1 Experiment No. 6

2 Experiment Title

Determination of V-Curve of a synchronous motor.

3 Objective

The objectives of this lab are as follows:

- To study the variation of armature current with respect to the field current in a synchronous motor under constant load
- To determine the V-Curve of a synchronous motor by plotting a graph of field current versus armature current.
- To understand the over-excited and under-excited operating conditions of a synchronous motor.

4 Theory

A synchronous motor operates at a constant speed synchronized with the frequency of the supply voltage. One of its distinguishing features is the ability to control its power factor by varying the excitation (field) current. The rotor winding is excited with direct current (DC) through slip rings, while the stator is powered by a three-phase alternating current (AC) supply.
Depending on the excitation level, the motor operates in the following modes:

- **Under-Excited:** The motor draws a lagging current, similar to an inductive load.
- **Normal-Excited:** The motor operates at unity power factor.
- **Over-Excited:** The motor draws a leading current, like a capacitive load.

V-Curve of Synchronous Motor

The V-curve is a plot of armature current (I_A) versus field current (I_f) at constant mechanical load. The curve resembles the shape of the letter "V". As the field current increases:

- The armature current initially decreases.
- At unity power factor, I_A is minimum.
- Beyond this point, I_A increases again with over-excitation.

This behavior is due to the interplay between excitation and the motor's reactive power behavior.

Voltage Equation of a Synchronous Motor

The synchronous motor voltage equation is given by:

$$E_A = V_\phi - I_A R_A - jX_s I_A \tag{1}$$

Where:

- E_A = Internal generated voltage (back EMF)
- V_ϕ = Terminal phase voltage
- I_A = Armature current
- R_A = Armature resistance
- X_s = Synchronous reactance

Power Developed by the Motor

The real power developed by a synchronous motor is:

$$P = \frac{E_A V_\phi}{X_s} \sin \delta \tag{2}$$

Where:

- P = Power output
- δ = Torque angle (also called power angle)

For a **generator**, δ is positive, indicating power supply. For a **motor**, δ is negative, signifying power consumption.

Types of Synchronous Motors

Synchronous motors can be classified into two major types:

1. **Non-Excited Synchronous Motors**
2. **Direct Current (DC) Excited Synchronous Motors**

Excited synchronous motors can be further categorized as:

- **Under-Excited:** V_ϕ lags E_A
- **Over-Excited:** V_ϕ leads E_A

Armature Current Behavior with Field Current

As the excitation voltage (E_A) increases, the armature current (I_A) initially decreases, reaching a minimum at unity power factor. This is followed by an increase in I_A as E_A continues to increase. The armature current behavior is as follows:

- At low E_A, I_A lags and the motor consumes reactive power.
- At unity power factor, I_A aligns with V_ϕ and behaves as a resistive load.
- At high E_A, I_A leads and the motor supplies reactive power to the system.

Graphical Representation

Plotting the field current (I_f) on the x-axis and the armature current (I_A) on the y-axis results in a characteristic "V" shape, known as the V-curve of a synchronous motor.

5 Circuit Diagram

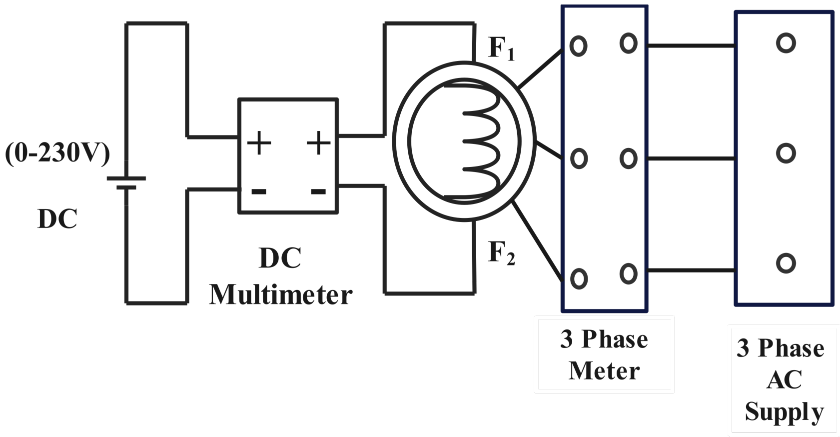

Figure 1: Experimental setup for obtaining V curve

6 Required Apparatus

1. Three-phase synchronous motor [Rated: $U = 400\,\text{V (Y)}/230\,\text{V}(\Delta),\ I = 0.57\,\text{A}/1\,\text{A},\ I_{\text{exc}} = 0.45\,\text{A}$]
2. Variable DC source [Rated: 0–$230\,\text{V},\ 3\,\text{A}$]
3. Tachogenerator [Rated: $I = 0.07\,\text{A max},\ n = 5000\,\text{rpm max}$]
4. DC multimeter [Rated: $600\,\text{V}$–$20\,\text{A}$]
5. AC multimeter [Rated: $500\,\text{V rms max},\ 5\,\text{A max}$]
6. Connecting wires
7. 3-phase fixed AC supply

Data Table:

Table 6.1 for obtaining V curve

SI. No.	Field Voltage, V_{field} (Volt)	Field Current, I_f (Amp)	Armature Current, I_A (Amp)	Active Power, P (Watt)	Reactive Power, Q (VAR)	Power factor ,pf
01.	20.51	0.040	0.461	22.4	105.2	0.2083
02.	37.45	0.082	0.375	21.2	85.8	0.2399
03.	4.82	0.105	0.321	20.6	72.7	0.2726
04.	55.52	0.125	0.296	19.5	65.8	0.2841
05.	60.38	0.136	0.274	19.1	60.6	0.3006
06.	65.01	0.150	0.260	18.7	58.0	0.3069
07.	71.17	0.157	0.230	18.3	51.5	0.3348
08	78.19	0.172	0.202	17.4	44.2	0.3663
09.	82.77	0.180	0.189	17.3	41.2	0.3872
10.	87.08	0.191	0.170	17.2	36.2	0.4292
11.	91.33	0.202	0.157	16.9	32.6	0.4602
12.	97.82	0.218	0.134	16.5	26.6	0.5271
13.	105.5	0.227	0.110	16.7	20.8	0.6261
14.	112.8	0.247	0.091	16.5	14.0	0.7625
15.	119.2	0.258	0.080	16.0	9.00	0.8716
16.	128.2	0.276	0.069	15.7	-6.10	0.9321
17.	139.7	0.301	0.088	15.7	-13.10	0.7678
18.	146.9	0.317	0.104	14.9	-19.10	0.6151
19.	150.6	0.320	0.115	15.3	-20.10	0.6057
20.	156.7	0.329	0.126	17.0	-24.40	0.5717
21.	168.8	0.355	0.164	16.8	-134.8	0.1237
22.	177.0	0.370	0.190	16.8	-132.8	0.1255

7 Graph

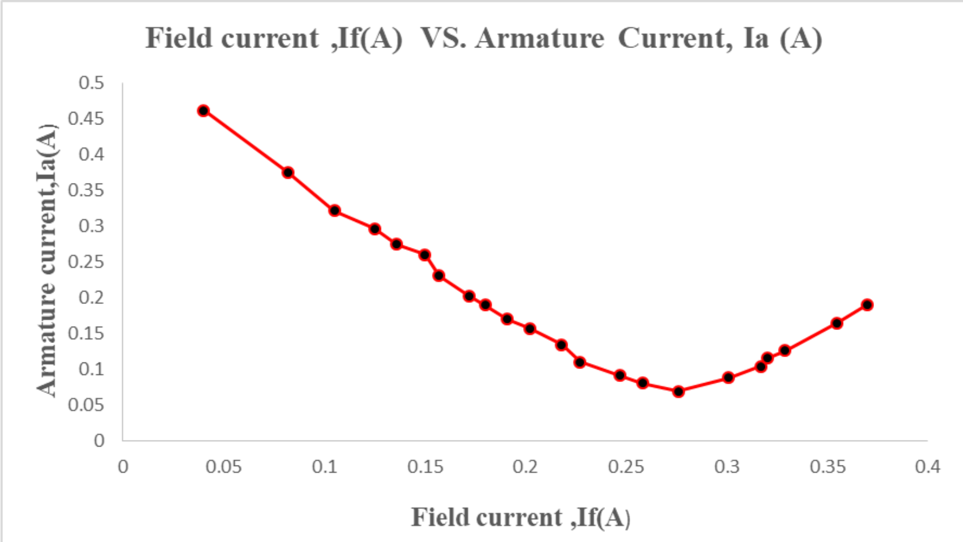

Figure 2: Obtained V curve of a synchronous motor

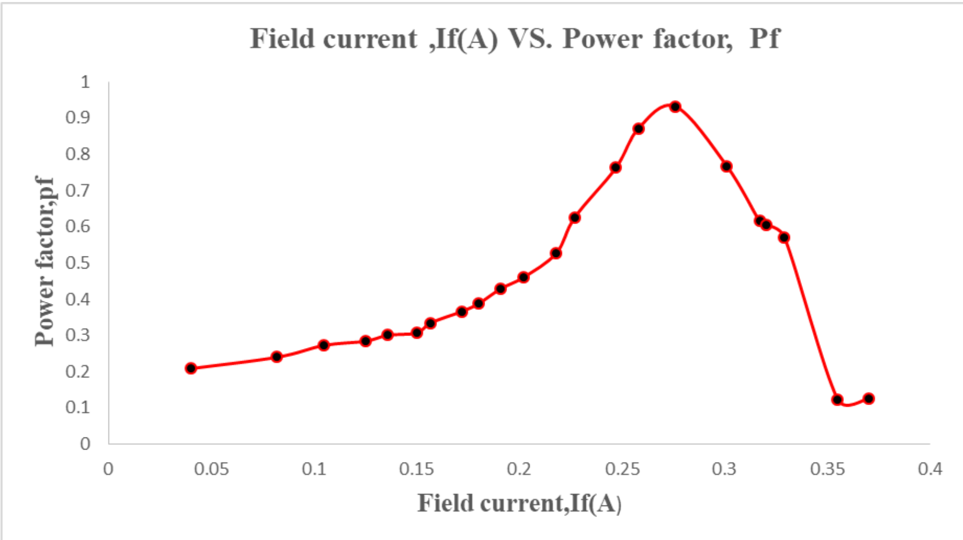

Figure 3: Obtained V curve of a synchronous motor

8 Discussion

In this experiment, the effect of field current on the armature current and power factor of a synchronous motor was observed. It was found that the armature current decreased to a minimum at normal excitation, corresponding to a unity power factor, and then increased with further excitation. From the V-curve, it was evident that under-excitation resulted in a lagging power factor, while over-excitation led to a leading power factor, as shown in the inverse V-curve. These results demonstrated that the power factor of a synchronous motor could be effectively controlled by adjusting the excitation level.

Overall, the experiment effectively demonstrated the critical role of the auxiliary winding and capacitor in enabling self-starting in single-phase induction motors.