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by Matthew Perry

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1. Executive Summary

In this assignment, research was carried out in regard to speed control methods for induction motors. From the investigation, it showed that there are several methods for speed control that alter the parameters of the supply that then affect the speed. Another investigation into power systems was researched that explained how local distributors can supply spaces such as a small factory, which also included how the factories can vary the supply to support induction machines used for their applications.????

An analysis on a single-phase transformer was completed by carrying out a series of tests. During the tests measurements were recorded to be able to calculate equivalent circuit parameters. Using the parameters, the circuit was built on multisim to verify the accuracy of the tests. Additionally, 4 different load tests were applied to the transformer to analyse the performance in terms of efficiency & regulation and compared with calculated, measured and simulated values.

A similar analysis was carried out on a three-phase induction motor. During this analysis, various tests were completed to obtain measurements to calculate equivalent circuit parameters. Using the parameters, the student was able to predict the performance of the motor and compare it with results from further tests and reference the outcomes against research completed.

In summary, this assignment detailed how to carry out suitable tests on a power system and an electrical machine. From the tests, it can be shown how an equivalent circuit benefitted the student by being able to predict the performance of the equipment while proving the accuracy of the results by comparing it to calculated, simulated and measured values.

this is a good summary

1. Work plan for Life-long Learning

This assignment will be approached methodically by firstly carrying out research in relation to operating principles of electrical machines, electronic power converters and basic power systems. Theoretical predictions will be calculated for the performance of single-phase transformer and three-phase induction motor and then safe precise experiments will be carried out on these machines while working with the risk assessment shown in Figure 14. Results gathered from both methods will be analysed and compared.

From completing this assignment, the student has gained an understanding on induction speed control and power systems that are used within industry. Additionally, how to implement tests on transformers or induction motors to produce an equivalent circuit to be able to predict or simulate the performance dependent on the load.

This last paragraph was not needed since this is a plan not a reflection

2. Research

3.1 Induction Speed Control

There are a range of speed control methods that employ power electronics. An investigation into 5 different methods is explained below.

3.1.1 Variable Voltage Constant Frequency Drives

In this technique the voltage applied to the stator is varied using an ac voltage converter while maintaining a constant frequency. This can be done by using a three-phase Y connected ac voltage controller (El-Hawary, 2002). The stator voltage can be varied with this method between minimum and maximum value by controlling the phase angle or the trigger angle ' α ' (GetMyUni, 2022).

3.1.2 Variable Voltage Variable Frequency Drives

In this technique the stator frequency is varied by altering the applied voltage or current. The air-gap flux is known to be directly proportional to the stator applied voltage and inversely proportional to the frequency. A reduction in the supply frequency will alter the speed of the motor and below synchronous speed it will be associated with an increase in the air gap flux if the applied voltage is maintained at the rated value (Le Doeuff & El Hadi Zaim, 2010). This drive can be used which employ squirrel-cage induction motors of all classifications

3.1.3 CSI Inverter

This inverter controls the current output to the motor which then affects the speed of the motor. This is used with other circuits that compares the reference speed and actual speed which creates an error used to generate a call for more or less current to the motor (Miller & R. Miller, 2014). An application that this method could be used in is for pumps and fans however at a light load it can have stability issues with a poor performance (Elprocus, 2022).

3.1.4 Cycloconverter

A cycloconverter can convert a fixed frequency alternating voltage/current to a variable voltage/current variable frequency to control ac machines. Using this method, the output frequency is usually limited to 33 to 50% of the input supply frequency, this is because distortion to the waveform can be avoided. This means this method is more suited towards low speed but high-power ac drives (Krishnan, 2001). This drive can be used in large horsepower applications up to 20,000 hp and can also benefit systems with reverse operation and regeneration.

3.1.5 Static Kramer Drive

A standard Kramer drive uses an auxiliary machine connected to the rotor of the circuit of a wound-rotor induction motor to convert a portion of the power from slip frequency to supply frequency. This power is then fed back to the mains. A Kramer drive employs a diode rectifier connected to the rotor circuit to convert a portion of slip frequency power to direct current which is then converted to alternating current at supply frequency by implementing a line commutated inverter. Speed control is then achieved through the control of the angle of firing, α , ($90^\circ < \alpha < 180^\circ$). Lastly, this drive can be used in applications such as large horsepower pumps and blower applications that need a limited range of speed control.

3.2.1 Power Systems

In the UK, the local distributor network steps down voltages from the 400kV AC and 275kV transmission network. This voltage is then stepped down to 132kV to 11kV and can be further reduced to 415V three phase which supports small to medium size commercial and industrial spaces (BRE Group, 2022). Correctly cited

Once the energy is supplied to a space such as typical factory, transformers are used to deliver different supplies to support induction machines such as induction motors. The transformers are critical to a factory because depending on which induction motor is used the supply voltage can vary, for example, from 230V to 690V (RS Components, 2022). Correctly cited

3.1.2 Step Up Transformers

A 3-phase step up transformer can increase the voltage and decrease the current. This is because when AC is being passed through the primary coil there is a changing magnetic field that is created in the iron core (Tameson, 2022). In a step-down transformer there is a larger number of turns in the primary coil and a smaller amount in the secondary (Daelim Belefic, 2021). An example of a commonly used step-up transformer could be 415V delta primary input with a 480V secondary output (Temco Industrial, 2022). Correctly cited

3.1.3 Step Down Transformers

A step-down transformer can reduce the voltage from a transmission level to a distribution level while increasing the current. A step-down transformer has many primary windings and a lower amount on the secondary (Daelim Belefic, 2021). An example of a commonly used step-down transformer could be a 415V delta primary input with a 240V secondary output (Temco Industrial, 2022). Correctly cited

3.1.4 Isolation transformer

While using induction machines that have phase shift, an isolated transformer may be used. These transformers can be used for changing voltage, power supply and rectifying power supplies. An isolation transformer is commonly 1:1 but may have different specifications dependent on the application. This transformer can reduce the capacitance of the primary and secondary winding and there is an isolating circuit between the primary and secondary windings which can inhibit disturbance such as motor starting, discharge and power grid switching (ATO, 2021).

3.1.5 Phase Converter

Lastly, if there is only a 230V AC supply available a phase converter can be used. A Phase converter can vary the voltage from 240V single phase to 415V 3 phase which would be fixed at 50Hz (Transwave, 2021).

This is a good research section with lots of Harvard citations

4. Transformer Investigation

Using suitable measuring equipment results were obtained shown in Table 2. Using these results calculations were then carried out to determine the approximate equivalent circuit parameters.

4.1 Open Circuit Test

The purpose of the open circuit test is to determine the no-load current and losses of the transformer.

While isolated, the multifunction measurement instrument is connected in the secondary side of the transformer. Then with the circuit energised, the voltage at rated frequency was applied from the supply to the secondary side. The primary side of the transformer was kept open, and the applied voltage was increased until the voltage gave a reading equal to the rated voltage of the secondary side. It was also important for the voltage to be much lower than normal on the primary side, additionally, the current should be less than its nominal value to prevent overheating and a rapid change in winding resistance (Wildi, 2006). Once this was met, as a group, all results were then documented.

From the results shown in Table 2, the voltage is the same as the supply, but the value of the no load current is very small compared to the full rated current. Additionally, the power reading of 28.8W represents the core and iron losses, this loss will then always occur regardless of the load.

4.1.2 Short Circuit Test

The purpose of the short circuit test is to determine the copper losses that are present on full load, this will be then used to find the efficiency of the transformer.

While isolated, the multifunction measurement instrument is connected to the primary side of the transformer and then the circuit was energised. The secondary side is shorted until the reading is equal to the rated current of the primary side. Once this was achieved, as a group we documented the results which are shown in Table 2.

Lastly, the results gathered from both tests can produce an approximate circuit parameter through using calculations can be shown in Figure 4 and Figure 5.

4.2 Load Tests

By calculating the parameters, an equivalent circuit was drawn using Multisim shown in Figure 12. This circuit is composed of resistive and inductive elements coupled together with a mutual flux that connects the primary and secondary windings.

Various load tests were carried out including resistive only, RL and RC. These loads were determined as a group using the potentiometers on the control board for suitable values. At each load primary and secondary values were recorded shown in Figure 6.

From conducting these experiments, voltage regulation and efficiency was measured, calculated, and simulated using Multisim.

Each load test resulted in a different regulation value because loading the transformers secondary winding affects the output voltage. This is because the secondary windings consist of both resistance and reactance, the internal voltage drop must occur in the windings of the transformer by an amount determined on the effective impedance and the load that is applied (Cobos, 2022).

4.2.1 Load Test Results

Load tests 1 (48.18 Ohms) and 2 (31.5 Ohms) were both resistive loads. Test 1 resulted in a lower V_2 voltage, and the power factor was measured and simulated as 1 this is because the reactive power equals 0. Test 2 resulted in a larger voltage drop and a larger power out. Due to the secondary terminal voltage decreasing it also indicates a lagging power factor.

Load test 3 consisted of a resistor and inductor in series. The measurements showed that there was a larger voltage drop over V_2 compared to tests 1 & 2 with a power out of 385.2W and a power factor of 0.499.

Load test 4 consisted of a resistor and capacitor in series, because it is capacitive, the no load voltage exceeded the induced no load voltage which created the voltage regulation to be negative, additionally the terminal voltage increased indicating a leading power factor.

4.3.1 Comparisons

Using Multisim, a schematic diagram of the equivalent circuit was created Figure 12, using the circuit open and short circuit tests were carried out to ensure the calculated parameters were correct.

The table below was created displaying the values for calculated versus simulated.

Open Circuit Test		
Method	Measured	Simulated
V _I	230.8V	230.8V
I ₁	0.55A	0.68A
P _{in}	28.8W	28.808W
Short Circuit Test		
Method	Measured	Simulated
V ₁	9.4V	9.4V
I ₂	3.48A	1.74A
I ₁	1.69A	1.722A
P _{in}	9.18W	9.578W

There is obviously something wrong here with the current as you have commented on below

Figure 1; Open & Short Circuit Test Results

From the results, it can be shown that the equivalent circuit was accurate. *a good deduction* The only major discrepancy is the I₂ value for the short circuit test and this is because it is a referred value. By scaling the referred value by the turn's ratio shows:

$$\frac{230}{110} = 2.09, 2.09 \times 1.74 = 1.74A$$

A table was created below that compares the load values measured, calculated, and Simulation (Multisim).

Measured		Multisim		Calculated	
Load Test 1					
V2	111.5V	V2	110.886v	V2	111.5V
I2	2.31A	I2	2.298a	I2	/
Pout	256.2W	Pout	254.7w	Pout	/
P.f	1	P.f	1	P.f	1
%Reg	0.986	%Reg	1.569	%Reg	1.595
%Eff	87.7	%Eff	97.96	%Eff	88.03
Load Test 2					
V2	108.6V	V2	109.975V	V2	108.6V
I2	3.5A	I2	3.491A	I2	/
Pout	385.2W	Pout	383.955W	Pout	/
P.f	1	P.f	1	P.f	1
%Reg	2.63	%Reg	2.39	%Reg	2.45
%Eff	92.64	%Eff	97.7	V2	90.36
Load Test 3					
V2	108.6V	V2	108.278V	V2	108.6V
I2	3.24A	I2	3.394A	I2	/
Pout	175.3W	Pout	215.484W	Pout	/
P.f	0.499	P.f	0.58641	P.f	0.499
%Reg	3.683	%Reg	3.99	%Reg	3.955
%Eff	83.47	%Eff	96.19	%Eff	80.25
Load Test 4					
V2	114V	V2	113.873V	V2	114V
I2	1.65A	I2	1.652A	I2	/
Pout	60W	Pout	55.362W	Pout	/
p.f	0.757	P.f	0.294	P.f	0.757
%Reg	-1.22	%Reg	-1.11	%Reg	-1.166
%Eff	75	%Eff	96.78	%Eff	65

Table 1; Load Test Comparison

Load Test 1 had discrepancies between measured versus calculated/simulated regarding regulation. The calculated value may be incorrect due to rounding issues or a slightly incorrect value of I2 or R2E. Load Test 2 has similar values across all results, however there is a discrepancy of almost 1.4V regarding the secondary voltage. Because of this, the simulated value is more accurate as other parameters are similar such as current and power. Load Test 3 & 4 has similar values in comparison to the methods in all results but power out. Lastly, the efficiency values for measured & calculated were similar compared to simulated. This is because the simulated power values did not include iron and copper losses thus affecting the efficiency calculation.

Incorrect, the equivalent circuit does include these losses since the open circuit voltage was used as the input and you are focusing on the load voltage

5. Three-phase Induction Motor Investigation

5.1 Three Phase Induction Motor Tests

Using suitable measuring equipment such as a multifunction measurement instrument, tachometer, and visual gauge 3 tests were carried out. These were a stator resistance test, no load and blocked rotor test.

While carrying out the tests, the students ensured that suitable PPE such as glasses when the motor was running and that the circuit was isolated while wiring according to the tests. The risk assessment was also referenced against to ensure safe working which can be shown in Figure 14.

In the no load test, the motor can run with no load at the rated voltage at rated frequency across the terminals. This is done by the motor being coupled to a variable speed drive and being driven at synchronous speed before applying to the rated voltage to the stator. The machine will then rotate at almost synchronous speed causing the slip to almost be equal to 0. At no-load, input power is equal to the core loss, stator copper loss, and friction and windage loss. In no-load condition, the current that passes through the circuit is very small. Calculations for this test can be shown in Figure 15.

During the blocked rotor test, the rotor is prevented from turning where $s=1$ and low voltage is then applied to the stator until the current rating is met. Calculations carried out for this test to determine the approximate per-phase equivalent circuit parameters can be shown in Figure 16.

The stator resistance test was measured by locking the rotor and applying a small DC voltage (10VDC) to the stator. The voltage and current measurements were used to calculate R_1 shown in Figure 17.

5.2 Performance of Motor

By gathering the circuit parameters from the experiments, a spreadsheet was produced that simulates the performance of the motor in terms of torque and stator current over a range of speeds showing the main regions of operation that include motoring generating and braking that can be shown in Figure 18.

Using the results and determining the equivalent circuit parameters a graph was created using the equation

$$T = \frac{3 \times V_s^2 \times R_2'}{\omega_s \times S \left(\left(R_1 \frac{R_2'}{S} \right)^2 (X_1 + X_2')^2 \right)}$$

a plus sign is missing

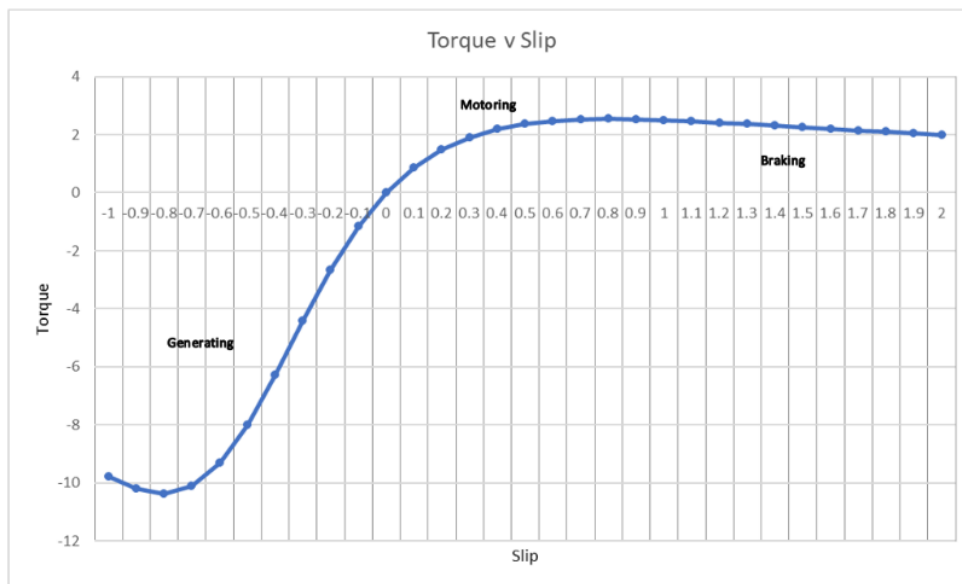


Figure 2; Motor Performance Regions

In the generating region, the slip and torque are both negative. The motor runs above synchronous speed and behaves as an induction generator.

In the motoring region, the slip of an induction motor is between zero to one. The rotor speed is less than synchronous speed and the torque of a motor varies from zero to full-load torque.

Lastly, in the braking region the slip is greater than 1. This represents the motor being driven in the opposite direction to the rotating stator field and produces positive torque, therefore, acting as a brake.

5.2.1 Simulating Performance

Two separate tests can be shown in Table 4 & Table 3. Firstly, the motor was tested under load for motoring. It can be shown that as the load increased, the rotor speed decreased and then increased the slip speed. A graph was created that shows an almost linear pattern between slip and torque.

How does this graph relate to the simulate results above?

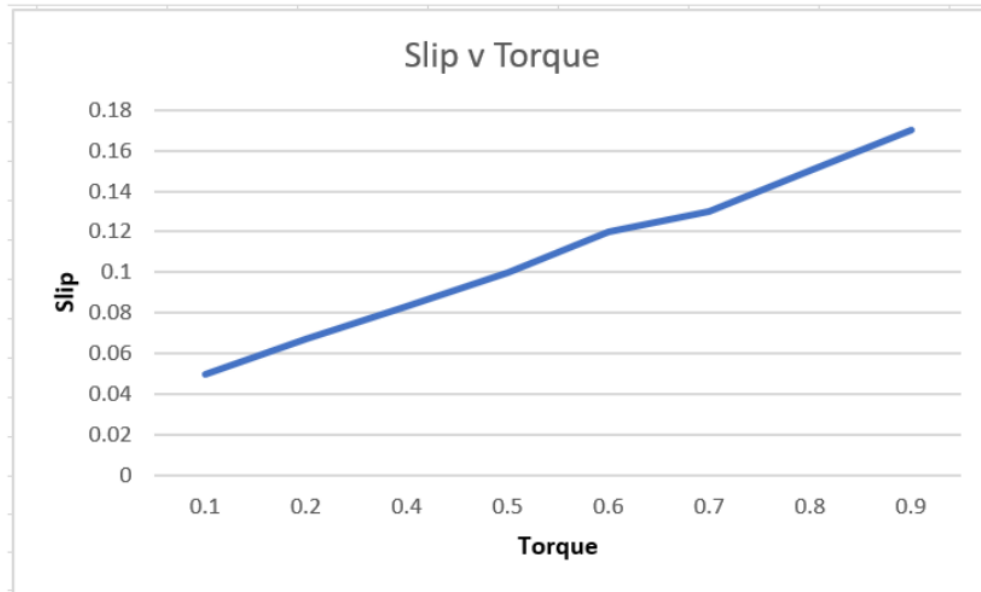


Figure 3; Induction Motor Slip Versus Torque

Secondly, the motor was run with a VFD drive to increase the speed further than synchronous speed. It showed that the higher the rotor speed, the less power was being used and became negative, while increasing the power factor. Additionally, the slip became negative.

Lastly, analysing the measured results from the two tests, it shows that the motor responded similar to the graph which was created shown in Figure 2.

5.2.2 Prediction of Performance

The 4-pole induction motor was connected to an inverter and Prony brake. While taking all necessary health and safety precautions, the stator voltage, stator frequency and rotor speed was measured under a small friction load for a ranging from 150 to 1500 which could demonstrate the inverter's performance. *Which frequencies were used?*

From the experiment the results can be shown in Table 5. Analysing the results, it shows that increasing the frequency and voltage the rotor and stator speed increases. As the speeds increase the fractional slip decreases.

From the research in page 6, it stated than with an increase of supply voltage/frequency, the speed of the motor would increase, which compares well with the results.

What was the V/f ratio?

6. Conclusions and Recommendations

In the research task, several methods of speed control for an induction motor were investigated. It shows that each method used varies a parameter that can alter the speed of an induction motor. For the chosen method, performance can be affected which means some controllers would be recommended for different applications. *Which is the best method?*

Also, the research consisted of an investigation into power systems. From this, it investigated how the local distributor supplies the appropriate voltage dependent on the site, but also how a small factory may vary the voltage using transformers to supply induction machines. Each transformer has different characteristics which need to suit the induction machine that is being supplied.

In the transformer task, tests were carried out to be able to create an equivalent circuit. This circuit was then verified on multisim to ensure its accuracy. By obtaining an accurate equivalent circuit, this enabled the student to perform load tests and analyse voltage regulation and efficiency. From these results, it gained an understanding of how the transformer performs under different loads. It can be shown that the variations in load current cause variations in the losses affecting regulation. The smaller the transformers voltage regulation, the less the variation in secondary terminal voltage with changes in the load, and this could be very useful to have in regulated power supply circuits.*In what way?*

In the motor task, results were recorded and then calculated to obtain equivalent circuit parameters. Using these parameters, the performance of the motor in terms of slip and torque could be predicted for 3 regions which are generating, motoring and braking. This gained an understanding of how the induction motor would perform suited with different loads.

In both tasks, the equivalent circuit parameters were used to simulate circuits using Multisim. Comparing the results in both tasks, showed that the circuit parameters were accurate and matched well, however regarding the transformers efficiency percentage that was calculated through simulation was inaccurate. This is because the simulation of the test did not include the core losses which affects the power readings used to calculate efficiency.

Incorrect, the equivalent circuit does include these losses since the open circuit voltage was used as the input and you are focusing on the load voltage.

Overall, this assignment has demonstrated how theoretical research compares with practical application. Additionally, it has enabled the student to be able to create equivalent circuits of future transformers or induction motors by a few simple measurements to then predict the performance. This will be instrumental in the students future career to avoid downtime & financial cost while being confident with their predictions.

Lastly, future recommendations include confirming the reading has been documented accurately before carrying out another measurement and that the reading has been rounded to the nearest decimal point. This is because it can cause small discrepancies with calculated results.

Further research has been completed to show proof of how a transformers voltage regulation is a function external to the transformer. This is because the change shown in the connected load creates a change in the transformer's terminal voltage between its "no-load" voltage and its "full-load" voltage shown in Figure 13. Additional research into phase converters regarding wiring, operation and circuit diagrams would be beneficial, this is because they are often used in the students workplace.

7. Team Working

For the experimental tasks, students were split into groups to share responsibilities and roles while sharing a common goal of effectively recording results. Before starting the tasks, each student spoke about if they had any needs that could be met to ensure a safe and welcoming workspace where all students felt like they belong.

In the transformer task Matthew, Harri & Jason worked together complete the appropriate steps to record the results. As a group, the team wired the circuit appropriately according to the tests required. Matthew used the multifunction measurement instrument to record values while reading them out for Jason to document and Harri to start calculating.

In the motor task, Matthew used the tachometer to record the stator speed, Harri increased the supply while recording values and Jason applied the pony brake while reading the torque value in the final task.

At the end of the tasks, as a group the students ensured that they had recorded all necessary data.

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9. Appendix

Transformer	
Open Circuit Test	
V _I	230.8V
I _I	0.55A
P _{in}	28.8W
Short Circuit Test	
V _I	9.4V
I ₂	3.48A
I ₁	1.69A
P _{in}	9.18W

Table 2; Transformer Open/Short Circuit Test Results

Task 3 (a)

Open circuit test

$V_I = 230.8V$ $I_I = 0.55A$ $P_{in} = 28.8W$

$$power\ lost = \frac{(V_I)^2}{R_C} = 28.8 = \frac{(230.8)^2}{R_C}$$

$$R_C = \frac{53268.64}{28.8} = 1849.1$$

$$I_C = \frac{V_I}{R_C} = \frac{230.8}{1849.61} = 124.78mA$$

$$I_o^2 = I_C^2 + I_m^2$$

$$0.55^2 = (124.78 \times 10^{-3})^2 + I_m^2$$

$$0.3025 = 0.01557 + I_m^2$$

$$I_m^2 = 0.3025 - 0.01557$$

$$I_m = \sqrt{0.28693} = 0.5356$$

$$X_m = \frac{V_I}{I_m} = \frac{230.8}{0.5356} = 430.918$$

Figure 4; Transformer Part (a) Calculations

Task 3 (a)

Short circuit test

Rated current output

$$= \frac{375}{112.6} = 3.34 \text{ A}$$

$$V_1 = 9.4 \text{ V}, I_1 = 1.69 \text{ A}, I_2 = 3.48 \text{ A} \quad P_{in} = 9.18 \text{ W}$$

$$Z_{1E} = \frac{V_1}{I_1} = \frac{9.4}{1.69} = 5.562$$

$$R_{1E} = \frac{P_{in}}{I_2^2} = \frac{9.18}{1.69^2} = 3.214$$

Leakage reactance

$$X_{1E} = \sqrt{Z_{1E}^2 - R_{1E}^2} \\ = \sqrt{5.562^2 - 3.214^2} = 4.539$$

$$Z_{2E} = \left(\frac{N_2}{N_1} \right)^2 (Z_{1E}) = \left(\frac{112.6}{230} \right)^2 (5.562) \\ = 1.33$$

$$R_{2E} = \left(\frac{N_2}{N_1} \right)^2 (R_{1E}) = \left(\frac{112.6}{230} \right)^2 (3.214) \\ = 0.7703$$

$$X_{2E} = \left(\frac{N_2}{N_1} \right)^2 (X_{1E}) = \left(\frac{112.6}{230} \right)^2 (4.539) \\ = 1.087$$

$$\frac{1.087}{100\pi} = 3.4 \text{ mH}$$

Figure 5; Transformer Part (a) Calculations

Task 3 (b)

Load Test 1 = $48.26\ \Omega$

$$V_1 = 230\text{V}$$

$$V_2 = 111.5\text{V}$$

$$P.f = 1.$$

$$I_1 = 1.39\text{A}$$

$$I_2 = 2.31\text{A}$$

$$P_{in} = 292.1\text{W}$$

$$P_{out} = 256.2\text{W}$$

$$R = V/I = 111.5/2.31 = 48.26\ \Omega$$

Load test 2 = $31.5\ \Omega$

$$V_1 = 230.1\text{V} \quad V_2 = 108.6\text{V} \quad P.f = 1$$

$$I_1 = 1.91\text{A} \quad I_2 = 3.5\text{A}$$

$$P_{in} = 415.8\text{W} \quad P_{out} = 385.2\text{W}$$

$$R = V/I = 108.6/3.5 = 31.5\ \Omega$$

Load Test 3 (R_L) = $R = 18.71\ \Omega \quad L = 82\text{mH}$

$$V_1 = 230\text{V}$$

$$V_2 = 108.6\text{V}$$

$$P.f = 0.499$$

$$I_1 = 2.09\text{A}$$

$$I_2 = 3.24\text{A}$$

$$P_{in} = 210\text{W}$$

$$P_{out} = 175.3\text{W}$$

Load Test 4 (RC) = $R = 20.27\ \Omega \quad C = 48.18\ \mu\text{F}$

$$V_1 = 229.8\text{V}$$

$$V_2 = 114\text{V}$$

$$P.f = 0.3$$

$$I_1 = 0.47\text{A}$$

$$I_2 = 1.65\text{A}$$

$$P_{in} = 80\text{W}$$

$$P_{out} = 60\text{W}$$

$$E_2 = 112.6\text{V}$$

Figure 6; Transformer Part (b) Load Test

Task 3 (b).

Load Test 1

measured.

$$\% \text{reg} = \frac{(E_2 - V_2)}{V_2} \times 100$$

$$= \frac{(112.6 - 111.5)}{111.5} \times 100 = 0.986$$

Calculated.

$$\% \text{reg} = \frac{I_2 (R_2 \cos \phi_2 - X_2 \sin \phi_2)}{V_2} \times 100$$

$$= \frac{2.31(0.7703 \times 1)}{111.5} \times 100 = 1.595$$

Load Test 2.

measured

$$\% \text{reg} = \frac{(E_2 - V_2)}{V_2} \times 100$$

$$= \frac{(112.6 - 110)}{110} \times 100 = 2.63$$

Calculated.

$$\% \text{reg} = \frac{I_2 (R_2 \cos \phi_2 - X_2 \sin \phi_2)}{V_2} \times 100$$

$$= \frac{3.5(0.7703 \times 1)}{110} \times 100 = 2.45$$

Figure 7; Transformer Part (b) Calculations

Load Test 3.

measured.

$$\begin{aligned}\% \text{reg} &= \frac{(E_2 - V_2)}{V_2} \times 100 \\ &= \frac{(112.6 - 108.6)}{108.6} = 3.683\end{aligned}$$

Calculated.

$$\% \text{reg} = \frac{I_2 (R_2 \cos \phi_2 + X_2 \sin \phi_2)}{V_2} \times 100$$

$$\cos \phi_2 = 0.499$$

$$\phi_2 = 1.04$$

$$\sin \phi_2 = 0.866$$

$$\begin{aligned}&= \frac{3.24(0.7703 \times 0.499 + 1.087 \times 0.866)}{108.6} \times 100 \\ &= 3.955.\end{aligned}$$

Load Test 4

measured

$$\begin{aligned}\% \text{reg} &= \frac{(E_2 - V_2)}{V_2} \times 100 = \frac{(112.6 - 114)}{114} \times 100 \\ &= -1.22\end{aligned}$$

Calculated.

$$\% \text{reg} = \frac{I_2 (R_2 \cos \phi_2 - X_2 \sin \phi_2)}{V_2} \times 100$$

$$\cos \phi_2 = 0.3$$

$$\phi_2 =$$

$$\sin \phi_2 = 0.9539$$

$$\% \text{reg} = \frac{1.65(0.7703 \times 0.3 - 1.087 \times 0.9539)}{114} \times 100$$

Figure 8; Transformer Part (b) Calculations

Efficiency.

Load Test 1

Measured.

$$\% \eta = \frac{\text{output power}}{\text{Input Power}} \times 100.$$

$$= \frac{256.2}{292.1} \times 100 = 87.7.$$

calculated.

$$\% \eta = \frac{\text{output VA} \times \text{P.f.}}{\text{output VA} \times \text{P.f.} + \text{Iron loss} + \text{copper loss}} \times 100$$

$$= \text{copper loss} = I^2 R_{IE} = 1.392 \times 3.214 = 6.21$$

$$= \text{Iron loss} = P_{out} = \cancel{256.2} 28.8 \text{ W (open C)}.$$

$$= \text{output VA} = V_2 \times I_2 = 111.5 \times 2.31 = 257.565.$$

$$= \frac{257.565 \times 1 \times 100}{257.565 \times 1 + \cancel{256.2} + 28.8 + 6.21} = 88.03.$$

Load Test 2.

Measured.

$$\% \eta = \frac{385.2}{415.8} \times 100 = 92.64.$$

calculated.

$$\text{Output VA} = V_2 \times I_2 = 108.6 \times 3.5 = 380.1$$

$$\text{copper loss} = I^2 R_{IE} = 1.91^2 \times 3.214 = 11.72$$

$$\text{Iron loss} = 28.8$$

$$\% \eta = \frac{380.1 \times 1 \times 100}{380.1 \times 1 + 28.8 + 11.72} = 90.36$$

Figure 9; Transformer Efficiency Calculations

Load test 3

measured

$$\% \eta = \frac{175.3}{210} \times 100 = 83.47.$$

calculated.

$$\text{Output } VA = V_2 \times I_2 = 108.6 \times 3.214 = 349.04$$

$$\text{Copper loss} = I_1^2 \times R_{1E} = 2.09^2 \times 3.214 = 14.039$$

$$\text{Iron loss} = 28.8$$

$$\begin{aligned} \% \eta &= \frac{349.04 \times 0.499 \times 100}{349.04 \times 0.499 + 28.8 + 14.039} \\ &= 80.25 \end{aligned}$$

Load Test 4

measured.

$$\% \eta = \frac{60}{80} \times 100 = 75$$

Calculated.

$$\text{Output } VA = V_2 \times I_2 = 114 \times 1.65 = 188.1$$

$$\text{Copper loss} = I_1^2 \times R_{1E} = 0.47^2 \times 3.214 = 0.7099$$

$$\text{Iron loss} = 28.8 \text{ W.}$$

$$\begin{aligned} \% \eta &= \frac{188.1 \times 0.3 \times 100}{188.1 \times 0.3 + 28.8 + 0.7099} \\ &= 65. \end{aligned}$$

Simulated.

Load Test 1

$$\% \eta = 254.7 / 260 \times 100 = 97.96.$$

Load Test 2

$$\% \eta = 383.995 / 393 \times 100 = 97.7.$$

Load Test 3

$$\% \eta = 215.484 / 224 \times 100 = 96.19$$

Load Test 4.

$$\% \eta = 55.362 / 57.2 \times 100 = 96.78$$

Figure 10; Transformer Efficiency Calculations

Task 3 (c); Simulated values
Simulated Reg%.

Load Test 1

$$\% \text{ reg} = \frac{(112.6 - 110.86)}{110.86} \times 100 = 1.569$$

Load Test 2

$$\% \text{ reg} = \frac{(112.6 - 109.97)}{109.97} \times 100 = 2.39$$

Load Test 3

$$\% \text{ reg} = \frac{(112.6 - 108.278)}{108.278} \times 100 = 3.99$$

Load Test 4

$$\% \text{ reg} = \frac{(112.6 - 113.873)}{113.873} \times 100 = -1.11$$

Figure 11; Transformer Part (c) Calculations

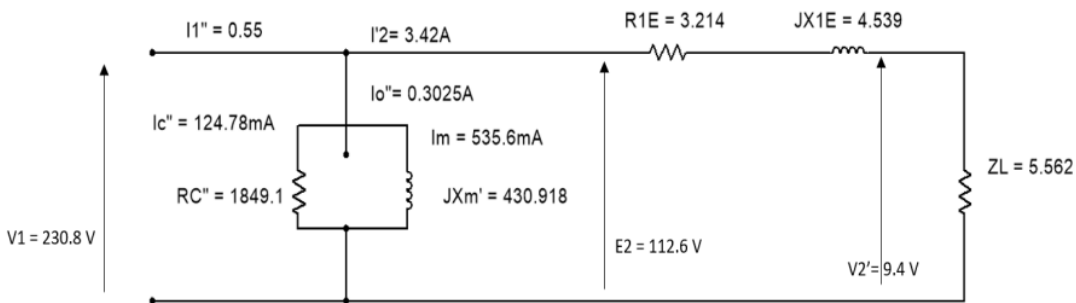


Figure 12; Transformer Equivalent Circuit

Proof how connected loads creates a change in the transformers terminal voltage between no-load V and full load V .

- Referencing Test 1 load.

$$\% \text{reg} = \frac{V(\text{no-load}) - V(\text{full load})}{V(\text{full load})}.$$

$$0.986 = \frac{V(\text{no-load}) - 111.5}{111.5}$$

$$0.986 \times 111.5 = V(\text{no-load}) - 111.5$$

$$V_{\text{drop}} = 111.5 \times \left(\frac{0.986}{100} \right) = 1.0993$$

$$\begin{aligned} V(\text{no-load}) &= 111.5 + 1.0993 \\ &= 112.599V. \end{aligned}$$

Figure 13; Proof of changing transformer loads changes voltage at secondary terminals

What are the hazards?	Who might be harmed and how?	What are you already doing to control the risks?	What further action do you need to take to control the risks?	Who needs to carry out the action?	When is the action needed by?	Done
Electrical Shock	Students & Lecturers; Use of electricity	Safe isolation procedures are in place currently. Emergency stops are located on the three-phase pannels and externally on benches.	N/A	N/A	N/A	N/A
Slips Trips & Falls	Everyone; Blocked pathways	Maintaining a clean working environment including any walking routes around the area.	When using the single phase transformer, do not trail any leads from mains supply. Ensure when chairs are used, they are then pushed in after use.	Signs to be available if trailing leads are present.	N/A	N/A
Flying Parts	Students & Lecturers; Loose parts on induction motor.	Wearing suitable PPE such as safety glasses . Parts will be visually inspected before use.	Possible maintenance check sheet by the equipment.	Maintenance	24/11/2022	No
Heavy Equipment	Students & Lecturers; Lifting heavy equipment such as single phase transformer.	Appropriate manual handling techniques.	Ensure that heavy equipment isnt stored at height.	Students or Lecturers	10/11/2022	Yes
Moving Parts	Students & Lecturers; Moving parts on induction motor.	Point of motion (motor shaft) will be guarded. Students are made aware to not come into contact with the moving part.	N/A	N/A	N/A	N/A

Figure 14; Risk Assessment

Task 4 (a); No Load Test.

$$V_0 = 215.46 \text{ V}$$

$$I_0 = 0.32 \text{ A}$$

$$P_0 = \text{Total Power} = 25 \text{ W}$$

$$V_0 = V_{\text{Line}}$$

$$215.46 \text{ /per phase}$$

$$0.32 \times \sqrt{3} = 0.56 \text{ A /per phase}$$

$$25 \div 3 = 8.3 \text{ W /per phase.}$$

$$* \text{ power factor} = \cos \phi = \frac{P_0}{V_0 I_0}$$

$$= \frac{8.3}{(215.46 \times 0.32)}$$

$$= 0.12$$

$$* R_c = \frac{V_0}{I_0 \cos \phi} = \frac{215.46}{0.32 \times 0.12}$$

$$= 5610 \Omega$$

$$* \phi_0 = \cos^{-1}(0.12)$$

$$\sin \phi = 0.99$$

$$* X_m = \frac{V_0}{I_0 \sin \phi} = \frac{215.46}{0.32 \times 0.99}$$

$$= 680.11 \Omega$$

$$* I_m = I_0 \sin \phi = 0.32 \times 0.99 = 0.3168 \text{ A.}$$

Figure 15; Induction Motor Part (a) Calculations

Task 4 (a); Blocked rotor test.

103V

303W

1.95A

$$V_{SC} = 103V$$

$$I_{SC} = 1.125A$$

$$P_{SC} = 101W$$

$$\ast \cos \phi_{SC} = \frac{P_{SC}}{V_{SC} I_{SC}} = \frac{101}{103 \times 1.125} = 0.8716$$

$$\ast \phi_{SC} = \cos^{-1}(0.8716)$$

$$\sin \phi_{SC} = 0.4902$$

* Short circuit impedance

$$Z_{SC} = \frac{V_{SC}}{I_{SC}} = \frac{103}{1.125} = 91.5 \Omega$$

$$\ast R_1 + R_2' = Z_{SC} \times \cos \phi_c$$
$$= 91.5 \times 0.8716$$

$$34.25 + R_2' = 79.7514$$

$$R_2' = 79.7514 - 34.25 = 45.5 \Omega$$

$$R_1 = 34.25 \Omega \quad R_2 = 45.5 \Omega$$

$$\ast X_1 + X_2' = Z_{SC} \times \sin \phi_c$$

$$X_1 + X_2' = 91.5 \times 0.4902$$

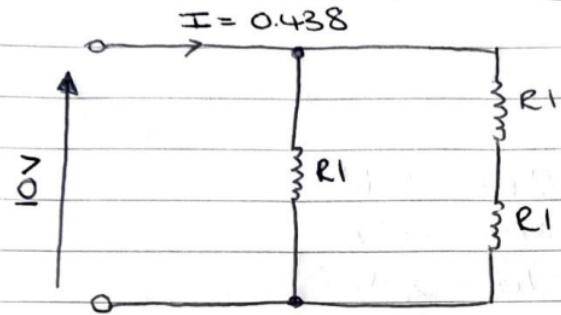
$$X_1 + X_2 = 44.85 \Omega$$

$$X_1 = 22.425$$

$$X_2 = 22.425$$

Figure 16; Induction Motor Part (a) Calculations

Task 4 (a); Stator Resistance.



$$I = \frac{10}{R_T}$$

$$\frac{R_1 \times 2R_1}{R_1 + 2R_1} = \frac{2R_1}{3}$$

$$R_T = \frac{2R_1}{3}$$

$$R_T = \frac{10}{I} = \frac{2R_1}{3}$$

$$R_1 = \frac{3 \times 10}{2I} = \frac{15}{I} = \frac{15}{0.438} = 34.25 \Omega$$

$$R_1 = 34.25 \Omega$$

Figure 17; Induction Motor Part (a) Calculations

S	T	0.1	0.835493	1.1	2.372063
-1	-9.43222	0.2	1.429778	1.2	2.327811
-0.9	-9.83917	0.3	1.837872	1.3	2.278949
-0.8	-9.98989	0.4	2.108139	1.4	2.227422
-0.7	-9.74265	0.5	2.278863	1.5	2.174611
-0.6	-8.98536	0.6	2.378756	1.6	2.121493
-0.5	-7.70893	0.7	2.428734	1.7	2.068752
-0.4	-6.0512	0.8	2.443811	1.8	2.016863
-0.3	-4.25511	0.9	2.434688	1.9	1.966146
-0.2	-2.56204	1	2.40897	2	1.916815
-0.1	-1.12638				
0	0				

Figure 18; Motor Performance in terms of torque

Driving Faster than Synchronous Speed		
Rotor Speed (Nr)	Power	P.f
3000	7.5	0.03
3050	-2.5	-0.113
3100	-71.5	0.298
3150	-135	0.476
3200	-193	0.587
3250	-248	0.655
3300	-313	0.708

Table 3; Induction Motor Task 4 (c)

Under Load		
Rotor Speed (Nr)	Fractional Slip S	Torque
2850	0.05	0.1
2800	0.066666667	0.2
2750	0.083333333	0.4
2700	0.1	0.5
2650	0.116666667	0.6
2600	0.133333333	0.7
2550	0.15	0.8
2500	0.166666667	0.9

Table 4; Induction Motor Task 4(c)

Fs (Hz)	Nr Rotor S	Vline	Fractional Slip S	Stator Speed n
5	102.5	111	0.316666667	150
10	256	117	0.146666667	300
15	418.5	121	0.07	450
20	568	125	0.053333333	600
25	721.2	129	0.0384	750
30	871.1	133	0.032111111	900
35	1018	137	0.03047619	1050
40	1171	140	0.024166667	1200
45	1322	144	0.020740741	1350
50	1473	159	0.018	1500

Table 5; Induction Motor Task 4(d)

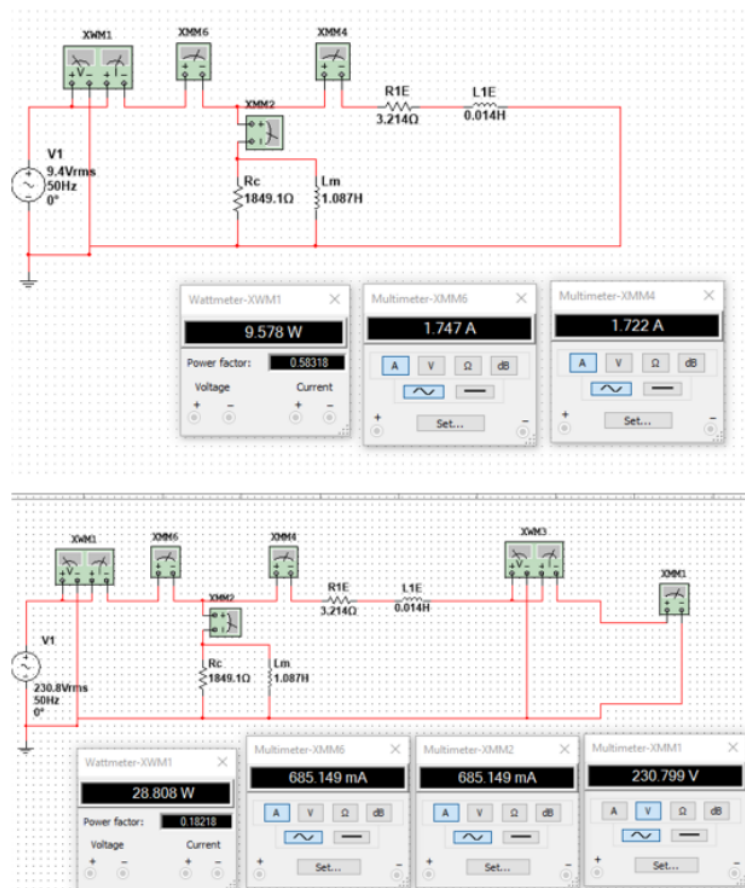


Figure 19; Open & Short Circuit Test

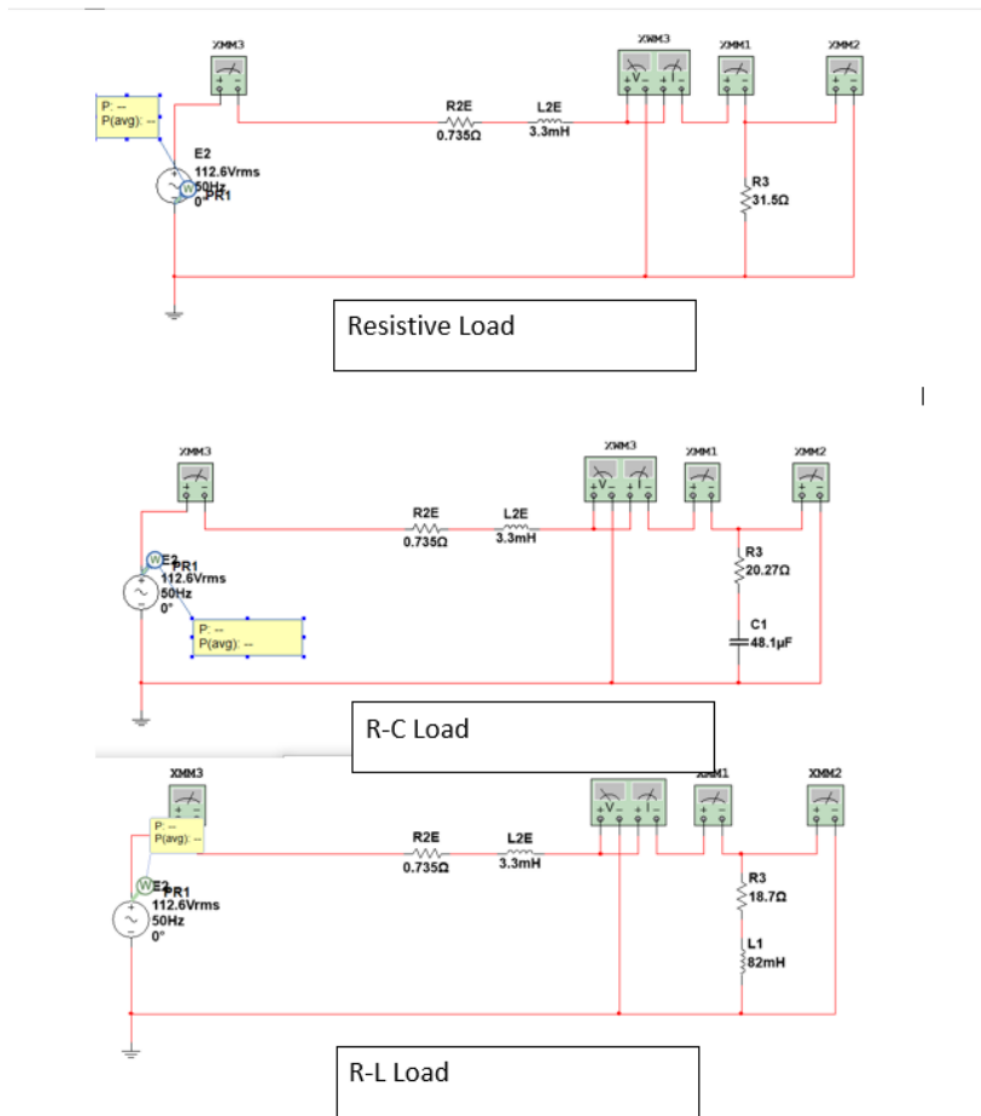


Figure 20; Simulated Configurations of Load Tests

FINAL GRADE

GENERAL COMMENTS

Instructor

70/100

PAGE 1

PAGE 2

PAGE 3

PAGE 4

Text Comment. ????

Text Comment. this is a good summary

PAGE 5

Text Comment. This last paragraph was not needed since this is a plan not a reflection

PAGE 6

Text Comment. Only 4 were required.

QM

Correctly cited

Text Comment. of what?

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Correctly cited

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Text Comment. Use surnames only in a citation

Text Comment. Use surnames only in a citation

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Correctly cited

Citation method conforms to Harvard standard, well done.

Text Comment. I expected a lower percentage on the lower figure

PAGE 7

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Citation method conforms to Harvard standard, well done.

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Correctly cited

Citation method conforms to Harvard standard, well done.

PAGE 8

Text Comment. This is a good research section with lots of Harvard citations

PAGE 9

PAGE 10

PAGE 11

Text Comment. There is obviously something wrong here with the current as you have commented on below

Text Comment. a good deduction

PAGE 12

Text Comment. Incorrect, the equivalent circuit does include these losses since the open circuit voltage was used as the input and you are focusing on the load voltage

PAGE 13

PAGE 14

Text Comment. a plus sign is missing

PAGE 15

Text Comment. How does this graph relate to the simulate results above?

PAGE 16

Text Comment. Which frequencies were used?

Text Comment. What was the V/f ratio?

PAGE 17

Text Comment. Which is the best method?

QM

Punctuation Error

Punctuation error

Text Comment. In what way?

Text Comment. Incorrect, the equivalent circuit does include these losses since the open circuit voltage was used as the input and you are focusing on the load voltage

PAGE 18

PAGE 19

PAGE 20

QM

Wide Range of Sources

You have shown good evidence of reading from a wide range of sources.

QM

Correct method of listing.

You have listed your sources correctly according to the Harvard method.

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GRADING FORM: NEW CSG-RUBRIC

MATTHEW PERRY

70

1. ENGAGEMENT WITH LITERATURE



A good research section with evidence of reading from a wide range of sources cited and listed correctly using the Harvard method. 14/20

14

2. KNOWLEDGE AND UNDERSTANDING



Good knowledge and understanding demonstrated in your research findings, transformer and motor investigation explanations. 13/20

13

3. COGNITIVE AND INTELLECTUAL



Good analysis of transformer and motor investigation results analysis and conclusions/recommendations 13/20

13

4. PRACTICAL APPLICATION



Good use of equipment for transformer and motor experiments and presentation of results 14/20

14

5. TRANSFERABLE SKILLS



A good executive summary, work plan, risk assessment and explanation of team working. Report is well structured, written and presented with clear diagrams. Word count not exceeded 16/20

16