

# Reactive power control

### **Causes of reactive power needs (consequently causing low power factor):**

- Motors having a lagging power factor (0.2 at light load and 0.8 at rated load)
- Arc lamps
- Electric discharge lamps
- Industrial heating furnaces
- Increased magnetization current due to higher voltage at light load

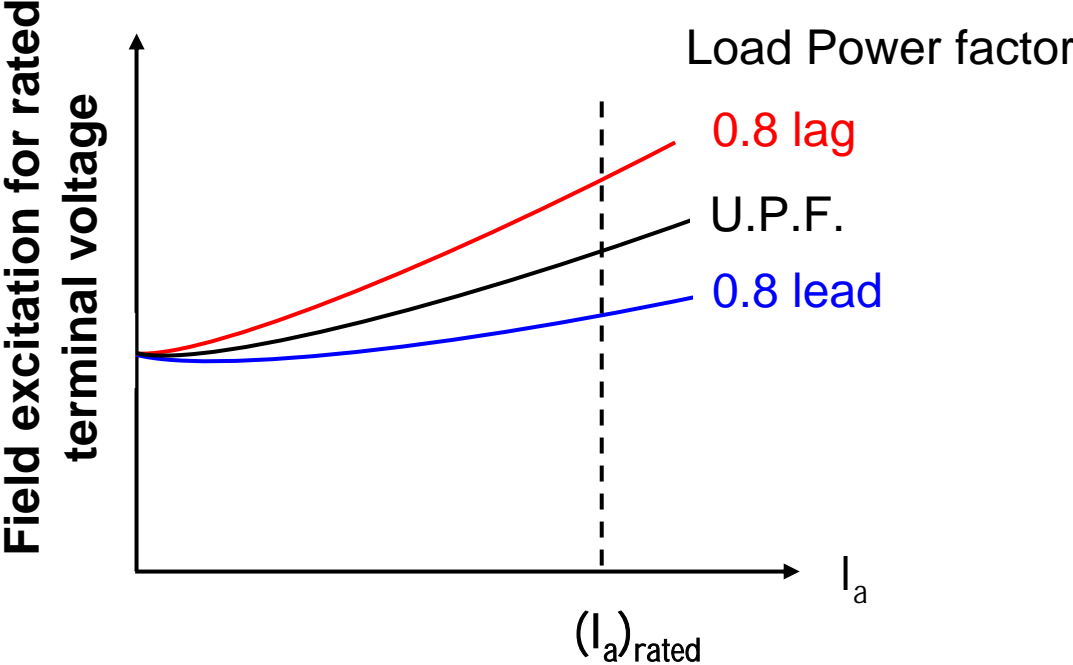
### **Low power factor operation should be avoided for the following reasons:**

- Large kVA rating
- Large copper losses
- Poor voltage regulation
- Poor utilization of installed capacity

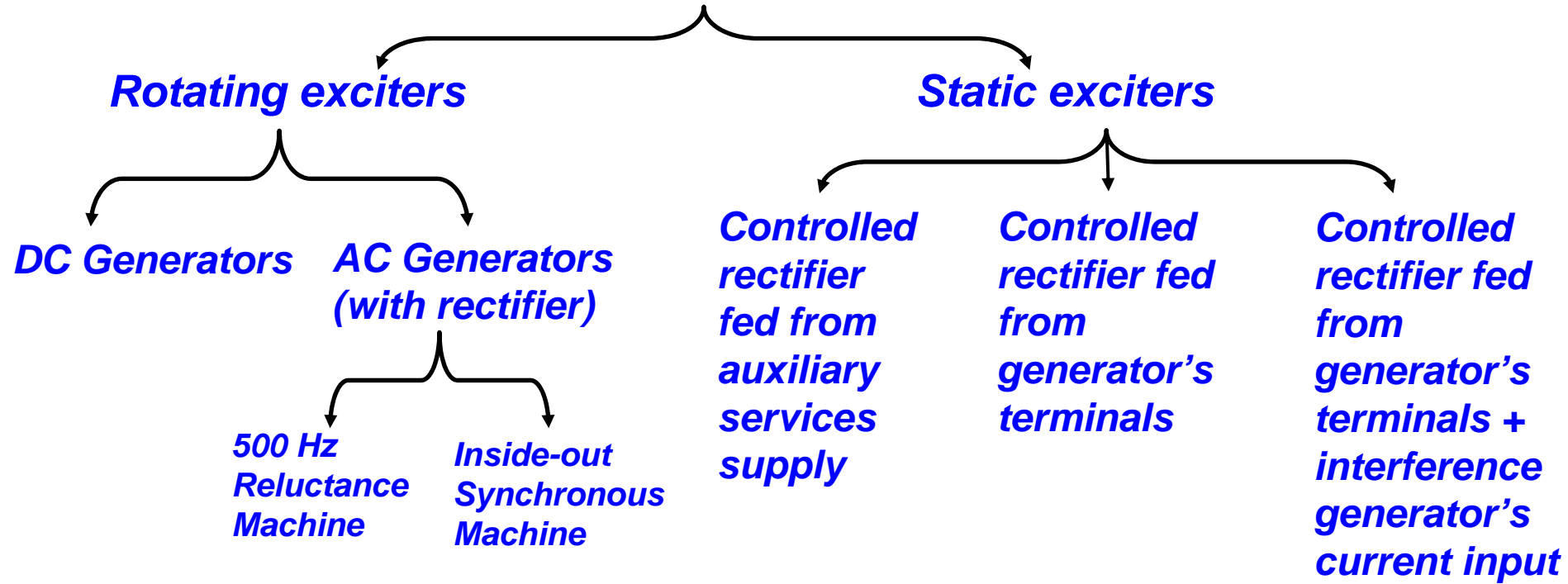
**Reactive power control in general is via:**

- **Excitation control**
- **Switching shunt capacitor banks or reactors, and static VAR systems or other FACTS**
- **Tap-changing and regulating transformers**

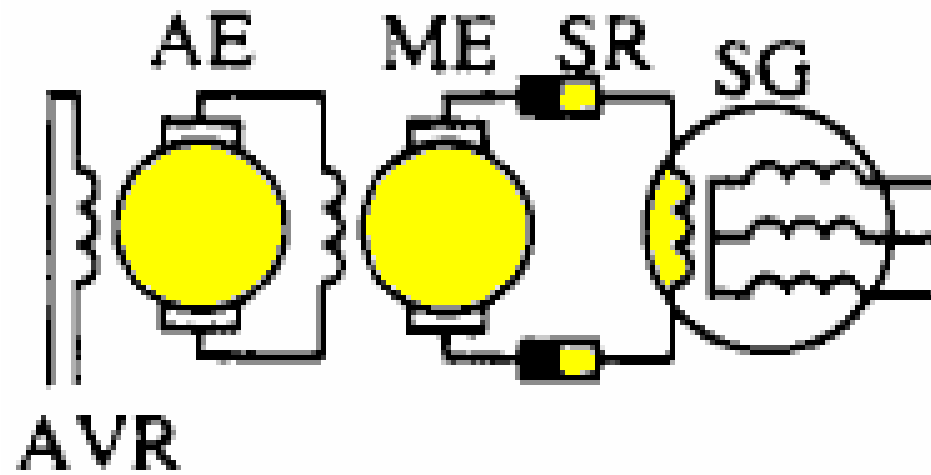
Excitation control:



# ***Excitation systems (Exciters)***

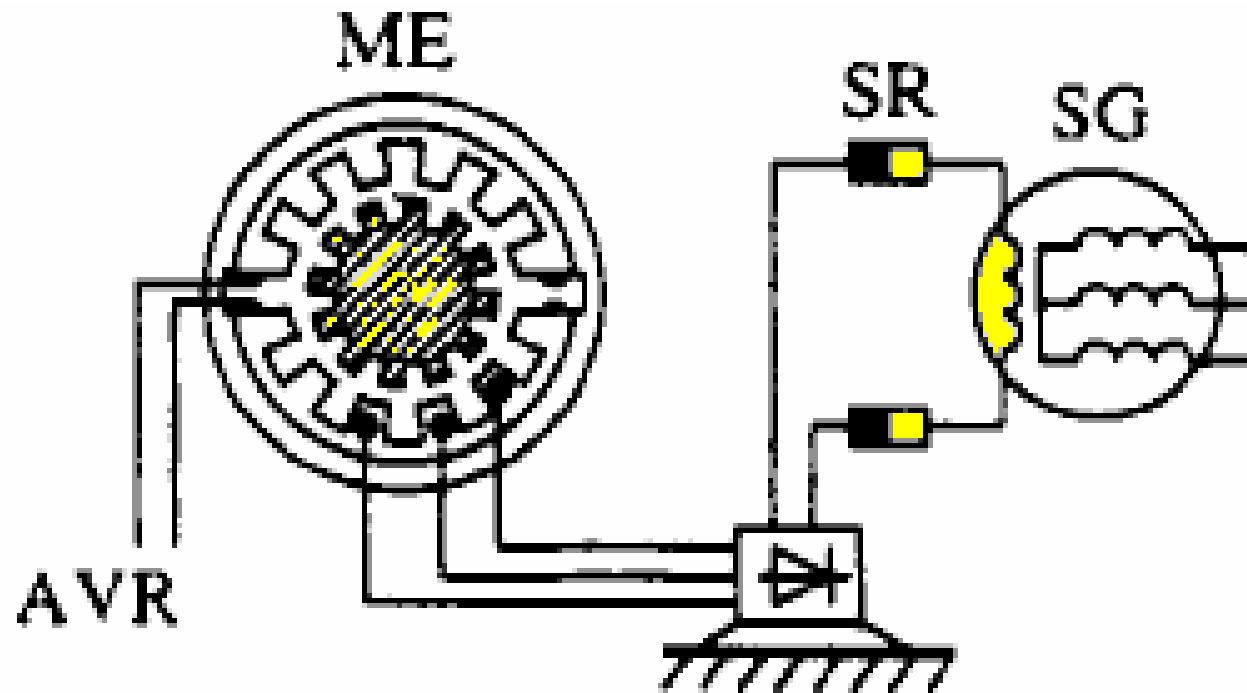


## **Rotating DC generator Exciter**



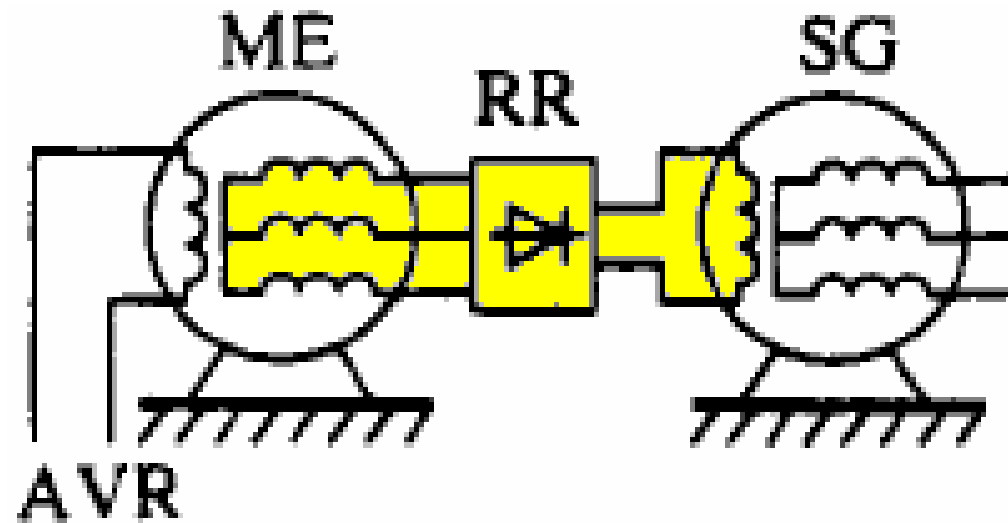
- Low ratings only

## **Rotating AC 500 Hz Reluctance Machine Exciter**



- Large
- Slip rings

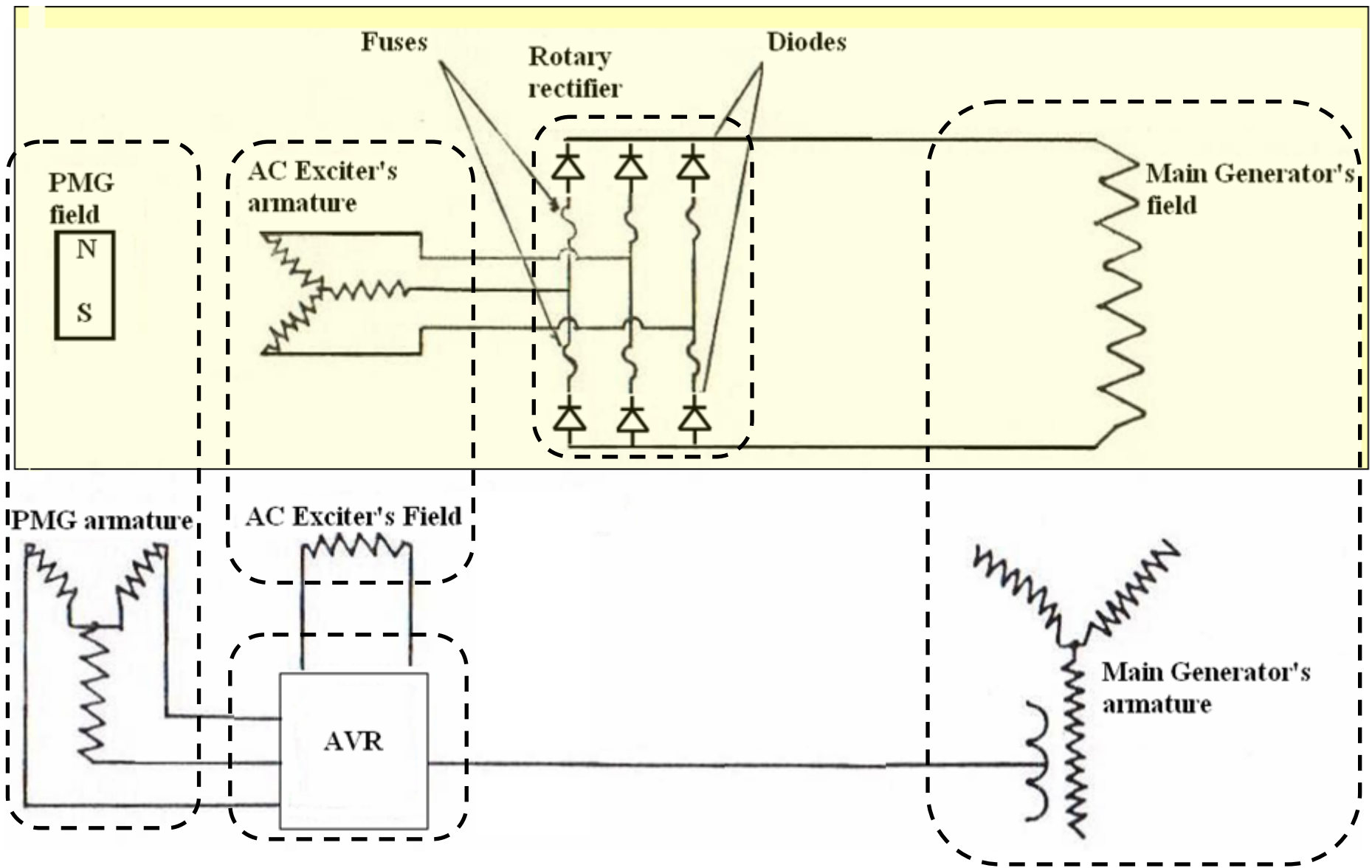
## **Rotating Rectifier AC alternator exciter**



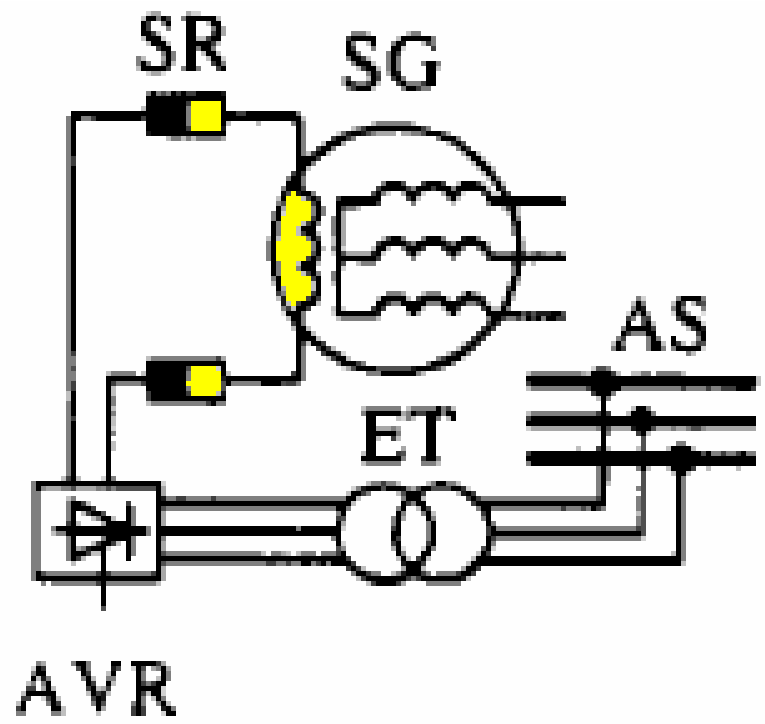
*Main exciter is an inside-out synchronous machine;  
(Field on stator and armature on rotor)*

**From 0.5 to 1S time-constant due to indirect control**

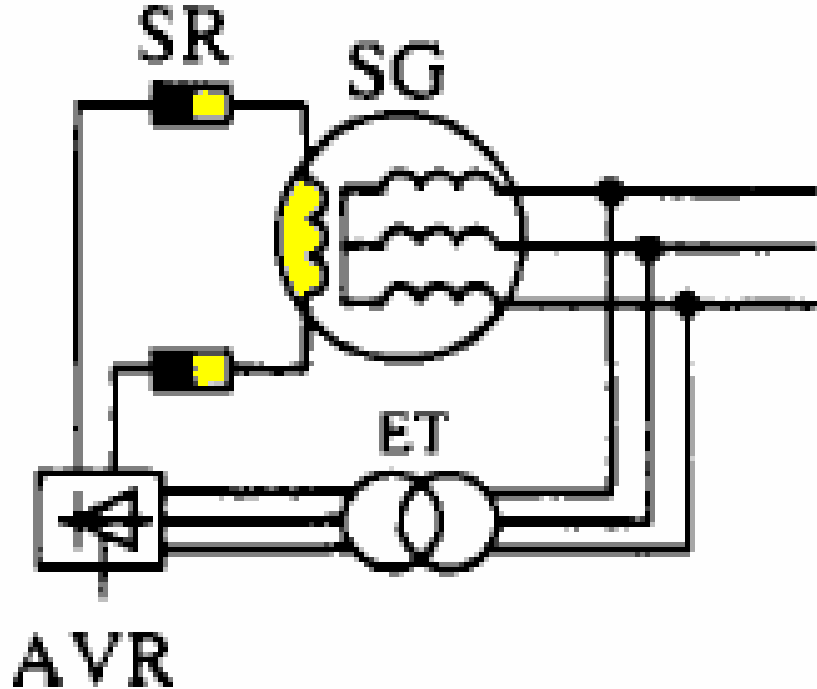




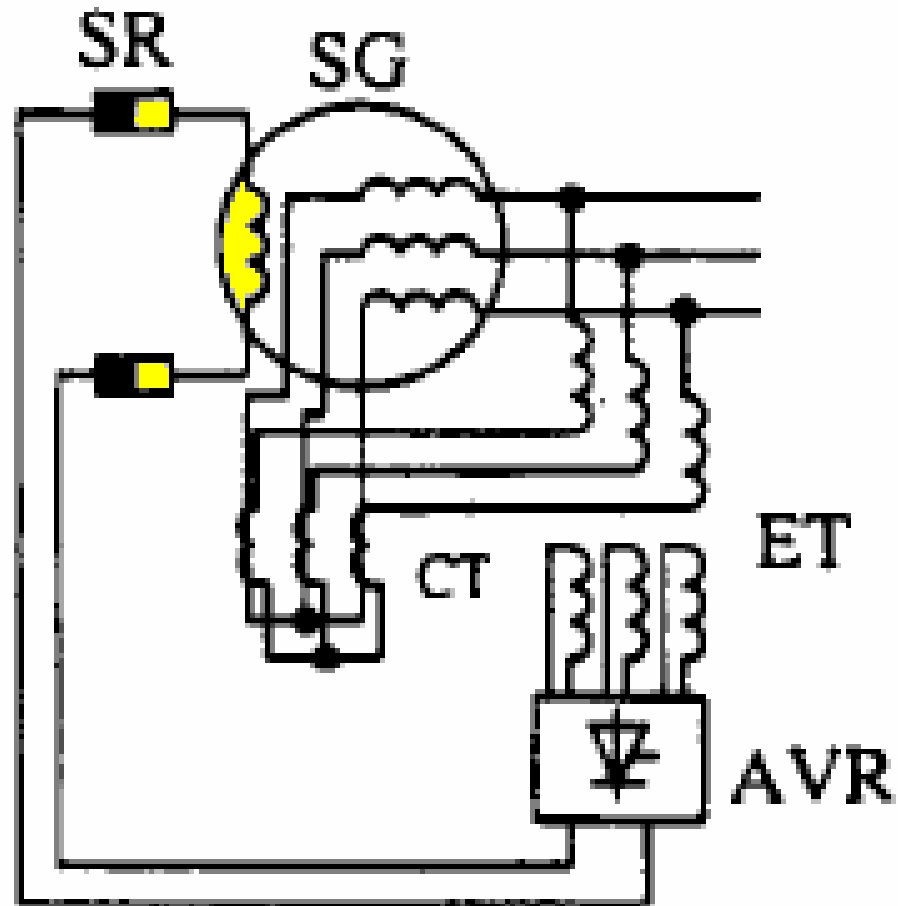
*Static Exciter with controlled rectifier fed from auxiliary supply*



*Static Exciter with controlled rectifier fed from generator's terminals*



***Static Exciter with controlled rectifier fed from generator's terminals  
+ interference generator's current input***



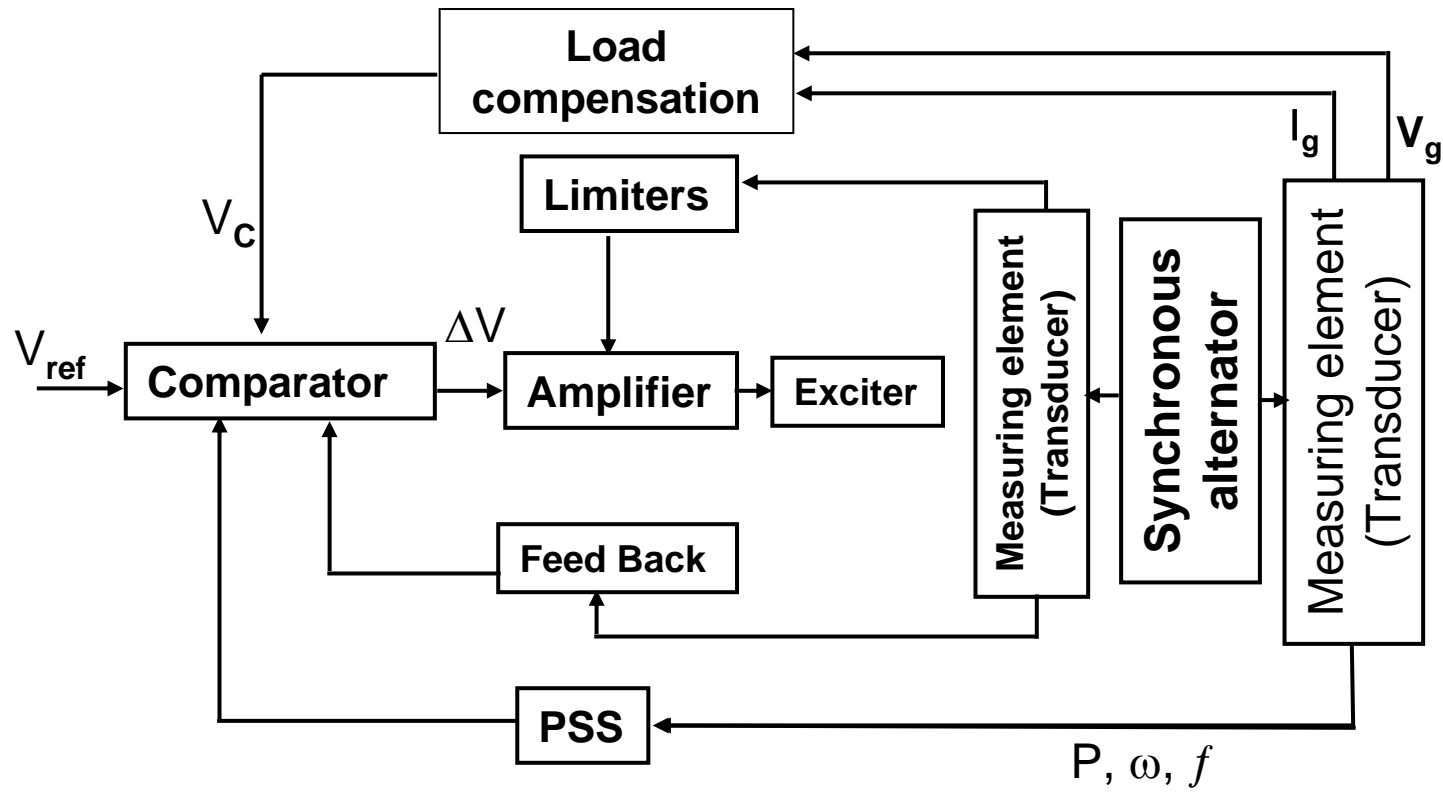
## *Automatic Voltage Regulators*

Automatic voltage regulator (AVR) regulates the generator's terminal voltage by controlling the amount of exciter's current fed to the generator's field winding. Usually, the generator's current, power and voltage are sensed as input control signals.

compared with the desired reference voltage  $V_{ref}$  to produce the voltage error  $\Delta V$ . This error is then amplified and used to alter the exciter output, and consequently the generator

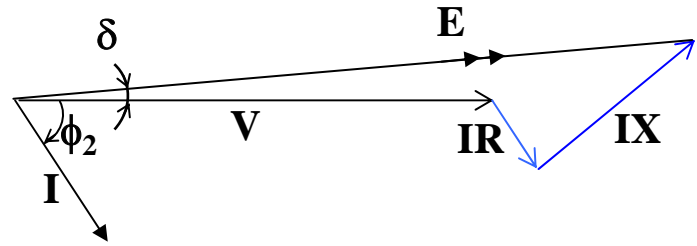
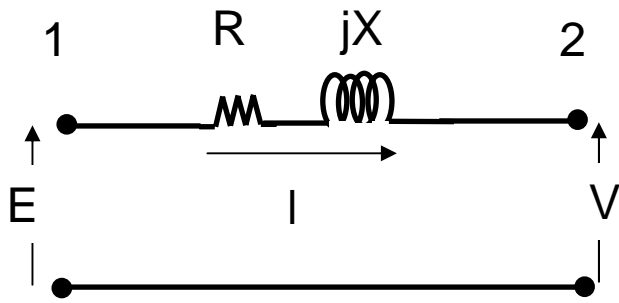
control system. The regulation process is stabilised using a negative feedback-loop taken directly from either the amplifier or the exciter. The voltage drop across the compensating impedance  $Z_C$  due to the generator current  $I_g$  is added to the generator voltage  $V_g$  to produce the compensated voltage  $V_C = |\bar{V}_g + (R_C + jX_C)\bar{I}_g|$  where  $\bar{Z}_C = R_C + jX_C$  is the compensation impedance. If load compensation is not employed  $\bar{Z}_C = \bar{0}$ ,  $V_C = V_g$ , and the AVR subsystem maintains constant generator terminal voltage.

The use of load compensation ( $\bar{Z}_C \neq \bar{0}$ ) means that the point at which constant voltage is maintained is "pushed back" into the network by a distance electrically equal to the compensation impedance. In case of parallel generators supplying a common busbar the compensation impedance must be smaller than the impedance of the step-up transformer in order to maintain stable reactive power dispatch between parallel generators. Usually  $X_C \approx 0.85X_T$ , where  $X_T$  is the reactance of the step-up transformer



The AVR subsystem also includes a number of limiters whose function is to protect the AVR, exciter and generator from excessive voltages and currents. They do this by maintaining the AVR signals between preset limits. Thus the amplifier is protected against excessively high input signals; the exciter and the generator against too high a field current; and the generator against too high an armature current and too high a power angle. The last three limiters have in-built time delays to reflect the thermal time constant associated with the temperature rise in the winding.

A power system stabiliser (PSS) is sometimes added to the AVR subsystem to help damp power swings in the system. PSS is typically a differentiating element with phase shifting corrective elements. Its input signals may be proportional to rotor speed, generator output frequency or the electrical real power output of the generator.



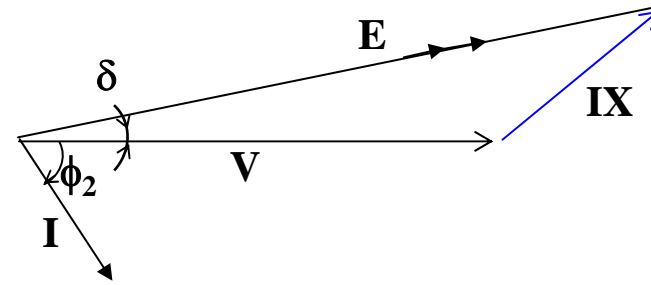
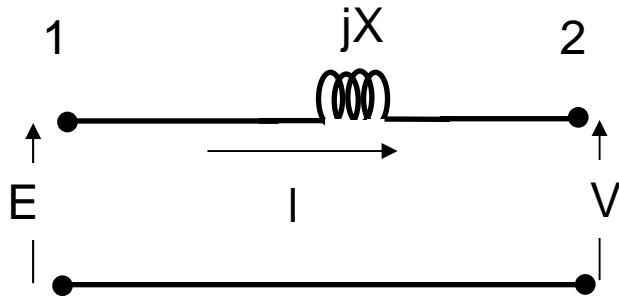
$$Z = R + jX = |Z| \angle \psi$$

$$S_1^* = \left( \frac{E^2}{Z} \angle (-\psi) \right) - \left( \frac{EV}{Z} \angle (-\psi - \delta) \right)$$

$$S_2^* = \left( \frac{EV}{Z} \angle (-\psi - \delta) \right) - \left( \frac{V^2}{Z} \angle (-\psi) \right)$$



**Neglecting armature resistance w.r.t. synchronous reactance:**

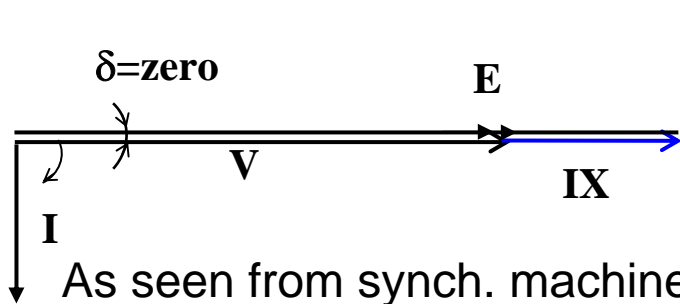


$$P = \frac{EV}{x} \sin \delta$$

$$Q = \frac{V}{x} [E \cos \delta - V]$$

*If generator produces reactive power ( $Q_2 > 0$ ):*

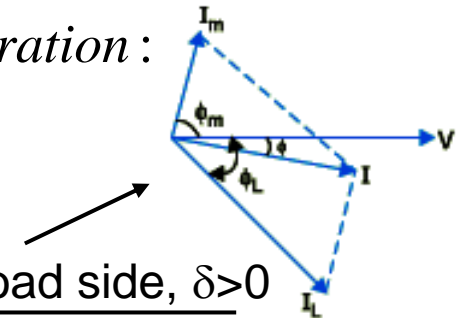
*$E \cos \delta > V$  which implies over-excitation*



*For synchronous condenser operation:*

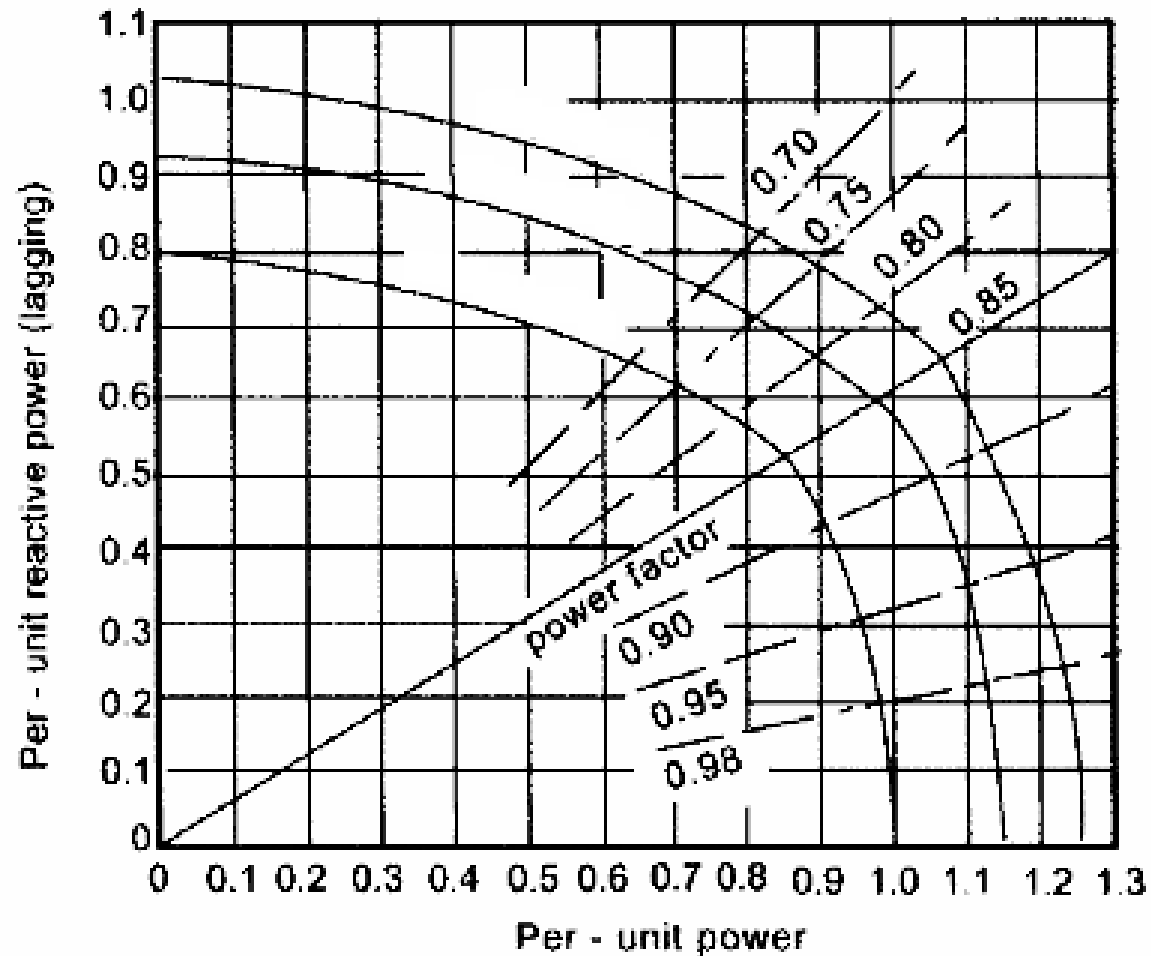
$$\delta = 0 \Rightarrow Q_2 = \frac{V(E - V)}{x}$$

*As seen from load side,  $\delta > 0$*



*If generator absorbs reactive power ( $Q_2 < 0$ ):*

*$E \cos \delta < V$  which implies under-excitation*



### Reactive capability curve of a synchronous generator:

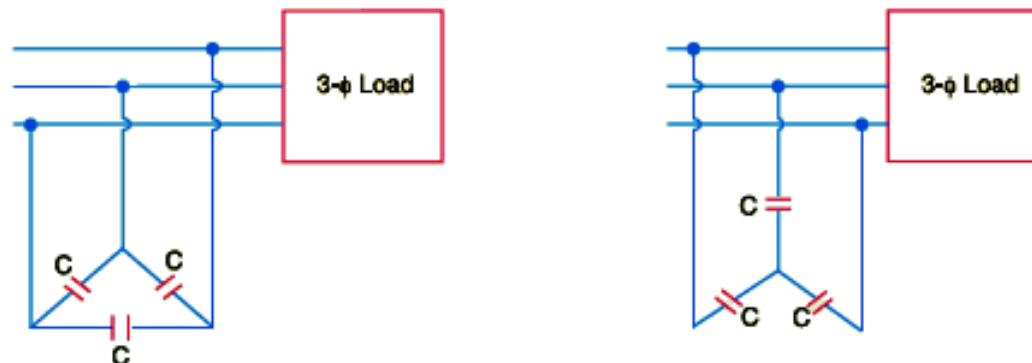
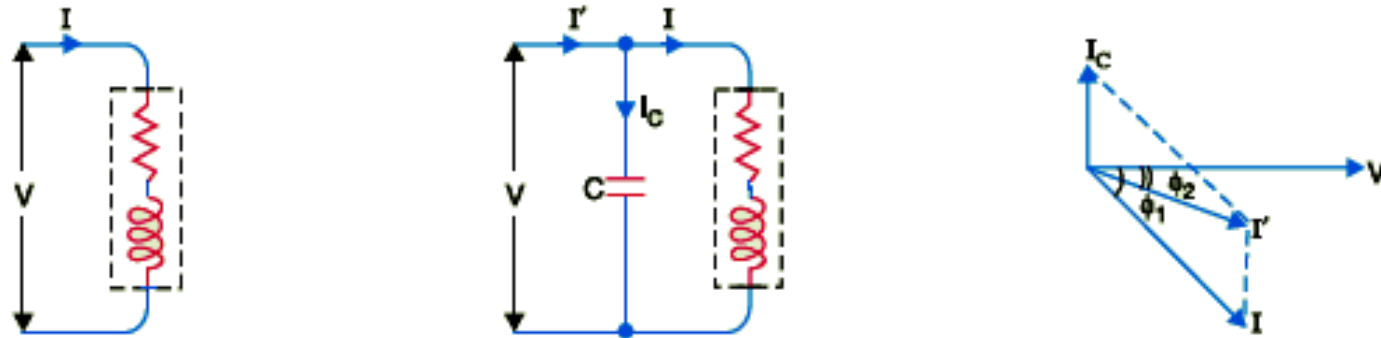
Gives maximum allowed reactive power loadings corresponding to various active power loadings at rated voltage operation.

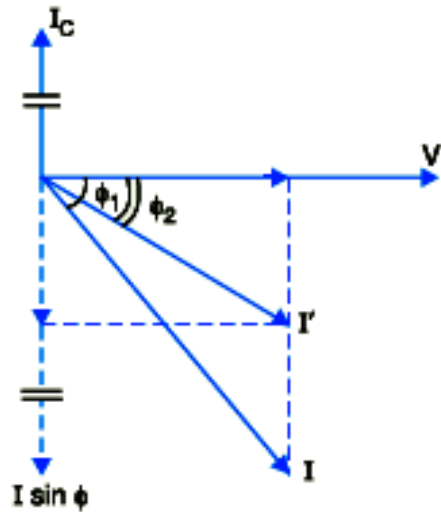
- Armature heating imposes constraints from rated power factor to U.P.F.
- Field winding heating imposes constraints for lower power factors than rated

## -Switching shunt capacitor banks or reactors, and static VAR systems or other FACTS

### Shunt capacitors

Adding a shunt capacitor results in a capacitive current leading the voltage by  $90^\circ$ . Accordingly, this corresponds to addition of a reactive generating source (negative reactive power). An outcome of this process is power factor correction:





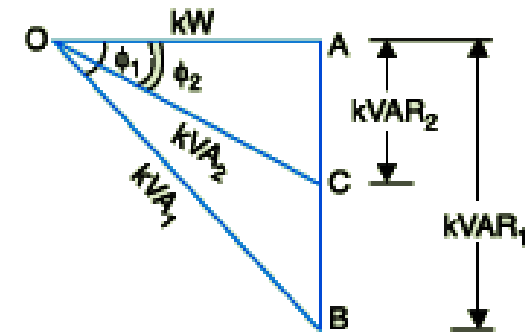
$$I' \sin \phi_2 = I \sin \phi_1 - I_C$$

$$\therefore I_C = I \sin \phi_1 - I' \sin \phi_2$$

$$\therefore C = \frac{I \sin \phi_1 - I' \sin \phi_2}{\omega V}$$

$$\therefore I \cos \phi_1 = I' \cos \phi_2$$

$$\therefore C = \frac{I(\sin \phi_1 - \cos \phi_1 \tan \phi_2)}{\omega V}$$



$$kVAR_C = kVAR_1 - kVAR_2$$

$$kVAR_C = kW(\tan \phi_1 - \tan \phi_2)$$