SCHOOL OF ENGINEERING

ELECTRICAL AND COMPUTER SYSTEMS ENGINEERING

LABORATORY REPORT MARKING RUBRIC

ECE3051: ELECTRICAL ENERGY SYSTEMS

Experiment Number: 5

Title of Lab Sheet: Synchronous Machine

Group Number: 8

No.	Student ID	Name of Group Members	Total Marks
1	30720230	Loh Jia Quan	99/100
2	31106889	Agill Kumar Saravanan	99/100
3	30719305	Huan Meng Hui	99/100
4	32194471	Tan Jin Chun	99/100
5	32259417	Chong Yen juin	99/100

MARKS BREAKDOWN

Section	Total Score	Actual Marks	Scoring Band	Criteria	Comment
Results	40		30-40	Clear and completely labelled figures of the experiment/simulation results with justifications and tables. A detailed caption is provided for each figure with an in-text figure reference. The x-axis and y-axis are labelled with the unit in the bracket. The legend is provided whenever it is deemed to be required. If there is more than one line, the lines should be clearly distinguishable with the visible difference such as dotted line, dashed line and solid line, even in black and white.	39
			20-30	Some of the figures of the experiment/simulation setup are not clear, do not have any labelling/ caption/ in-text caption reference/ distinguishable multiple lines and are blurry. The table and justification have mistakes or errors.	
			0-20	Insufficient amounts of figures and labelling of the experiment/simulation layout setup, which is not correct and/or unclear. The table is not filled.	
Discussion	40		30-40	Complete data collection and presentation using tables/figures/ graphs with appropriate labels. Discussion of the results with prudent judgment. Have a comparison of the measured results with theoretical values and in-text citations from the peer-reviewed references. The comprehensive comparison, evaluation and justification of the results are given with clear explanation to demonstrate the understanding of the laboratory.	40
			20-30	The discussion shows little understanding of what the experiment/simulation is all about. Brief comparison, evaluation and justification of the results, with unclear/ incorrect explanation on the theoretical and experimental/ simulation results.	
			0-20	Only restatement of the results without commenting on the expected key points.	

				Incorrect judgment/ arguments were used. No comparison, evaluation and justification of the results, with an unsatisfactory explanation on the theoretical and experimental/ simulation results.	
Conclusion, References and Appendix	20		15-20	Explained how the aims of the experiment have been achieved. The key features of the methods used, the most important results and the findings of the laboratory have been summarized. Complete references list to any book, articles and websites is provided with proper in-text citations in correct formatting. The appendix is provided in detail.	20
			10-15	A conclusion is drawn but is not supported by the experimental/ simulation evidence and a clear understanding of the findings. Incomplete references to the books or any other sources used in the report and the in-text citations are inappropriate or incorrect. The appendix is partially provided.	
			0-10	No sensible conclusion. The referencing is presented in the wrong format. No evidence, attachments, appendices are attached. Irrelevant referencing was used. Unclear understanding of the experiment without a summarized conclusion and the evidence of results. No appendix is provided.	
Total	100				99

Examiner/ Assessor of ECE3051: Electrical Energy Systems
Date: 19/5/2023

EXPERIMENT 5

SYNCHRONOUS MACHINE

Characteristics of a three-phase synchronous generator

1. Preliminary

Nameplate data for the machines [8 Marks]

(Insert a picture or table showing the nameplate data of the synchronous and DC machine used in this experiment)

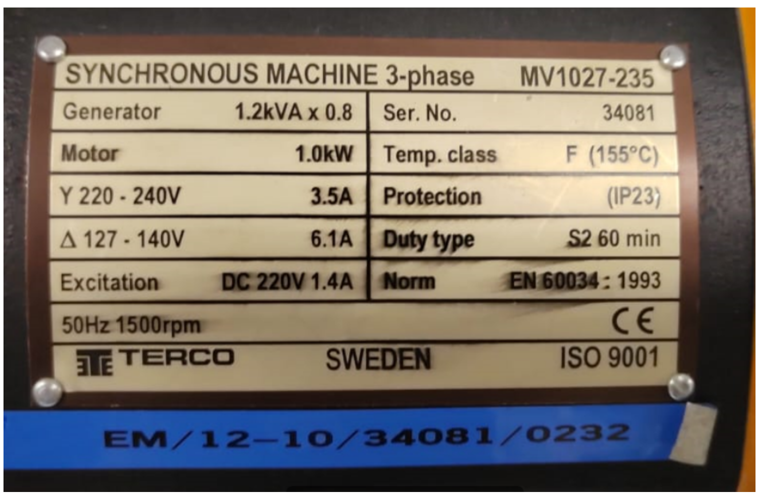

Fig. 1. Nameplate data of synchronous machine

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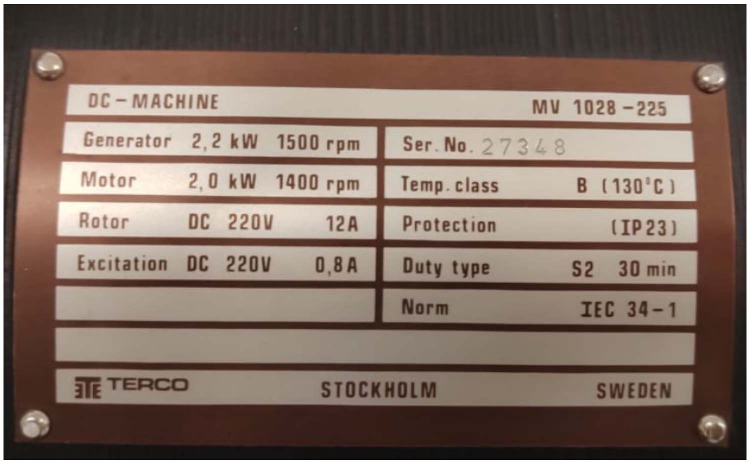
[

Fig. 2. Nameplate data of DC machine

Experimental wiring and experimental setup [8 Marks]

(Insert a picture of your experimental setup and label all the equipment used.)

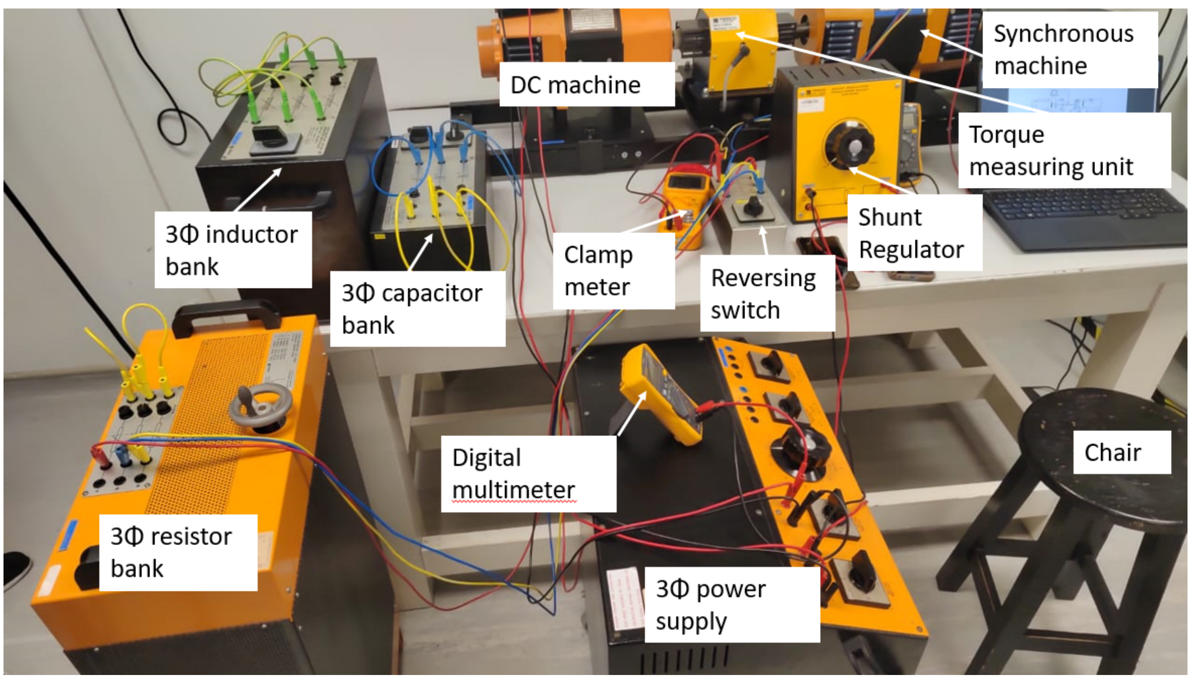


Fig. 3. Experiment Setup

2. No-load test [6 Marks]

(Fill up the necessary data/ measurements from the experiment into the table below.)

checked

Excitation current, I_m (A)	**Stator induced voltage, U (V)**
0.004	3.068
0.053	13.90
0.101	25.74
0.150	52.00
0.202	71.90
0.251	90.10
0.302	107.90
0.351	126.40
0.400	143.80
0.450	159.80
0.501	175.30
0.550	191.90
0.600	206.20
0.653	220.30
0.701	233.40
0.750	246.20
0.801	256.70
0.850	268.20
0.900	277.30

3. Short-circuit test [6 Marks]

(Fill up the necessary data/ measurements from the experiment into the table below.)

Excitation current, I_m (A)	**Armature current, I_A (A)**
0.001	0.21
0.049	0.47

checked

0.101	0.82
0.148	1.20
0.205	1.53
0.251	1.90
0.301	2.30
0.350	2.62
0.402	3.07
0.449	3.30

checked

Load test

Resistive load [5 Marks]

(Fill up the necessary data/ measurements from the experiment into the table below.)

Excitation current, I_m (A)	**Armature current, I_A (A)**	**Stator induced voltage, U (V)**
0.676	0.56	220.7
0.662	0.60	216.8
0.659	0.70	214.2
0.656	0.80	211.7
0.654	0.90	208.9
0.652	1.00	206.7
0.650	1.10	205.6
0.649	1.20	203.5
0.648	1.30	200.4
0.646	1.40	200.1
0.645	1.50	198.4
0.644	1.60	196.2
0.643	1.70	194.6
0.642	1.80	190.8
0.641	1.90	187.5
0.641	2.00	185.5
0.640	2.10	183.0
0.639	2.20	182.1
0.638	2.30	180.1
0.637	2.40	176.8
0.637	2.50	173.4

checked

0.637	2.60	171.7
0.637	2.70	167.5
0.636	2.80	166.0
0.635	2.90	162.9
0.635	3.00	161.2
0.635	3.10	158.6
0.635	3.20	154.9
0.635	3.30	153.1

Inductive load [5 Marks]

(Fill up the necessary data/ measurements from the experiment into the table below.)

Excitation current, I_m (A)	Armature current, I_A (A)	Stator induced voltage, U (V)
0.638	**0.62**	**198.2**
0.637	**1.00**	**181.2**
0.637	**1.31**	**167.4**
0.637	**1.60**	**151.3**
0.637	**1.83**	**140.4**
0.637	**2.00**	**132.8**
0.637	**2.20**	**123.0**
0.636	**2.40**	**116.8**
0.635	**2.55**	**108.5**
0.635	**2.65**	**102.7**

checked

0.635	**2.75**	**98.0**

Capacitive load [5 Marks]

(Fill up the necessary data/ measurements from the experiment into the table below.)

Excitation current, I_m (A)	**Armature current, I_A (A)**	**Stator induced voltage, U (V)**
0.636	0.59	237.5
0.636	1.08	254.9
0.635	1.74	271.8
0.635	2.37	289.3
0.635	**3.07**	**306.1**

checked

Discussion

a. Graphs of the no-load characteristic and short-circuit characteristic (Joshua)

[2 Marks]

(Insert the graphs of the no-load characteristic and short-circuit characteristic in the same diagram and with common I_m axis.)

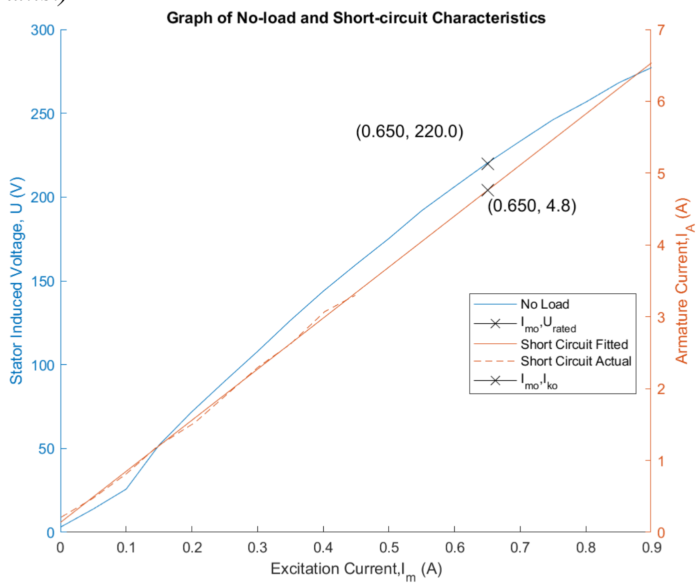


Fig. 4. Graph of no-load, short-circuit characteristic. Y-axis is Stator Induced Voltage, U (V) and X-axis is Excitation Current, I_m (A)

b. Graphs of the three load characteristics [3 Marks] (JQ)

(Insert graphs of the three load characteristics in the same diagram and with common I_A axis.)

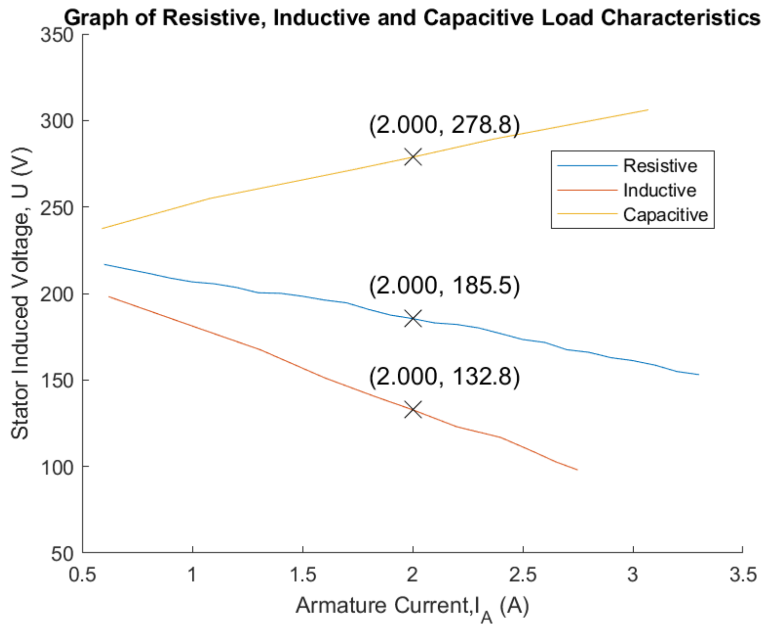


Fig. 5. Graph of resistive, inductive, capacitive load characteristics; Y-axis is Stator Induced Voltage, U (V) and X-axis is Armature Current, I_A (A)

c. No-load characteristic and the excitation current [2 Marks] (Joshua)

(Read and state the excitation current I_{mo} corresponding to the rated voltage (220V) from the graph above.)

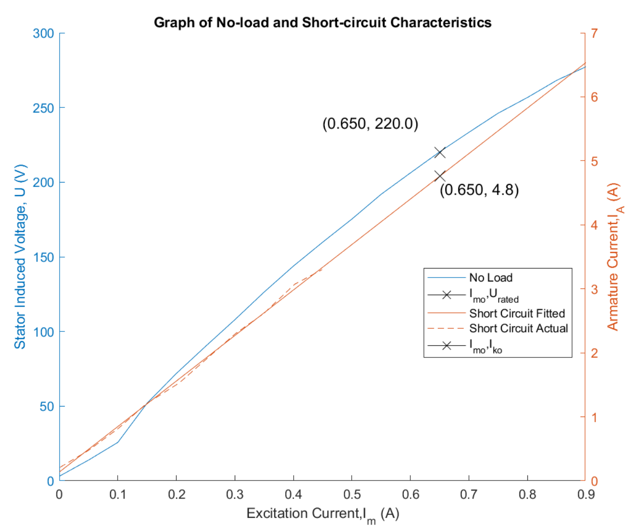


Fig. 6. Graph of no-load, short-circuit characteristic. Y-axis is Stator Induced Voltage, U (V) and X-axis is Excitation Current, I_m (A); Read graph to obtain the excitation current

Excitation current I_{mo} corresponding to the rated voltage 220V obtained from the no-load characteristic graph is 0.65A.

d. Short-circuit characteristic and the short-circuit current [2 Marks] (Joshua)

checked

(Read and state the short-circuit current I_{ko} obtained at the excitation current I_{mo} from the graph above.)

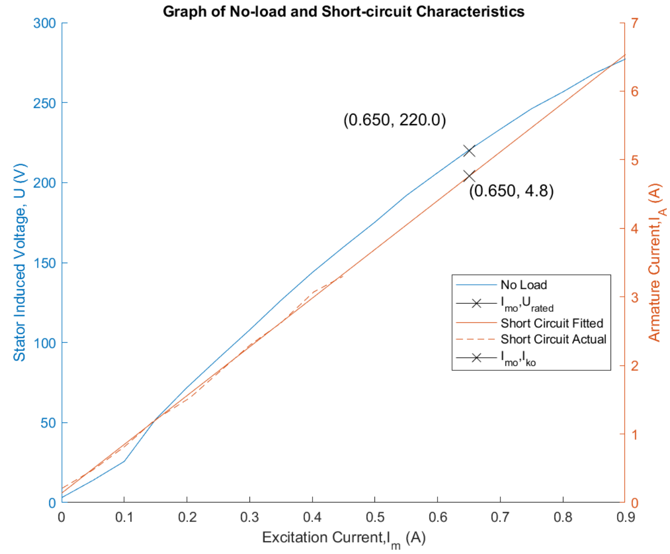


Fig. 7. Graph of no-load, short-circuit characteristic. Y-axis is Stator Induced Voltage, U (V) and X-axis is Armature Current, I_A (A); Read graph to obtain the excitation current and short circuit current

As our readings were unable to obtain the short-circuit current at the rated excitation current without exceeding the rated short-circuit current (3.5A), the current graph has to be interpolated.
Short-circuit current I_{ko} corresponding to the excitation current I_{mo} obtained from the interpolated no-load characteristic graph is 4.8A.

e. Synchronous reactance of the generator per phase [2 Marks] (Joshua)

(Calculate the synchronous reactance of the generator per phase as $X_s = U_n/I_{ko} = 127/I_{ko}$ Ω/phase.)

$$X_s = \frac{U_n}{I_{ko}} = \frac{\Omega}{phase} X_s = \frac{127}{4.8} = 26.46\frac{\Omega}{phase}$$

f. Short-circuit ratio of the generator [2 Marks] (Joshua)

(Calculate the short-circuit ratio of the generator $k_c = I_{ko}/I_n$, where I_n = rated current of the generator.)

$$K_c = \frac{I_{ko}}{I_n} = \frac{4.8A}{3.5A} = 1.37A$$

wrong unit (minus 1 mark)

checked

g. Three vector diagrams [2 Marks]

(Draw three vector diagrams to scale with E = 127 V, I_A = 2 A and φ = 0º, +90º and -90º, respectively. The numerical value of X_s can be obtained from part e.)

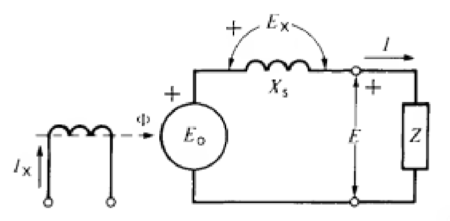


Fig. 8. Equivalent Circuit of Synchronous Generator

$$Xs = 26.46\,\frac{\Omega}{phase}$$

A. Resistive Load

$$I = 2\angle 0° A$$
$$E_{terminal} = 127\angle 0° V$$
$$E_x = I * jXs = 2 * j26.46 = j52.92\,V$$
$$Stator\ Induced\ Phase\ Voltage,\ E_0 = E + E_x = 127 + 52.92j = 137.58\angle 22.62°\,V$$
$$Stator\ Induced\ Line\ Voltage,\ U = E_0 * \sqrt{3} = 238.303\angle 22.62°\,V$$

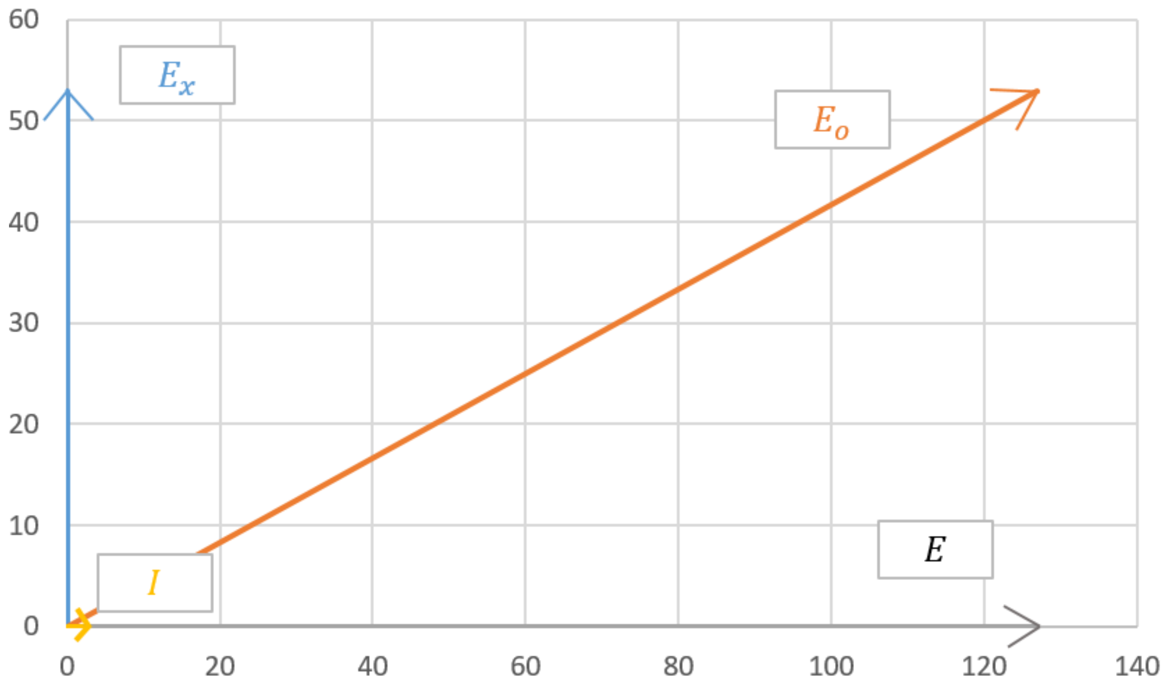


Fig. 9. Vector diagram of Resistive Load

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B. *Inductive Load*

$I = 2\angle -90° A$

$E = 127\angle 0° V$

$E_x = I * jXs = 2\angle -90° * j26.46 = 52.92\, V$

$Stator\ Induced\ Voltage_{Phase},\ E_0 = E + E_x = 127 + 52.92 = 179.92\, V$

$Stator\ Induced\ Line\ Voltage,\ U = E_0 * \sqrt{3} = 311.63\, V$

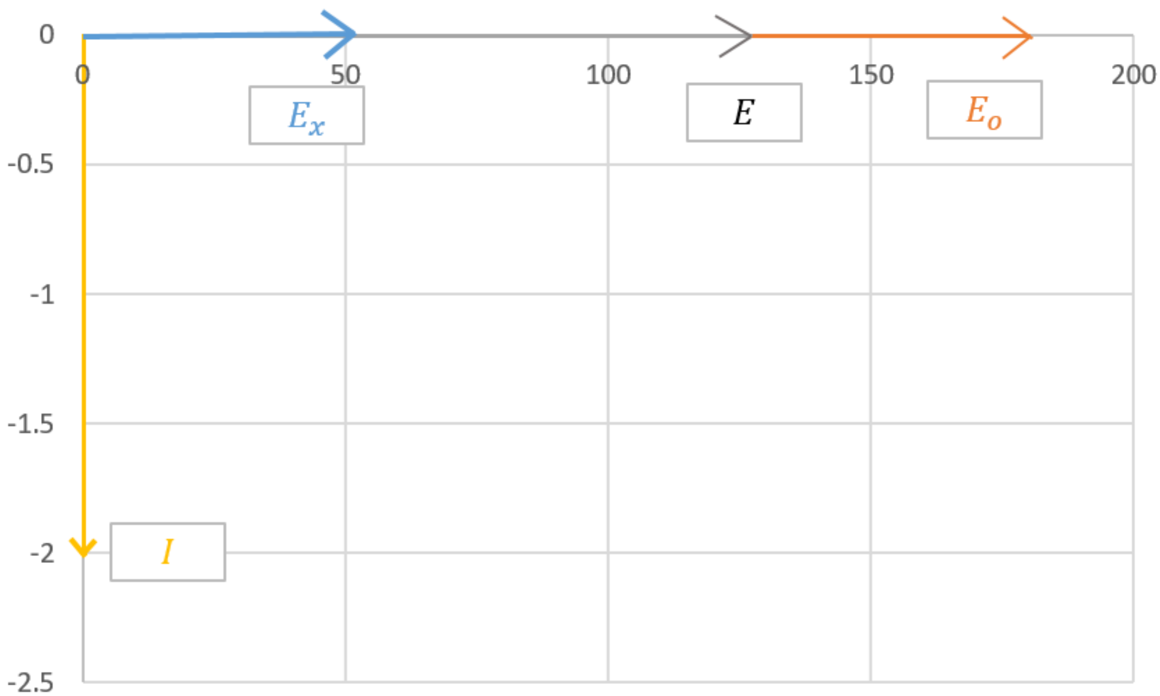

Fig. 10. Vector diagram of Inductive Load

C. *Capacitive Load*

$I = 2\angle 90° A$

$E = 127\angle 0° V$

$E_x = I * jXs = 2\angle 90° * j26.46 = -52.92\, V$

$Stator\ Induced\ Voltage_{Phase},\ E_0 = E + E_x = 127 - 52.92 = 74.08\, V$

$Stator\ Induced\ Line\ Voltage,\ U = E_0 * \sqrt{3} = 128.31\, V$

checked

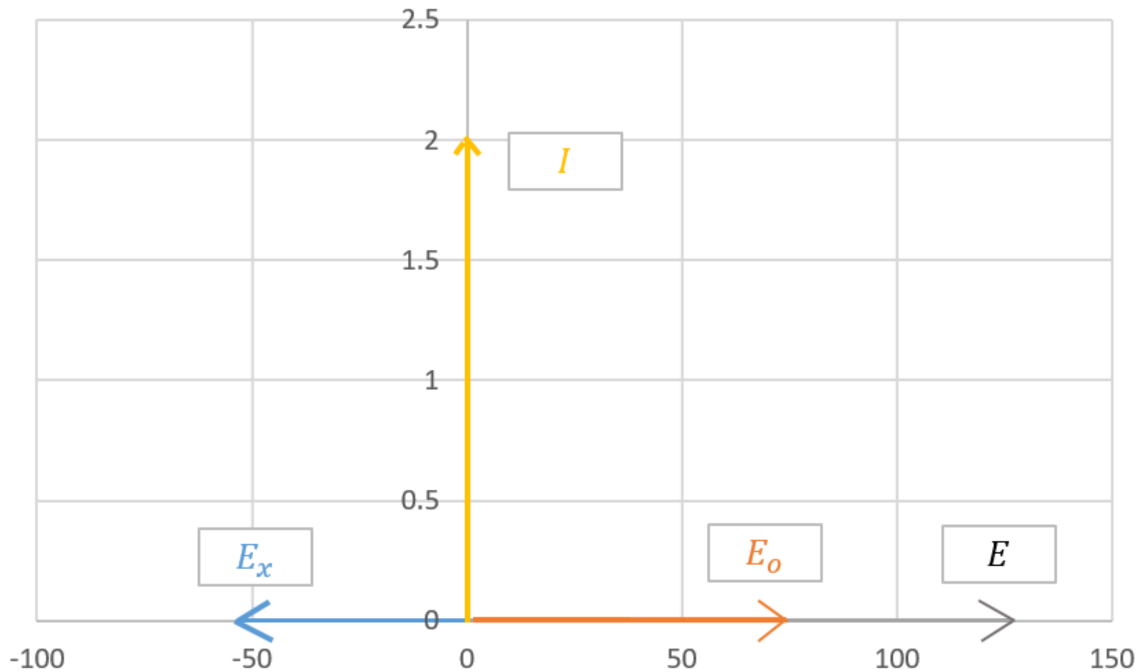

Fig. 11. Vector diagram of Capacitive Load

h. Comparison of vector diagrams with the corresponding values on the load characteristic [2 Marks]

(Read U in the vector diagrams and compare with the corresponding values on the load characteristic.)

	Armature current, I_A (A)	*stator induced phase voltage, U (V)*	*stator induced line voltage U_{line} (V)*
Resistive Load	*2*	*137.58*	*238.303*
Capacitive Load	*2*	*74.08*	*128.31*
Inductive Load	*2*	*179.92*	*311.63*

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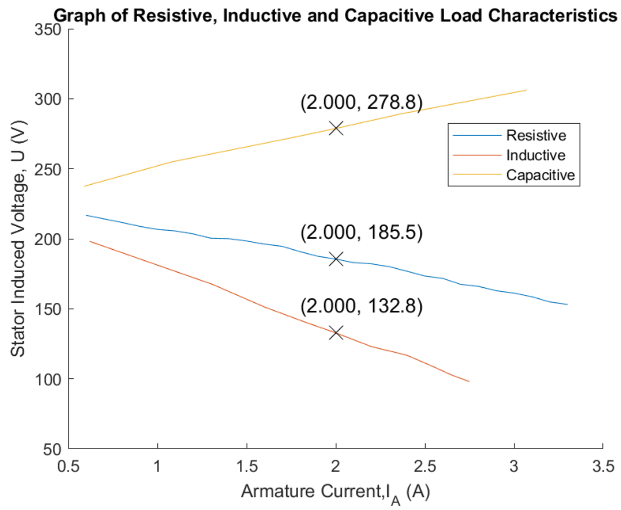

Fig. 12. Graph of R, L, C load characteristics, read graph to obtain U

	Armature current, I_A (A)	*stator induced phase voltage, U (V)*	*stator induced line voltage U_{line} (V)*
Resistive Load	*2*	*107.10*	*185.5*
Capacitive Load	*2*	*160.97*	*278.8*
Inductive Load	*2*	*76.67*	*132.8*

Comparison

	Armature current, I_A (A)	*stator induced phase voltage, U (V)*		*stator induced line voltage U_{line} (V)*	
		Vector	*Graph*	*Vector*	*Graph*
Resistive Load	*2*	*137.58*	*107.10*	*238.303*	*185.5*
Capacitive Load	*2*	*74.08*	*160.97*	*128.31*	*278.8*
Inductive Load	*2*	*179.92*	*76.67*	*311.63*	*132.8*

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The values of stator induced phase voltage, U, read from the phasor diagram have discrepancies with the experimental value read from the graphs.

One specific reason for the discrepancies between the phasor diagram and the experimental values is ***voltage regulation*** in the synchronous generator, the terminal voltage will change when the type of load changes.

The phasor diagram, in our calculation, assumes a constant terminal voltage (127V phase voltage), , leading to significant discrepancies in the results.

In our experimental setup, when the load is inductive, the stator induced voltage (read from graph) is the smallest because the terminal voltage will decrease as the armature current increases, as shown by the equation below
$U = E + E_x$; When E decreases, U will also decrease.

When the load is capacitive, the stator induced voltage will increase significantly (from graph) and become the largest in this experimental setting - as the armature current increases, the terminal voltage will increase. The relationship is trivial as shown above.

When the load is switched to resistive, the stator induced voltage (from graph) will decrease, but not as much as that of inductive loads'. This is because terminal voltage will decrease by a small margin as the armature current increases, albeit not to the same magnitude as inductive load.

That is the reason for the difference in values of phasor diagram and graph values, the changes of terminal voltage are not taken into account for computing the stator induced voltage as armature current varies.

checked

Discussion

1. Explain in detail the purpose of no-load, short-circuit and load test conducted in this experiment. [10 Marks]

The tests that are conducted in this experiment to describe the behavior of a real synchronous generator, that is the relationship between the excitation current, armature current and stator induced voltage when there is open-circuited, short-circuited, and connected with different types of load which are the resistive, capacitive and inductive load.

No-load test

The purpose of the no-load test is to determine the nominal excitation current at the specified stator voltage . In this test, the generator is operated at rated speed with no load connected to it. The field current is gradually increased, and the corresponding values of open-circuit voltage and field current are recorded. The open-circuit characteristic is a plot of the open-circuit voltage versus field current, and it provides information on the magnetization characteristics of the generator. The no-load test is essential for determining the generator's voltage regulation and for designing the excitation system. The no-load test is carried out to determine the open-circuit characteristic (also known as the saturation curve) of the synchronous generator. The nominal excitation current at the specified stator voltage even when the synchronous motor's magnetization characteristic may not be linear. The no-load test can also be used to determine the best excitation current for the short circuit test and the no-load impedance in the synchronous generator [2].The no-load test is conducted with the rotor rotating at synchronous speed and no load torque. The purpose for this procedure is to measure the no-load losses such as core loss, friction loss, and windage loss of a synchronous generator. These losses occur because the alternator spins unnecessarily, reducing its efficiency and wasting energy. To create an appropriate torque, only a small amount of electricity is required.The magnetizing path impedance is high enough to block current passage. This means that only a small current is delivered to the machine. This causes the stator-impedance value to decrease and the rated voltage to be applied across the magnetizing branch. However, the decrease in stator-impedance value and power consumed due to stator resistance are negligible compared to the applied voltage.

Short-circuit test

The purpose of the short circuit test is to compute the synchronous reactance of the synchronous motor.All of the electricity will travel via the synchronous reactance since the motor is short-circuited. The voltage provided, E, is kept constant at 127V per phase, the synchronous reactance can be computed using the formula, Xs = E/Isx. The short circuit test can also be used to gather information about the capacity of the synchronous generator. The test is performed by short-circuiting the machine's terminals. The armature reaction of the machine prevents it from becoming saturated during testing. It would be possible to determine the value of the armature current, internal impedance and the synchronous reactance from measuring the short-circuited current [3].

Load test

The load test is carried out to examine the impact of the load on the stator voltage and to confirm the accuracy of the synchronous reactance derived from the no-load and short circuit tests.The load bank generator test will subject the generator to varying load conditions in order to assess how the generator handles the increased power demand [4].Depending on the loading conditions (resistive, inductive and capacitive), the armature reaction's impact may differ which will result in a shift from positive inductive loading to negative in capacitive loading. The direction of current flow is critical to

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the alternator under inductive or capacitive loads when the voltage is applied. In an inductive load, the current lags voltage by up to half a cycle.In a capacitive load, the current leads voltage. High-reactive loads require more current from the alternator than fully resistive loads. The load test is performed to determine how the stator voltage varies with the armature current under different loading conditions.

2. Discuss the change in voltage regulation of a synchronous generator when it is connected to different types of load (resistive, inductive, capacitive). [10 Marks]

The voltage regulation of the synchronous generator when it is connected to the resistive load

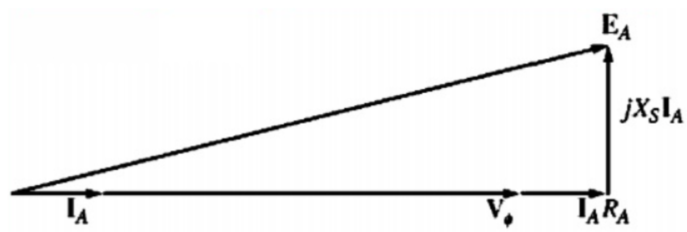

Fig 13: The phasor diagram of a synchronous generator at unity p.f (power factor) [6]

With a resistive load, the stator voltage drops as the armature current rises. As a result, the voltage regulation is on the positive side. Because the synchronous reactance creates a voltage drop, the voltage at resistive loads is reduced. When a resistive load is connected to a synchronous generator, it has a unity power factor which will result in an increase in the magnitude of induced current Ia. Since the power factor is 1, the current angle will be the same as the terminal voltage E.

The voltage regulation of the synchronous generator when it is connected to the inductive load

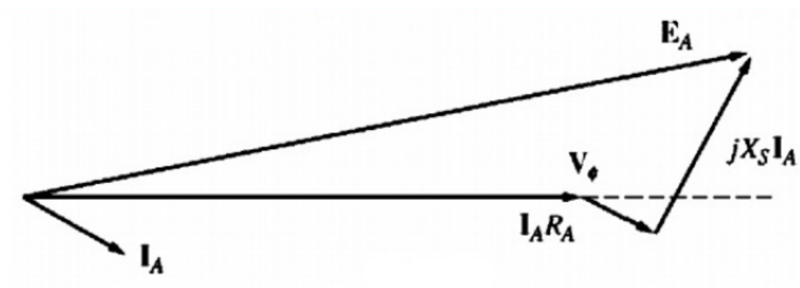

Fig 14: The phasor diagram of a synchronous generator at lagging p.f (power factor) [6]

When an inductive load is connected to a synchronous generator, the stator voltage decreases as the armature current increases. This results in a positive voltage regulation that grows faster than that of a resistive load as the armature current increases. Inductive loads produce a lagging current, which, as shown in the inductive load vector diagram, leads to a significant reduction in voltage magnitude *at the synchronous reactance. As a result, the voltage regulation of an inductive load is greater than that of a resistive load.*

The voltage regulation of the synchronous generator when it is connected to the capacitive load

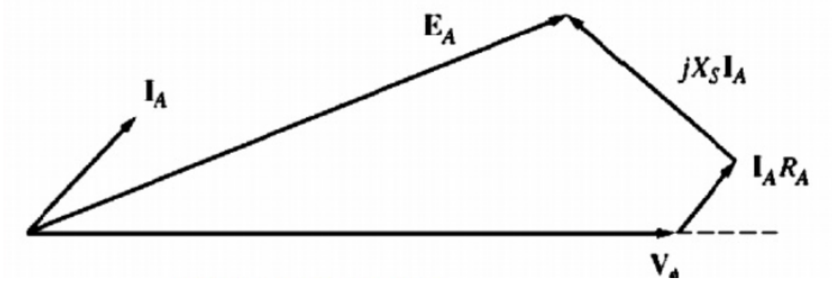

Fig 15: The phasor diagram of a synchronous generator at leading p.f (power factor) [6]

When a capacitive load is connected to a synchronous generator, the stator voltage increases as the armature current increases and negative voltage regulation is used. Capacitive loads provide reactive power to the line, resulting in a voltage that is higher than that of the generator. A capacitive load generates a leading current that is converted into a voltage gain by the synchronous reactance when viewed from the vector diagram's perspective, resulting in an increase in voltage.

Conclusion and Findings [14 Marks]

(Include your conclusion on the experiment done. State the learning outcomes of this experiment.)

Three experiments were performed in this lab which are the no-load test, the short-circuit test, and the load test. During the load test, three types of loads were utilized which are resistive, inductive, and capacitive loads. The experiments are carried out to measure the excitation current, armature current and the stator voltage characteristic of the three-phase synchronous generator.

The no-load test

In the no-load test, increasing the excitation current resulted in an increase in the induced stator voltage. The no-load test was carried out by varying the excitation current from approximately 0A to 0.9A with steps of approximately 0.05. As we can see from the graph, the no-load characteristic of the generator is linear until the excitation current reaches 0.85A, at which point the iron parts within the machine become saturated. The saturation of iron parts can cause non-linearity in the generator's behavior, which may explain the change in the no-load characteristic beyond an excitation current of 0.85A.

The short-circuit test

In the short-circuit test, an increase in the excitation current will result in a corresponding increase in the armature current. The short circuit test is conducted by increasing the excitation current from approximately 0A to 0.45A with steps of approximately 0.05. We can also conclude that the armature reaction prevents the machine from saturating when it is short circuited.

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The load test
Finally, during the load test, resistive and inductive loads were found to cause a decrease in the stator induced voltage as the armature current increased. In the case of the capacitive load, the stator induced voltage increased with an increase in the armature current.

References [6 Marks]

[1] T. Wildi, "Synchronous Generators," in Electrical Machines, Drives, and Power Systems, 6th ed., UK: Pearson, ch. 16, pp. 350.

[2]"Open Circuit Test and Short Circuit Test of Synchronous generator." Theengineeringknowledge.com. https://www.theengineeringknowledge.com/open-circuit-test-and-short-circuit-test-of-synchronous-generator/(accessed May 5, 2023).

[3] "What is Generator Load Bank Testing and How Is It Done?" loadbanksdirect.com. https://www.loadbanksdirect.com/about-lbd/blog/how-is-load-bank-generator-testing-done#:~:text=A%20load%20bank%20generator%20test,of%20testing%20the%20power%20 equipment.(accessed May 5, 2023).

[4]"Synchronous Generator Operating Alone." Thengineeringknowledge.com. https://www.theengineeringknowledge.com/synchronous-generator-operating-alone/(accessed May 5, 2023).

[5] Habib (2021) The load characteristics of alternator: Practical example, ICEEET. Available at: https://www.iceeet.com/load-characteristics-of-alternator/ (Accessed: 13 May 2023).

[6] Henry, "Phasor Diagram of a Synchronous Generator," The Engineering Knowledge, Oct. 06, 2019. https://www.theengineeringknowledge.com/phasor-diagram-of-a-synchronous-generator/

[7] "Phasor Diagram of Synchronous Generator or Alternator," Electrical Deck - All about Electrical & Electronics. https://www.electricaldeck.com/2021/01/phasor-diagram-of-synchronous-generator-or-alternator.html (accessed May 13, 2023).

******** THE END *******

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