Electrical Machines Laboratory
Department of Electrical Engineering
Indian Institute of Technology, Bombay

Experiment-6

Name of the experiment: Synchronization of the alternator with the grid.

Objective:

1. To study the synchronization of alternator with the grid by 3 lamp dark method.
2. To study the control of real and reactive power delivered by an alternator.

Theory:

Synchronous alternator

In a synchronous generator, a DC current is applied to the rotor winding producing a rotor magnetic field. The rotor is then turned by external means producing a rotating magnetic field, which induces a 3-phase voltage within the stator winding.The rotor of a synchronous machine is a large electromagnet. The magnetic poles can be either salient (sticking out of rotor surface) or non salient construction.Rotors are made laminated to reduce eddy current losses.By the definition, synchronous generators produce electricity whose frequency is synchronized with the mechanical rotational speed.

$$f = \frac{PN}{120}$$

f-frequency of induced emf
P-no of poles of the machines
N- speed of the rotor

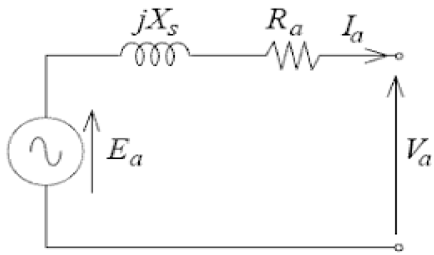
Per phase equivalent circuit of a synchronous generator

The internally generated voltage in a single phase of a synchronous machine Ea is not usually the voltage appearing at its terminals. It equals the output voltage V only when there is no armature current in the machine. The reasons that the armature voltage E is not equal to the output voltage V are:

1. Distortion of the air-gap magnetic field caused by the current flowing in the stator (armature reaction).
2. Self-inductance of the armature coils.
3. Resistance of the armature coils.

Xs- **Synchronous reactance**, Ea-**excitation emf**, Va-**generator terminal voltage**, Ra-**armature resistance** Xa **is the armature reaction reactance**, Xl **is the leakage reactance**.

*All the above quantities are taken in per-phase.



Per-phase equivalent circuit of wound rotor alternator

Xs=Xa+Xl
Ea=Va +Ia*(Ra+jXs)

Synchronization

The process of connecting two alternators or an alternator and an infinite bus bar system in parallel is known as synchronization. At the moment of closing the circuit breaker (closing the 3-pole single throw switch to connect the alternator to the grid in this experiment), the voltages across the three phases of the breaker are as close to zero as possible and remain so after the switch is closed. To ensure that, the following conditions must be met:

1. The generated rms voltage must be equal to the grid rms voltage.
2. The frequency of the generated voltage must be equal to that of the grid.
3. The phase sequence of the generated voltage must be the same as that of the grid.
4. The phase angle of the generated voltages must be equal to that of grid lines.

Departure from the above conditions will result in large circulating current flowing through the alternator

With constant load on the synchronous alternator(Transfering a particular value of real power to the grid), the variation of field current changes the armature current drawn by the motor and also its operating power factor. As such, the behavior of the synchronous alternator is described below under three different modes of field excitation.

1. Normal excitation:

The armature current is minimum at a particular value of field current,which is called the normal field excitation. The operating power factor of the alternator is unity at this excitation .

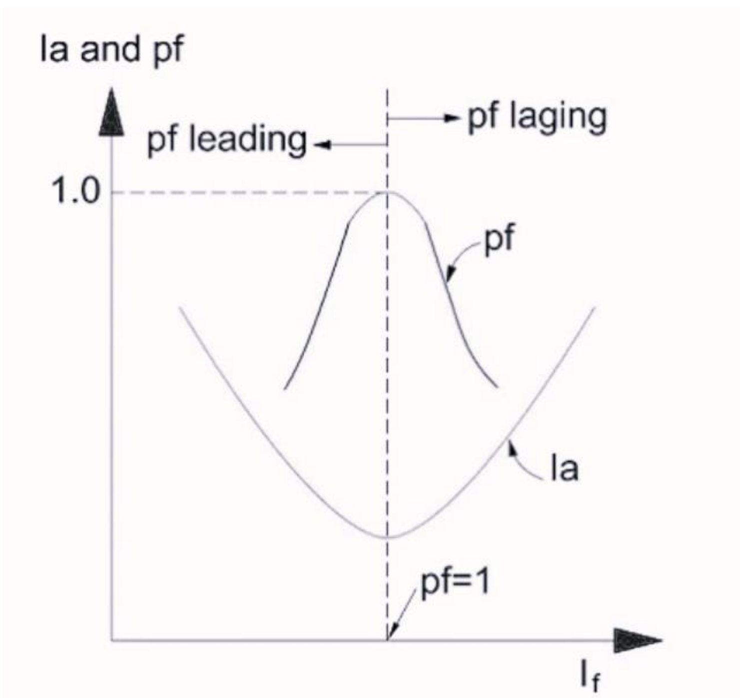
2. Under excitation:

When the field current is decreased gradually below the normal excitation,the armature current increases and the operating power factor of the alternator decreases. The power factor under this condition is leading. Thus, the synchronous alternator delivers leading current, when it is under excited.

3. Over Excitation:

When the field current is increased gradually beyond the normal excitation, the armature current again increases and the operating power factor decreases.However, the power factor is lagging under this condition which means the alternator is delivering the reactive power.

If the above variation of field current and the corresponding armature current are plotted for a constant load, a curve of the shape of 'V' is obtained as shown in fig. Such a characteristic of a synchronous alternator is commonly called the 'V' curve. The characteristic curve plotted between input power factor and the field current for a constant load on the alternator are of the shape of inverted 'V' and are known as inverted 'V' curves.



Ia- Armature current of alternator
If-field current of alternator

<u>Active power control</u>

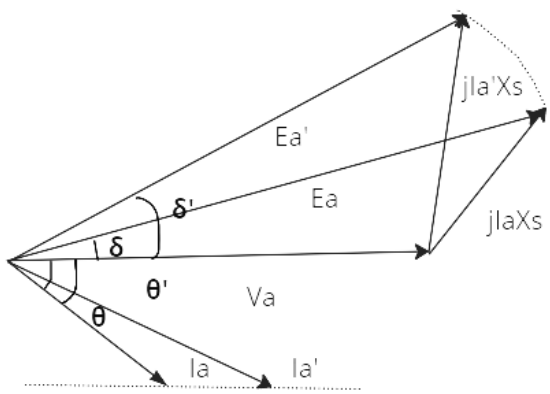
Synchronous machine is connected to the grid. There is no change in excitation of the synchronous machine.The mechanical power input to the machine is varied by varying the torque of the dc motor that is mechanically coupled to the alternator. The effect of change in shaft input is governed by the following eq.

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

As the shaft input is varied E and V remains constant and P changes so δ changes. Also

$$P = V * Ia * \quad cos\delta$$

so as P changes, θ and $Ia * cos\theta$ changes but $Ia * sin\theta$ remains constant since reactive power does not change; this is indicated using the dotted line adjoint to the current phasor.

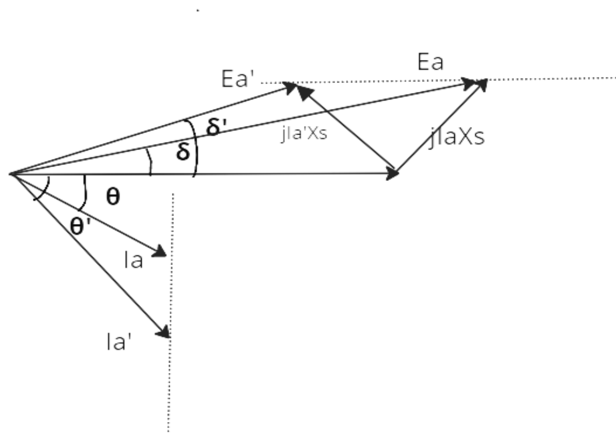


Reactive power control

To vary the reactive power supplied by the synchronous alternator, the dc excitation of the alternator is varied keeping the shaft input constant.The effect of change in excitation is shown using the phasor diagram given below.

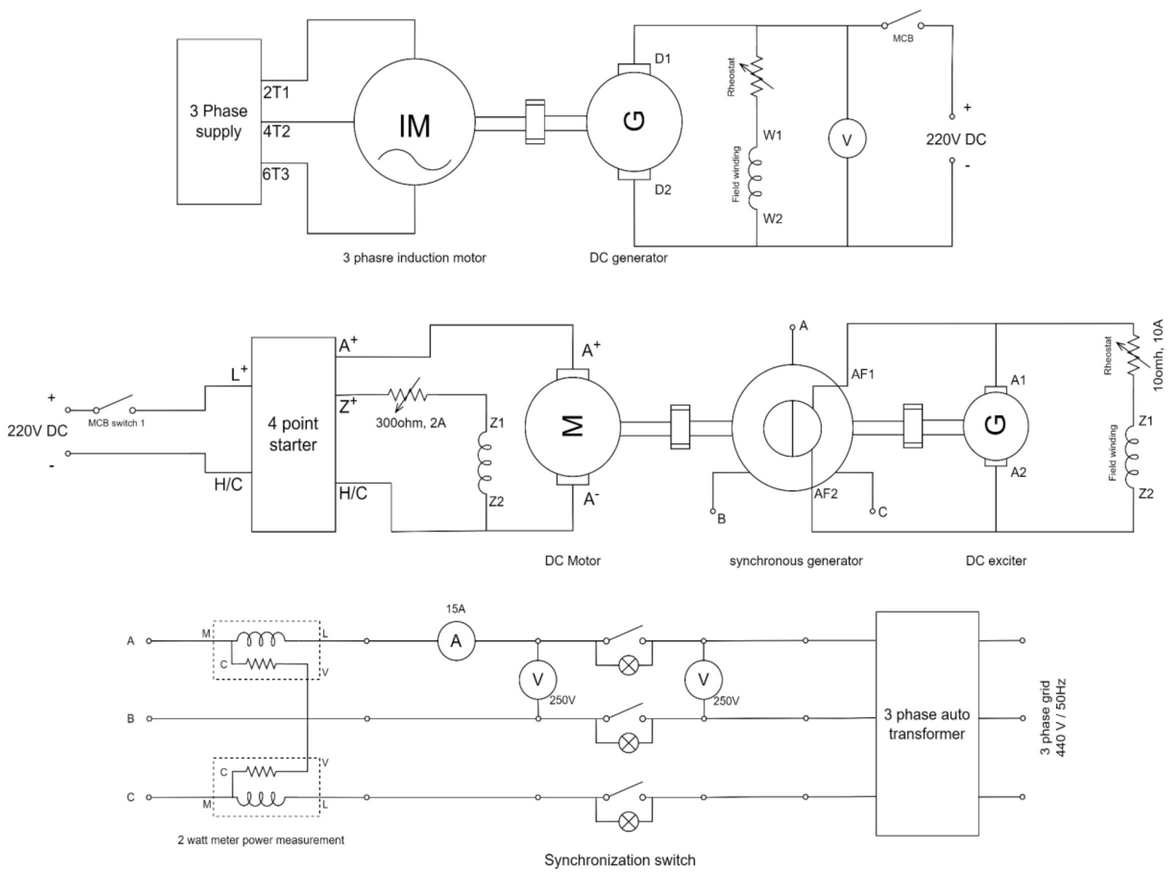
$$P = \frac{EV\ sin\delta}{X}$$

Here the shaft input to the alternator is kept constant hence the active power output P must be constant. Here excitation emf E is varied hence Esin(δ) must be kept constant,which is indicated by the dotted lines above phasor E in the phasor diagram. Active power is also equal to V* $Ia * cos\theta$,since active power input is kept constant the $Ia * cos\theta$ is also constant which is indicated by the dotted line adjoining the current phasor.



θ is the power factor angle(angle between V and Ia)
δ is the torque angle(angle between V and E)
Ia is the per phase armature current
Ea is the excitation emf
V is the terminal voltage of the alternator

Connection diagram



***This connection diagram is as per the setup existing in the Electrical Machines lab.**

Procedure: Do the connections as per the above connection diagram.

1. First turn on the 3-phase induction motor by turning on the 3-phase DOL starter and adjust the field supply of the DC generator to make the DC bus voltage 220VDC.
1. Switch on the MCB (switch 1) to carry forward the DC supply to 4 point starter.
2. Now, slowly and gradually start the DC motor using a 4 point starter.
3. By adjusting the field supply rheostat of the DC motor, We can adjust the input power of the prime mover of the synchronous alternator.
4. Turn on the 3-phase grid supply. And adjust the autotransformer such that the 230V can appear at the voltmeter connected between the output terminal of the autotransformer.
5. To make the voltage equal across the synchronization switch, adjust the field supply of the DC exciter by varying the rheostat.
6. To make the generated voltage and frequency the same as the grid frequency,the speed of the alternator is varied by adjusting the field supply of the DC motor by varying the respective rheostat.
7. Now, observe the glowing & dimming of bulbs. Close the synchronization switch when all the bulbs get dark.
8. After synchronization, by varying the DC motor field/ armature voltage of the dc machine the prime mover power can be changed and measured by the use of wattmeters connected to the output of the alternator.
9. The field excitation of a synchronous alternator can be varied to vary the reactive power delivered by the alternator.

NOTE: These steps are followed in the setup existing at Electrical machines lab, for the setup existing in Power Systems lab steps from step number 2 has to be followed with a modification in step 2.
Modification: There is no 4 point starter in the power systems lab, The DC machine has to be used as a prime mover.

Results:

1. Synchronization of the alternator with the grid.
2. Plot the armature current vs field current of alternator (V CURVE)
3. Plot the power factor vs field current of alternator (INVERTED V CURVE)

Prelab Activity:

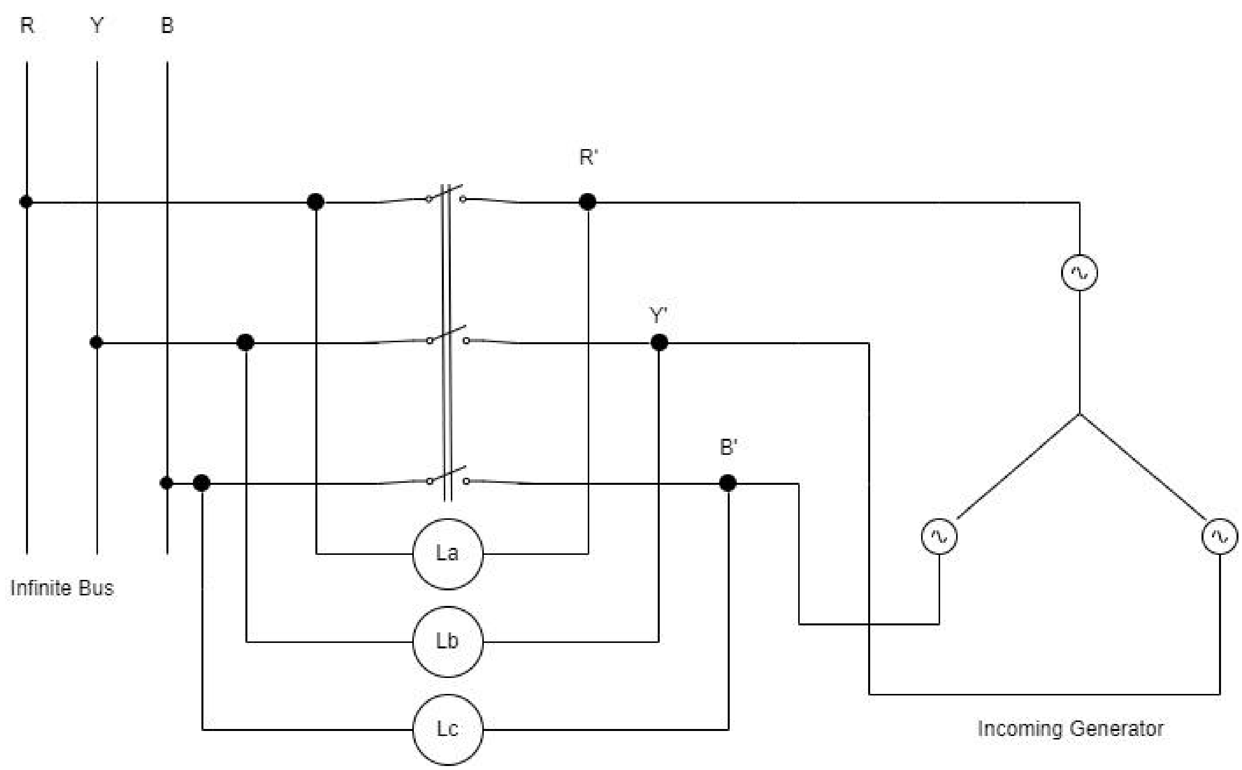
1. **Write in brief the precautions to be followed while synchronizing the alternator with the grid.**
2. **Draw the schematic showing connection between the grid and alternator with appropriate symbols of switches, alternator.**
3. **Explanation of active power control and reactive power control with formulas and necessary phasors.**

Post lab Activity: (Please write answers in brief)

1. **Plot V-curve and inverted V-curve and identify the region of the curve where alternator is delivering and consuming reactive power also mention the nature of excitation in the respective regions.**
2. **During synchronization you found that bulbs are not dimming and glowing simultaneously(All doesnt become dark together and bright together), what does that mean? Can you close the synchronization switch at this time? If not, write the steps which need to be taken to ensure proper synchronization.**
3. **A three phase synchronous generator is to be connected to the infinite bus. The lamps are connected as shown in the figure for the synchronization. The phase sequence of bus voltage is R-Y-B and that of incoming generator voltage is R'-Y'-B'. It was found that the lamps are becoming dark in the sequence La-Lb-Lc.**

Is the phase sequence of the alternator and the grid same? If not then which of them is having high frequency?

Justify your answer.



Questions:

1. Explain the effect of change of excitation of a synchronous generator on its power factor.
2. Explain the effect of change of excitation of a synchronous generator on its armature current.
3. With the given excitation a synchronous alternator delivers at a unity PF .If the load is increased , what will be the power factor and current for the same excitation?
4. Why does the V curve shift upwards and the inverted V curve shift right as the load increases.
5. Explain the effect of change of excitation of a synchronous generator on its armature current.
6**.**What did your TA change to ensure the complete dimming of bulbs ? Explain why it was necessary?
7.What did your TA control for matching the alternator frequency with the grid frequency and how can it be ensured without the use of any frequency meter?