Electrical Machines Laboratory

Department of Electrical Engineering, IIT Kharagpur

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Experiment #3

Synchronous Machine Experiments

Objectives

Study of different operating conditions of synchronous machine coupled with a DC machine using MATLAB/Simulink.

- Grid synchronization of synchronous machine
- V & inverted V-curve of synchronous machine in motoring & generating mode
- P - δ operating points of synchronous machine in motoring & generating mode

Machine Parameters and Ratings

DC Machine	Synchronous Machine
Power = 20 kW	Power = 20 kVA
Speed = 1500 RPM	Frequency = 50 Hz, Pole pairs = 2
Armature voltage, current = 300 V, 65 A	Armature voltage, current = 400 V (L-L rms), 30 A
Field voltage, current = 300 V, 5.7 A	Field voltage = 400 V

Procedure

1. **Operating the DC Machine at Rated Speed**

    - At starting, maximum field voltage and minimum armature voltage is applied for the DC-Machine to limit the starting current.
    - Gradually, the armature voltage is increased to rated value and speed is adjusted to nearly close to rated value by changing the field excitation.

(**Note**: Refer to Fig. 1 for the DC Machine connection. For this step, the synchronous machine block can be commented out.)

2. **Synchronous Machine excitation at No-Load**

   - The synchronous machine block is now mechanically coupled to the DC Machine. (Using the 'Mechanical input' setting in both the machines set to Mechanical rotational port and then connecting it to each other. Finally, connecting a 'Solver Configuration' block to that green connection wire.)
   - The Synchronous machine excitation is kept at 0 until the DC machine reaches its rated speed and the armature terminals are kept open.
   - The field excitation of the synchronous machine is then gradually increased to its rated value in steps and the no-load rms voltage at the armature terminals of the synchronous machine is noted at each step.

(**Note**: To avoid simulation error for No-Load case because of the open armature terminals of the synchronous machine, a three-phase star-connected resistive load of very high value ($\geq$ 1e6 Ω each) can be connected through a three-phase breaker block (Initial Status = Closed). At this point, the current drawn by the high resistive load is so negligible compared to the machine current rating that this simulates the no-load condition of the machine.)

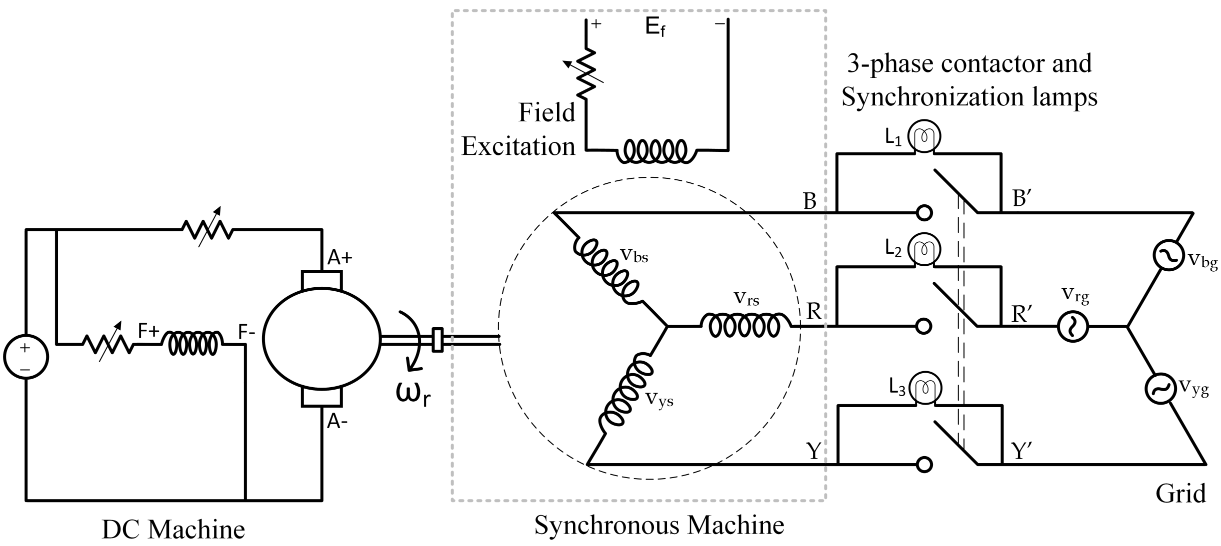

Figure 1. Complete connection diagram for grid-synchronization using three dark lamp method.

3. **Grid Synchronization**

- For simulating the grid, three-phase AC source is added with voltage set to 400 V (L-L rms) and frequency set to 50 Hz.
- The synchronous machine can be connected to the grid only if the following conditions are met: Both the grid and machine generated voltages must have equal line voltage magnitude, frequency and phase sequence.
- Fig. 1 shows the complete connection diagram for grid-synchronization using three dark lamp method.
- A three-phase breaker can be used as the three-phase synchronization switch (Initial Status = Open)
- For checking the grid-synchronization criteria, the instantaneous values of the Grid and Machine generated voltage is compared individually for all 3 phases and a logic value is obtained at output according to the following:

Logic	**Condition**	**Status of Lamps**	**Action to be taken**
1	Grid and Machine voltage rms and phase sequence matching for all 3 phases	Dark	No-Load Breaker Switch = Open Synchronization Switch = Closed (As Synchronization is allowed)
0	Otherwise	Bright	No-Load Breaker Switch = Closed Synchronization Switch = Open (As Synchronization is not allowed)

- Once the difference of both the rms value and phase sequence of the Grid and Machine generated voltage are nearly equal to 0 (equivalent to logic state 1 and all dark lamps), the Grid-connection switch is closed and No-Load connection switch is opened and the machine is synchronized to the grid.

(**Note**: When all the Lamps become dark instantaneously, the simulation can be paused at that instant to change the synchronization switch Logic value from 0 to 1.)

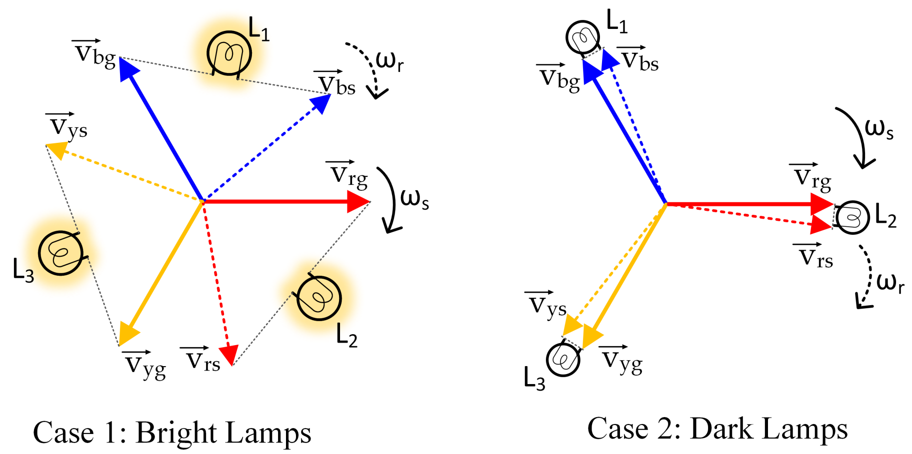

Figure 2. Status of three lamps for different phase conditions of machine and grid voltage.

4. **Synchronous machine loading in generating and motoring mode**
   - The synchronous machine can now be loaded as generator/motor for different load power operating points by varying the field excitation of the DC Machine.
   - A particular load output power (generating/motor) is set following the above step.
   - Now, varying the field excitation of synchronous machine above and below the normal excitation state (corresponding to unity power factor), the armature current can be increased/decreased (within rated current limits). Plotting the armature currents with field excitation, V-curves are obtained.

Theory

'V' Curves of Synchronous Machine

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 (or grid), 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 VIcosϕ constant. Because of their shape (Fig. 3), 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". If the power factor is plotted against excitation for various load conditions, we obtain a set of curves known as 'Inverted V-Curves'. From inverted V-curves (Fig. 4), it is observed that the power factor is lagging when the motor is under excited and leading when it is over-excited. In between, the power factor is unity.

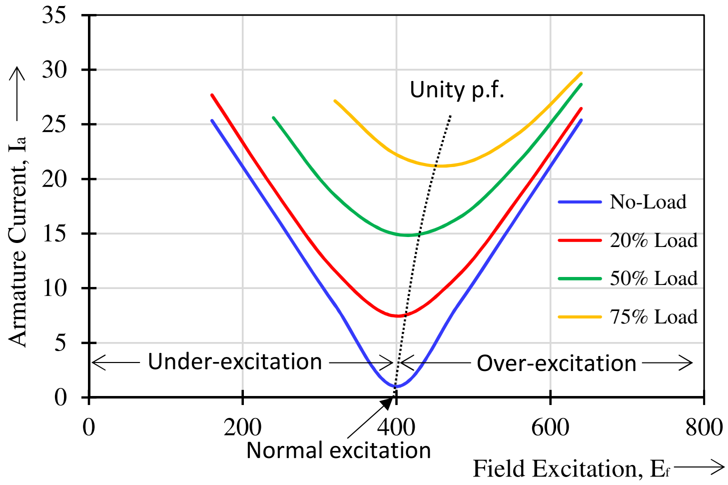

Figure 3. V Curves of synchronous Machine.

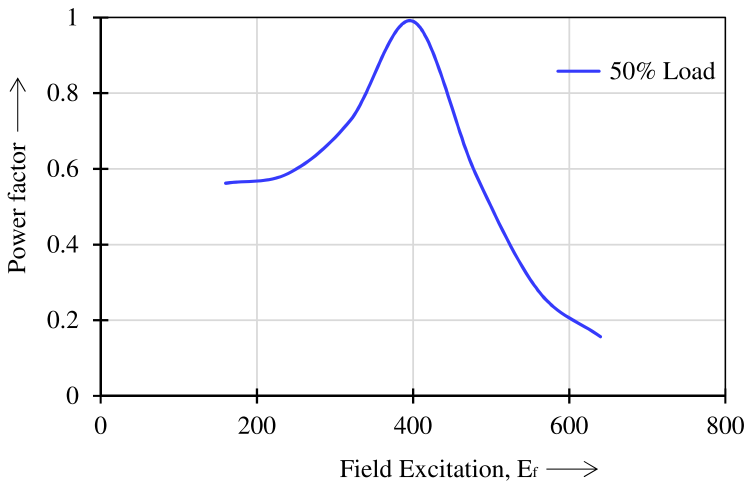

Figure 4. Inverted V-Curve of Synchronous Machine.