

Mason Morgan

by Mason Morgan

A GOOD REPORT THAT COVERS THE MAIN REQUIREMENTS OF THE BRIEF. DECLARED WORD COUNT SEEMED ITSD AND THE APPENDICES CONTAINED A LOT OF UNREFERENCED MATERIAL.

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Assignment: Transformers and Induction Motors

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Good Structure

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1. Executive summary

During this report fundamental research was carried out into induction motors and how they can be applied in industry. It is crucial to collect this research before continuing the report. As part of the research into induction motors it was important to understand how motor speeds can be affected by different factors. Later, research was continued into how industries are supplied with power and where it comes from. It was soon apparent that transformers convert the high voltage from distribution lines and step it down to a suitable voltage which can be used in industries.

After covering in depth research into transformers and induction motors highlighted by the above information, this could be carried into the practical sections. With the research gathered It meant that there was now a better understanding on tasks that were to come.

Transformer tests involved in report:

- Open circuit test
- Short circuit test
- Determining voltage regulation and efficiency

It is essential to make detailed comparisons between all tests, these include simulation, practical and calculated tests. All three sets of results can be analysed and compared for any trends and/or patterns.

Induction motor tests involved in report:

- Stator resistance test
- No-load test
- Blocked rotor test

Calculations, practical results, simulation test will evidently be compared to datasheets as a comparison to determine how accurate the results can get. A useful way to display all data recorded in the multiple tests is to tabulate into tables for easy comparison against one another.

A conclusion must be made towards the end of the report to provide a detailed summary of what was found.

2. Research

2.1. Induction machine speed control methods using power electronic convertors.

The magnetic field will be determined through the rate of speed the motor travels. There are three factor that will determine the rate at which the stator travels at synchronous speed, these are:

1) The frequency

The applied voltage does not affect the speed of the field, only the speed of the rotor.

2) Applied voltage.

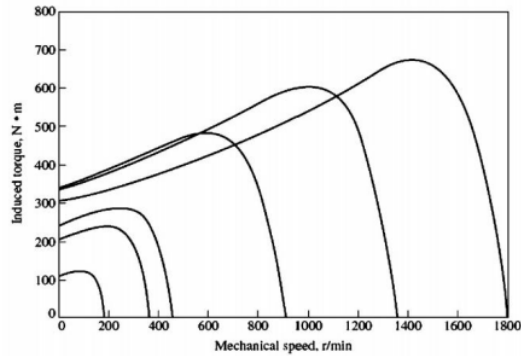
3) The number of pairs of poles

(methods, 2020) Correctly cited

Speed Control by Changing Frequency

Often the induction motor can run much higher frequencies than its base design value. When an induction travels faster there are benefits, some of these being improved cooling due to better air circulation. However, at the higher speeds there comes windage loses, increased friction and increased iron losses down to the higher frequencies but the better cooling of the motor allows higher current densities to be used. Throughout the operation of the induction motor a higher supply voltage will be required to ensure a constant flux density in the airgap because of higher frequency values being applied which increases the impedance of the windings. (eepower, 2020) Correctly cited

There are two main methods for frequency changing. The first uses rotating machinery to achieve the desired result. The second method uses electronic switching to synthesize an irregular-shaped alternating current wave from DC. (Electrical Academia, 2020) [Correctly cited](#)



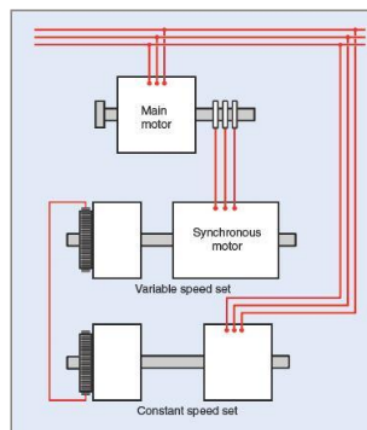
(TheEngineeringKnowledge, 2020) [Correctly cited](#)

Figure 1: Induction motor speed dependant on the frequency

Figure 1 shows an impedance / speed graph. It illustrates that by increasing the induced torque, this in turn increases the mechanical speed output.

Rotating Machinery for Frequency Control

Figure 2 illustrates another method for speed control. The Kramer method has been used to control the speed of a wound-rotor induction motor. In the application in Figure 2 it alternates the brush position for each phase which controls the speed of the motor. (Science direct, 2020) [Correctly cited](#)



(Electricalacademia, 2020)

Figure 2: Kramer drive using rotating machines.

The two most common methods of speed control are:

- 1) Unequal voltages applied to stator windings.
- 2) Unequal resistances inserted in rotor windings.

(Machine design, 2020)

Electronic Frequency Control

An example of electronic frequency control that can be used is through an inverter, please see figure 3. Method a uses an uncontrolled rectifier circuit whereas method b uses a controlled rectifier.

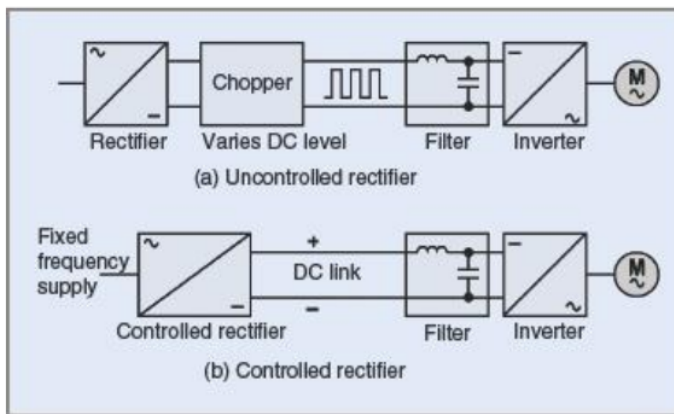


Figure 3: Block diagrams of variable frequency motor drives

Frequency of power supply can easily be varied using power electronics devices like inverter, this can be illustrated by figure 5. The inverter converts DC power into AC power and feeds to the induction motor. As a result, the Inverter output may be either constant voltage variable frequency or variable voltage variable frequency. (Electrical concepts, 2021)

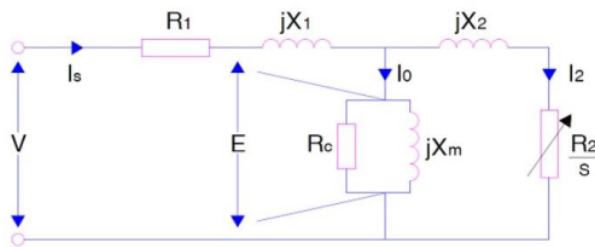


Figure 4: Induction motor equivalent circuit

(concepts, 2021)

Other factors involved are the type of circuits in the unit and whether the final output sends a signal of its own performance to the unit's input for monitoring and self-adjustment of the unit. The examples of the speed control can be seen below in figure 4.

<i>Type of motor</i>	<i>Speed characteristic, no load to full load</i>	<i>Method of speed control</i>
AC, squirrel cage, multi-speed	Speed drop up to 5% from or two or more initial speeds	Pole changing. Windings of different pole numbers, or reconnect one winding to change the pole number
AC, squirrel cage, single-speed	Speed drop up to 15%, depending on design	Primary voltage control. Stator frequency control at constant volts per cycle
AC, slip-ring	Speed drop up to 50%, depending on rotor resistance	Secondary resistor connected to slip-rings. Machine and solid-state conversion feedback of rotor power
AC, synchronous	No speed drop. Speed set by stator frequency	Adjustable frequency from motor generator set or solid-state frequency converter

(Csanyi, 2020)

Correctly cited

Figure 5: Methods of speed control

Voltage boost at low frequencies

At low frequencies, the stator supply voltage can be boosted to maintain the magnetising voltage and hence maintain rated flux in the machine. It is possible to accelerate a motor from zero speed to rated speed smoothly and without the high inrush currents normally associated with induction machine starting when some form of constant Volts per Hertz operation, with voltage boosting at lower frequencies is used.

A variable voltage, variable frequency drive can operate over a wide speed range. There are three distinct operating modes, illustrated in the diagrams below. (Drives, 2021)

Correctly cited

1. Below base speed
2. Constant power
3. Field weakening, constant slip speed.

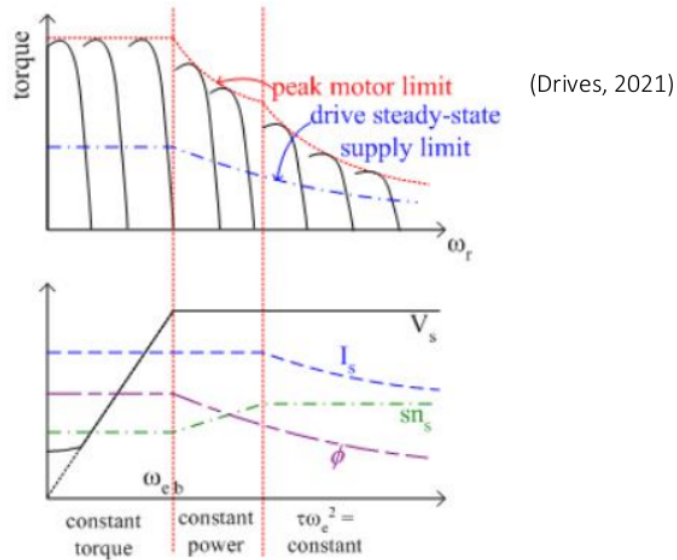


Figure 6: methods of voltage boost

2.2. Industrial applications of induction machines

There are many applications in industry's which apply induction motors, some of these are listed below.

- Lifts
- Cranes
- Hoists
- Large capacity exhaust fans
- Driving lathe machines
- Crushers
- Oil extracting mills
- Textile etc.
- Compressor
- Lathe machines
- Conveyors

(GardenGuides, 2020)

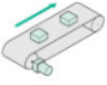
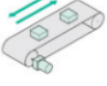
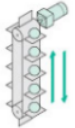
Type	Features	Output Power	Power Supply
	AC Induction Motors are suitable for applications where the motor is operated continuously in one direction.	1 W (1/750 HP) up to 3 HP	Single-Phase 100-120 VAC Single-Phase 200-240 VAC Three-Phase 200-240 VAC
	AC Reversible Motors are suitable for applications where the motor reverses its direction repeatedly.	1 W (1/750 HP) up to 3 HP	Single-Phase 100-120 VAC Single-Phase 200-240 VAC Three-Phase 200-240 VAC
	AC Motors with Electromagnetic Brake are suitable for applications where the load must always be held in place.	6 W (1/125 HP) up to 3 HP	Single-Phase 100-115 VAC Single-Phase 200-230 VAC Three-Phase 200-230 VAC

Figure 7: Induction machines used in conveyor systems.

(technology, 2021)

A useful example to use are conveyors. Where the speed needs to be controlled or varied during operation. By combining a control circuit with the motor, speed changes can be performed. Speed control motors are optimal for switching between high speed and low speed operation and for arbitrary adjustment of speed. Figure 6 explains some different types that the motor can be applied.

2.3. Power Systems required to deliver a three-phase, 415VAC supply to a typical factory.

A typical power system that would deliver 415VAC to an industry would include a transformer to control the HV power coming into the industry by stepping it down to a suitable operating voltage. There are some variations of transformers that are used in different circumstances, these include:

- Electric arc furnace transformer
- DC electric arc furnace transformer (DC EAF)
- Rectifier transformers
- Convector transformers
- Line feeder

(Electrical Engineering Portal, 2020)

Citation Needed

3. Transformer Investigation

3.1. Open Circuit test

It was crucial that the correct equipment was used for this practical. Firstly, a power supply was needed. The electrical supply used to power the transformer primary was a FEEDBACK bench power supply. This supply sent a stable 240VAC signal to the mains of the transformer.

It was then possible to utilise the secondary transformer connections to create an open circuit and short circuit test. It was important to connect our supply to the NANOVIP watt meter which could determine all readings for V, A, W, P.F

The purpose of this test is to check what core losses are in the transformer. It is important to understand that the copper losses are affected by the increase and decrease in load. This can be backed up with evidence recorded. ****EXPERIMENTAL SETUP****

Open Circuit practical results and calculations

An equivalent circuit has been built for an open-circuit test, but no values have yet been found to place inside. From the calculations obtained which can be seen by figure 8 in the annexe they can now be placed inside data tables and an open circuit equivalent circuit. Before the equivalent circuit is built all data collected from the calculations has been placed in a data table below noted as Table 1.

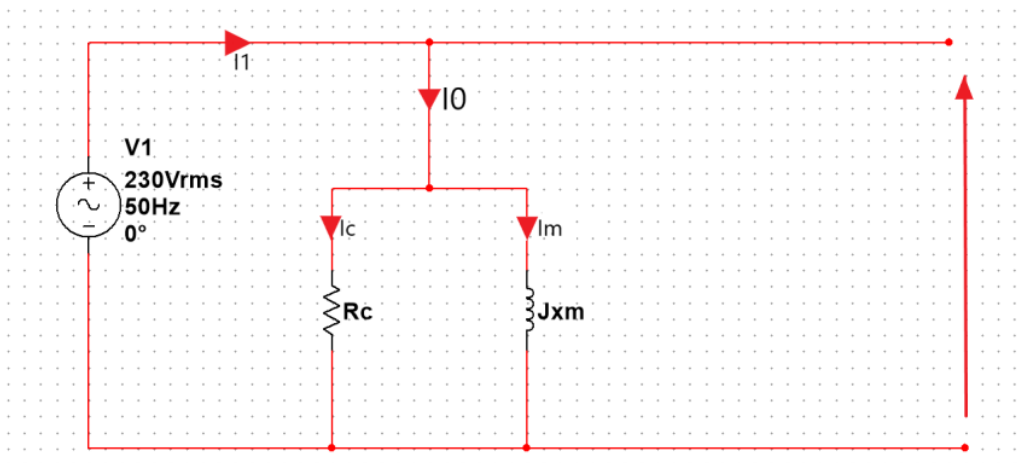


Figure 8: Open circuit equivalent circuit

Equivalent circuit values		
Voltage (V)	230	112
Current (mA)	542	-----
Power (W)	34.6	-----
Power Factor (P.F)	0.27	-----

Table 1: Equivalent circuit values for an open circuit test

The data show results for both components used in the open circuit test, these being the resistor (R_c) and the inductor (X_m) values, the equivalent circuit has been set up and shown in the annexe with the final calculated values. Values have also been determined for the current flowing at point I1 and I0. Current values for I_c and I_m can then be determined through the values found previously for R_c and X_m .

Open circuit table of results

Component Values		
R_c	1528.9 ohms	
I_c	0.15 Amps	
I_m	0.521 Amps	
X_m	441.5 ohms	1.405H
V1	230 Volts	
I1	0.542 Amps	

Table 2: Open circuit equivalent circuit component values

Through table 2 it is easier to understand what values have been calculated for what. The diagram shows the original equivalent circuit used for the open circuit test but with the inserted calculated values of R_c and X_m along with the current values from the primary voltage then the effect that both the inductor and resistor have on the circuit.

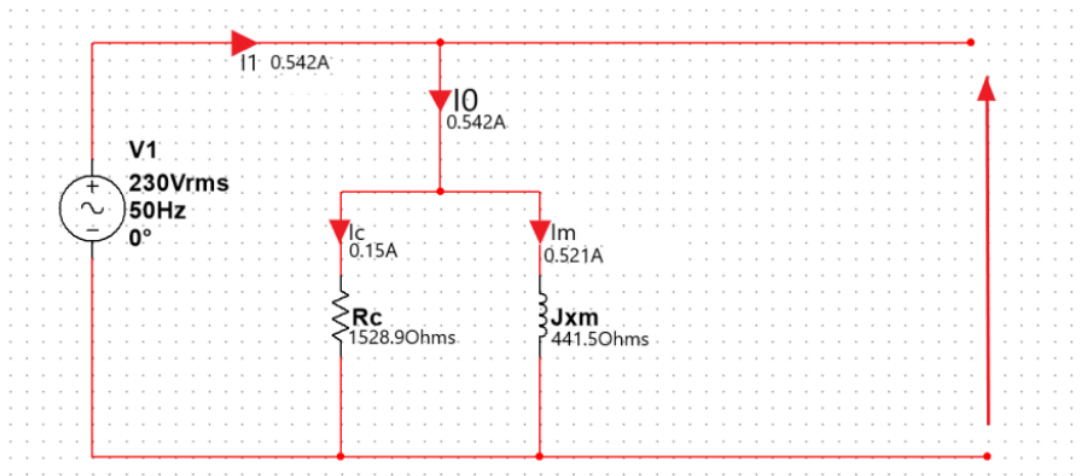


Figure 9: Finished equivalent circuit / Open circuit.

Figure 9 shows the finalised values placed inside the open circuit equivalent circuit. Values have been determined for both the resistor and Inductor to provide open circuit conditions and all current values following up to the components have also been found.

3.2. Short Circuit test

A closed-circuit test is often used to determine the impedance voltage. To carry out the closed-circuit test we needed to firstly short out or connect the secondary side of the transformer. The same equipment was used for this closed-circuit test as the open circuit test.

A low voltage starting at 0V can be applied to the primary side of the transformer. If the voltage was too high, then this would create short circuit conditions at rated voltage. To adjust the supply a variac was implemented to vary the input voltage value on the primary. The voltage result obtained on the secondary of the transformer from this test will be the final impedance voltage used in the data table.

A more detailed explanation of the closed-circuit test can be found in the annexe.

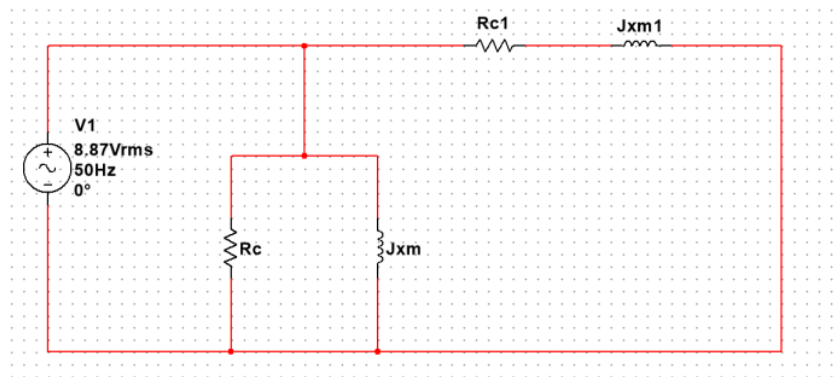


Figure 10: Equivalent open circuit

Figure 10 has been constructed with closed circuit configurations in mind. Although the components for the open circuit have been placed in the circuit the current will not be allowed to flow this way, meaning $I_0 = 0$.

*112 is incorrect
since the
secondary is
shorted out*

Equivalent circuit values		
Voltage (V)	8.87	112
Current (mA)	1.69	-----
Power (W)	7.98	-----
Power Factor (P.F)	0.53	-----

Table 3: Equivalent circuit values for a closed circuit

Table 3 shows the values used to provide short circuit conditions for the equivalent circuit.

Short circuit table of results

A table of results has been constructed to summarise all results found through the calculations made for the short circuit test. To determine final values for the resistor and the inductor which are used gain the same result as the practical are determined through the different values shown in table 4.

Calculation Values		
Z1E	5.25 Ohms	
R1E	4.7219 Ohms	
X1E	2.2948 Ohms	7.3mH
Z2E	1.3125 Ohms	
R2E	1.1805 Ohms	
X2E	0.5737 Ohms	1.83mH
I2	3.866A	

Table 4: Final calculated values for short circuit test

Figure 11 shows the equivalent circuit with the final values for the resistor and the inductor connected in series. It will be valuable to later compare these values to the simulation results and the practical results to determine trends or patterns but also evaluate how accurate the results are.

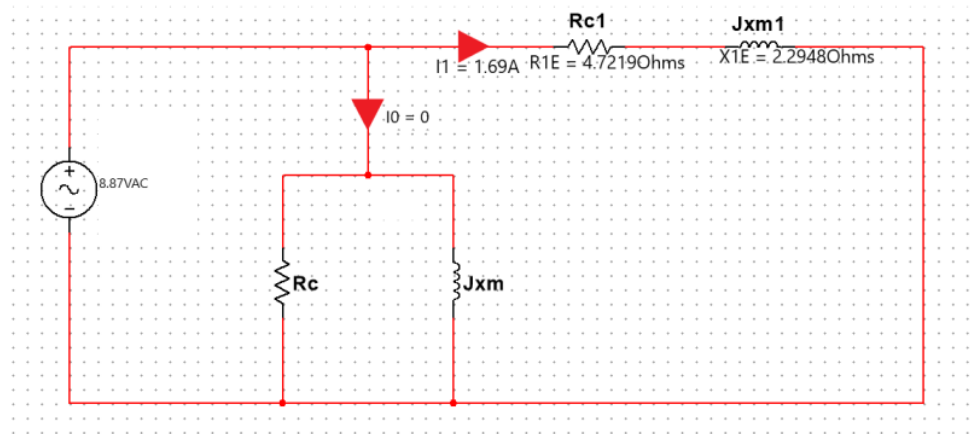


Figure 11: Finished equivalent closed-circuit.

3.3. Working safely in a group to achieve results.

Use the third Person

Through the entirety of these tasks, it was essential that we were able to work safely and effectively as part of a team. Through conjunction of these tests, we found it best to coordinate different tasks to different people. As a group of three we assigned each other different tasks to undertake. For the practical's, one person would monitor the change in value on the LCR meter, one person would monitor either the speed of the induction motor through a speed regulating meter or monitoring the changing values of the transformer on an open or closed-circuit test or taking photos of the practical, whilst the other person would be recording all the live data.

3.4. Predicting voltage regulation and efficiency through the load tests

The load test requires the primary side of the transformer to be connected to the variable power supply, whilst the secondary is also connected to the variable power supply, the secondary connections are connected in series with a resistive load, to create loaded conditions. AC voltage is selected, and the variable power dials are used to apply the required input voltage for test conditions, as each power supply is only capable of 130vAC, the test voltage of 230vAC was obtained by using and adjusting both variable supplies.

With the primary voltage set as close as possible to the required value of 230vAC, the Nanovip tester is then used to measure the primary test values, by connecting live and neutral of the tester to the primary power source and the clamp around the primary phase cable, the readings are then displayed on the tester and recorded.

The tester is then used to measure the values of the secondary values, the live and neutral of the tester are connected to the secondary power and the clamp around the secondary phase cable, the readings are then displayed on the tester and recorded.

The voltage regulation and efficiency calculations can be seen in the annexe.

Resistive load test

Table 5 shows the values used for the resistive load test. The results show that the current is almost doubled on the secondary side of the transformer compared to the primary. The significant differences shown in this test are the Voltage and current readings.

RL Test		
	Primary Values	Secondary Values
Voltage (V)	229	109
Current (I)	1.79	3.24
Power (W)	389	355
Power Factor (P.F)	0.95	1.00

Table 5: Voltage regulation results

Later a voltage regulation calculation can be used with the component values found, shown by in the annexe.

Component Values		
E2	113v	
V2	109v	
R2E	1.1805 Ω	
X2E	0.5737 Ω	1.83mH
I2	3.866A	
ZL	33 Ω	

Table 6: Voltage Regulation Component Values

At this stage, now that the voltage regulation calculations have been derived and values have been found from the closed-circuit test components along with the 33Ω resistive load, a multisim circuit can be constructed. This is shown by figure 12.

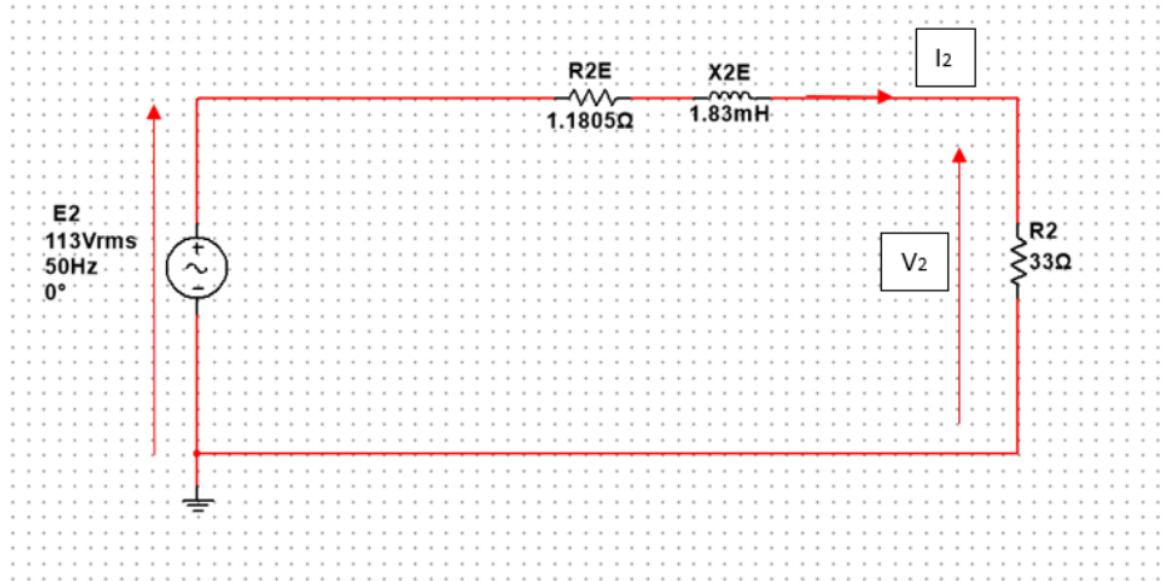


Figure 12: Voltage Regulation RL equivalent circuit

Full Load test

After the resistive load test was completed a full load test was then conducted. The test uses additional components to replicate the full load conditions, these involve an inductor (93Ω) and a resistor (36.5Ω). During the test, the primary and secondary values are recorded exactly like the resistive test previously.

Voltage Regulation		
	Primary Values	Secondary Values
Voltage (V)	229	108
Current (I)	2.86	5.44
Power (W)	634	587
Power Factor (P.F)	0.97	1

Table 7: Full Load Voltage Regulation Test Values

With the circuit voltage values measured, component values obtained from the copper loss test results, along with the 36.5Ω resistive and 93mH load, the full load equivalent circuit could be built using multisim.

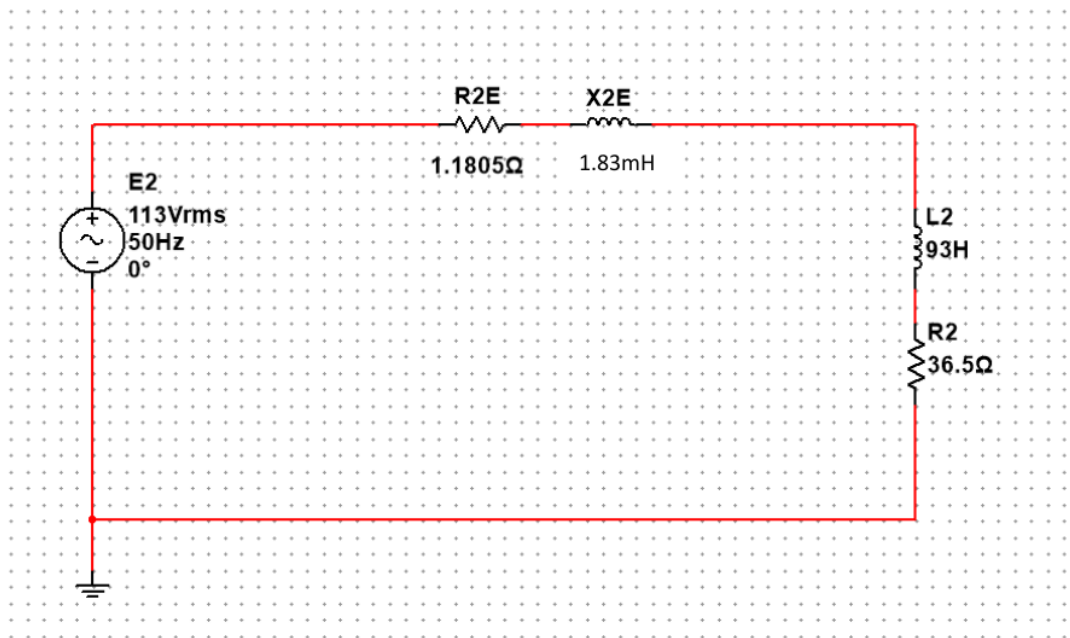


Figure 13: Voltage Regulation Full Load Equivalent Circuit

Overload test

An overload test was then conducted. The readings for the test can be seen for both the primary and secondary of the transformer in table 8.

Voltage Regulation - Overload		
	Primary Values	Secondary Values
Voltage (V)	230	109
Current (I)	2.75	4.92
Power (W)	624	543
Power Factor (P.F)	0.97	1

Table 8: Overload Test Values

With the circuit voltage values measured, component values obtained from the copper loss test results, along with the 28.3Ω resistor and $48\mu\text{F}$ capacitance load, the overload equivalent circuit could be built using multisim.

Both a resistor and a capacitor were implemented into the equivalent circuit to reach overload conditions.



Figure 14: Voltage Regulation Overload Equivalent Circuit

3.5. Simulation results for an Open circuit

The results gathered from the simulation tests can be seen below in tables 9 and 10.

Values used in the Open Circuit test		
	Primary Values	Secondary Values
Voltage (V)	230	229.999
Current (mA)	540.741	540.741
Power (W)	34.6	5.2953e-5
Power Factor (P.F)	0.27820	1

Table 9: Simulated open circuit

Through inserting the values from the previous open circuit calculated figures for both the inductor and resistor values can now be determined for R1 and I1.

Component values (Simulated equivalent open circuit)	
R1	34.6W
I1	540.74mA
Rc	1528.9Ω
Lm	1.405H
R1E	4.7219Ω
L1E	7.3mH
IO	540.74mA

Table 10: Simulated equivalent circuit values for an open circuit test

The simulation was constructed on multisim and an image of the test can be seen in the annexe of the open circuit test in the annexe.

Now that the simulated results have been obtained for the Open circuit it is now possible to compare all three sets of resultant data, these being the transformer data sheet supplied with the transformer, the practical / simulated values, and the simulation results just obtained.

3.6. Simulation results for a Closed circuit

Table 11 shows the values applied to the simulated closed-circuit test which was constructed on multisim. Due to a low voltage being required for the closed circuit test a variac was used in the simulation. A maximum voltage was determined of 8.98 on the primary side of the transformer.

Inputted values into Closed Circuit		
	Primary Values	Secondary Values
Voltage (V)	8.98	0
Current (A)	1.72	1.71
Power (W)	13.85	0
Power Factor (P.F)	0.89	1

Table 11: Closed circuit simulated circuit

Once the values for closed circuit test across the transformer have been found these can be used to determine the component values for the rest of the circuit. Values for Resistor and Inductor have been found and all simulated values can now be used to determine how accurate all three sets of results really are with each other.

Component values (Simulated equivalent Closed circuit)	
R1	13.85W
I1	1.72A
Rc	1528.9Ω
Lm	1.405H
R1E	4.7219Ω
L1E	7.3mH
IO	21.11mA

Table 12: Simulated closed-circuit component values

3.7. Comparing practical results against simulation results

Below are comparisons between all three tests for the Open and Closed-circuit tests along with the Load test results. The Open circuit test results show that the primary voltages are practically the same, but this was expected. As for the secondary values there are slight differences between all three sets of results but are very similar. A current value could not be derived from the transformer datasheet but the practical and simulated values for current on the primary side are very similar. The power output does show a larger difference between the datasheet values compared to both practical and simulated values however the practical and simulated power results are very similar. The power factor could not be obtained for the datasheet however the practical and simulation values are again very similar with minimal difference.

Open circuit // Iron Losses						
	Datasheet transformer		Practical Values		Simulated Values	
Voltage (V)	230	112	230	113	230	115
Current (I)	N/A		542mA		540.74mA	
Power (W)	20.6		34.6		34	
Power Factor (P.F)	N/A		0.27		0.2782	

Table 13: Open circuit practical and simulated values against datasheet

The closed-circuit results show the practical and simulated values for both methods are again very accurate. Although the power reading for the simulated values is almost double that of the practical values.

Closed Circuit // Iron Losses						
	Datasheet transformer		Practical Values		Simulated Values	
Voltage (V)	N/A	N/A	8.98	N/A	8.98	N/A
Current (I)	N/A	N/A	1.69A	3.866A	1.724	3.866A
Power (W)	9.05	N/A	7.89	N/A	13.854	N/A
Power Factor (P.F)	N/A	N/A	0.53	N/A	0.89495	N/A

Table 14: Closed circuit practical and simulated values against datasheet

Load test results // Theoretical results						
	Resistive Load test		Load test		Overload test	
Voltage (V)	229	109	229	108	230	109
Current (I)	1.79	3.24	2.86	5.44	2.75	4.92
Power (W)	389	355	634	587	624	543
Power Factor (P.F)	0.95	1.00	0.97	1	0.97	1

Table 15: Load test results compiled.

The load test values for all three methods show that all voltages and power factor values are practically set up the same both in the primary and the secondary. The biggest differences seen in these three methods are the Current and Power values. The Current in the Resistive load test show much lower current values than that in the Load and Overload test. The Power rating again is much lower in the resistive load test compared to the Load and Overload test.

The results show that due to adding an inductor to the resistive load test there will be Current and Wattage values which are practically double. A very similar trend is shown for adding a capacitor to the resistive load test.

4. Three-phase Induction Motor Investigation

4.1. Stator Resistance Test

Practical results

Table 16 shows the Voltage and Current values across all three phases of the induction motor.

	L1	L2	L3
Voltage (V)	11.8	11.8	11.8
Current (mA)	330mA	330mA	330mA

Table 16: Results gathered for the Stator Resistance Test

Experimental setup

The stator resistance test takes its measurements by locking the rotor. Once the rotor has been locked DC current can be applied to the Stator. Both the voltage and current values can then be used to calculate R_1 .

4.2. No-Load Test

	L1	L2	L3
Voltage (V)	214	214	214
Current (A)	529	529	529
Power (W)	61.2	61.2	61.2
Power Factor (P.F)	0.31	0.31	0.31

Table 17: Results gathered for the No Load Test

Experimental setup

To carry out a No-load test the motor was coupled to a variable speed drive and driven at synchronous speed before applying rated voltage to the stator. The Induction motor was connected in STAR configuration.

4.3. Blocked rotor Test

Table 18 shows the test results for the blocked rotor test.

	L1	L2	L3
Voltage (V)	25.7	25.7	25.7
Current (mA)	489	489	489
Power (W)	19.2	19.2	19.2
Power Factor (P.F)	0.88	0.88	0.88

Table 18: Results gathered for the Blocked-Rotor Test

Experimental setup

This test setup prevents the rotor from turning ($s=1$) and a low voltage applied to the stator such that rated current flows.

4.4. Working safely in a group

It was crucial to work as part of a team during these three tests. As a team it was useful to divide the tasks up and assign jobs to different team members. As a group of 3 we decided to assign the data recording to 1 team member this meant that all data read out was captured by this team member, the data reading to another, this meant that any live data was called out by this person and 1 person in charge of the equipment like the speed controller for the slip speed test data table and regulating the amount of torque being applied to the motor.

4.5. Performance of the motor

Induction motor torque / slip curve line graph

Figure 15 shows a simulation for the performance of the motor in terms of torque and stator current over a range of speeds. Data has been captured whilst varying the motor speed between a minimum rpm value of -3000 and a maximum rpm value of 5970. The values for both slip and torque were recorded alongside the varying speed of the motor and has been placed in table 13 in columns of slip and torque.

From these results a graph can be constructed illustrating the pattern made.

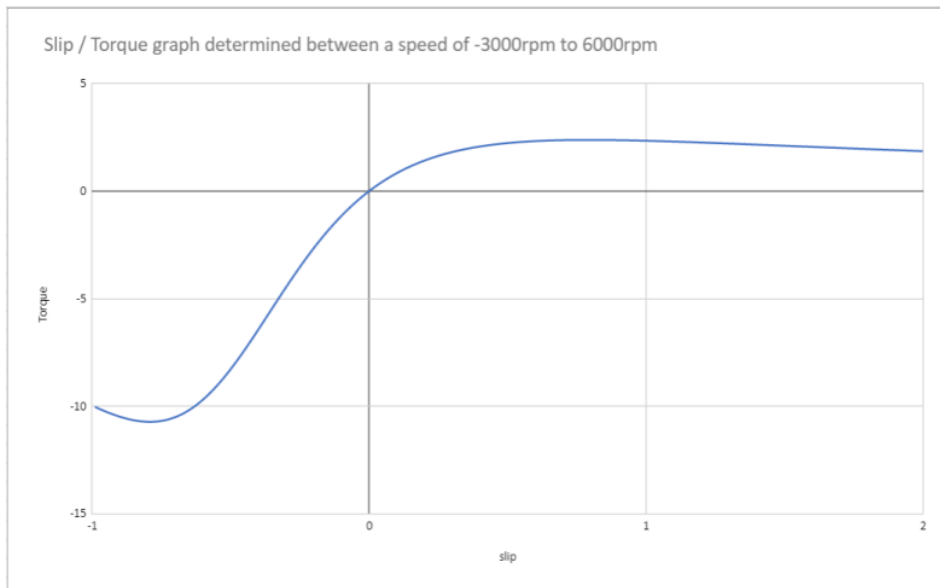


Figure 15: Speed / Torque graph whilst varying the speed of the motor.

Motoring

$$s = 0 \text{ and } s = -1$$

Positive torque is developed in forward direction where:

$$\omega R < \omega S \quad i.e. \quad nR < nS$$

Generating

Machine is being driven faster than synchronous speed in the same direction.

$$S = \frac{nS - nR}{nS} = \frac{50 - 60}{50} = -0.2$$

Negative slip produces negative torque causing a braking effect also.

$$S = \frac{nS - 2nS}{nS} = -1$$

Braking

When the motor is driven in the opposite direction to the rotating stator field, nR becomes negative.

$$S = \frac{nS - (-nS)}{nS}$$

$$= \frac{2nS}{nS} = 2$$

This creates a positive torque in a negative direction and therefore acts as a brake.

Testing the motor under load

Unloaded speed = 2859rpm

0.1n/m torque 215V

Speed	Torque	Slip	Volts	Current	Power (W)	Power Factor (P.F)
2859	0.1	-2	213	628mA	154	0.66
2862	0.2	-1.9	213	633mA	161	0.65
2799	0.3	-1.8	212	720mA	201	0.76
2764	0.4	-1.3	212	811mA	233	0.81
2725	0.5	-0.9	212	872mA	268	0.84
2673	0.6	-0.6	211	986mA	314	0.87
2602	0.7	-0.2	211	1.12A	368	0.89
2550	0.8	0	211	1.24A	409	0.9

Table 19: Motor test results under load

Table 19 shows the results of an unloaded test which was run up to a maximum of 2859rpm.

By recording this data, we can later make comparisons against the loaded test.

Loaded speed test / Actual values.

	0 nm	0.1 nm	0.2 nm	0.3 nm	0.4 nm	0.5 nm	0.6 nm	0.7 nm	0.8 nm
V	213	213	213	212	212	212	211	211	211
A	651mA	643mA	633mA	720mA	811mA	872mA	986mA	1.12A	1.24A
W	162	161	161	201	238	268	314	368	409
P. F	0.67	0.66	0.65	0.76	0.81	0.84	0.87	0.89	0.90

Table 20: Loaded speed test

Table 20 illustrates the loaded test on the motor. It can be expected that when the load is increased on the motor in terms of nm, the values for current, power, and power factor increase steadily.

Predicted values.

Synchronous speed (2994rpm)	Voltage	Current	Power	Power Factor
	214V	536mA	421W	0.21

Table 21: Predicted values for motor at synchronous speed

Predicted values have been made for motor running at synchronous speed displayed by table 21.

Generating

Above synchronous speed	3100rpm	216V	628mA	81.2W	-0.34
	3198rpm	217V	843mA	187W	-0.59
	3302rpm	218V	1.13A	304W	-0.71

Table 22: Above synchronous speed results

A test was then carried out for the motor running at above synchronous speed and the answers are shown by table 22. The results show that as the speed of the motor increases the values increase.

$$T = \frac{3 * 214^2 * 44.73}{314.16 * S \left[\left(35.75 + \frac{44.73}{S} \right)^2 + 42.76^2 \right]}$$

Equation 1: Torque equation

The torque equation can be derived from equation 1 highlighted above.

5. Conclusions and Recommendations

To conclude, from the research gathered an induction motor has three separate ways of altering its speed. It is also apparent that transformers are the main source of stepping down high voltages from distribution lines and converting into a suitable voltage for industries to use and evidence has been used to back this up.

After the research was carried out the research into transformers tests could be created. After conducting the open circuit test there were similarities across all three sets of data, these being the transformer datasheet, the practical results, and the Simulated results. The results show that all voltages across the primary are the same. From the evidence displayed in the transformer section it can be said that the results all results conducted against the datasheet are very accurate.

The short circuit tests again, like the open test had very similar results for both the primary and secondary voltage as well as very similar Power factor readings. The only standout results apparent from this test was the current ratings. The practical and simulated were almost double that of the primary and secondary readings of the datasheet values.

The load tests for resistive, load and overload show similar results within the voltage Power Factor, but again have more significant differences with regards to the current and wattage ratings. The resistive load test shows almost half of the readings for the Load Test and the Overload Test. An inductor was implemented into the Load test circuit and a capacitor was used in the overload circuit.

With regards to the induction motors tests the stator resistance test shows the same values across all three phases for the voltage and the current.

The No-Load Test again show the same results across all three phases as well as the Blocked rotor test.

A slip / torque graph was recorded from the induction motor practical. The graph showed a steady incline up to maximum rpm and levelled out. Tests were utilised for the loading and unloading of the motor. The values showed for the loaded motor test that when the load increases the Current, Power and P.F increase at a steady rate.

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Correct method of listing.

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Appendix

Transformer testing and evidence.

RS Part No		260-4244
Transformer Type		CM7501
Continuous Output Rating (VA)		375
Intermittent, 5 mins on 15 mins off. (VA)		750
Primary Voltage (V)		230
Frequency		50/60Hz
Off-Load Secondary Volts (V)		113.8
Full-Load secondary Volts (V)		109.6
Regulation at Continuous Rating		4%
Efficiency at Continuous Rating		90%
Iron Loss (Watts)		20.16
Copper Loss at Continuous rating	Primary (Watts)	9.05
	Secondary (Watts)	10.74
Insulation Resistance at 2kV for 1 Minute		>200MΩ
Flash Test Voltage for 1 minute		2kV
Primary Winding Resistance at 20 °C		1.79Ω
Secondary Winding Resistance at 20 °C		0.52Ω
Winding Temperature Rise	Primary (°C)	96
	Secondary (°C)	89
Primary Thermal Circuit Breaker Rating		3Amp
Dimensions, Width x Depth x Height (mm)		160x210x220
Weight (Kg)		9
Output Sockets		1x16A BS EN 60309

Figure 16: Datasheet for 230VAC – 110VAC transformer



Figure 17: Specific transformer used in practical.

Open circuit

- The secondary side of the transformer is left open circuit. This now means there will be no secondary current active.
- Connect the primary side of the transformer to the supply of the feedback bench supply.
- Using the combinational leads, we also shared the supply to our Nanovip watt meter so that we could take the V, A, W, P.F. readings during the test.
- Primarily what we want to read on the open circuit test is core losses
- The type of losses that we saw in the test were as soon as the magnetic field is established by the exciting current because as soon as we connect it to the voltage supply with no secondary load the only type of current we're going to see is exciting current, that exciting current builds up our magnetic field in the core of our transformer and because we have a magnetic field in the core of our transformer we end up with core losses which consist of our hysteresis losses which is the magnetic flipping of those domains in the core which gives us energy lost through heat.
- We also have a circulating eddy current which built up because we had a magnetic field interacting with the conductive core and we also have our flux leakage losses
- Once there is power put on the transformer there should be some current reading, this is called the exciting current.
- The purpose of this test is to check what core losses are in the transformer.
- The copper losses are affected by the increase and decrease in load.

Figure 18: Open circuit test explanation

Open circuit calculations

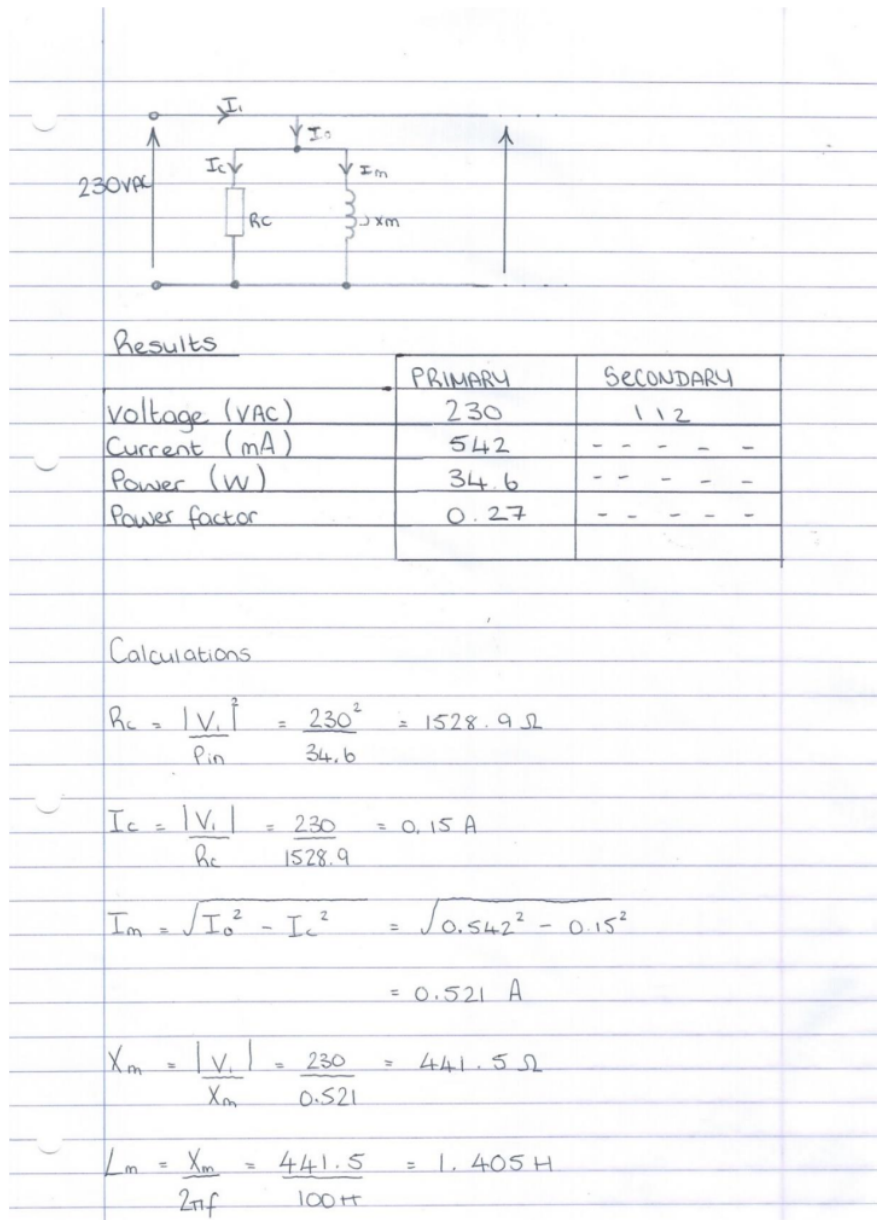


Figure 19: Open circuit calcs and results

$$V_{sc} = V_{bf} = 25.7 \text{ /phase}$$

$$I_{sc} = \frac{I_{br}}{\sqrt{3}} = \frac{489mA}{\sqrt{3}} = 282mA$$

$$P_{sc} = \frac{1}{3}P_{bc} = \frac{1}{3} * 19.2w = 6.4w$$

$$\cos\phi_{sc} = \frac{P_{sc}}{V_{sc} * I_{sc}} = \frac{6.4}{25.7} * 282 * 10^{-3} = 0.3831 \text{ lagging}$$

$$\phi_{sc} = \cos^{-1}(0.3831) = 27.98$$

$$\sin\phi = \sin(27.98) = 0.4692$$

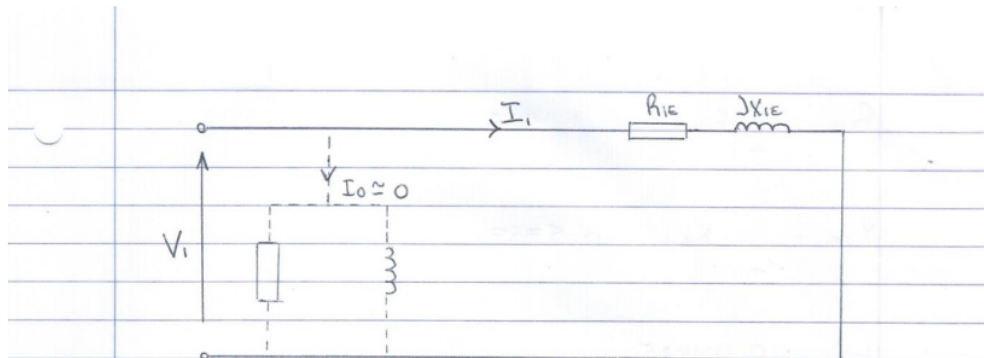
$$Z_{sc} = \frac{V_{sc}}{I_{sc}} = \frac{25.7}{282 * 10^{-3}} = 91.13\Omega$$

$$R_1 + R_2' = Z_{sc} * \cos\phi_{sc} = 91.13 * 0.3831 = 80.48\Omega$$

$$\therefore R_2' = Z_{sc} * \sin\phi_{sc} = 91.13 * 0.4692 = 42.76\Omega$$

Figure 20: Continued calcs for open circuit test

Closed circuit Calculations.



Results

	PRIMARY	SECONDARY
Voltage (VAC)	8.87	112
Current (A)	1.69	- - - -
Power (W)	7.98	- - - -
Power factor (p.f)	0.53	- - - -

Calculations

$$Z_{1E} = \frac{V_1}{I_1} = \frac{8.87}{1.69} = 5.25 \Omega$$

$$R_{1E} = \frac{P_{in}}{I^2} = \frac{7.98}{1.69^2} = 4.7219 \Omega$$

$$X_{1E} = \sqrt{5.25^2 - 4.7219^2} = 2.2948 \Omega$$

$$L_{1E} = \frac{X_{1E}}{100\pi} = \frac{2.2948}{100\pi} = 0.0073 H$$

$$Z_{2E} = \left(\frac{N_2}{N_1}\right)^2 \times Z_{1E} = \left(\frac{1}{2}\right)^2 \times 5.25 = 1.3125 \Omega$$

Figure 21: Closed circuit calculations part. 1

$$R_{2E} = \frac{1}{4} R_{1E} = 1.1805$$

$$X_{2E} = \frac{1}{4} X_{1E} = 0.5737$$

$$L_{2E} = 0.001825$$

Figure 22: Closed circuit calculations part. 2

- The secondary side of the transformer need to be connected or shorted.
- A voltage must then be applied to the primary side to get rated current on the secondary to flow.
- A starting voltage of 0V must be applied. If the rated 240VAC was used initially then there would be a high current value on the secondary causing short circuit conditions.
- A variac is used to adjust the voltage throughout the test.

Rated current on Primary: $I_p = \frac{375VA}{230V} = 1.63A$

Equation 2: Rated Primary current

Rated current on Secondary: $I_s = \frac{375VA}{110V} = 3.409A$

Equation 3: Rated Secondary current

- The rated current on the primary and secondary will be used to determine what the impedance voltage is.
- A measuring instrument will now be connected to the link shorting out the secondary side to determine a secondary current reading.
- The voltage will be increased until the measured voltage is the same as equation 5 above.
- Once the measured current value matches the calculated current value the voltage reading can then be recorded on the primary side of the transformer.
- The Voltage recorded will be the impedance voltage.

$$\%Impedance = \frac{Impedance(V)}{230V}$$

Equation 4: how to determine Impedance (%)

- The short circuit test can also be used to determine the copper losses ($I^2 \cdot R$).

$$I_2 = \left(\frac{N_2}{N_1}\right)^2 * 1.69 = 3.866Amps$$

Equation 5: working out I_2

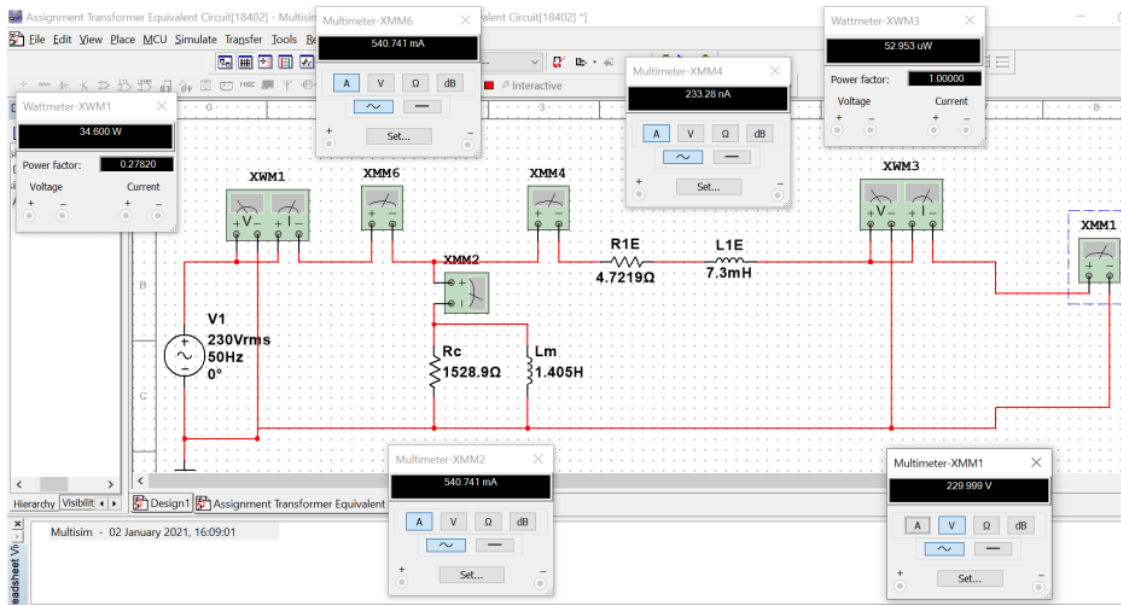
$$X_{1E} = 2\pi fL = L_{1E} = \frac{X_{1E}}{2\pi f} = \frac{2.2948}{2\pi \times 50} = 0.0073H \text{ or } 7.3mH$$

Equation 6: X_{1E} Inductive Value Calculation

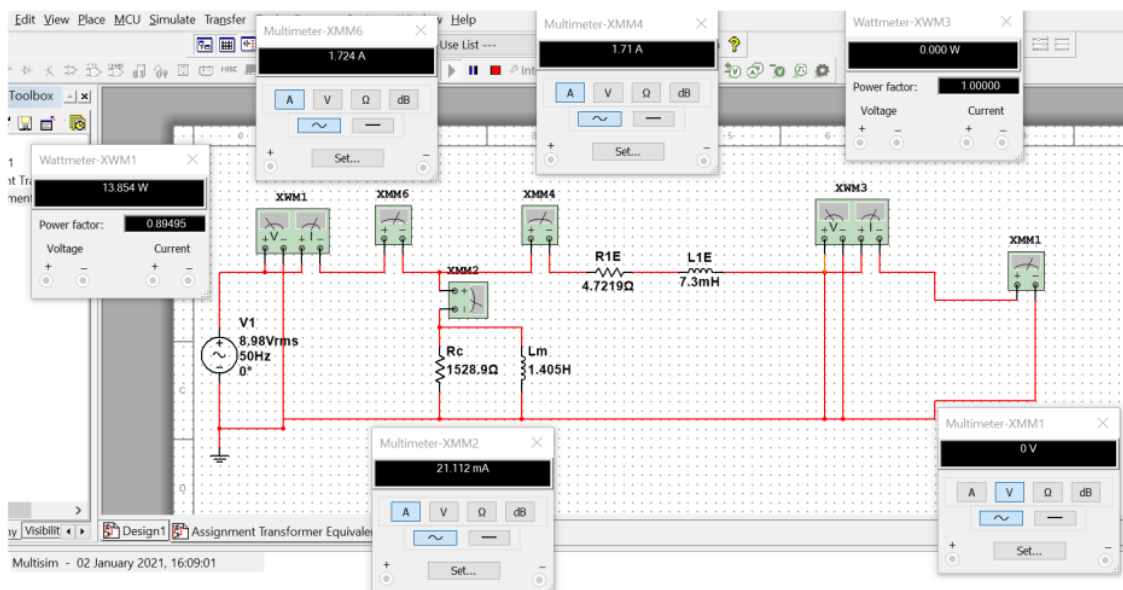
$$X_{2E} = 2\pi fL = L_{2E} = \frac{X_{2E}}{2\pi f} = \frac{0.5737}{2\pi \times 50} = 0.00183 H \text{ or } 1.83 mH$$

Equation 7: X_{2E} Inductive Value Calculation

Simulated open-circuit test results



Simulated closed-circuit results.



Induction Motor Test



Figure 23: Motor practical setup

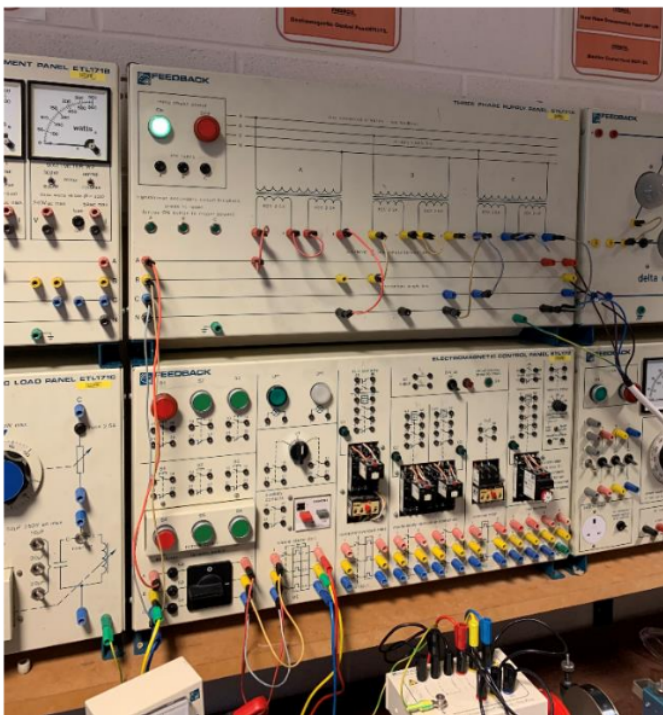


Figure 24: FEEDBACK power supply and control gear



Figure 25: Adjusting the rpm

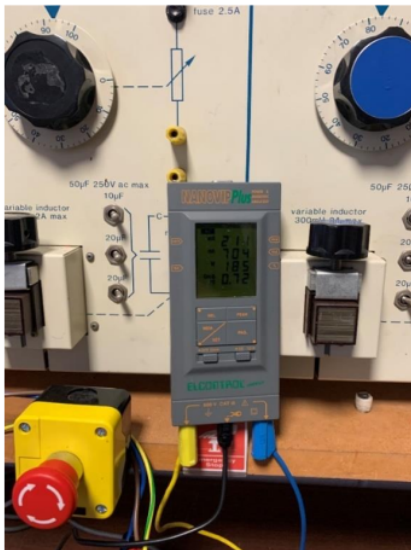


Figure 26: NANOVIP value no. 2

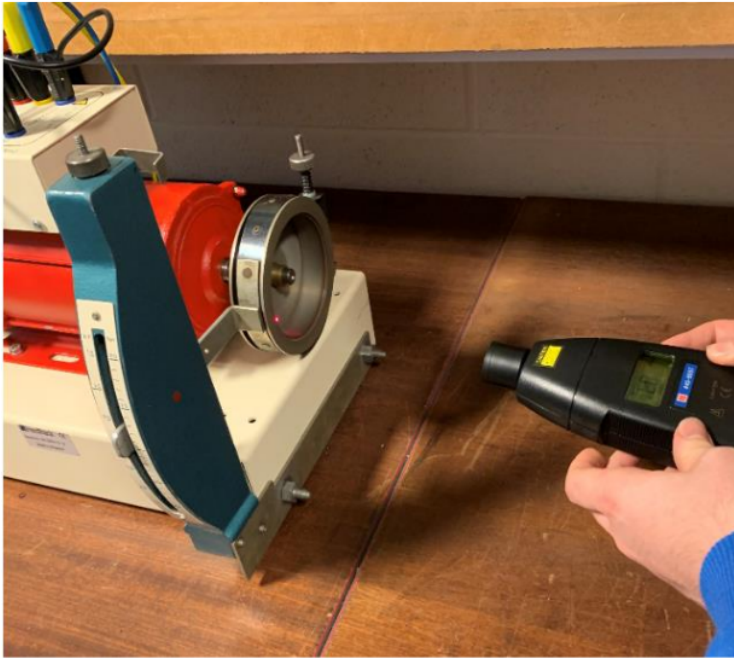


Figure 27: Using equipment to record the motor speed



Figure 28: Varying the motor speed on dial

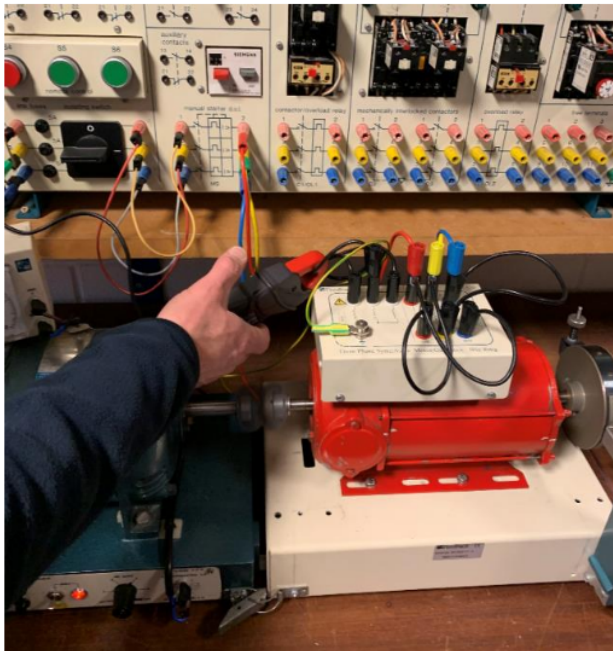


Figure 29: Wiring arrangement (STAR)



Figure 30: NANOVIP value no. 3



Figure 31: NANOVIP value no. 4



Figure 32: NANOVIP value no. 5

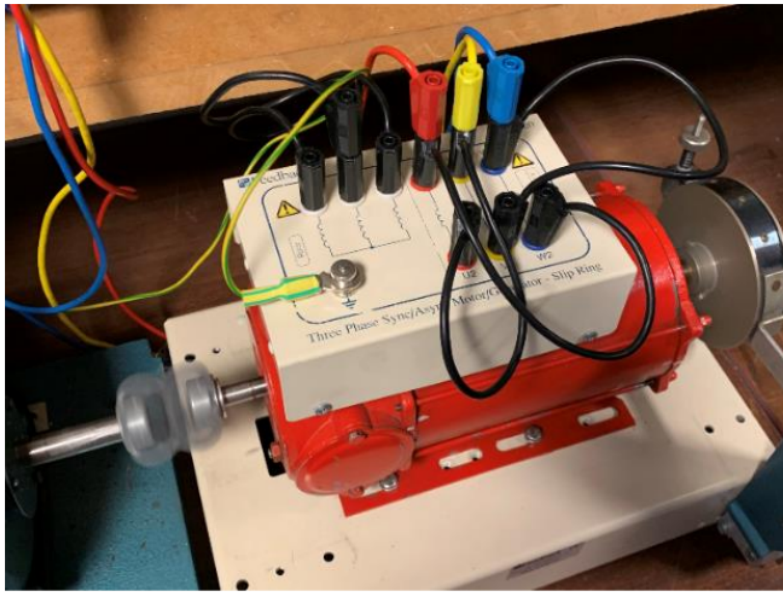


Figure 33: Induction Motor wiring configuration in Star

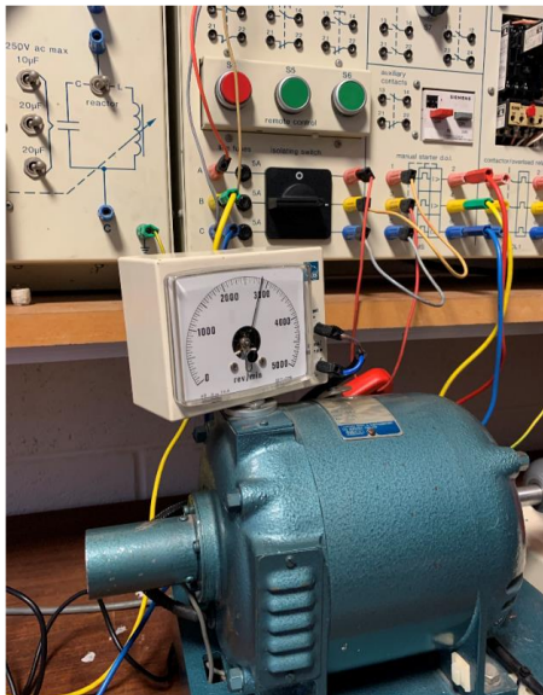


Figure 34: Induction motor rpm speed gauge

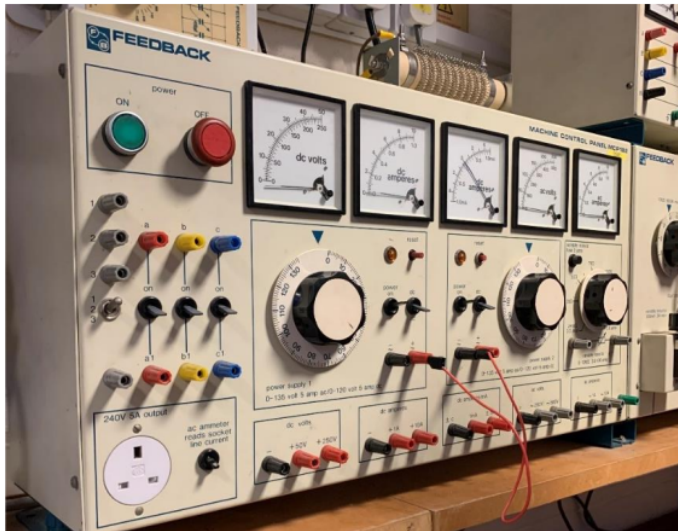


Figure 35: Practical setup for a closed circuit

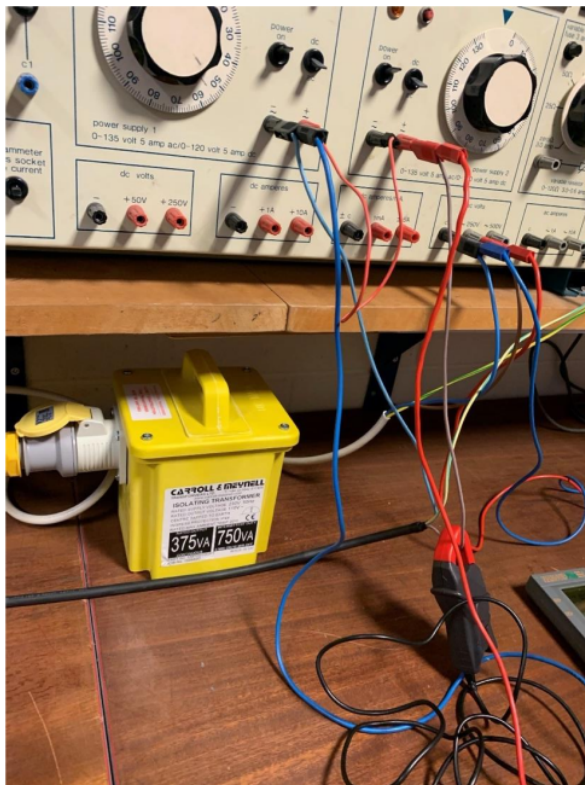


Figure 36: Utilising test equipment like clamp meters

Restive Load Test results

$$\phi = \cos^{-1}(0.95) = 18.2^\circ = \sin(18.2) = 0.312$$

Equation 8: Cos & Sin Values for RL test

$$\% \text{ Regulation} = \frac{I_2 (R_2 E \times \cos \phi + X_2 E \sin \phi)}{V_2} \times 100 = V_2$$

Equation 9: % regulation final value calcs. with symbols

$$= E_2 - I_2 (R_2 E \times \cos \phi + X_2 E \sin \phi)$$

Equation 10: % regulation final value calcs. with symbols simplified version

$$V_2 = 113 - 3.24 (1.1805 \times 0.95 + 0.5737 \times 0.312) = 108.79V$$

Equation 11: % regulation final value calcs. with values

Full Load Test

$$\phi = \cos^{-1}(0.97) = 14.07^\circ = \sin(14.07) = 0.243$$

Equation 12: Cos & Sin Values

$$\% \text{ Regulation} = \frac{I_2 (R_2 \cos \phi \mp X_2 \sin \phi)}{V_2} \times 100 = V_2$$

Equation 13: % Regulation simplified equation

$$= E_2 - I_2 (R_2 \cos \phi \mp X_2 \sin \phi)$$

Equation 14: % Regulation equation using symbols

$$V_2 = 113 - 5.44 (1.1805 * 0.97 + 0.5737 * 0.243) = 106.01V$$

Equation 15: Voltage Regulation Calculation

Over-Load Test

$$\phi = \cos^{-1}(0.97) = 14.06^\circ = \sin(14.06) = 0.24$$

Equation 16: Cos & Sin Values

With the $\cos\phi$ and calculated $\sin\phi$ values, along with the calculated component values and test voltages from the practical testing, the voltage regulation can be calculated.

$$\begin{aligned}\% \text{ Regulation} &= \frac{I_2 (R_2 E \cos\phi_2 \mp X_2 E \sin\phi)}{V_2} \times 100 = V_2 \\ &= E_2 - I_2 (R_2 E \cos\phi_2 \mp X_2 E \sin\phi)\end{aligned}$$

Equation 17: Percentage regulation

$$V_2 = 113 - 4.92 (1.1805 \times 0.97 + 0.5737 \times 0.24) = 106.69V$$

Equation 18: Voltage Regulation Calculation

Data recording

Slip	Torque	Speed (rpm)
2	1.856694	-3000
1.91	1.899722	-2730
1.8	1.953856	-2400
1.7	2.004350	-2100
1.6	2.055767	-1800
1.5	2.107677	-1500
1.4	2.159452	-1200
1.3	2.210191	-900
1.2	2.258616	-600
1.1	2.302911	-300
1	2.340514	0
0.8	2.379637	600
0.6	2.324802	1200
0.4	2.072981	1800
0.2	1.420428	2400
0	0.000000	3000
-0.2	-2.652347	3600
-0.4	-6.434660	4200
-0.6	-9.694099	4800
-0.8	-10.72460	5400
-0.99	-10.032282	5970

Table 23: Simulated torque and stator current data recording

R1	R2'	V1	X1+X2'	ws
35.75	44.44	214	43.28	314.156

Table 24: Induction motor values

FINAL GRADE

GENERAL COMMENTS

Instructor

56/100

PAGE 1

Text Comment. Word count is excess -5 point penalty

PAGE 2

QM

Good Structure

Report is structured exactly as stated in the assignment brief.

PAGE 3

PAGE 4

PAGE 5

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PAGE 8

Text Comment. The applied voltage does not affect the speed of the field, only the speed of the rotor.

QM

Correctly cited

Citation method conforms to Harvard standard, well done.

QM

Correctly cited

Citation method conforms to Harvard standard, well done.

PAGE 9

QM

Correctly cited

Citation method conforms to Harvard standard, well done.

QM

Correctly cited

Citation method conforms to Harvard standard, well done.

QM

Correctly cited

Citation method conforms to Harvard standard, well done.

PAGE 10

PAGE 11

QM

Correctly cited

Citation method conforms to Harvard standard, well done.

QM

Correctly cited

Citation method conforms to Harvard standard, well done.

PAGE 12

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QM

Citation Needed

Cite Source:

Please use the link below to find links to information regarding specific citation styles:
http://www.plagiarism.org/plag_article_citation_styles.html

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Text Comment. 112 is incorrect since the secondary is shorted out

PAGE 18

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QM

Use the third Person

You are referring to first or second persons (I, we, you, us etc) whereas you should use the third person thus depersonalising it.

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QM

Correct method of listing.

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

QM

Wide Range of Sources

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

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GRADING FORM: NEW CSG-RUBRIC

MASON MORGAN

56

1. ENGAGEMENT WITH LITERATURE



Engagement with an extensive range of relevant and credible literature. Consistently accurate application of referencing. (14/20)

14

2. KNOWLEDGE AND UNDERSTANDING



Knowledge is reasonably extensive. Exhibits very competent critical understanding of the well-established concepts and principles of the subject and the main methods of enquiry. Breadth and depth of knowledge. (12/20)

12

3. COGNITIVE AND INTELLECTUAL



Some critical evaluation and analysis of concepts and principles, though descriptive in parts. An emerging awareness the limits of their knowledge and ability to use evidence to support the argument though with some tendency to assert/state opinion rather than argue on the basis of reason and evidence. Mostly valid arguments and logical judgements. (10/20)

10

4. PRACTICAL APPLICATION



A very good application of a range of established methods, materials, tools and/or techniques. Very good consideration of the context of the application, with perceptive insights. Consistent, accurate and logical application of theory to practice, making appropriate links between the two. Can identify problems and propose appropriate solutions outside the context in which

12

they were first studied. Evidence of some creativity. (12/20)

5. TRANSFERABLE SKILLS



Can communicate well, confidently and consistently in a suitable medium for the audience. Work is coherent, fluent, well-structured and organised. Can work very well autonomously and/or as part of a team, with very good contribution to group activities. Demonstrates very good skills for employment requiring the exercise of personal responsibility and decision-making, with just occasional minor weakness. (13/20) Word count exceeded, penalty applied (-5)

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