitive load fig (b) shows voltage using shunt reactive compensator of radial line is to be connected ll to the load

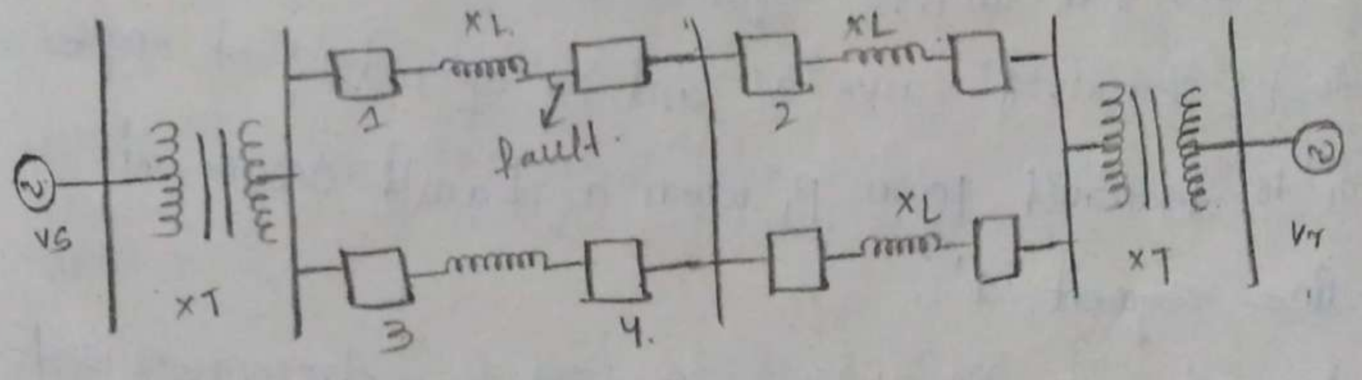
→ shunt reactive compensation can effectively increases the vtg stability limit by supplying reactive load. & resulting terminal vtg.

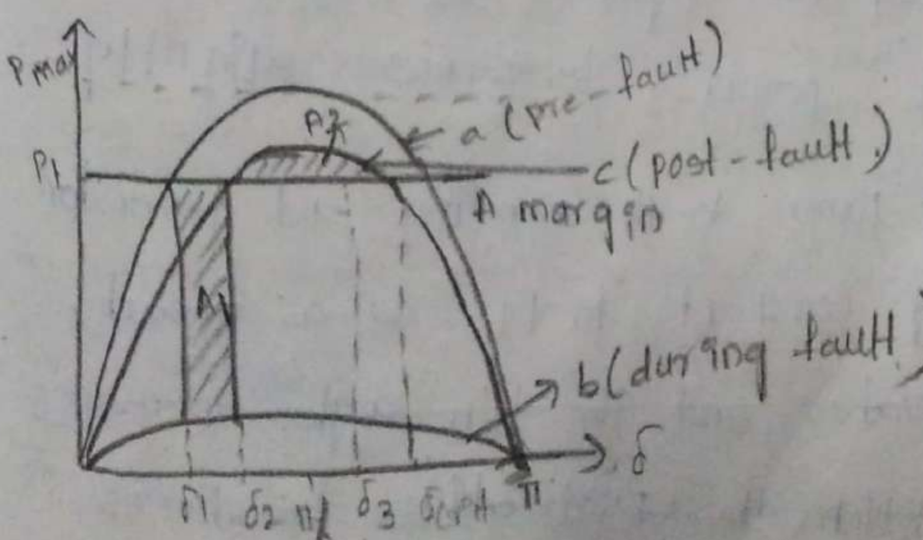
$V - V_r = 0$ shown in fig b.

→ Reactive shunt compensation is used in practically to regulate the voltage at a given bus against load variation.

→ Improvement of Transient stability :-

(a)




..(b)

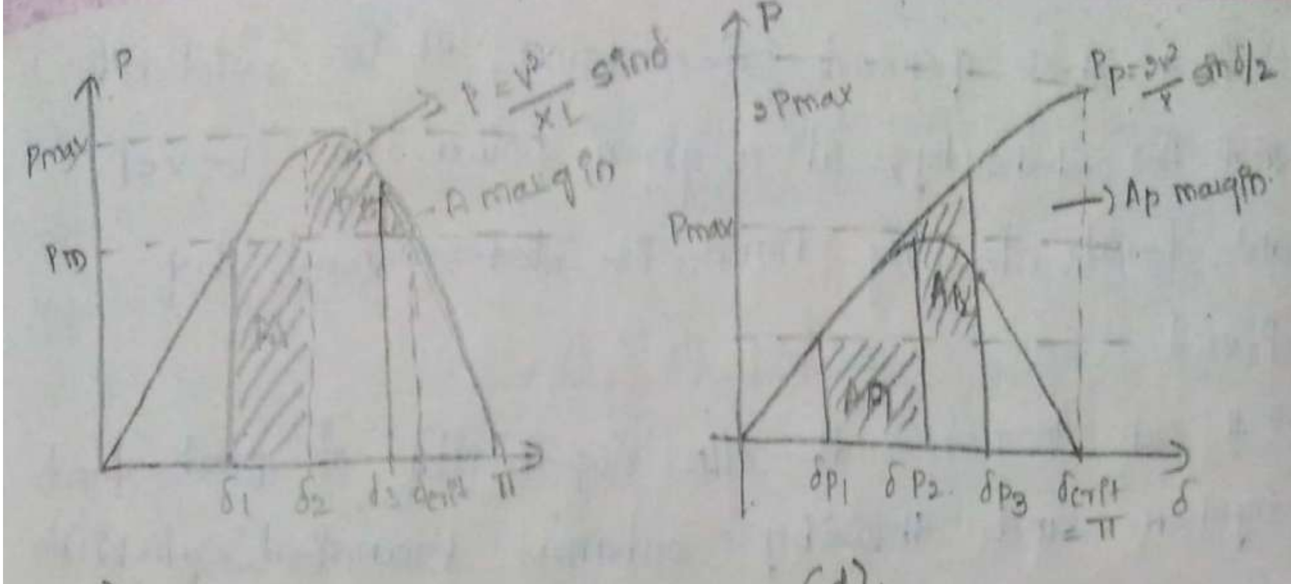
→ Illustration of the equal area criteria for transient stability of a two m/c, two-line power system

→ shunt compensation will be able to change the power flow in the system during and following disturbances is as to increase the transient stability limit and provide effective power oscillation damping.

The potential effectiveness of shunt on transient stability improvement can be convienitently evaluated by the "equal area criteria".

→ Assume that complete system is characterised by the "p" versus "δ" curve "a" and is operating at angle $\delta_1$ to transmit power $P_1$ when a fault occurs at line segment "1".

→ During the fault the system is characterised by the "p" electric power decreases slightly while mechanical i/p power to the sending end generator remains substantially constant to $P_1$. as a result, the generator accelerates and the t/m angle increases from $\delta_1$ to $\delta_2$ at which the protective breakers disconnect the faulted line segment "1" and the sending end generator absorbs accelerating




(c) (d).

energy represented by area A1

→ After fault clearing without line segment "1" the degraded system is characterized by P vs δ curve "c". At one angle δ on curve "c" the transmitted power exceeds the mechanical I/P power $P_1$ and the sending end generator starts to decelerate. However angle δ further increase due to the kinetic energy stored in the m/c.

→ The max angle reached at $\delta_3 = \delta_{critical}$, beyond which the decelerating energy would not balance the accelerating energy and synchronism b/w the sending end and receiving end could not be restored.

The area "A margin" between $\delta_3$ & $\delta$ critical represent the transient stability margin of the system.

⇒ from above general discussion, it is evident that the stability, at a given power t/In level and fault clearing time is determined by P vs δ.

→ It can increase the t/In capability of post-fault system and thereby enhance transient stability

→ comparision of fig "c" & "d" shows increase in the transient stability to the ideal mid point compensation with not restricted var o/p can provide by effective segmentation of the t/In line. If uncompensated sys has transient stability margin, shunt comp sys has increase the transmittable without decreasing this margin.

→ 23/4/22. Methods of Controller VAR Generation

In this 2 types of controllers is there.

i) static VAR compensator.

ii) static VAR Generators

Variable Impedance → TCR (Thyristor control Reactor), TSR (T switch reactor), FC-TCR (fixed capacitor - Thyristor control reactor).

Variable Generators

i) SVG :-

whose o/p is varied so, has to maintain / control the specific parameters of the electrical power system.

→ It is a sufficiently functioning device it. will draws a Reactive current from an Alternating power source.

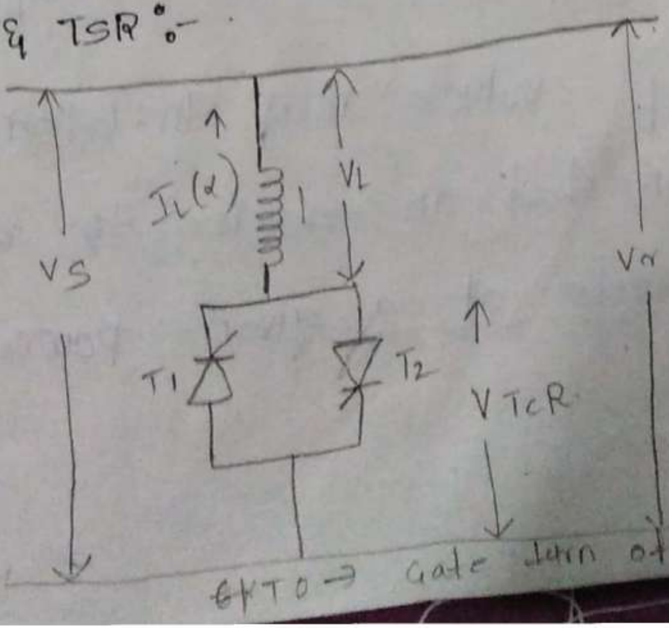
→ The control I/p of VAR Gen'r can be arbitrary (with in the operating range). Reactive current Impedance / power to the Reference the SVG delivers at it's o/p.

→ The SVG is used as power amplifier it faithfully produces the Required signal at the desired power levels.

Variable Impedance type.

Static VAR. Generator :-

* TCR & TSR :-




* T1 → +ve half cycle

* T2 → -ve half cycle

The control range of thy is 90° to 180°

thyristors are used

GTO → Gate turn off

→ Two thyristors are connected in the anti parallel ($T_1$ & $T_2$) GTO (Gate turnoff thyristor)

→ series connected with air cored Reactor is shown in fig.

→ $T_1$ will conducts during the +ve half cycle. & $T_2$ will conducts during the -ve half cycle.

→ The control Range of thyristors is 90° to 180°

→ fig ① shows single phase, thyristor controlled Reactor it consists of fixed air cored Reactor of Inductance (L). In a bidirectional thyristor valves (switches)

→ currently available thyristor are drawn vtg range 400V - 900V

→ conduction currents 3000 - 6000 Amps.

→ In practically valves may thyristors are 10 - 20 connected in series to require blocking vtg levels at a given power rating.

operation :-

→ Thyristor valve coming into the conduction by applying gate pulses to same polarity.

→ The valving automatically blocks after the AC current cross to 0, unless the gate signal is re applied.

→ It will operate on natural commutation (or) line commutation the current in the reactor can be controlled from max to zero by the method of thyristor delay angle control.

→ the thyristor valve is delay with respective to the heat of applied vtg in each half cycle, at the duration of current control.

$$V_S = V_L + V_{TCR} \quad \text{—— (1)}$$

$$V_S = V_L \quad \text{—— (2)}$$

$V_{TCR}$ = There is no drop vtg

$$\therefore V_S = V_L = L \frac{di_L}{dt} \quad \text{—— (3)}$$

$$V_S(t) = V \cos \omega t$$

$$i_L(t) = \frac{1}{L}\int_{\alpha}^{\omega t} V_s(t)\,dt$$

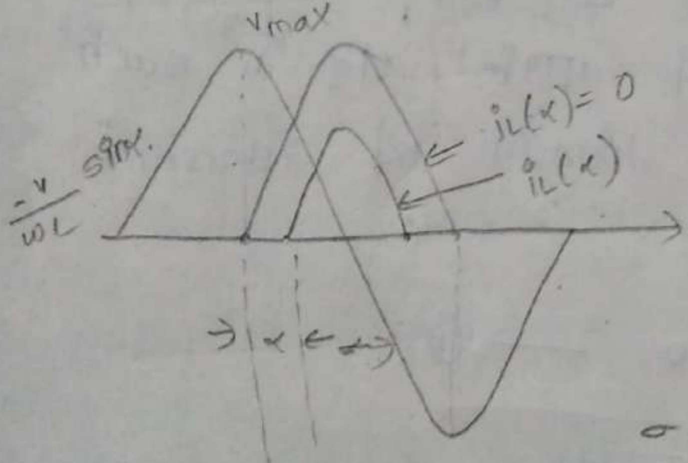
$$= \frac{1}{L}\int_{\alpha}^{\omega t} V \cos\omega(t)\,dt$$

$$= \frac{V}{L}\int_{\alpha}^{\omega t} \cos\omega t\,dt$$

$$= \frac{V}{L}\left[\frac{\sin\omega t}{\omega}\right]_{\alpha}^{\omega t}$$

$$i_L(t) = \frac{V}{\omega L}\left[\sin\omega t - \sin\alpha\right]$$

If current flowing inductor is ↑ses the absorption capacity of VAR ↑ses

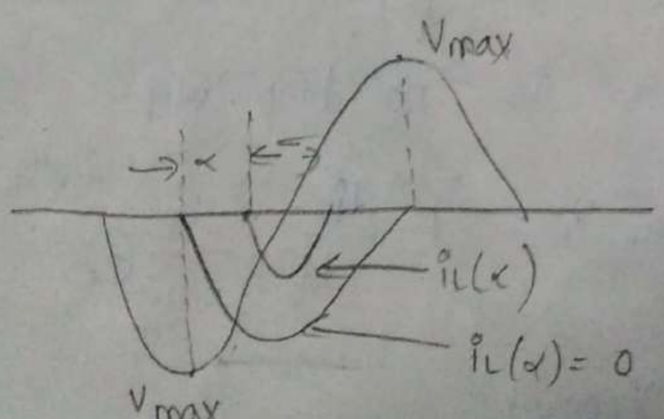



$\omega t \; \frac{V}{\omega L}\sin\alpha$

$\alpha \rightarrow$ firing angle

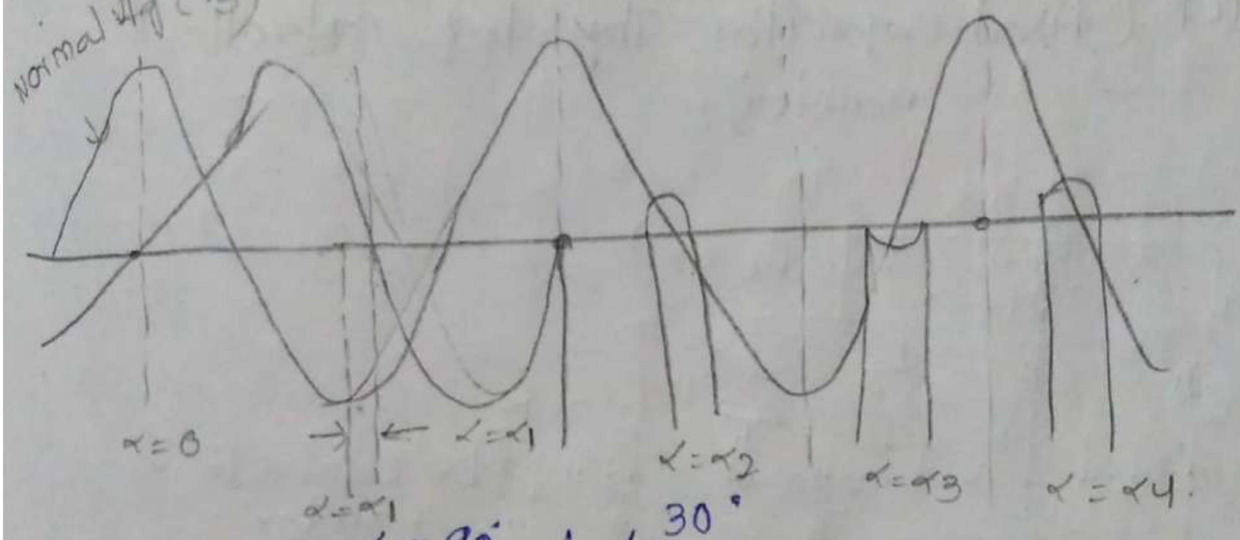
$\sigma \rightarrow$ conduction angle

$\sigma + 2\alpha \rightarrow$ +ve half cycle



Above fig shows delay angle firing angle controlled for +ve & -ve half cycles the method of current controlled during the +ve & -ve half cycles shown in above figure. when the vtg is max. at fig ($i$ max) at that current in the inductor $i_L(\alpha) = 0$ still not stop to absorb the reactive power.

It starts from $\alpha = 90°$ to $180°$ up to that period only inductor its stores the reactive power




$\alpha = 90° + \alpha_1$ 30°

$\alpha = 90° + \alpha_2$ 40°

$\alpha = 90° + \alpha_3$ 50°

$\alpha = 90 + \alpha_4$ 60°

Positive half cycle → $(\alpha \leq \omega t \leq \pi - \alpha)$

Negative half cycle → $(\pi + \alpha \leq \omega t \leq 2\pi - \alpha)$

when ever $\alpha \rightarrow \uparrow$ses from $0^\circ$ to max value

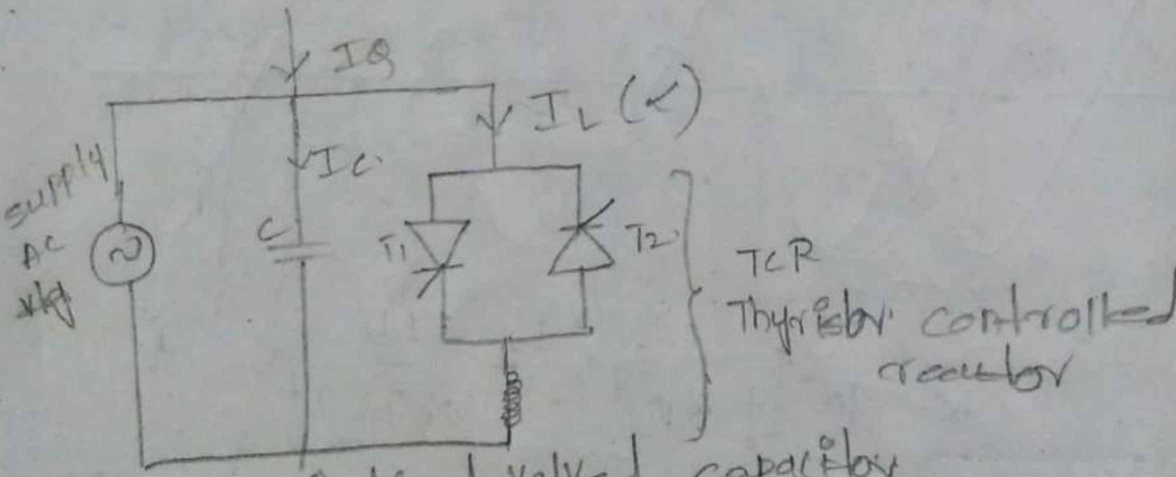
$\alpha = 0$ , $\alpha = \alpha_1$ , $\alpha = \alpha_2$ , $\alpha = \alpha_3$ , $\alpha = \alpha_4$

* By $\uparrow$ ses the '$\alpha$' the conduction angle $\downarrow$ ses and also current flowing inductor is $\downarrow$ ses the amplitude

$$I_{CF}(\alpha) = \frac{V}{\omega L}\left(1 - \frac{2}{\pi} \frac{-1}{\pi} \sin 2\alpha\right) \quad (3)$$

31/5/22 from eqn $\frac{V}{\omega L}\left[\sin \omega t - \sin \alpha\right]$

**FC-TCR (fixed capacitor Thyristor controlled reactor).**




$$I_Q = I_C + I_{LF}(\alpha)$$

Above fig show's the fixed capacitor - TCR

* Above fig shows

(a) without using coupling T/f.

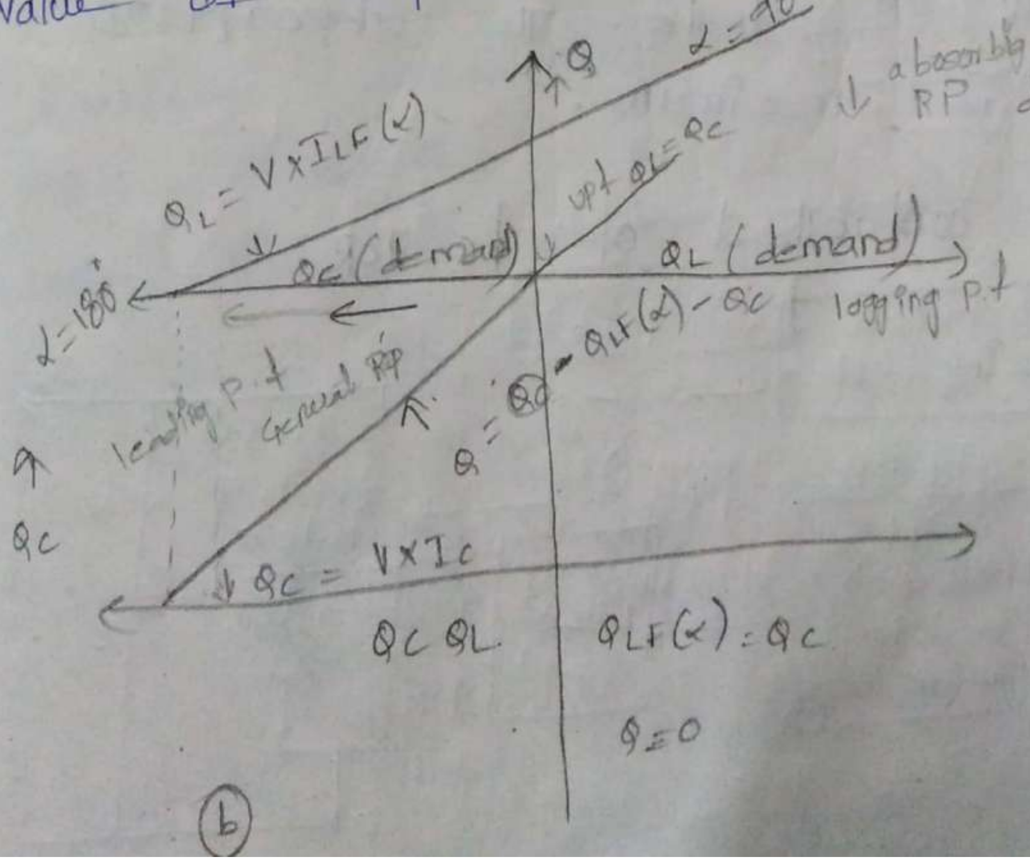
The current in the reactor by varing firing angle ($\alpha$) $\alpha = 90°$ to $180°$

$\alpha = 90°$ TCR absorb's max reactive power
$\alpha = 180°$ fully on state.

when $\alpha = 180°$ There is no absorbtion of RP from bus. In this state TCR is in 'off' state.

→ The capacitor value is fixed. with the help of filter n/w to generate RP required but it provides a low impedance at selected frequencies

→ This FC-TCR consists of variable reactor (Ind) (controlled via delay angle $\alpha$) and fixed value of capacitor.




Var demand vs o/p chr's

(b)

fc "$Q_c$" oppose the variable var generation ($Q_L$). absorption to provide required total var o/p $Q = Q_{LF}(\alpha) - Q_c$

1) when ever $\alpha = 180^\circ$ TCR is fully off state in this cond'n. The capacitor only generate reactive power in to the bus

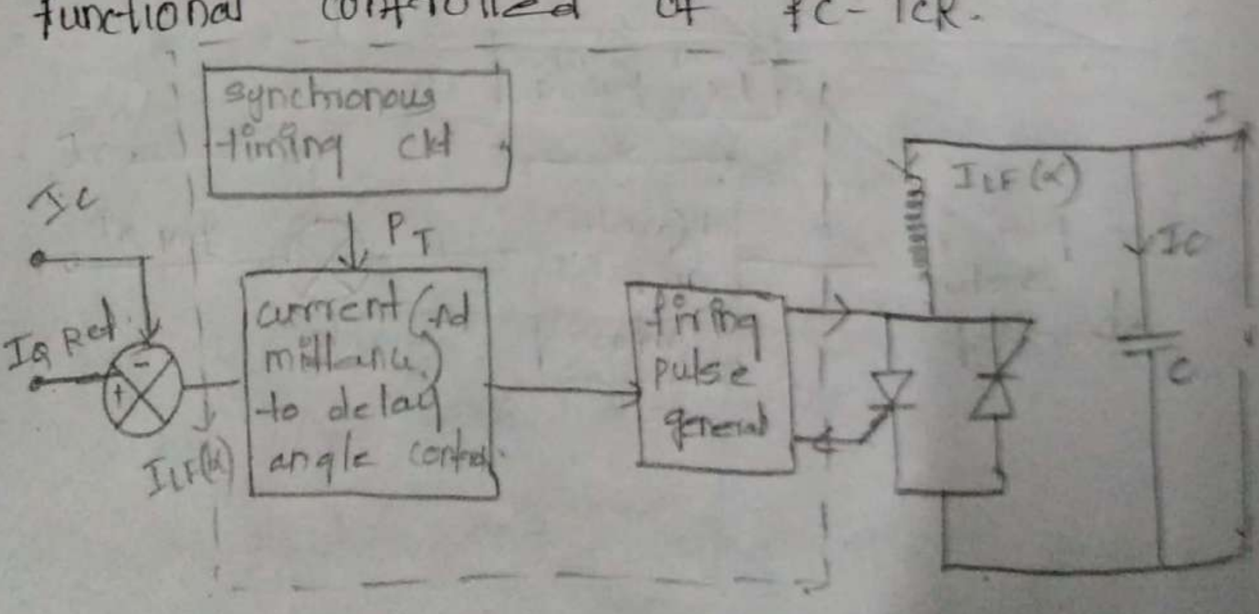
$\therefore Q = 0 - Q_c$

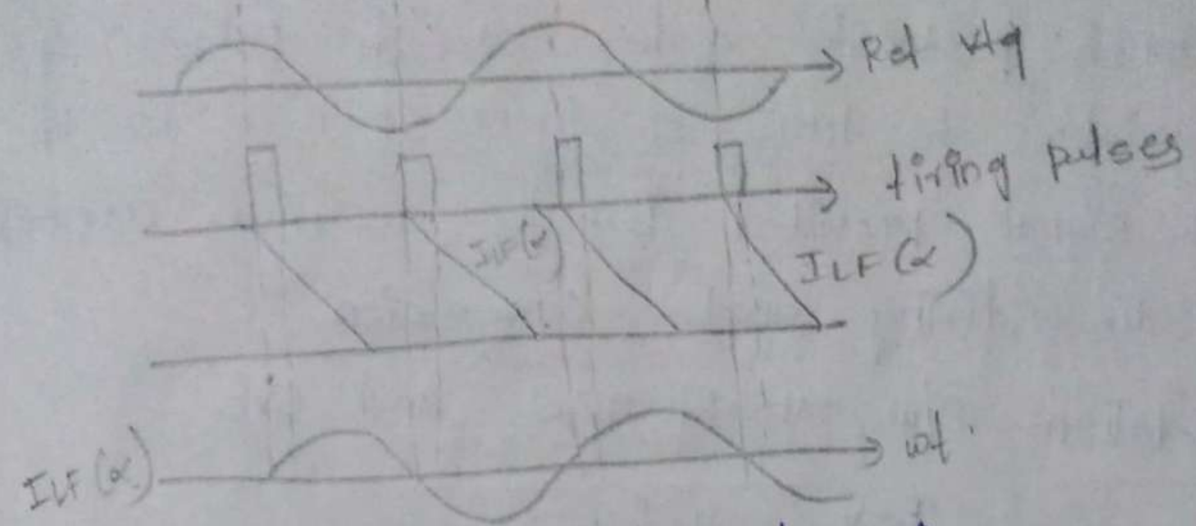
2) under the upf cond'n there is no absorption and gen of RP.

→ $Q_{LF}(\alpha) = Q_c$, The resultant $Q = 0$. There is no gen, no absortion of RP.

3) when ever $\alpha = 90^\circ$ In this cond'n tcR is in fully on state. The absorption of RP is maximum.

functional controlled of fc-TcR.






→ The control of Thyristor control in FC-TCR VAR generator need to provide 4 basic

1) synchrous timing :-
This fcn is provided by phase Locked loop ckt, that turns in synchronosim with AC sys vtg and gen timing pulses wrpto vtg.

2) Reactive current (or) (admittance) to firing angle conversion.

3) computation of reactor current $I_{LF}(\alpha)$ from total o/p current.

$$I_Q = I_C - I_{LF}(\alpha)$$

→ In this +ve → Inductive o/p current
-ve → capacitive o/p current.

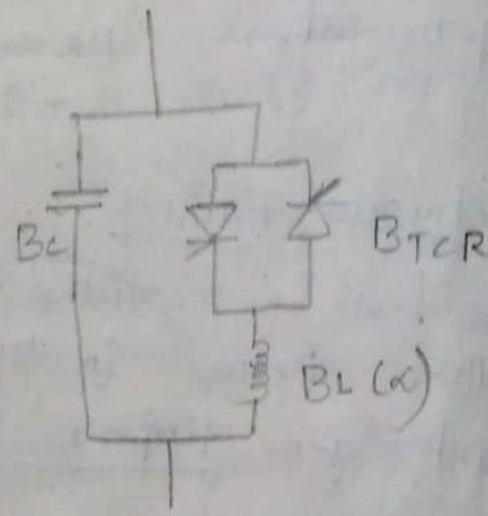
4) Thyristor pulse generation. This is done by the firing pulse generator.

→ which produces gate current pulses for thyristor to turn on in response to the o/p signal provided by the reactive current to the firing angle conversion.

Relation B/w susceptance and SVC

$$I_{SVC} = V \cdot j B_{SVC}$$

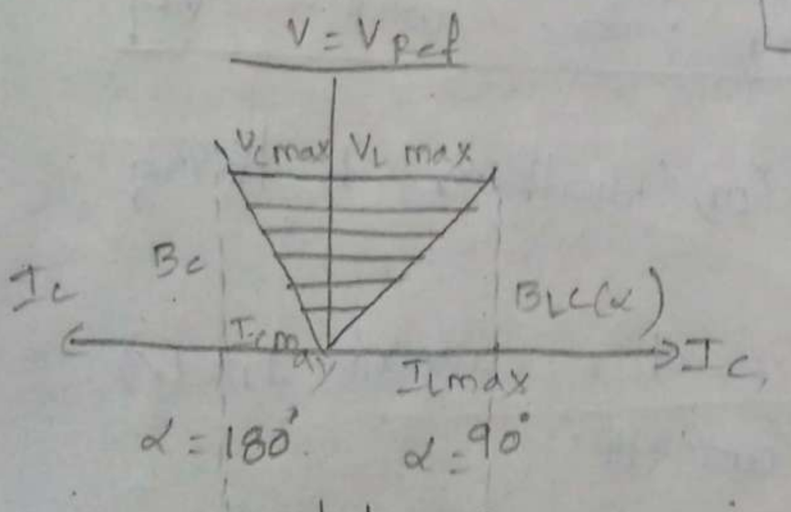
$$B_{SVC} = B_C + B_{TCR}$$




$$B_{TCR} = 0$$

$$\alpha = 180^\circ$$

$$B_{SVC} = B_C$$




V-I Chr's of FC-TCR.

Bc → capacitive admittance.

BL → maximum inductive admittance

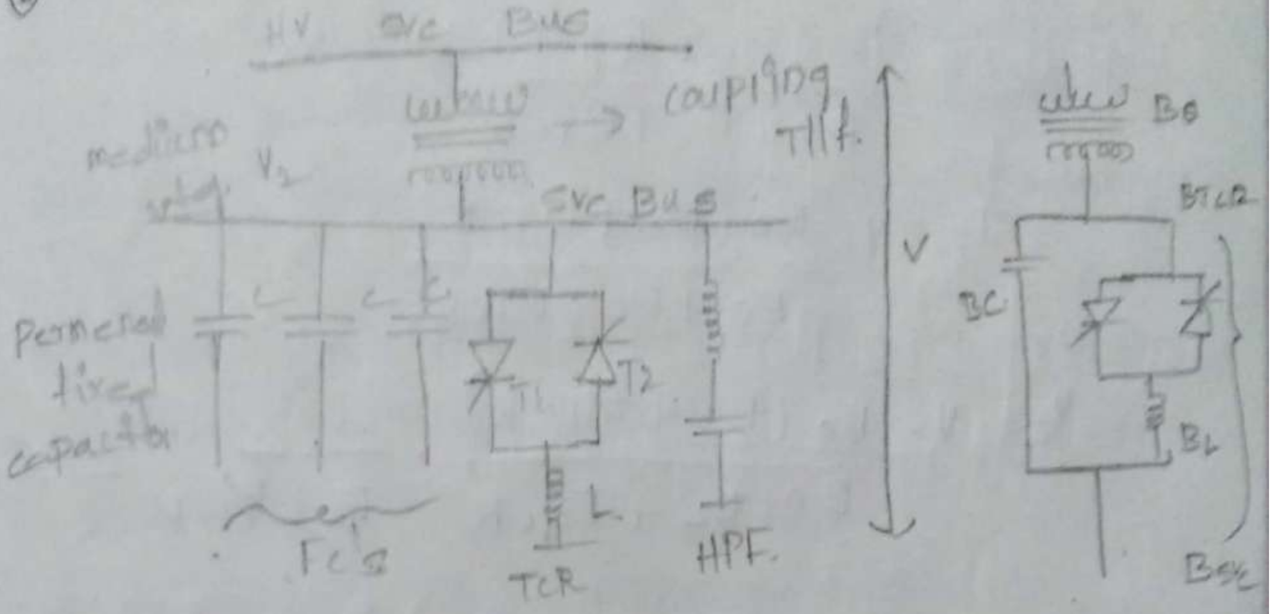
$I_{Lmax}$ → inductive current limit

$I_{Cmax}$ → capacitive current limit.

$\alpha = 90°$

$B_{TCR} = max$

(b) FC - TCR with coupling T/f.




$$\Rightarrow B_{SVC} = \frac{B_o (B_C + B_{TCR})}{B_o + B_C + B_{TCR}} \quad \text{--- (1)}$$

divide Nr & Dr with Bo

$$B_{SVC} = \frac{1}{1 + \frac{B_C + B_{TCR}}{B_o}} (B_C + B_{TCR}) \quad \text{--- (2)}$$

$B_{SVC} \rightarrow$ maximum of fc - TCR.

$\alpha = 180°$

$B_{TCR} = 0$

$$B_{SVC\,max} = \frac{B_o B_C}{B_o + B_C} \quad \text{--- (3)}$$

$B_{SVC} \rightarrow$ minimum $\alpha = 90°$

$$B_{SVC}\ \text{minimum} = \frac{B_o (B_C + B_{TCR})}{B_o + B_C + B_{TCR}} \quad \text{--- (4)}$$

$$V_2 = I_2 \cdot j \frac{1}{B_C + B_{TCR}}.$$

$$I_2 = V \cdot j B_{SVC}$$

$$B_{SVC} = \frac{B_O(B_C + B_{TCR})}{B_O + B_C + B_{TCR}}.$$

$$I_2 = V \cdot \frac{B_O(B_C + B_{TCR})}{B_O + B_C + B_{TCR}}$$

$$V_2 = V \cdot \frac{B_O(B_C + B_{TCR})}{B_O + B_C + B_{TCR}} \cdot \frac{1}{B_C + B_{TCR}} \quad \text{— (5)}$$

$$V_2 = V \cdot \frac{B_O}{B_O + B_C + B_{TCR}}.$$

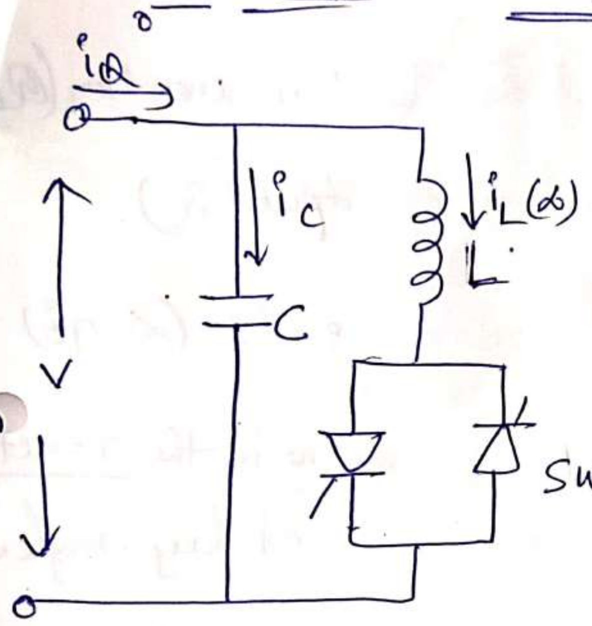
when ever to design fc-TCR the coupling T/f of secondary Wdg must be know.

Sd

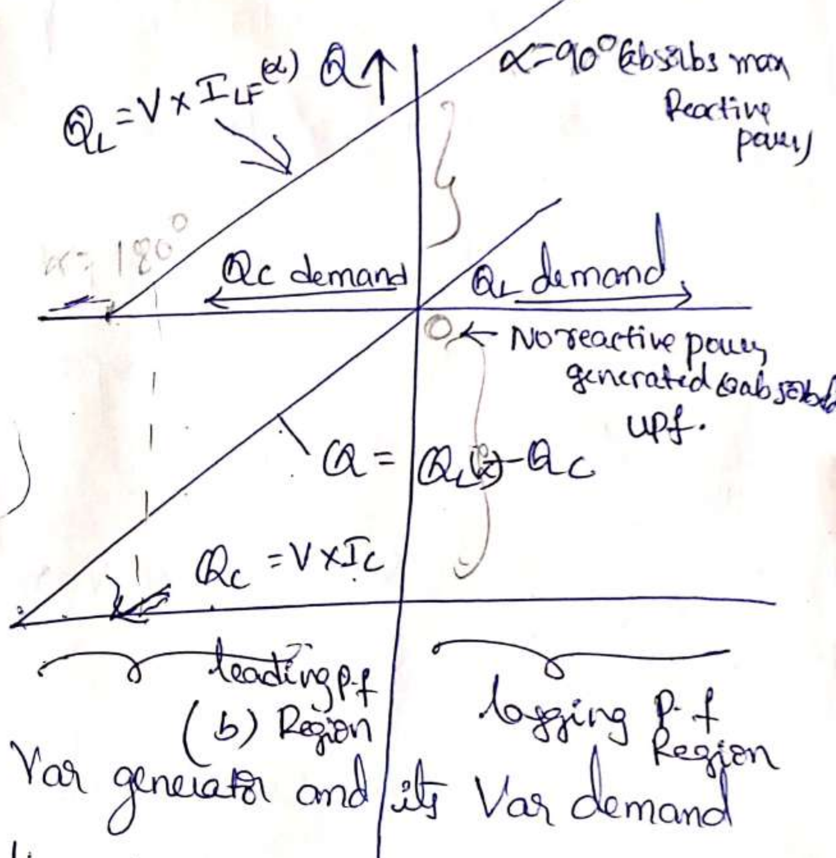
## UNIT- IV ①

# SVC and STATCOM

## Fixed Capacitor - Thyristor Controlled Reactor (FC-TCR)




(a) $I_Q = I_C + I_L(\alpha)$




(b)

Basic FC-TCR type static Var generator and its Var demand Versus Var output characteristics.

→ Above fig shows fixed capacitor thyristor controlled reactor (FC-TCR). The current in the reactor is varied by firing angle control.

→ The Capacitor value is fixed with the help of filter network to generate reactive power required, but it provides a low impedance at selected frequencies.

→ This FC-TCR Consists Variable reactor (Inductor) (controlled by delay angle α) and fixed Valued Capacitor.

→ Var demand Vs output char shown in fig.

→ fixed Capacitor ($Q_C$) opposes the Variable Var generation ($Q_L$) absorption to provide req total Var output (Q).

→ At max Var output TC reactor is off (α=90°)

→ To decrease the Capacitive o/p, the Current in the reactor is increased by decreasing the delay angle α.

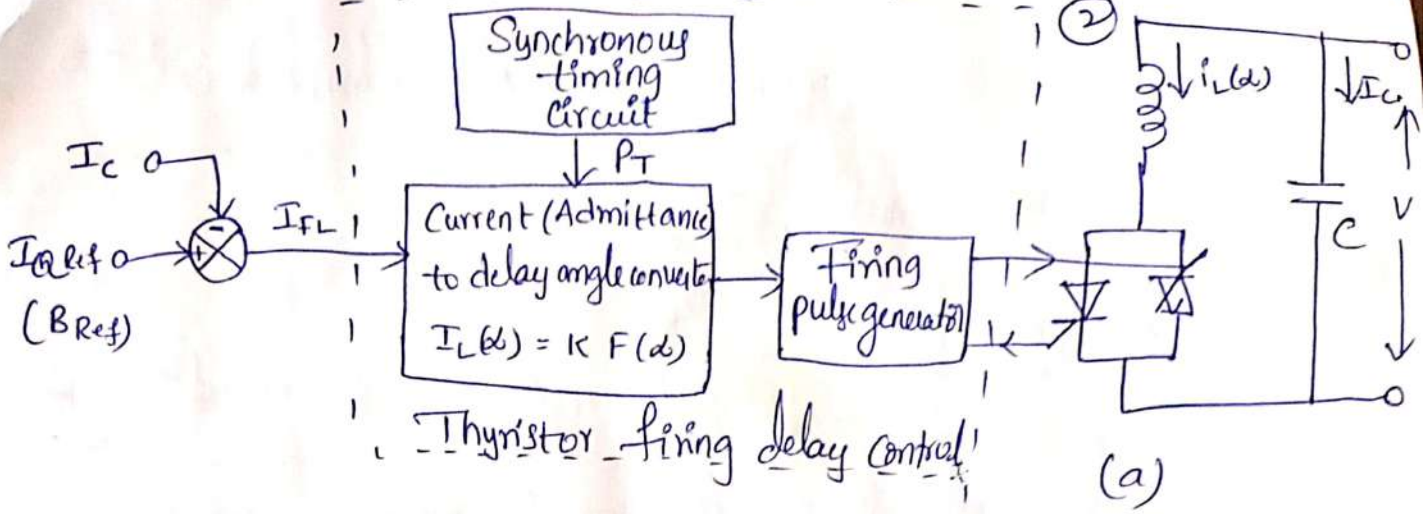
C↓ o/p  $I_L$↑

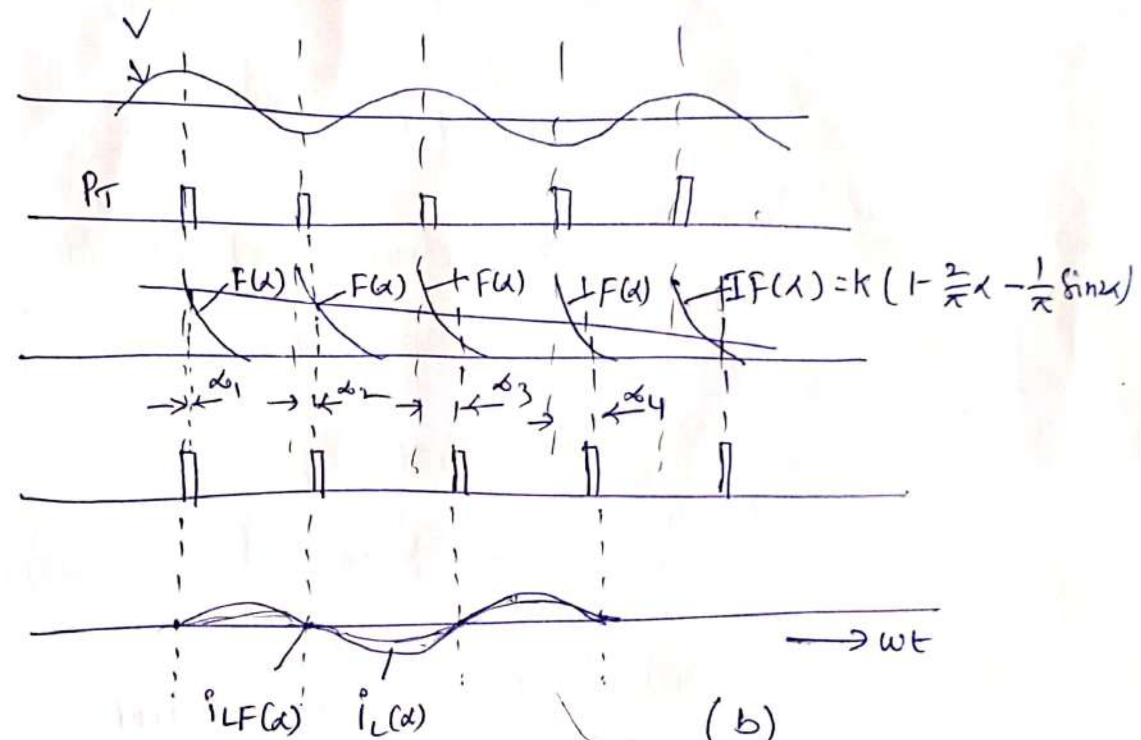
→ At 'zero' o/p Var, the Capacitive & Inductive Currents become equal, and Capacitive & Inductive Vars Cancel out.

Varc = VarL ='0' o/p

→ further decreasing the delay angle the Inductive Current becomes larger than the Capacitive Current, the resultant Var output is Inductive.

→ at zero delay angle, the thyristor-Controlled reactor Conducts current over the full 180° interval, results Inductive Var o/p is equal to diff b/w the Var generated by the Capacitor & those absorbed by the fully Conducting reactor.




(a) Functional control scheme for the FC-TCR type static Var generator.
(b) waveforms.

→ The control of the thyristor-controlled reactor in FC-TCR type Var generator need to provide four basic functions.

1) is Synchronous timing :- This function is provided by phase locked loop ckt that runs in synchronism with the ac system voltage and generates timing pulses wrt voltage

→ Second function is reactive current (or admittance) to firing angle conversion.

→ 3rd function is Computation of reactor Current $I_{LF}$ from total output current $I_Q$.

i.e $I_Q = I_C - I_{QRef}$. Subtracting Capacitive Current.

+ve polarity means Inductive o/p current

-ve " " Capacitive o/p Current

→ 4th function is Thyristor firing pulse generation. This is done by the firing pulse generator.

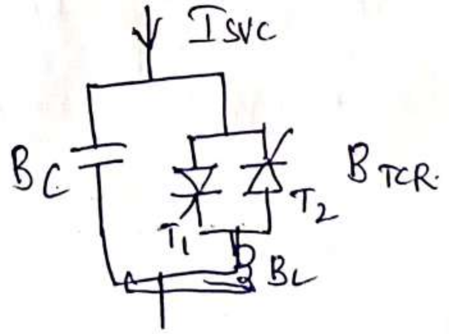
which produces the necessary gate current pulse for thyristor to turn on in response to the output signal provided by the reactive Current to firing angle Conversion.

→ Taking a block box view point of FC-TCR type var generator Can be Considered as a Controllable reactive admittance Connected to the ac system.

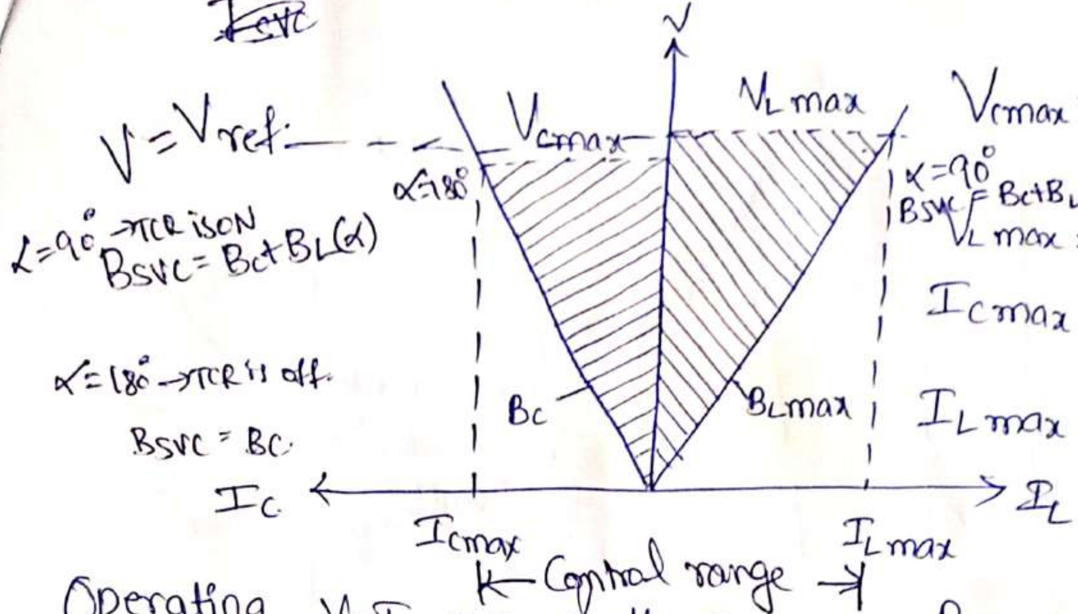
Relation b/w Susceptance and $I_{svc}$.

$I_{SVC} = V . j B_{SVC}$.

where $B_{SVC} = B_C + B_{TCR}$



FSVC (3)




$V_{cmax}$ = Voltage limit for Capacitor

$V_{L\,max}$ = " " for TCR

$I_{cmax}$ = Capacitive current limit

$I_{L\,max}$ = Inductive Current limit

Operating V-I area of the FC-TCR type Var generator.

$B_{L\,max}$ = Max Inductive admittance

$B_C$ = admittance of Capacitor.

→ above V-I operating area of the FC-TCR Var generator is defined by maximum Capacity of Capacitive & Inductive admittance and Voltage, current ratings of Capacitor, Inductor & thyristor.

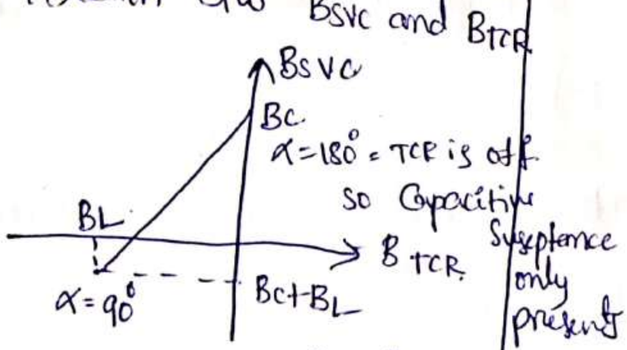
→ Transfer function of FC-TCR is $G(s) = k e^{-T_d s}$

(s) is Laplace transform operator

k is a gain Constant

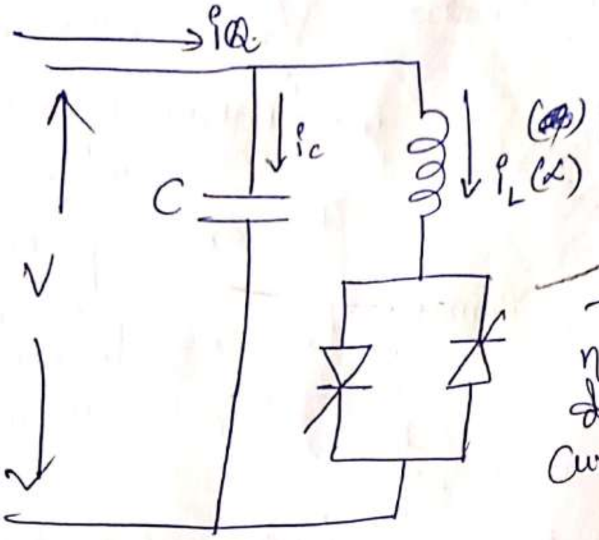
Td firing delay angle (α)

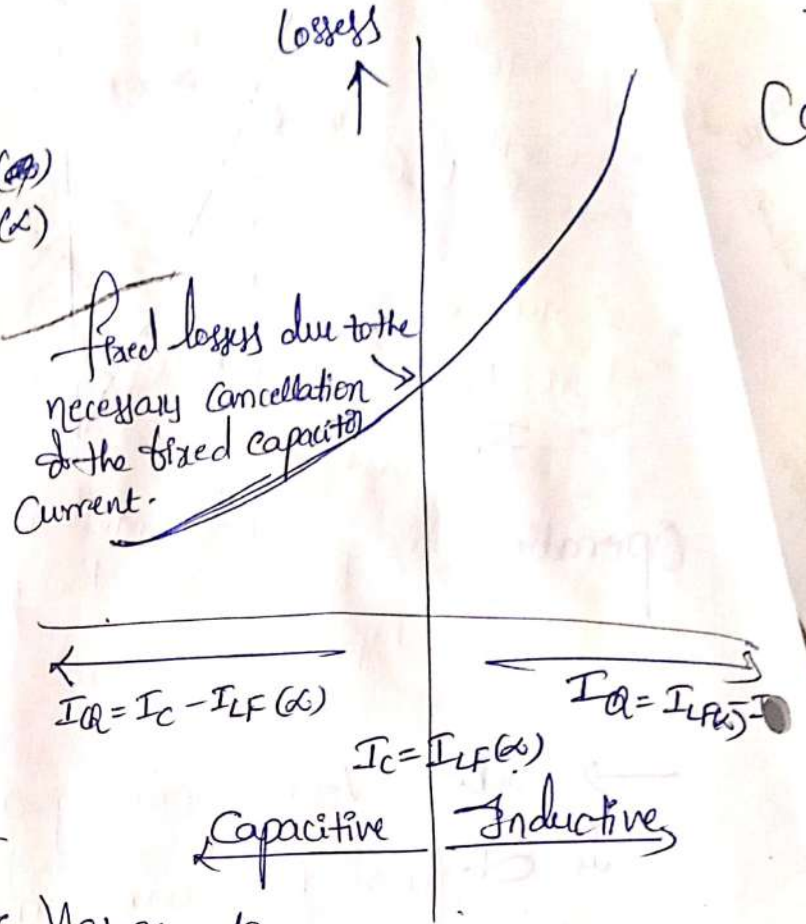
Relation b/w Bsvc and BTCR




α=180° → TCR is off

α=90° → TCR is fully on ...




→ Loss Vs Var o/p char of FC-TCR type static Var generator.

In FC-TCR type Var generator, there are 3 major losses occurred ① The Capacitor losses (small)
② Reactor losses (these Increase with square of current)
③ Thyristor losses (These are almost linear with current)

→ Thus total losses Increases with increasing in current

| $I_{Losses}\uparrow$ $I\uparrow$ |

and decreases with decreasing the Capacitive Var output. Shown in fig (a).

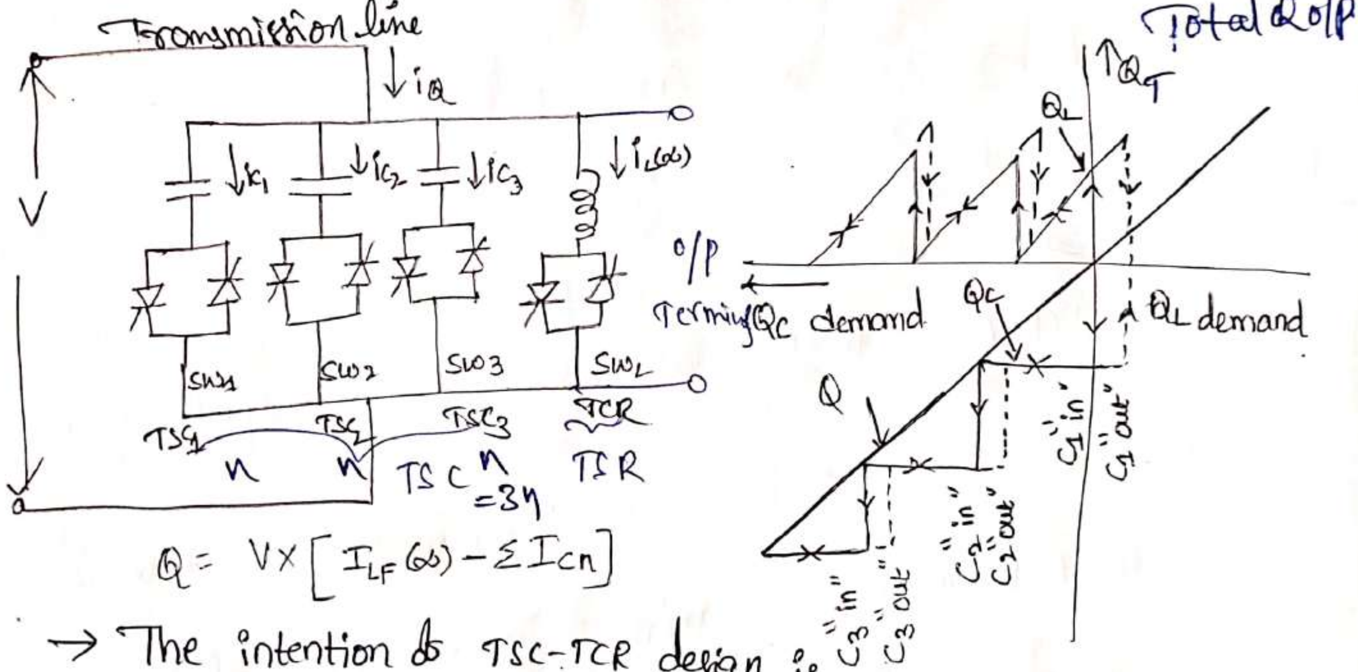
→ Zero o/p is obtained by cancelling Capacitive Vars with Inductive $(I_C = I_L)$

(u)

→ These loss char Curve is, advantageous when avg Capacitive Var o/p is relatively high this type is application req Industrial p.f Correction.

and disadvantageous when avg Var o/p is low, Dynamic Compensation of Power transmission system.

## Thyristor-Switched Capacitor - Thyristor-Controlled Reactor (TSC-TCR) :-




$$Q = V \times \left[ I_{LF}(\alpha) - \Sigma I_{cn} \right]$$

→ The intention of TSC-TCR design is minimizing stand by losses and increasing operating flexibility
(↳ wastage of fuel losses)

→ For a given Capacitive output range, it consists of 'n' TSC branches and one TCR. The 'n' number of branches determines Operating Voltage level, maximum Var output, current rating of the thyristor Valves, bus work and installation cost. etc of Course, Inductive range also Can be expanded to any maximum rating by employing additional TCR branches.

operation:-

→ The total Capacitive output range is divided in to 'n' intervals. In the first Interval, the o/p of the Var generator is Controllable in the zero to $Q_{cmax}/n$ range, where $Q_{cmax}$ is the total rating provided by all TSC branches.

In this One Capacitor bank is Switched in (by firing, for example, thyristor Valve $Sw_1$,) and Simultaneously the current in the TCR is set by appropriate firing delay angle so that The Sum of the Var output of TSC (negative) and that of TCR (positive) equals the Capacitive output required.

→ In 2nd, 3rd .... & $n^{th}$ intervals, the output is Controlled in the $Q_{cmax}/n$ to $2Q_{cmax}/n$, $2Q_{cmax}/n$ to $\frac{3Q_{cmax}}{n}$ .... and $(n-1)Q_{cmax}/n$ to $Q_{cmax}$ range by Switching in the 2nd, 3rd and $n^{th}$ Capacitor bank using the TCR to absorb the Supply Capacitive vars.

Ex

$n=5$ $Q_{cmax} = 10$ MVAR.

Introduce 5 branches $2 \times 5 = 10$ MVAR $- 1$ TCR $= 9$ MVAR

our req is 9MVAR. ↓ absorbs supply Capacitive Var.

→ By being able to switch the Capacitor banks in and out within one cycle of the appalied ac voltage, the maximum Surplus Capacitive Var in the total output range can be restricted to that produced by one Capacitor bank, and thus, theoritically, the TCR should have the same Var rating as the TSC.

⇒ Var demand Versus Var output characteristics of the TSC-TCR type Var generator is shown in fig (b). The Capacitive Var output, $Q_T$ $Q_C$ is changed in step-like manner by the TSC, and the relatively small Inductive Var output of the TCR, $Q_L$, is used to cancel the surplus Capacitive Vars.

Ex:- Explained Hence theroticalls the TCR should have the same Var rating as the TSC.

⇒ A functional Control scheme of TSC-TCR shown bel

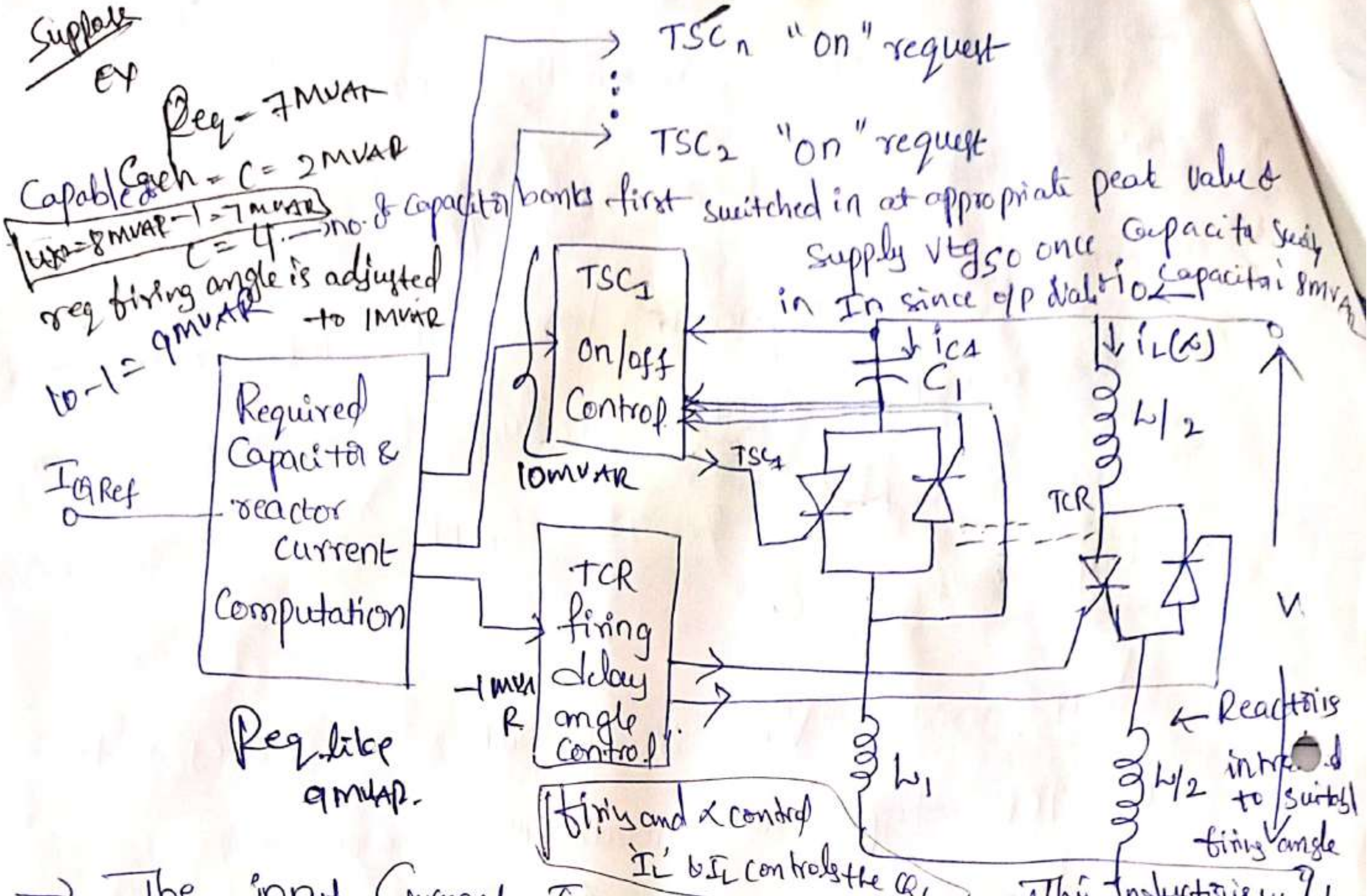
It provides 3 major functions-

→ 1) Determines the no. of TSC branches needed to be switched in to approximate the req Capacitive output Current and computes the amplitude of Inductive Current needed to cancel the surplus Capacitive Current.

→ 2) Controls the switching of the TSC branches in a "transient-free" manner.

→ 3). Varies the Current in the TCR by firing delay angle Control.

Suppose Ex




→ The input current $I_{QRef}$ represents the magnitude of the requested output current is divided by the amplitude $I_C$ of the current that a TSC branch would draw at the given amplitude V of the ac voltage. The result, gives the no. of Capacitor banks needed.

1st function

→ The difference in magnitude b/w activated capacitor currents $\Sigma I_{Cn}$ and the reference current $I_{QRef}$ giving the amplitude of $I_{LF}$ of fundamental reactor current req.

2nd function

→ basic logic for 2nd function (Switching for TSC branches) is shown in fig 5.24(c). This follows two simple rules for "transient-free" manner switching summary.

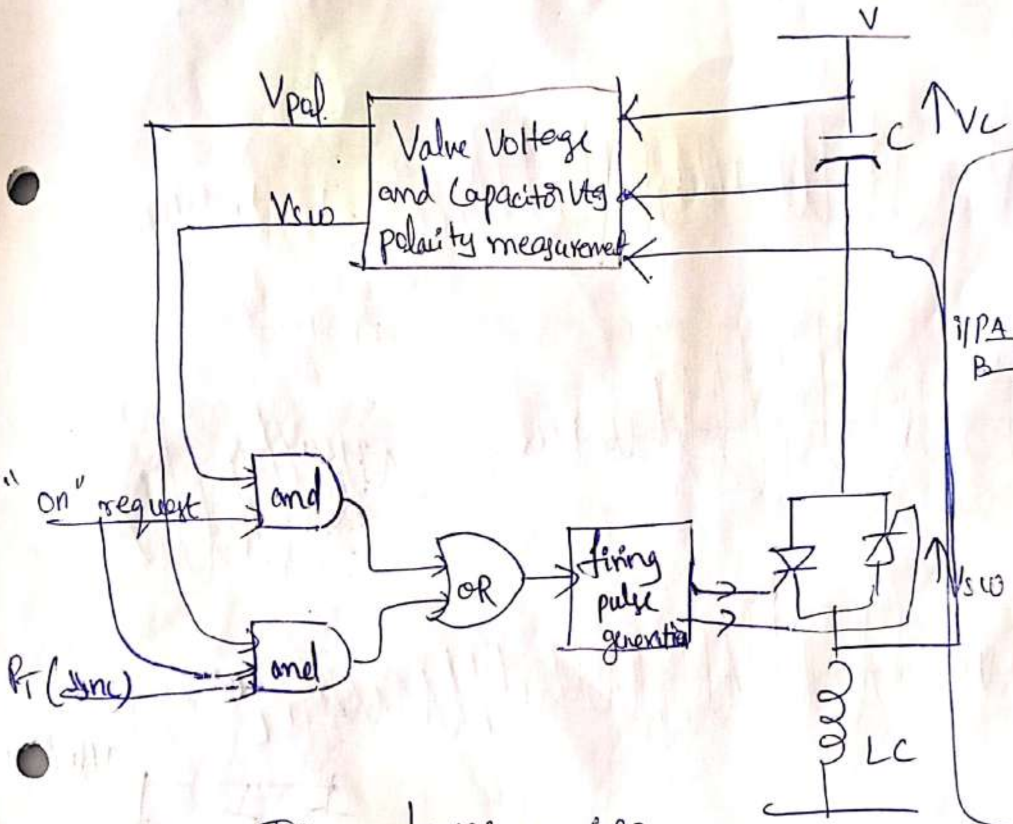
$V_s = V_c$ then i is transient free manner.

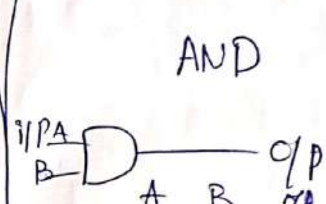
Supply vtg = Capacitor vtg.

To Switch the Capacitor bank. (6)

→ That is, either Switch the Capacitor bank when the Vtg across the thyristor Valve becomes zero & when thyristor Valve Voltage is at a minimum.

→ The actual firing pulse generation for the thyristor in TSC Valve is Similar to that used for the TCR.




| A | B | o/p |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 1 |

TSC turns on if: "On" = 1 and $V_{sw} = 1$

or

"On" = 1 and $P_T = 1$ and $V_{pol} = 1$

$V_{sw} = 1$ when $V_c = V$

$P_T = 1$ when $v = V$

$V_{pol} = 1$ when sign $v$ = Sign $V_c$

Case (i) - $V_c < V$ ← peak Vtg.

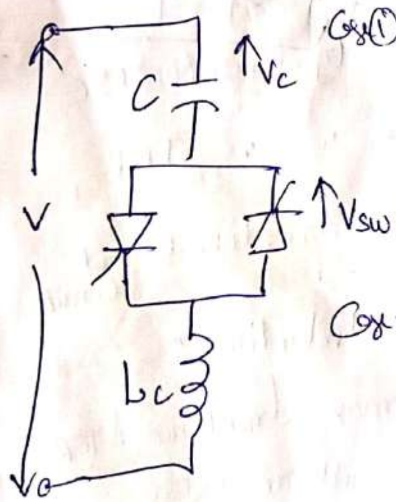
$V_c = V$ ← instantaneous ac vtg.

$V_{sw} = 0$

Case (ii) $V_c < V$

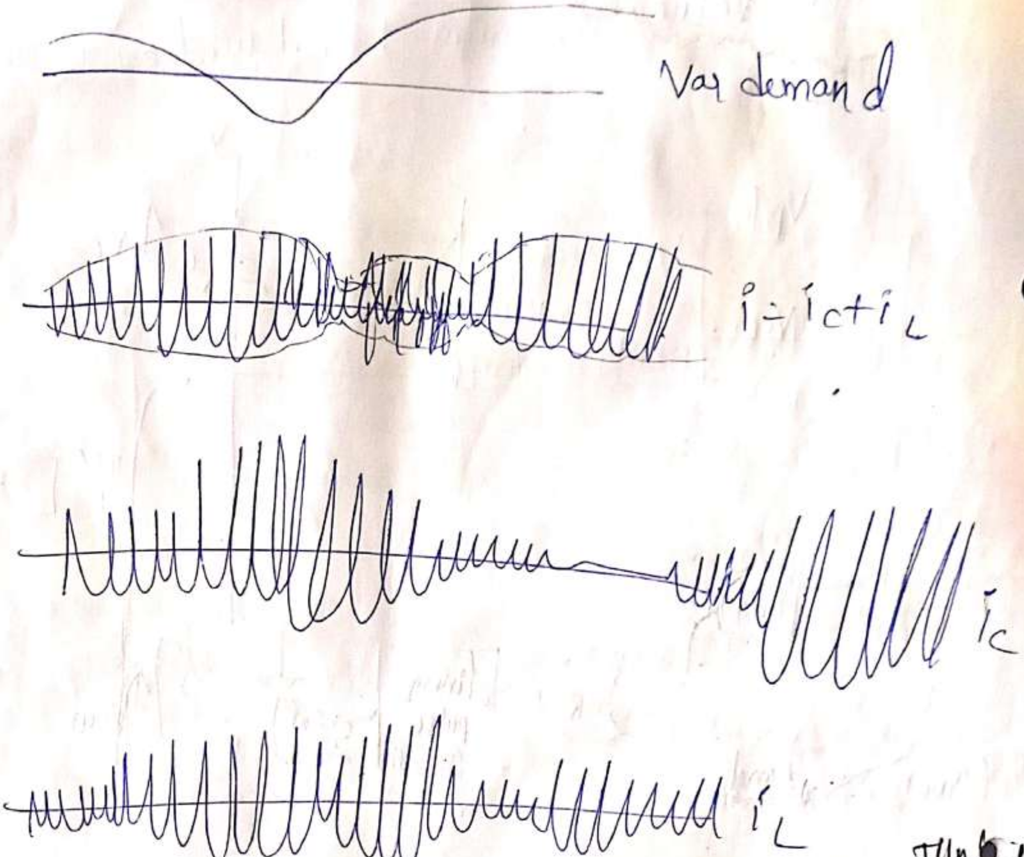
$\alpha = 0$

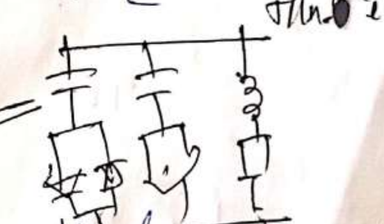
$V_{sw}$ = min

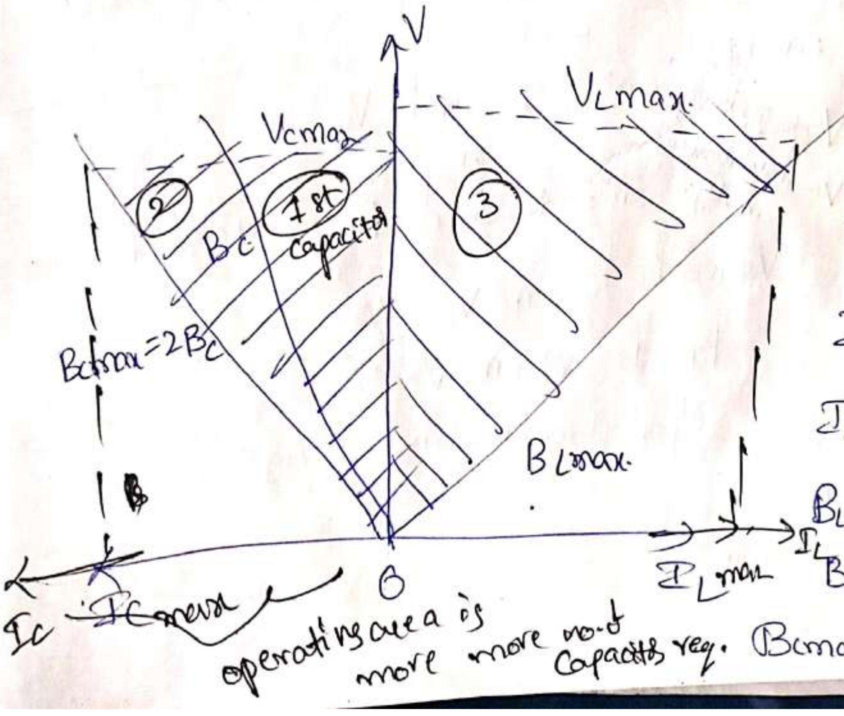


→ The third function (TCR firing delay angle control) is similar to FC-TCR. The operation of TSC-TCR type var generator with 3 capacitor banks is shown below.

$$I_{QRef} = I_{Q} = I_C + I_L$$




$V_{cmax}$ = Vtg limit for TSC

$V_{Lmax}$ = " " TCR

$I_{cmax}$ = Capacitive Current limit

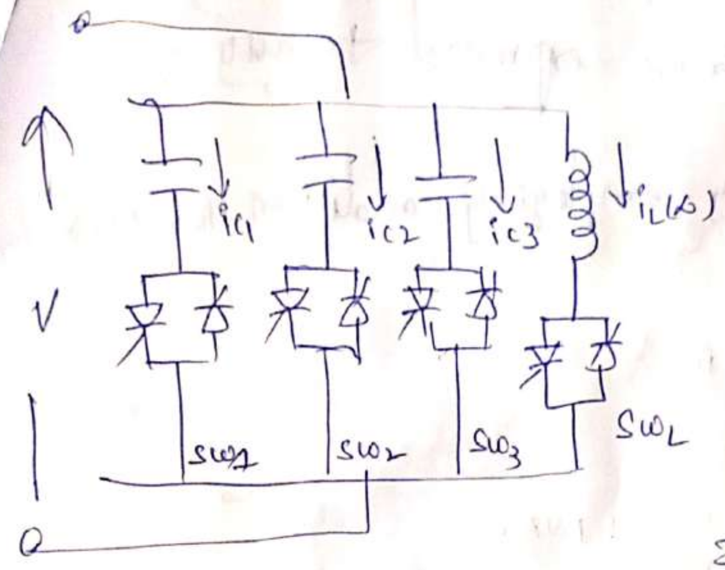
$I_{Lmax}$ = Inductive " "

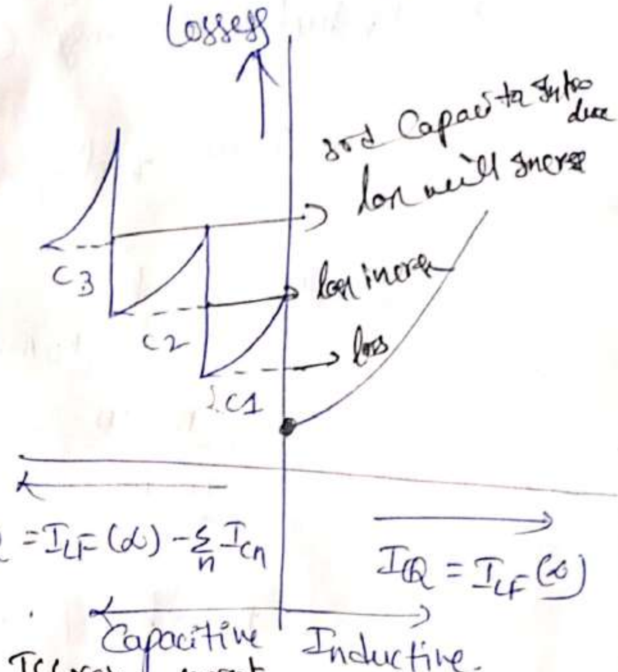
$B_{Lmax}$ = max admittance of TCR

$B_c$ = admittance of TSC

$B_{cmax}$ = max capacitive admittance

e)




loss vs o/p chq of TSC-TCR shown above.

At or slightly below zero var output, all capacitor banks are switched out, the TCR current is zero or negligibly small, and consequently, the losses are zero or almost zero.

→ as the capacitive output is increased, an increasing no. of TSC banks are switched in with the TCR absorbing the surplus capacitive vars.

→ ~~More over, losses of TCR vary from max to zero b/w~~ Switching of TSC banks are added successively.

→ The main design intention is decreases the stand by losses

→ It consists of 'n' no. of TSC branches & one TCR.

→ 'n' no. of branches determines operating vtg.

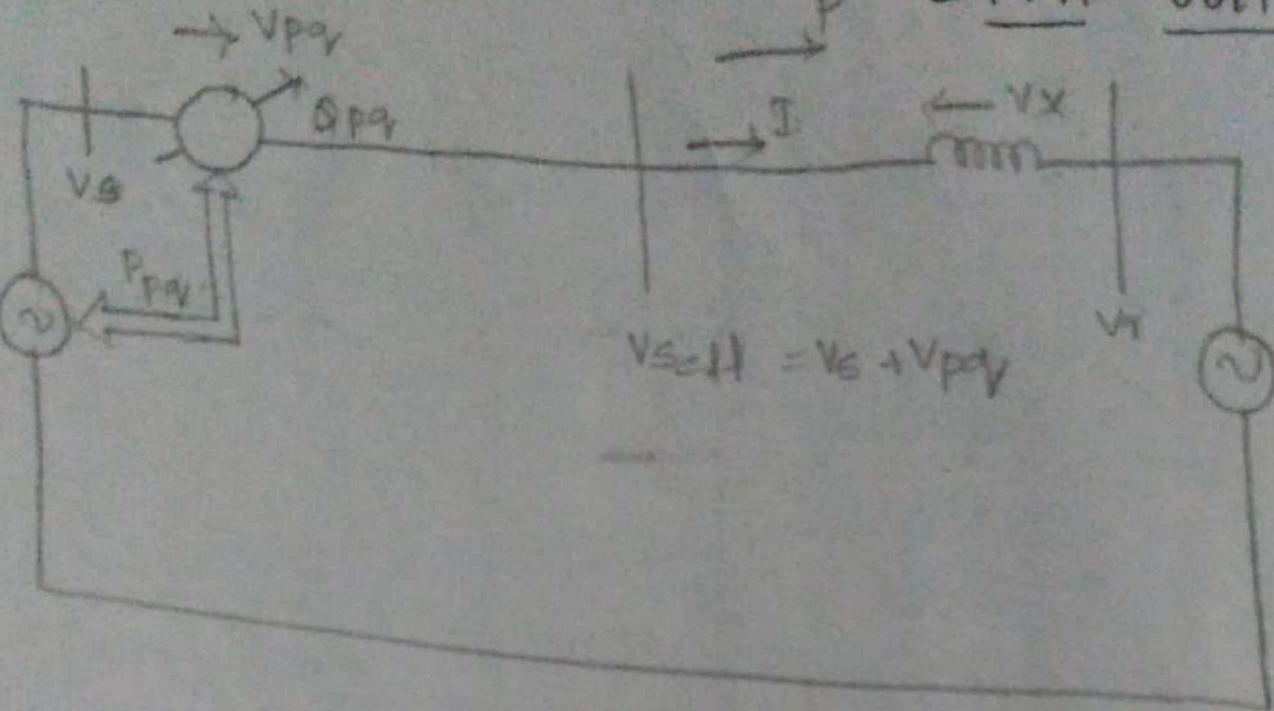
~~Suppose~~ → either connected in star or delta

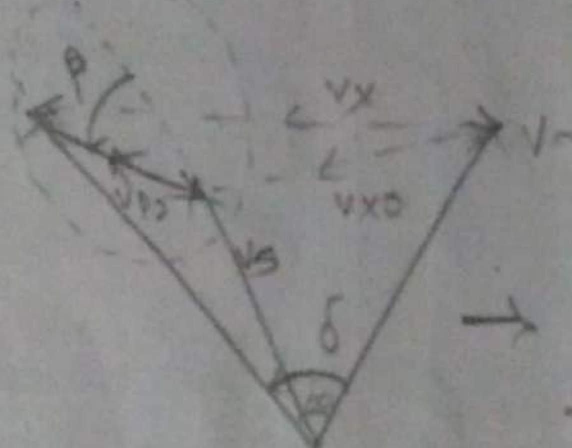
$$Q = V \times [ I_{LF}(\alpha) - \sum I_{cn} ]$$

Tot var o/p this scheme — $I_{LF}(\alpha)$ ↓ Inductive current; $\sum I_{cn}$ ↓ 'n' no. of capacitive currents.

# UNIT-5

→ Unified power flow controller :- (UPFC)
- 1991 UGI



→ Phasor diagram

→ To control active & Reactive power
↓
Real tym

Vpq → injected vtg.

## Introduction of UPFC :-

* The UPFC concept was introduced by Gyugyi in 1991

* UPFC was introduced for the real time control & dynamic compensation of AC t/m system

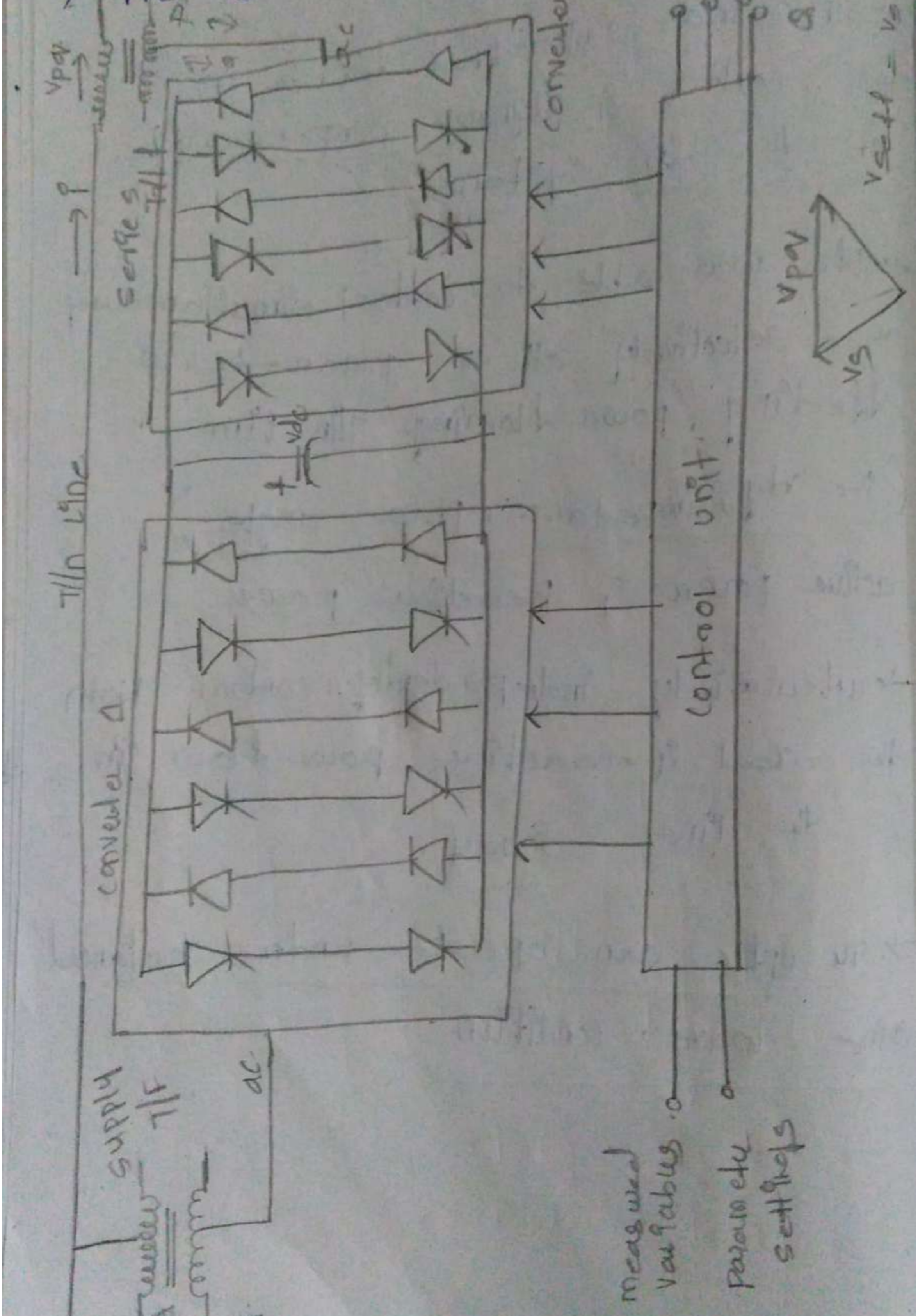
* UPFC was able to control simultaneously or selectively all the parameter's affecting power flowing. T/m Line (i.e Vtg, impedance, phase angle), active power & Reactive power

* alternatively, independently control both the real & reactive power flow in the line. → 297

* The UPFC can operate under balanced sine wave condition.

## → Basic operating principle

1) upfc is



→ fig ⑤ show's UPFC controller by 2 Back to Back vtg source converter

1) UPFC is a generalised synchronous vtg source (SVS). represented at the fundamental freq by vtg phasor $V_{pq}$

② It controllable magnitude $V_{pq}$

$V_{pq}. (0 \leq V_{pq} \leq V_{pq\,max})$

and angle $\rho (0 \leq \rho \leq 2\pi)$ 0 to 360°

In series with T/In line.

2) UPFC consist's of 2 voltage source converter's, converter-1 (STATCOM) and converter-2 (SSSC) with common DC link $V_{dc}$ provided by dc stroage capacitor.

→ fig shows Ideal ac-to ac power converter in which the real power can freely flow in either direction b/w the ac terminals of the converter and each converter can independently generate are absorb reactive power as its own ac o/p terminals.

→ converter 2 provides main fun of UPFC by injecting a vtg (VPq) and with controllable magnitude "Vpq" & angle "ρ" in series with the line via series (Injection T/f) T/f & this injection vtg acts like synchronous AC vtg source.

→ The t/n line current flows to this vtg source. results in reactive and the real power exchange b/w it and ac source.

→ The Reactive power exchange and the ac terminals i.e at the terminals of series injection T/f is generated internally by the converter.

→ The Real power exchange at the ac terminals is converted in to DC power which appear's at the dc link as a positive or Negative real power demand.

## Basic operation of converter - 1

It is to supply and absorb the real power demand by converter - 2 at a common dc link, to support the real power exchange resulting from the series the vtg injection.

→ The dc link power demand of con-2 is converted to back to ac by con-1 and it coupled to the trn line. with a shunt connected tlf

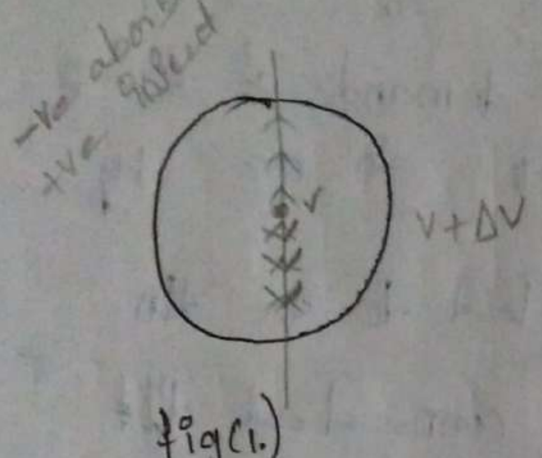
→ In addition to the real power 'p' of con-2, con-1 also generates or absorb controllable reactive power by providing shunt reactive compensation of line.

Note : There can be no reactive power flow to the upfc dc link.

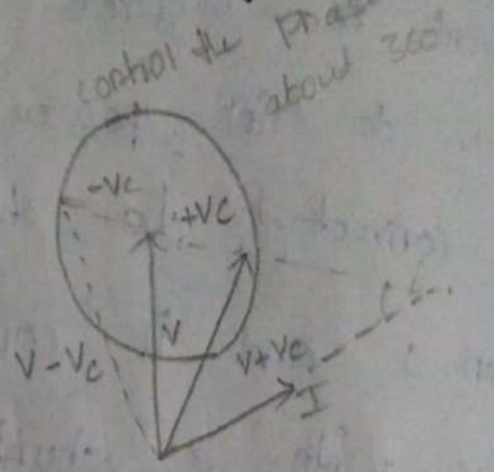
Conventional Transmission control capabilities

control capabilities are mainly 4 type's

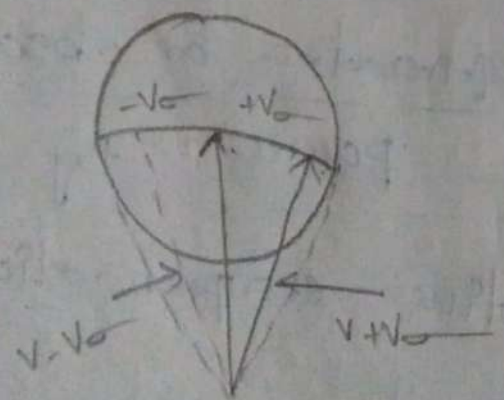
1) voltage regulation
2) line impedance compensation
3) phase shifting
4) simultaneous control of vtg, impedance and phase angle.



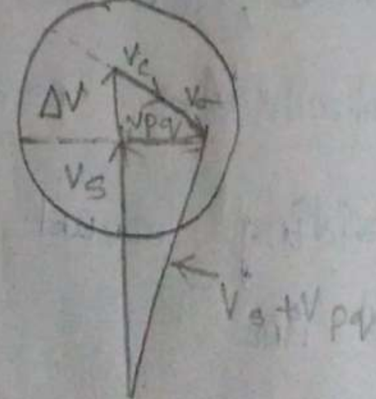
fig(1.)



fig(2)



fig(3)



fig(4.)

fig ① show's vtg regulation with continously variable inphase/ anti-phase vtg injection for vtg increment.

$$V_{pq} = V \pm \Delta V$$

+ This is obtain by tap changing T/f

+ fig ② show's Vpq is the injected in quadrature with line current "I". This is similar to series capacitive and inductive line compensation attain by SSSC.

+ The injected series compensating vtg can be kept constant. It is independent of line current variations

+ fig ③ shows phase angle regulation, where Vpq = V— is injected with an angular induction relation wrspt supply vtg that achieves design phase shift without any change in magnitude.

+ fig ④ shows multiple power flow control executed by simittaneously taminal vtg regulation (±ΔV) series capacitive like compensation ($V_q$), Phase shifting ($V_\sigma$)

$$V_{pq} = \Delta V + V_q + V_\sigma$$

$P - jQ = \frac{V_s V_r}{X} \sin\delta \rightarrow V_{pq} = 0$ — ① without any compensator

$P - jQ = V_r \left[\frac{V_s + V_{pq} - V_r}{X}\right]^* \sin\delta \Rightarrow$ with upfc.

$V_{pq} \neq 0$

$$P - jQ = V_r \left[\frac{V_s - V_r}{X}\right]^* + \frac{V_r V_{pq}^*}{-jX}$$

Independent Real and Reactive power flow control.

$V_{pq}$ = injected compensating vtg

$$V_{pq} = 0 \quad \text{— ①}$$

There is no injected vtg.

No compensator using.

$$P_0(\delta) = \frac{V_s V_r}{X} \sin\delta \quad \text{— ②}$$

$$Q_0(\delta) = \frac{-V_s V_r}{X} (1 - \cos\delta) \quad \text{— ③}$$

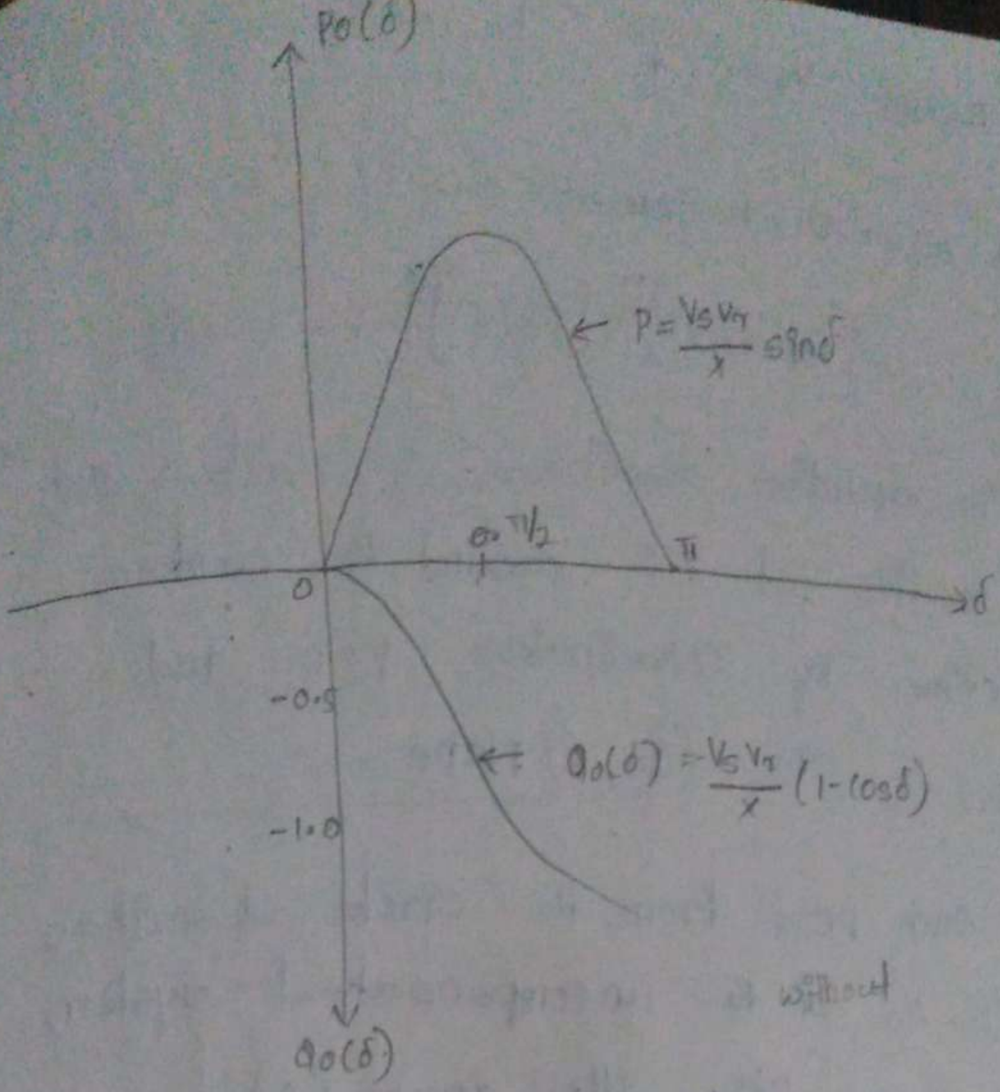
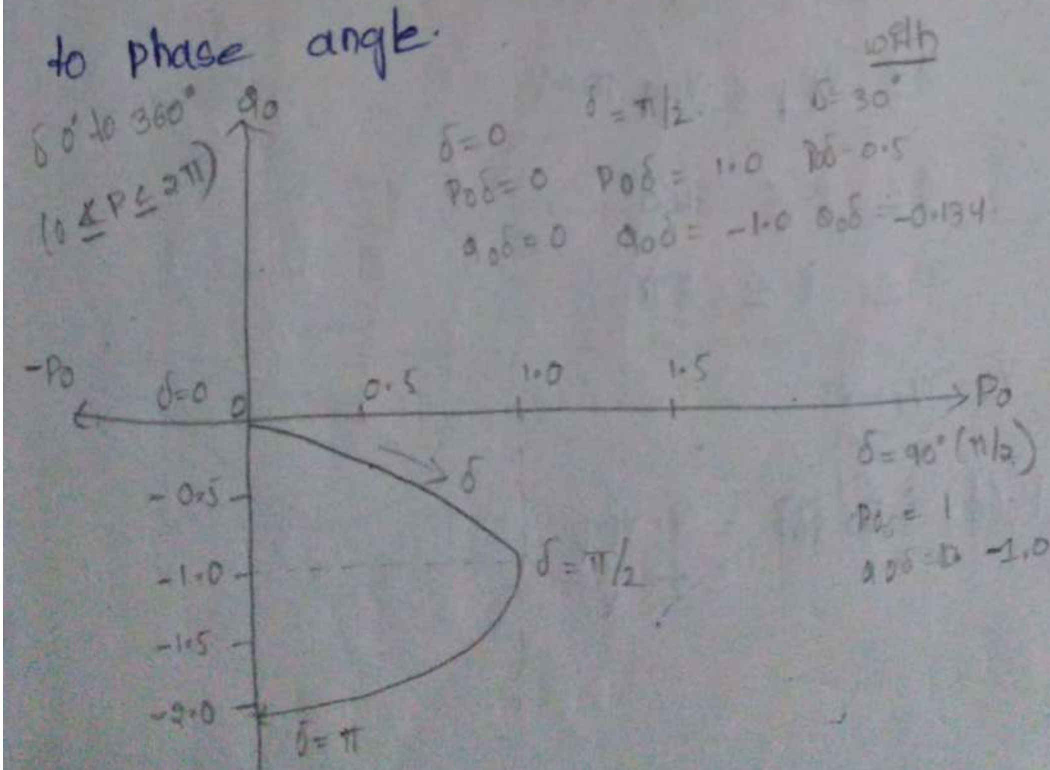



fig (1) shows the relation b/w Real power Po(δ), Reactive power with respect to phase angle.



→ Assume $\frac{V_s . V_r}{X} = 1$

The equation becomes.

$$\left[q_0(\delta)+1\right]^2+\left[P_0(\delta)\right]^2=1 \quad \text{—— (4)}$$

This equation describes a circle with a radius of 1.0 around the centre define by coordinates $P=0$ and $Q_r=-1$ in $(Q_r, P)$ plane.

→ Each point from the circle describes $P_0, Q_0$ of the uncompensated system at a specific Tx/n angle $(\delta)$

$\therefore V_{pq} \neq 0$

$0 \leq V_{pq} \leq V_{pq\,max}$

$0 \leq \rho \leq 360°$

$0 \leq \rho \leq 2\pi$

$V_s = V_r = V$

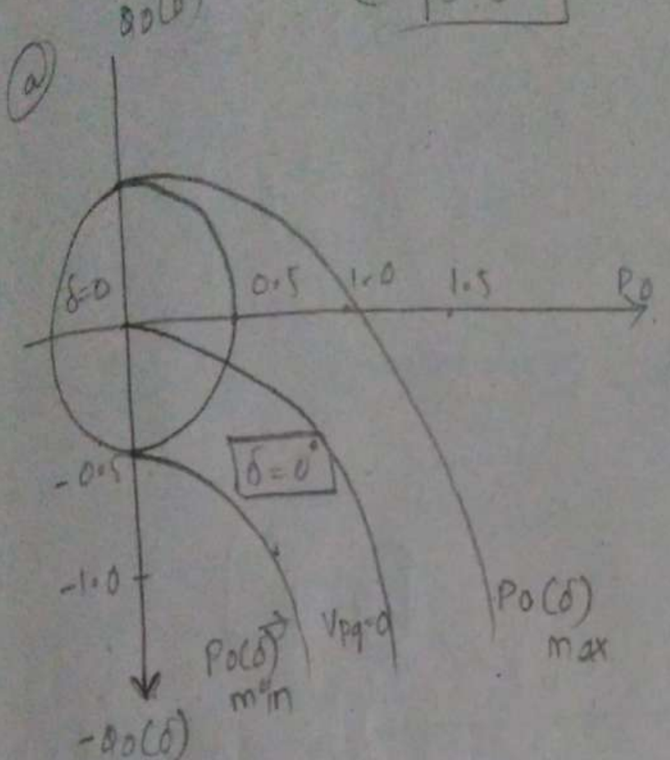
$P_0(\delta)$ & $Q_0(\delta) = \frac{V_r V_{pq}}{X}$

→ this is the radius of circle.

$$\left[P(\delta,P) - P_0(\delta)\right]^2 + \left[Q(\delta,P) - Q_0(\delta)\right]^2 = \left[\frac{V \cdot V_{pq\,max}}{X}\right]^2$$

Con

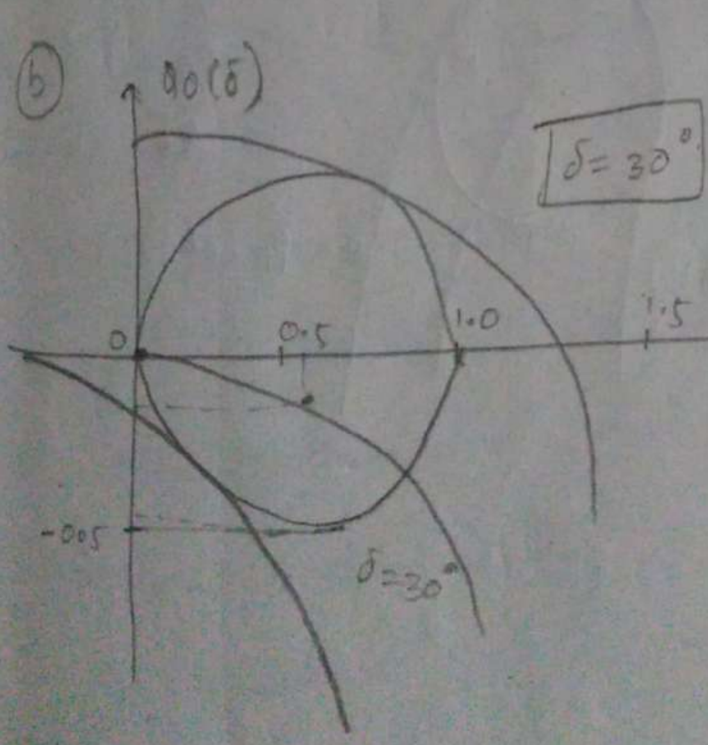
@ $\delta = 0^\circ$



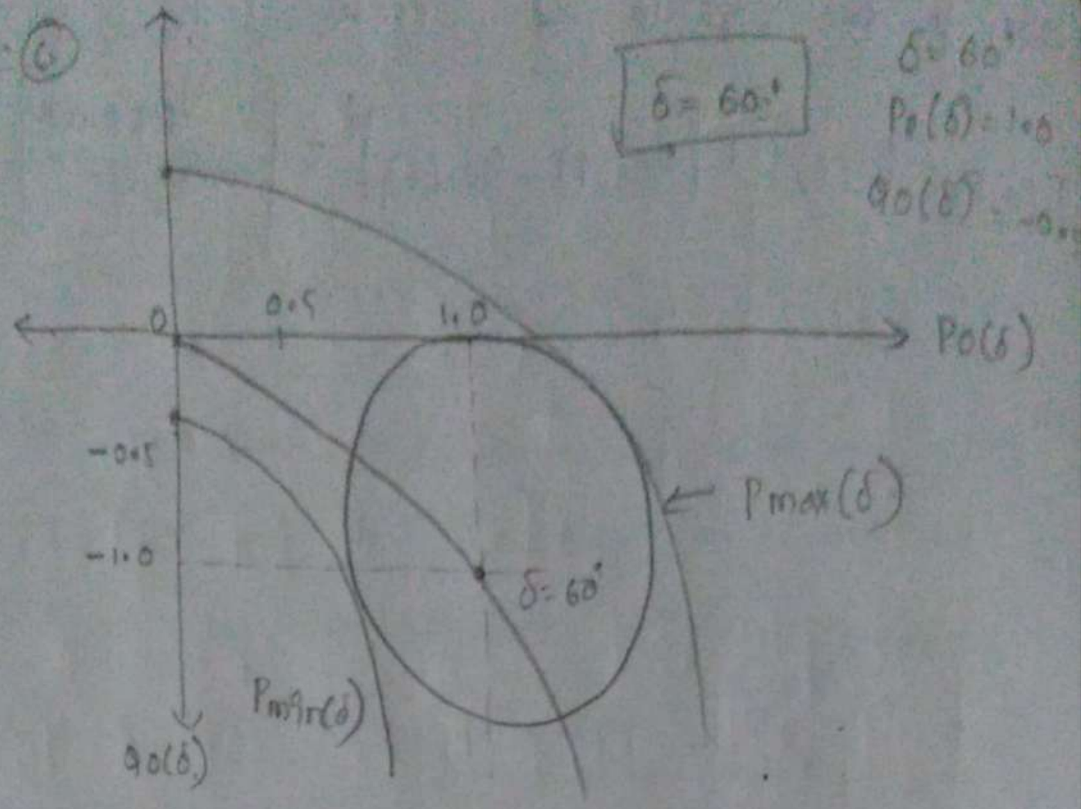

$\delta = 30^\circ$

$P_0(\delta) = 0.5$

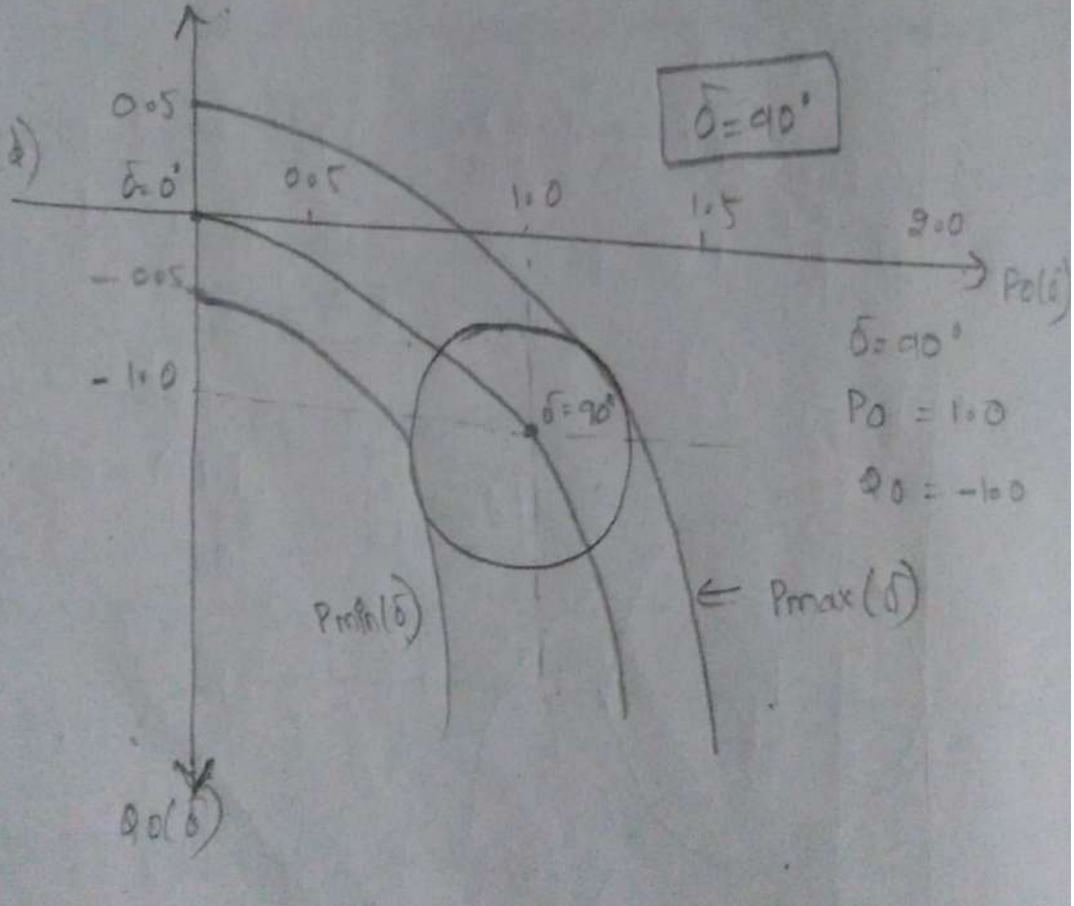
$Q_0 = -0.5$



(6)


δ = 60°
δ = 60°
Po(δ) = 1.0
Qo(δ) =
0
0.5
1.0
Po(δ)
-0.5
-1.0
Pmax(δ)
δ = 60°
Pmin(δ)
Qo(δ)

(b)


δ = 90°
0.5
δ = 0°
0.5
1.0
1.5
2.0
Po(δ)
-0.5
-1.0
δ = 90°
Po = 1.0
Qo = -1.0
δ = 90°
Pmax(δ)
Pmin(δ)
Qo(δ)

control region of the attainable power and Receiving & reactive power 'QR' with upfc control with a tlln line,

→ $\delta$ = fig (a), 0°

$\delta$ = 30 , fig (b)

$\delta$ = 60°, fig (c)

$\delta$ = 90°, fic (d) shown above.

→ In fig (a) illustrates, tlln angle = 0

$$\delta = 0$$

$$V_{pq} = 0$$

$$P_0 = 0$$

$$Q_0 = 0$$

that means the system is at stand still at the origin of Qr, P coordinates

→ This circle around origin at the. Qr, P, gives the corresponding values of Real power and Reactive power.

→ similar control chr's for real power 'P' & reactive power 'Q' can be

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absorbed at angles 0°, 30°, 60°, 90°, shown in fig (a), b, c, d,

→ At any t/ln angle 'δ' (0 to 360°), the transmitted power 'P' as well as reactive power 'Q' can be controlled freely by the upfc.

→ It is a unique capability to control the real & reactive power flow at any t/ln angle.