1 Experiment No. 7

2 Experiment Title

Observation of Load Characteristics of three phase Synchronous motor.

3 Objective

The objectives of this lab are as follows:

- To observe the variation of armature current with mechanical load.
- To analyze the effect of excitation on motor performance under varying loads

4 Theory

A synchronous motor is a type of AC motor in which the rotor rotates at exactly the same speed as the stator's rotating magnetic field. This constant speed is called the **synchronous speed** and is given by:

$$N_s = \frac{120f}{P} \tag{1}$$

where, N_s = synchronous speed in rpm, f = supply frequency in Hz, P = number of poles of the motor.
Unlike induction motors, the synchronous motor does not experience slip under steady-state conditions and maintains constant speed regardless of load variations, as long as it remains in synchronism.

Starting Mechanism

When a three-phase AC supply is applied to the stator, it produces a rotating magnetic field. However, the rotor initially cannot lock into this field directly. Therefore, auxiliary starting mechanisms, such as damper windings (similar to squirrel cage rotors) or external prime movers, are used to bring the rotor speed close to synchronous speed. Once this condition is achieved, the rotor's magnetic field locks with the stator's rotating field, allowing synchronous operation.

Voltage Equation

The per-phase voltage equation of a synchronous motor is:

$$V_\phi = E_A + I_A R_A + jI_A X_s \tag{2}$$

where, V_ϕ = stator terminal voltage per phase, E_A = internal generated EMF per phase, I_A = armature current per phase, R_A = armature resistance, X_s = synchronous reactance.
If the armature resistance R_A is neglected, the equation simplifies to:

$$V_\phi = E_A + jI_A X_s \tag{3}$$

Load Characteristics

As the mechanical load on the motor shaft changes, the synchronous motor exhibits specific load-dependent behaviors:

1. **Constant Speed:** The rotor speed remains constant and equal to synchronous speed regardless of load changes. This is a defining characteristic of synchronous motors.
2. **Torque Angle (δ):** The torque angle δ is the angle between the stator magnetic field and the rotor magnetic field. As the load increases, the motor increases torque by increasing δ. If δ exceeds a critical value (associated with pull-out torque), the motor loses synchronism.
3. **Armature Current (I_A):** With increasing mechanical load, the armature current increases to meet the required torque. This current increase is not due to a change in speed but is driven by torque demand.
4. **Power Factor Variation:** The power factor of a synchronous motor is dependent on the level of field excitation:
   - Under-excited ($E_A < V_\phi$): Lagging power factor.
   - Normal excitation ($E_A = V_\phi$): Unity power factor.
   - Over-excited ($E_A > V_\phi$): Leading power factor.

   As load increases, the power factor shifts further in the lagging direction for under-excited machines and less leading for over-excited ones.

Power and Torque Expression

The electromagnetic torque developed by a synchronous motor is given by:

$$T = \frac{3EV}{\omega_s X_s} \sin\delta \tag{4}$$

where, E = internal EMF, V = terminal voltage, ω_s = synchronous angular speed, X_s = synchronous reactance, δ = torque angle.

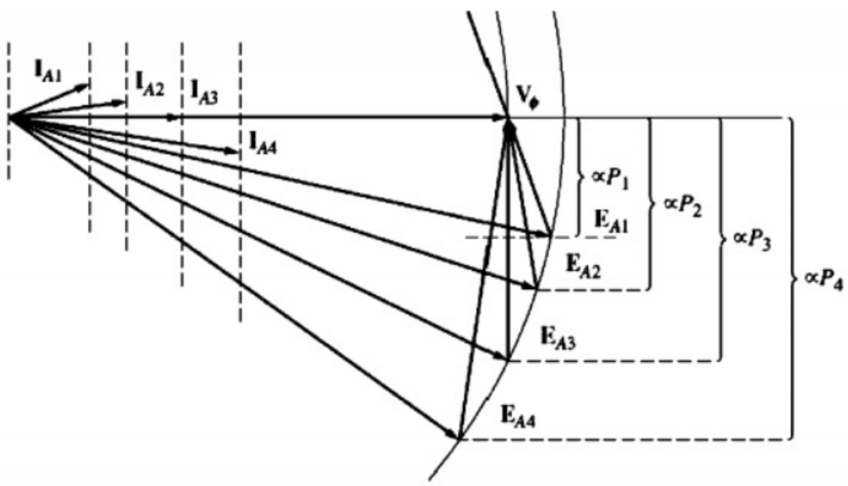

Figure 1: The phasor diagram of increase load on the operation of a synchronous motor

4.1 Effect of Load on Phasor Diagram

As the load increases:

- The torque angle δ increases.
- The vector jX_sI_A becomes longer to maintain the voltage relation between E_A and V_ϕ.
- The armature current I_A increases in magnitude.
- The power factor angle θ changes accordingly—becoming less leading or more lagging.

Since the field current (I_F) and supply frequency remain constant, the magnitude of $E_A = K\phi\omega$ remains unchanged. However, as δ increases, E_A swings further below the horizontal axis in the phasor diagram. The tip of jX_sI_A must reach from the tip of E_A to V_ϕ, leading to an increase in I_A and a change in the power factor.

5 Circuit Diagram

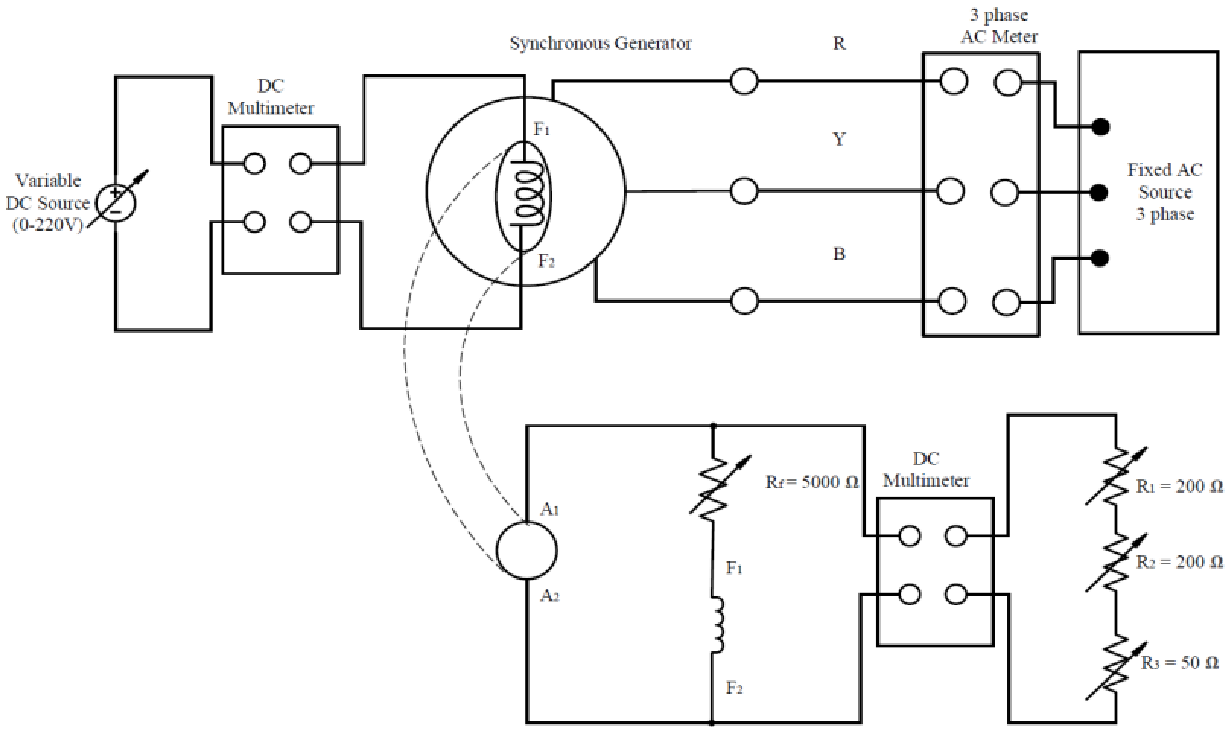

Figure 2: Experimental Setup of Synchronous Motor under load variations

6 Required Apparatus

1. **DC Motor**
   (a) Power: 300W , Speed: 3000 rpm
   (b) Voltage: 220V
   (c) **Excitation (Series)**: D1-D2, Current: 1.9A, **Excitation (Separate)**: F1-F2, Current: 1.8A, Excitation Voltage: 220V, Excitation Current: 0.1A

2. **Synchronous Motor**
   (a) Power: 350W ,Power Factor: $\cos\phi = 1$,Speed: 3000 rpm
   (b) Voltage: 400V (star) / 230V (delta) ,Current: 0.7A (star) / 1.2A (delta)
   (c) Excitation Voltage: 220V ,Excitation Current: 0.45A

3. **Resistors**
   (a) 50Ω: Power = 500W, Current = 3.16A
   (b) 200Ω: Power = 500W, Current = 1.58A
   (c) 5000Ω: Power = 500W, Current = 0.31A

4. **Tachometer**
   (a) For 0.6V/rev: 300V at 5000 RPM , For 2mV/rev: 10V at 5000 RPM
   (b) Maximum Current: 0.07A
   (c) Maximum Speed: 5000 RPM

5. **AC Multimeter**
   (a) 500V AC RMS
   (b) 5A

7 Data Table

Table 1: Experimental Data of Synchronous Motor under load variations

SL No.	Load Current, I_A (A)	Active Power, P (W)	Reactive Power, Q (VAR)	Motor Current, I_M (A)
01.	0.197	28.0	71.4	0.304
02.	0.206	30.5	71.2	0.343
03.	0.205	30.6	72.2	0.338
04.	0.211	30.4	71.5	0.334
05.	0.212	29.7	71.6	0.339
06.	0.210	28.3	72.3	0.338
07.	0.205	28.6	71.9	0.336
08.	0.202	29.1	70.9	0.335
09.	0.195	28.9	71.5	0.332
10.	0.104	28.9	71.1	0.333
11.	0.203	28.4	70.2	0.331
12.	0.208	28.1	70.7	0.329
13.	0.215	28.6	70.6	0.331
14.	0.218	28.6	70.2	0.334

8 Discussion

In this experiment, the load characteristics of a synchronous motor were tested under a fixed supply voltage. The motor was operated at a constant synchronous speed throughout the test, indicating that proper synchronization had been achieved.
As mechanical load was gradually increased, corresponding load and motor currents were recorded. It was observed that the motor current varied slightly with load, implying that the increments in mechanical load were relatively small and that the field excitation had likely been maintained at a constant level. Active and reactive power values remained nearly unchanged, which suggested minimal fluctuation in the power factor.
No instance of loss of synchronism was encountered during the experiment. This indicated that the motor had been operated within its stability limit and that the pull-out torque had not been exceeded.
Overall, the synchronous motor's behavior under varying load conditions exhibited stable electrical performance and confirmed the theoretical expectation of constant-speed operation, regardless of changes in load.