Electrical Equipment - Course 230.2

GENERATORS: PART 4

PARALLELING AND SYNCHRONIZING

---

1. OBJECTIVE

The student must be able to:

1. Explain how dc systems are paralleled.
2. Explain how the following systems are synchronized and paralleled:
   (a) single phase ac
   (b) three phase ac
3. Explain how three phase ac generators are synchronized and paralleled.
4. (a) Explain the precautions that must be observed when
   - paralleling dc supplies,
   - synchronizing and paralleling 3 phase ac supplies,
   - synchronizing and paralleling 3 phase ac generators.

   (b) Explain the consequences of not observing these precautions.

2. INTRODUCTION

Electrical systems consist of dc, single phase ac and three phase ac circuits. As part of normal operational procedures, dc supplies have to be coupled to other dc supplies and ac supplies also have to be coupled to other ac supplies. Generators have to be coupled to the Ontario Hydro grid.

2.1 Definitions

The term **paralleling** is the action of joining one electrical supply to another.

The term **synchronizing** is the action of bringing each phase of an ac voltage into coincidence with each phase of another ac voltage.

This lesson explains how paralleling and synchronizing are correctly done. Incorrect paralleling and synchronizing will, in all probability, cause severe damage to plant equipment. Personnel may also be injured.

3. PARALLELING dc SYSTEMS

Figure 1 shows two 250 V dc systems (for example class 1) ready to be paralleled using a breaker. If voltmeters shown by (V) are simultaneously connected across the breaker contacts, they will read zero. (This assumes that both dc systems are at or near 250 V). After the breaker has been closed, and the systems have been paralleled, because both voltages are similar, little or no currentwill flow between the two systems.

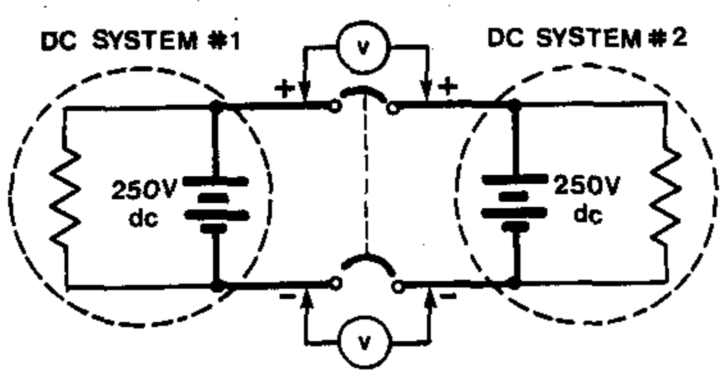

Figure 1: dc supplies ready for paralleling.

Figure 2 shows the condition when the two systems are incorrectly connected and cannot be paralleled. The polarities of supply #2 are reversed and both voltmeters will read 250 V. If the breaker was closed under this condition, because of the low resistance of the batteries and connections, an enormous current would circulate. This current would, in all probability cause severe damage to the batteries, breakers and busbars due to burning and arcing. Anyone in the vicinity of this burning and arcing would receive injuries.

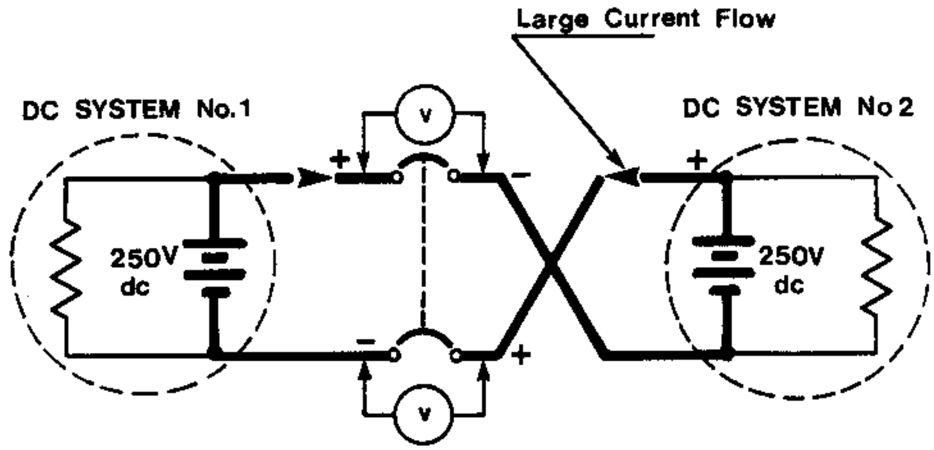

Figure 2: dc supplies which must not be paralleled.

4. SYNCHRONIZING AND PARALLELING SINGLE PHASE ac SUPPLIES

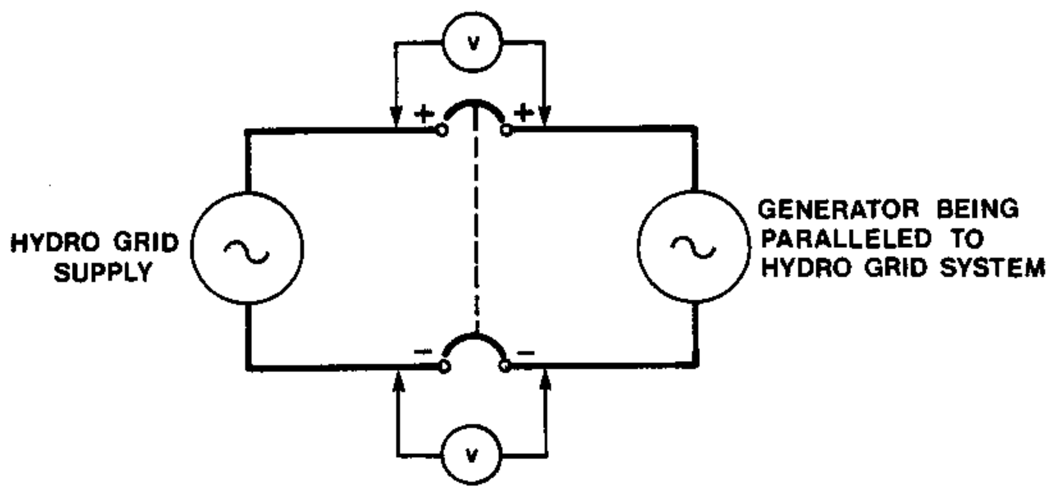

Figure 3: Paralleling single phase ac supply

Figure 3 shows an ac generator which is to be paralleled to the grid. The speed of the generator must be increased until its **frequency** matches the grid frequency (60 Hz). The excitation must be adjusted until the **voltage** matches the grid voltage. The **phase angle** between the generator and grid must be reduced to zero.

When voltmeters are connected across the breaker they will read zero only when the following three conditions are fulfilled:

(a) the generator and grid voltages are equal in magnitude.

(b) generator and grid voltages have the same polarity.

(c) the phase angle between the generator and grid voltages is zero.

When the three conditions listed above occur, the *generator and grid voltages are said to be in* **synchronism.**

If the phase angle is not zero, see Figures 4(a) and 4(b), a voltage will exist across the breaker. Figure 5 shows the vectors of supply and generator voltages when the generator voltage is *lagging* by 45°. The dashed vector indicates the voltage across the breaker.

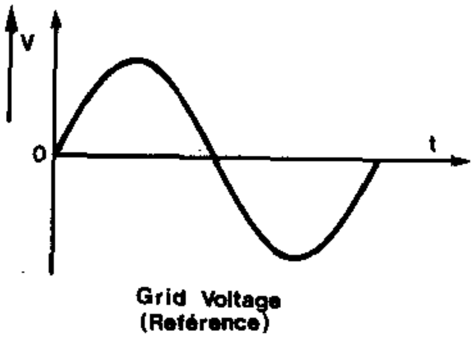

Figure 4(a)

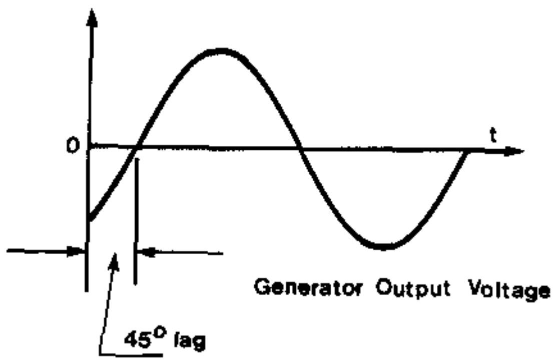

Figure 4(b)

Diagrams showing the supply and generator voltage waveforms out of phase of 45°.

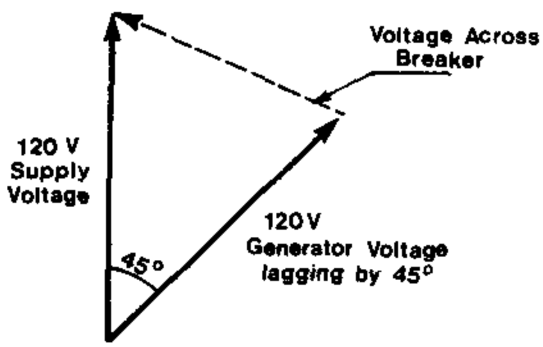

Figure 5: Vector diagram of voltages 45° out of phase.

Before the breaker can be closed, the waveforms must be brought into co-incidence, see Figures 6(a) and 6(b). When the waveforms are in co-incidence, there will be no voltage difference across the breaker and the breaker can be safely closed. The generator will then be paralleled to the grid.

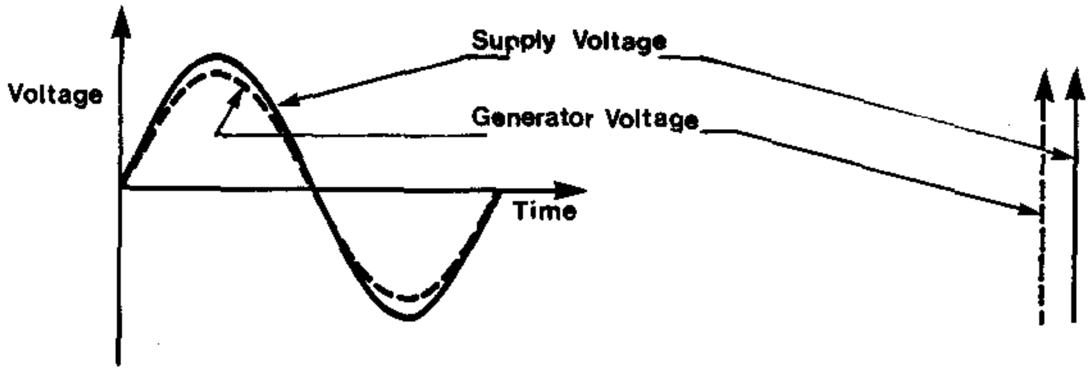

Figure 6(a) Figure 6(b)

Diagrams showing voltage waveforms and voltage vector for two equal voltages which are in phase.

4.1 The Synchroscope

As explained above, two voltmeters can be used to indicate the generator and grid are in synchronism. Ontario Hydro, in common with other utilities, uses an instrument known as **synchroscope** to indicate synchronism. See Figure 7. A synchroscope gives a more accurate indication of synchronism than two voltmeters connected across the breaker contacts. The position of the pointer indicates the difference in phase angle. If there is a small difference in frequency (up to 2 Hz) the pointer will rotate. With larger frequency differences, the synchroscope is designed not to rotate. The pointer will rotate in the SLOW direction when the generator frequency is below system frequency. The pointer will rotate in the FAST direction if the generator frequency is greater than system frequency. When the pointer indicates zero degrees phase angle difference, (at the 12 o'clock position) (see Figure 6) and the pointer is steady, the voltages are "in phase" and the frequencies of the generator and system are equal.

Note, it is vitally important to check the correct operation of the synchroscope before each synchronizing is attempted. To do this, the generator is operated at less than synchronous speed, and the synchroscope must rotate in the SLOW direction. Similarly, when the generator is operated at *a speed greater than synchronous, the synchroscope* must rotate in the FAST direction.

Voltmeters are used to measure the magnitude of the grid and generator voltages. When the generator and grid voltages are equal and the synchroscope is steady at the zero degrees position, the breaker can be closed to parallel the generator to the grid.

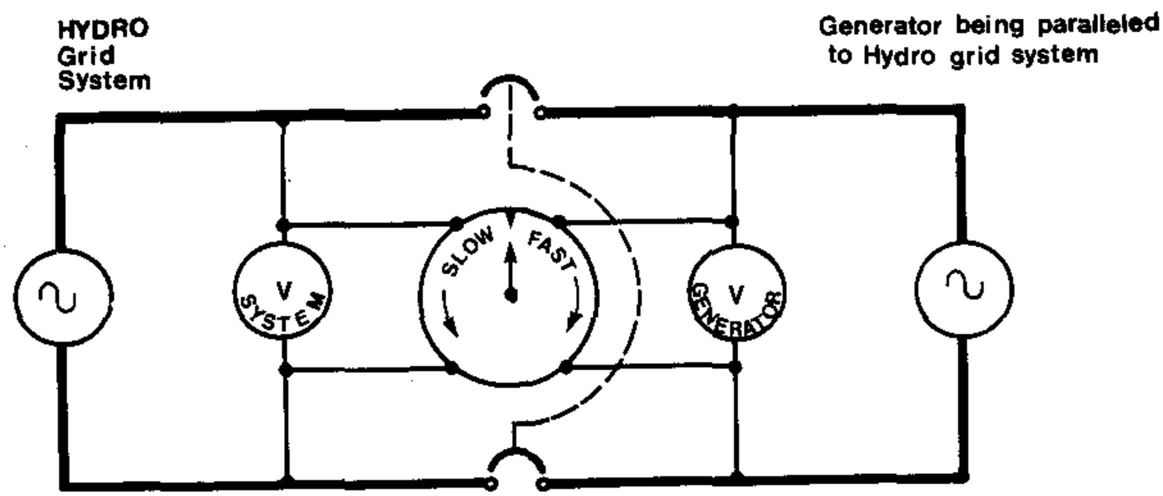

Figure 7: Checking phase angle and frequency using a synchroscope. Voltmeters used for checking voltage magnitudes.

4.2 Synchronizing Out of Phase

If the circuit breaker is closed when the synchroscope does not indicate zero degrees, the breaker will be joining together the generator which is out of phase with the system. When this occurs, the magnetic forces produced by the rotor and the magnetic forces produced by the stator will not be co-incidental. From Figure 8, it can be seen that the resultant magnetic force will apply a large torque to the rotor.

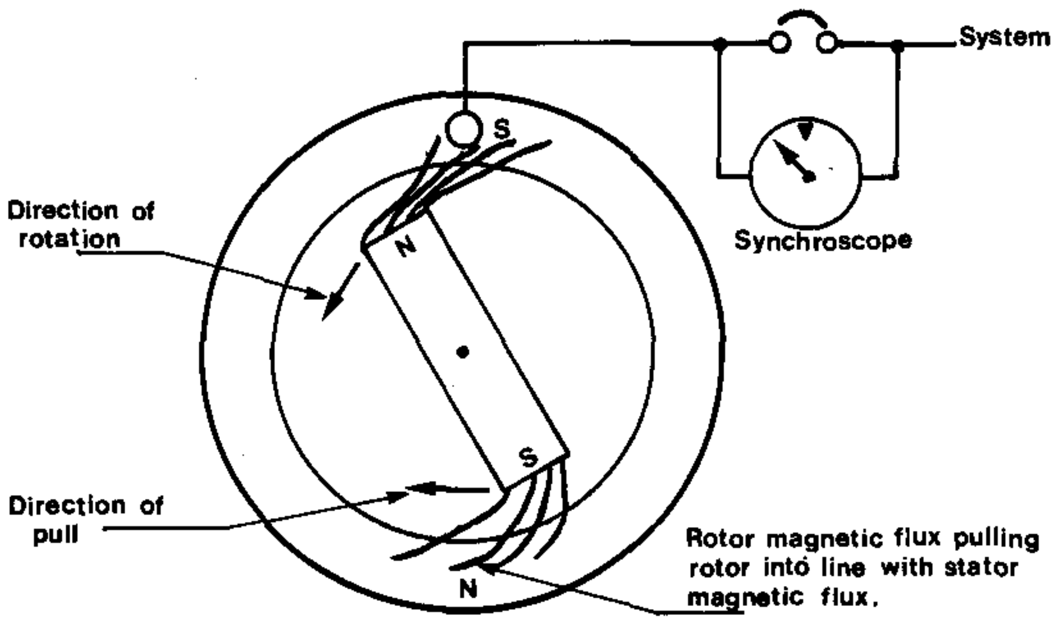

Figure 8: Magnetic forces produced when generator breaker is closed "out of synchronism".

This effect takes place the instant the breaker is closed and due to the accelerating effect on the rotor, places an immense mechanical torque on the generator and turbine shafts. The generator windings and connections are subjected to enormous currents and magnetic forces. Depending on the phase angle when the breaker is closed, the forces may be sufficient to permanently distort the generator windings and break the turbine to generator coupling bolts. On some occasions, the generator transformer has been severely damaged. This is due to enormous currents and magnetic forces occurring in the transformer.

5. PARALLELING OR SYNCHRONIZING 3-PHASE SUPPLIES

All conditions for synchronizing single phase supplies apply to three phase as well. In addition, with 3-phase systems, the phase rotation, R, W, B, must be observed for both supplies, see Figure 9.

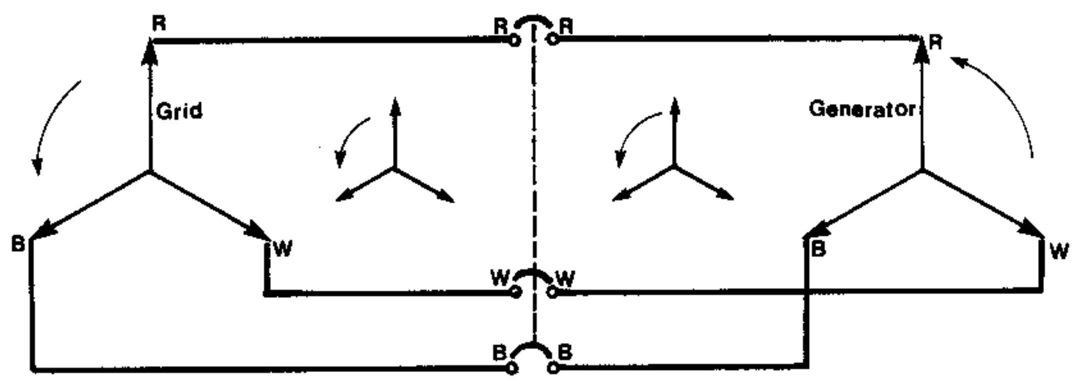

Figure 9: Diagram showing the vector conditions that must be satisfied before two three-phase generators can be synchronized.

Failure to observe this precaution will involve connecting a system which has a RWB clockwise rotation being connected to a system which has a RWB anti-clockwise rotation. Both systems will try and rotate in different directions at the same time. Damage will follow to windings, busbars and breakers.

The phase sequences RWB, are checked for the generator and the supply during commissioning, and if correct need not be re-checked unless connections are altered or distrubed.

6. *SUMMARY*

Before dc systems can be paralleled:	Checked by
(a) Voltage magnitdue must be equal. (b) Polarities must be correct.	Voltmeter Voltmeter

Before single phase ac systems can be paralleled:	Checked by
(a) Voltage magnitudes must be equal. (b) Polarities must be correct. (c) Frequencies must be the same. (d) Phase angle must be zero.	Voltmeter Synchroscope Synchroscope Synchroscope

Before 3-phase ac systems can be paralleled:	Checked by
(a) Voltage magnitudes must be equal. (b) Polarities must be correct. (c) Frequencies must be the same. (d) Phase angle must be zero. (e) Phase sequences R,W,B, must the be the same	Voltmeter Synchroscope Synchroscope Synchroscope Phase Rotation Indicator

ASSIGNMENT

1. (a) Define **paralleling,** when referred to electrical supplies.

   (b) Define **synchronizing,** when referred to electrical supplies.

2. State the conditions that have to be satisfied and the instruments that are used to check the conditions when:

   (a) Two dc supplies are paralleled.

   (b) Two single phase ac supplies are paralleled.

   (c) Two three phase ac supplies are paralleled or synchronized.

   (d) A generator is synchronized to the grid.

3. Describe, step-by-step how a three phase generator is synchronized and then paralleled with the grid.

4. Great stresses are placed on the stationary and rotating components of an ac generator if synchronization is not done correctly. Explain, using labelled diagrams, how these stresses occur.

J.R.C. Cowling