

1809812

by Liam George

VERY GOOD RESEARCH AND CONSISTENT CITATIONS
WERE APPARENT. VERY GOOD KNOWLEDGE WAS
DEMONSTRATED AND CRITICAL ANALYSIS WAS
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1. Executive Summary

A good brief summary

Research was carried out into the applications of a DC machine within industry, and the different methods of control from an AC supply. The parker 512C drive was analysed and the construction and operation was described.

Using multisim, 3 different firing angle values were chosen which consisted of 120° , 100° and 80° and measurements carried out on the simulation. Calculations were made and the Average Armature voltage was compared as shown in table 4.

The firing angle was then fixed at 100° and the effects of loading the motor was simulated by varying the back EMF to three different battery voltages of 80v, 60v and 40v which showed the current wave forms altering and becoming continuous as the motor was loaded.

Using the 40v applied back EMF load, calculations were carried out and the waveform measured and the Average Armature voltage compared as shown in table 5.

A practical investigation was then carried out by using the DC motor and the Parker 512C drive as shown in section 4.5. Three different speeds were chosen of 502rpm, 1003rpm and 1500rpm. Using the Pico scope 6 software measurements were taken for t_1 and t_2 values and calculations carried out allowing the average armature voltage to be compared as shown in table 9.

The motor was then loaded by using the pony brake at 3 different loads, 0.5nm, 1.0nm and 1.5nm and the values for current and voltage taken as shown in table 10.

A medium length transmission line was simulated and calculations carried out with results shown in table 11 for comparison and table 12 showing the power loss and efficiency of the line.

2. Research

2.1 Industrial DC machine applications

Within industry DC machines are widely used in many applications due to having less inertia, providing quicker acceleration and deceleration times and constant Torque throughout the speed ranges. This is beneficial in many applications that require full torque at low speeds when an excessive load is present at start up.

For this reason DC machines are most commonly used in many applications where constant torque is needed, such as :-

- Lifts
- Elevators
- Extruders
- Mixers
- Conveyors
- Cranes
- Presses
- Feeders

Also there are many advantages within Industry to using a DC machine such as :-

- Simple Speed control
- Physically smaller in size *modern induction motors are actually smaller than DC motors*
- lower cost *induction motors are cheaper*
- Simple design *induction motors are simpler design*
- Smaller low cost drives, converters

Citation needed.

The DC machine can be Split into 2 categories which consist of separately excited and Self excited.

Separately excited is where the field is supplied separately by an external DC source to provide excitation as shown below in the circuit diagram, figure 1.

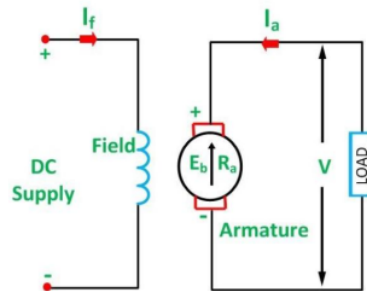


Figure 1 - Separately excited circuit (globe, 2021)

Self-excited Dc motors consist of 3 types, Series, Shunt and Compound wound motors, all of which the windings are supplied by the motor allowing self-excitation. The 3 different motors are connected in different formations as described below providing different starting and running techniques for various applications and loads.

Series wound Dc motor :- The field windings are connected in series with the armature as shown below in figure 2.

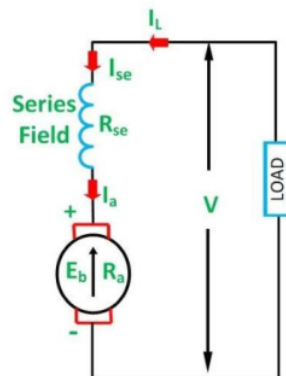


Figure 2 - Series wound circuit (globe, 2021)

The series wound Dc motor is most commonly used in applications where speed control is not necessary as regulation is inaccurate as the load limits the speed of the motor.

Shunt wound Dc motor:- The field windings are connected in parallel with the armature as shown below in figure 3.

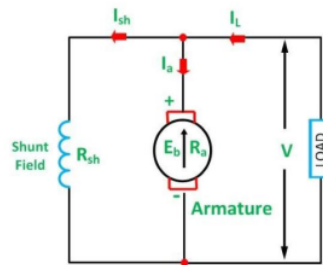


Figure 3 - Shunt wound circuit (globe, 2021)

These motors are most commonly used where speed regulation is essential due to the motors speed not being effected by the load.

Dc compound motor :- A combination of both the series and the shunt field winding formation as shown below in figure 4.

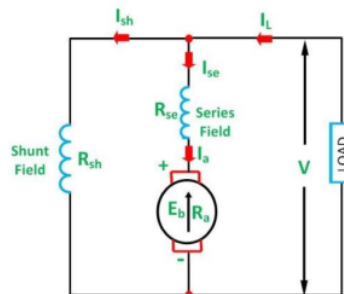


Figure 4 - Compound circuit (globe, 2021)

The Compound motor has the Characteristics of both the series and the shunt motor and is used in much larger applications where the starting torque is needed, but also will speed up or slow down depending on the load, where speed control can be carried out by the series field windings.

The compound wound motor can also be connected as cumulative, which is where both the shunt and field windings are connected together in a way that the current that flows in the windings help each other to magnetise. Opposite to this the compound motor can be connected as differential, which is where the motor is connected so that the current that flows repel each other minimizing magnetization.

(mawdsleysber, 2020)

2.2 Methods of control of DC machines from an AC supply

There are 3 methods in which a DC motor speed can be controlled :-

- Varying the voltage supply
- Varying Flux and current in the field windings
- Varying armature voltage and resistance

From an AC supply the control of a DC machine can be carried out by various different methods as described below.

Full wave bridge rectifier :- Consists of a circuit made up of 4 diodes used for rectification as shown below in figure 5, AC is supplied into the circuit and the diodes which are arranged in series pairs are switched when the AC supply is in its positive and negative half cycle, switching the pairs simultaneously. Diodes 1 and 2 are used to conduct when the AC supply is within its positive half cycle whilst 3 and 4 become reverse biased allowing current to flow through the load. This becomes opposite once the AC supply is in the negative half cycle, which allows 3 and 4 to conduct and 1 and 2 become reverse biased. The DC output can also be smoothed by adding a smoothing capacitor across the load as shown below in figure 6. The speed of the DC motor can be controlled using a phase controller which is adjusted using a potentiometer or rheostat, which alters the firing of the device changing the waveform and voltage supplied to the motor, thus speeding the motor up or down.

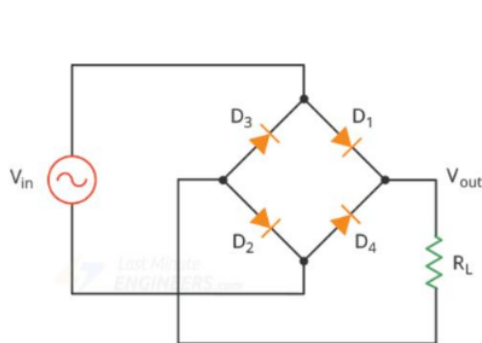


Figure 5 - Full wave bridge rectifier circuit

(engineers, 2019)

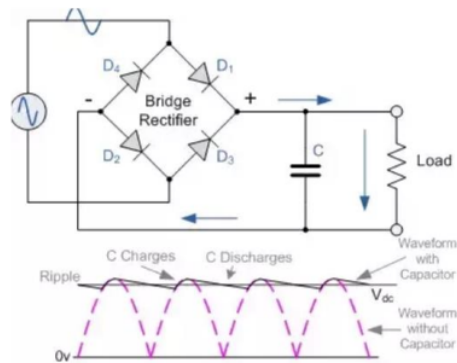


Figure 6 - Added smoothing capacitor

(quora, 2019)

*how would it be controlled as diodes give a fixed voltage output
you should have considered a thyristor drive*

PWM – Pulse width Modulation is carried out the same way as phase control by using a full bridge rectifier to convert the AC supply into a DC output as shown below in figure 7. but instead of switching the diodes for control it uses digital signals from a control circuit as shown in figure 8 which uses a series of periodic pulses controlled by a timer which switches the dc supply on and off to the motor whilst the frequency remains constant. This process creates a square wave, which when the switch is on, the pulse width is longer allowing the motor to speed up and once the switch is off the motor will slow down. The speed of the motor is controlled by the amount of time the switch is on which varies the pulse widths supplying the motor.

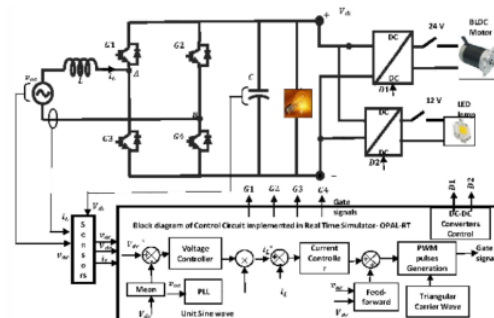


Figure 7 - PWM Circuit

(Rakesh, 2016)

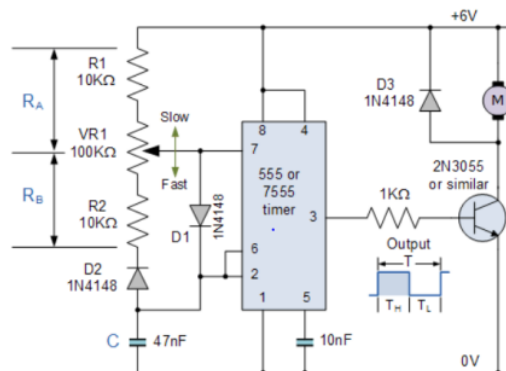


Figure 8 - PWM Digital control circuit

(electronics-tutorial, 2019)

H Bridge – The H bridge Dc motor controller is made up of 4 switches in a H formation as shown in figure 9, this circuit uses a series of paired switches to control the motor to its required specification. This is known as a 4 quadrant which allows the motor rotation to be switched and sped up or slowdown using regenerative braking depending on the switch formation as shown in figure 10. Also in figure 11 shows the magnitude of the motor and supply in each quadrant.

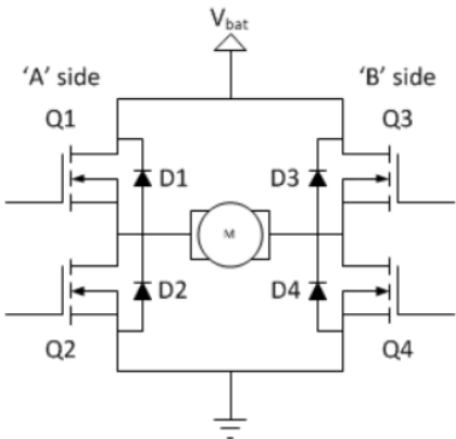


Figure 9 - H bridge circuit

(modularcircuits, 2019)

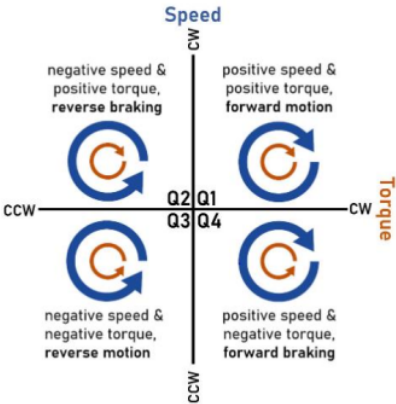


Figure 10 - 4 Quadrant diagram

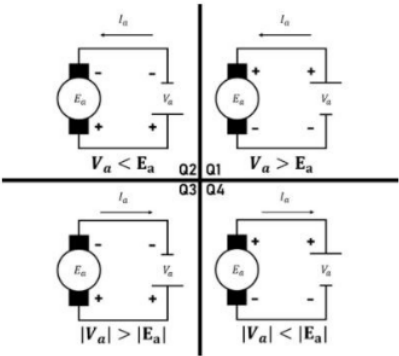


Figure 11 - Magnitude in each quadrant

(Cavallo, 2019)

your earlier research was supposed to be linked to the Parker drive with a half controlled full wave controlled thyristor rectifier

2.3 Construction and operation of the Parker 512C single quadrant DC drive

The construction block diagram of the Parker 512C single quadrant DC drive is shown in appendix 9.1.

In figure 12 below, the right hand side of the Isolation boundary consists of :-

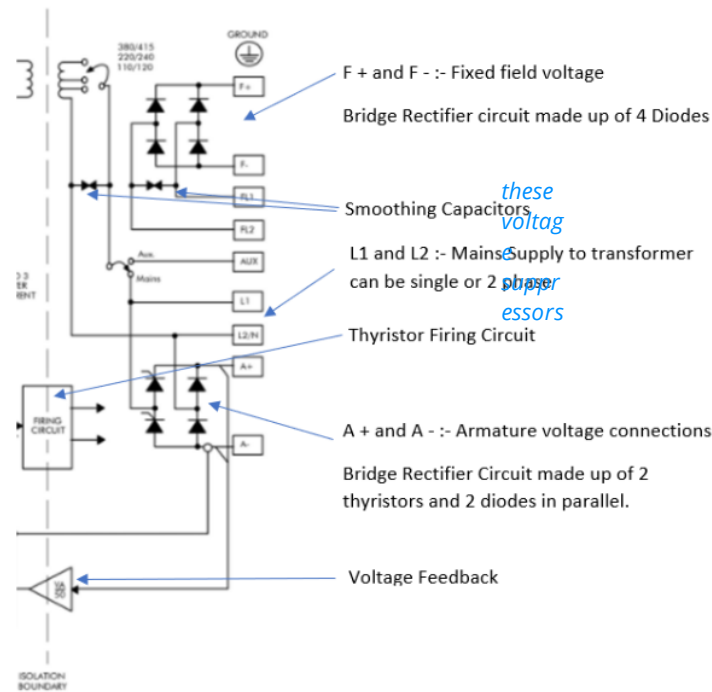


Figure 12- Parker 512C drive

(Parker, 2016)

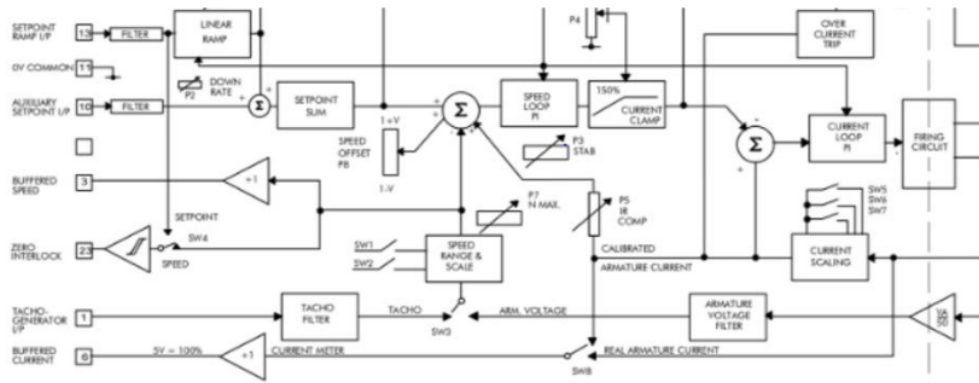
The Bridge rectifiers are used within the circuits to provide full rectification and ensure a positive waveform is produced. (electronic, 2019)

The smoothing capacitors provide a more constant voltage by smoothing out the DC voltage. *where are the capacitors?*

Thyristors are used within the Armature circuit to control the speed of the motor, which is determined by the Thyristor firing circuit controlling the firing angles.

The Voltage feedback from A + and A – provides feedback into the Armature voltage filter which cleans it up.

On the left hand side of the boundary isolation line the main components which are used within the speed control process and feedback are shown below in figure 13.



The feedback from A+ and A- is fed into the isolation amplifier and passed into the armature voltage filter which is used to clean the signal up before stopping at the selector switch, which allows the signal to be switched between tacho feedback, terminal 1 or armature voltage feedback for the speed range and scale block.

The current is fed back as a current loop PI controller which is the inner loop to the Thyristor firing circuit and back into a current scaling block before being feedback to the summing block on the right hand side, or into the P5 IR compensation which would feed the current back into the speed outer loop which is added to the voltage of the armature voltage feedback. This allows the drive to run without tacho feedback when the switch is switched over to armature voltage feedback which allows the drive to sense the motor is being overloaded, as the back EMF drops the current rises allowing the drive to sense the drop and input more positive feedback which increases the voltage fed into the motor and increase the speed simultaneously.

Results should have been summarized in a table and the waveforms should be in the appendix

3. Simulation of a Half-Controlled Rectifier Circuit

Using Multisim, a single-phase, full-wave, half-controlled rectifier connected to a DC motor armature modelled as a load containing an inductance, a resistance and a battery (used for back EMF), was created as shown below in figure 14.

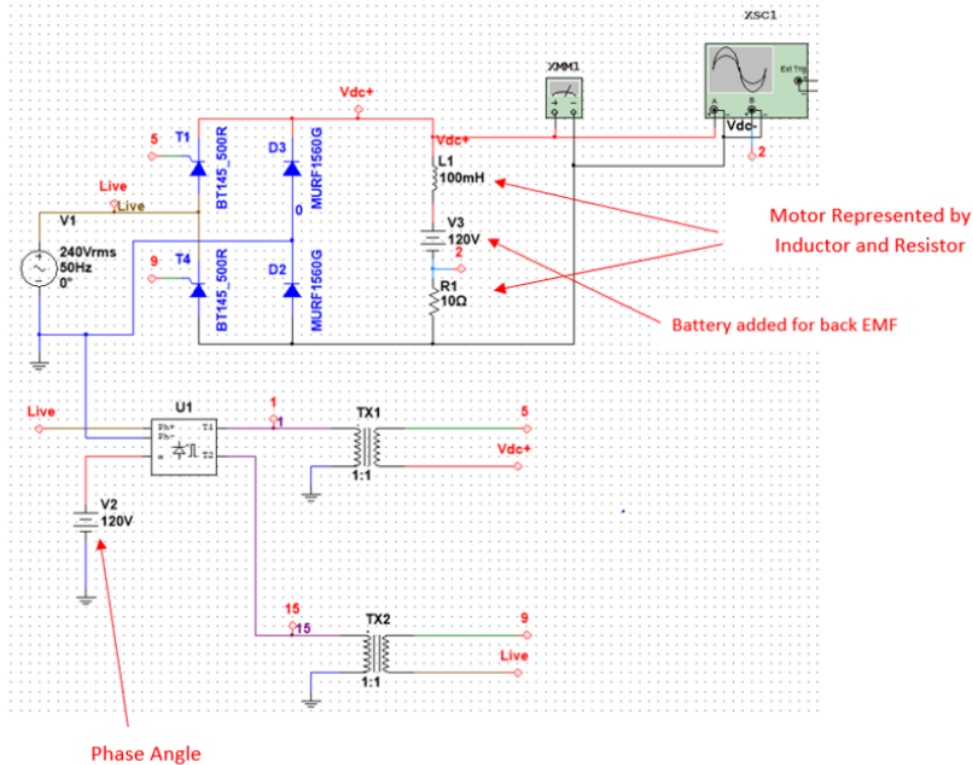


Figure 14 - Single-phase, full-wave, half-controlled rectifier circuit

Using the Multisim simulation as shown above, by changing the Phase Angle controller α input, the firing angle can be altered. By choosing three different firing angles with an Input of 120° , 100° and 80° values are measured on multisim and calculations carried out.

The Vpk value was measured on multisim by reducing the phase angle to 20° and using the cursor as shown in Appendix 9.2 the Vpk value = 337.2V.

Also the value for back EMF voltage can be found as shown in Appendix 9.3 which shows the value for $E = 120V$.

The Half period value can also be simulated and measured as shown in Appendix 9.4 which shows the simulated Half period value = 10.00ms.

3.1 Phase Firing Angles

3.1.1 120° Phase Angle

120° is inputted into the Phase angle controller and measurements taken as shown below in figure 15 and 16 with calculations carried out in Appendix 9.5.

T1 is measured by placing cursor 1 and cursor at the selected points as shown below in figure 15, which shows $T1 = 718.232 \mu\text{s}$ or .718ms.

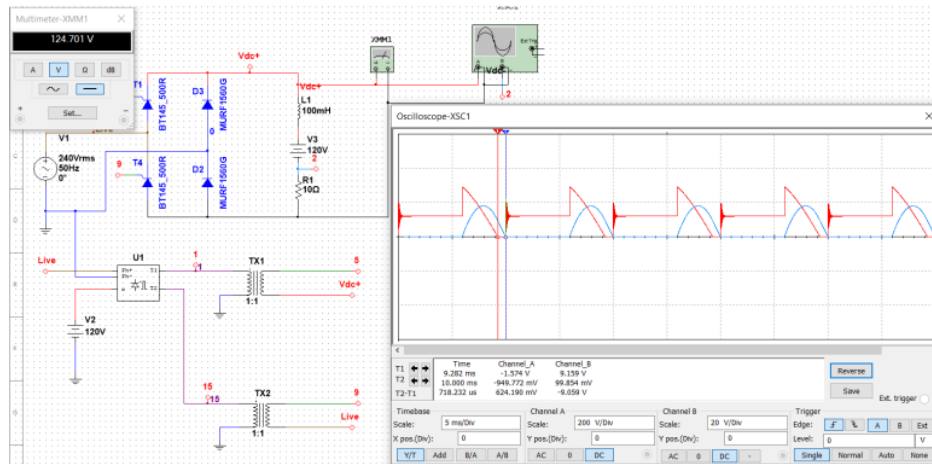


Figure 15 - 120 deg T1 measurement

T2 is measured by repositioning cursor 2 at the point where the Thyristor switching takes place and the firing angle is produced which shows the time delay as shown below in figure 16 with a value for $T2 = 6.685 \text{ ms}$.

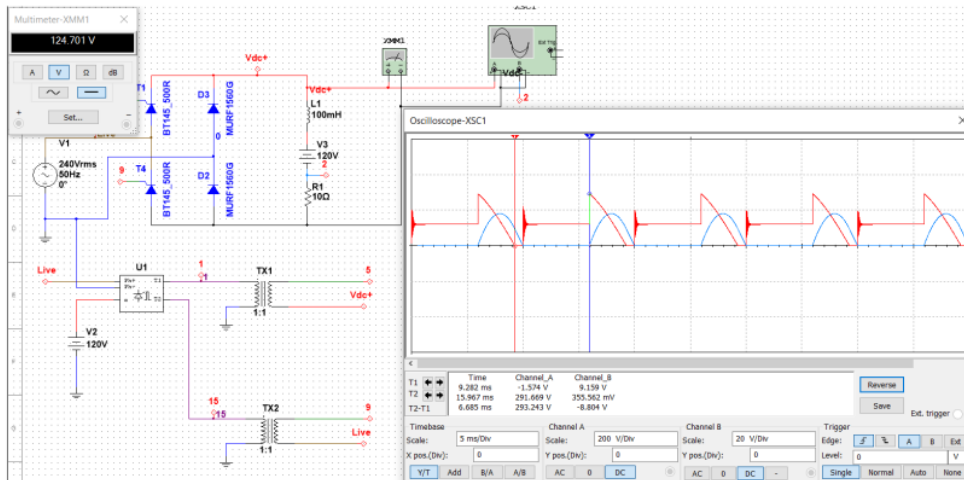


Figure 16 - 120 deg T2 measurement

As shown above in the Simulations for 120° phase angle the average armature voltage, $AV = 124.701V$.

Calculations using the Measured Simulated values were carried out in Appendix 9.5 and a comparison table showing calculated and simulated values shown below in table 1.

120v Phase Angle Comparison			
	Simulated	Calculated	Difference
t1 (ms)	0.718		
t2 (ms)	6.685		
V Pk (V)	337.2		
β (rad)		0.23	
α (rad)		2.1	
V av (V)	124.701	124.6	0.101

Table 1 - 120 deg comparison table

3.1.2 100° Phase angle

100° is inputted into the Phase angle controller and measurements taken as shown below in figure 17 to 18 with calculations carried out in Appendix 9.6.

T1 is measured by placing cursor 1 and cursor at the selected points as shown below in figure 17, which shows T1 = 1.768ms

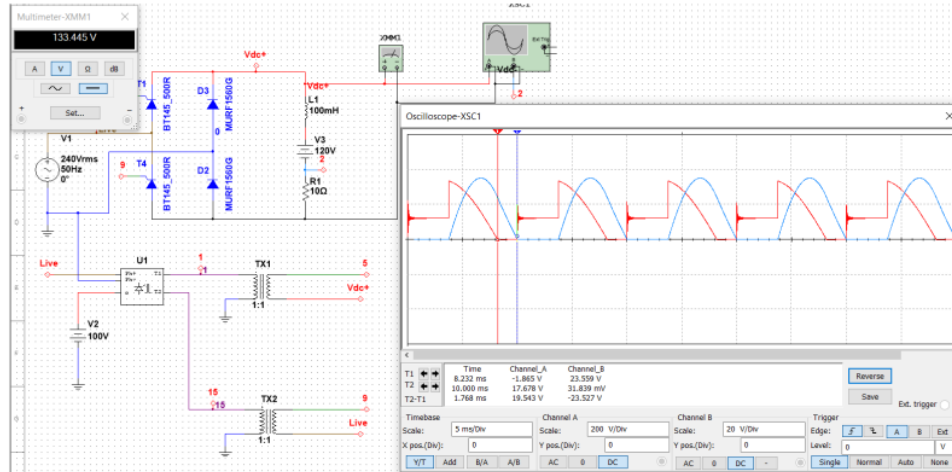


Figure 17 - 100 deg T1 measurement

T2 is measured by repositioning cursor 2 at the point where the Thyristor switching takes place and the firing angle is produced which shows the time delay as shown below in figure 18, with a value for T2 = 5.53 ms.

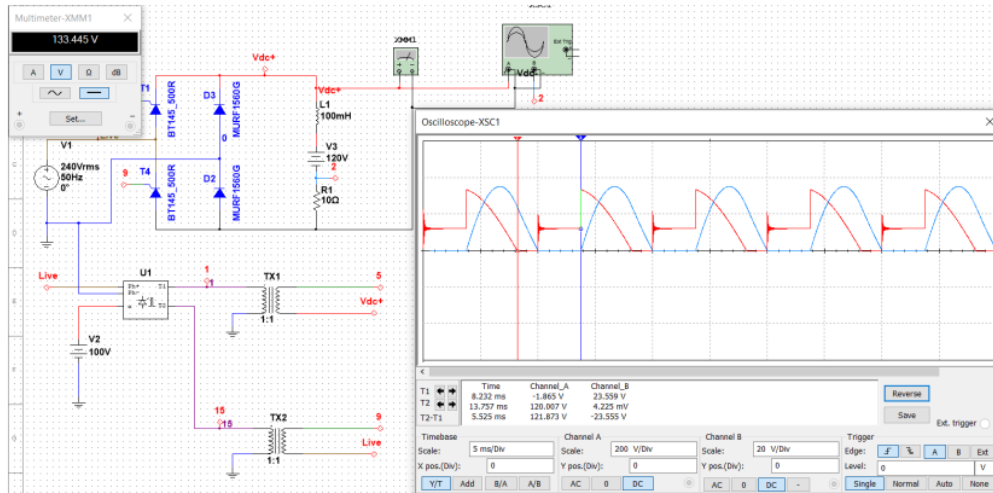


Figure 18 - 100 deg T2 measurement

As shown above in the Simulations for 100° phase angle the average armature voltage, $AV = 133.445V$.

Calculations using the Measured Simulated values were carried out in Appendix 9.6 and a comparison table showing calculated and simulated values shown below in table 2.

100° Phase Angle Comparison			
	Simulated	Calculated	Difference
t1 (ms)	1.77		
t2 (ms)	5.53		
V Pk (V)	337.2		
β (rad)		0.56	
α (rad)		1.74	
V av (V)	133.445	134.3	0.855

Table 2 - 100 deg comparison table

3.1.3 80° Phase angle

80° is inputted into the Phase angle controller and measurements taken as shown below in figure 19 to 20 with calculations carried out in Appendix 9.7

T1 is measured by placing cursor 1 and cursor at the selected points as shown below in figure 19 which shows T1 = 2.71ms

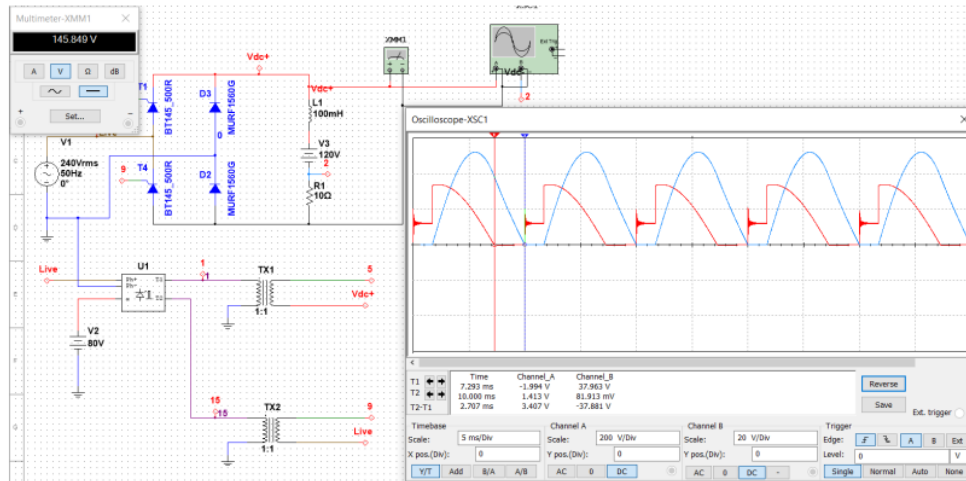


Figure 19 - 80 deg T1 measurement

T2 is measured by repositioning cursor 2 at the point where the Thyristor switching takes place and the firing angle is produced which shows the time delay as shown below in figure 20 with a value for T2 = 4.42 ms.

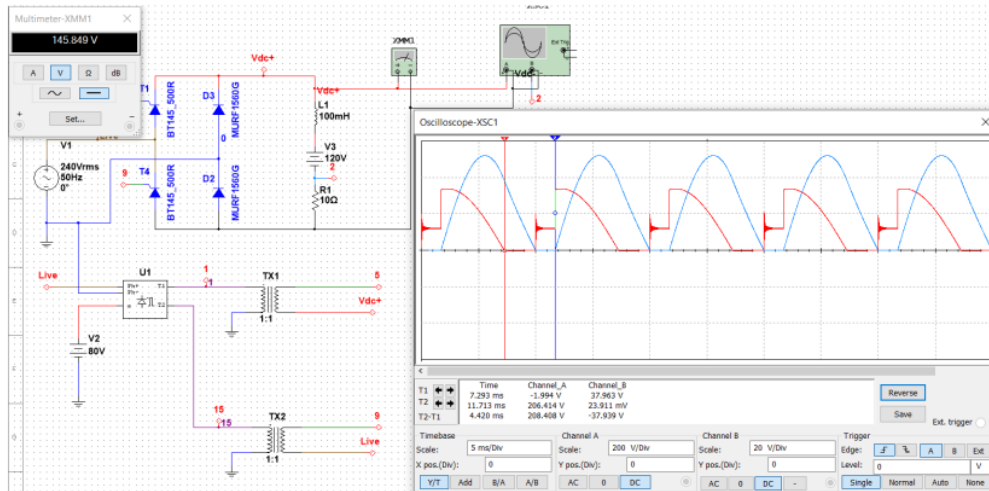


Figure 20 - 80 deg T2 measurement

As shown above in the Simulations for 80° phase angle the average armature voltage, AV= 145.849V.

Calculations using the Measured Simulated values were carried out in Appendix 9.7 and a comparison table showing calculated and simulated values shown below in table 3.

80° Phase Angle Comparison			
	Simulated	Calculated	Difference
t1 (ms)	2.71		
t2 (ms)	4.42		
V Pk (V)	337.2		
β (rad)		0.85	
α (rad)		1.39	
V av (V)	145.849	147.26	1.411

Table 3 - 80 deg comparison table

From the 3 tests carried out above it can be seen in table 4 below that there are minor discrepancies between the calculated and simulated values with the difference rising as the firing angle decreases.

Average armature voltage comparison table			
Phase angle	Simulated	Calculated	Difference
120 (deg)	124.701v	124.6v	0.101v
100 (deg)	133.445v	134.3v	0.855v
80 (deg)	145.849v	147.26v	1.411v

Table 4 - Average armature voltage comparison table

3.2 Mechanical loading (Varying EMF)

Using the fixed Phase Firing angle of 100 degrees on the multisim circuit, section 3.2 requires the back EMF to be varied by altering the battery voltage which simulates the effect of mechanical loading the motor.

Three different values have been chosen to show continuous current are 80v, 60v and 40v and simulations shown below in figures 21, 22 and 23.

3.2.1 80v back EMF

In figure 21 below an 80v back EMF has been applied and the blue waveform shows that the current is discontinuous.

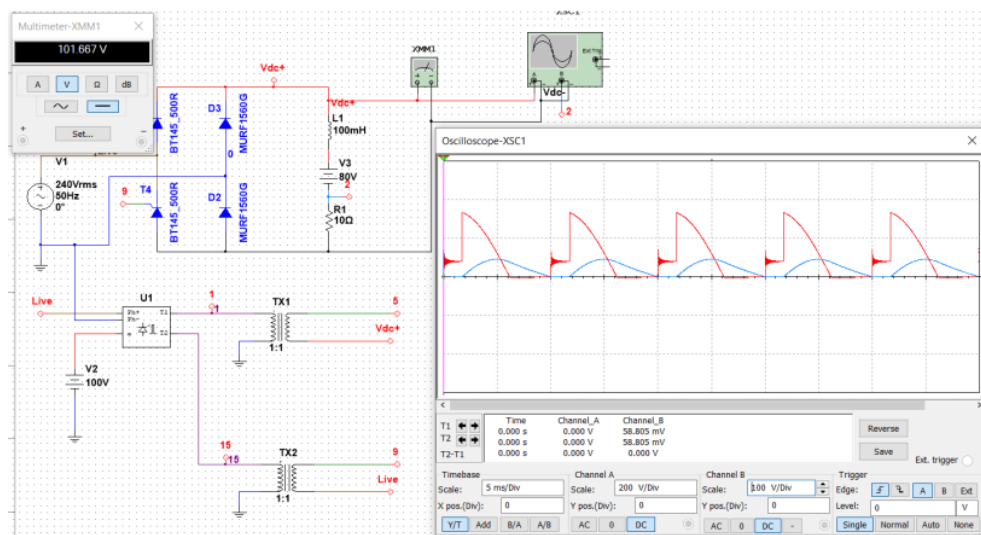


Figure 21 - 80v back EMF

3.2.2 60v back EMF

A 60v back emf is applied to the circuit and the waveforms show that the back emf has reduced significantly and the current shown in blue is nearly continuous as shown in figure 22 below.

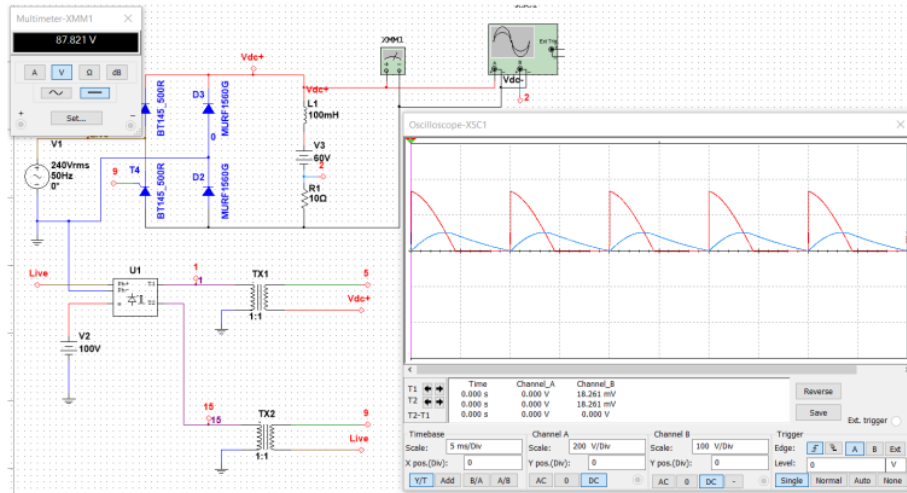


Figure 22 - 60v back EMF

3.2.3 40v back EMF

As shown in figure 23 below a 40v back EMF has been applied and you can see that the current shown in blue is continuous and doesn't reach zero, which produces a ripple waveform.

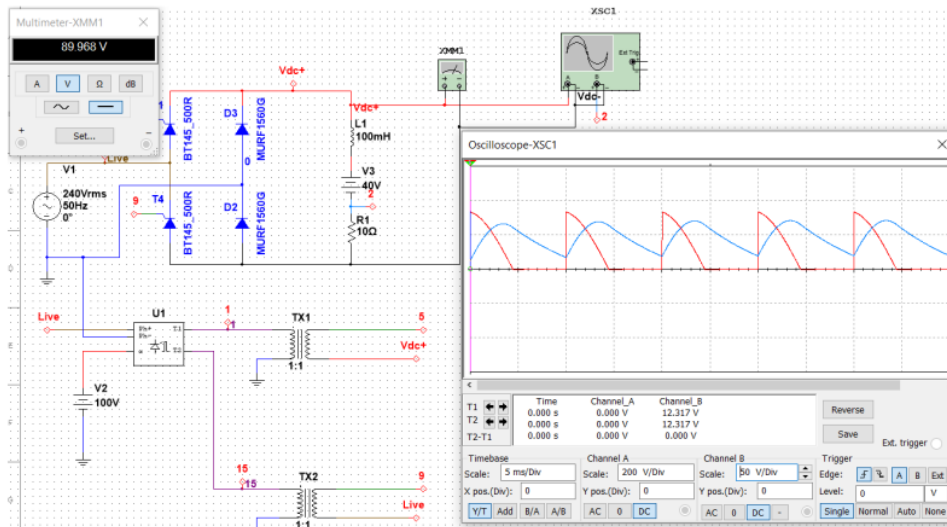


Figure 23 - 40v back EMF

3.2.4 40v back EMF Av calculations

Using the continuous current example which uses the 40v applied back emf, calculations were made as shown in Appendix 9.8 to find the Average armature voltage.

T2 is measured as shown below in figure 24 which shows $t_2 = 5.514$.

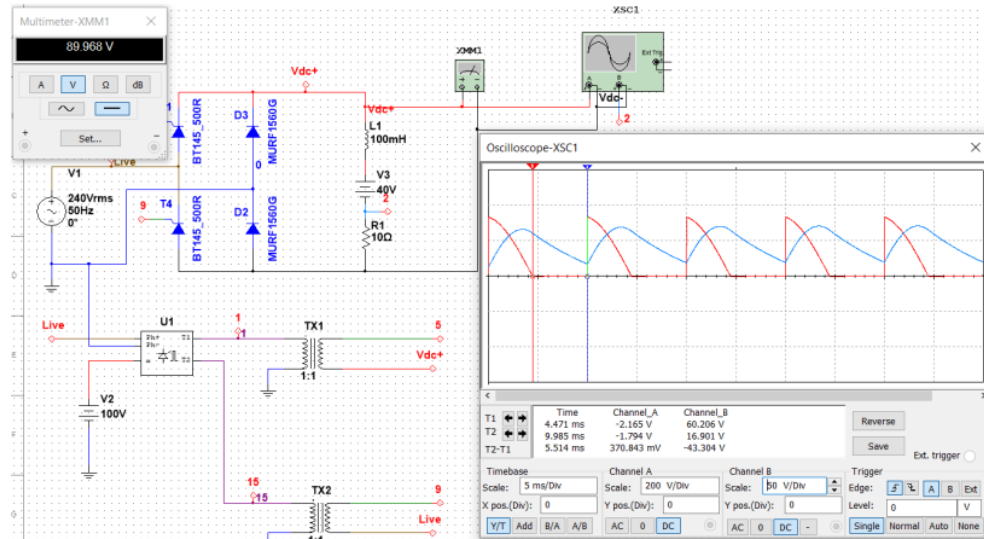


Figure 24 - 40v back emf T2 measurement

Calculations were carried out in appendix 9.8 using the measured simulated values above and recorded in a comparison table 5 below.

40v back emf, Continuous current comparison			
	Simulated	Calculated	Difference
t2 (ms)	5.514		
V Pk (V)	337.2		
α (rad)		1.71	
V av (V)	89.968	90.31	0.342

Table 5 - 40v back emf comparison table

It can be seen in table 5 above that there is very little difference between the simulated average voltage and the calculated average voltage which confirms the calculations are correct.

3.3 Simulation Circuit Explanation

From the simulation circuit shown below in figure 25 it can be seen that a circuit has been constructed to model the Parker 512C drive with added components to represent the motor which consists of a 100mH inductor, 120V battery which simulates added back Emf and a 10 Ohm resistor. It can be seen that there is a 240V ac supply which is fed into the bridge rectifier which is made up of 2 diodes and 2 Thyristors.

The 2 Thyristors within the bridge rectifier are switched by using the phase angle controller, which controls speed and the torque by the set firing angle.

The 2 diodes act as commutating diodes which block Negative voltage feedback, which allow the thyristors to switch on and off due to the commutating loop.

The Phase angle input is represented by a supply into the Phase angle controller which controls the thyristor pulses by producing pulses on 1 phase and 1 on the other phase. This is isolated from the circuit by using the Isolating transformers and connected at point 5 and 9 as shown below in figure 25.

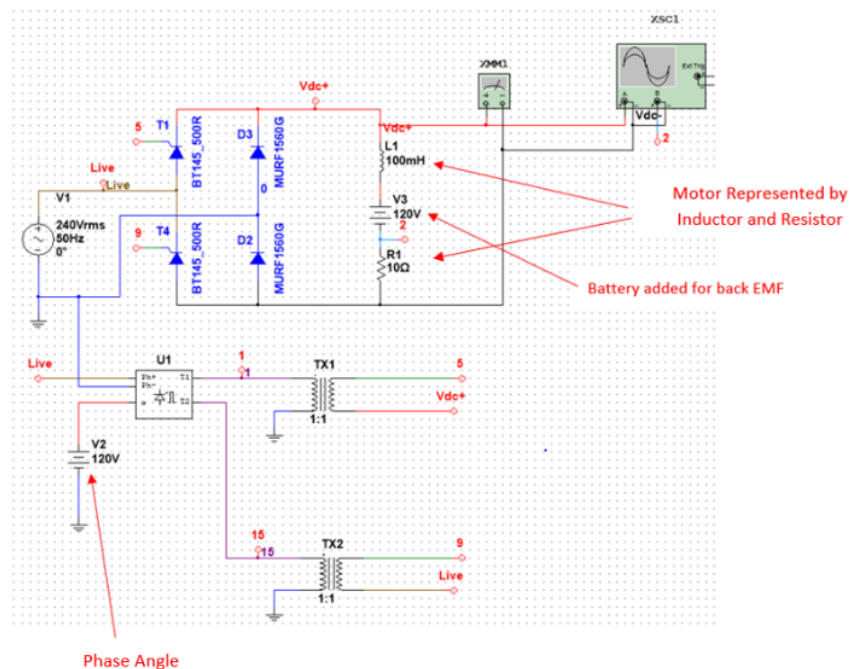


Figure 25 - Multisim Simulated half controlled rectifier circuit

4. Practical Investigation into a Single Quadrant DC drive

A Parker 512C DC drive was connected to a DC motor, pony brake and measuring equipment as shown below in section 4.5.

The motor was energised and armature voltage and current waveforms were recorded using three different speed set-points under no-load conditions as shown below.

The Vpk max measured value shown on figure 26 below.

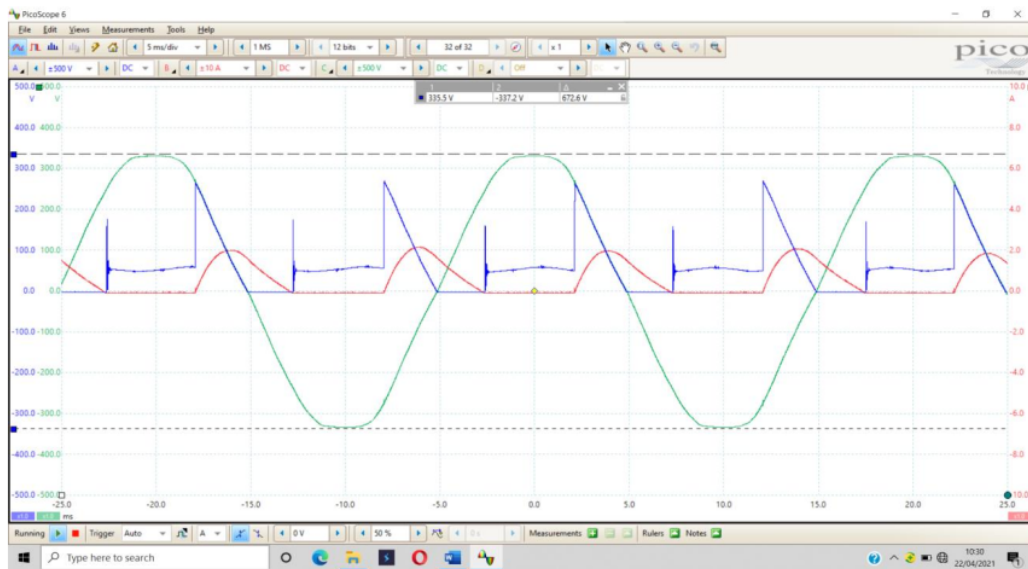


Figure 26 - Vpk measured value

$$V Pk = \frac{672.6}{2}$$

$$V Pk = 336.3 V$$

4.1 502 rpm speed setpoint

From the waveform shown in figure 27 below t_1 is measured using cursors at the selected points which shows $t_1 = 1.76$ ms.

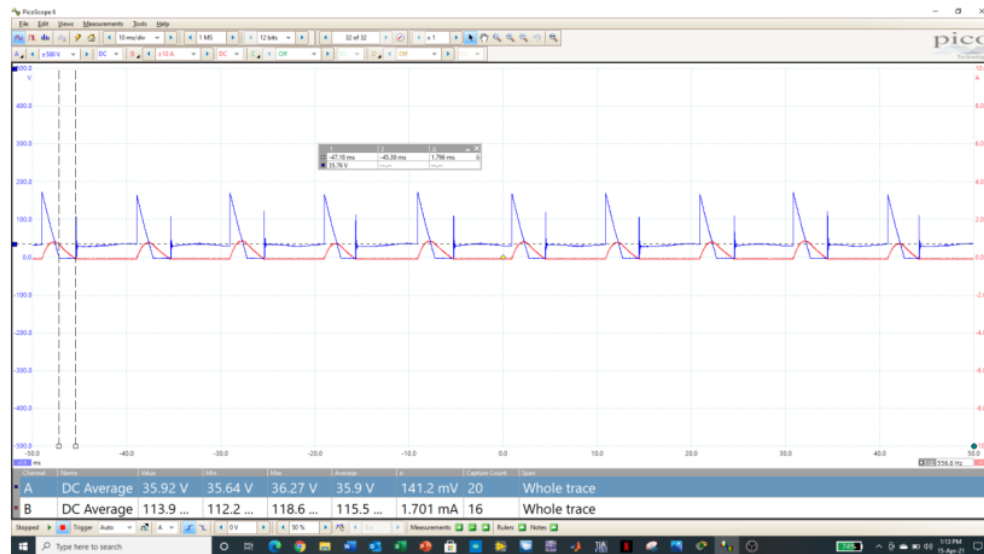


Figure 27 - 502 rpm T_1 measurement

T_2 is measured by positioning the cursor at the points shown in figure 28 below, which shows $T_2 = 8.218$ ms

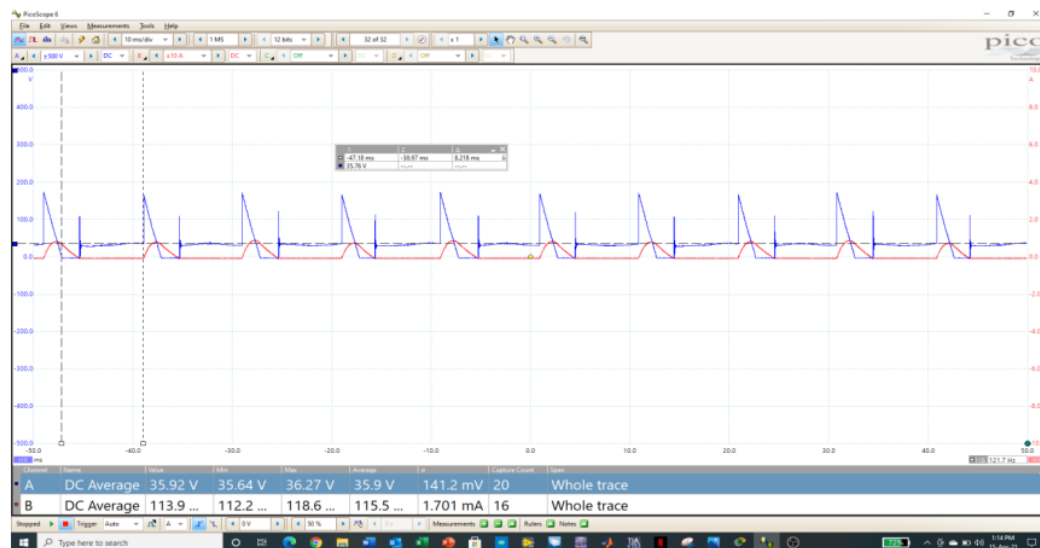


Figure 28 - 502 rpm T_2 measurement

As shown above in figures 27 and 28 with the speed set to 502rpm the average armature voltage is $AV = 35.9V$.

Calculations using the measured t_1 and t_2 values were carried out in appendix 9.9 and shown in the comparison table 6 below.

Speed setpoint Av comparison table			
	Simulated	Calculated	Difference
502 rpm	35.9v	39.55v	3.65v

Table 6 - 502rpm Av comparison table

4.2 1003 rpm speed setpoint

From the waveform shown in figure 29 below t_1 is measured using cursors at the selected points which shows $t_1 = 816.3 \mu\text{s}$ or .816ms.

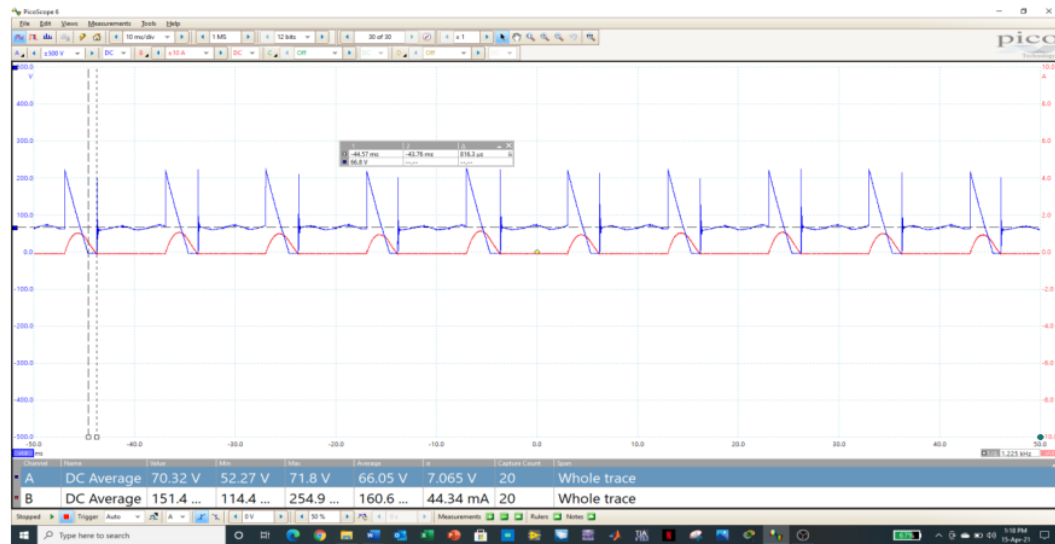


Figure 29 - 1003 rpm T_1 measurement

T_2 is measured by positioning the cursor at the points shown in figure 30 below which shows $T_2 = 7.619\text{ms}$.

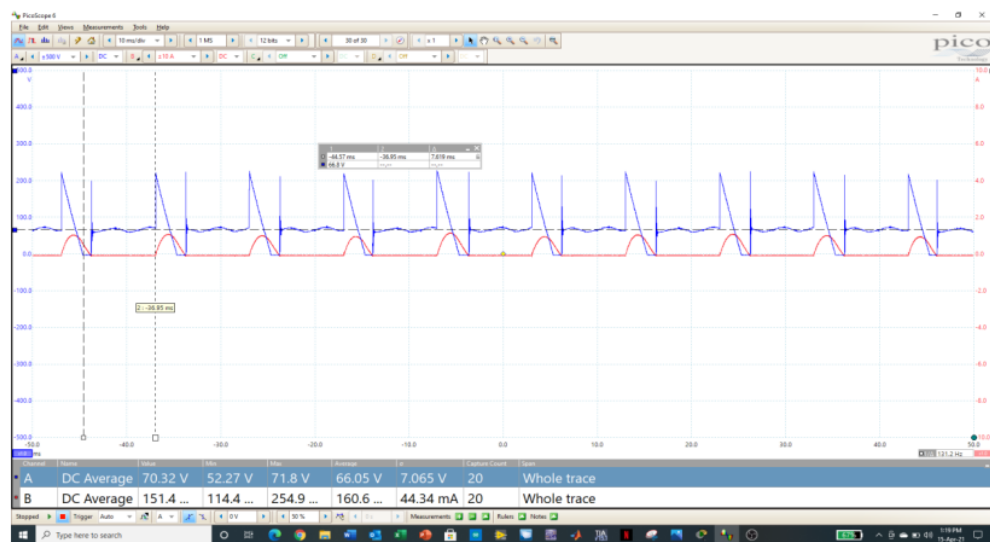


Figure 30 - 1003 rpm T_2 measurement

As shown above in figures 29 and 30 with the speed set to 1003 rpm the average armature voltage increases to $AV = 66.05V$.

Calculations using the measured t_1 and t_2 values were carried out in appendix 10 and shown in the comparison table 7 below.

Results should be closer than this

Speed setpoint Av comparison table			
	Simulated	Calculated	Difference
1003 rpm	66.05v	74.13v	8.08v

Table 7 - 1003 rpm Av comparison table

4.3 1500rpm speed setpoint

From the waveform shown in figure 31 below t_1 is measured using cursors at the selected points which shows $t_1 = 756.8 \mu\text{s}$ or .756ms.

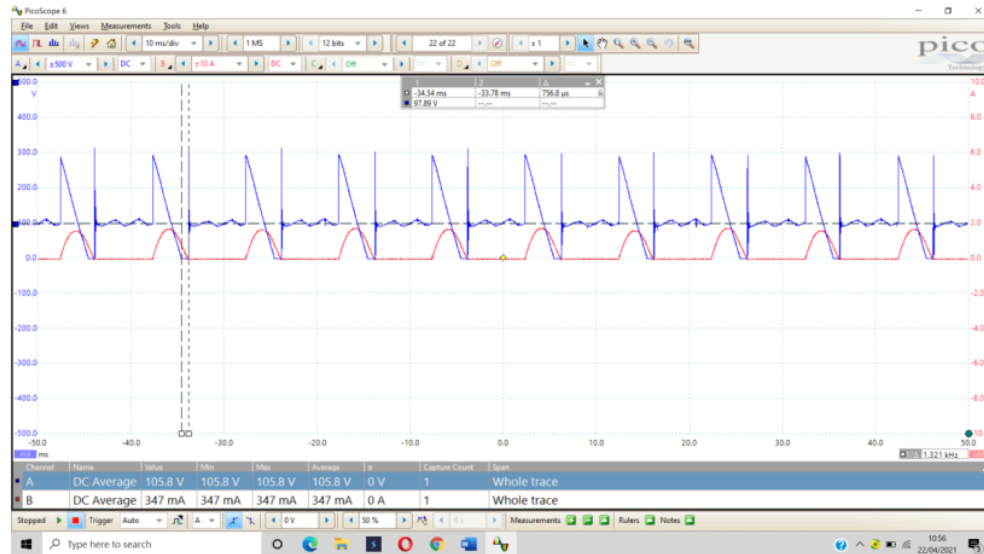


Figure 31 - 1500 rpm T_1 measurement

T_2 is measured by positioning the cursor at the points shown in figure 32 below which shows $T_2 = 6.88 \text{ ms}$.

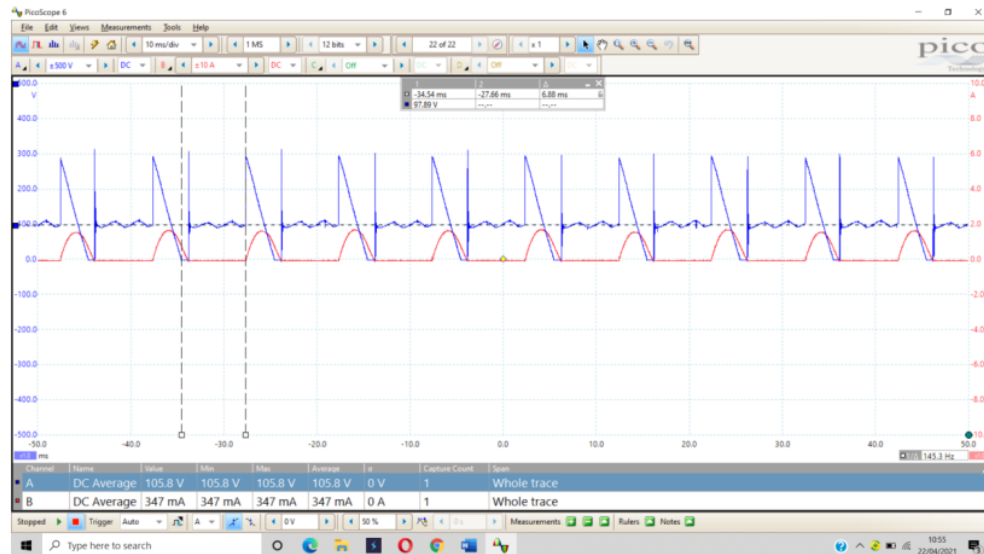


Figure 32 - 1500rpm T_2 measurement

As shown above in figures 31 and 32 with the speed set to 1500rpm the average armature voltage increases to $AV = 105.8v$.

Calculations using the measured t_1 and t_2 values were carried out in appendix 10.1 and shown in the comparison table 8 below.

Speed setpoints Av comparison table			
	Simulated	Calculated	Difference
1500 rpm	105.8v	107.39v	1.59v

Table 8 - 1500 rpm Av comparison table

In table 9 below shows the measured and calculated armature voltage and the difference between both. Which shows that as the speed increases the average armature voltage increases.

Comparison table			
Speed (rpm)	502	1003	1500
V max (V)	336.3	336.3	336.3
E	35.76	66.8	97.89
t_1 (ms)	1.76	.816	.756
t_2 (ms)	8.218	7.619	6.88
B (rads)	0.55	0.26	0.24
α (rads)	2.58	2.39	2.16
V aV (V) measured	35.9	66.05	105.8
V av (V) Calculated	39.55	74.13	107.39
Difference	3.65	8.08	1.59

Table 9 – 3 Speed set points comparison table

Between the measured and calculated there is a significant difference between them with the most being 8.08V at 1003 rpm, 3.65v at 502 rpm and 1.59v at 1500rpm as shown in table 9 above. This could be down to Human error or rounding errors.

4.4 mechanical loading effects

The motor was set to a speed of 1003 rpm and as shown below from figure 33 to 35 three different mechanical loads were applied and armature current waveforms taken.

A load of 0.5nm is applied to the motor by applying pressure on the pony brake and the graph shown below in figure 33 which shows a peak current of 1.193A at a voltage of 77V

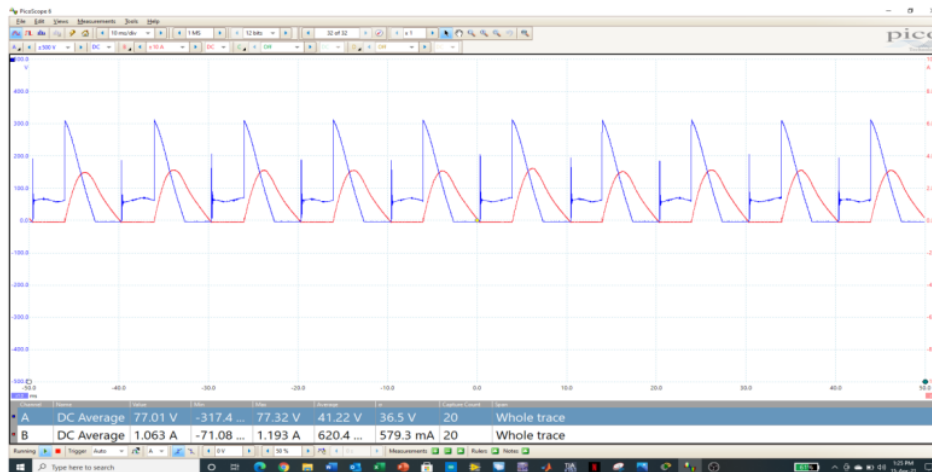


Figure 33 - 0.5 nm load waveform

A load of 1.0nm is applied as shown in figure 34 below which shows the peak current at 2.1A and the voltage at 82.46V

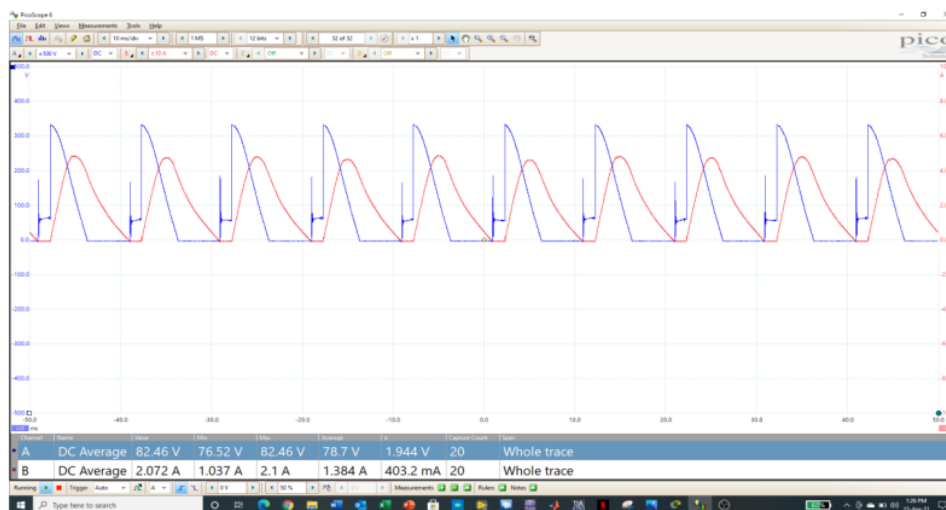


Figure 34 - 1.0 nm load waveform

A load of 1.5nm is applied as shown in figure 35 below which shows the peak current at 3.556A and the voltage at 88.8V.

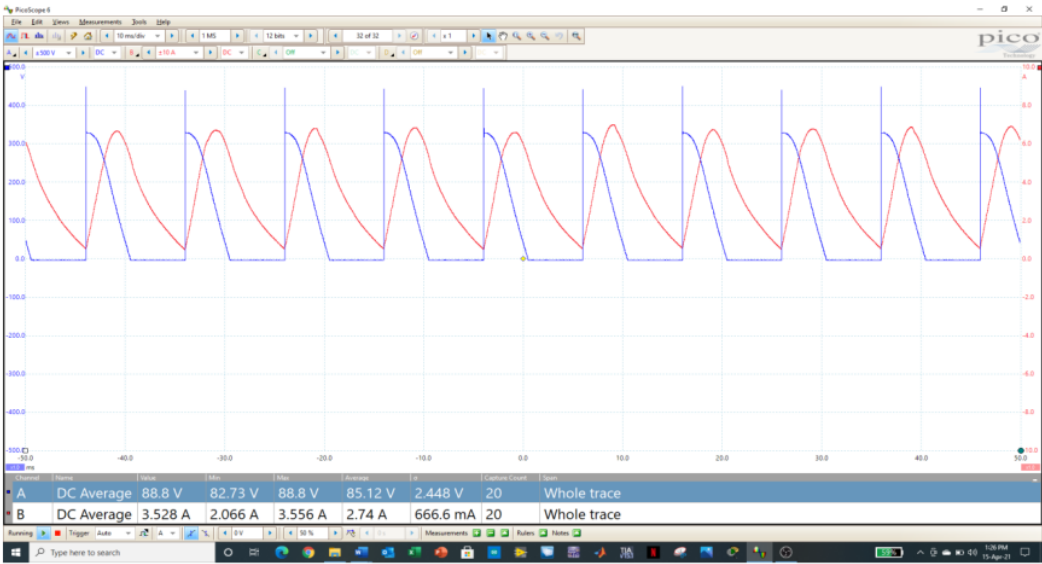


Figure 35 - 1.5nm load waveform

Shown in table 10 below are the current pk value and the voltage comparisons over the three applied loads.

Load Comparison table			
Load applied (nm)	0.5	1.0	1.5
Current Pk value (Amps)	1.193	2.1	3.556
Voltage (V)	77	82.46	88.8

Table 10 - Load Comparison table

As table 10 and figures 33 to 35 shows above, the current at 0.5nm is dis-continuous and as the load increases to 1.0nm the current period minimises but is still dis-continuous. When increased to 1.5 nm load it can be seen that the voltage rises to maintain the speed and the current becomes continuous.

4.5 Practical experiment explanation

The practical experiment was carried out using the parker 512C drive as shown in figure 36 below, connected to a DC motor as shown in figure 37 below.

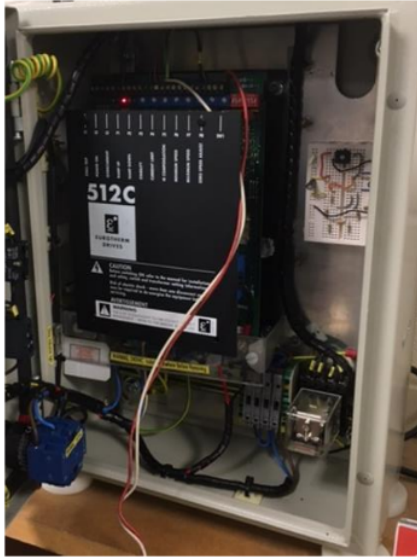


Figure 36 - Parker 512C drive



Figure 37 - DC motor set up

Pico scope measuring equipment was used to monitor the process and provide voltage and current measurements waveforms using pico scope 6 software installed on the laptop. A clip on ammeter was used to measure current and a pico scope attachment to measure voltage fed back into the pico scope control box as shown in figure 38 below. Also to measure speed a non contact tachometer was used as shown below in figure 38.



Figure 38 - Pico scope measuring components

The experiment was carried out following all Covid 19 restrictions whilst working as a team to obtain the results needed. Masks were worn and a 2 meter distance between team members was kept at all times. All safety measures were in place and safety gear such as safety glasses worn at all times.

The experiment was carried out throughout the 3 different speeds and measurements were taken from the pico scope 6 software, measuring t_1 and t_2 from the waveforms.

The Motor was then loaded at 3 different applied loads using the Pony brake as shown below in figure 39 and results measured from the waveforms to show the effects of loading the motor and the characteristics of the drives control.

Once finished the motor and measuring equipment was disconnected and wiped down adhering to covid 19 restrictions.

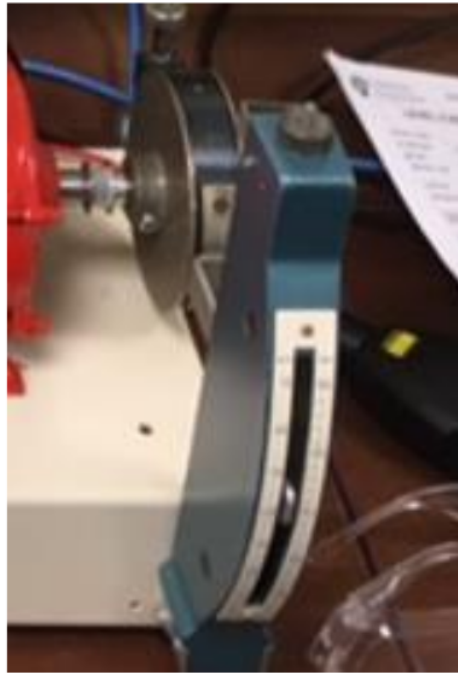


Figure 39 - Pony Brake

5. Simulation of a Medium Length Transmission Line

A single phase 50Hz transmission line with the line constants shown below has been created on multisim with a load impedance of $250 + j130\Omega$ as shown in figure 40.

Resistance = 21Ω Inductance = 177mH Capacitance = $1.4\mu\text{F}$

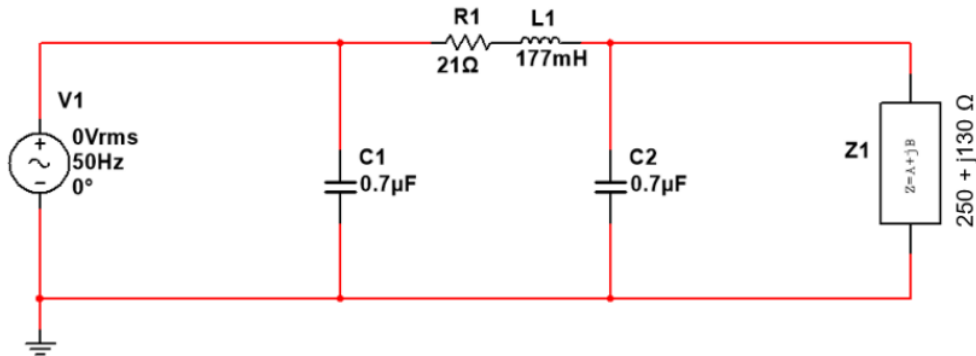


Figure 40 - Multisim Transmission line circuit

As shown in Appendix 10.2 the series impedance and shunt admittance have been calculated.

The sending end voltage, current and power factor has also been calculated as shown in Appendix 10.2 with the load at the receiving end being 293.124A at 82.596KV and a power factor of 0.88722 lagging. A Phasor Diagram produced as shown in figure 41 below.

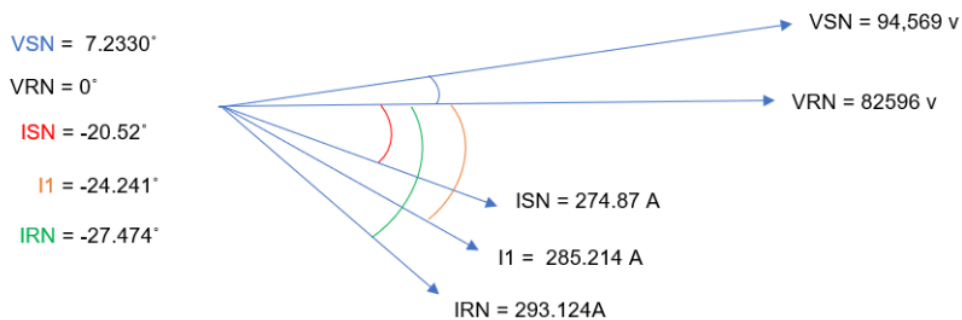


Figure 41 - Phasor Diagram

Using the calculations in Appendix 10.2 a single phase AC source with the VSN voltage of 95.327KV has been added to take measurements on multisim to prove the calculations as shown below in figure 42.

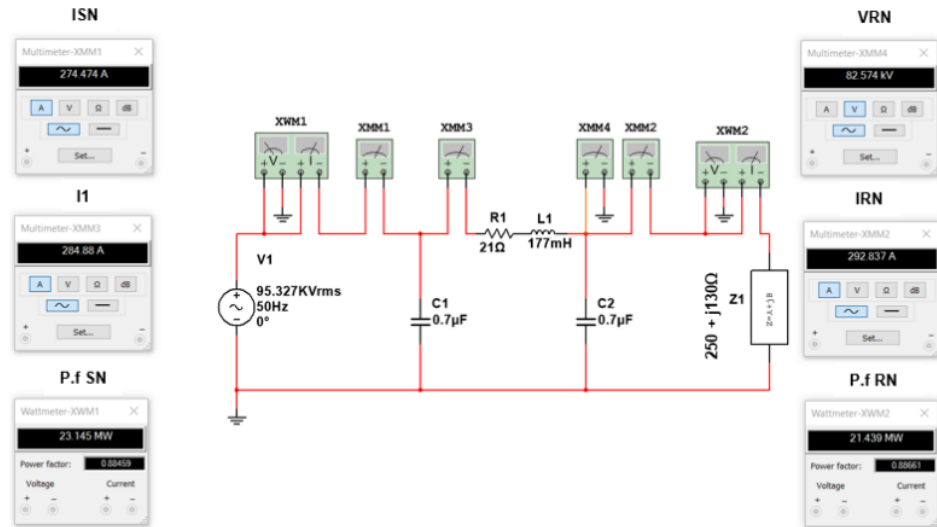


Figure 42 - Multisim Circuit with measured values

A table with simulated values and calculated values shown below in table 11.

Transmission line Comparison table			
	Calculated	Measured	Differences
VSN (V)	95327.385		
VRN (V)	82.596	82.574	0.022
IRN (A)	293.124	292.837	0.287
I1 (A)	285.214	284.88	0.334
ISN (A)	274.87	274.474	0.396
P.f SN	0.885	0.885	0
P.f RN	0.88722	0.88661	0.61

Table 11 - Transmission line comparison table

As shown in figure 42 above, the Power on the sending and receiving end can be seen in XWM1 and XWM2 watt meters, which allows us to work out the power loss and efficiency of the transmission line as shown in table 12 below.

Power Loss			
	Sending end	Receiving end	Differences
Power (Mw)	23.145	21.439	1.706

Table 12 - Power loss table

6. Conclusion and Recommendations

Section 3 consisted of simulating a half controlled rectifier circuit on multisim and analysing the performance. Firstly 3 different firing angles were chosen and waveforms analysed, simulated results and calculated results are shown in table 4 which shows that as the firing angle decreases the voltage increases. The comparison table shows very minor discrepancies between the simulated and calculated value which seems that as the phase angle reduces the difference between the simulated and calculated values increase around 0.5 volts per 20 degrees.

The firing angle was then set to 100 degrees and the battery voltage was changed from 80v to 60v then 40v and the waveforms were analysed which shows that as the back EMF was decreased the loading is increased and the current becomes continuous producing a ripple waveform.

The 40v back EMF was applied and calculations carried out and the average voltage compared with simulated, which as shown in table 5 the difference between the simulated and the calculated is minimal.

The Practical investigation was carried out on three different speeds and measurements taken on the pico 6 software and calculations carried out. As shown in table 9 the simulated results and calculated values were compared and there is a significant difference between the both average voltages with the most being at 1003rpm with a difference of 8.08v. At 502rpm there was a difference of 3.65v and at 1500rpm a difference of 1.59v. This could be down to human error or equipment calibrations.

Using the pony brake, the motor was loaded over 3 different loads of 0.5nm, 1.0nm and 1.5nm and waveforms were analysed. As shown in table 10, when the mechanical loading is increased the current increases and the voltage increases proportionally to compensate and maintain the motor speed at the required 1003rpm, also showing the current waveform becoming continuous.

Simulation of a medium transmission line was carried out and measured values and calculated values as shown in table 11 are almost identical with negatable differences which could be caused by rounding errors. The efficiency of the transmission line is shown in table 12 which shows a power loss of 1.706mW between the sending end and the receiving end, proving the transmission line to be efficient.

Each section carried out in the assignment relates to the research and investigation theory work carried out in section 2.

Recommend carrying out the practical simulation and calculations shown in table 9 again and ensure calibrations and calculations are correct and carried out correctly proving errors.

7. Team Working

Teamwork was at a minimum within this assignment due to COVID 19 situations but once restrictions were relaxed slightly the practical experiment was carried out following all Covid 19 restrictions whilst working as a team to obtain the results needed. Masks were worn and a 2 meter distance between team members was kept at all times. All safety measures were in place and safety gear such as safety glasses worn at all times.

Once finished the motor and measuring equipment was disconnected and wiped down adhering to covid 19 restrictions.

8. References

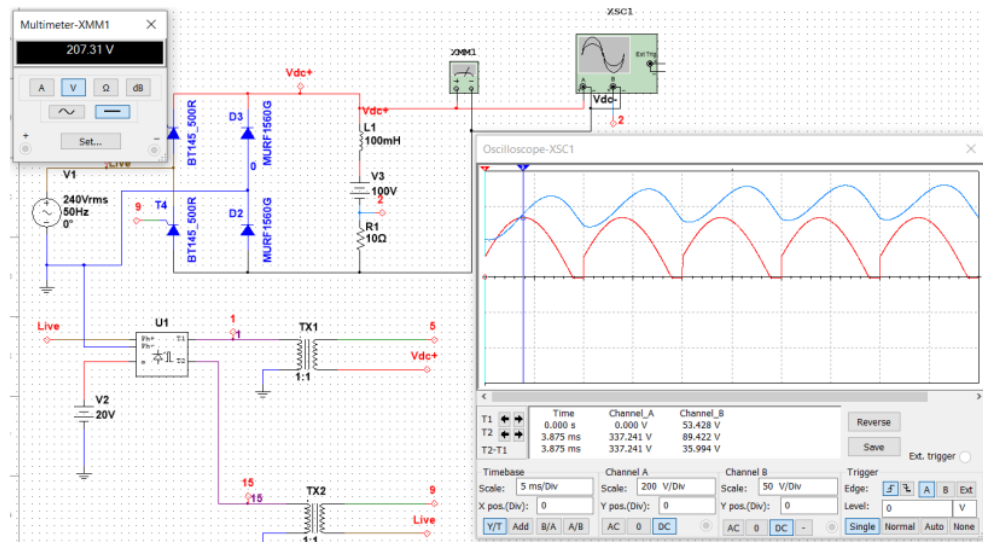
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9.1 Parker 512C construction and operation



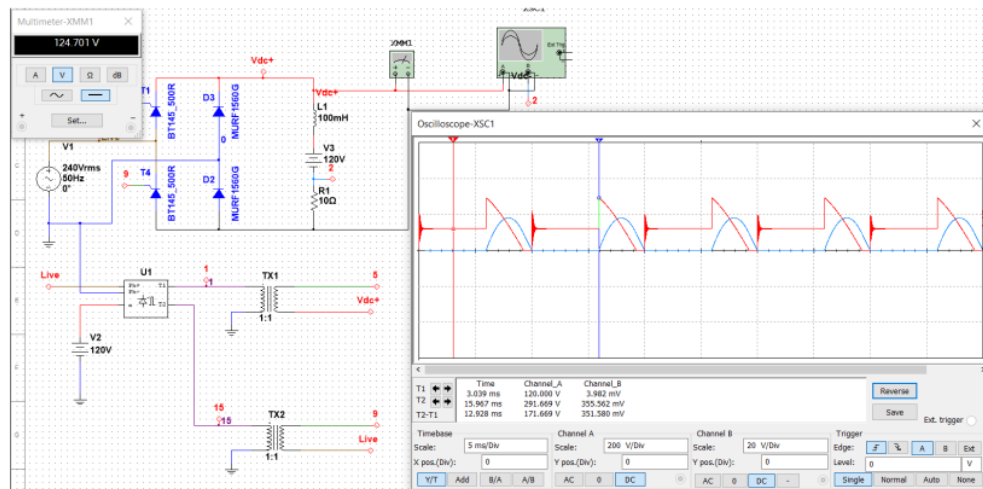
9.2 Vpk max value

Vpk max value = 337.2V



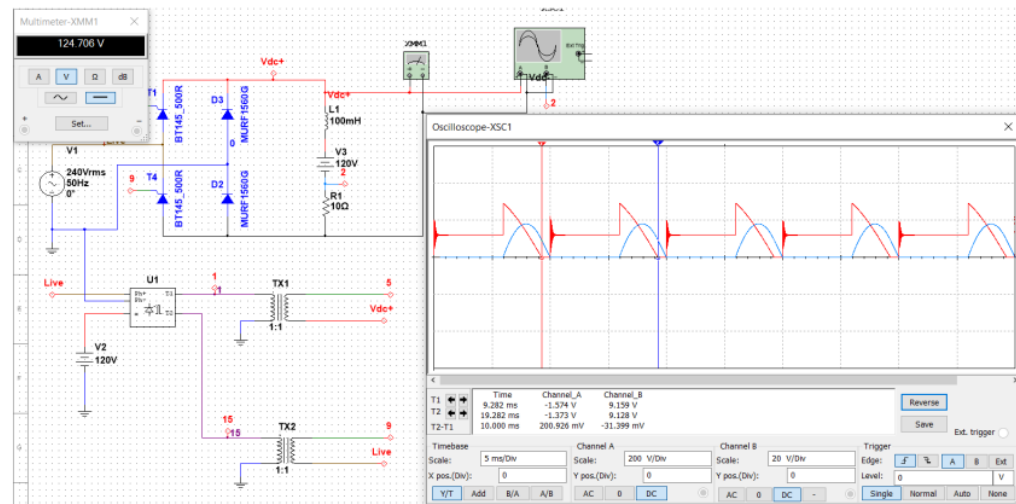
9.3 Back EMF value E

Back EMF voltage E = 120V



9.4 Half period value

Half period Value = 10ms



9.5 120° Phase Angle Calculations

$$\frac{1}{f} = \frac{1}{50} = 20ms$$

$$Half\ Period = 10ms$$

Measured values –

$$t1 = .718ms$$

$$t2 = 6.69ms$$

$$V_{pk\ max} = 337.2v$$

$$E = 120v$$

Convert to Radians –

$$\beta = \frac{t1}{10} \times \pi = \frac{.718 \times 10^{-3}}{10} \times \pi$$

$$\beta = 0.23\ rad$$

$$\alpha = \frac{t2}{10} \times \pi = \frac{6.69 \times 10^{-3}}{10} \times \pi$$

$$\alpha = 2.1\ rad$$

Average Armature Voltage –

$$V_{av} = \frac{1}{\pi} \left\{ E (\alpha - \beta) + \int_{\alpha}^{\pi} V_{pk} \sin \theta \ d \theta \right\}$$

$$= \frac{E(\alpha - \beta)}{\pi} + \frac{V_{pk}(1 \cos(\alpha))}{\pi}$$

$$V_{av} = \frac{120}{\pi} \times (2.1 - 0.23) + \frac{337.2}{\pi} \times (1 + \cos(2.1))$$

$$V_{av} = 71.43 + 53.15$$

$$V_{av} = 124.6V$$

9.6 100° Phase Angle Calculations

$$\frac{1}{f} = \frac{1}{50} = 20ms$$

$$Half\ Period = 10ms$$

Measured Values –

$$t_1 = 1.77ms$$

$$t_2 = 5.53ms$$

$$V_{pk}|_{max} = 337.2v$$

$$E = 120v$$

Convert to Radians –

$$\beta = \frac{t_1}{10} \times \pi = \frac{1.77 \times 10^{-3}}{10} \times \pi$$

$$\beta = 0.56\ rad$$

$$\alpha = \frac{t_2}{10} \times \pi = \frac{5.53 \times 10^{-3}}{10} \times \pi$$

$$\alpha = 1.74\ rad$$

Average Armature Voltage –

$$V_{av} = \frac{1}{\pi} \left\{ E(\alpha - \beta) + \int_{\alpha}^{\pi} V_{pk} \sin \theta \ d\theta \right\}$$

$$= \frac{E(\alpha - \beta)}{\pi} + \frac{V_{pk} (1 + \cos(\alpha))}{\pi}$$

$$V_{av} = \frac{120}{\pi} \times (1.74 - 0.56) + \frac{337.2}{\pi} \times (1 + \cos(1.74))$$

$$V_{av} = 45.07 + 89.26$$

$$V_{av} = 134.33\ V$$

9.7 80° Phase Angle Calculations

$$\frac{1}{f} = \frac{1}{50} = 20ms$$

$$Half\ Period = 10ms$$

Measured Values –

$$t1 = 2.71ms$$

$$t2 = 4.42ms$$

$$V_{pk\ max} = 337.2v$$

$$E = 120v$$

Convert to Radians –

$$\beta = \frac{t1}{10} \times \pi = \frac{2.71 \times 10^{-3}}{10} \times \pi$$
$$\beta = 0.85\ rad$$

$$\alpha = \frac{t2}{10} \times \pi = \frac{4.42 \times 10^{-3}}{10} \times \pi$$
$$\alpha = 1.39\ rad$$

Average Armature Voltage –

$$V_{av} = \frac{1}{\pi} \left\{ E(\alpha - \beta) + \int_{\alpha}^{\pi} V_{pk} \sin \theta \, d\theta \right\}$$

$$= \frac{E(\alpha - \beta)}{\pi} + \frac{V_{pk} (1 + \cos(\alpha))}{\pi}$$

$$V_{av} = \frac{120}{\pi} \times (1.39 - 0.85) + \frac{337.2}{\pi} \times (1 + \cos(1.39))$$

$$V_{av} = 20.63 + 126.63$$

$$V_{av} = 147.26\ V$$

9.8 40V back EMF continuous current calculations

Below are the calculations for the chosen continuous current, using a 40V back EMF.

As the current is continuous and the back EMF has disappeared β does not need to be calculated.

$$\frac{1}{f} = \frac{1}{50} = 20ms$$

$$Half\ Period = 10ms$$

Measured Values –

$$t_2 = 5.514\ ms$$

$$V_{pk} = 337.2\ v$$

Convert to radians –

$$\alpha = \frac{t_2}{10} \times \pi = \frac{5.514 \times 10^{-3}}{10} \times \pi$$

$$\alpha = 1.73\ rad$$

Average armature voltage –

$$V_{av} = \frac{337.2}{\pi} \times (1 + \cos(1.73))$$

$$V_{av} = 90.31\ V$$

9.9 502rpm calculations

$$\frac{1}{f} = \frac{1}{50} = 20ms$$

$$Half\ Period = 10ms$$

Measured values –

$$t1 = 1.76ms$$

$$t2 = 8.218ms$$

$$Vpk\ max = 336.3v$$

$$E = 35.76v$$

Convert to Radians –

$$\beta = \frac{t1}{10} \times \pi = \frac{1.76 \times 10^{-3}}{10} \times \pi$$
$$\beta = 0.55\ rad$$

$$\alpha = \frac{t2}{10} \times \pi = \frac{8.218 \times 10^{-3}}{10} \times \pi$$
$$\alpha = 2.58\ rad$$

Average Armature Voltage –

$$V_{av} = \frac{1}{\pi} \left\{ E (\alpha - \beta) + \int_{\alpha}^{\pi} V_{pk} \sin \theta \, d\theta \right\}$$
$$= \frac{E(\alpha - \beta)}{\pi} + \frac{V_{pk}(1 - \cos(\alpha))}{\pi}$$

$$V_{av} = \frac{35.76}{\pi} \times (2.58 - 0.55) + \frac{336.3}{\pi} \times (1 - \cos(2.58))$$

$$V_{av} = 23.11 + 16.44$$

$$V_{av} = 39.55v$$

10. 1003 rpm calculations

$$\frac{1}{f} = \frac{1}{50} = 20ms$$

$$Half\ Period = 10ms$$

Measured values –

$$t1 = .816ms$$

$$t2 = 7.619ms$$

$$Vpk\ max = 336.3v$$

$$E = 66.8v$$

Convert to Radians –

$$\beta = \frac{t1}{10} \times \pi = \frac{.816 \times 10^{-3}}{10} \times \pi$$

$$\beta = 0.26\ rad$$

$$\alpha = \frac{t2}{10} \times \pi = \frac{7.619 \times 10^{-3}}{10} \times \pi$$

$$\alpha = 2.39\ rad$$

Average Armature Voltage –

$$V_{av} = \frac{1}{\pi} \left\{ E (\alpha - \beta) + \int_{\alpha}^{\pi} V_{pk} \sin \theta \ d\theta \right\}$$

$$= \frac{E(\alpha - \beta)}{\pi} + \frac{V_{pk}(1 \cos(\alpha))}{\pi}$$

$$V_{av} = \frac{66.8}{\pi} \times (2.39 - 0.26) + \frac{336.3}{\pi} \times (1 + \cos(2.39))$$

$$V_{av} = 45.29 + 28.84$$

$$V_{av} = 74.13\ V$$

10.1 1500 rpm calculations

$$\frac{1}{f} = \frac{1}{50} = 20ms$$

$$Half\ Period = 10ms$$

Measured values –

$$t1 = .756\ ms$$

$$t2 = 6.88\ ms$$

$$Vpk\ max = 336.3v$$

$$E = 97.89v$$

Convert to Radians –

$$\beta = \frac{t1}{10} \times \pi = \frac{.756 \times 10^{-3}}{10} \times \pi$$

$$\beta = 0.24\ rad$$

$$\alpha = \frac{t2}{10} \times \pi = \frac{6.88 \times 10^{-3}}{10} \times \pi$$

$$\alpha = 2.16\ rad$$

Average Armature Voltage –

$$V_{av} = \frac{1}{\pi} \left\{ E (\alpha - \beta) + \int_{\alpha}^{\pi} V_{pk} \sin \theta \ d\theta \right\}$$

$$= \frac{E(\alpha - \beta)}{\pi} + \frac{V_{pk}(1 - \cos(\alpha))}{\pi}$$

$$V_{av} = \frac{97.89}{\pi} \times (2.16 - 0.24) + \frac{336.3}{\pi} \times (1 - \cos(2.16))$$

$$V_{av} = 59.83 + 47.56$$

$$V_{av} = 107.39V$$

10.2 Medium length transmission line calculations

Resistance = 21Ω

Inductance = 177mH

Capacitance = $1.4\mu\text{F}$

Impedance and Shunt admittance calculations

Impedance =

$$\begin{aligned}Z_s &= 21 + j\omega \times 177 \times 10^{-3} \\Z_s &= 21 + j \times 2\pi \times 50 \times 177 \times 10^{-3} \\Z_s &= 21 + j55.606\end{aligned}$$

In polar form -

$$\begin{aligned}Z_s &= \sqrt{21^2 + 55.606^2} \angle \tan^{-1}\left(\frac{55.606}{21}\right) \\Z_s &= 59.439 \angle +69.311^\circ\end{aligned}$$

Shunt admittance =

$$\begin{aligned}\gamma &= j\omega c \\\gamma &= j \times 2 \times \pi \times 50 \times 1.4 \times 10^{-6} \\\gamma &= j0.439 \times 10^{-3}\end{aligned}$$

In polar form –

$$\gamma = 0.439 \times 10^{-3} \angle +90^\circ$$

Sending end voltage, current and power factor calculations

The load at the receiving end is 293.124A at 82.596KV with a power factor of 0.88722 lagging.

VRN -

$$\begin{aligned} VRN &= 82.596 \times 10^3 \angle 0^\circ \\ VRN &= 82596 \angle 0^\circ \end{aligned}$$

IRN -

$$\begin{aligned} IRN &= 293.124 \angle -\cos^{-1}(0.88722) \\ IRN &= 293.124 \angle -27.474^\circ \end{aligned}$$

Using the nominal π Circuit

I1 -

$$\begin{aligned} I1 &= IRN + VRN \times \frac{Y}{2} \\ &= 293.124 \angle -27.474^\circ + 82596 \angle 0^\circ \times \frac{0.439 \times 10^{-3}}{2} \angle 90^\circ \\ &= 293.124 \angle -27.474^\circ + 18.130 \angle 90^\circ \\ &= 293.124 \cos(-27.474^\circ) + j 293.124 \sin(-27.474^\circ) + 18.130 \\ &= 260.066 - j 135.232 + j 18.130 \\ &= 260.066 - j 117.102 \text{ Amps} \end{aligned}$$

In polar form -

$$\begin{aligned} I1 &= \sqrt{260.066^2 + 117.102^2} \angle -\tan^{-1}\left(\frac{117.102}{260.066}\right) \\ I1 &= 285.214 \angle -24.241 \text{ Amps} \end{aligned}$$

VSN –

$$\begin{aligned}
 VSN &= VRN + I1 Zs \\
 VSN &= 82596 \angle 0^\circ + 285.214 \angle -24.241^\circ \times 59.439 \angle 69.311^\circ \\
 &= 82596 \angle 0^\circ + 16952.835 \angle 45.07^\circ \\
 &= 82596 + 16952.835 \cos(45.07) + j 16952.835 \sin(45.07) \\
 &= 82596 + 11972.810 + j 12002.101 \\
 &= 94568.81 + j 12002.101
 \end{aligned}$$

In polar form –

$$\begin{aligned}
 VSN &= \sqrt{94568.81^2 + 12002.10^2} + \tan^{-1} \frac{12002.101}{94568.81} \\
 VSN &= 95327.385 \angle 7.2330^\circ
 \end{aligned}$$

ISN –

$$\begin{aligned}
 ISN &= I1 + VSN \times \frac{Y}{2} \\
 ISN &= 260.066 - j 117.102 + 95327.385 \angle 7.2330^\circ \times \frac{0.439 \times 10^{-3}}{2} \angle 90^\circ \\
 &= 260.066 - j 117.102 + 20.924 \angle 97.2330^\circ \\
 &= 260.066 - j 117.102 - 2.6344 + j 20.757 \\
 &= 257.432 - j 96.345
 \end{aligned}$$

In polar form –

$$\begin{aligned}
 ISN &= \sqrt{257.432^2 + 96.345^2} - \tan^{-1} \frac{96.345}{257.432} \\
 ISN &= 274.87 \angle -20.52^\circ
 \end{aligned}$$

The angle between VSN and ISN =

$$\begin{aligned} & VSN \angle^{\circ} - ISN \angle^{\circ} \\ & 7.2330 - (-20.52) \\ & = 27.753^{\circ} \end{aligned}$$

The Power factor at sending end =

$$\begin{aligned} & = \cos (27.753^{\circ}) \\ & = 0.8850 \text{ Lagging} \end{aligned}$$

FINAL GRADE

GENERAL COMMENTS

Instructor

60/100

PAGE 1

PAGE 2

Text Comment. Good structure

PAGE 3

PAGE 4

Text Comment. A good brief summary

PAGE 5

Text Comment. modern induction motors are actually smaller than DC motors

Text Comment. induction motors are cheaper

Text Comment. induction motors are simpler design

Text Comment. Citation needed.

PAGE 6

PAGE 7

PAGE 8

Text Comment. how would it be controlled as diodes give a fixed voltage output

Text Comment. you should have considered a thyristor drive

PAGE 9

Text Comment. your earlier research was supposed to be linked to the Parker drive with a half controlled full wave controlled thyristor rectifier

Text Comment. these voltage suppressors

Text Comment. where are the capacitors?

Text Comment. Results should have been summarized in a table and the waveforms should be in the appendix

Text Comment. Results should be closer than this

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GRADING FORM: NEW CSG-RUBRIC

LIAM GEORGE**60****1. ENGAGEMENT WITH LITERATURE**

Engagement with a wide range of literature, including sources retrieved independently. Selection of relevant and credible sources. Very good use of referencing, with no/very few inaccuracies or inconsistencies. (13/20)

13**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**

Sound critical evaluation and analysis of concepts. Is selective in the range of evidence used and synthesises rather than describes. Ability to devise arguments that show awareness of different

12

stances, and use evidence convincingly, to support appropriate and valid judgements. (12/20)

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 they were first studied. Evidence of some creativity. (13/20)

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5. TRANSFERABLE SKILLS



Can communicate effectively in a suitable medium for the audience, but may have minor errors. Mostly coherent, organised work, in a suitable structure and is for the most part clearly expressed. Can work effectively independently and/or as part of a team, with clear contribution to group activities. Demonstrates the skills for employment requiring the exercise of personal responsibility and decision-making, with some areas of strength and some of minor weakness. Word count exceed. You must develop the ability to write things more succinctly. (10/20)

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