EEE363

Electrical Machines

Lecture # 17

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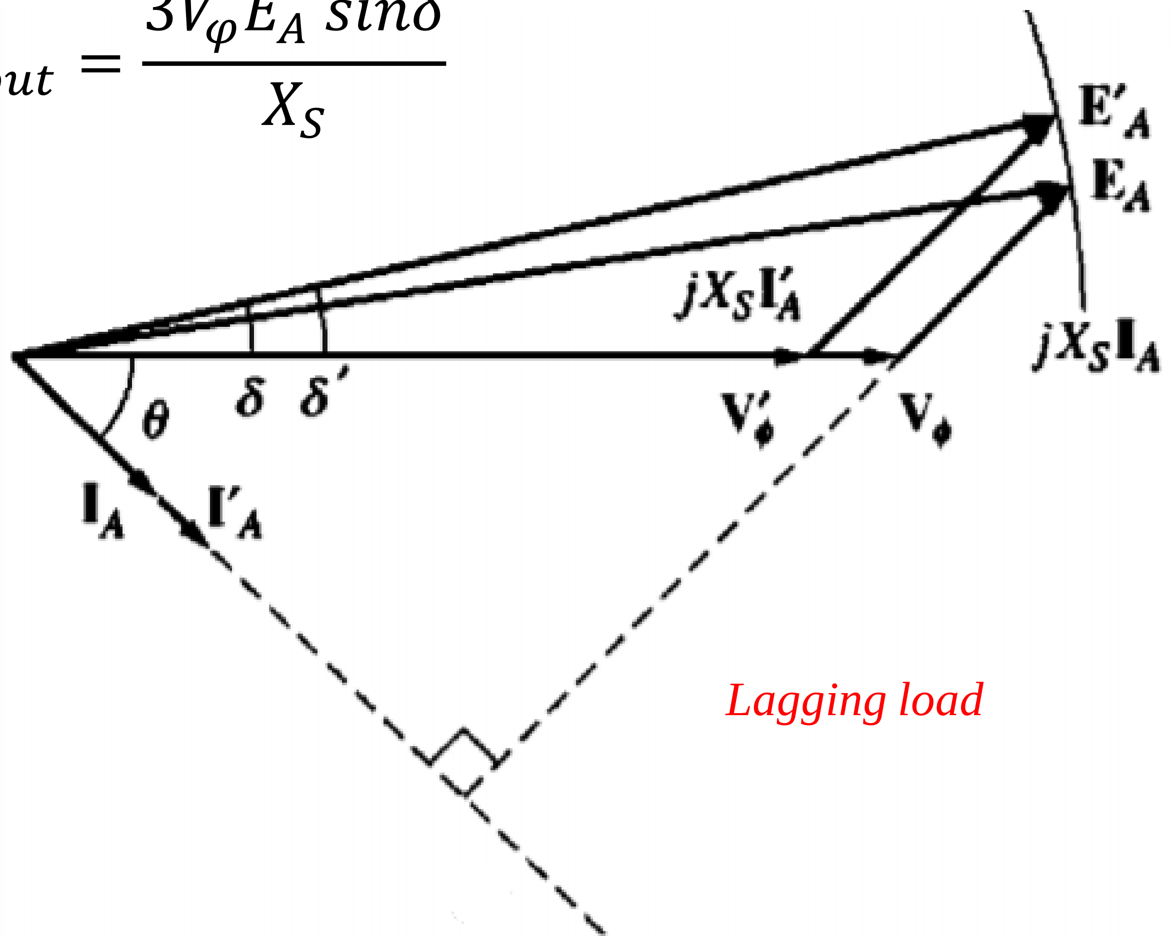
Effect of load change on Alternator

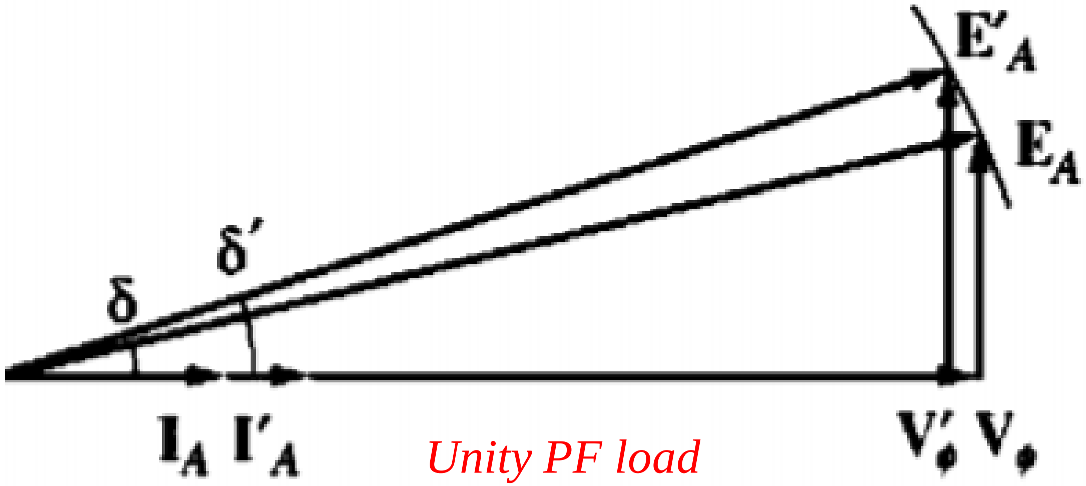
- ✓ An increase in the load is an increase in the real and/or reactive power drawn from the generator.
- ✓ Such a load increase increases the load current drawn from the generator.

$$P_{out} = \frac{3V_{\varphi}E_A\,sin\delta}{X_S}$$



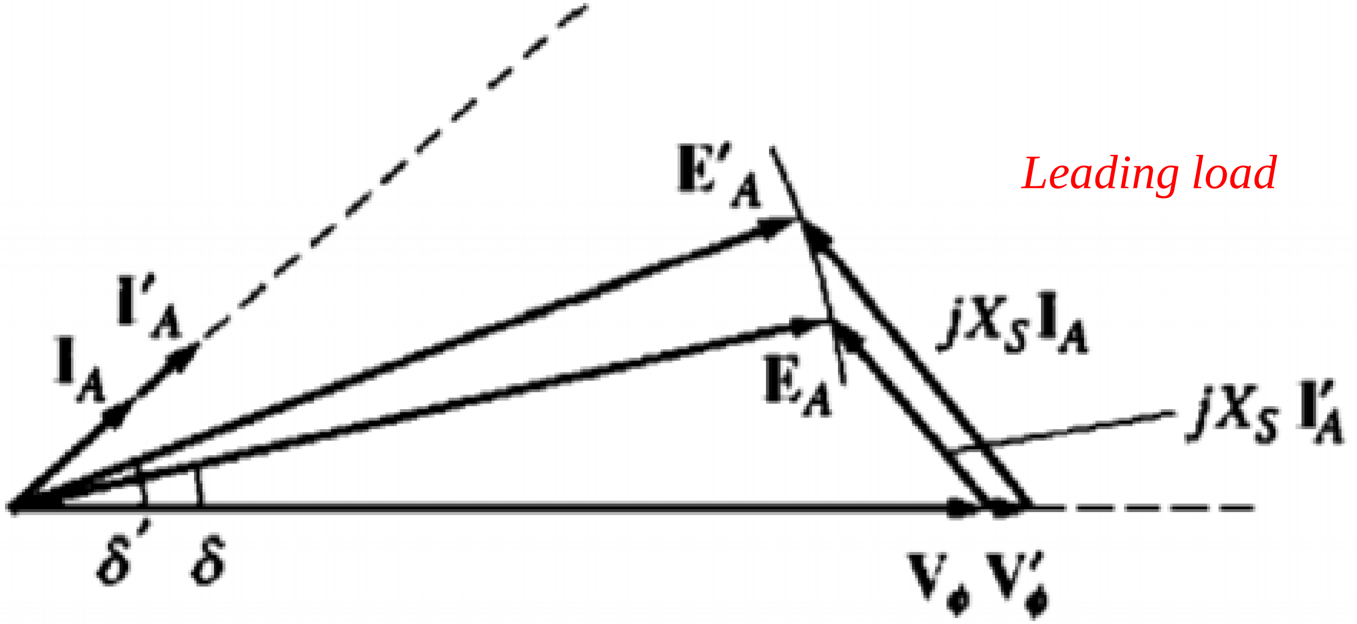
Lagging load

Effect of load change on Alternator



Unity PF load

Leading load



Problem # 1

A 480-V, 60Hz, Δ-connected, four-pole synchronous generator has the OCC shown in the fig. This generator has a synchronous reactance of 0.1 Ω and armature resistance of 0.015 Ω. At full load, the machine supplies 1200 A at 0.8 PF lagging. Under full-load conditions, the friction and windage losses are 40 kW. and the core losses are 30 kW. Ignore any field circuit losses.

(a) What is the speed of rotation of this generator?

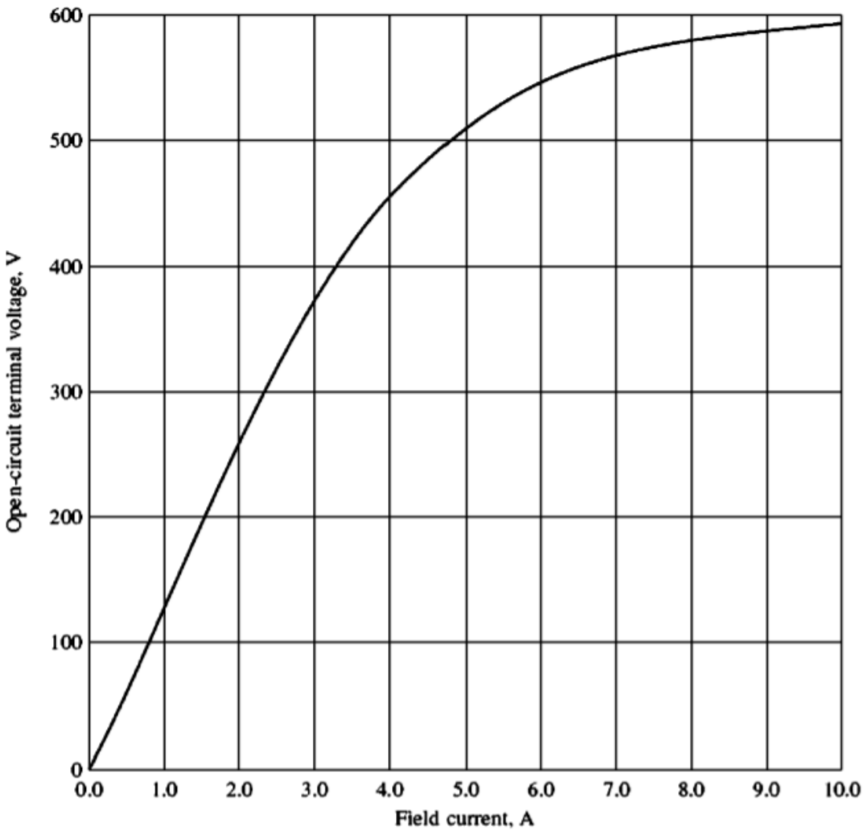
(b) How much field current must be supplied to the generator to make the terminal voltage 480 V at no load?

(c) If the generator is now connected to a load and the load draws 1200 A at 0.8 PF lagging, how much field current will be required to keep the terminal voltage equal to 480 V?

(d) How much power is the generator now supplying? How much power is supplied to the generator by the prime mover? What is this machine's overall efficiency?

(e) If the generator's load were suddenly disconnected from the line, what would happen to its terminal voltage?

(f) Finally, suppose that the generator is connected to a load drawing 1200 A at 0.8 PF *leading*. How much field current would be required to keep V_T at 480 V?



$V_{T.OC}$	200	300	400	450	480	515	545	580
I_f	1.5	2.3	3.3	4.0	4.5	5.0	6.0	8

← OCC data

Problem # 1 contd…

(a) $$n_m = \frac{120 f_e}{P} = \frac{120(60\text{ Hz})}{4\text{ poles}} = 1800\text{ r/min}$$

(b) In this machine, $V_T = V_\phi$. Since the generator is at no load, $\mathbf{I}_A = 0$ and $\mathbf{E}_A = \mathbf{V}_\phi$. Therefore, $V_T = V_\phi = E_A = 480$ V, and from the open-circuit characteristic, $I_F = 4.5$ A.

(c) If the generator is supplying 1200 A. then the armature current in the machine is

$$I_A = \frac{1200\text{ A}}{\sqrt{3}} = 692.8\text{ A}$$

Regulation?

$$\begin{aligned}
\mathbf{E}_A &= \mathbf{V}_\phi + R_A\mathbf{I}_A + jX_S\mathbf{I}_A \\
&= 480\angle 0^\circ\text{ V} + (0.015\ \Omega)(692.8\angle -36.87^\circ\text{ A}) + (j0.1\ \Omega)(692.8\angle -36.87^\circ\text{ A}) \\
&= 480\angle 0^\circ\text{ V} + 10.39\angle -36.87^\circ\text{ V} + 69.28\angle 53.13^\circ\text{ V} \\
&= 529.9 + j49.2\text{ V} \\
&= 532\angle 5.3^\circ\text{ V}
\end{aligned}$$

The required field current is 5.6 A (from the OCC curve).

Problem # 1 contd...

(d)

$$P_{out} = \sqrt{3}V_T I_L \cos\theta \quad = \sqrt{3}(480\text{ V})(1200\text{ A})\cos 36.87° = 798\text{ kW}$$

$$P_{in} = P_{out} + P_{elec\ loss} + P_{core\ loss} + P_{mech\ loss} + P_{stray\ loss}$$

$$P_{elec\ loss} = 3I_A^2 R_A \quad = 3(692.8\text{ A})^2(0.015\ \Omega) \quad = 21.6\text{ kW}$$

$$P_{in} = 798\text{ kW} + 21.6\text{ kW} + 30\text{ kW} + 40\text{ kW} = \quad 889.6\text{ kW}$$

$$\eta = \frac{P_{out}}{P_{in}} \times 100\% \quad = \frac{798\text{ kW}}{889.6\text{ kW}} \times 100\% \quad = \quad 89.75\%$$

(e) If the generator's load were suddenly disconnected from the line, the current $\mathbf{I}_A$ would drop to zero, making $\mathbf{E}_A = \mathbf{V}_\phi$. Since the field current has not changed, $|\mathbf{E}_A|$ has not changed and $\mathbf{V}_\phi$ and V_T must rise to equal $\mathbf{E}_A$. Therefore, if the load were suddenly dropped, the terminal voltage of the generator would rise to 532 V.

Problem # 1 contd…

(f) If the generator were loaded down with 1200 A at 0.8 PF leading while the terminal voltage was 480 V, then the internal generated voltage would have to be

$$\mathbf{E}_A = \mathbf{V}_\phi + R_A\mathbf{I}_A + jX_S\mathbf{I}_A$$

$$= 480\angle 0° \text{ V} + (0.015\ \Omega)(692.8\angle 36.87° \text{ A}) + (j0.1\ \Omega)(692.8\angle 36.87° \text{ A})$$

$$= 480\angle 0° \text{ V} + 10.39\angle 36.87° \text{ V} + 69.28\angle 126.87° \text{ V}$$

$$= 446.7 + j61.7 \text{ V}$$

$$= 451\angle 7.1° \text{ V}$$

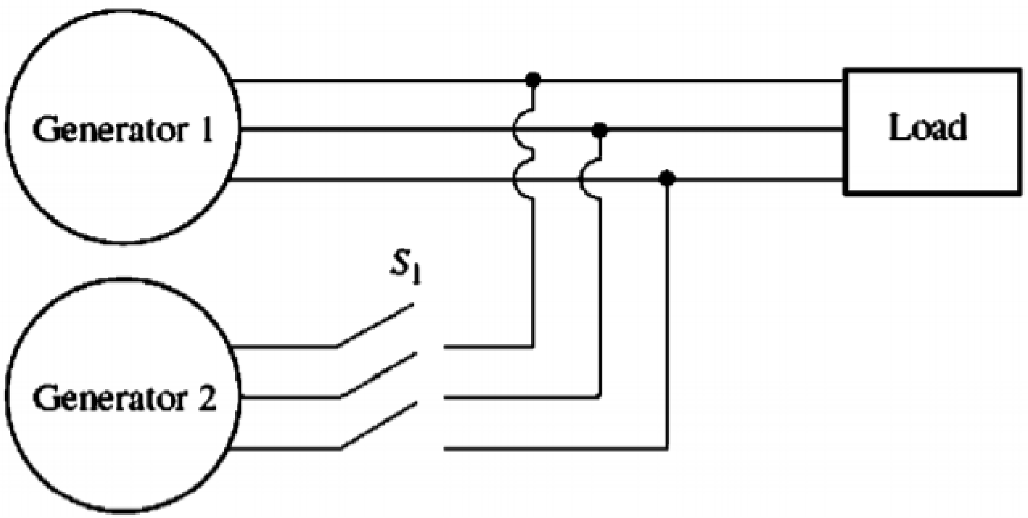
Required field current is 4.1 A (OCC)

(g) Also calculate P_{conv} , τ_{ind} and τ_{app}

Parallel operation of Alternator

Why are synchronous generators operated in parallel?

- ✓ Several generators can supply a bigger load than one machine by itself.
- ✓ Having many generators increases the reliability of the power system, since the failure of anyone of them does not cause a total power loss to the load.
- ✓ Having many generators operating in parallel allows one or more of them to be removed for shutdown and preventive maintenance .



Condition for synchronisation/paralleling

1. The rms line voltages of the two generators must be equal.

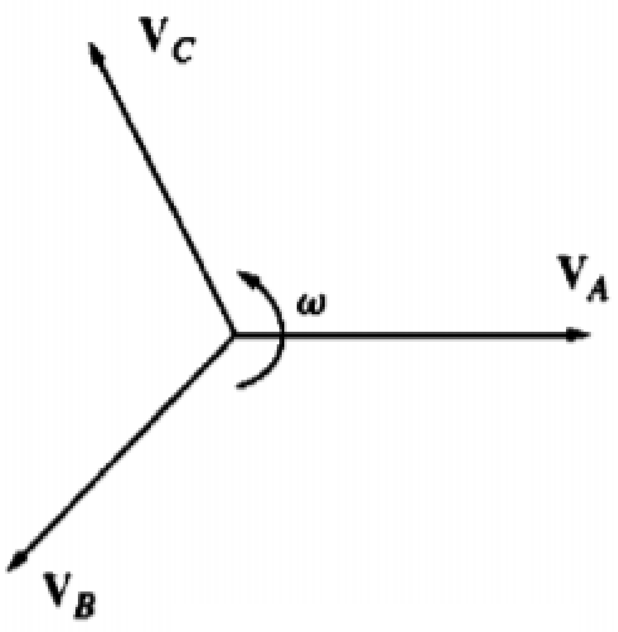
2. The two generators must have the same phase sequence.

3. The phase angles of the two ‘a’ phases must be equal.

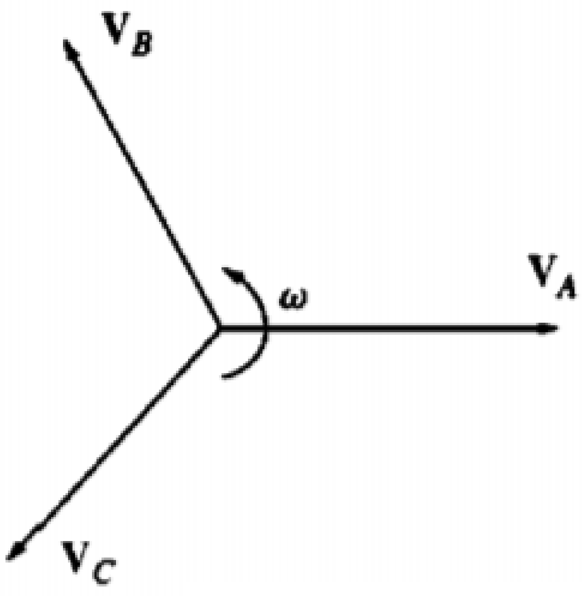
4. The frequency of the new generator must be slightly higher than the frequency of the running system.

Same phase sequence

This ensures that the sequence in which the phase voltages peak in the two generators is the same.

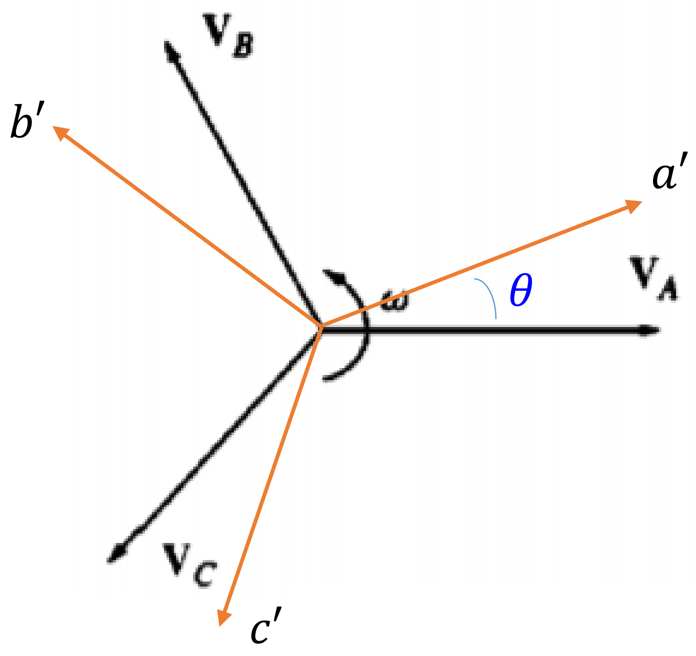


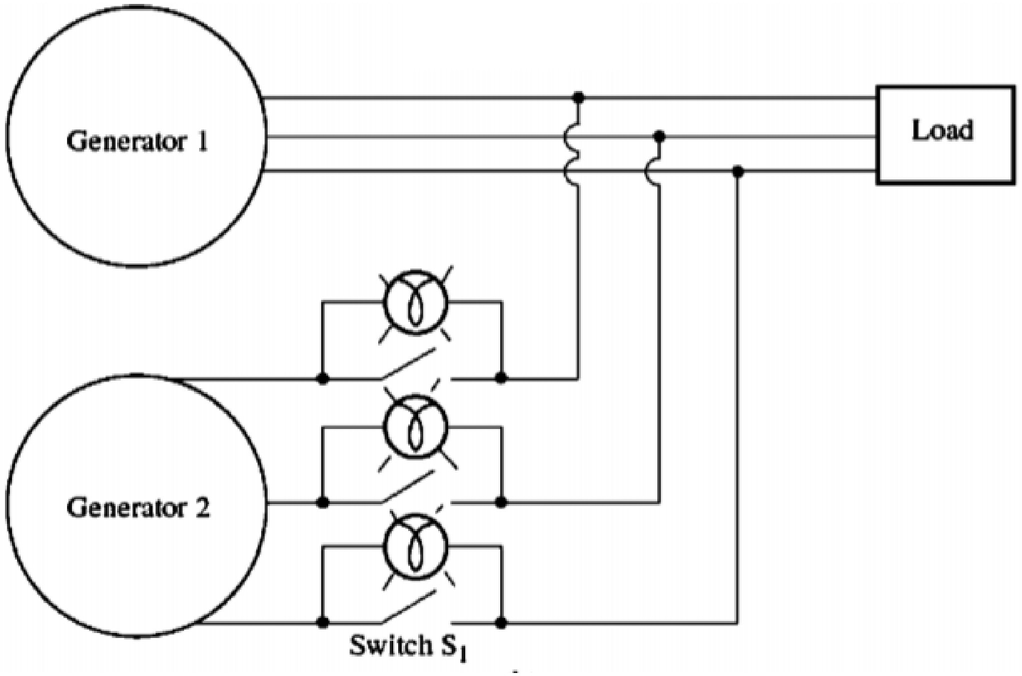
abc sequence



acb sequence

Phase sequence/angle

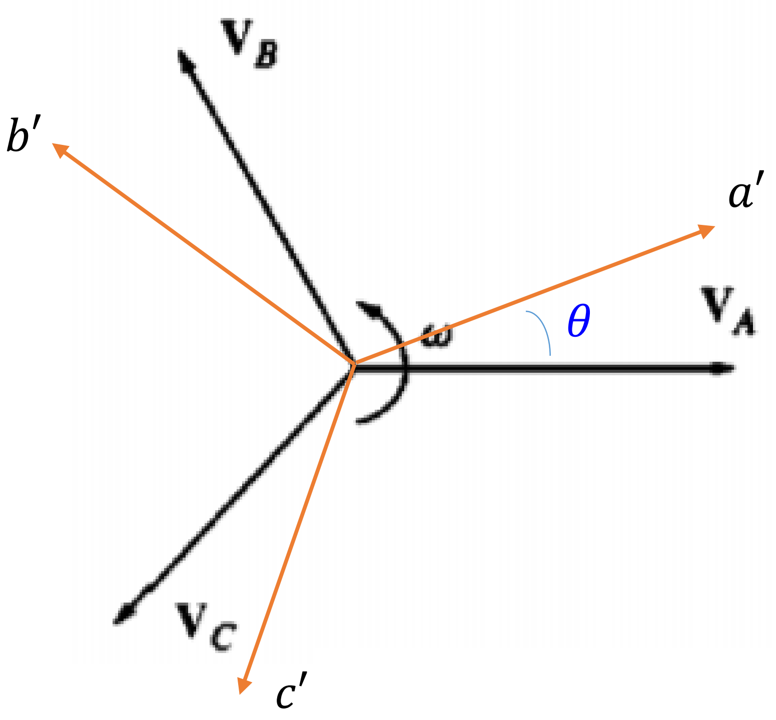




How can one tell when the two systems are finally in phase?

Synchroscope

A synchroscope is a meter that measures the difference in phase angle between the 'a' phases of the two systems.

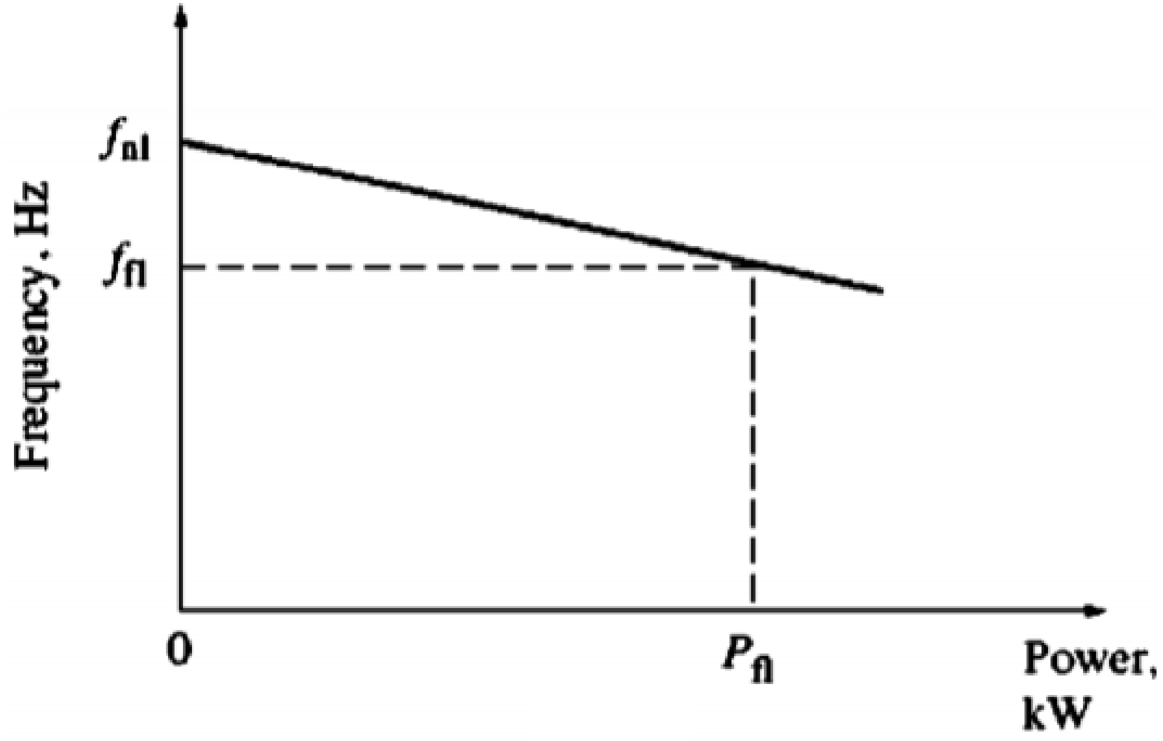


a synchroscope checks the relationships on only one phase. It gives no information about phase sequence.

Frequency-Power characteristics

As the power drawn from the alternator increases, the frequency of the system decreases.

The decrease in speed is in general nonlinear, but some form of governor mechanism is usually included to make the decrease in speed linear with an increase in power demand.



$$P = S_P\,(f_{nl} - f_{sys})$$

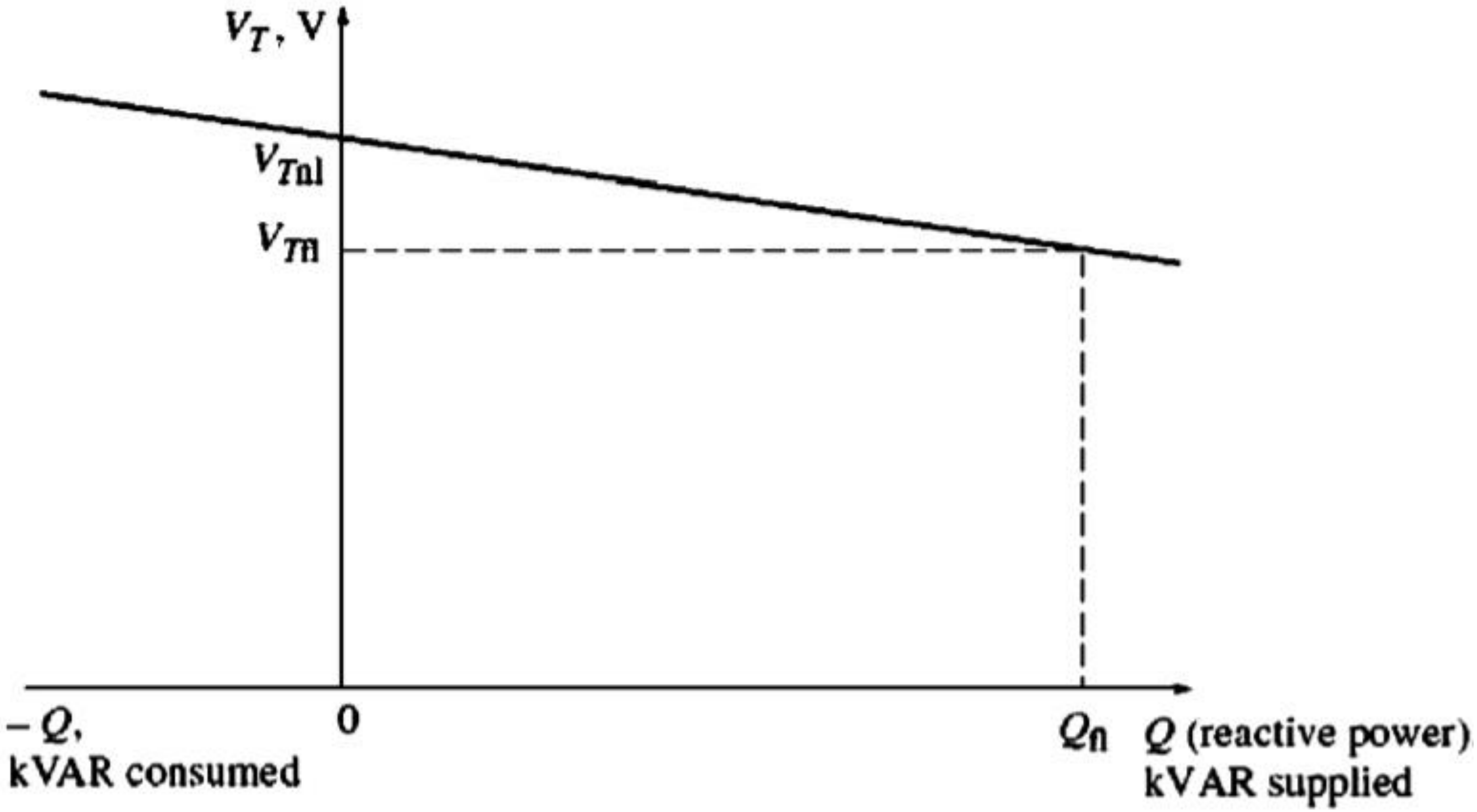
P = power output of the generator

f_{nl} = no-load frequency of the generator

f_{sys} = operating frequency of system

s_P = slope of curve, in kW/Hz or MW/Hz

Voltage-Reactive power characteristics

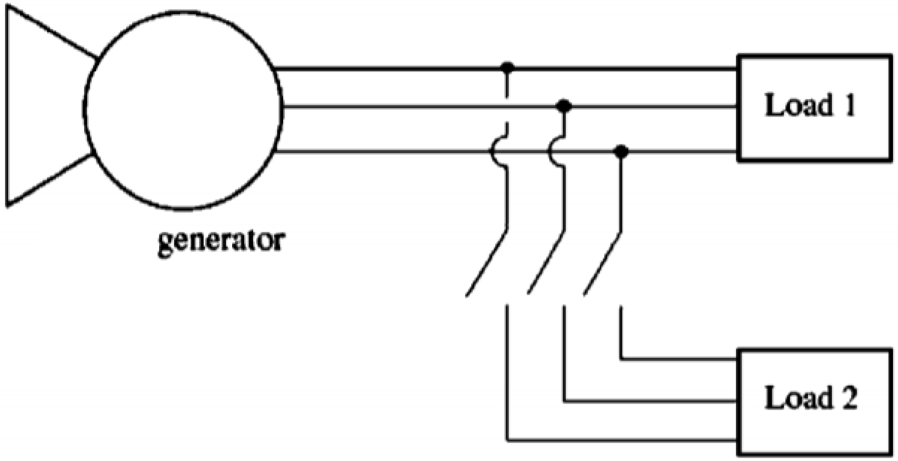


When a lagging load is added to a synchronous generator, its terminal voltage drops. Likewise, when a leading load is added to a synchronous generator, its terminal voltage increases.

Problem # 2

Figure below shows a generator supplying a load. A second load is to be connected in parallel with the first one. The generator has a no-load frequency of 61.0 Hz and a slope s_p of 1 MW/Hz. Load 1 consumes a real power of 1000 kW at 0.8 PF lagging. while load 2 consumes a real power of 800 kW at 0.707 PF lagging.

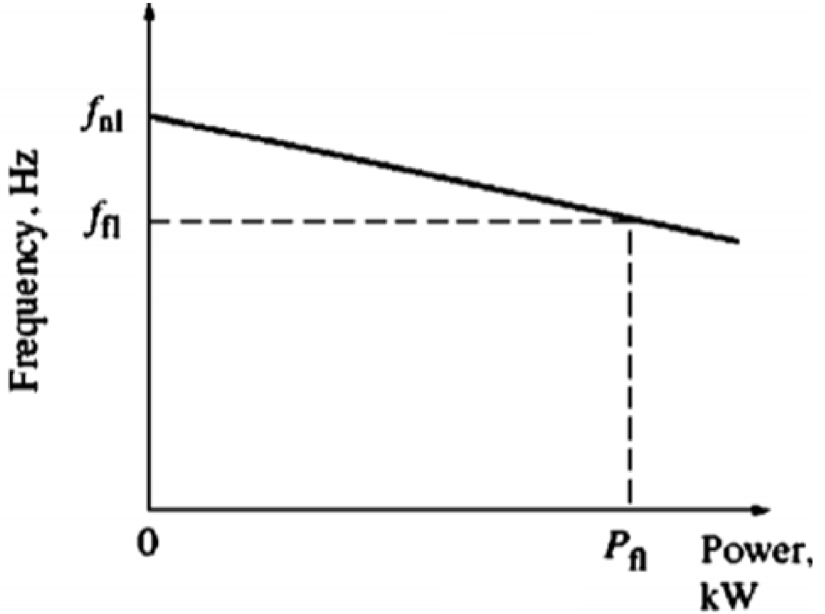
a) Before the switch is closed. what is the operating frequency of the system?
b) After load 2 is connected. what is the operating frequency of the system?
c) After load 2 is connected. what action could an operator take to restore the system frequency to 60 Hz?



(a) $P = S_P\,(f_{nl} - f_{sys})$

$$f_{sys} = f_{nl} - \frac{P}{S_P} = 61\text{ Hz} - \frac{1000\text{ kW}}{1\text{ MW/Hz}} = 61\text{ Hz} - 1\text{ Hz}$$

$= 60\text{ Hz}$



Problem # 2 contd…

(b) After load 2 is connected,

$$f_{sys} = f_{nl} - \frac{P}{S_P} = 61\ \text{Hz} - \frac{1800\ \text{kW}}{1\ \text{MW/Hz}} = 61\ \text{Hz} - 1.8\ \text{Hz} = 59.2\ \text{Hz}$$

(c) After the load is connected, the system frequency falls to 59.2 Hz. To restore the system to its proper operating frequency, the operator should increase the governor no-load set points by 0.8 Hz, to 61.8 Hz. This action will restore the system frequency to 60 Hz.