Synchronous Generators

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Introduction

The objective of today's laboratory is to learn about specific tests we can perform on synchronous generators to find their circuit characteristics. Namely, the following tests:

- Short Circuit Test (SCC)
- Open Circuit Test (OCC)

Additionally we will also be investigating the proper procedure in connecting/synchronizing our generator with the power grid. This is important to improve our understanding of power systems by better understanding a vital component within them.

Results

The recorded values are presented below in tabular format.

I_f [A]	0.35	0.4	0.45	0.5	0.55	0.6
V_1 [V]	80.3	90.9	101.1	110.8	120.2	129.1
V_2 [V]	80.1	90.6	100.5	110.2	119.9	128.6
V_3 [V]	80.4	90.7	100.6	110.3	120	131.8
V [V]	80.3	90.7	100.7	110.4	120	129.8

Table 1: Open Circuit Test Measurements (1800 RPM)

I_f [A]	0.35	0.40	0.45	0.50	0.55	0.60
I_1 [A]	0.8	0.91	1.01	1.13	1.25	1.36
I_2 [A]	0.8	0.92	1.02	1.15	1.26	1.38
I [A]	0.8	0.92	1.02	1.14	1.26	1.37

Table 2: Short Circuit Test Measurements (1800 RPM)

I_f [A]	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8	0.85
V_1 [V]	214	214.4	214.5	214.4	214.5	214.4	214.5	214.4	214.5	214.4	214.5
V_2 [V]	214.3	214.2	214.3	214.4	214.4	214.5	214.4	214.5	214.4	214.5	214.4
I_1 [A]	1.37	1.26	1.15	1.04	0.92	0.81	0.7	0.58	0.47	0.34	0.22
I_2 [A]	1.34	1.23	1.11	0.99	0.88	0.77	0.66	0.54	0.43	0.31	0.2
P_1 [W]	231.0	212.9	194.4	175.7	155.5	136.8	118.3	98.0	79.4	57.4	37.2
P_2 [W]	226.3	207.6	187.4	167.3	148.7	130.2	111.5	91.3	72.6	52.4	33.8

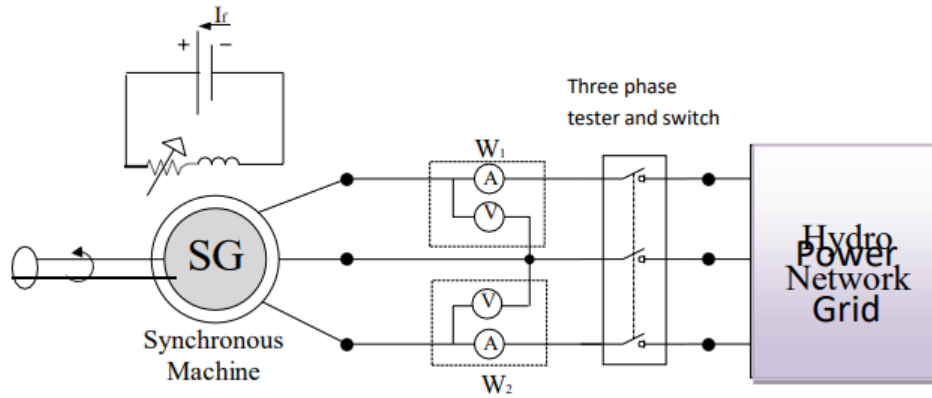Table 3: Synchronization with Power Grid Measurements, with phase angle of 38 deg

The values in Table 1 were recorded through performing the open circuit test on the generator. This involves connecting the generator as shown in Circuit 1. The values in table 2 were recorded through performing the short circuit test on the generator. This involves connecting the generator as shown in Circuit 2. Lastly, the values in table 3 were found by connecting Circuit 3.
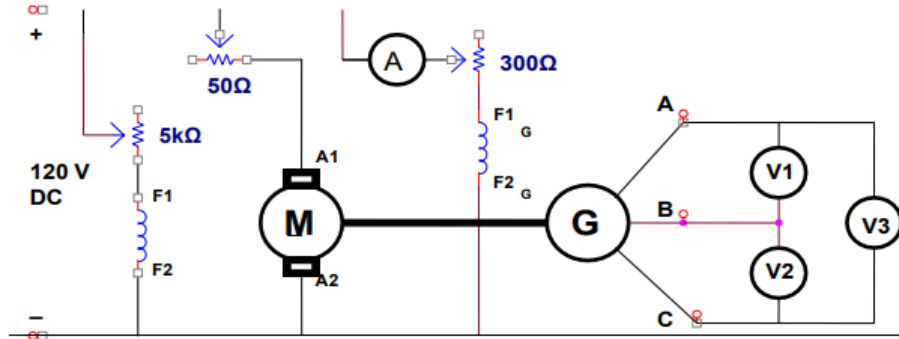
Circuit 1: Open Circuit Test Configuration
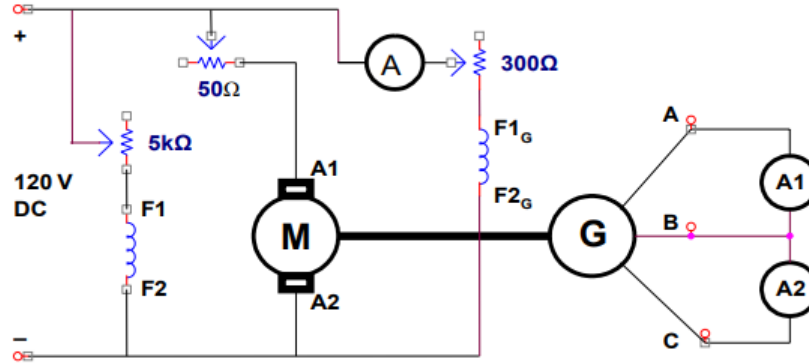
Circuit 2: Short Circuit Test Configuration

Circuit 3: Synchronization with the Power Grid

Discussion

The results gathered in the previous section make sense, and align with theory. We know that synchronous generators operate through inducing a current in the stator, by means of a rotor with some magnetic field determined by the magnitude of a field current I_f. The data in Table 1 supports this theory, as we can see that the average voltage V increases with an increasing I_f, in other words we can write $V \propto I_f$.

This is also as expected with the short circuit test, we know that the induced voltage is stagnant (produces no current) during the open circuit test, but during the short circuit test there is an induced current but no voltage (due to the short circuit), thus we should see similar behavior: $I \propto I_f$, which is what we do observe in Table 2.

In terms of Table 3, we simply tabulated the measured values while following the procedure outlined in the lab manual.

Questions

Prelab

1. Starting this type of motor requires gradually ramping up the voltage supplied to the windings. This works because the field windings are connected in parallel with the armature windings, essentially we start it up slowly by energizing both the field and armature and slowly increasing the voltage.

2. To modify the speed in a shunt motor you should add a potentiometer connected in series with the armature windings, this will limit the amount of current flowing into the field, effectively modifying speed.

3. We can control the mechanical output power (speed x torque) by increasing the speed of the motor, by increasing the field current of the motor. This would involve adding a potentiometer in the armature winding to modify this field current, increasing the motor speed by correctly adjusting the potentiometer.

4. To prevent damage during the short circuit test (SCC). The voltage of the generator should be low. We do this to avoid the setup from damage due to high currents.

5. Each wattmeter in the two-wattmeter setup is used to read line-to-line voltage, line current, and phase power.

6. Since the wattmeter measures current in terms of polarity + to -, we should take the absolute value of the reading as it means essentially the same thing.

7. To connect to the grid, we need to match the voltage, frequency, and phase (power angle) to the grid's values for those parameters.

8. After Synchronization we should not change the characteristics of the motors, as that would cause a mismatch with the grid. Before Synchronization we can change this by changing the field current of the shunt motor, similar to the description in question 2.

Postlab
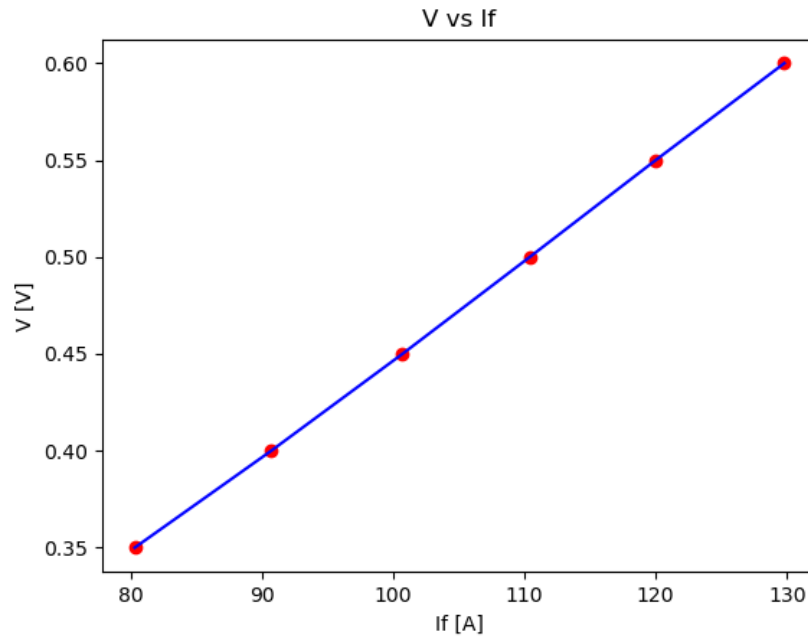
The questions outlined in the lab manual are answered here in order.

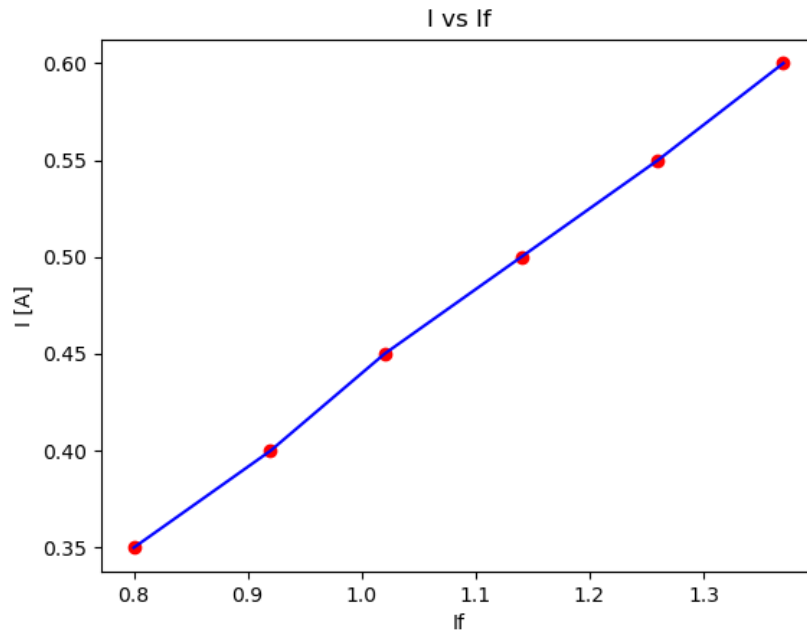1. The nameplate data from the synchronous generator and motor are shown here:

Image 1: Motor and Generator Nameplates

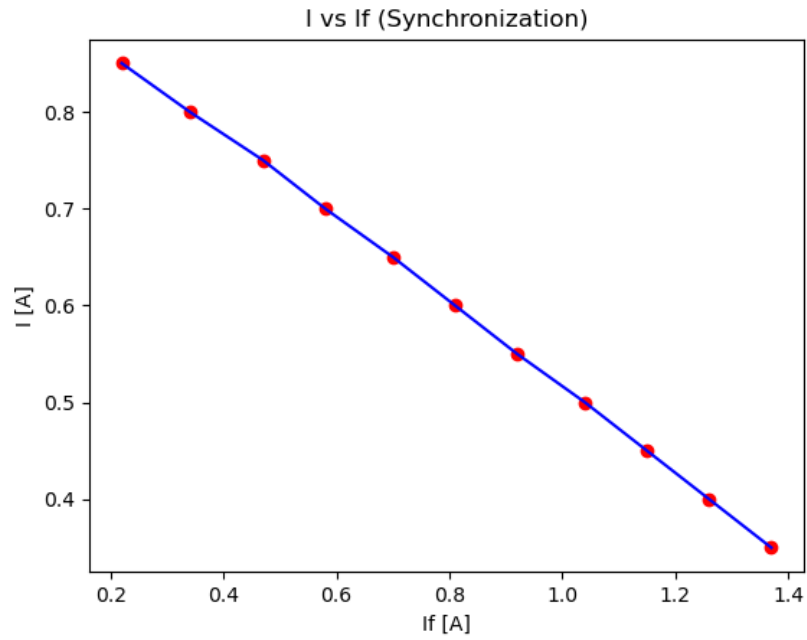2. The plot of V vs I_f for the OCC (Table 1) is shown here:

Plot 1: V vs If

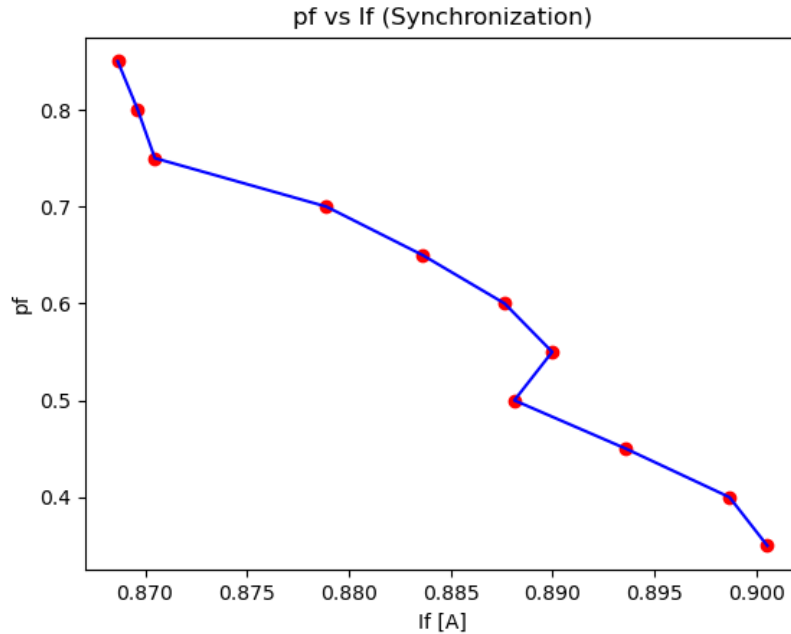3. The plot of I vs I_f for the SCC (Table 2) is shown here:

Plot 2: I vs If

4. The plot of I vs I_f for the Synchronization (Table 3) is shown here:

Plot 3: I vs If for the Power Grid Synchronization

5. The plot of pf vs I_f for the Synchronization (Table 3) is shown here:

Plot 4: power factor (pf) vs. If for the Power Grid Synchronization

6. Calculation of synchronous reactance X_s and resistance R_a for the synchronous machine is done below:

We can find X_s by dividing the open circuit voltage V_o by the short circuit current I_s. Doing this with the rightmost-value in Table 1 and Table 2 gives:

$$X_s = \frac{V_o}{\sqrt{3}I_s} = \frac{129.8}{\sqrt{31.37}} = 54.73\Omega$$

7. *See the* **Discussion** *Section**

8. Precautions taken for this lab experiment were to always start the three potentiometers at their required setting. This involved starting the 5k and 50 ohm at their max, and the 300 ohm at its minimum. We also made sure to unplug the live wires before modifying anything in the circuit, and made sure to get T.A sign off on circuits we connected before powering them on.

Conclusions

Performing the Open Circuit Test (OCC) and Short Circuit Test (SCC) experiments on the synchronous machine provided us with key insights in the operation of a synchronous machine. The OCC showed that Voltage is proportional to Field Current (which was as expected). The SSC showed the same behaviour, that current was proportional to field current, which was also as expected.

Successfully synchronizing the machine with the power grid, taught us safety precautions and the use of strobe meters to test for phase angle. Overall this lab helped to deepen our understanding of the actual use of synchronous machines, beyond their basic operating principles.