SYNCHRONOUS MACHINE

Introduction

Practically all power is generated with synchronous generators and operations similar to those examined in this experiment are carried out daily in the electricity generating stations around the country. In this experiment the requirements for connecting a synchronous machine to a network will be examined as well as the operation of a synchronous machine.

Background

The most common configuration for a 3 phase machine is to have 3 separate, symmetrically disposed, windings on the stator and a single winding on the rotor. Rotor connections are made using slip- rings.

Dc current flowing in the rotor winding will set up a magnetic field which will link across the air-gap to with the stator windings. If the rotor is rotating the flux linking the stator windings will be varying and this changing flux will induce a voltage in these stator winding. The frequency of the induced voltage will be set by the rotor speed and the magnitude of the voltage will be set by the speed and magnitude of the flux (proportional to dc current). Since the windings on the stator are physically displaced the voltage in each winding will be phase displaced. In virtually all cases the windings will be symmetrically disposed (is phase separated by 120°) therefore the voltage phase displacement will be 120°. The phase rotation will be set by the rotation direction.

When it is required to switch a synchronous generator onto a power system it is important that there be no disturbance. For example if there is difference in the voltage of the incoming generator and the system voltage a current will flow. It is required that no current flows when the generator is switched in.

A very simple, but very useful, equivalent circuit for a synchronous generator is an ac voltage source in series with an inductance. It is usually only necessary to consider 1 phase if the system is balanced, ie same conditions in all phase except for the phase difference. This equivalent circuit is shown in figure 1.

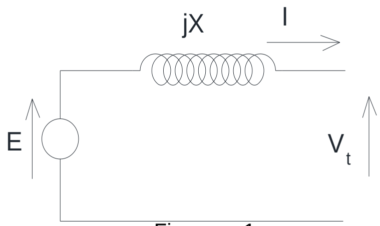


Figure 1

The dc current flowing in the field winding will set the magnitude of E and the frequency is set by the mechanical speed.

Once the machine is connected to a network, ie the 3 stator windings connected to a 3-phase supply, then current flowing in these 3 windings sets up a rotating magnetic field. For the machine to operate as a synchronous machine when connected to a network then the mechanical speed, ie the speed at which the rotor magnetic field is rotating in the air-gap, must be identical to the speed at which the magnetic field due to the 3-phase network is rotating. The interaction between these two rotating magnetic fields causes the energy conversion between electrical and mechanical energy.

Before the synchronouc machine is connected to the network the two independent ac voltage sources

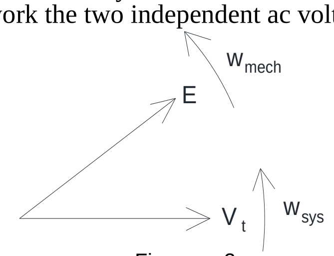


Figure 2

E and V_t can be considered as shown in the phasor diagram of figure 2. In order that no current will flow when the connection is made the following conditions must be satisfied:

- The magnitude of the voltages, E and V_t must be equal;
- The anglar velocitions, ω_{sys} must equal ω_{mech};
- The phase between E and V_t must be equal;
- The phase sequence must be the same, ie the direction of rotation of the two systems.

Apparatus

* Synchronous motor, slip-ring type,0.5kW, 380V, 4 pole.
* Torque dynamometer, TERCO swinging frame dc machine, 2kW.
* General Purpose electrical meter, V, I, P, Var etc.
* Voltmeters, MI, 400V.
* Synchroscope
* Contactor.
* Stroboscope, 25Hz.

Reference

- Slemon & Straughan, *Electric Machines*, chapter 5

Procedure

Generator Controls

As usual identify all the equipment. Note the ratings of the synchronous machine and the dynamometer dc motor. These ratings should not be exceeded during the experiment.

The dc motor will be used as the prime mover here. It will be operating as the “engiene” driving the synchronous machine. It should be connected up for you by your TA and the speed can be adusted by varying the dc voltage on the armature terminals. The field current on this machine should be left constant as set by your TA. You can simply regard this dc machine as the engine and the speed/power will be adjusted by varying the dc terminal voltage.

For this part of the experiment connect the 3 phase output of the synchronous machine to the terminals of the 3-phase contactor. This contactor will be used later to connect the generator to the ac network.

Connect a voltmeter between any pair of lines and connect an ammeter in series with one of the lines. Also connect the frequency meter between any two lines. Refer to figure 4.

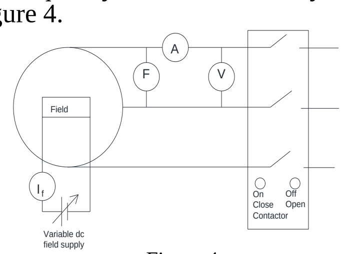


Figure 4

Make sure that the variable voltage supply to the dc machine is set to minimum and switch on. Adjust the speed of the machine and bring up to about 1200 RPM. Now observe the output voltage of the synchronous generator and note that is can be adusted by varying the field current of the syschronous machine. Take 5 or 6 reading over the range 0 to max (about 400V) and note the relationship.

Now set the line voltage at about 300 Volts and adjust the speed leaving the field current constant. Observer the relationship between electrical frequency and mechanical speed. Also note that the ac voltage varies as the frequency varies.

Synchronisation

Now add the synchroscope to the circuit as shown in figure 5 and connect the other side of the contactor through the digital multifunction meter to the fixed bench ac power supply.

Synchronisation of the generator to the system involves the synchronisation of four parameters as discussed earlier:

- Voltage
- Frequency
- Phase
- Phase sequence

The synchroscope is essentially a phase meter and as it is connected in this experiment it shows the phase difference between the incoming generator and the system. When the needle is pointing to the 12 o clock position the voltages are in phase. When there is a difference in frequencly between the two voltages this results in a continuously varying phase difference and therefore the needle will rotate at the difference is frequency between the two voltages. There is a maximum speed that the needle can rotate and this function only operates when the two frequencies are close. As well as using the synchroscope to set the phase it is very useful in making the final speed adjustment.

Adjust the generated terminal voltage to be as close as possible to the system voltage. Now adjust the generated frequency to be as close as possible to the system frequency. This corresponds to 1500 rpm. As you approach system frequency the synchroscope will slow down and stop when the frequencies are the same. The position of the needle indicates the relative phase difference between the two systems. The 12 O clock position indicates phase alignment. At this stage you should check that that the phase sequence is the same on both sides of the contactor. Call your demonstrator and he will show you how to use a phase sequence meter.

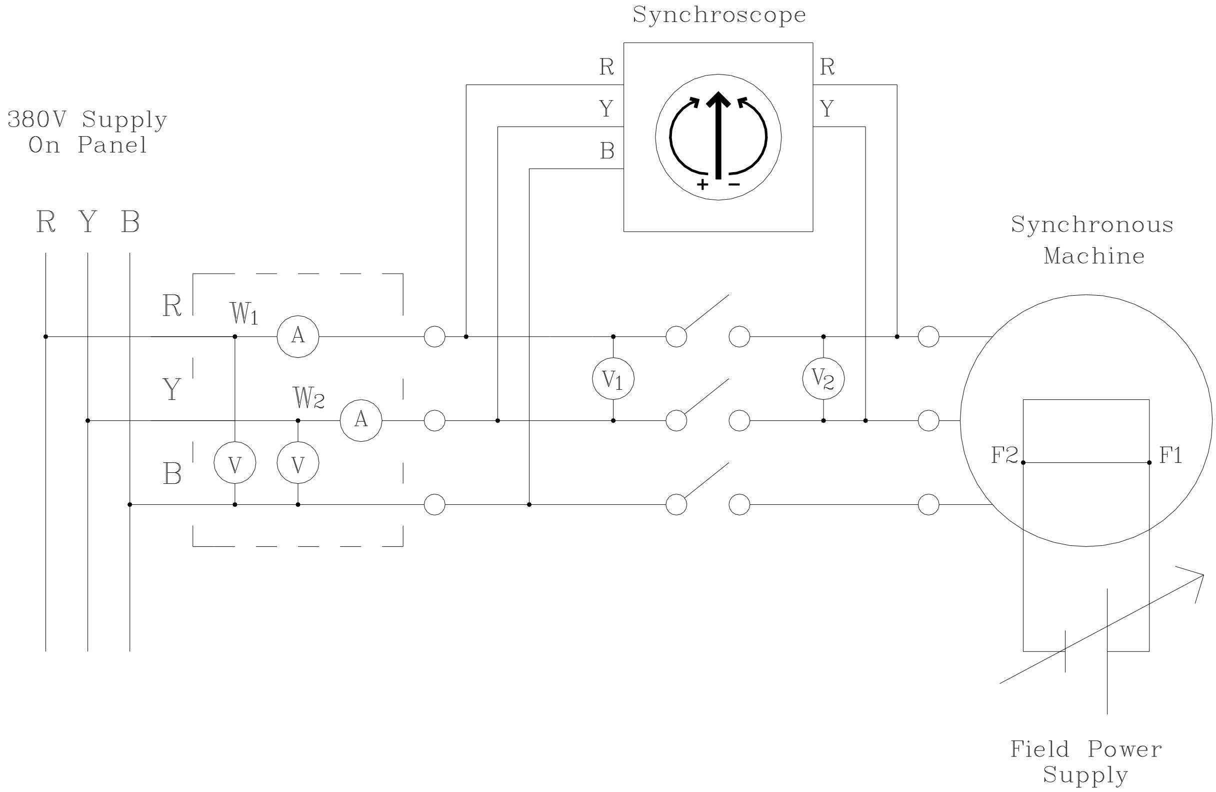
Now get the phases to align by getting the synchroscope to stop in the 12 O clock position. When this is accomplished close the contactor and the synchronous machine is connected to the system network and is ready to generate power onto the grid network. The speed will remain fixed, determined only by the system frequency as long as the machine remains in synchronism.

Your TA will demonstrate how power can be generated as well as VAR.

Stroboscopic examination

You should at some stage during the experiment observe the machine shaft while holding the strobe near it. Be extremely careful as the shaft will appear to be stationary. Note the apparent change in shaft position as the machine load is increased and decreased. The flashing of the strobe light is phase synchronised to the mains supply.

Tidy up all leads and switch off bench supply and instruments after experiment.



Jeremiah O’Dwyer
March, 2015.