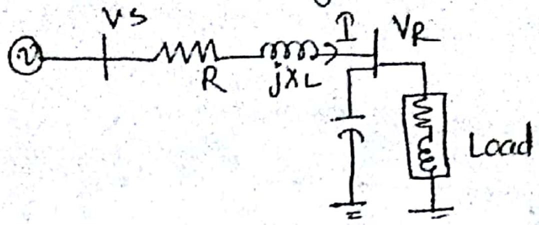
Unit-3

1. Principles of regulating the voltage

- Add shunt capacitors to reduce the current magnitude I and make it in phase ~~sub~~ with voltage



Voltage drop in transmission line $I(R+jX_L)$

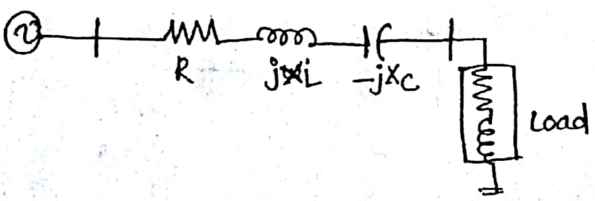
Shunt capacitor added → I decreases → I(Z) decreases → V_R incre

- Add voltage regulators, which boost the voltage at receiving end.
- conductor lines to a larger size to reduce the impedance

$$R = \frac{\rho l}{A} \quad , \quad L \propto \ln\left(\frac{d}{r}\right)$$

$$A\uparrow \rightarrow R\downarrow \quad , \quad r\uparrow \rightarrow L\downarrow$$

- change substation or service transformers to a larger sizes to reduce impedance Z.
- Add dynamic reactive power (VAR) compensation for rapidly changing loads.
- Add series capacitor to cancel the inductive impedance



Initial drop $I(R+jX_L)$

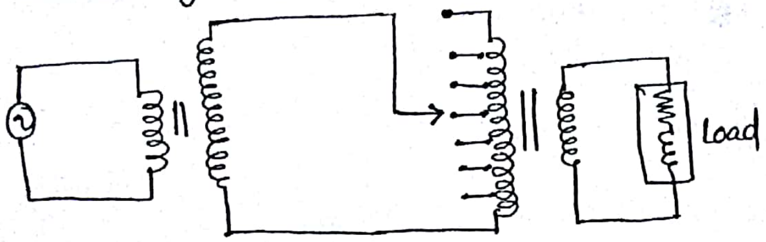
after capacitor connected $I(R+j(X_L-X_C))$

$$X_C\uparrow \rightarrow Z\downarrow \rightarrow I(Z)\downarrow \rightarrow V_R\uparrow$$

2. Devices for voltage regulation

1. utility step voltage regulators
2. Electronic tap changing regulators
3. Ferroresonant Transformers
4. motor-generator sets
5. static Var compensators

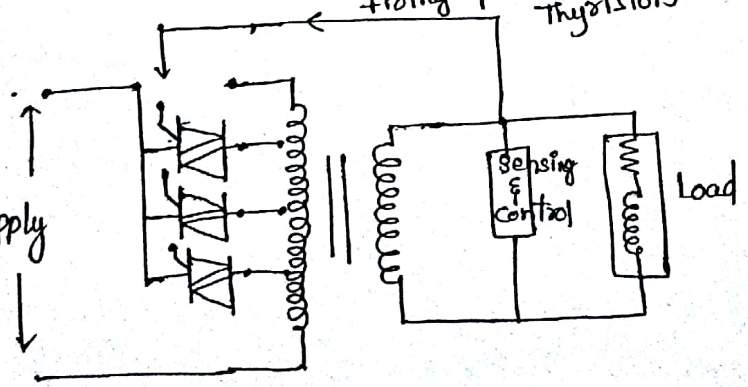
→ utility step voltage regulators:-



Tapchanging

- The utility tap-changing regulators can regulate from ±10% of incoming line voltage in 32 steps.
- utility voltage regulators (or) Load tap changing Transformers are relatively slow in operation.
- The time delay is at least 15 sec
- These are useful only for slow changing loads.

Electronic Tap changing regulators:-

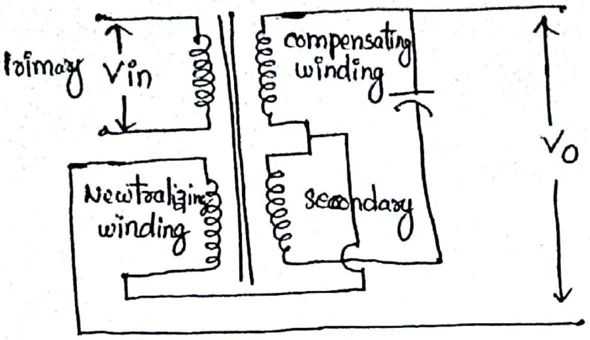


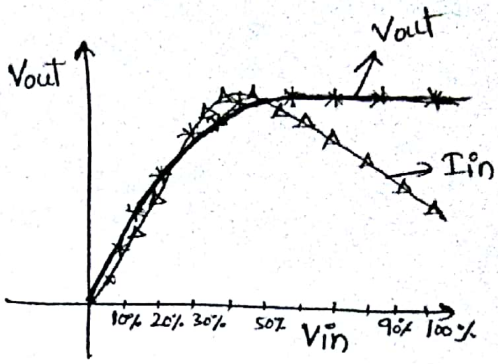
- To decrease the time delay electronic tap changing regulators will be used while regulating voltage.
- Use SCRs or TRIACs to quickly change taps and hence voltage.

- Electronic tap changing regulators popular for medium-power applications.

Ferroresonant Transformers :-

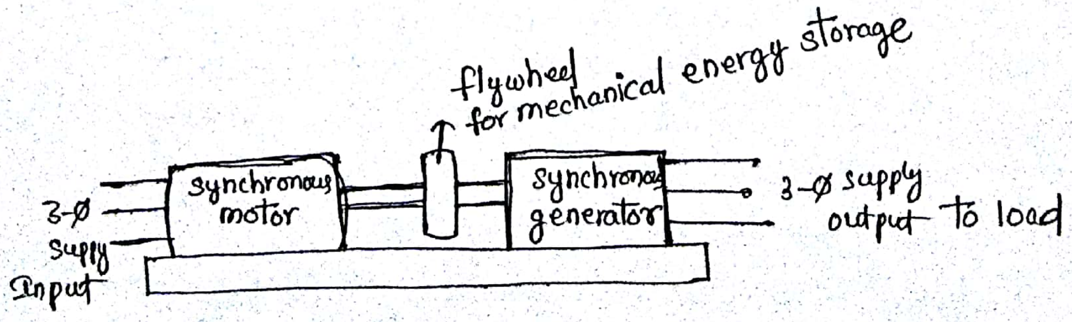
- Ferroresonant transformers are also alled as constant voltage transformers.





- useful for constant voltage, low power loads
- FTs are 1:1 Transformers, which are excited high on their saturation curves, there by providing an output voltage which is not significantly affected by input voltage variations.
- Till the input voltage is reduced down to 30V, the output voltage stays constant.
- If the input voltage is reduced further the output voltage begins to collapse.
- As the input voltage is reduced, the current ~~drawn~~ drawn by the ferroresonant transformer increases.

Motor-generator sets:-



- Motor-generator sets commonly decouple the load from the electric power system, shielding the load from electrical transients.

• Voltage regulation is provided by the generator excitation control.

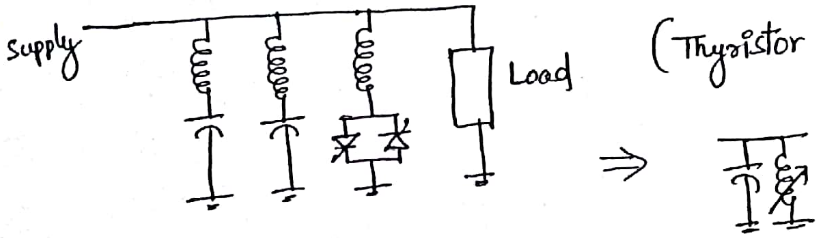
• The major drawback of motor generator sets is their response time to large load changes.

Static Var compensator:-

• SVCs are regulate voltage by responding very quickly to supply or consume reactive power.

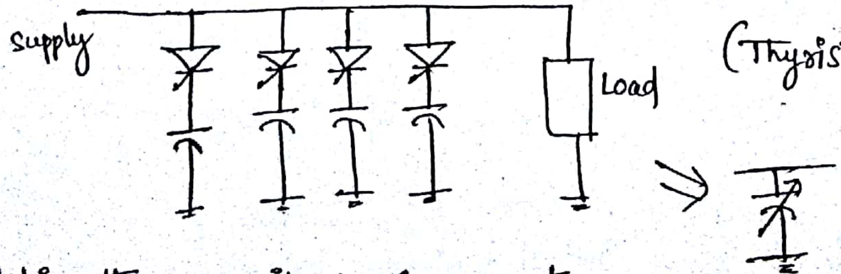
• There are two main types of static VAR compensators in common usage.
  - Thyristor controlled rectifier (TCR)
  - Thyristor switched capacaitor (TSC)

• In TCRs fixed capacacitor bank to provide leading powerfactor and the reactor is controlled in various amounts to get desired power factor.



(Thyristor controlled rectifier)

• Thyristor switched capacitor operates by switching multiple steps of capacitor quickly to match the load requirements as closeley as possible.



(Thyristor switched capacitors)

• switching the capacitors in or out of the system, controls the amount of reactive power delivered to the system by the TSC.

• TCR is combination of fixed capacitor plus variable reactor. TSC is variable capacitor only.

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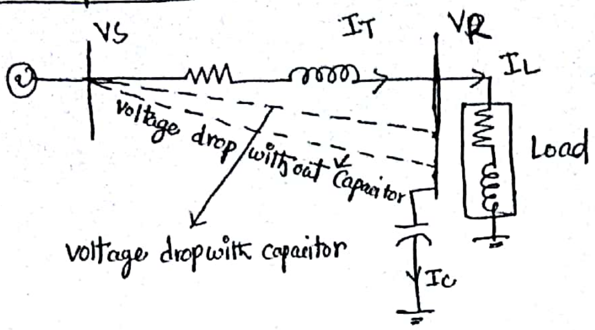
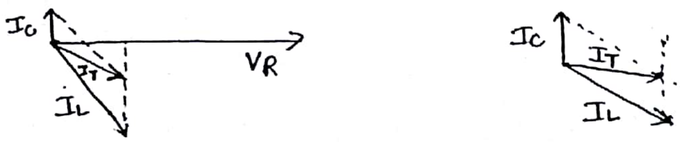
3 Capacitor for voltage regulation

- Capacitors are used for voltage regulation either in shunt or series configuration.

→ Shunt capacitor :-

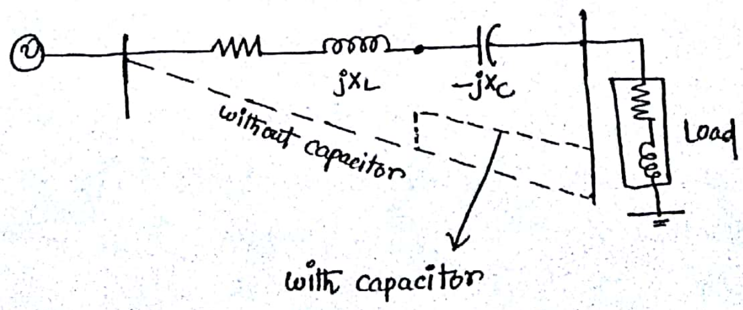
- 

- By connecting a shunt capacitor at load bus bar current in the transmission line decreases so voltage drop in the transmission line will decrease



$$(I_T)\downarrow \;\rightarrow\; I_T(Z_T)\downarrow \;\rightarrow\; V_R\uparrow$$

Series capacitor :-

- 

- capacitor connected in series with the feeder results in a voltag rise at the end of the feeder
- If a series capacitor present in a CKT impedance of the feeder will decrease as well as voltage drop in the feeder

will decreases and voltage at receiving end will increase.

- Real power loss in the feeder (I_L^2R) will increase with load increase so series capacitors on distribution system is very limited.

4. End user capacitor applications

The reasons than an end user connect power factor correction ~~capa~~capacitor are to

→ Reduce electricity bill

→ Reduce i^2R loss, heating in the lines and transformers

→ Increase the voltage at the load, increase the efficiency of operation

→ Reduce current in the lines allowing additional load to be served with building new CKTS.

→ <u>% Voltage rise</u>:-

- If capacitors connect in inductive loads voltage will rise at end user bus bar.
- The voltage rise by the end user from the installation of capacitor is

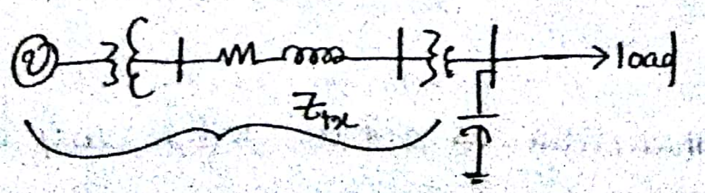
$$\%\Delta V = \frac{KVAR_{capacitor}}{KVA_{Transformer}} \times (\% Z_{tx})$$

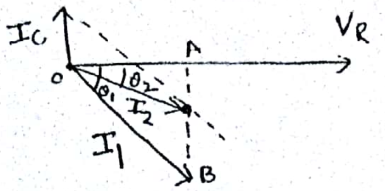
$\%\Delta V$ = Percent voltage rise

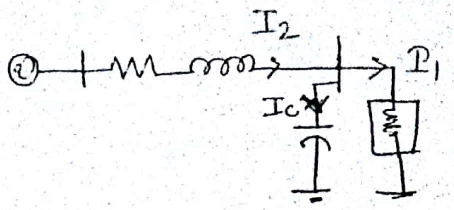
$KVAR_{cap}$ = capacitor bank rating

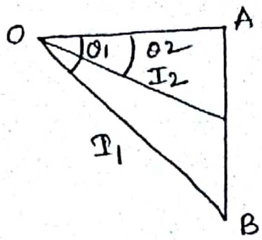
KVA_{TF} = Step down transformer rating

Z_{tx} = Power system impedance upto the point at which the capacitor is connected.









$I_1 \rightarrow$ Initial current in transmission line before the capacitor is connected.

$I_2 \rightarrow$ Current in the transmission line After the capacitor is connected.

$\cos\theta_1 \rightarrow$ Power factor befor capacitor connection

$\cos\theta_2 \rightarrow$ Power factor after capacitor connection

Reduction in the current $= I_1 - I_2$

% reduction in the current $= \dfrac{I_1 - I_2}{I_1} \times 100 \longrightarrow (1)$

from OAB Triangle $I_1 \cos\theta_1 = I_2 \cos\theta_2$

$$I_2 = \frac{I_1 \cos\theta_1}{\cos\theta_2} \longrightarrow (2)$$

substituting I_2 value in equation (1)

$$\% \Delta I = \frac{I_1 - \frac{I_1 \cos\theta_1}{\cos\theta_2}}{I_1} \times 100$$

$$\% \Delta I = \left(1 - \frac{\cos\theta_1}{\cos\theta_2}\right) \times 100.$$

→ **Reduction in power system losses:-**

Initial power loss $= P_{L1} = I_1^2 R$

Power loss after capacitor connection $= P_{L2} = I_2^2 R$

Loss reduction $= P_{L1} - P_{L2}$

% Loss reduction = $\frac{P_{L_1} - P_{L_2}}{P_{L_1}} \times 100$

$$= \frac{I_1^2 R - I_2^2 R}{I_1^2 R} \times 100$$

$$= \frac{I_1^2 - I_2^2}{I_1^2} \times 100$$

$$= \frac{1 - \left(\frac{I_2}{I_1}\right)^2}{1} \times 100$$

$$\left[\because I_2 = \frac{I_1 \cos\theta_1}{\cos\theta_2} \qquad \frac{I_2}{I_1} = \frac{\cos\theta_1}{\cos\theta_2} \right]$$

$$\% \text{ Loss reduction} = \left[1 - \frac{\cos^2\theta_1}{\cos^2\theta_2}\right] \times 100$$

Keep in mind that this formula gives percentage loss reduction till the line where the capacitor is connected. there is no reduction in losses in the lines between the capacitor and the load.

→ **Displacement power factor Versus True powerfactor :-**

- Cosine of angle difference between fundamental voltage and fundamental current is called Displacement power factor

  $$DPF = \cos(\angle V_1, I_1)$$

- The ratio between Real power and apparent power called True power factor.

  $$TPF = \frac{P}{S}$$

- The True power factor is the true measure of the efficiency with which the real power is being used

- Capacitors compensates only for the fundamental frequency reactive power and can't completely correct the true power factor to unity when there are harmonics present in current.

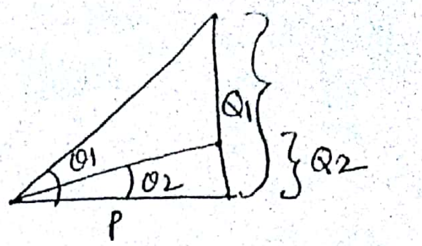
- The maximum value of TPF you can get when harmonics present

$$(TPF)_{max} = \sqrt{\frac{1}{1 + (THD)^2_{current}}}$$

$$(THD)_{current} = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + \cdots}}{I_1}$$

- The KVAR of capacitor required to correct the load to a desired power factor is given by

$$Q_c = P(\tan\theta_1 - \tan\theta_2)$$



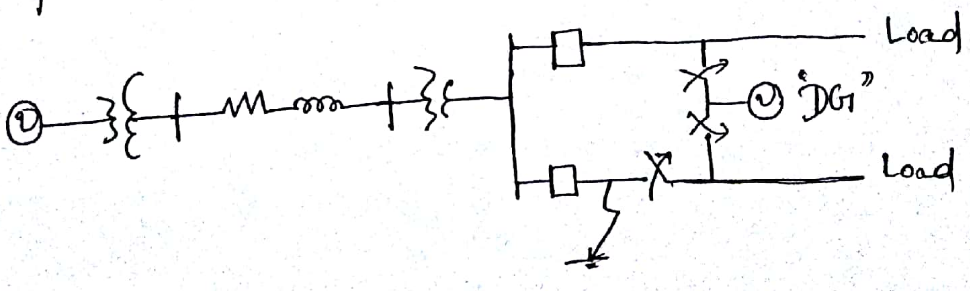
$\therefore Q_c = Q_1 - Q_2$

$Q_c = P\tan\theta_1 - P\tan\theta_2$

- After selecting estimated capacitor sizes, two power quality checks should be done
  - i) Determine no load voltage rise to make sure that that voltage will not rise above 1.1pu
  - ii) Determine the impact of the capacitors on harmonics

⑤ Regulating utility voltage with distributed resources:

- Distributed resources or distributed generators (DG) are particulary useful when there are a relatively few number of hours each year when the load approaches the system capacity limits.
- By using DGs in system to gain additional system capacity, loss reduction, improved reliability and voltage regulation.
- Its control and responses are faster than tap changing Transformers.



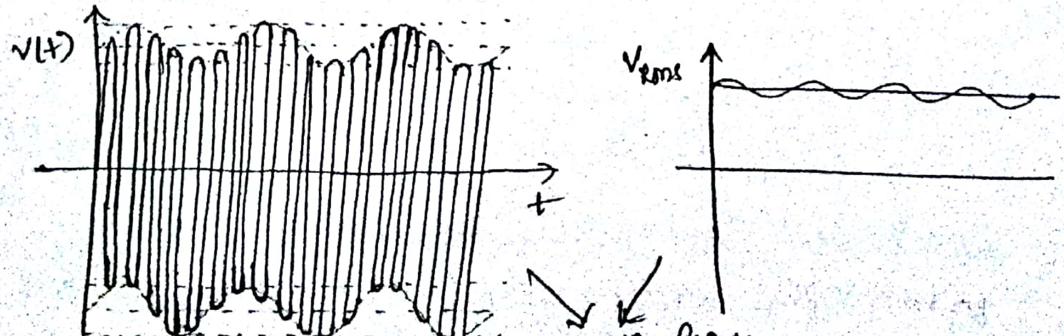
- By using DGs can continue the service to the unfaulted portion of the feeder and also useful in peak load conditions
- DG is used to power and power factor control.
- But DGs will not operate in normal conditions to regulate the voltage.

... distributed generation

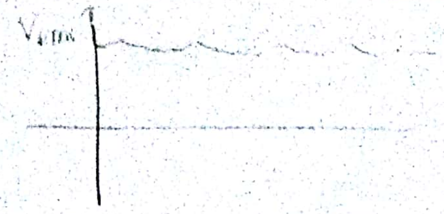
- Recipsocation engines
- combustion turbines
- fuel cells
- battery storage
- wind turbines
- Photo voltaics.

(6) Flicker

- A continuous or occational change in the voltage or current is called flicker.
- main reason for flicker is "the system is too weak to support the load variations".
- flicker → voltage fluctuations, voltage flicker, light flicker, Lamp flicker
  synonyms
- fluctuations in the system voltage that can result in observable changes in light output.
- whether the voltage fluctuations cause observable or objectionable flicker is depends on
  - Percent voltage modulation
  - frequency of voltage fluctuations.
- Flicker canbe seperated into 2 types
  - cyclic
  - non-cyclic
- cyclic flicker means periodic voltage fluctuations
- Non-cyclic means occational voltage fluctuations



cyclic flicker



Non-cyclic flicker voltage (rms) waveform

- Percent voltage modulation $= \dfrac{V_{max} - V_{min}}{V_0} \times 100\%$

  V_{max} — maximum value of modulated signal

  V_{min} — minimum value of modulated signal

  V_0 — average value of normal operating voltage

- The typical frequency range of observable flicker is < 30 Hz with magnitude < 1 percent

Sources of flicker:-

- Reasons for flicker is
  - system is too weak for the load variations
  - continuous change in the current for a short time period.

- Large ~~induction~~ industrial plant located at end of weak distribution feeder is one of the reasons. As load increases or decreases the current in the line varies, voltage drop varies results voltage fluctuation.

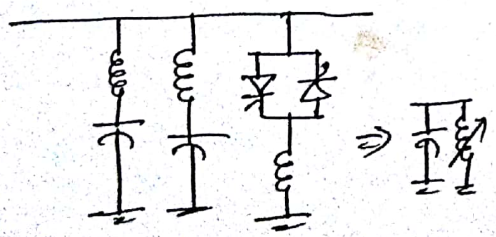
- Another source is Electric arc furnace (EAF). EAFs are non linear, time varying loads that often cause large voltage flutuations. most of the large current fluctuations occur at the begining of the melting cycle. This melt down period can generally result in flicker in the range 1 to 10 Hz

- Large induction machines starting and widely varying load torque are also known to produce voltage fluctuations. At starting induction machines take large current results large voltage drop in distribution lines.

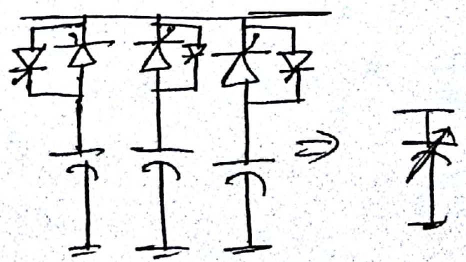
- Harmonic and interharmonic currents also one of the causes of voltage fluctuations

Mitigation techniques of flicker:-

- By increasing system capacity can decrease the voltage fluctuations. increasing system capacity means "reconductoring, replacing the existing transformers with higher KVA ratings, increasing the operating voltage."
- connecting Series reactors with electric arc furnace, amount of flicker can be reduced. Series reactors stabilize the current variations because reactors doesn't allow sudden change of currents.
- Series capacitor can also be used to reduce the effect of flicker.
- By using step-starter, it is possible to reduce starting current of induction motor while starting.
- static var compensators are very efficient in controlling the voltage flicker. SVR deliver the reactive power during heavy load conditions and draw reactive power during light loading conditions.
- Thyristor switched capacitors (TSC) can also be used to reduce voltage fluctuations by delivering reactive power to system corresponding the load changes.



Thyristor controlled reactor



Thyristor switched capacitors