SCHOOL OF ENGINEERING

ELECTRICAL AND COMPUTER SYSTEMS ENGINEERING

LABORATORY REPORT MARKING RUBRIC

ECE3051: ELECTRICAL ENERGY SYSTEMS

Experiment Number: 3

Title of Lab Sheet: AC Induction Motor & Drive System

Group Number: 8

No.	Student ID	Name of Group Members	Total Marks
1	30720230	Loh Jia Quan	98/100
2	31106889	Agill Kumar Saravanan	98/100
3	30719305	Huan Meng Hui	98/100
4	32194471	Tan Jin Chun	98/100
5	32259417	Chong Yen juin	98/100

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.	40
			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.	18
			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				98

Examiner/ Assessor of ECE3051: Electrical Energy Systems

Date: 19/4/2023

EXPERIMENT 3

AC INDUCTION MOTORS AND DRIVE SYSTEMS

1. Preliminary

Nameplate data for the induction and dc motors [4 Marks]

(Insert a picture of the nameplate data for both the induction and dc motors. Alternatively, you may insert a data table in writing)

Fig. 1. Nameplate data for the induction machine.

Fig. 2. Nameplate data for the DC machine.

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Experimental setup [8 Marks]

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

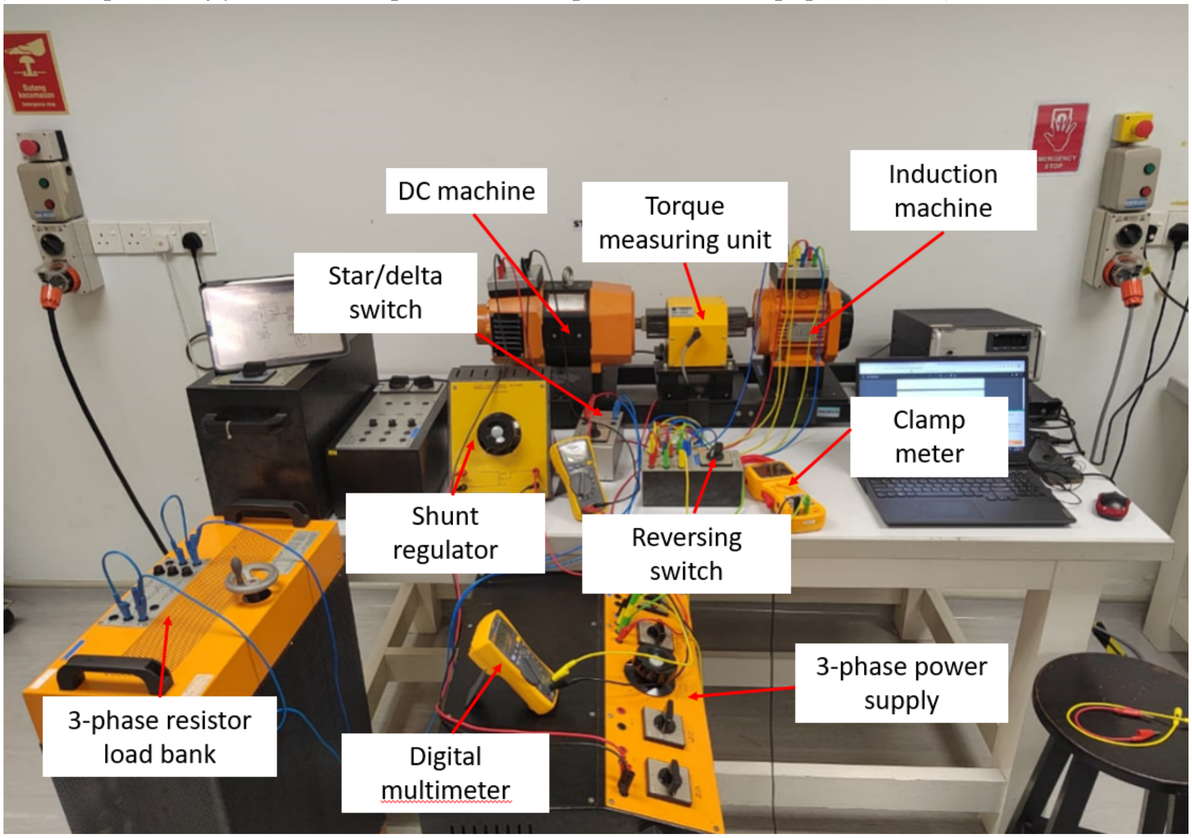

Fig. 3. Experimental setup in the lab with equipment labeling.

Fig. 4. Torque measuring unit display in lab

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Equivalent circuit parameters and torque-speed characteristic

Locked-rotor test results [8 Marks]

Measurements	Value (Unit)
Stator voltage, V	$29.75V_{RMS}$
Stator current, I	$4.46A_{RMS}$
Input real power, P	86 W
Input reactive power, Q	101 VAR

Calculate the series elements of the motor equivalent circuit [8 Marks]

(Include your calculations for determining the series elements of the motor equivalent circuit.)

assuming that the slip, $\eta = 1.0$, and ignore R_0 and X_0 because it is equivalent to a transformer short circuit test

$3P_\phi$

$$3I^2\left(R_1 + R_2^{'}\right) = 3 \times P_{input} 3 * 4.46^2\left(R_1 + R_2^{'}\right) = 3 * (86)$$

$$(R_1 + R_2') = 4.32\,\Omega$$

$Z = (R_1 + R_2') + j(X_1 + X_2')$

$$|Z| = \frac{|V|}{|I|} = \sqrt{\left(R_1 + R_2^{'}\right)^2 + j\left(X_1 + X_2^{'}\right)^2} \frac{29.75}{4.46} = \sqrt{(4.32)^2 + j\left(X_1 + X_2^{'}\right)^2}$$

$$\left(X_1 + X_2^{'}\right) = 5.08\Omega$$

Assuming $X_1 = X_2'$ and $R_1 = R_2'$, we obtain

$$\frac{X_1 + X_2'}{2} = \frac{5.08}{2} = 2.54\,\Omega$$

$$\frac{R_1 + R_2'}{2} = \frac{4.32}{2} = 2.16\,\Omega$$

Therefore, the values are

$$R_1 = R_2' = 2.16\,\Omega$$

$$X_1 = X_2' = 2.54\,\Omega$$

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No-load test results (Small Slip) [4 Marks]

Measurements	Value (Unit)
Stator voltage, V	132.8 V_{RMS}
Stator current, I	2.97 A_{RMS}
Input real power, P	61 W
Input reactive power, Q	392 VAR

Results (Zero Slip) [4 Marks]

Measurements	Value (Unit)
Stator voltage, V	145.2 V_{RMS}
Stator current, I	4.43 A_{RMS}
Input real power, P	98 W
Input reactive power, Q	708 VAR

Calculate the shunt elements of the motor equivalent circuit [8 Marks]

(Include your calculations for determining the shunt elements of the motor equivalent circuit)

<u>*No load test at synchronous speed (zero slip)*</u>
Slip = 0
Neglect I_2 and rotational losses at zero slip

Magnetic loss = $P_{3\phi} - 3I_1^2R_1$
From Question 1, $R1$ = 2.16Ω, $P_\phi = 105\ W,\ I_1 = 4.43\ A_{rms},\ X_1 = 2.54\Omega$
Magnetic Losses, P_m = 3-phase power - 3 $* \ I_1^2R_1 = 3(99) - 3(4.43)^2(2.16) = 169.83W$

R_0 can be calculated from the magnetic losses

$$R_0 = \frac{3V_{ph}^2}{Magnetic\ Losses} = \frac{3(145.2)^2}{169.83} = 372.426\Omega \qquad X_0 = \frac{V_{ph}}{I_1} - \frac{X_1}{P_m} = \frac{145.2}{4.43} - \frac{2.54}{169.83} = 32.76\Omega$$

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No load test at synchronous speed (zero slip)

$$\text{Rotational loss, } P_{rotational} = 3P_{3\phi} - 3 \times I_1^2 R_1 - P_m P_{rotational} + P_m$$
$$= 3(61) - 3(2.97)^2(2.16)$$
$$= 125.84W$$

Load test results [8 Marks]

Speed (rpm)	Stator voltage (V)	Stator current (A)	Real powe r (W)	Reactive power (VAR)	Torque (Nm)
1492	133.5	3.03	90	395	0.5
1482	133.3	3.05	256	381	1.6
1473	133.1	3.19	420	379	2.7
1463	133.0	3.36	570	369	3.7
1453	132.8	3.55	704	371	4.6
1443	132.3	3.85	880	374	5.8
1433	132.5	4.14	943	369	6.3
1423	131.9	4.30	1082	379	7.3
1413	132.3	4.47	1181	384	8.0

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Calculate the theoretical slip and motor speed for the measured power, and compare them with the experimental values. [8 Marks]

(Show all working steps and calculations)

Synchronous speed, n_s=1500 rpm = 157.08 rad/s

Experimental results

Measured speed, n (rpm)	Slip, $\eta = \frac{n_s - n}{n_s}$
1492	0.0050
1482	0.0120
1473	0.0180
1463	0.0246
1453	0.0313
1443	0.0380
1433	0.0447
1423	0.0513
1413	0.0580

Theoretical

3-phase power, $P_{3\phi}$ (W)	Torque, T_L (Nm)	Motor speed $n = \frac{9.55 P_{3\phi}}{T_L}$	Slip, $\eta = \frac{n_s - n}{n_s}$
90	0.5	1719	-0.1460
256	1.6	1528	-0.0187
420	2.7	1485.556	0.0096
570	3.7	1471.216	0.0192
704	4.6	1461.565	0.0256
880	5.8	1448.966	0.0340
943	6.3	1429.468	0.0470
1082	7.3	1415.493	0.0563
1181	8.0	1409.819	0.0601

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Comparison between theoretical and experimental slip and motor speed

Experimental		Theoretical	
Motor Speed (RPM)	Slip	Motor Speed (RPM)	Slip
1492	0.0050	1719	-0.1460
1482	0.0120	1528	-0.0187
1473	0.0180	1485.556	0.0096
1463	0.0246	1471.216	0.0192
1453	0.0313	1461.565	0.0256
1443	0.0380	1448.966	0.0340
1433	0.0447	1429.468	0.0470
1423	0.0513	1415.493	0.0563
1413	0.0580	1409.819	0.0601

It can be observed at low motor speeds (1413-1473), the theoretical and measured motor speeds as well as the calculated slip values are in the same range. It can also be observed as the motor speed decreases, the slip increases. We attribute the deviations to friction within the rotor and stator coils that led to joule losses as the theoretical values are calculated based on power measurements.

However, when the experiment reaches the 1482 and 1492 RPM range, the theoretical and experimental values differ significantly. A negative slip indicates the induction motor has operated in the generating region, which is unexpected behavior. This large motor speed derived from the power could be due to the motor drawing high apparent power from the line sources, thus increasing the real power dissipated, however, as the rated speed is below 1500 RPM, the torque measuring unit is unable to reflect said theoretical speed in the measurements.

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Discussion

1. Explain in detail the relationship between torque and slip (%) for an induction motor. [10 Marks]

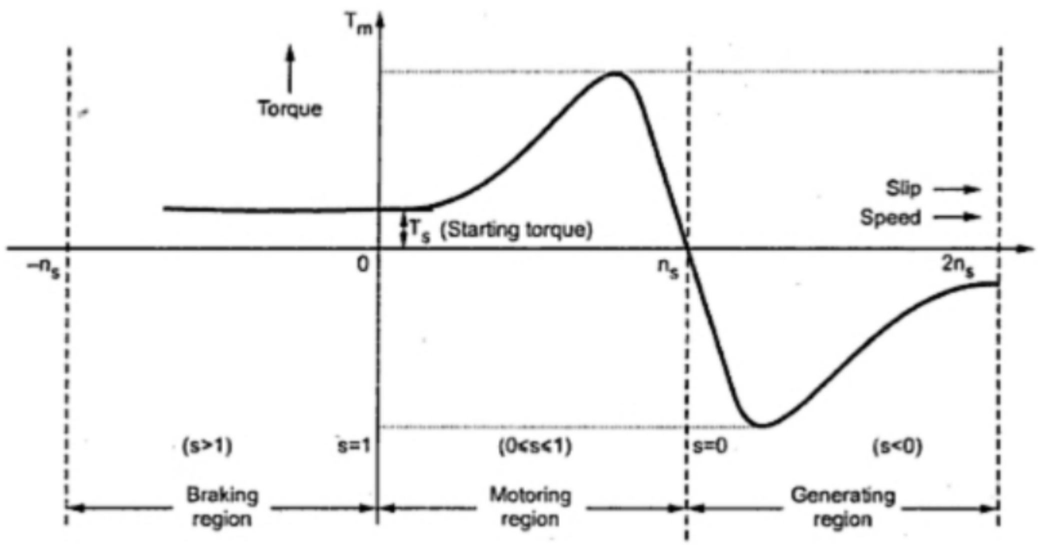

Fig 5: Torque-Slip Curve for 3-phase induction motor [2]

An induction motor is a type of AC motor that works by inducing a rotating magnetic field in the stator (stationary) winding, which then induces currents in the rotor (rotating) winding. These currents in turn produce a magnetic field in the rotor that interacts with the stator field, causing the rotor to turn.

Torque, which is the rotational force generated by the motor, is directly related to the interaction between the magnetic fields of the stator and rotor. The greater the interaction between these fields, the greater the torque produced by the motor.

Slip, on the other hand, is a measure of how much the rotor speed differs from the synchronous speed of the rotating magnetic field in the stator. The synchronous speed is determined by the frequency of the AC power supplied to the motor and the number of poles in the stator winding.

Now, to understand the relationship between torque and slip, it's important to consider the concept of "maximum torque." The maximum torque that an induction motor can produce occurs at a specific value of slip, known as the "pull-out" or "breakdown" slip.

At lower values of slip, the motor is able to produce torque, but the torque is not at its maximum. As slip increases, the motor reaches its maximum torque point, and then as slip continues to increase beyond this point, the torque begins to decrease.

The torque produced by an induction motor is given by the equation:

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$$\tau = k\frac{sV_1^2}{R_2}$$

where T is the torque produced by the motor, k is a constant that depends on the motor design, s is the slip of the motor, R2 is the rotor resistance, and V1 is the applied voltage.

The slip of the motor is given by the equation:

$$s = \frac{N_S - N}{N_S}$$

where Ns is the synchronous speed of the motor and N is the actual speed of the motor.

Thus, we can rewrite the torque equation as:

$$\tau = \frac{k(N_S - N) \times V_1^2}{R_2 \times N_S}$$

From this equation, we can see that the torque produced by the motor is directly proportional to the slip of the motor. In other words, the greater the slip of the motor, the greater the torque produced.

The relationship between torque and slip is not linear. At low slip values, the torque produced by the motor increases as slip increases, but at higher slip values, the torque starts to decrease.

2. Justify the differences between the theoretical (calculated) values and the measured values obtained from this experiment. List at least five methods to prevent any error while obtaining the calculated and measured values. [10 Marks]

Theoretical (calculated) values and measured values in any experiment are inevitably going to differ for a variety of reasons, including measuring instrument limits, environmental circumstances, human error, etc. Analyzing the sources of mistakes that contribute to these differences allows for the justification of the discrepancies between theoretical and measured values.

Instrumental error: The precision of measuring devices used to measure electrical quantities and motor speed, such as voltmeters, ammeters, wattmeters, and torque meters, can have an impact on the accuracy of the measured values.

Human error: Human error can occur during the measurement process due to misreading of values, incorrect data entry, or incorrect calculations.

Ambient conditions: The performance of the motor and, consequently, the measured values, is affected by environmental factors such as temperature, humidity, or the motor condition

Power supply fluctuations: Fluctuations in power supply voltage and frequency can affect the performance of the motor and the accuracy of the measured values.

Mechanical losses: The efficiency of the motor and the precision of the measurement values may both be affected by friction losses

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To prevent errors, some of the methods can be used:

1. Instrument calibration: Doing routine calibration on measuring devices can increase their accuracy and lower instrumental errors.

2. Multiple measurements and take average: Taking multiple measurements then average them help in reducing random errors and improve the accuracy of the measured values.

3. Experiment environment control: Keeping the experimental setup's temperature and humidity constant, and lubricating the motor might decrease the impact of outside factors on the measured data.

4. Use of reliable power supply: Reduce the effect of power supply fluctuations on the motor performance and measured values.

5. Minimizing mechanical losses: Minimizing mechanical losses (friction) in the motor can improve its performance and reduce the effect of mechanical losses on the measured values.

Conclusion and Findings [14 Marks]

In this lab, we have performed a total of 3 main tests which are the locked-rotor test, no load test (small slip and zero slip respectively) and the load test.

Firstly, the locked-rotor test involved locking the rotor and increasing the variac voltage to the point where the rated stator current was achieved. The measured values were then used to calculate the required equivalent circuit parameters.

Secondly, in the no-load test at small slip, the AC input voltage was increased until it reached the rated voltage of 230V. The measured values were used to calculate the remaining equivalent circuit parameters.

Thirdly, in the no-load test at zero slip, the DC supply was turned on and the AC input voltage was adjusted to restore the motor speed to a value close to its synchronous speed of 1500rpm. Some equivalent circuit parameters were measured and the rotational losses were calculated using values obtained from both no-load tests.

Finally, in the load tests, an AC supply of 230V was applied along with the DC supply. The resistive load and shunt regulator were adjusted regularly to decrease the speed by 10rpm to take the required readings. Through these tests, the torque-speed characteristics of the motor were explored from both experimental and theoretical perspectives.

The aims of this experiment are:
(i) To find the equivalent circuit parameters of a three phase, wound rotor AC induction motor.
(ii) To measure the torque-speed characteristics of the motor from standstill to synchronous speed when operated from a 50 Hz supply.

In the experiment, a three-phase, wound rotor AC induction motor was tested to determine its equivalent circuit parameters. The locked-rotor test was conducted to measure the stator voltage, current, input real and reactive power, and using the V/A/W meter, the values of R1, R2', X1, and X2' were calculated using a slip value of 1. Similarly, the no-load test was conducted to measure the set speed, stator voltage, current, input real and reactive power, and using the V/A/W meter, the values of R0, X0, and magnetic losses were calculated using a slip value of 0. Additionally, the rotational loss

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was determined using the measured values from the locked-rotor and no-load tests at small slip. Thus, the first aim of the experiment, which was to find the equivalent circuit parameters of the motor, was achieved.

To complete the experiment, load tests were carried out on the motor. These tests involved taking readings of stator voltage and current, input real and reactive power, speed, and motor torque for decrements of every 10-rpm starting from 1492 rpm. By conducting these tests, the torque-speed characteristic of the motor was determined from synchronous speed to the point where the excitation current reached its rated value, i.e., the full load condition was met. Thus, the second aim of the experiment was also accomplished.

The comparison of the measured values are listed in the table below.

Test	Stator Voltage, V	Stator Current, I	Input Real Power, P	Input Reactive Power, Q
Locked-Rotor Test	29.75 V_{RMS}	4.46 A_{RMS}	86 W	101 VAR
No-Load Test (Small Slip)	132.8 V_{RMS}	2.97 A_{RMS}	61 W	392 VAR
No-Load Test (No Slip)	145.2 V_{RMS}	4.43 A_{RMS}	98 W	708 VAR

As we can see, the experimental results in the table above are very similar to the theoretical value.

In the locked-rotor test, the rotor does not rotate and the speed will become zero. Thus, the full load current passes through the stator current at a high current value of 4.46 $A_{RMS\ which}$ is quite similar to its rated value [1].

During the no-load test with small slip, the rotor requires only a small torque to overcome frictional and iron losses, resulting in a small slip [2]. A small slip indicates that the rotor speed (n) is very close to the speed of the rotating magnetic field (ns).

Conversely, during the no-load test with zero slip, the rotor speed (n) is equal to the rotating magnetic flux speed (ns). Since n was held constant at around 1500 rpm (actual value is 1492 rpm), it is the speed of the rotating magnetic field (ns) that increases during the no-load test with zero slip, leading to an increase in V, I, P, and Q.

Regarding the load test (as observed from the load test results above), all measured values (stator current, real power, and torque) except stator voltage and reactive power increase as the speed decreases. However, the stator voltage and reactive power remain relatively constant as the speed decreases. This might be due to the fact that the resistance of the load stays constant during the load test, resulting in no change in load voltage and no impact on the stator voltage. As the load is resistive, the change in rotor speed should not affect reactive elements in the motor. The series elements and shunt elements of the motor equivalent circuit were also calculated in this experiment.

From the load tests, we also found that torque increases linearly with the decreasing motor speed when the motor speed is operating within the region from synchronous speed to full load condition (where the excitation current reaches its rated value) [3].

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References (Minimum 3 References) [6 Marks]

[1] Electrical4U. "Blocked Rotor Test of Induction Motor". Electrical4U.com. 2023 [Online] Available: https://www.electrical4u.com/blocked-rotor-test-of-induction-motor/ (Accessed: 11 April 2023).

[2] "High slip region", Electricallive.com, 2023. [Online]. Available: https://electricallive.com/2015/03/torque-slip-characteristics-in-three.html (Accessed: 11 April 2023).

[3] T. Wildi, "Three-Phase Induction Machines," in Electrical Machines, Drives, and Power Systems, 6th ed., UK: Pearson, ch. 13, pp. 271-314.

[4] S. M. Corp., "What are Torque Motors and how they work?," What Are Torque Motors and How They Work?-Blog-Sesame Motor Corp. [Online]. Available: https://www.sesamemotor.com/blog_detail/en/what-are-torque-motors#:~:text=Torque%20motor%20is%20a%20special,by%20increasing%20the%20rotor%20resistance. [Accessed: 16-Apr-2023].

[5] "Induction Motor," Induction Motor - an overview | ScienceDirect Topics. [Online]. Available: https://www.sciencedirect.com/topics/earth-and-planetary-sciences/induction-motor#:~:text=and%20Gas%2C%202019-,Induction%20Motors,magnetic%20field%20in%20the%20stator. [Accessed: 16-Apr-2023].

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in text citation for reference 4 and 5 not found (minus 2 marks)

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