ECSE 362 - Fundamentals of Power Engineering

Lab 4: The Synchronous Machine

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Lab section: 003

Introduction

The lab is split into 7 main sections. For the first section, the team focused on the examination of the construction of the three-phase synchronous machine where we identify Stator/Rotor windings, poles, and slip rings. During the second section, the team learned about field excitation effect and plotted AC stator current against DC rotor excitation current and power factor against DC rotor excitation current graphs. In the third section, the focus is now on the maximum loading and pull-out torque. The fourth and fifth section is dedicated to determining the characteristics of the synchronous generation. The remaining two sections allow the team to learn how to synchronize an alternator to the electric utility system.

1. Synchronous Machine Construction and Characteristics

2)
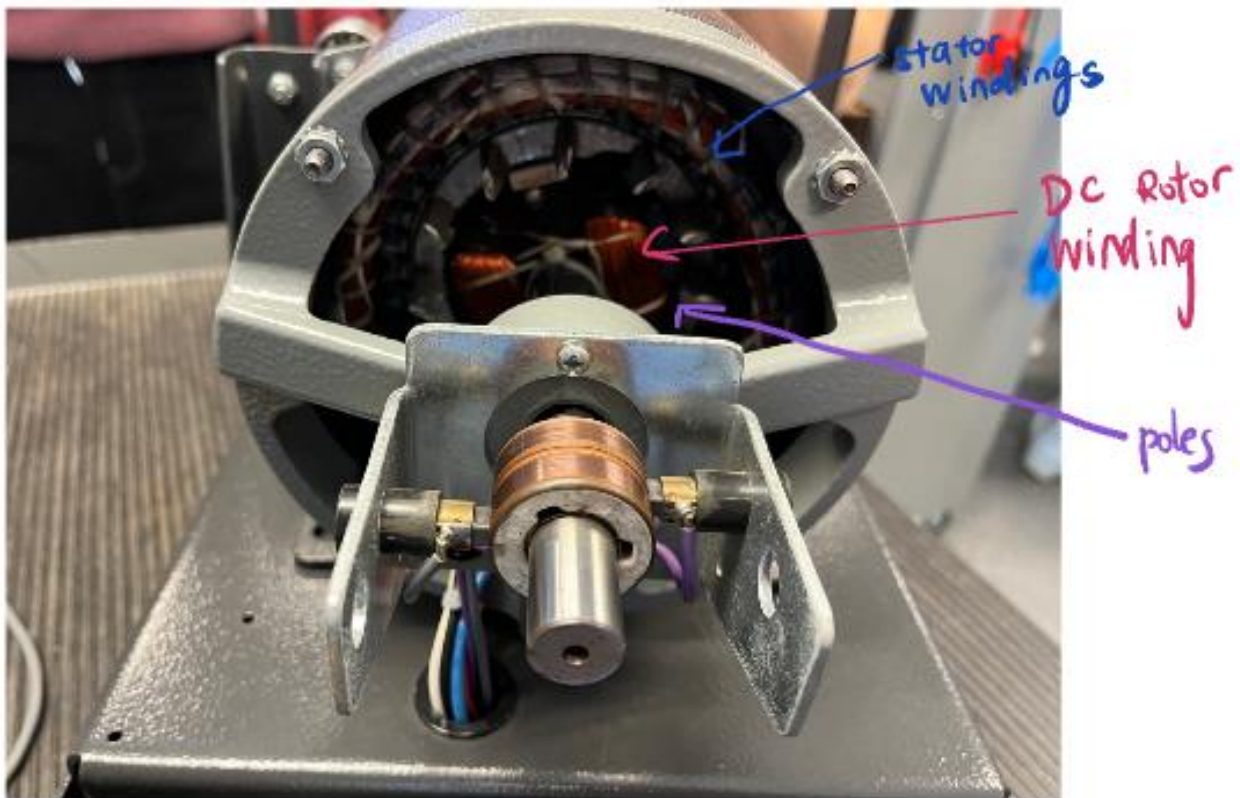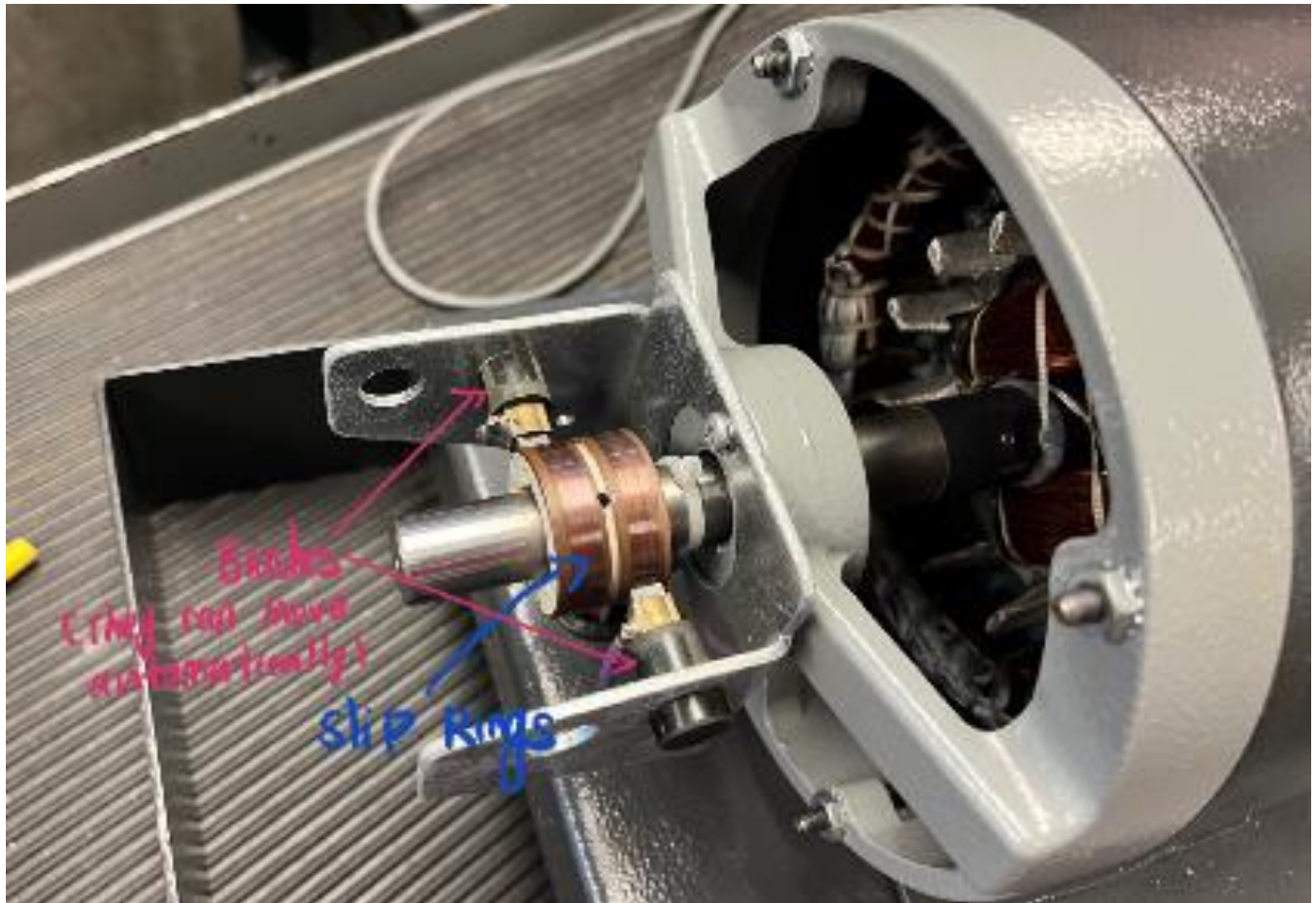
3) Viewing from the front face of the module:

(i) $V_{rated\ stator} = 208V$

(ii) $V_{rated\ stator} = 0.8\ A$

(iii) Terminals 7 and 8 are voltage ports for the rotor windings

(iv) $V_{rated\ rotor} = 208V$

(v) Rated speed: 1800 rpm | Rated power: 120VA

SYNCHRONOUS MOTOR / GENERATOR

EXCITER

MIN.   MAX.

150 Ω

120 V 1 A

120 V 1 A

120 V

4

5

3   6

7   120 V – DC   8

MOTOR RATING   B-97729   GENERATOR RATING

175 W – 1800 r/min – 208 V – 0.8 A   120 VA – 1800 r/min – 208 V – 0.33 A
3 ～ – 60 Hz   3 ～ – 60 Hz

Lab-Volt
8241-00
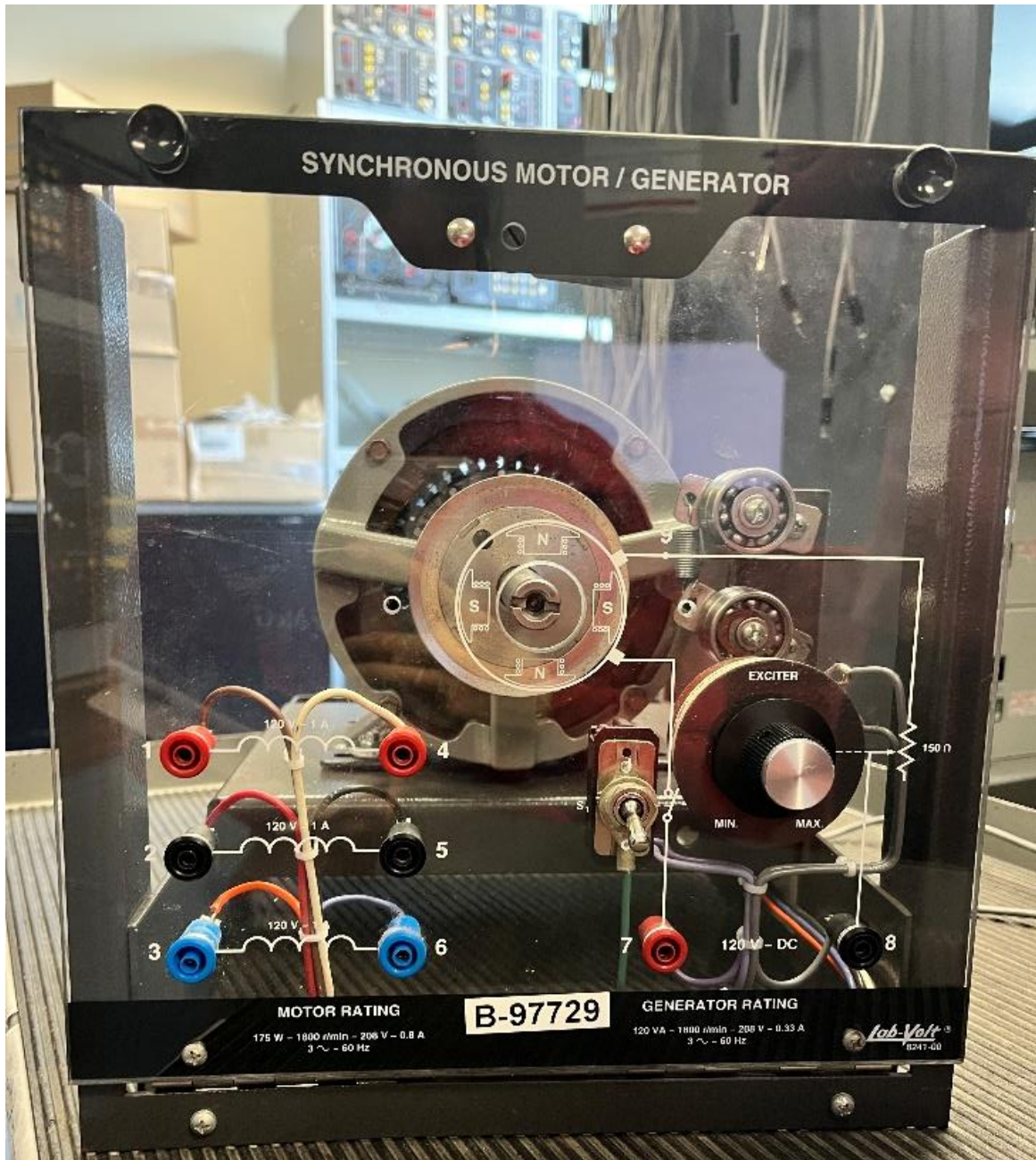
2. Field Excitation Effects
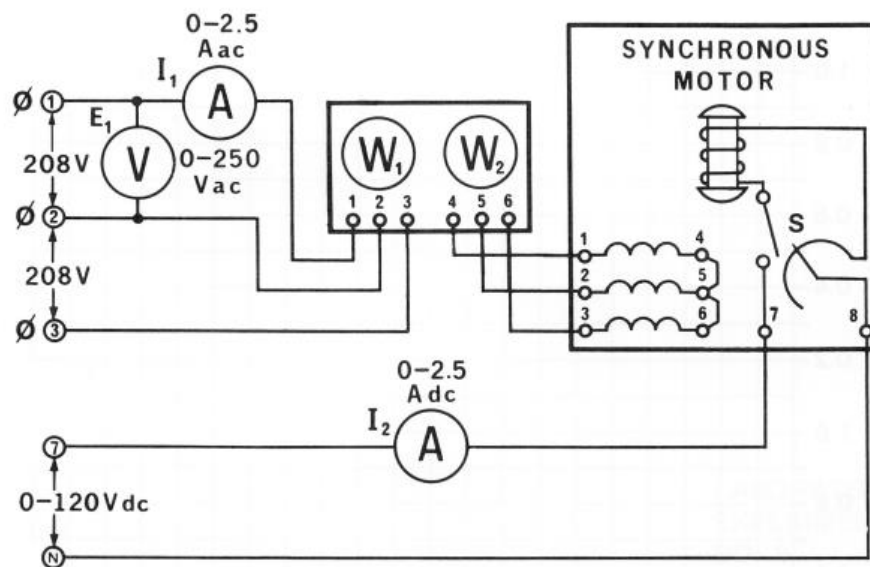
3. Measurements and screenshots:

	Table 1					
	I2	E1	I1	S	P	pf
	0	208	1.18	427.2	131.9	0.309
	0.1	208	0.962	350.1	114.8	0.328
	0.2	208	0.731	266.1	100	0.376
	0.3	208	0.548	199.6	91.78	0.46
	0.4	208	0.353	125.8	84.6	0.673
	0.5	208	0.265	95.85	83.39	0.87
	0.6	208	0.236	86.07	83.47	0.97
	0.7	208	0.323	116.9	86.17	0.737
	0.8	208	0.445	161.2	88.73	0.55

Panel 1 (top-left)

M1 E1	M2 E2	M3 E3
E1	E2	E3
209.8		
AC V	AC V	AC V

M7 I1	M8 I2	M9 I3
I1	I2	I3
1.180	0.008	
AC A	AC A	AC A

M13 PQS1 (E1,I...	M14 PQS1 (E1,I...	M15 PF (E1,I1)...
PQS1 (E1,I1) 3~	PQS1 (E1,I1) 3~	PF (E1,I1) 3~
427.2	131.9	0.309
S VA	P W	True

Panel 2 (top-right)

M1 E1	M2 E2	M3 E3
E1	E2	E3
210.2		
AC V	AC V	AC V

M7 I1	M8 I2	M9 I3
I1	I2	I3
0.962	0.105	
AC A	AC A	AC A

M13 PQS1 (E1,I...	M14 PQS1 (E1,I...	M15 PF (E1,I1)...
PQS1 (E1,I1) 3~	PQS1 (E1,I1) 3~	PF (E1,I1) 3~
350.1	114.8	0.328
S VA	P W	True

Panel 3 (middle-left)

M1 E1	M2 E2	M3 E3
E1	E2	E3
210.1		
AC V	AC V	AC V

M7 I1	M8 I2	M9 I3
I1	I2	I3
0.731	0.205	
AC A	AC A	AC A

M13 PQS1 (E1,I...	M14 PQS1 (E1,I...	M15 PF (E1,I1)...
PQS1 (E1,I1) 3~	PQS1 (E1,I1) 3~	PF (E1,I1) 3~
266.1	100.0	0.376
S VA	P W	True

Panel 4 (middle-right)

M1 E1	M2 E2	M3 E3
E1	E2	E3
210.4		
AC V	AC V	AC V

M7 I1	M8 I2	M9 I3
I1	I2	I3
0.548	0.302	
AC A	AC A	AC A

M13 PQS1 (E1,I...	M14 PQS1 (E1,I...	M15 PF (E1,I1)...
PQS1 (E1,I1) 3~	PQS1 (E1,I1) 3~	PF (E1,I1) 3~
199.6	91.78	0.460
S VA	P W	True

Panel 5 (bottom-left)

M1 E1	M2 E2	M3 E3
E1	E2	E3
205.7		
AC V	AC V	AC V

M7 I1	M8 I2	M9 I3
I1	I2	I3
0.353	0.401	
AC A	AC A	AC A

M13 PQS1 (E1,I...	M14 PQS1 (E1,I...	M15 PF (E1,I1)...
PQS1 (E1,I1) 3~	PQS1 (E1,I1) 3~	PF (E1,I1) 3~
125.8	84.60	0.673
S VA	P W	True

Connected to DACI #G386954 (Ready) Sampling Window : Extended

Panel 6 (bottom-right)

M1 E1	M2 E2	M3 E3
E1	E2	E3
209.3		
AC V	AC V	AC V

M7 I1	M8 I2	M9 I3
I1	I2	I3
0.265	0.498	
AC A	AC A	AC A

M13 PQS1 (E1,I...	M14 PQS1 (E1,I...	M15 PF (E1,I1)...
PQS1 (E1,I1) 3~	PQS1 (E1,I1) 3~	PF (E1,I1) 3~
95.85	83.39	0.870
S VA	P W	True

Panel 1 (top-left):

M1	E1	M2	E2	M3	E3
	E1		E2		E3
209.2					
AC	V	AC	V	AC	V

M7	I1	M8	I2	M9	I3
	I1		I2		I3
0.236		**0.600**			
AC	A	AC	A	AC	A

M13	PQS1 (E1,I...	M14	PQS1 (E1,I...	M15	PF (E1,I1)...
PQS1 (E1,I1) 3~		PQS1 (E1,I1) 3~		PF (E1,I1) 3~	
86.07		**83.47**		**0.970**	
S	VA	P	W	True	

Panel 2 (top-right):

M1	E1	M2	E2	M3	E3
	E1		E2		E3
208.8					
AC	V	AC	V	AC	V

M7	I1	M8	I2	M9	I3
	I1		I2		I3
0.323		**0.701**			
AC	A	AC	A	AC	A

M13	PQS1 (E1,I...	M14	PQS1 (E1,I...	M15	PF (E1,I1)...
PQS1 (E1,I1) 3~		PQS1 (E1,I1) 3~		PF (E1,I1) 3~	
116.9		**86.17**		**0.737**	
S	VA	P	W	True	

Panel 3 (bottom):

M1	E1	M2	E2	M3	E3
	E1		E2		E3
209.3					
AC	V	AC	V	AC	V

M7	I1	M8	I2	M9	I3
	I1		I2		I3
0.445		**0.804**			
AC	A	AC	A	AC	A

M13	PQS1 (E1,I...	M14	PQS1 (E1,I...	M15	PF (E1,I1)...
PQS1 (E1,I1) 3~		PQS1 (E1,I1) 3~		PF (E1,I1) 3~	
161.2		**88.73**		**0.550**	
S	VA	P	W	True	

5) $Q = \sqrt{427.2^2 - 131.9^2} = 406.3\ var$ | pf = 0.309 lagging

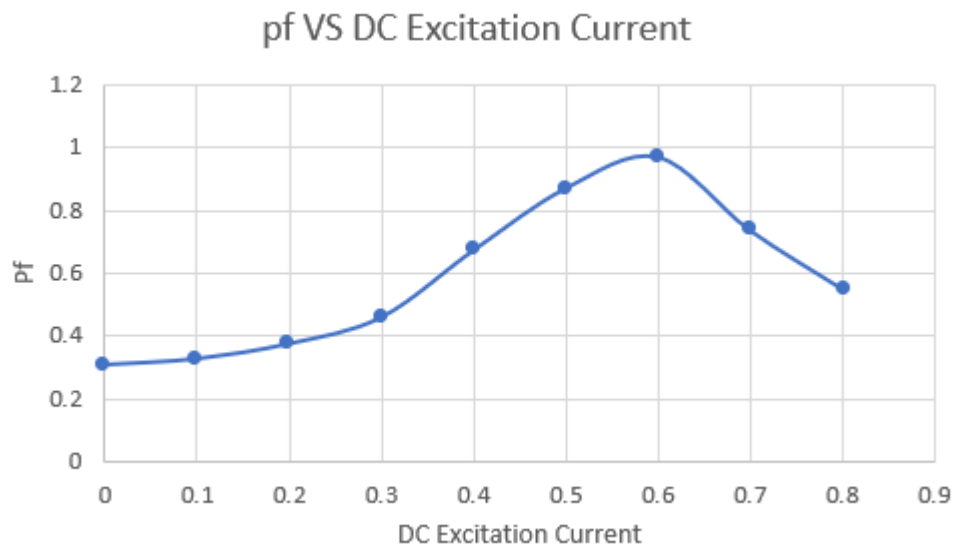6) $Q = -\sqrt{161.2^2 - 88.73^2} = -134.58\ var$ | pf = 0.55 leading

7) $Q = \sqrt{86.07^2 - 83.47^2} = 20.99\ var$ | pf = 0.97 lagging

Supplementary questions:

(a)

AC Stator Current VS DC Excitation Current

AC Stator Current (A) vs DC Excitation Current (A)

(b)

pf VS DC Excitation Current

pf vs DC Excitation Current
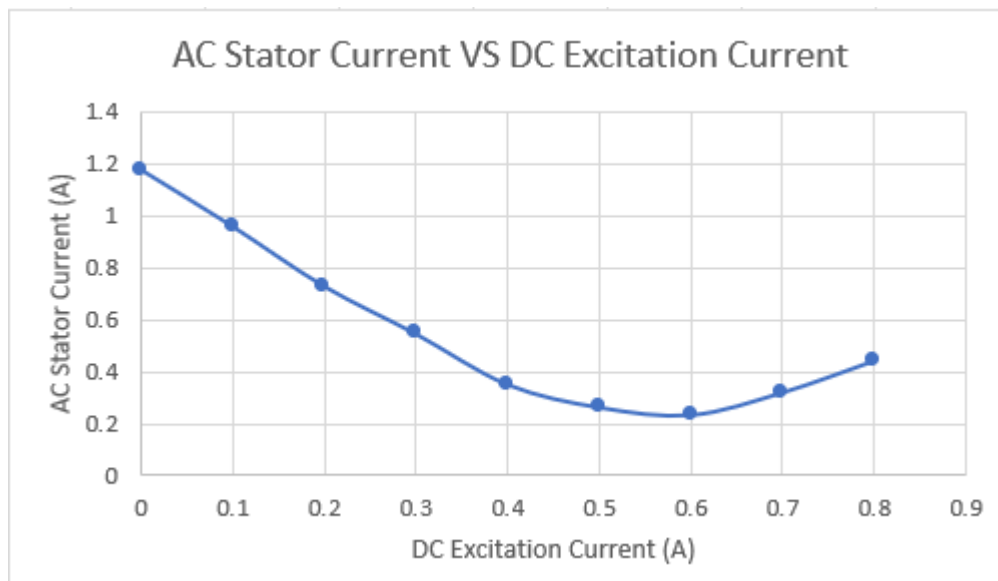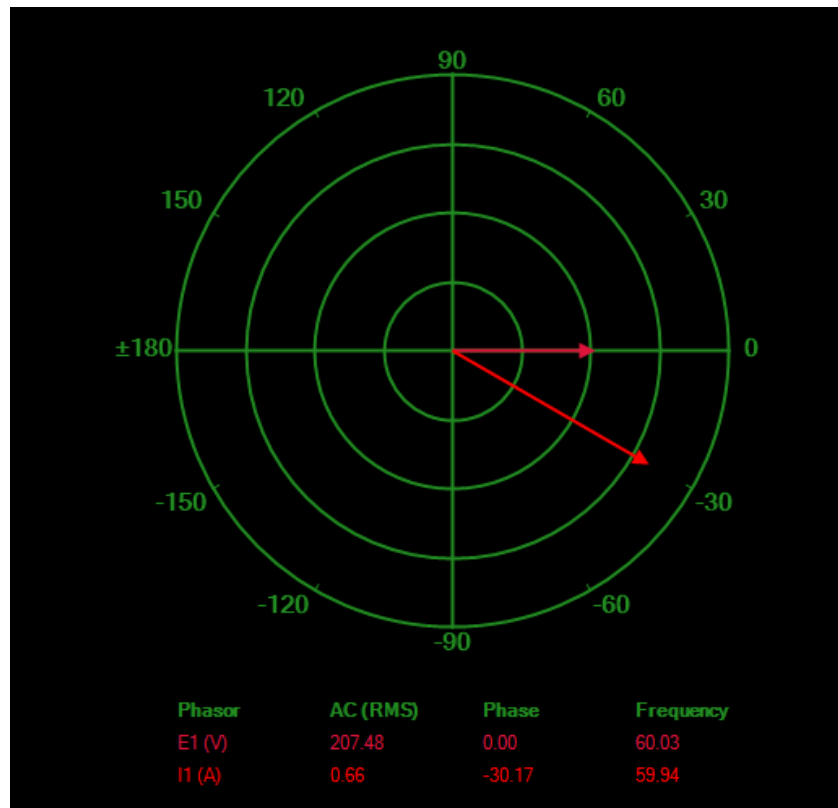
c) As DC excitation increases, the AC stator current decreases. When it reaches its minimum of 0.236 A when DC current equals to 0.6 A, the AC stator current would increase until DC excitation current reaches it maximum. With the increase of DC excitation current, the power factor would increase till its maximum at 0.97 when DC current equals to 0.6A and AC current equals to 0.236A. Then it would start to decrease till maximum DC current reached.

# 3. Maximum Loading and Pull-Out Torque

3) Machine current lags machine voltage by 30 degrees.

Phasor	AC (RMS)	Phase	Frequency
E1 (V)	207.48	0.00	60.03
I1 (A)	0.66	-30.17	59.94

M1 E1	M2 E2	M3 E3	M4 E4
E1	E2	E3	E4
206.6	**124.3**		
AC V	AC V	AC V	AC V

M7 I1	M8 I2	M9 I3	M10 I4
I1	I2	I3	I4
0.648	**0.584**		
AC A	AC A	AC A	AC A

M13 PQS1 (E1,I…	M14 PQS1 (E1,I…	M15 PQS1 (E1,I…	M16 PF (E1,I1)…
PQS1 (E1,I1) 3~	PQS1 (E1,I1) 3~	PQS1 (E1,I1) 3~	PF (E1,I1) 3~
231.7	**231.2**	**1.059**	**0.998**
S VA	P W	Q Var	True

4) Max torque: 1.924 Nm, RPM drops to ~1400

5) Because Q is negative following generator convention, the power factor would be leading.

M1	E1	M2	E2	M3	E3	M4	E4
	E1		E2		E3		E4
206.8		122.2					
AC	V	AC	V	AC	V	AC	V

M7	I1	M8	I2	M9	I3	M10	I4
	I1		I2		I3		I4
0.764		0.801					
AC	A	AC	A	AC	A	AC	A

M13	PQS1 (E1,I...	M14	PQS1 (E1,I...	M15	PQS1 (E1,I...	M16	PF (E1,I1)...
PQS1 (E1,I1) 3~		PQS1 (E1,I1) 3~		PQS1 (E1,I1) 3~		PF (E1,I1) 3~	
273.4		237.9		-134.1		0.870	
S	VA	P	W	Q	Var	True	
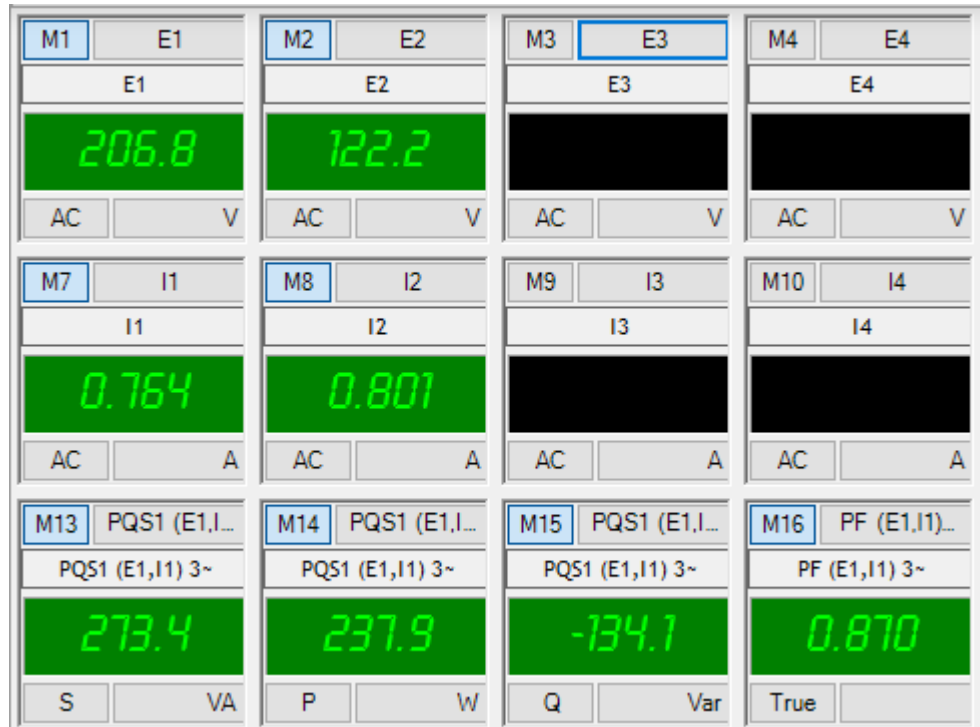
6) Pull-out torque at I2 = 0.8 A is T = 2.347 Nm

Supplementary questions

1) (a) 231.7 VA

(b) 213.2 W

(c) 1.059 var

(d) 0.998 lagging

(e) $P = E_2 \times I_2 = 124.3 \cdot 0.584 = 72.59 \, W$

(f) $P_{mech} = P_{elec} = 231.2W$

(g) Full load torque: $P_{full\ load} = 186 \, W$ (1/4 horsepower)

$$\mu = \frac{P_{out}}{P_{in}} = \frac{231.2}{231.2 + 72.59} \times 100 = 76.1 \, \%$$

2) Pull out torque = **2.347 Nm** | Full load torque = **1.924 Nm** | Ratio = 2.347/1.924 = **1.22**

3) (a) 273.4 VA

(b) 237.9 W

(c) -134.1 var

(d) 0.870 leading

(e) $P_{dc} = EI = 122.2 \times 0.801 = 97.88\ W$

(f) Mechanical output power = 237.9 W

4) Negative

5) As the degree of DC excitation increases, the strength of the magnetic field increases. The force it created leads the motor to create.
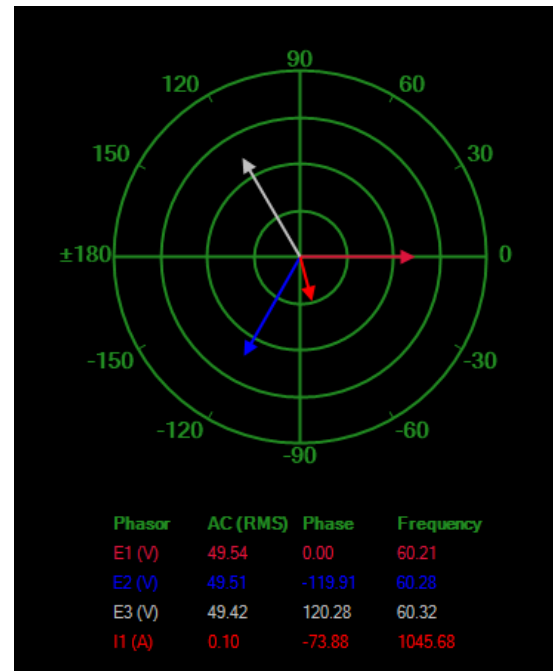
4. The Three-Phase Alternator

Alternative instructions: Remove the Squirrel Cage entirely. Dynamometer to CW Prime Mover/Brake. Synchronous speed 1800 rpm. Note for switch S: up is close (1), down is open (0).
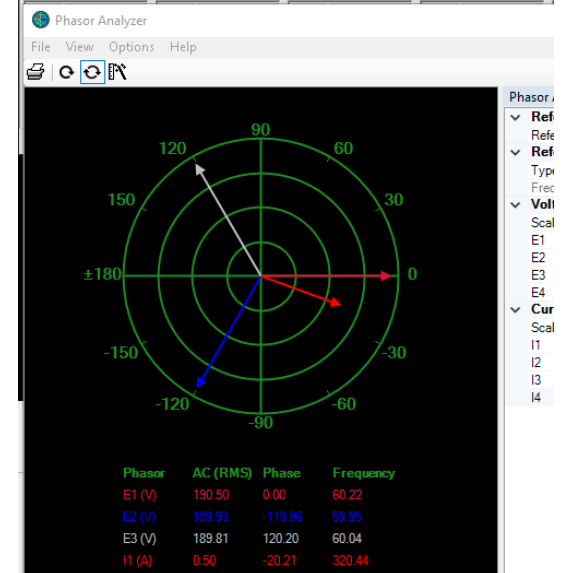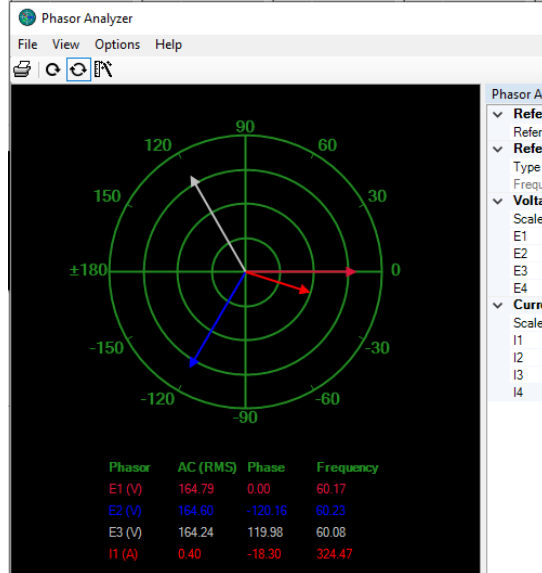
3.

M1	E1	M2	E2	M3	E3	M4	E4
	E1		E2		E3		E4
4.032		4.051		4.025			
AC	V	AC	V	AC	V	AC	V

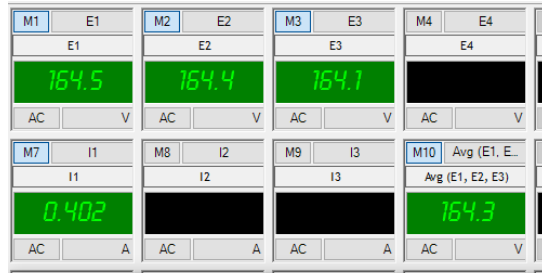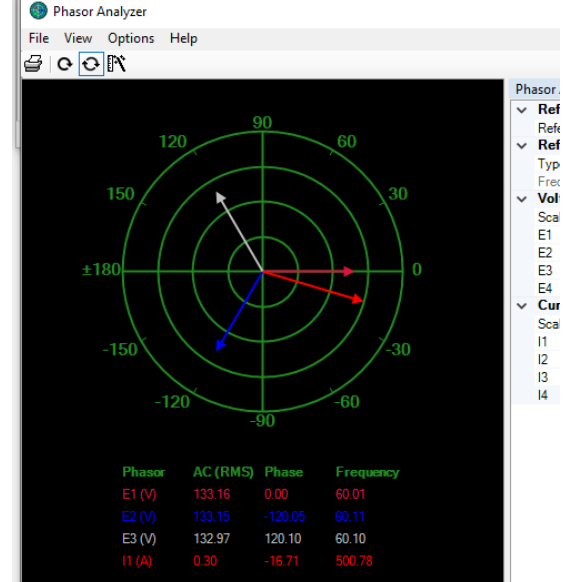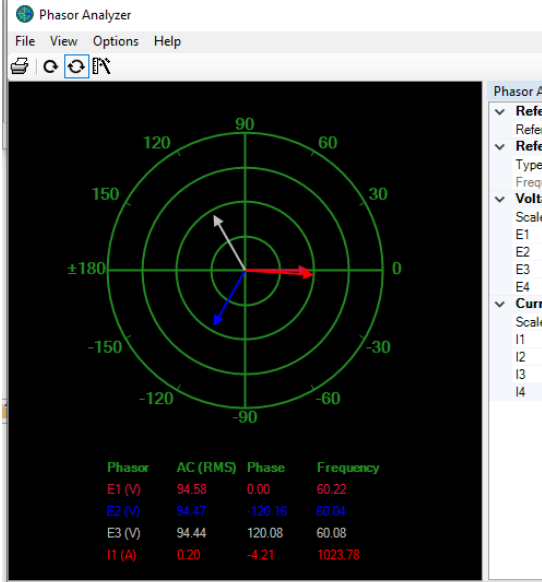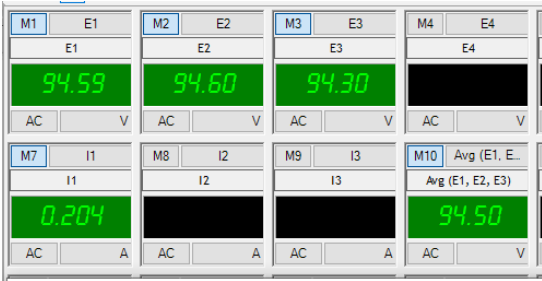| M7	I1	M8	I2	M9	I3	M10	Avg (E1, E...)
	I1		I2		I3		Avg (E1, E2, E3)
0.007						4.036	
AC	A	AC	A	AC	A	AC	V

There is an AC voltage generated without DC excitation due to the lingering magnetization in the stator/rotor from previous lab sections.

4. Measurements for E1, E2, E3, and proof that they are 3-phase balanced:

Phasor	AC (RMS)	Phase	Frequency
E1 (V)	49.54	0.00	60.21
E2 (V)	49.51	-119.91	60.28
E3 (V)	49.42	120.28	60.32
I1 (A)	0.10	-73.88	1045.68

5. Table 2, with the first entry from Step 3. Measurements and screenshots are below.

Table 2				
I1	E1	E2	E3	Eavg
0	4.032	4.051	4.025	4.036
0.1	49.36	49.33	49.21	49.3
0.2	94.59	94.6	94.3	94.5
0.3	131.8	131.8	131.4	131.7
0.4	164.5	164.4	164.1	164.3
0.5	190.1	189.9	189.7	189.9
0.6	207.9	207.8	207.6	207.8
0.7	222.9	222.6	222.5	222.7
0.8	233.4	233.2	233	233.7
0.9	241.4	241	240.9	241.7

Panel 1 (top-left)

M1 E1	M2 E2	M3 E3	M4 E4
E1	E2	E3	E4
94.59	94.60	94.30	
AC V	AC V	AC V	AC V

M7 I1	M8 I2	M9 I3	M10 Avg (E1, E...)
I1	I2	I3	Avg (E1, E2, E3)
0.204			94.50
AC A	AC A	AC A	AC V

Phasor Analyzer

Phasor	AC (RMS)	Phase	Frequency
E1 (V)	94.58	0.00	60.22
E2 (V)	94.47	-120.16	60.04
E3 (V)	94.44	120.08	60.08
I1 (A)	0.20	-4.21	1023.78

Panel 2 (top-right)

M1 E1	M2 E2	M3 E3	M4 E4
E1	E2	E3	E4
131.8	131.8	131.4	
AC V	AC V	AC V	AC V

M7 I1	M8 I2	M9 I3	M10 Avg (E1, E...)
I1	I2	I3	Avg (E1, E2, E3)
0.301			131.7
AC A	AC A	AC A	AC V

Phasor Analyzer

Phasor	AC (RMS)	Phase	Frequency
E1 (V)	133.16	0.00	60.01
E2 (V)	133.15	-120.05	60.11
E3 (V)	132.97	120.10	60.10
I1 (A)	0.30	-16.71	500.78

Panel 3 (bottom-left)

M1 E1	M2 E2	M3 E3	M4 E4
E1	E2	E3	E4
164.5	164.4	164.1	
AC V	AC V	AC V	AC V

M7 I1	M8 I2	M9 I3	M10 Avg (E1, E...)
I1	I2	I3	Avg (E1, E2, E3)
0.402			164.3
AC A	AC A	AC A	AC V

Phasor Analyzer

Phasor	AC (RMS)	Phase	Frequency
E1 (V)	164.79	0.00	60.17
E2 (V)	164.60	-120.16	60.23
E3 (V)	164.24	119.98	60.08
I1 (A)	0.40	-18.30	324.47

Panel 4 (bottom-right)

M1 E1	M2 E2	M3 E3	M4 E4
E1	E2	E3	E4
190.1	189.9	189.7	
AC V	AC V	AC V	AC V

M7 I1	M8 I2	M9 I3	M10 Avg (E1, E...)
I1	I2	I3	Avg (E1, E2, E3)
0.504			189.9
AC A	AC A	AC A	AC V

Phasor Analyzer

Phasor	AC (RMS)	Phase	Frequency
E1 (V)	190.50	0.00	60.22
E2 (V)	189.93	-119.96	59.95
E3 (V)	189.81	120.20	60.04
I1 (A)	0.50	-20.21	320.44

Panel 1 (top-left)

M1 E1	M2 E2	M3 E3	M4 E4
E1	E2	E3	E4
207.9	207.8	207.6	
AC V	AC V	AC V	AC V

M7 I1	M8 I2	M9 I3	M10 Avg (E1, E...)
I1	I2	I3	Avg (E1, E2, E3)
0.600			207.8
AC A	AC A	AC A	AC V

Phasor Analyzer — File View Options Help — Auto Scale

Phasor	AC (RMS)	Phase	Frequency
E1 (V)	207.90	0.00	59.98
E2 (V)	207.84	-119.95	60.05
E3 (V)	207.53	120.18	59.95
I1 (A)	0.60	-56.59	180.20

Connected to DACI #G386954 (Ready)

Panel 2 (top-right)

M1 E1	M2 E2	M3 E3	M4 E4
E1	E2	E3	E4
222.9	222.6	222.5	
AC V	AC V	AC V	AC V

M7 I1	M8 I2	M9 I3	M10 Avg (E1, E...)
I1	I2	I3	Avg (E1, E2, E3)
0.708			222.7
AC A	AC A	AC A	AC V

Phasor Analyzer — File View Options Help

Phasor	AC (RMS)	Phase	Frequency
E1 (V)	222.95	0.00	60.06
E2 (V)	222.96	-120.01	60.22
E3 (V)	222.74	120.25	60.10
I1 (A)	0.71	20.65	179.85

Connected to DACI #G386954 (Ready)

Panel 3 (bottom-left)

M1 E1	M2 E2	M3 E3	M4 E4
E1	E2	E3	E4
233.4	233.2	233.0	
AC V	AC V	AC V	AC V

M7 I1	M8 I2	M9 I3	M10 Avg (E1, E...)
I1	I2	I3	Avg (E1, E2, E3)
0.806			233.7
AC A	AC A	AC A	AC V

Phasor Analyzer — File View Options Help

Phasor	AC (RMS)	Phase	Frequency
E1 (V)	233.86	0.00	60.19
E2 (V)	233.87	-119.98	60.25
E3 (V)	233.55	120.14	60.19
I1 (A)	0.81	13.94	179.06

Panel 4 (bottom-right)

M1 E1	M2 E2	M3 E3	M4 E4
E1	E2	E3	E4
241.4	241.0	240.9	
AC V	AC V	AC V	AC V

M7 I1	M8 I2	M9 I3	M10 Avg (E1, E...)
I1	I2	I3	Avg (E1, E2, E3)
0.899			241.1
AC A	AC A	AC A	AC V

Phasor Analyzer — File View Options Help

Phasor	AC (RMS)	Phase	Frequency
E1 (V)	241.54	0.00	59.98
E2 (V)	241.54	-120.01	60.06
E3 (V)	241.32	120.19	60.09
I1 (A)	0.90	-51.85	178.60

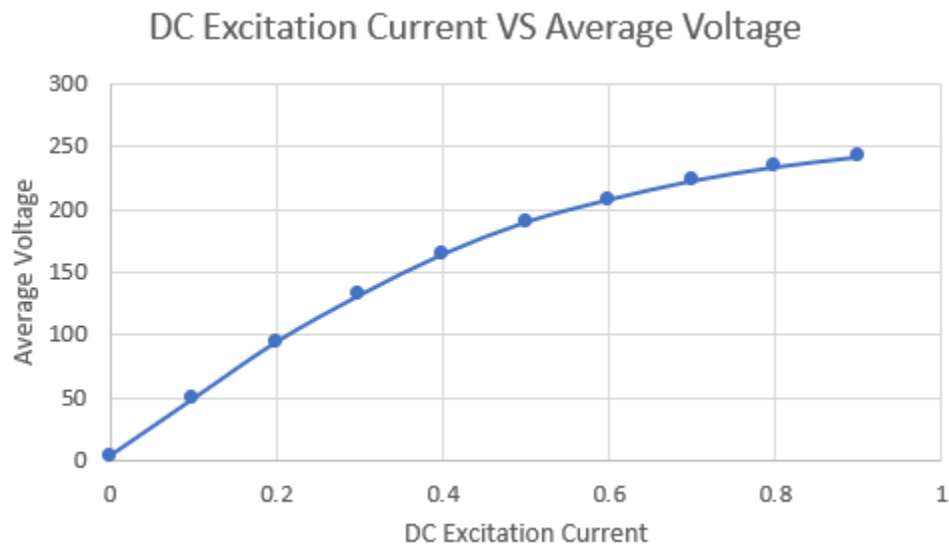7. (v) I_2 peaked to **2.856 A** at the moment of switch closure when performing a short circuit.

(vi) At steady state, I_1 = **0.585 A** and I_2 = **1.320 A**.

Supplementary questions

    1. (a)

DC Excitation Current VS Average Voltage
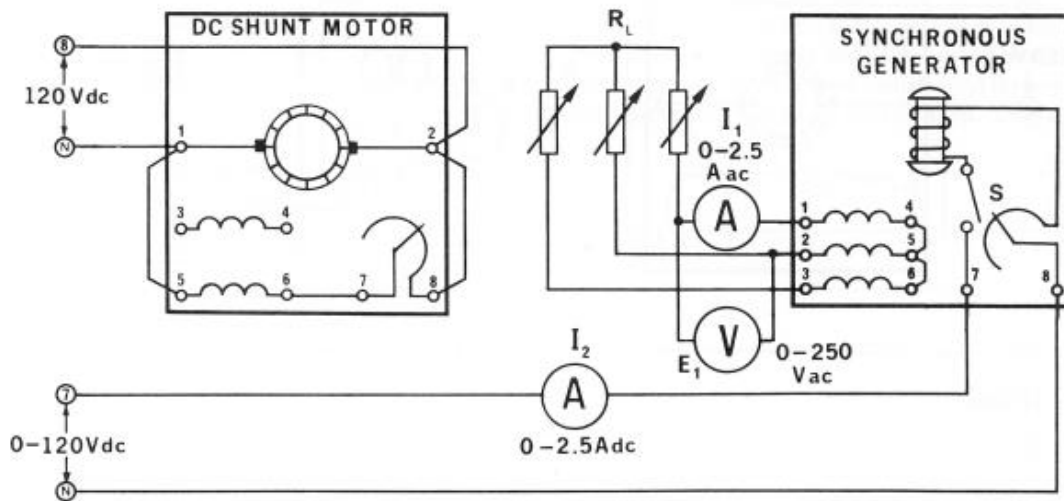

    (b) 164.3 V

    (c) 181.9 V

    (d) Saturation happens. As magnetic flux density in the core approach max, increase in DC current only results in small increase in flux density. Therefore, there will be a smaller increase in stator voltage.

    2. $Z_{base} = \dfrac{V^2}{S} = \dfrac{208^2}{120} = 360.5\ \Omega$

    $Z = \dfrac{V}{I} = \dfrac{208\ V}{2.856A} = 72.83\ \Omega$

    $Z_{p.u} = \dfrac{Z}{Z_{base}} = \dfrac{72.83}{360.5} = 0.202\ p.u$
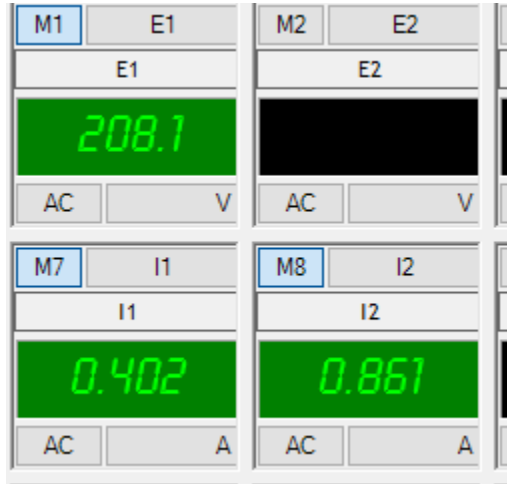
5. The Alternator Under Load

3) With resistive load:
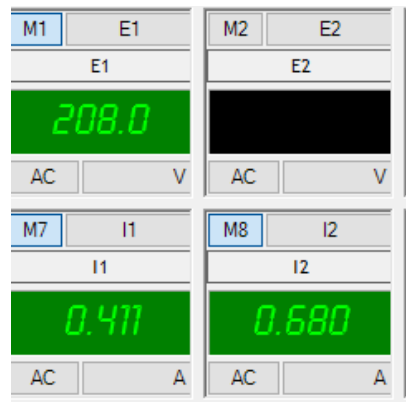
No load: removing resistive load increases induced voltage (MMF) and rotational speed (rpm)
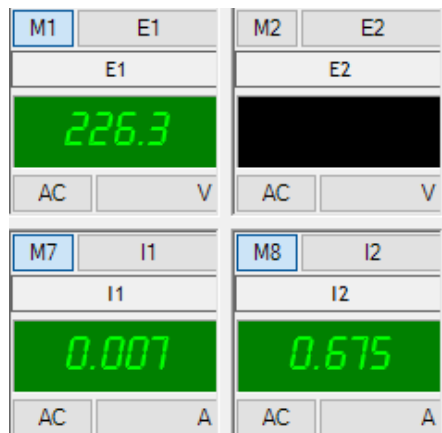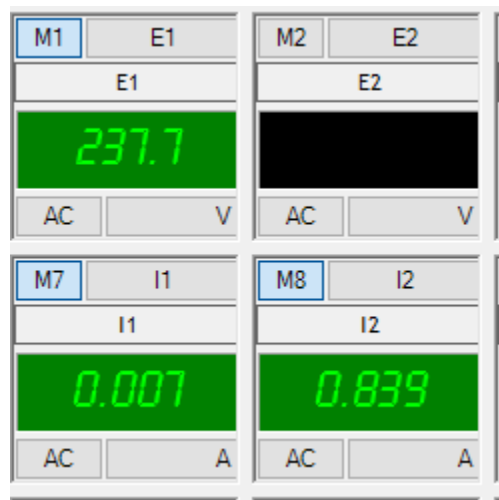
$$Voltage\ regulation = \frac{|E_{fl} - E_{nl}|}{E_{fl}} \times 100 = \frac{|208 - 226.3|}{208} \times 100 = 8.8\ \%$$

4. Inductive load ($Z_L = 300\Omega$) measurements:

M1	E1	M2	E2
	E1		E2
	208.1		
AC	V	AC	V

M7	I1	M8	I2
	I1		I2
	0.402		**0.861**
AC	A	AC	A

No load measurements: remove inductive load leads to increase MMF, increase voltage, rotational speed stay the same

M1	E1	M2	E2
	E1		E2
	237.7		
AC	V	AC	V

| M7	I1	M8	I2
	I1		I2
	0.007		**0.839**
AC	A	AC	A

$$Voltage\ regulation = \frac{|E_{fl} - E_{nl}|}{E_{fl}} \times 100 = \frac{|208 - 237.7|}{208} \times 100 = 14.3\ \%$$

Oppose the rotor MMF because of the lagging power factor of inductive load.

5. Capacitive load ($Z_C = 300\Omega$) measurement:

M1	E1	M2	E2
	E1		E2
	208.0		
AC	V	AC	V

M7	I1	M8	I2
	I1		I2
	0.399		0.355
AC	A	AC	A
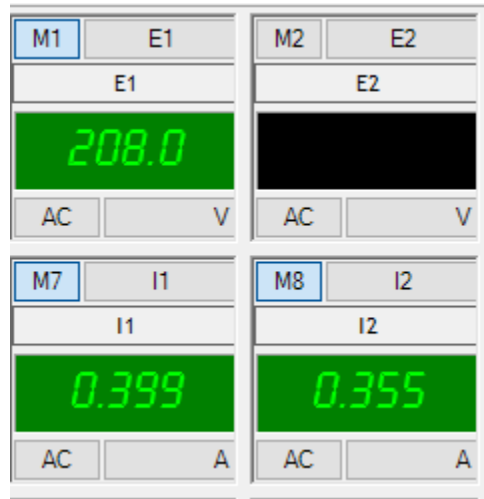
No load measurement: Remove capacitive load leads to voltage drops while rotational speed stays the same.

M1	E1	M2	E2
	E1		E2
	158.8		
AC	V	AC	V

M7	I1	M8	I2
	I1		I2
	0.008		0.368
AC	A	AC	A
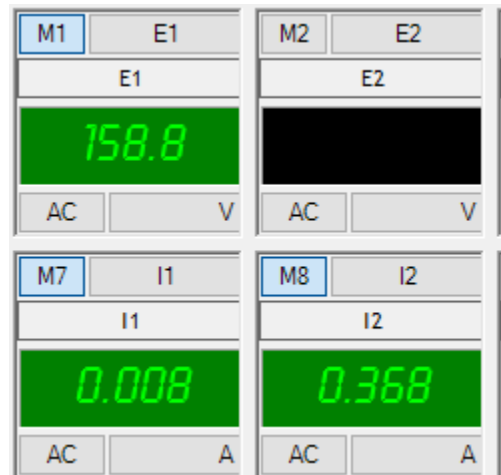
$$Voltage\ regulation = \frac{|E_{fl} - E_{nl}|}{E_{fl}} \times 100 = \frac{|208 - 158.8|}{208} \times 100 = 23.7\ \%$$

Aids the rotor MMF because of the leading power factor of capacitive load.
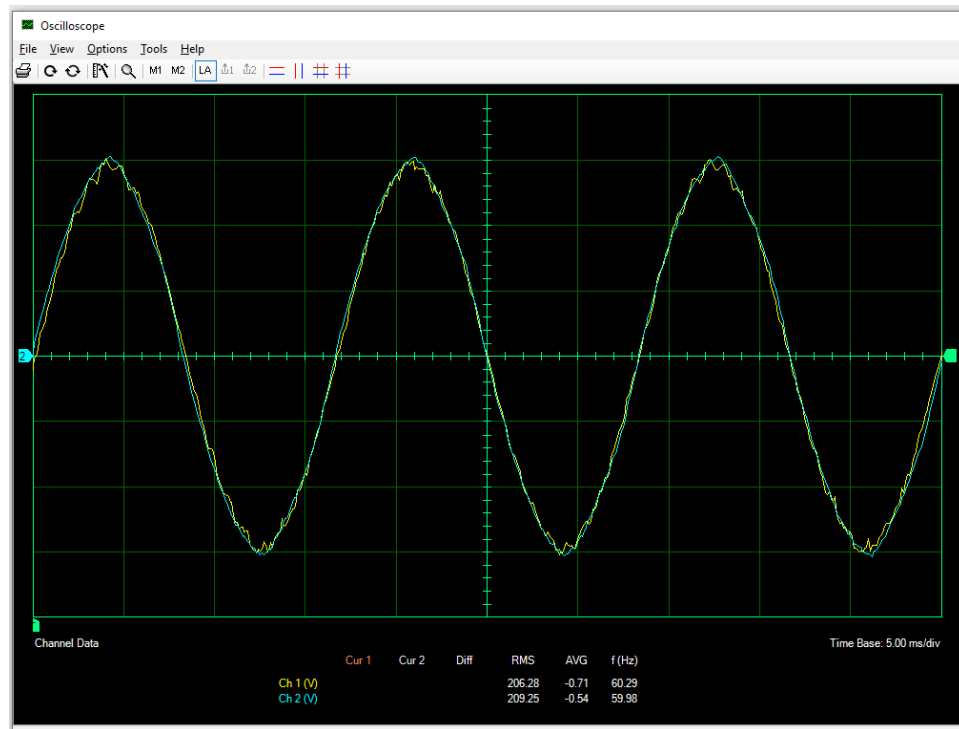
6. Alternator Synchronization

Figure: Voltages from the generator and the grid are in phase
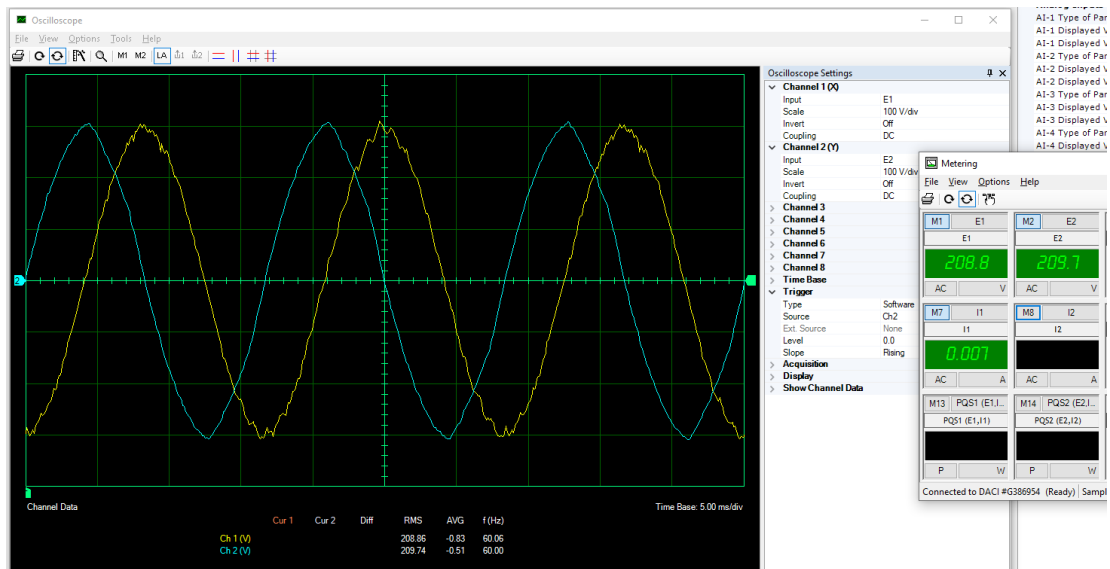(CH1: The generator, CH2: The grid)

Figure: Voltages from the generator and the grid are out of phase
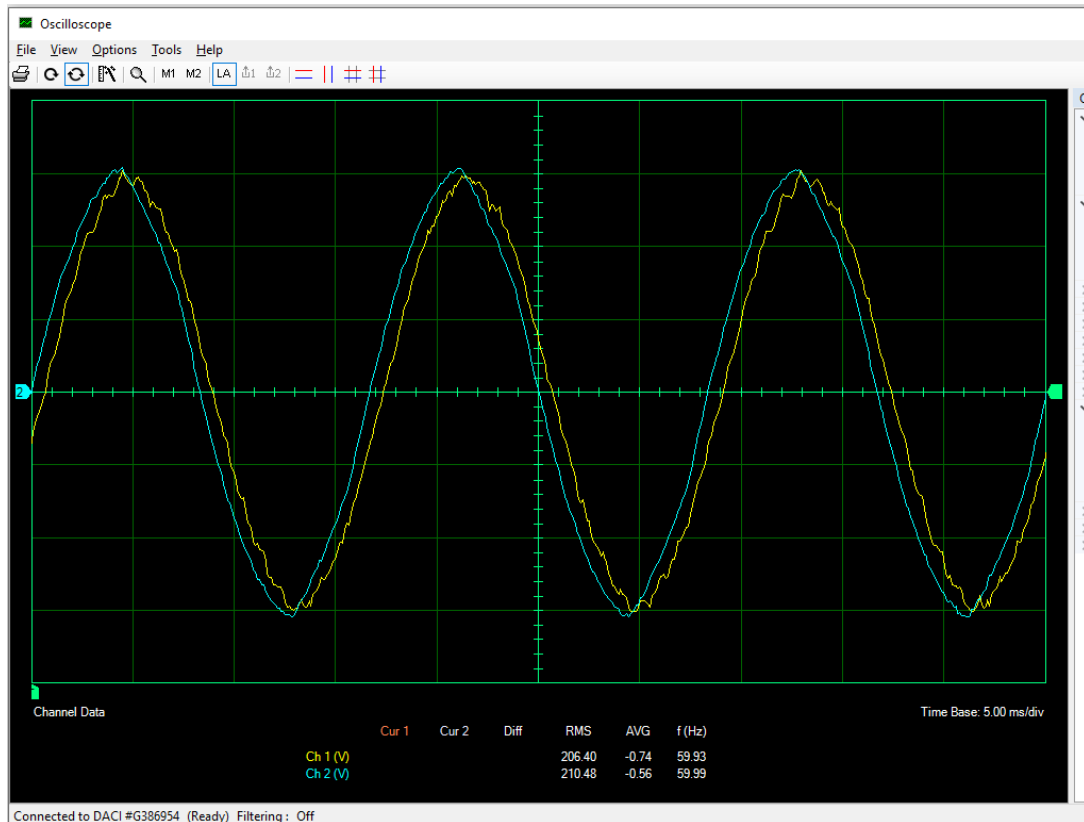(CH1: The generator, CH2: The grid)

Figure: Voltages from the generator and the grid are close to be in phase
(CH1: The generator, CH2: The grid)

1800rpm gives the lowest light blinking frequency, deviate from it increases the blinking light frequency. When the voltages have the same phase value, the bulb is dark. When they are out of phase, the bulb is bright.

5. Close the synchronizing switch when all three lights are …

- Dark: I_1 peaked at **0.491A** at the moment of closure

- Dimmed: I_1 peaked at **0.617A** at the moment of closure

- Bright: I_1 peaked at **2.058A** at the moment of closure, along with an audible loud bang.

6. I_1 starts at 0.007 A and spiked to 0.416A during moment of closure.

7. Lights blink in a direction (shining from right to left),

When we do counterclockwise, angle become 0, 120, -120 (phase b and c are flipped)

We can swap cable in terminal B and C, and it will blink altogether again.

1. Must have equal line voltage, frequency, phase sequence, phase angle, and waveform.

7. Alternator Power
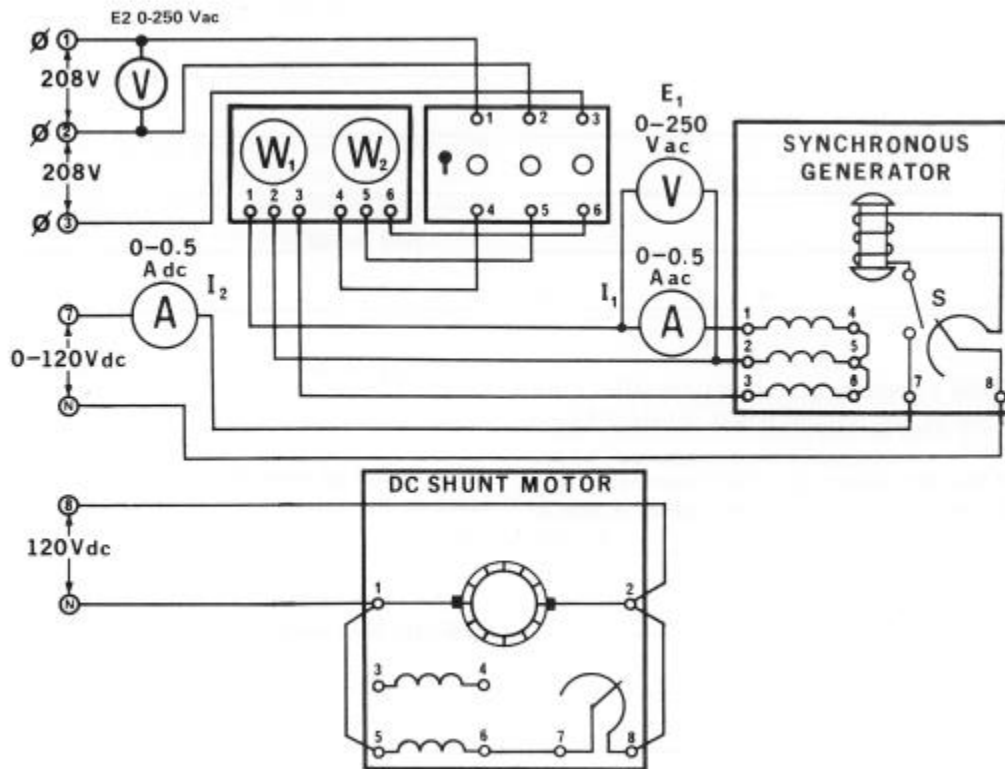
3. The alternator is now "floating" on the power line. It is neither receiving nor delivering power to the line. After synchronization, here are the measurements of E_1, I_1, and I_2 (E_2 is the grid's line voltage)

M1	E1	M2	E2
	E1		E2
211.5		**211.8**	
AC	V	AC	V

M7	I1	M8	I2
	I1		I2
0.007		**0.612**	
AC	A	AC	A

P and Q ~ 0 here:

M1	E1	M2	E2	M3	E3
	E1		E2		E3
209.9		**210.0**			
AC	V	AC	V	AC	V

M7	I1	M8	I2	M9	I3
	I1		I2		I3
0.042		**0.596**			
AC	A	AC	A	AC	A

M13	PQS1 (E1,I...	M14	PQS1 (E1,I...	M15	PQS1 (E1,I...
PQS1 (E1,I1) 3~		PQS1 (E1,I1) 3~		PQS1 (E1,I1) 3~	
-0.049		**-1.876**		**14.87**	
P	W	Q	Var	S	VA

or

M1	E1	M2	E2	M3	E3
	E1		E2		E3
209.9		**210.0**			
AC	V	AC	V	AC	V

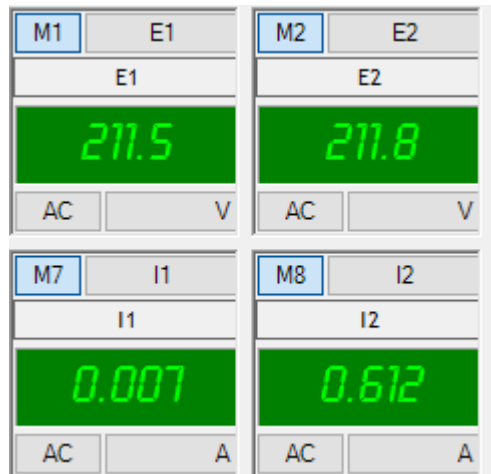| M7	I1	M8	I2	M9	I3
	I1		I2		I3
0.047		**0.597**			
AC	A	AC	A	AC	A

M13	PQS1 (E1,I...	M14	PQS1 (E1,I...	M15	PQS1 (E1,I...
PQS1 (E1,I1) 3~		PQS1 (E1,I1) 3~		PQS1 (E1,I1) 3~	
-1.414		**0.077**		**16.97**	
P	W	Q	Var	S	VA

4. Slowly increased till I1 = 0.33A,

M1	E1	M2	E2	M3	E3
	E1		E2		E3
210.1		**209.9**			
AC	V	AC	V	AC	V

M7	I1	M8	I2	M9	I3
	I1		I2		I3
0.335		**0.815**			
AC	A	AC	A	AC	A

M13	PQS1 (E1,I...	M14	PQS1 (E1,I...	M15	PQS1 (E1,I...
PQS1 (E1,I1) 3~		PQS1 (E1,I1) 3~		PQS1 (E1,I1) 3~	
-7.462		**121.0**		**122.3**	
P	W	Q	Var	S	VA
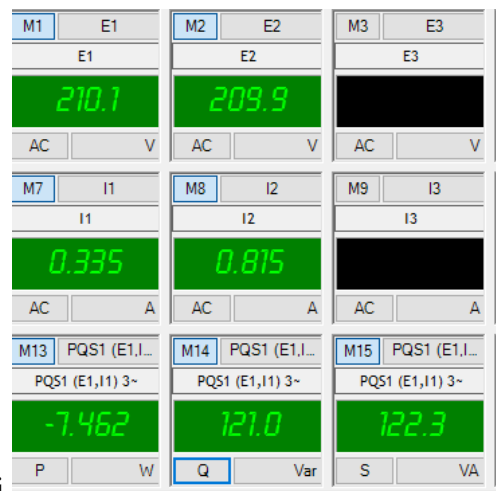
4.i.

An increase in DC excitation leads to both reactive and active power to increase.

5. P = 0W or reach as closely to 0 as possible because of losses in the machine.
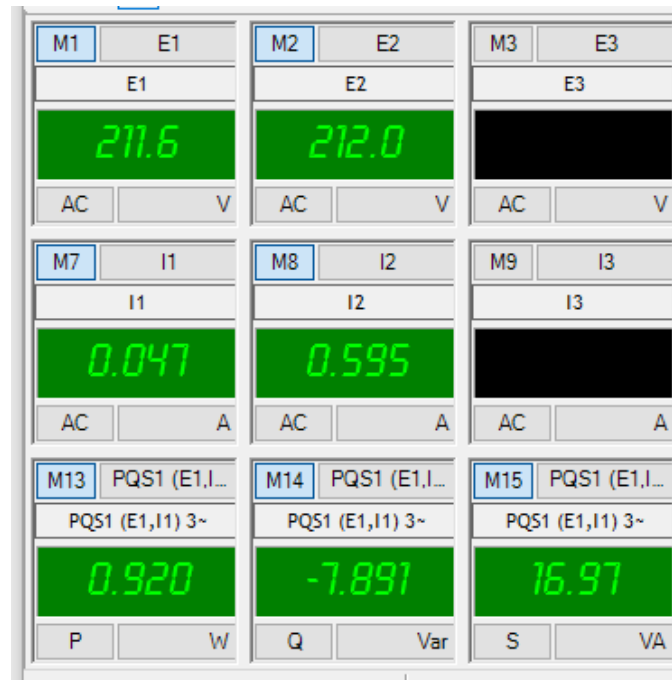
M1	E1	M2	E2	M3	E3
	E1		E2		E3
	211.6		212.0		
AC	V	AC	V	AC	V

M7	I1	M8	I2	M9	I3
	I1		I2		I3
	0.047		0.595		
AC	A	AC	A	AC	A

M13	PQS1 (E1,I...	M14	PQS1 (E1,I...	M15	PQS1 (E1,I...
	PQS1 (E1,I1) 3~		PQS1 (E1,I1) 3~		PQS1 (E1,I1) 3~
	0.920		-7.891		16.97
P	W	Q	Var	S	VA

6. A decrease in DC excitation affect mainly the **reactive** power delivered by the alternator. The nature of the reactive power is different from Step 4.

M1	E1	M2	E2	M3	E3
	E1		E2		E3
	210.0		210.2		
AC	V	AC	V	AC	V

M7	I1	M8	I2	M9	I3
	I1		I2		I3
	0.331		0.391		
AC	A	AC	A	AC	A

M13	PQS1 (E1,I...	M14	PQS1 (E1,I...	M15	PQS1 (E1,I...
	PQS1 (E1,I1) 3~		PQS1 (E1,I1) 3~		PQS1 (E1,I1) 3~
	-3.305		-119.3		120.5
P	W	Q	Var	S	VA
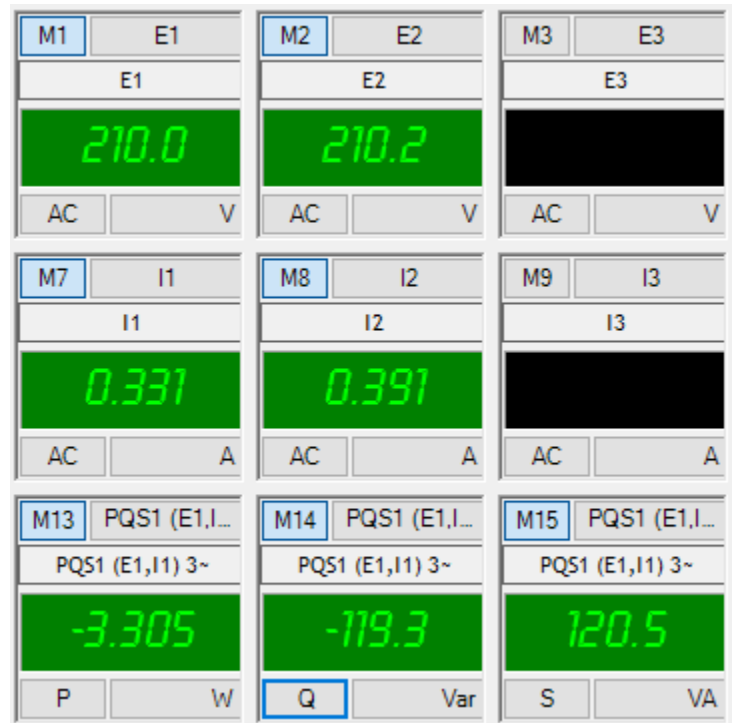
7. S = 0VA or reach as closely to 0 as possible due to loss.

M1	E1	M2	E2	M3	E3
	E1		E2		E3
210.3		**210.3**			
AC	V	AC	V	AC	V

M7	I1	M8	I2	M9	I3
	I1		I2		I3
0.044		**0.601**			
AC	A	AC	A	AC	A

M13	PQS1 (E1,I...	M14	PQS1 (E1,I...	M15	PQS1 (E1,I...
	PQS1 (E1,I1) 3~		PQS1 (E1,I1) 3~		PQS1 (E1,I1) 3~
-3.591		**-0.332**		**15.11**	
P	W	Q	Var	S	VA

8. Decrease DC excitation voltage to get I_1 = 0.33A. An increase in torque leads to both P and Q to decrease (in source convention).

M1	E1	M2	E2	M3	E3
	E1		E2		E3
210.6		**210.7**			
AC	V	AC	V	AC	V

M7	I1	M8	I2	M9	I3
	I1		I2		I3
0.330		**0.396**			
AC	A	AC	A	AC	A

M13	PQS1 (E1,I...	M14	PQS1 (E1,I...	M15	PQS1 (E1,I...
	PQS1 (E1,I1) 3~		PQS1 (E1,I1) 3~		PQS1 (E1,I1) 3~
-5.078		**-119.4**		**120.5**	
P	W	Q	Var	S	VA

M1	E1	M2	E2	M3	E3
	E1		E2		E3
210.8		**211.0**			
AC	V	AC	V	AC	V

M7	I1	M8	I2	M9	I3
	I1		I2		I3
0.326		**0.402**			
AC	A	AC	A	AC	A

M13	PQS1 (E1,I...	M14	PQS1 (E1,I...	M15	PQS1 (E1,I...
	PQS1 (E1,I1) 3~		PQS1 (E1,I1) 3~		PQS1 (E1,I1) 3~
-3.267		**-117.9**		**118.9**	
P	W	Q	Var	S	VA

10. Here, $Q = 120.9\ var$ following generator convention, i.e., it's an inductive load on the alternator.

M1 E1	M2 E2	M3 E3	M4 E4
E1	E2	E3	E4
210.1	**210.0**		
AC V	AC V	AC V	AC V
M7 I1	M8 I2	M9 I3	M10 I4
I1	I2	I3	I4
0.337	**0.810**		
AC A	AC A	AC A	AC A
M13 PQS1 (E1,I...	M14 PQS1 (E1,I...	M15 PQS1 (E1,I...	M16 PF (E1,I1)...
PQS1 (E1,I1) 3~	PQS1 (E1,I1) 3~	PQS1 (E1,I1) 3~	PF (E1,I1) 3~
-11.79	**120.9**	**122.5**	**0.096**
P W	Q Var	S VA	True

11. Here, $Q = -120.6\ var$ following generator convention, i.e., it's a capacitive load on the alternator.

M1 E1	M2 E2	M3 E3	M4 E4
E1	E2	E3	E4
210.0	**210.3**		
AC V	AC V	AC V	AC V
M7 I1	M8 I2	M9 I3	M10 I4
I1	I2	I3	I4
0.427	**0.452**		
AC A	AC A	AC A	AC A
M13 PQS1 (E1,I...	M14 PQS1 (E1,I...	M15 PQS1 (E1,I...	M16 PF (E1,I1)...
PQS1 (E1,I1) 3~	PQS1 (E1,I1) 3~	PQS1 (E1,I1) 3~	PF (E1,I1) 3~
96.16	**-120.6**	**155.3**	**0.619**
P W	Q Var	S VA	True