**EXPERIMENT P3: SYNCHRONISATION OF GENERATORS**

Related course: KIE3009 (Energy Conversion and High Voltage Transmission)

**OBJECTIVES:**

1. To perform synchronisation of two generators
2. To observe the behaviour of synchronous generators connected to a power system

**EQUIPMENT:**

Two motor-generator sets (M1-G1 and M2-G2), synchroscope, three-lamp box module, double frequency meter, double voltmeter, synchronisation switch

**INSTRUCTIONS:**

1. Record all your results and observations in a log book / paper
2. Follow the demonstrator's instructions throughout the experiment

**REFERENCE(S):**

Refer to the main references of KIE3009

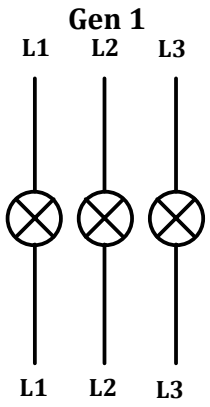
**INTRODUCTION:**

**Parallel Operation of Generators**

The connection between large power generation stations and the use of AC generators to supply load for a station involves simultaneous operation of multiple generation units. To operate a generator simultaneously with other generators or with a bus system supplied by other sources, **4 conditions** must be met when connecting the generator to the grid:

| Condition | Descriptions | How to adjust |
|---|---|---|
| **Voltage** | The rms voltage generated by the generator must be the same with the voltage of the main grid system/bus. If there is a voltage difference between them, connecting the generator to the grid will cause a large MVAR flow between them and possibly damage the generator. | Change the generated voltage by adjusting the field current of the generator. |
| **Phase sequence** | The voltage phase sequence ($3\varphi$) of the generator must be the same as the phase sequence of the grid. | To change the phase sequence, change the connection of any 2 phases of the generator to the grid. |
| **Frequency** | The frequency of the voltage produced by the generator must be equal to the frequency of the voltage produced by the grid. | To change the generator frequency, change its speed by changing the field current of the DC motor. In a real generation station, the generator speed can be changed by controlling the steam / water supplied to the turbine. |
| **Phase angle** | The phase angle between the voltage produced by the generator and the voltage produced by the grid must be zero. If the phase angle of the generator is lagging the grid, a large in-rush current will flow to the generator, damaging the generator. If the generator is leading the grid, it will push power into the grid. | If the phase angle is not the same, change the phase of the generator by changing the speed of its prime mover (steam / water). |

**Methods to Determine Synchronisation between Different Generators**

| Method | Descriptions | Figure |
|---|---|---|
| **Dark-lamp method** | Dark-lamp method can be used to see the difference of phase angle and frequency of two generators. A lamp is connected between two generators at each phase. Following observations are made on the 3 lamps:<br>1. The 3 lamps light on and off simultaneously with the frequency equals to the difference of the two generators. Changing the speed of any two generators will change the lamps on/off pattern.<br>2. If the lamps are glowing in a 'disco' manner, it means all lamps do not glow simultaneously and the phase sequence of both generators is different. If this happens, change any two lines of any generator across the lamp.<br>3. If the frequency and voltage of both generators are the same and in phase, there is no voltage difference across the lamp. Thus, all lamps will light off. This is the right time to close the synchronisation switch. |  <br>Dark-lamp method |
| **Synchros-cope** | It can only be used to check the frequency and phase angle between two generators. When both generators are in phase, the synchroscope needle will be at the 12 o'clock and the synchronisation switch can be closed.<br>If the generator is exactly out-of phase (phase angle of 180°), the synchroscope will be pointing at 6 o'clock. |  <br>Synchroscope |

**PROCEDURES:**

**Precaution: Before starting any connection, make sure that the Synchronisation Switch and all power supplies are OFF.**

1. Make sure that the circuit connection is as shown in Figure 1. Do not change the connection without permission from the lab demonstrator or technician. The motor-generator set attached to the three-level rack is named M1-G1 while the motor-generator set attached to the orange panel is named M2-G2. G1 represents the Main Grid while G2 is the generator that will be synchronised with the Main Grid.
2. Make sure that the external rotor resistor (starter) connected to M1 is at maximum before the motor starts to rotate. This is to ensure that the starting armature current into the motor is minimum, avoiding damage of the motor.
3. Switch ON the main power and DC power supplies connected to M1-G1 and M2-G2.
4. Adjust the DC power supplies that are connected to M1-G1 until the voltage output of G1 is between 200V and 300V (line-to-line) and its frequency is between 45 and 55 Hz. The voltage and frequency of G1 can be seen from the voltmeter and frequency meter on the orange panel, labelled with "I."
5. Adjust the voltage and frequency of G2 until they are equal to the voltage and frequency of G1. Use the knob labelled with "SPEED SET" and "VOLTAGE SET" on the orange panel to adjust the voltage and frequency of G2. The voltage and frequency of G2 can be seen from the voltmeter and frequency meter on the orange panel, labelled with "II."

6. Observe the 3-lamp indicator. If all lamps are on and off simultaneously or blinking, it means that G1 and G2 are still not synchronised. If this happens, repeat steps 4 and 5 until all lamps are off. However, due to an unknown problem in the system, all lamps will not turn off completely although the frequency and voltage of both sets are the same (within few seconds, the lamps will turn on and then turn off again). Therefore, when all lamps are off for more than 3 seconds, it is treated as both generators are synchronised. **If the lamps turn on, wait until all lamps turn off again. While all lamps are completely off, quickly turn the synchronisation switch on the orange panel from 0 to 1.**
7. If the synchronisation has been done correctly, there will be no current, no real power (Watt) and no reactive power (Var) flowing between G1 and G2. Look at the Wattmeter and Varmeter readings on the orange panel to verify this.

**Notes: In actual practice, the voltage and frequency of synchronous generators are set at the rated value. However, in this experiment, it is not necessary to set the voltage and frequency at the rated value because the objective is only to demonstrate how to perform generator synchronisation.**

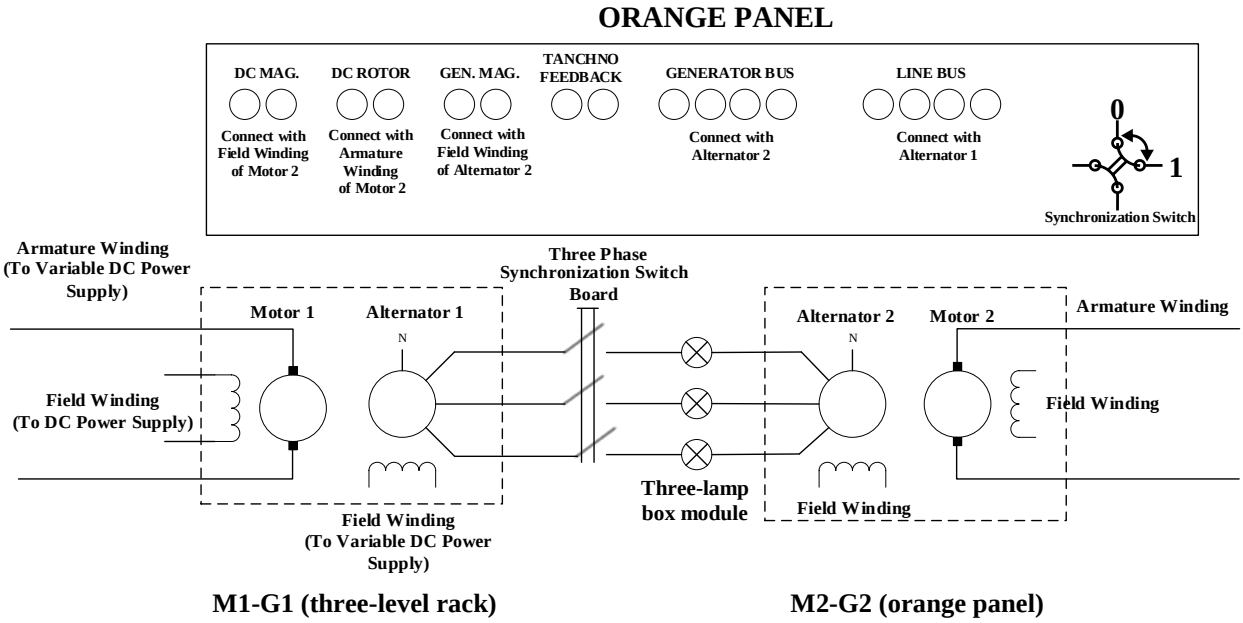



Figure 1: Circuit for synchronised operation of two synchronous generators

**OBSERVATION:**

**BEHAVIOUR OF SYNCHRONOUS MACHINE CONNECTED TO A POWER SYSTEM**

Using the synchronised generator (G2), conduct the following experiments:

**1. Changes of DC Motor Field Current (Steam Supply)**

a) Slowly reduce the field current of the DC motor of Set No. 2 by changing the field resistance using the "SPEED SET" knob on the orange panel. The motor will try to rotate at a higher speed. However, this will not happen since it has been strongly connected to the power system through a synchronous machine. What happens is that the mechanical power will be transferred to the power system in the form of current flow. Check the Watt Meter and it will be observed that the AC current meter shows quite a high reading while the Varmeter shows near zero reading (In a normal power generating station, this effect can be achieved by increasing the steam supplied to the system and power flows from Set No. 2 to Set No. 1).

b) Now, increase the field current of the motor using the "SPEED SET" knob on the orange panel. The motor will try to reduce its rotation speed but to no avail. The Wattmeter reading is inverted, showing that the power flows in the opposite direction (i.e. from Set No. 1 to Set No. 2). G2 now serves as a synchronous motor that drives the DC machine as a generator. The Var meter will continue to show zero reading.

c) Increase the armature voltage (DC rotor voltage) of the DC motor for Set No. 2 using "SPEED SET" knob on the orange panel and record the generated voltage and frequency reading (Set No. 1 and Set No. 2) in Table 1. Record for any 5 readings.

Table 1

| | | | | | | |
|---|---|---|---|---|---|---|
| Set 2 | Armature voltage (V) | | | | | |
| | Generated voltage (V) | | | | | |
| | Frequency (Hz) | | | | | |
| Set 1 | Generated voltage (V) | | | | | |
| | Frequency (Hz) | | | | | |

d) Reduce the armature voltage (DC rotor voltage) of the DC motor for Set No. 2 using "SPEED SET" knob on the orange panel and record the generated voltage and frequency reading (Set No. 1 and Set No. 2) in Table 2. Record for any 5 readings.

Table 2

| | | | | | | |
|---|---|---|---|---|---|---|
| Set 2 | Armature voltage (V) | | | | | |
| | Generated voltage (V) | | | | | |
| | Frequency (Hz) | | | | | |
| Set 1 | Generated voltage (V) | | | | | |
| | Frequency (Hz) | | | | | |

**2. Changes of Generator Field Current**

a) Adjust the field current of the DC motor of Set No. 2 using "SPEED SET" knob such that there is no current flowing between Set No. 1 and 2. Observe that the Watt meter and Var meter show zero reading. This is the condition found before synchronisation.

b) Increase the field current of the generator Set No. 2 by turning the "VOLTAGE SET" knob on the orange panel. Observe that both the AC current meter and Var meter shows rather high reading, while the Watt meter still shows zero reading. This shows that only reactive power is transferred to the power system. Real power cannot be transferred in this condition because the mechanical power input to the generator is not changed (i.e. the steam input to the turbine remains unchanged).

c) Now, decrease the field current of the generator Set No. 2 by turning the "VOLTAGE SET" knob on the orange panel and observed the watt meter and VAR meter. If the field current of the generator is reduced to a lower value, Var will be seen flowing in the opposite direction; that is, from Set No. 1 to Set No. 2, or from the power system to generator. Watt meter is still seen to show near zero reading.

d) Increase the excitation voltage (stator voltage) of generator for Set No. 2 by turning the "VOLTAGE SET" knob and record down the generated voltage and frequency for 5 readings (Set 1 and Set 2) in Table 3.

Table 3

| | | | | | | |
|---|---|---|---|---|---|---|
| Set 2 | Excitation voltage (V) | | | | | |
| | Generated voltage (V) | | | | | |
| | Frequency (Hz) | | | | | |
| Set 1 | Generated voltage (V) | | | | | |
| | Frequency (Hz) | | | | | |

d) Reduce the excitation voltage of the DC motor for Set No. 2 by turning the "VOLTAGE SET" knob and record down the generated voltage and frequency (Set 1 and Set 2) for 5 readings in Table 4.

Table 4

| | | | | | | |
|---|---|---|---|---|---|---|
| Set 2 | Excitation voltage (V) | | | | | |
| | Generated voltage (V) | | | | | |
| | Frequency (Hz) | | | | | |
| Set 1 | Generated voltage (V) | | | | | |
| | Frequency (Hz) | | | | | |

**QUESTIONS:**

1. Discuss the results obtained in Table 1 to Table 4.
2. Why it is a must that two or multiple generators operate in synchronous manner?
3. Explain the theory of synchroscope and its utilization in parallel operation of generator.
4. State the effect of wrong synchronisation.
5. How does the frequency meter work?

**END OF EXPERIMENT**