2.12 Types of Electrical Power

(1) Instantaneous Power [$p(t)$] :-

The instantaneous power $p(t)$ absorbed by an element is the product of the instantaneous voltage $v(t)$ across the element and the instantaneous current i through it.

$$p(t) = v(t)\, i(t)$$

* The instantaneous power (in watts) is the power at any instant of time.
* It is the rate at which an element absorb energy.
* instantaneous quantities are denoted by lower case letters.

(II) Average power :-

The instantaneous power changes with time and is therefore difficult to measure.

The average power is more convenient to measure. In fact the wattmeter, the instrument for measuring power responds to average power.

"The average power, in watts, is the average of the instantaneous power over one period."

$$P_{av} = \frac{1}{T}\int_0^T p(t)\, dt$$

(III) **Apparent Power (S):-**

The apparent power (in VA) is the product of the rms values of voltage and current.

$$S = V_{rms} \cdot I_{rms}$$

unit → ~~voltage~~ Volt-Ampere

The apparent power is so called because it seems apparent that the power should be the voltage-current product, by analogy with dc resistive circuits. It is measured in Volt-Ampere or VA to distinguish it from average or real power, which is meacured in watts.

(IV) **Complex Power :-**

Complex power (in VA) is the product of the rms voltage phasor and the complex ~~congu~~ conjugate of the rms current phasor.

As a complex quantity, its real part is real power P and its imaginary part is reactive power Q.

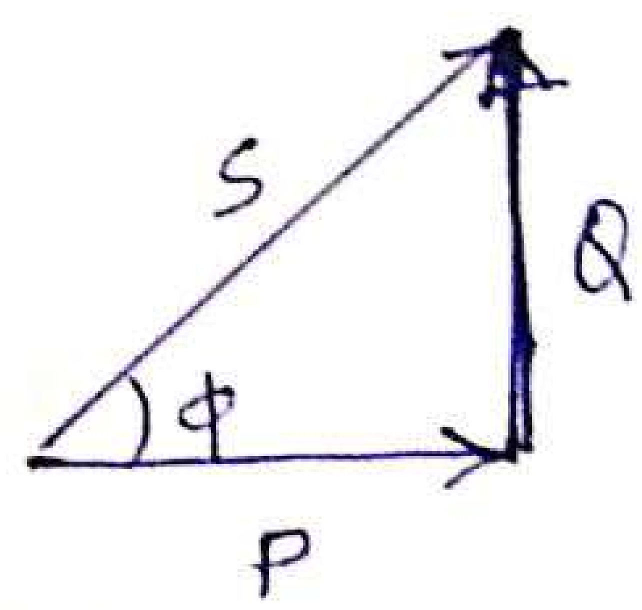
$$S = V_{rms} \cdot I_{rms}^{*}$$

$$S = P + jQ$$

$$P = VI \cos\phi$$

$$Q = VI \sin\phi$$

$$S = \sqrt{P^2 + Q^2}$$



'Power Triangle'

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Utility companies supply customers with voltampere but bill them for watts

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(V) Active Power or True Power:- (P)

Power that actually used in circuit (dessipated in resistance) is true or active power and is measured in Watts or KW.

$$P = VI\cos\phi$$

(VI) Reactive Power :- → The reactive power Q is a measure of the energy exchange between the source and the reactive part of the load.

Power that is returned to the source by the reactive components in the circuit is called reactive power and is measured in VAR (Volt-Ampere reactive)

$$Q = VI\sin\phi$$

Note:-

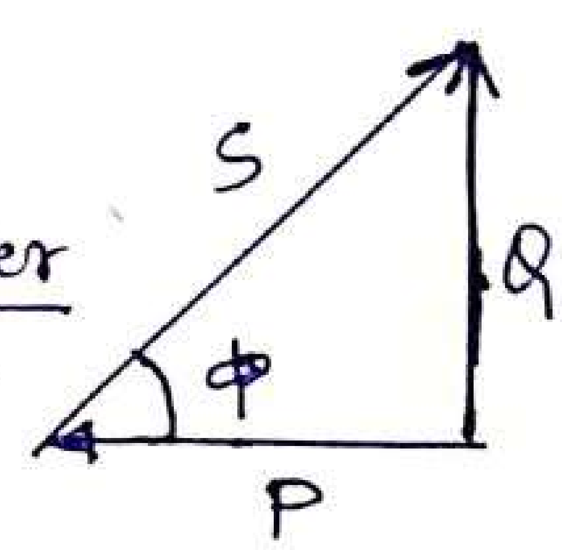
2.13 Power Factor Improvement :-

ⓐ Power factor:-

The power factor is the cosine of the phase difference between voltage and current. It is also the cosine of the angle of the load impedance.

~~Power~~

Power factor $\cos\phi = \frac{P}{S} = \frac{\text{Active Power}}{\text{Apparent Power}}$



" The power factor may also be regarded as the ratio of the real power dissipated in the load to the apparent power of the load."

→ Power factor is said to be lagging if the current lags behind voltage and leading if the current leads the voltage.

→ The significance of power factor lies in the fact that utility companies supply customers with voltampere but bill them for watts

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(b) Causes of Low Power factor :-

(I) Most domestic loads such as washing machines, air conditions, fans, refrigerators etc. and industrial loads such as induction motors are inductive and operate at lower power factor.

(II) Many ac machines such as transformer, induction motors absorb reactive power to produce their magnetic fields, this decrease the power factor. Reactive power required by the inductive loads increases the amount of apparent power (KVA) in our distribution system. This increase in reactive and apparent power result in larger power factor angle [Fig. 1 (b)]. As ϕ increases $\cos\phi$ decreases

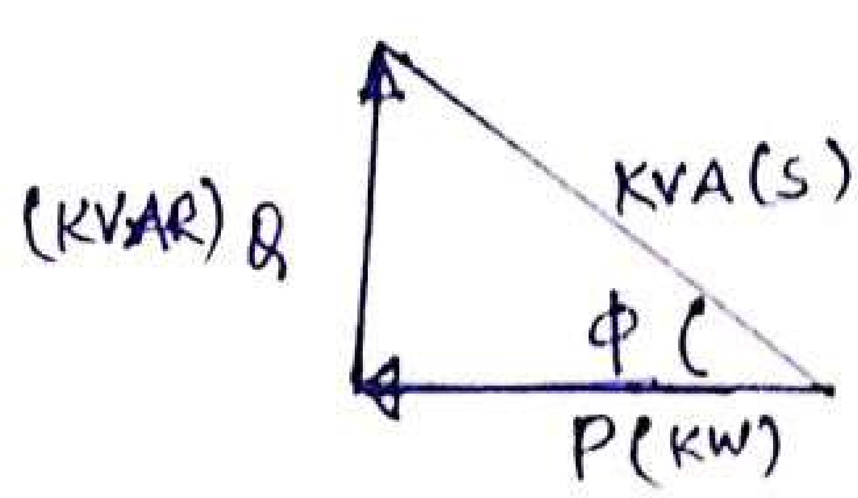

Fig. 1 (a)

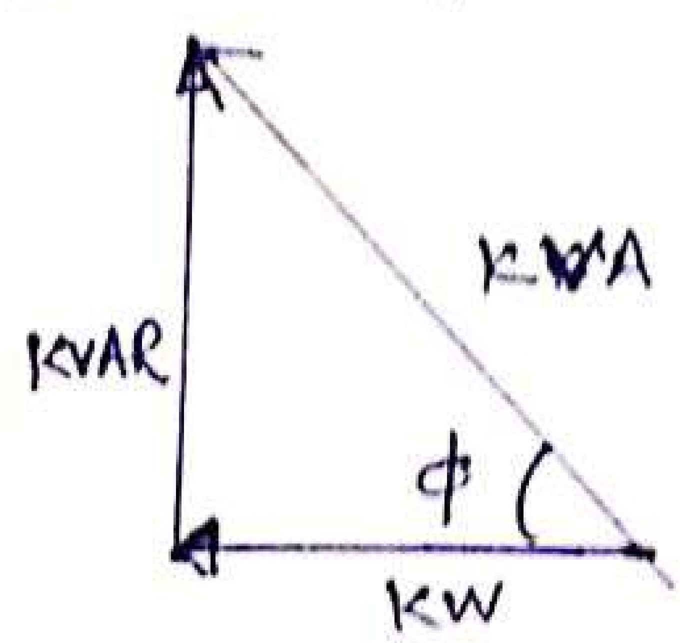

Fig. 1 (b)

So inductive loads with larger ~~KVAR~~ KVAr results in low power factor.

(c) Effect / Problems of Low Power Factor :-

$$P = VI\cos\phi$$

P ↓ fixed, V ↓ fixed

$$\Rightarrow I \propto \frac{1}{\cos\phi}$$

if $\cos\phi$ is low, Current will be higher

(I) Higher current produces larger voltage drop in cables and other apparatus. This results in poor voltage regulation.

(II) Higher current increases the i^2R (ohmic loss) which reduces the performance and efficiency of the electrical apparatus.

(III) Power factor below 1.0 requires a utility to generate more than the minimum volt-amperes necessary to supply the real power (watts). This increases generation and transmission cost.

(IV) If the load power factor were as low as 0.7 then, S Apparent power $S = \frac{P \text{ (active Power)}}{\cos\phi}$

$S = \frac{1}{0.7} \times P$

$S = 1.4$ times of P.

$\cos\phi_1 = 1$, $I_1 = I$		$I_2^2 = 1.96 \approx 2 \times I$
$\cos\phi_2 = 0.7$, $I_2 = ?$		
$I_2 = \frac{\cos\phi_1}{\cos\phi_2} \times I = \frac{1}{0.7} \times I = 1.4I$		
loss $\propto I^2$		

Hence Line current in the circuit would also 1.4 times the current required at unity power factor. So the losses in the circuit would be doubled ($1.96 \approx 2$) (losses $\propto I^2$) result in all components of the system such as generator, conductors, transformers and switchgear would be increased in size to carry the extra current.

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(e) Power factor Correction by Static Capacitor :-

"The process of increasing the power factor without altering the voltage or current to the original load is known as power factor correction."

In this method a capacitor is connected in parallel with load for power factor improvement.

Consider an inductive load consisting of Resistor (R) and inductor L connected to an ac supply. Current I_1 lags the voltage V by angle θ_1 so power factor is $\cos\theta_1$.

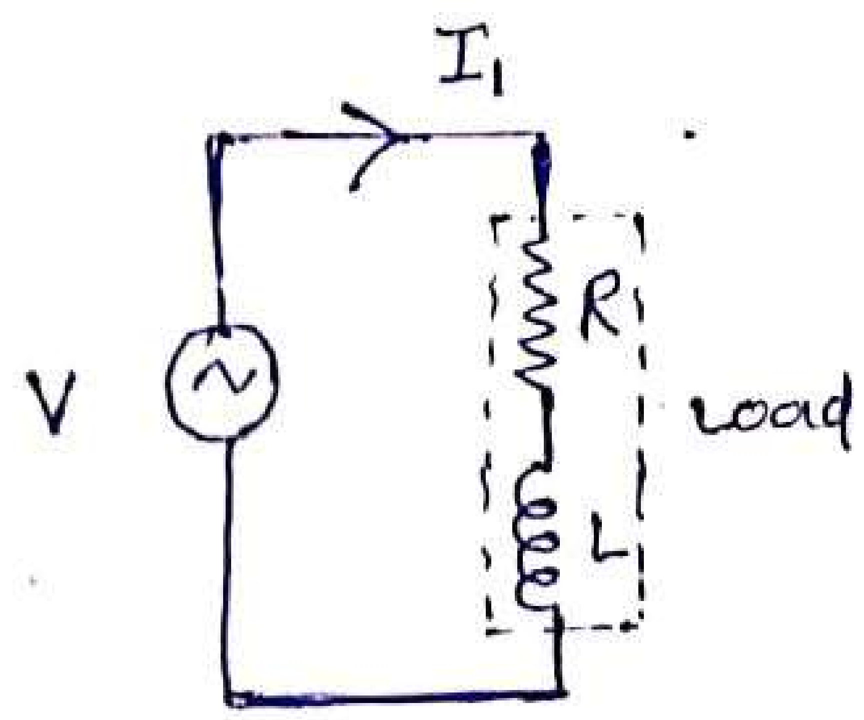

Fig. 1 (a)

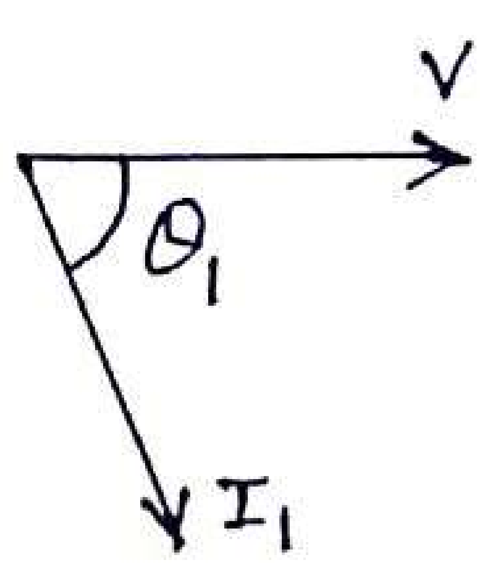

Fig. 1 (b) Phasor diagram

Let us now for improving the power factor connect a capacitor parallel to a load. This capacitor takes a leading current from the supply. The capacitor produces a reactive power in opposite direction hence reactive power decreases.

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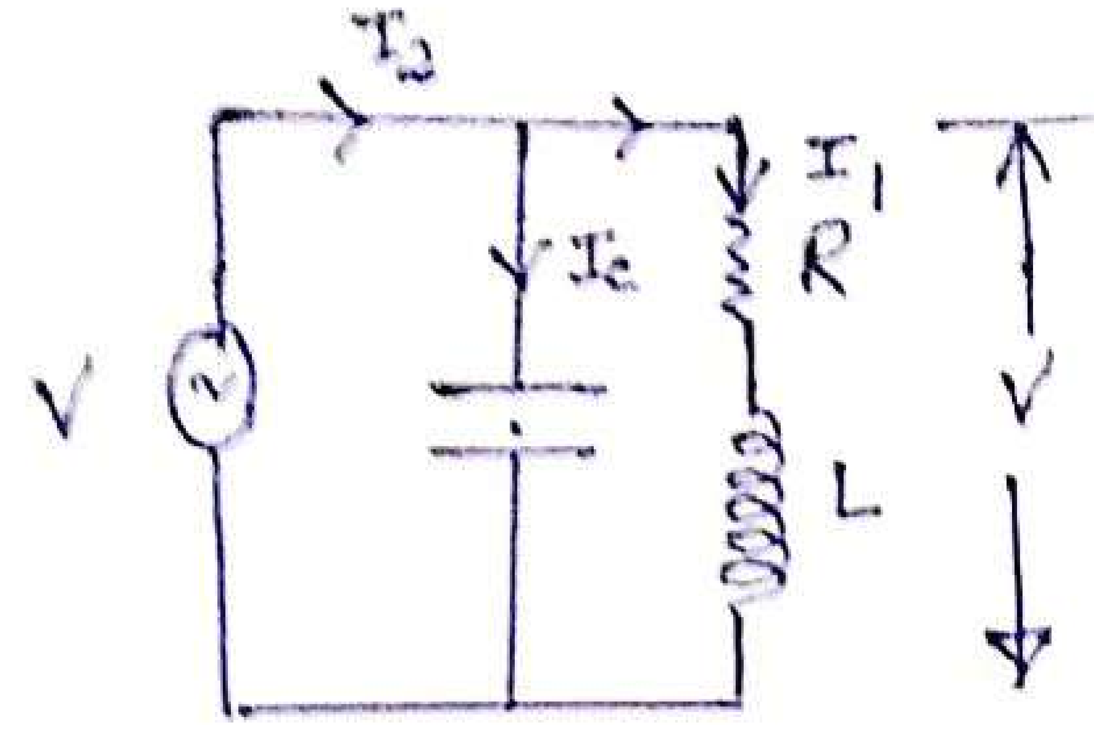

Fig. 2 (a)

$Q_1 = VI_1 \sin\theta_1$
$Q_2 = VI_2 \sin\theta_2$
$Q_c = Q_1 - Q_2$

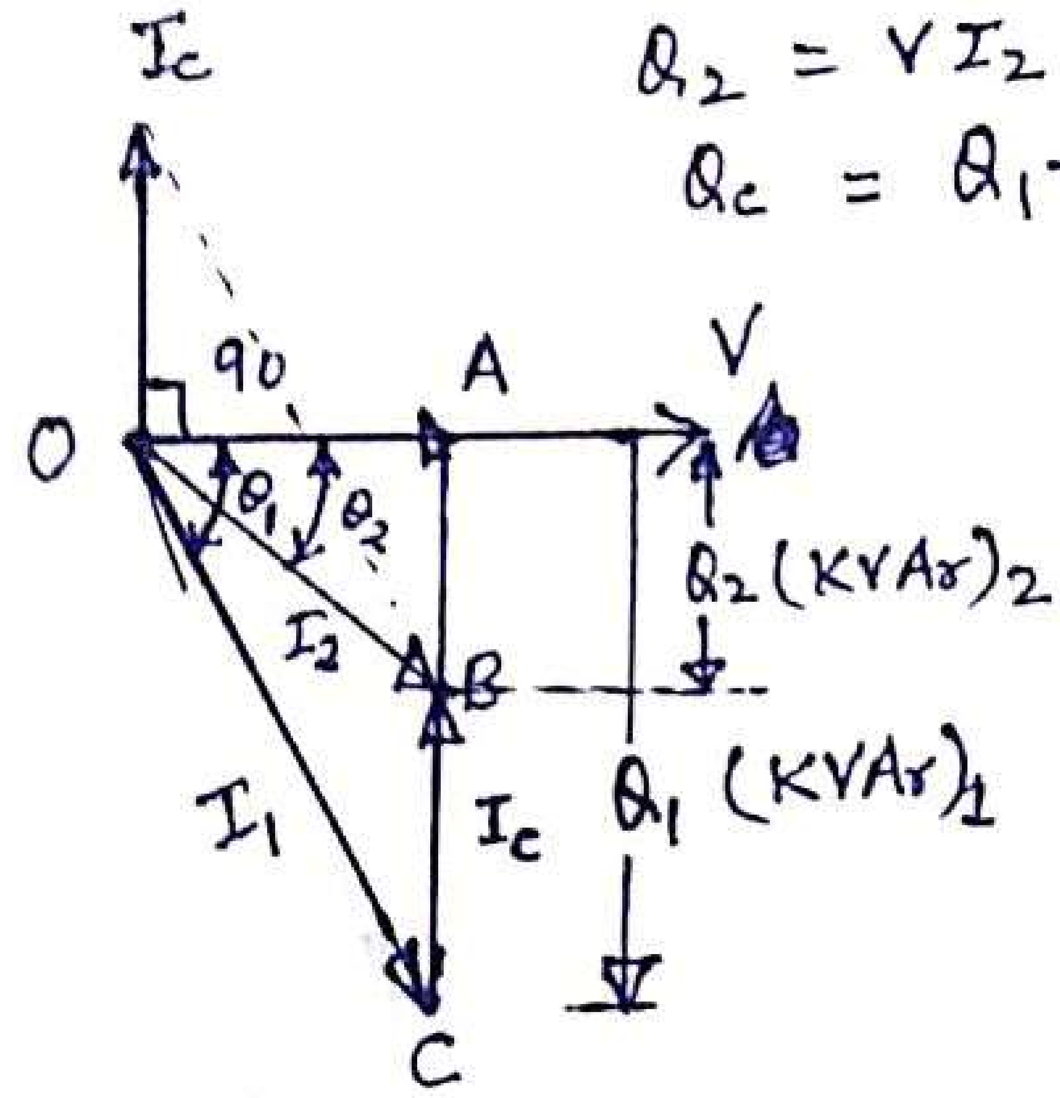

Fig. 2 (b) Phasor diagram

from Phasor diagram:–

Horizontal component of I_1 $= OA$
$= I_1 \cos\theta_1$

Horizontal component of I_2 $= OA$
$= I_2 \cos\theta_2$

both are equal

Hence $\boxed{I_1 \cos\theta_1 = I_2 \cos\theta_2}$ $\Rightarrow$ $I_2 = \dfrac{\cos\theta_1}{\cos\theta_2} I_1$

Since $\theta_2 > \theta_1$ so $\boxed{\cos\theta_2 > \cos\theta_1}$ $\Rightarrow$ $\boxed{I_2 < I_1}$

Hence, current drawn from the supply is less than the load current I_1, Hence if power factor reduces then apparent power (VI) from supply will also reduce.

$V I_2 \cos\phi_2 = V I_1 \cos\phi_1$ = Active power (P)

This shows that active or true power taken from supply has not altered.

<u>Calculation of value of Capacitor</u> :–

AC → vertical component of current $I_1 = I_1 \sin\theta_1$

AB → vertical component of current $I_2 = I_2 \sin\theta_2$

from phasor diagram – $BC = AC - AB$

$\boxed{I_c = I_1 \sin\theta_1 - I_2 \sin\theta_2}$

Reactive power supplied by capacitor $\boxed{Q_c = Q_1 - Q_2}$

$I_c = \dfrac{V}{X_c} = \dfrac{V}{1/\omega C} = V\omega C$

$V \cdot I_c = VI_1 \sin\theta_1 - VI_2 \sin\theta_2$

Hence $\boxed{Q_c = V \cdot I_c}$ KVAr

$\boxed{C = \dfrac{I_c}{V\omega} = \dfrac{I_c}{V \cdot 2\pi f}}$

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Problems on Power factor Correction

Q.1 ~~A Single~~ A Fluorescent lamp takes a current of 0.75 A when connected across a 240V, 50 Hz supply. The power consumed by the lamp is 80W. Calculate the values of the capacitance to be connected in parallel with the lamp to improve the power factor to (a) unity (b) 0.95 lagging.

(b) Ans - 7.457 μF

Sol. (a) $I_1 = 0.75\,A$, $V = 240V$, $P = 80\,Watt$

$$\cos\phi_1 = \frac{P}{V \cdot I_1} = \frac{80}{240 \times 0.75} = 0.444 \Rightarrow \sin\phi_1 = \sqrt{1-\cos^2\phi_1} = \sqrt{1-0.44^2} = 0.897$$

$$\therefore \phi_1 = \cos^{-1}(0.44) = 63.61^\circ$$

(a) $\cos\phi_2 = 1$, $\quad I_c = I_1 \sin\phi_1 - I_2 \sin\phi_2$

$\Rightarrow \sin\phi_2 = 0$

$\Rightarrow \phi_2 = 0^\circ$

$$I_2 \cos\phi_2 = I_1 \cos\phi_1$$

$$I_2 \times 1 = 0.75 \times 0.44$$

$$I_2 = 0.33\,A$$

$$I_c = 0.75 \times 0.897 - I_2 \times 0$$

$$I_c = 0.673\,A$$

$$C = \frac{I_c}{2\pi f \times V} = \frac{0.673}{2 \times \pi \times 50 \times 240} = 8.91\,\mu F$$

I_c can also be calculated by formula -

$$\boxed{I_c = I_1 \cos\phi_1 (\tan\phi_1 - \tan\phi_2)}$$

Q.2 A single phase 50 Hz motor takes 20 A at 0.75 power factor from a 230V sinusoidal supply. Calculate the KVAr and capacitance to be connected in parallel to raise the power factor to 0.9 lagging. What is new supply current.

→ Do it yourself

Ans - $C = 82.53\,\mu f$ $\quad$ $\boxed{I_2 = 16.67\,A}$

$Q_c = 1.3716\,KVAr$

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(d) Methods of Power factor Improvement :-

(1) Power factor correction can be done by supplying reactive power of opposite sign adding capacitors or inductors which act to cancel the inductive or capacitive effects of the load, respectively.
For example, the inductive effect of motor may be reduced by locally connected capacitors, sometimes when the power factor is leading due to capacitive loading, inductors are used to correct the power factor. [Static Capacitor used for correction]

(2) Minimizing operation of idling or lightly loaded motors because low power factor is caused by running induction motor lightly loaded.

(3) Avoiding operation of equipment above its rated voltage.

(4) Replacing standard motors as they burn out with energy-efficient motors.

(5) By using synchronous condenser. Synchronous condenser is a synchronous motor operated at ~~lo now l~~ no load with over excitation to it's field winding. Synchronous condenser acts as capacitor.

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