Electrical and Computer Engineering Department
ECCE322 – Electric Machines Lab
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Design of Experiment: Synchronization of Synchronous Generator to Grid

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Lab Components	Grade
Introduction (35%)	
Procedure (25%)	
Results & Discussion (35%)	
Neatness (5%)	
TOTAL GRADE (100%)	

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"As a Khalifa University student, I will not lie, cheat, steal, or use any unfair means in academic work and will behave according to university rules and UAE societal norms and expectations."

DON'T switch on until the instructor check your connection

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Objective:

- Design an Experiment to synchronize the synchronous generator to grid.

Introduction/ Theoretical Background:

Synchronous generators are usually operated in parallel to supply the power demanded by the load.

Pre- lab Question 1:

Why are generators operated in parallel?

(1) Paralleling generators allow for supplying power to bigger loads.

(2) Paralleled generator systems are more reliable than synchronous generators operating independently, where the failure of any of the paralleled generators does not result in total power loss to the load.

(3) Paralleling generators allows one or more to be removed for shutdown and preventive maintenance.

(4) If only one generator is used to supply power to the load, and is not operating at near full load conditions, it is relatively inefficiently. However, if many generators are paralleled, then only a fraction of the generators can be operated at near full load conditions and are hence more relatively efficient.

The Conditions Required for Paralleling

Before paralleling two generators as shown in figure 1, a set of conditions must be met to avoid damaging the generators or losing power to the load. Those conditions are listed below.

(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 angle of the two phases must be equal.

(4) The frequency of the new generator, called the oncoming generator, must be slightly higher than the frequency of the running system.

Conditions (1), and (3) regarding voltage magnitude and phase ensures that the voltages in all phases of G_1 are exactly equal to that of G_2 at all times. Condition (2) ensures that the sequence in which the phase voltages peak in the two generators is the same; otherwise, a large current would flow, damaging the generators. If Condition (4) is not met, then large power transients would be produced until both generators stabilize at a common frequency. However, the two generators' frequency cannot be exactly equal; they must differ by a small amount to avoid having the oncoming generator operating as a motor thus consuming power rather than supplying power.

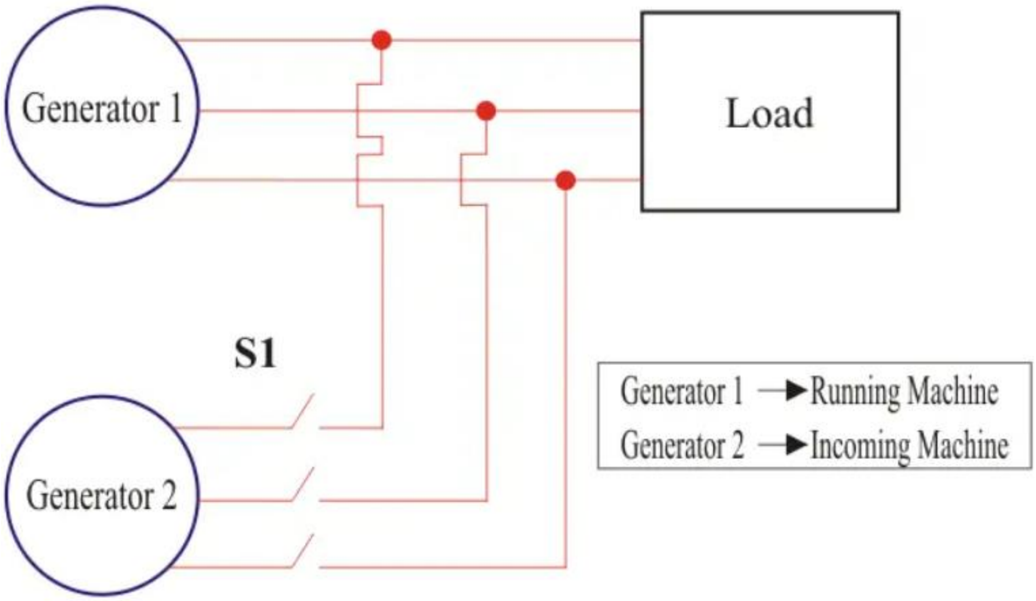

Figure 1. The connections of paralleling two generators supplying a load.

The General Procedure for Paralleling Generators

- Achieve equal rms line voltages of the oncoming generator and the running system.

Recall that the terminal voltage of a generator can be controlled by adjusting its field current, hence for the incoming generator's line voltage to equal to the running system's line voltage:

(1) Use two voltmeters connected at the terminals of the oncoming generator and the running system.

(2) Adjust the field current of the oncoming generator until the two voltmeters read the same rms line voltage, which is that of the running system.

- Adjust the frequency of the oncoming generator to be slightly higher than that of the running system.

  Assume paralleling the generator with a large power system, then the frequency and voltage of the grid become independent of the generator's operator, which in our case is the ***DC motor***. The mechanical rate of rotation of the synchronous generator is given by Eq. 1.

$$n_m = f_{es} \cdot \frac{120}{P} \qquad \text{Eq. 1}$$

Pre- lab Question 2:

Assuming the gird or load of the system is the UAE's grid, what should be the assumed electrical frequency produced by the generator?

f_{es} = **50 Hz**.

Pre- lab Question 3:

*Given that $\boldsymbol{f_{es}}$ = 50 Hz, and that the generator used has four poles, (**P = 4**); Calculate the resulting mechanical speed of the generator (n_m):*

Using Eq. 1 and substituting the given parameters, n_m is calculated to be **1500 rpm**.

Pre- lab Question 4:

Lis the two methods used to control the speed of a DC motor.

(1) adjusting the field resistance (and hence the field current).

(2) adjusting the armature voltage of the motor.

Adjusting the field resistance is used for small adjustments of the speed, while adjusting the armature voltage, is used for large adjustments of the speed. Therefore, for the electrical frequency produced by the generator to be slightly higher than 50 Hz, the following steps must be followed:

(1) Adjust the armature voltage until the motor speed recorded is close to 1500 rpm.
(2) To get a speed slightly higher than 1500 rpm, adjust the field current.
(3) To achieve higher speeds, the field resistance must be adjusted such that the ammeter current reading decreases, and vice versa.

- Check that both the oncoming generator and running system have the same phase sequence.

One way of checking the phase sequence is to use the *three-light-bulb method*. The three light bulbs indicate that the phase sequence of both systems is the same if all three light bulbs get bright and dark together. If the bulbs get bright and then dim alternately or in succession, then the systems have opposite phase sequences, and one of the phase sequences must be reversed. The corresponding procedure for this step is described below.

(1) Connect the terminals of the oncoming generator to the synchronizing device and connect the running system to the terminals of the synchronizing device.
(2) Observe the *synchronizing lamps*; if the lamps get bright in succession, then swap any two wires connected from either terminal of the synchronizing device. Otherwise, the phase sequence of the two systems is the same, and no reversing is needed.

- Shut down the switch of the synchronizing device connecting both systems.

The switch connecting the two systems must be shut when the phase angles of both systems are equal. In the previous steps, the frequency of the two systems was made to be very nearly equal. For that, the voltages in the two systems will change phase with respect to each other very slowly. The synchronizing device also has a *Zero Voltmeter*, which indicates when the two systems are in phase. To finally shut off the switch connecting the two systems:

(1) Observe the Zero Voltmeter of the synchronizing machine. When the arrow is in the horizontal position, turn on the switch commutator of the synchronizing machine, hence connecting both systems in parallel.

Equipment Required:

- M: DC Machine MV1028 (Alt. MV1034)
- TD: Torque transducer and torque measuring unit MV1051
- G: Synchronous Machine MV 1008
- Rmy: Shunt RegulatorMV 1905
- Im: Ammeter 12A MV 1923
- IF: Ammeter 1A MV 1923
- If: Ammeter 1A MV 1922
- VG1: Voltmeter 500V MV 1926
- VG2: Voltmeter 500V MV 1926
- F: Power pack MV 1300
- Synchronizing Device

Circuit Diagram:

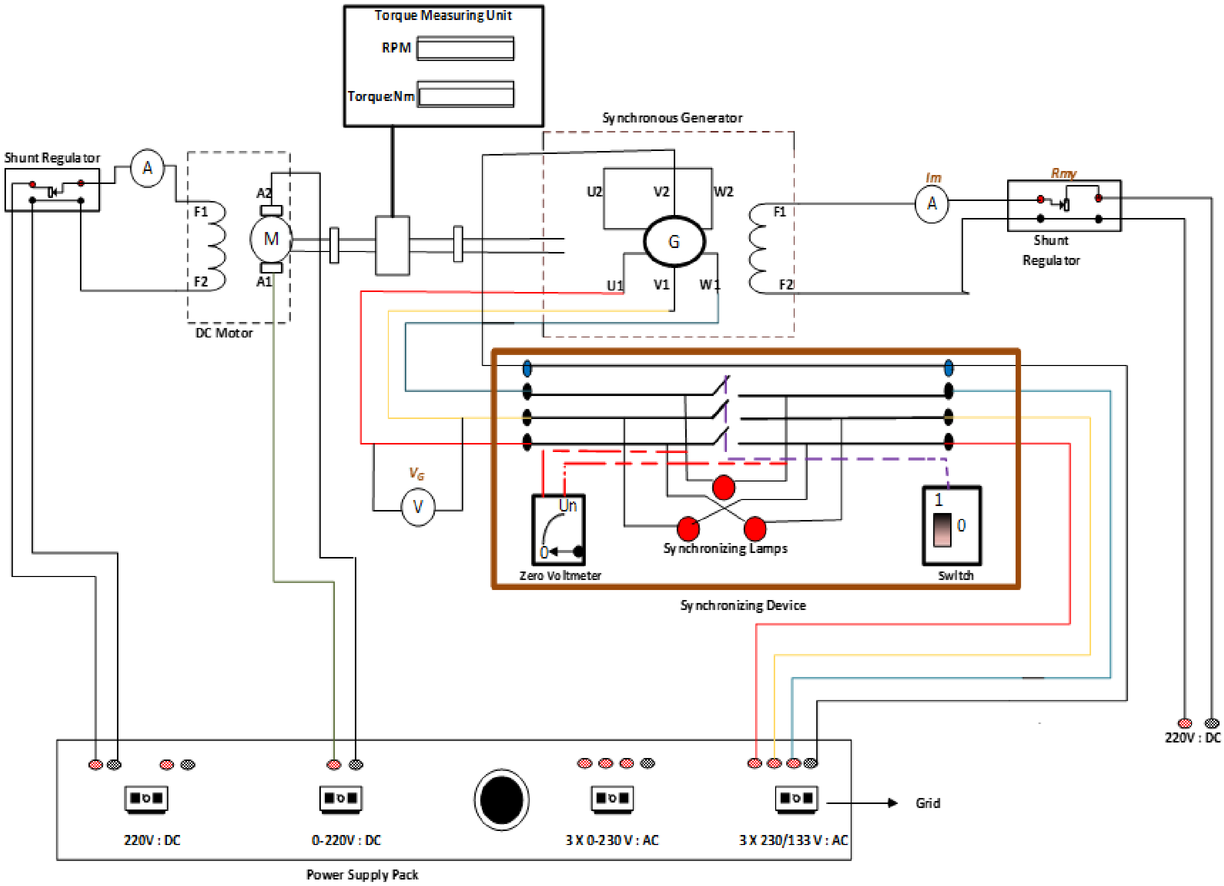

Figure 2. Synchronization connection

Procedure:

The general procedure for the synchronization of synchronous generators to the grid was described in the introduction. In this section, the design of experiment procedures is described in more detail as follows:

(1) Connect the circuit as shown in figure 2.
(2) Let the instructor check your connection.
(3) Record the voltmeter reading of the terminal voltage of the grid.
    Recorded Voltage: **235 V**
(4) Adjust the shunt regulator R_{my} to control the field current to the synchronous generator until the voltmeter reading of the terminal voltage of the synchronous generator is equal to that measured across the grid. With this step, the first condition is met.
(5) Turn on the variable DC voltage switch. Turn on the Fixed DC voltage switch.
(6) Bring the speed to close to **1500 rpm** (synchronous speed of generator) by (a). Slowly raising the variable DC voltage (increasing the armature voltage) of the motor. (b) To fine-tune the speed to a speed slightly higher than 1500 rpm, adjust the DC motor shunt rheostat (adjusting the motor's field current).
(7) Observe the *synchronizing lamps*, swapping any two wires connected from either terminal of the synchronizing device if the lamps get bright in succession. However, if the lamps get bright and dim all at the same time, no swapping is necessary.
(8) Observe the *Zero Voltmeter* of the synchronizing machine. At the moment the voltmeter's arrow is in the horizontal position, turn on the switch commutator of the synchronizing machine, thereby paralleling the two systems.

Post-Lab Discussion:

(1) Propose a different method for checking when the two systems are in -phase.

Another simple, yet not as accurate as the method used above (Zero Voltmeter of the synchronizing device), is to observe the synchronizing lamps of the synchronizing device; when the synchronizing lamps are dim, the voltage difference across them is zero, and the two systems are in-phase.

(2) Propose a different method for checking whether both systems have the same phase sequence.

Instead of observing the flashing pattern of the synchronizing lamps of the synchronizing device, an induction motor can be connected to both systems. If the motor rotates in the same direction, then both systems have the same phase sequence; otherwise, swapping of any two phases is necessary.

(3) In the introduction, it was mentioned that the grid to which the generator is paralleled to is a very large power system, such that once the switch of the synchronizing device is shut, the generator's operator (DC motor) has no effect on the power system.

How can this be tested experimentally? What happens to the power drawn by the generator's operator?

Once the switch paralleling the two systems is shut, increasing the DC motor shunt rheostat (thus decreasing the motor's field current) should normally increase the synchronous speed of the generator. However, no change in speed should be observed, and the power drawn by the motor is delivered to the load. Moreover, once the switch paralleling the two systems is shut off, the measured speed must increase corresponding to the reduced field current of the motor (or raised DC motor shunt rheostat).