Synchronous Machine Power Characteristics

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1 INTRODUCTION

The objective of this lab was to get exposed to synchronous motors and explore another, easier, way to driving them into synchronization (unlike lab 6 where we used light bulbs). Initial tests consisted of obtaining a V curve through using the dynamometer to apply different torques to the motor. This was for the reactive power characteristics. For the real power characteristics we used sudden loading method to find maximum torque which with speed can be used to find max power. Finally in the third part of the lab we operated the synchronous machine as a generator, all we did was take a few measurements when the torque direction was reversed and the machine was operated as a generator.

All data/measurements taken are provided in the appendix at the bottom of the document.

2 RESULTS

2.1 *Reactive Power Tests*

The data collected from the first part of the lab is below, which can be used to obtain a V curve.

Table 1: Torque = 0Nm

Rf (ohms)	Vab (V)	Vcb (V)	Ia (A)	Ic (A)	If (A)	Power (W)
500	172.2	172.6	2.4	2.4	.37	120
250	172.6	172.9	.67	.74	.64	112
166.6	172.6	172.9	.78	.76	.78	110
125	172.7	173.3	1.7	1.7	.9	115
100	172.8	173.6	2.4	2.3	.99	150
83.3	172.5	173.6	2.9	2.9	1.05	100
71.4	173.5	174	3.4	3.2	1.1	150
62.5	173	173.8	3.7	3.6	1.1	150
55.56	173.7	173.8	3.8	3.8	1.2	120
50	173.6	173.9	4.1	4	1.2	140

Table 2: Torque = 1Nm

Rf (ohms)	Vab (V)	Vcb (V)	Ia (A)	Ic (A)	If (A)	Power (W)
500	172	172	2.7	2.8	.37	340
250	172	173	1.2	1.3	.6	330
166.6	172.4	173	1.17	1.2	.8	330
125	173	174	1.8	1.8	.9	330
100	173	174	2.3	2.3	1.0	335
83.3	173	174	2.8	2.7	1.05	340
71.4	173	174	3.2	3.1	1.1	350
62.5	173	174	3.5	3.4	1.12	350
55.56	173	174	3.8	3.6	1.2	360

Table 3: Torque = 2Nm

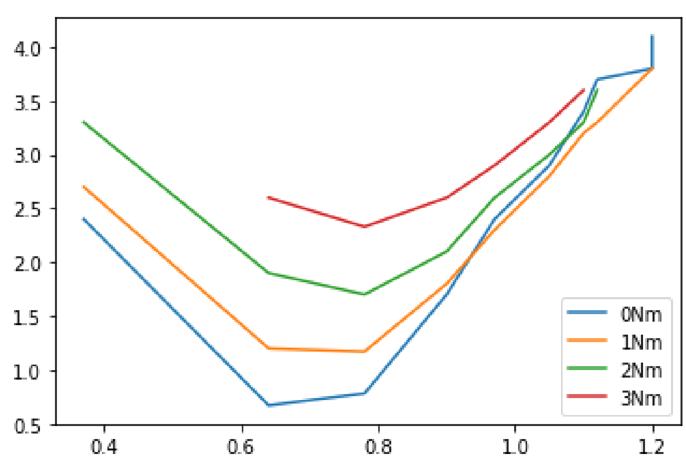
Rf (ohms)	Vab (V)	Vcb (V)	Ia (A)	Ic (A)	If (A)	Power (W)
500	171	172	3.3	3.3	.37	530
250	171	172	1.9	2.0	.6	520
166.6	172	172	1.7	1.8	.8	510
125	172	173	2.1	2.2	.9	520
100	172	173	2.6	2.6	1.0	525
83.3	172	173	3.0	3.0	1.03	530
71.4	172	173	3.3	3.3	1.1	535
62.5	172	173	3.6	3.5	1.1	535

Table 4: Torque = 3Nm

Rf (ohms)	Vab (V)	Vcb (V)	Ia (A)	Ic (A)	If (A)	Power (W)
500	OVER RATED	NA	NA	NA	NA	NA
250	171	171	2.6	2.7	.6	710
166.6	171	172	2.33	2.4	.8	700
125	171	172	2.6	2.6	.9	710
100	171	172	2.9	3.0	1.0	720
83.3	171	172	3.3	3.3	1.02	720
71.4	171	172	3.6	3.5	1.1	720

Putting this data on a graph we get the following curves:

Fig.1 V Curves (Ia vs If)



With the above data we can also calculate Qin by the following formula (We had to do it this way since we did not record separate watt-meter readings and only recorded the sum of the 2):

$$S = \sqrt{3} \cdot V \cdot I Q = \sqrt{S^2 - P^2}$$ **Equation 1.**

$$Q = \sqrt{S^2 - P^2}$$ **Equation 2.**

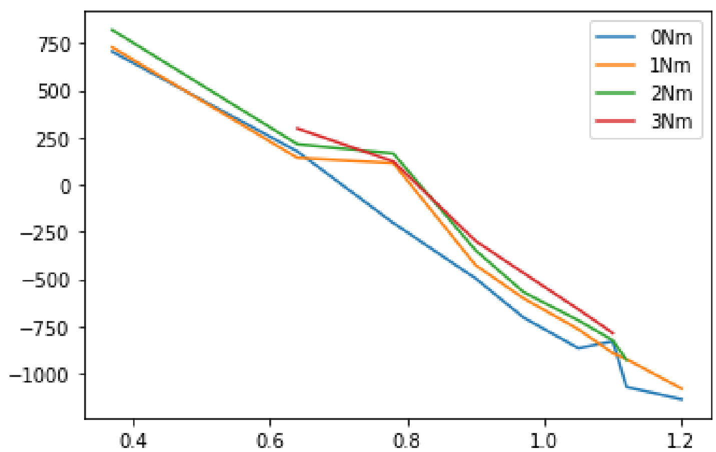
These are the Q values we get.

Table 5: Reactive Power Values

Torque (Nm)	500Ω	250Ω	166.7Ω	125Ω	100Ω	83.3Ω	71.4Ω	62.5Ω	55.56Ω
0	706	176.9	202.8	496.8	704.6	866.7	829.4	1072	1137.6
1	728.9	142.8	114.7	426.6	602.3	767	892.7	924.8	1080.2
2	821.2	215.1	165.7	347.8	569.5	719.6	824.8	929.5	NA
3	NA	298.2	123.6	298.2	468.3	661	786.4	NA	NA

If we plot this against field current, these are the graphs we get:

Fig.2 Qin Vs If



This trend makes sense because we are minimising cos() which is the negative part in Q formula. So higher torque means more Qin.

2.2 *Real Power Tests*

In this part of the lab we did a similar test as before but also recorded the torque angle, we also ran the tests at 60% voltage.

Table 6: Real Power Values

Torque (Nm)	Vab (V)	Vcb (V)	Ia (A)	Ic (A)	If (A)	Power (W)	Delta (degrees)
0	121.3	122	.93	1.00	.38	100	250
.5	121	121	1.35	1.44	.37	115	255
1	120.1	120.8	1.8	1.9	.37	310	260
1.5	119.5	120.1	2.4	2.4	.37	410	265
2	118.7	119.4	3.08	3.15	.37	500	272

To find the power curve we have to use the following equation, where $\Delta\delta$ is the difference between no load torque power and our point, P1 is the power at a point and Po is the power at no load.

$$tan(\delta_0) = \frac{sin(\Delta\delta)}{\frac{P1}{P0}cos(\Delta\delta)} \qquad \textbf{Equation 3.}$$

With this equation this is data we get:

Table 7: δ_o Values

Torque(Nm)	$\Delta\delta$	δ_0
0.5	5	.0759
1.0	10	.0568
1.5	15	.0653
2.0	22	.0806

The average δ_o we get is .0697. With this value we can get Pmax by the following equation:

$$P_{in} = P_{max}sin(\delta_0) \qquad \textbf{Equation 4.}$$

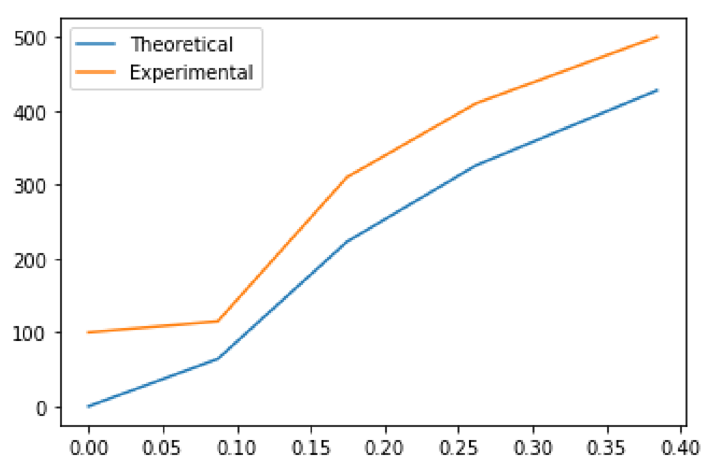
Table 8: P_{max} Values

Torque(Nm)	P_{max}
0.5	735.9
1.0	1282.2
1.5	1259.9
2.0	1140.97

The average P_{max} we get is 1105W.

Here is a plot of theoretical and experimental Power vs Torque-Angle plots:

Fig.3 Real Power Experimental vs Theoretical



As expected the curves are fairly close together and follow a very similar trend. It makes sense that P increases when the torque angle is increasing because the Power formula is:

$$P = \frac{3 \cdot E_a \cdot V_a}{x_s} \cdot \sin(-\delta)$$ **Equation 5.**

so an increasing delta gives a higher power magnitude.

Next we found maximum sudden loading by slowly increasing torque and we found it to be 2.2Nm. We can find this theoretically we need to use the equal area criteria. Using the curves we got from above and knowing T critical is 2.2Nm, we can find T max through:

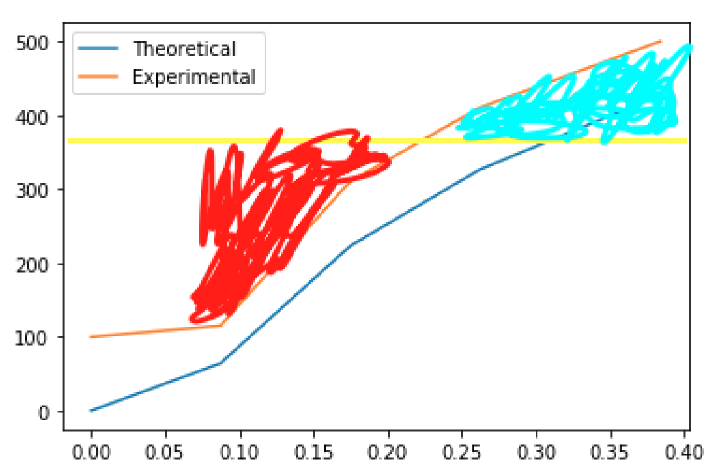
$$T_{\text{max}} = P_{\text{max}}/\omega_s$$ **Equation 6.**

So T_{max} = 500/188.5 = 2.65Nm

$\delta_{\text{critical}} = \arcsin 2.2/2.65 = pi - .97 = 124.4\,\text{deg}$

So roughly if we had more data these 2 areas should match to prove the equal area criteria:

Fig.4 Equal Area Criteria



2.3 *Generator Characteristics*

For this part we did the same as before but running the machine as a generator.

Table 9: Generator Data

Torque (Nm)	Vab (V)	Vcb (V)	Ia (A)	Ic (A)	If (A)	Power (W)	Delta (degrees)
0	121	121.5	.93	.98	.38	90	247
.5	121.6	122.3	.89	.88	.37	-30	242
1	122	122.6	1.19	1.08	.37	-115	237
1.5	122.3	123	1.53	1.49	.37	-205	232
2	122.7	123.4	1.98	1.89	.37	-290	227

Doing similar calculations as above we get the following results:

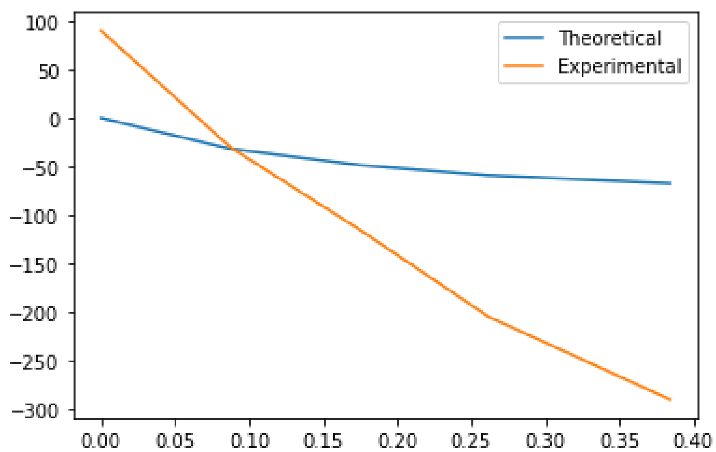
Table 10: Pmax and Delta

Torque(Nm)	$\Delta\delta$	δ_0	P_{max}
0.5	-5	.2567	-124.6
1.0	-10	.1371	-354.5
1.5	-15	.1171	-505.4
2.0	-20	.1125	-599.5

The average delta we get is .156 and average power is -396W.

Plotting the results we get this:

Fig.5 Generator Power Experimental vs Theoretical



3 CONCLUSION

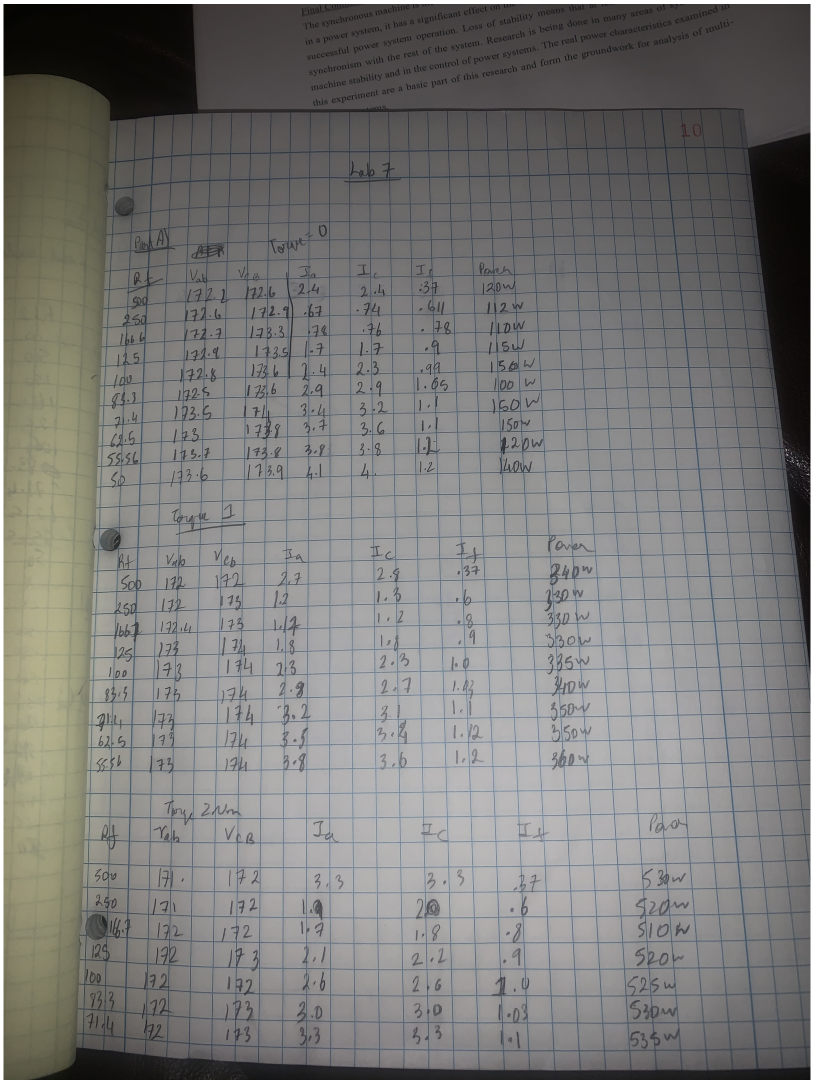
This lab gave us a good look into synchronous machines and how they are operated to work like we want. The experiments we did showed the benefits of using synchronous motors and how they are more efficient. Further we also inspected torque vs current effect and how higher rotor resistance affected Voltage and field current. The OCC and SCC allowed us to get values to draw the equivalent circuit, similar to an induction motor.

4 REFERENCES

[1] P.W. Sauer, P.T. Krein, P.L. Chapman, *ECE 431 Electric Machinery Course Guide and Laboratory Information*, University of Illinois at Urbana-Champaign, 2005.

5 APPENDIX

Raw Data:



Lab 7

Part A)

Torque = 0

R_f	V_{ab}	V_{cb}	I_a	I_c	I_f	Power
500	172.2	172.6	2.4	2.4	.37	120W
250	172.6	172.9	.67	.74	.611	112W
166.6	172.7	173.3	.78	.76	.78	110W
125	172.9	173.5	1.7	1.7	.9	115W
100	172.8	173.6	2.4	2.3	.99	150W
83.3	172.5	173.6	2.9	2.9	1.05	100W
71.4	173.5	174	3.4	3.2	1.1	150W
62.5	173	173.8	3.7	3.6	1.1	150W
55.56	173.7	173.8	3.8	3.8	1.2	120W
50	173.6	173.9	4.1	4.	1.2	140W

Torque 1

R_f	V_{ab}	V_{cb}	I_a	I_c	I_f	Power
500	172	172	2.7	2.8	.37	340W
250	172	173	1.2	1.3	.6	330W
166.7	172.4	173	1.17	1.2	.8	330W
125	173	174	1.8	1.8	.9	330W
100	173	174	2.3	2.3	1.0	335W
83.3	173	174	2.8	2.7	1.03	340W
71.4	173	174	3.2	3.1	1.1	350W
62.5	173	174	3.5	3.4	1.12	350W
55.56	173	174	3.8	3.6	1.2	360W

Torque 2Nm

R_f	V_{ab}	V_{CB}	I_a	I_c	I_f	Power
500	171.	172	3.3	3.3	.37	530W
250	171	172	1.9	2.0	.6	520W
166.7	172	172	1.7	1.8	.8	510W
125	172	173	2.1	2.2	.9	520W
100	172	172	2.6	2.6	1.0	525W
83.3	172	173	3.0	3.0	1.03	530W
71.4	172	173	3.3	3.3	1.1	535W

in a power ...
successful power system operati... synchronism with the rest of the system. Research is ... The real power cha... machine stability and in the control of power systems. The real power ... groundwork for analysis of ... this experiment are a basic part of this research and form the groundwork for analysis of ... systems.

2Nm Continued

Rf	Vab	VcB	Ia	Ic	If	Power
62.5	172	173	3.6	3.5	1.1	535W

3Nm

Rf	Vab	Vcb	Ia	Ic	If	Power
500	Overrrated	Ia				
250	171	171	2.6	2.7	.6	710W
166.7	171	172	2.33	2.4	.8A	700W
125	171	172	2.6	2.6	.9	710W
100	171	172	2.9	3.0	1.0	720W
83.3	171	172	3.3	3.3	1.02	720W
71.4	171	172	3.6	3.5	1.1	720W

Part B

Torque	Vab	VCB	Ia	Ic	If	Power	δ
0Nm	121.3	122	.93	1.00	.37	100W	250
0.5Nm	121	121	1.35	1.44	.37	115W	255
1	120.1	120.8	1.8	1.9	.37	310W	260
1.5	119.5	120.1	2.4	2.4	.37	410W	265
2	118.7	119.4	3.08	3.15	.37	500W	272

Max Torque is 2.2 to reach out of sync

Part C

Torque	Vab	VcB	Ia	Ic	If	Power	δ
0Nm	121	121.5	.93	.98	.37	90W	247
.5	121.6	122.3	.89	.88	〃	-30W	242
1.0	122	122.6	1.19	1.08		-115W	237
1.5	122.3	123	1.53	1.49		-205W	232
2.0	122.7	123.4	1.94	1.89		-290W	227