Experiment No. 6

'*V*' CURVES OF A SYNCHRONOUS MACHINE

Theory:

V-curve of a synchronous machine shows its performance in terms of variation of armature current with field current when the load and input voltage to the machine is constant. When a synchronous machine is connected to an infinite bus, the current input to the stator depends upon the shaft-load and excitation (field current). At a constant load, if excitation is changed the power factor of the machine changes, i.e. when the field current is small (machine is under-excited) the P.F. is low and as the excitation is increased the P.F. improves so that for a certain field current the P.F. will be unity and machine draws minimum armature current. This is known as normal excitation. If the excitation is further increased the machine will become over-excited and it will draw more line current and P.F. becomes leading and decreases. Therefore, if the field current is changed keeping load and input voltage constant, the armature current changes to make $VIcos\phi$ constant. Because of their shape (Fig. 6.1), graphs of variation of armature current with excitation are called 'V' curves. If the 'V' curves at different load conditions are plotted and points on different curves having same P.F. are connected the resulting curve is known as "compounding curves".

Starting of synchronous machines:

A synchronous machine does not possess starting torque but once brought near to synchronous speed, it is capable of developing torque. Synchronous machine can be started either by means of some auxiliary machine coupled to its shaft or by running it as an induction machine till it attains a speed near to the synchronous speed.

Usually starting synchronous machines as an induction motor is quite common. In this case, the field circuit of the synchronous machine is closed through high resistance and reduced voltage is applied across the stator windings. Due to three-phase balanced supply into the windings of the stator a rotating magnetic field is set up which rotates at synchronous speed. This rotating field interlinks with the damper winding (short circuited copper grids placed on the pole shoes), which behaves just like the squirrel cage rotor of an induction motor. Thus the motor starts as an induction motor in the direction of rotating field and comes to full speed which is slightly less than synchronous speed and field circuit of the synchronous machine can be connected to the D.C. supply. During starting, the field winding is closed through high resistance to reduce the current in the field winding.

Laboratory Work:

1. Write down the specification of the machine on your observation book.
2. Draw the circuit diagram as shown in Fig. 6.2 and clearly show all the ranges of the meters according to the specification of the machine. Get it approved by the Lab. Instructor.
3. Make the connections as shown in Fig. 6.2 and get it checked by the Lab. Instructor.

4. Start the synchronous machine using standard separately excited DC machine.
5. Connect the field of the synchronous machine to the D.C. supply as soon as the machine attains its rated speed (or near to this speed).
6. Synchronize this synchronous machine with the three phase grid using 3-lamp method as discussed at the end of this write-up.
7. Dc supply of the armature winding of the dc machine should be replaced by loading rheostat as shown in figure 6.2.
8. At no-load (without taking any output from the coupled D.C. machine) vary the field current of the synchronous machine with the help of sliding rheostat and correspondingly record the armature current.
9. As soon as the above observation is completed, bring the field current to a value so that the armature current is minimum.
10. Increase the load on synchronous machine by loading the coupled D.C. machine with the help of loading rheostat such that the armature current of synchronous machine reads 25% of its full rated value at unity power factor.
11. Vary the field current and record the corresponding values of armature current.
12. Remove the load (disconnect completely the loading rheostat) and repeat the instruction number 8 and 9.
13. Increase the load on the synchronous machine by loading the coupled generator with the help of loading rheostat such that the armature current of synchronous machine reads 50% of its full rated value at unity power factor.
14. Repeat the instruction number 10.
15. Repeat the instruction number 11.
16. Repeat the instruction number 12 but for 75% of its full rated value at unity power factor.
17. Repeat the instruction number 11.
18. Repeat the instruction number 12 and stop the machine.
19. Observe the load angle of the synchronous machine when you apply load on synchronous machine by Stroboscope for 25%, 50% and 75% load.

Report:

1. Plot V-curves (armature current versus field current) for different values of load, i.e. (a) At no load, (b) at 25% load, (c) At 50% load and (d) At 75% load.
2. Draw unity power factor compounding curve and mark the leading and lagging power factor regions of V-curves.

Discussion:

When load is applied to a synchronous machine, the machine poles fall back a certain angle δ behind the forward rotating poles of the stator. The value of this angle depends upon the load power factor and the excitation of the machine.

For cylindrical rotor machines these quantities are related by the expression:

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

where, P = Power developed
V = Applied voltage
E = Induced voltage due to field excitation
X_S =Synchronous reactance
δ = Load angle.

For a machine working at particular excitation (and therefore constant K) a sudden increase in load has to be accompanied by a decrease in the value of δ. To accomplish this, the rotor momentarily accelerates, but does not become stable at the approximate value of load angle (say δ_1), and travels further on account of its inertia, decreasing the load angle to a value lower than δ_1. Under this condition, the developed power becomes less than the load power, and the rotor slows down to increase the load angle. Again, on account of inertia, the rotor travels and the load angle becomes more than δ_1. The rotor then tends to accelerate and the oscillations of the rotor about the mean position of equilibrium continue. These oscillations are known as hunting.

To suppress the tendency of hunting, synchronous machine field poles are provided with damper windings which consists of copper bars placed in slot in the pole shoes and short circuited at the two ends, as in squirrel cage rotor.

From the expression of power developed, it may be noted that for a particular power output, the value of δ depends upon excitation. Further the maximum possible value of δ for which a cylindrical-rotor machine remains inherently stable is 90°. It is thus clear that an under-excited machine is less stable than an over-excited one.

Questions:-

1. State the conditions for synchronization of two alternators.
2. State the effect of wrong synchronization.
3. State why pair of lamps are required in lamp method of synchronization?
4. Explain the necessity of synchronization of alternators.
5. State the advantages of using number of small generating units instead of single large unit for supplying power.
6. Why the frequency of incoming alternator is kept slightly higher than bus-bar frequency?
7. What is the difference between synchronous motor and synchronous condenser?
8. For the given test set up how can you make the synchronous machine become a generator feeding power to the bus?
9. If the two 400V machines are to be synchronized by either dark lamp or bright lamp method what will be the voltage rating of the bulb?
10. What is synchroscope?

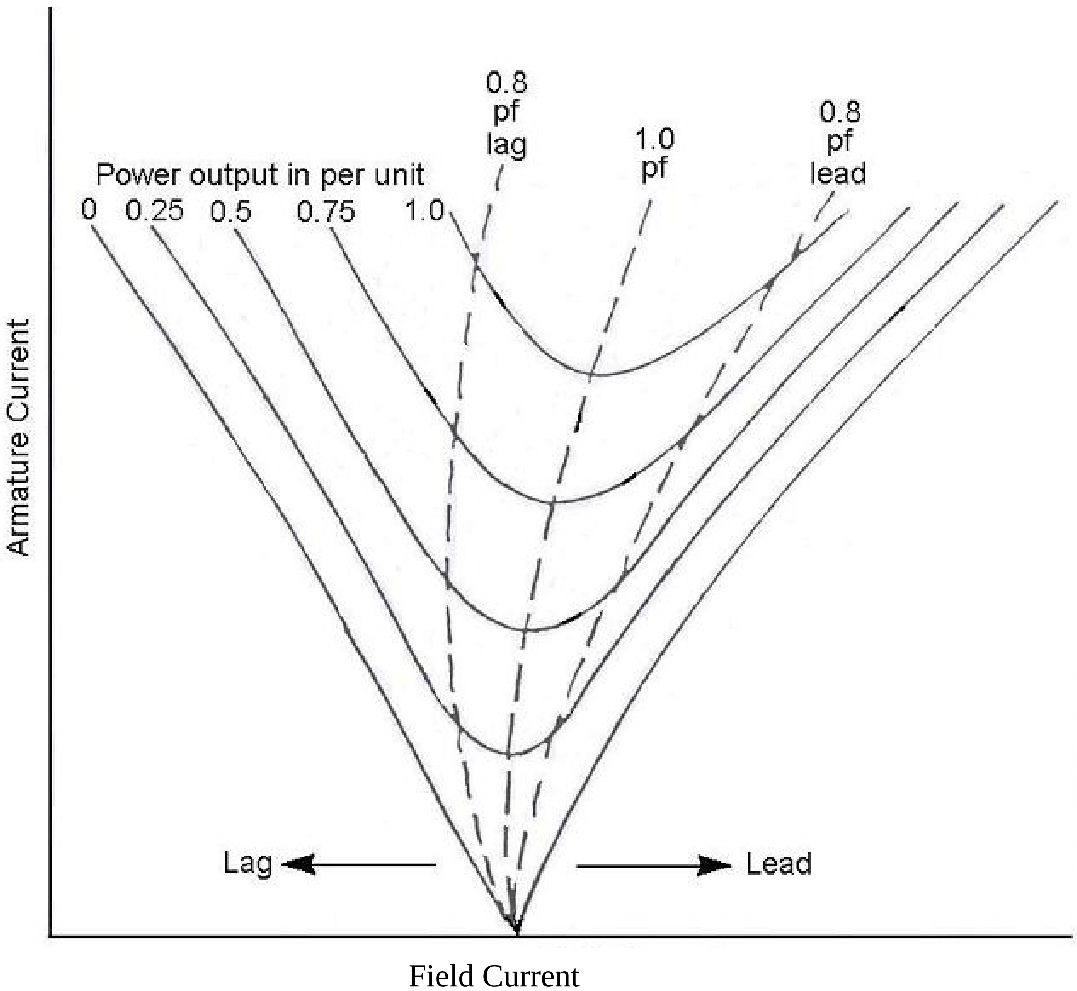

FIG. 6.1: Synchronous Motor V-curves

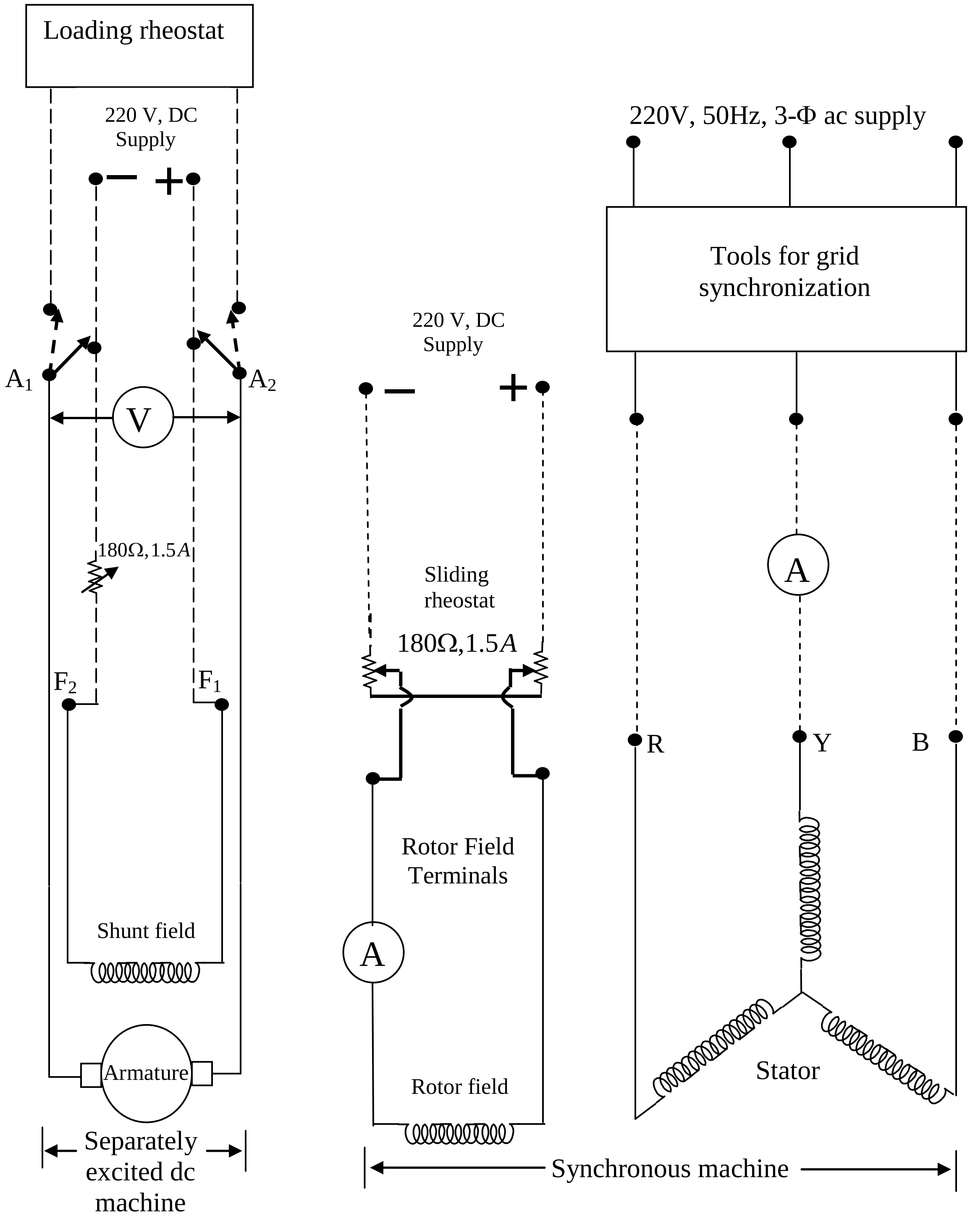

Fig. 6.2: Setup for Synchronous Machine

Synchronization of synchronous machine with grid

Theory:

Synchronous machine can be connected to the grid (represented by an equivalent generator) only when each of the voltages between the terminals $R_g\ R_s$, $Y_g\ Y_s$ and $B_g\ B_s$ is zero at any instant of time. This condition is fulfilled when the line voltages on the generator side are equal, at all instants of time, to the corresponding voltages on the bus bar side. This is possible only if the following conditions are fulfilled:

- The voltages V_{grid} and $V_{synchronousMachine}$ are equal in magnitude and are in phase.
- Both the Grid and synchronous generator must have same frequency of supply voltage.
- The generator and grid voltages should have the same phase sequence.

When these conditions are fulfilled, the synchronizing switch between the generator and the grid can be switched on. Fulfillment of these conditions is checked by the following methods:

A. *<u>Synchronization by three dark lamp method</u>:*

Connect the D.C. motor - synchronous generator as shown in figure 6.2. Start the D.C. motor and bring its speed to the synchronous speed of the generator (1500-rpm). Adjust the field excitation of the synchronous machine so that about rated voltage (400V, L-L) is obtained. Assume that the grid has 400V, L-L. Let the phase sequence of the generator terminals RYB be the same as that of the respective terminals of the grid, RYB. The voltage phasors for this condition are shown in figure 6.3.If the generator frequency is slightly more than that of the bus, then the phasors R_g, Y_g and B_g move anti-clockwise relative to R_s, Y_s, and B_s. The voltages across the lamps L_R, L_Y and L_B (which are indicated by the phasors $R_g\ R_s$, $Y_g\ Y_s$ and $B_g\ B_s$) will increase & decrease simultaneously and therefore, the three lamps will brighten up and darken at the same time.

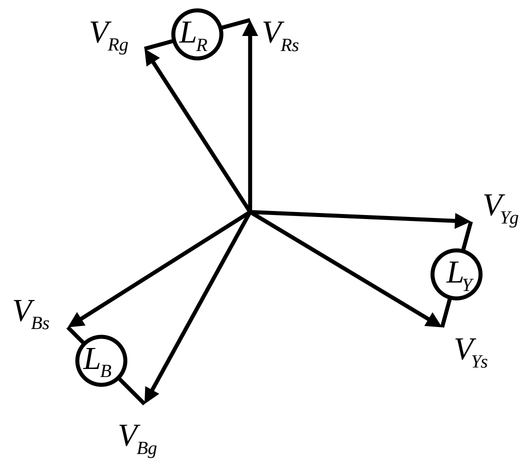

Figure 6.3 Voltage Phasors and Lamp connection for dark lamp method.

If the phase sequences are $R_g\ Y_g\ B_g$ and $R_s\ B_s\ Y_s$, for this condition the voltages across lamps given by phasors $R_g\ R_s, Y_g\ Y_s$ and $B_g\ B_s$ are not equal to each other at any instant. Therefore the lamps go through their zero voltage one after the other. The phase sequences are thus different and can be corrected by interchanging any two terminals either on the generator side or on the bus side. When such a change is made *both the three-phase main switch S2 and the D.C. main switch S1 should be switched off.*

With the phase sequence corrected, if there is a large difference between the frequency of the generator and that of the bus, the lamps will brighten & darken in quick succession. By adjusting the speed of the generator, this rapidity can be reduced, which indicates that the frequencies are coming closer and the lamps will brighten up & darken slowly.

The correct moment of synchronization in this method is when all the lamps are completely dark, at which time all the voltages of bus are exactly in phase with the corresponding voltages of the generator. At this moment the synchronizing switch S3 is closed and the generator is synchronized with the mains.

B. Bright lamp method:

C. Method of using synchroscope:

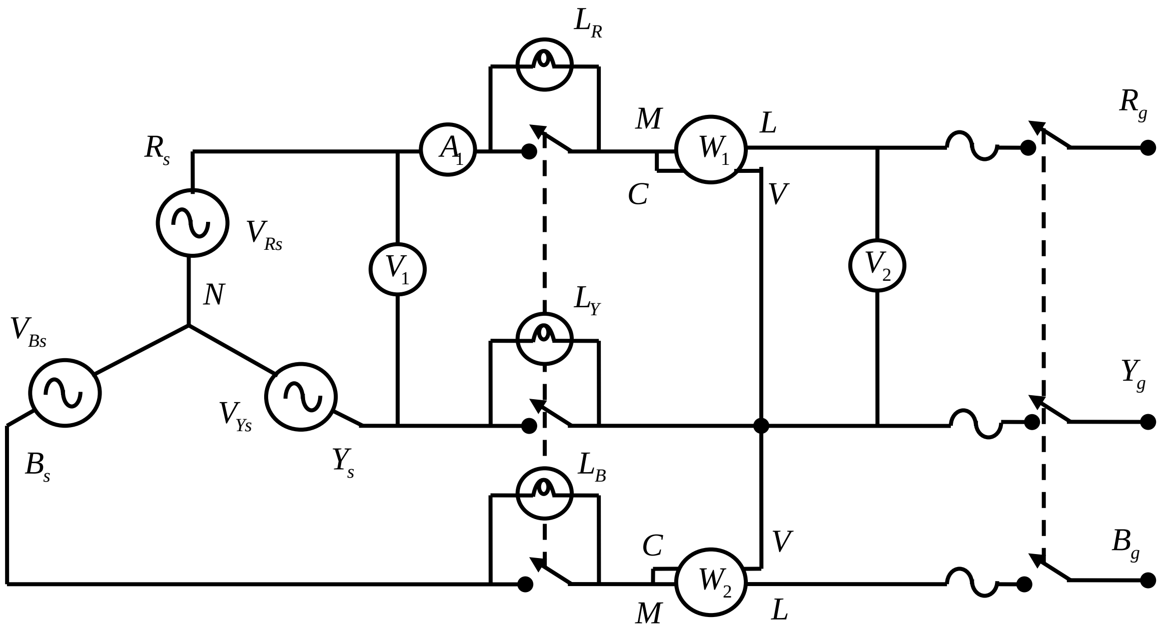

Fig. 6.3 Synchronization with grid using lamp method