

1809799

by Thomas Grennan

THE REPORT WAS VERY THOROUGH AND DEMONSTRATED VERY GOOD KNOWLEDGE AND CRITICAL UNDERSTANDING. THE WORD COUNT WAS EXCESSIVE AND YOU ALSO USED SEVERAL LARGE TABLES WITH A LARGE AMOUNT OF TEXT. THIS IS ONE ASPECT YOU WILL NEED TO IMPROVE ON WITH THE MAJOR PROJECT YEAR.

MARK AGREED



FILE	11301_THOMAS_GRENNAN_1809799_179200_39966944.DOCX (5.6M)		
TIME SUBMITTED	06-MAY-2021 10:11PM (UTC+0100)	WORD COUNT	8928
SUBMISSION ID	152045552	CHARACTER COUNT	48213

Course: HND Electrical and Electronic Engineering

Module: SGEE5006 Power and Machines

Assignment: DC Motors and Drives, and AC Transmission Lines

Name: Thomas Grennan

University number: 1809799

Date submitted: 06/05/2021

Word count: 3922

Your word count is excessive because you didn't read and interpret the research question carefully enough.

Contents

Table of Figures.....	3
Table of Tables.....	4
1. Executive Summary.....	5
2. Research.....	6
2.1 Industrial DC Machine Applications.....	6
2.2 Methods of control of DC machines from an AC supply.....	10
2.3 Construction and operation of a typical single quadrant DC drive such as the Parker 512C.....	15
3. Simulation of a Half-Controlled Rectifier Circuit.....	19
3.1 Explanation of the Simulation Circuit.....	19
3.2 The Effect of changing the firing angle at a fixed load.....	20
3.3 The effect of changing the load at a fixed firing angle.....	21
4. Practical Investigation into a Single Quadrant DC Drive.....	22
4.1 Investigation into the Off Load Performance of a Single Quadrant DC Drive.....	22
4.2 Investigation into the Under-Load Performance of a Single Quadrant DC Drive.....	23
5. Simulation of a Medium Length Transmission Line.....	25
6. Overall Conclusions and Recommendations.....	27
7. Team Working.....	29
8. Citation List.....	30
9. Appendix.....	33
9.1 Simulation of a Half-Controlled Rectifier Circuit.....	33
9.1.1 Changing the firing angle.....	33
9.1.2 Changing the back EMF.....	38
9.1.3 Calculations for changing the back EMF at a fixed load.....	40
9.2 Practical investigation into a Single Quadrant DC Drive.....	41
9.2.1 Off Load Performance of a Single Quadrant DC Drive.....	42
9.3 Calculations for the simulation of a medium length transmission line.....	47

Table of Figures

Figure 1 – Series DC Motor Diagram (Vyas, 2019)	6
Figure 2 – Self-excited DC Shunt Motor Circuit (ElProCus, 2019)	7
Figure 3 – DC Motor with Rheostat (Sharma, 2016).....	8
Figure 4 – Separately-Excited DC Motor Diagram (Electrical4U, 2020).....	9
Figure 5 – Thyristor Symbol (TeX, 2018)	10
Figure 6 – Single-Pulse Rectifier Circuit and Waveform (Hughes, 2013)	11
Figure 7 – Single-Phase Fully Controlled Converter (ElectronicsTutorials, 2018).....	12
Figure 8 - Single-Phase Half-Controlled Converter Circuit (Kharagpur, 2015).....	12
Figure 9 – Three-Phase Four Quadrant Converter (ElProCus, 2021)	13
Figure 10 – Diagram showing four quadrants of a four quadrant drive (circuitglobe, 2020).....	14
Figure 11 – Parker 512C Block Diagram (Parker, 2016)	15
Figure 12 – Parker 512C Control Terminals (Parker, 2016)	16
Figure 13 – Parker 512C Power and Field Terminals (Parker, 2016)	17
Figure 14 – Parker 512C Potentiometers (Parker, 2016)	17
Figure 15 – Annotated Diagram of Multism Half-Controlled Rectifier Circuit.....	19
Figure 16 – Armature voltage and current waveform at 0.5NM.....	23
Figure 17 Armature voltage and current waveform at 1.0NM.....	23
Figure 18 - Armature voltage and current waveform at 1.5NM.....	24
Figure 19 – Nominal π circuit for a medium length transmission line with results	25
Figure 20 – Average Voltage measurement for Half-Controlled rectifier on Multisim	34
Figure 21 – 80 degree firing angle T1.....	35
Figure 22 - 80 degree firing angle T2	35
Figure 23 - 100 degree firing angle T1	36
Figure 24 - 100 degree firing angle T2	36
Figure 25 - 120 degree firing angle T1	37
Figure 26 - 120 degree firing angle T2	37
Figure 27 – Changing the back EMF, 90V EMF at 80°	38
Figure 28 - Changing the back EMF, 80V EMF at 80°	38
Figure 29 - Changing the back EMF, 70V EMF at 80°	39
Figure 30 - Changing the back EMF, 60V EMF at 80°	39
Figure 31 – Practical Set-up	41
Figure 32 – Vpk for Armature voltage.....	41
Figure 33 – Off-Load Practical, T1 at 502 RPM	42
Figure 34 - Off-Load Practical, T2 at 502 RPM	42
Figure 35 - Off-Load Practical, T1 at 1003 RPM	43
Figure 36 - Off-Load Practical, T2 at 1003 RPM	44
Figure 37 - Off-Load Practical, T1 at 1500 RPM	45
Figure 38 - Off-Load Practical, T2 at 1500 RPM	45
Figure 39 – Nominal π circuit for a medium length transmission line complex load values	47

Table of Tables

Table 1 - Methods of Series DC Motor Speed Control (Daware, 2018)	7
Table 2 – Methods of Shunt DC Motor Speed Control (electricalcafe, 2018)	9
Table 3 – Results for the effect of changing the firing angle at a fixed load	20
Table 4 – Results for the effect of changing the Load – Simulation Values.....	21
Table 5 – Results for the effect of changing the Load – Comparison of Back EMF Values.....	21
Table 6 – Results for the off-Load Performance of a Single Quadrant DC Drive	22
Table 7 – Results for the Under Load Performance of a Single Quadrant DC Drive	24
Table 8 - Comparison of Calculation vs Simulation for the medium length transmission line.....	25
Table 9 - Comparison of efficiency for the medium length transmission line	26

1. Executive Summary

Two unnecessary sentences

*Too long, should be
around 300 words*

This report consists of 4 significant sections. Section 2 outlines the research undertaken which sets a basis of which the report is built upon. The research task focused on DC machines, specifically DC Motors explored in three different sections, these being: Industrial DC machine applications, Methods of control of DC machines from an AC supply and the construction and operation of a single quadrant DC drive, *this clause says nothing to your reader* this research element provided the underpinning knowledge needed for the following tasks.

Section 3 focused on the simulation and analysis of a Half-Controlled Rectifier Circuit. A circuit was created in Multisim with a load consisting of a resistor, inductor and battery for the back EMF was connected across the output terminals to imitate a DC motor. The first experiment was to alter the firing angle of the drive in order to observe the effects this had on the waveform. Current, voltage and timings were noted and converted into radians to calculate the average armature voltage to compare simulation to theory. The second experiment was to observe the effect of mechanical loading, this was simulated by altering the back EMF to show continuous current, voltage and current waveforms were recorded for three different loads, the average voltage was then calculated for one example of continuous current, the obtained results were then analysed.

Section 4 is a practical experiment based on section 3 using the Parker 512C DC drive. The drive was connected to a DC motor and Picoscope analysis equipment were used to record voltage and current waveforms for three different speeds, results were taken and analysed and calculations were performed to calculate the average voltage. A Prony brake was then connected onto the motor shaft to simulate a mechanical load, three different loads were applied to the shaft and the waveforms were observed and analysed and the DC drive performance was explained.

Section 5 was centred around the Simulation of a Medium length transmission line, a nominal π circuit was designed in Multisim with a load impedance of $250 + j130\Omega$. Calculations were then performed to calculate the series impedance and shunt admittance, the sending end voltage, current and power factor were calculated as the receiving end values were known. All calculations were tabulated and compared with the Multisim readings to prove the reliability of this method. Further tests were performed to measure the power at the sending and receiving end to determine the efficiency of the line.

The final section concluded the report with overall conclusions and recommendations.

You have spent too much time explaining the operation of a DC motor from a DC supply. Only the applications were required. You should have read the question more carefully.

2. Research

2.1 Industrial DC Machine Applications

There are many industrial machines that are powered by DC, the most popular being the DC motor. There are two main variations of the DC Motor, these being the Series Motor and the Shunt Motor. Before the availability of variable-voltage supplies DC Motors were required to operate off a single, often constant DC voltage, due to this the armature and field circuits were designed for connection in series or parallel (Shunt). Series and Shunt motors offer widely differing characteristics, with series motors being suited to traction applications and shunt motors being suited to applications where a constant speed is needed (Hughes, 2013).

Series DC Motor

Series DC Motors have their field winding connected in series with the armature winding, a diagram of this circuit is seen in figure 1. The windings of a series DC motor have very few turns, this is to provide a minimum resistance to draw large equal current through the field and armature, due to this the field coils are created with large gauge wire which is required for the motor to draw full load current (Electrical4U, 2020). Due to the small windings series DC motors have a low winding resistance, therefore, when a DC voltage is applied a large current is drawn and a huge magnetic force is produced, producing a large torque in the motor shaft which spins the armature producing mechanical energy (Linquip, 2020). Due to this characteristic, the series motor is suited to applications with high starting loads such as cranes and hoists, they are also used as starter motors for other motors and in other industrial applications (Mawdsleys, 2019). The negative aspects of the series DC motor are its speed control, this is due to its speed being inversely proportional to its load, this means that the heavier the load on the shaft, the slower the speed of the motor's armature, as this load decreases the speed increases. Another negative aspect of the series motor is that under no-load it has the capability to self-destruct due to its poor speed regulation (Linquip, 2020).

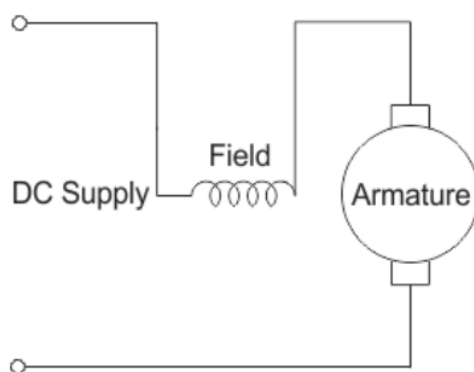


Figure 1 – Series DC Motor Diagram (Vyas, 2019)

However, there are various methods available to control the speed of a series DC motor, examples of the methods of series DC motor speed control are seen in table 1.

Methods of Series DC Motor Speed Control	
Method	Explanation
Variable Resistance in Series with the Armature	By introducing resistance in series with the armature, voltage across the armature can be reduced. And, hence, speed reduces in proportion with it.
Field Diverter	A variable resistance is connected parallel to the series field; this is known as a diverter. The desired amount of current can be diverted through this resistor, in turn reducing the flow of current through the field coil. Due to flux being inversely proportional to speed the flux can be decreased to the desired amount and speed can be increased.
Armature Diverter	The Armature Diverter method has a diverter connected across the motor's armature. For a given constant load torque, if armature current is reduced then the flux must increase, as $T_a \propto I_a$. This will result in an increase in current taken from the supply and hence flux Φ will increase and subsequently speed of the motor will decrease.
Series-Parallel Control	This system is widely used in electric traction, where two or more mechanically coupled series motors are employed. For low speeds, the motors are connected in series, and for higher speeds, the motors are connected in parallel. When in series, the motors have the same current passing through them, although voltage across each motor is divided. When in parallel, the voltage across each motor is same although the current gets divided.

Table 1 - Methods of Series DC Motor Speed Control (Daware, 2018)

Shunt DC Motor

In electrical engineering terminology the term shunt is often used to describe a parallel circuit. Hence, DC motors that have their field winding which produces a constant magnetic field within the stator, connected in parallel with the armature winding are known as shunt motors. In this configuration the power supply output is split between the field winding and armature winding, splitting the current into two parallel paths. Correctly cited (Collins, 2015), shunt motors offer a low starting torque, however, they offer excellent speed regulation. A model of the DC shunt motor is seen in figure 2.

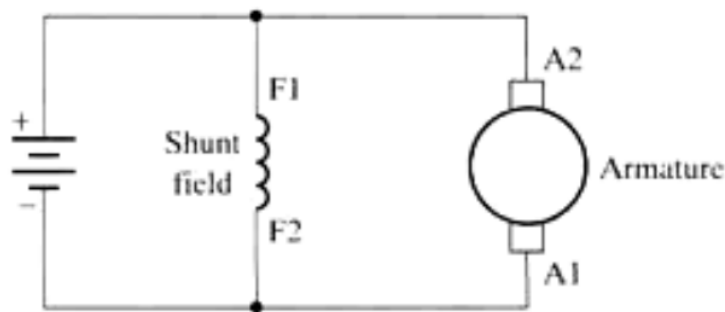


Figure 2 – Self-excited DC Shunt Motor Circuit (ElProCus, 2019)

The windings of the series DC motor had few turns with a large gauge wire, whereas, the DC shunt motor windings use smaller gauge wire with far more turns. The DC shunt motor winding configuration limits the current drawn through the coil and produces a stronger magnetic field. This configuration reduces the field current, as the field and armature are in parallel it increases the armature current. The motors direction can be easily changed by swapping the polarity of either the field or armature coil (Cavallo, 2018).

When a large armature current is drawn by the shunt motor, a back EMF is produced, this EMF is produced as the armatures magnetic field rotates through the stator field, the back EMF reduces the current through the winding of the armature and opposes the voltage. As speed is proportional to back EMF, when the speed of the motor increases so does the back EMF, this is a beneficial aspect of the shunt motor as it allows for them to self-regulate their speed, even under a heavy load, this is why shunt motors are commonly referred to as “constant-speed” motors. Due to these characteristics, DC Shunt motors are suited to applications where a constant speed is needed, these applications include conveyor systems, lathes and centrifugal pumps (Electrical4U, 2020).

As the speed of a DC motor is inversely proportional to the flux per pole, the motor speed can be increased by decreasing the flux and vice versa, this is known as the flux control method. The flux is controlled through the use of a variable resistor called a “Rheostat”, this rheostat is connected in series with the field winding in order to add more resistance in the field winding to decrease the flux in the motor, in turn increasing the speed. This is an efficient method of speed control as the field current is small there are minimum current losses, however, the flux can be reduced to the point where the motor is running faster than it should, in turn weakening the flux field which will have adverse effects on the commutators, a circuit diagram for this is seen in figure 3 (electrical4easy, 2018).

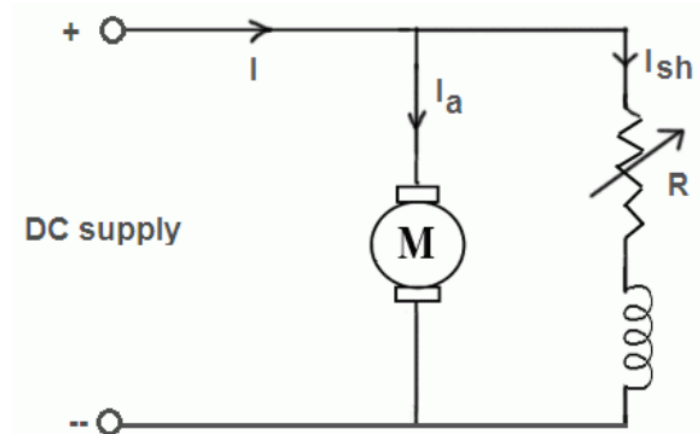


Figure 3 – DC Motor with Rheostat (Sharma, 2016)

Other methods of speed control for DC shunt motors are explained as seen in table 2.

Methods of Shunt DC Motor Speed Control	
Method	Explanation
Armature Control Method	The speed of a dc motor is directly proportional to the back emf E_b and $E_b = V - I_a R_a$. That means, when supply voltage V and the armature resistance R_a are kept constant, then the speed is directly proportional to armature current I_a . Thus, if we add resistance in series with the armature, I_a decreases and, hence, the speed also decreases. Greater the resistance in series with the armature, greater the decrease in speed.
Multiple Voltage Control	In this method, the shunt field is connected to a fixed exciting voltage and armature is supplied with different voltages. Voltage across armature is changed with the help of suitable switchgear. The speed is approximately proportional to the voltage across the armature.

Table 2 – Methods of Shunt DC Motor Speed Control (electricaleasy, 2018)

Separately-Excited DC Motor

Another type of DC motor used in industry is the “Separately Excited DC Motor”, Unlike the self-excited motors seen in figures 1 and 2 whereby the field and armature are supplied by the same supply voltage, the separately-excited DC motor has a different supply applied to the field and armature windings. Due to this, the armature current will not flow through the field windings like it does in a standard DC motor. A diagram of a separately excited motor is seen in figure 4 (Electrical4U, 2020),

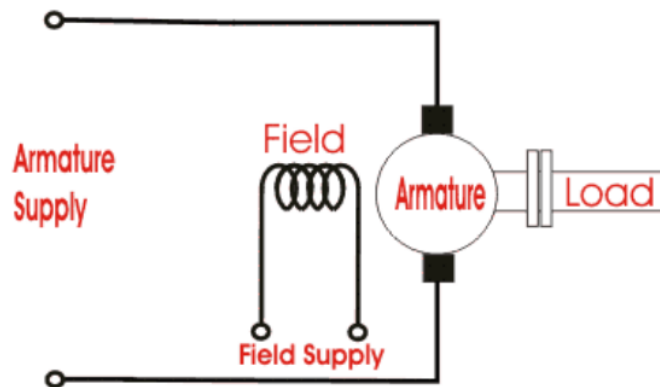


Figure 4 – Separately-Excited DC Motor Diagram (Electrical4U, 2020)

Separately-excited DC motors are used in applications as actuators, often in trains for traction purposes. The speed control of these motors use some of the same principles as the DC Shunt and Series motors, these being the Field rheostat method and the Armature control method (electronics-tutorials, 2017).

2.2 Methods of control of DC machines from an AC supply

In order for a DC Motor to be controlled from an AC supply, electronic circuits are needed to rectify the AC into DC. The majority of DC drives draw their power from a 50Hz supply voltage at Single-Phase 230VAC or Three-Phase 415VAC. In nearly all power electronic converters the first stage is to convert AC into an unpolished form of DC. When a “constant” DC voltage is needed a simple diode circuit can be used, however, when the DC voltage needs to be controlled, much like in DC drives for speed control, a controlled rectifier is required. The majority of these rectifiers contain an electronic component called a thyristor, this is an electronic switch with two main terminals called the anode and cathode and also has a switch-on terminal called the gate (Hughes, 2013).

A thyristor operates like a diode whereby current will only flow from the anode to the cathode when a small voltage is applied to its gate, unlike a diode which will forward conduct as soon as a voltage over 0.7V is applied. When this small voltage is applied to the gate, the thyristor is ‘fired’, this means it has been switched allowing current to build up, once current has built up sufficiently the thyristor latches in and remains on allowing the gate pulse to be removed, the thyristors non-conducting state can only be re-established once the anode-cathode current has reduced to zero and remains at zero until the thyristor turn-off time elapses, this is around 200 microseconds. The electronic symbol of a thyristor is seen in figure 5. (ElectronicsTutorials, 2019).

An inappropriately large image that could be seen from 50 feet away. I am reading your report no more than 2 feet away.

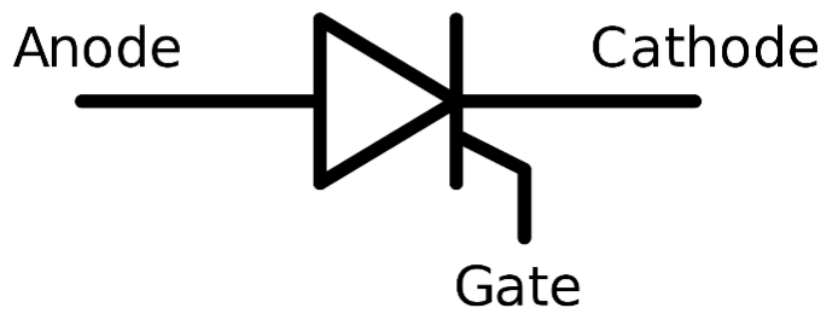


Figure 5 – Thyristor Symbol (TeX, 2018)

Single-Pulse Rectifier

The most basic phase-controlled rectifier is that of the single-pulse rectifier. When the AC supply voltage is in its positive half-cycle the forward current is blocked until the gate pulse is applied, until this pulse is applied the voltage across the resistive load is at 0V. When the gate is pulsed, the thyristor is fired and the voltage across it falls to zero, the load voltage then becomes equal to the supply voltage minus the volt-drop across the thyristor. When the supply voltage reaches zero, so does the current and the thyristor switches off enabling its current blocking ability, in turn blocking all current flow for the negative half-cycle (Hughes, 2013).

This does not produce a smooth DC waveform; however, it is still a DC waveform due to its positive mean value, this mean voltage is controlled by altering the delay angle of the firing pulses. This configuration creates a single rectified output peak per each complete cycle, this is why it is known as the single-pulse rectifier or “half-wave” circuit. The output voltage for this type of circuit is not ideal and this circuit is not utilised in drive systems, most drives use set ups with four or six thyristors as this produces far better waveforms per cycle. Figure 6 shows a single-pulse thyristor-controlled circuit alongside the output waveform it produces (Hughes, 2013). Correctly cited

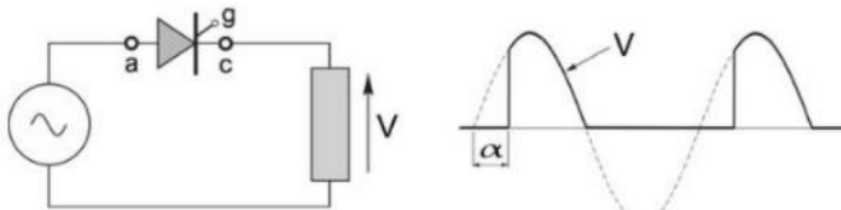


Figure 6 – Single-Pulse Rectifier Circuit and Waveform (Hughes, 2013)

Single-Phase Fully Controlled Converter

Figure 7 displays a single-phase fully controlled converter circuit. The single-phase fully-controlled converter is a two-quadrant drive, and is typically used in motor applications up to 15kW. The armature converter gives $+V_a$ or $-V_a$ and allows for operation within the first and fourth quadrants. During the regeneration for direction reversal for the flow of power, the motors back EMF can be reversed by reversing the field excitation. This reversal of the armature or field allows for operation within the second and third quadrants. This system has unidirectional current with both positive and negative voltage polarity, due to this unidirectional current they can be operated either as a controlled rectifier or an inverter. Unidirectional converters are also known as Single-Quadrant Drives (Rashid, 2013).

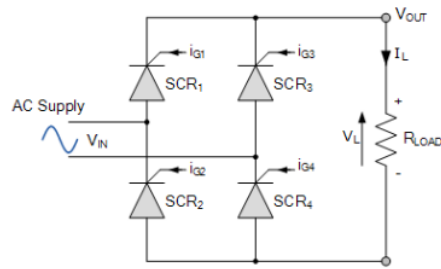


Figure 7 – Single-Phase Fully Controlled Converter (ElectronicsTutorials, 2018)

In the fully-controlled converter configuration, the average DC load voltage is controlled through the use of two thyristors per half-cycle. Thyristors T1 and T4 are fired together as a pair during the positive half-cycle, whereas during the negative half-cycle thyristors T2 and T3 are fired as a pair 180° after T1 and T4.

During the continuous conduction operation, the four thyristors are constantly switched as alternating pairs, this allows for the management of average DC output voltage. Much like the single-pulse rectifier circuit the output voltage can be controlled by varying the thyristors firing angle delay, therefore, the average output voltage of the full-controlled rectifier is calculated using the equation below:

$$V_{AVE} = \frac{V_{MAX}}{\pi} \times \cos(\alpha)$$

Single-Phase Half Controlled Converter

Some applications that do not require the inverter mode operation that the single-phase full wave converter offers. In applications where this mode is unneeded, two of the thyristors of a single phase fully controlled converter are replaced by diodes as seen in figure 8.

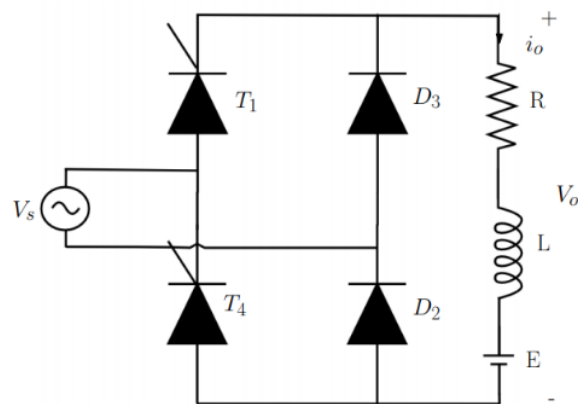


Figure 8 - Single-Phase Half-Controlled Converter Circuit (Kharagpur, 2015)

The result of replacing these thyristors with diodes creates a single-phase half-controlled converter. This type of converter is a single quadrant converter which has one polarity of DC voltage and current at the output terminals (Kharagpur, 2015).

Within the half-controlled rectifier circuit, the diodes carry current for far longer duration than the thyristors do in the full-controlled circuit. As the diodes in the half-controlled circuit only have the ability to block negative voltage, the diodes in the circuit conduct for both the positive and negative input half-cycle. In order for any load current to flow, T1 or T4 and their corresponding diode (D2 and D3) must conduct together for load current to flow. From this, the average voltage V_{AVE} depends on the firing angle of the two thyristors in the half-controlled circuit as the diodes are not controllable and allow for the flow of current whenever forward biased. This is the continuous current mode of operation as the current is continuous throughout, if the current falls to zero it is operating in the discontinuous mode (S., 2014)

Four Quadrant Converter

The most elegant method of controlling a DC motor is through the use of a Four-Quadrant DC Converter, these converters can operate with a single-phase supply or a three-phase supply as seen in figure 9, this AC supply is converted to DC through the use of thyristors. Unlike single quadrant converters which can only generate positive voltage with a positive flow of current from the converter to the motor. Four-quadrant converters utilise two fully-controlled full wave rectifier circuits. This converter configuration allows for far greater control over the motor (Dostal, 2020).

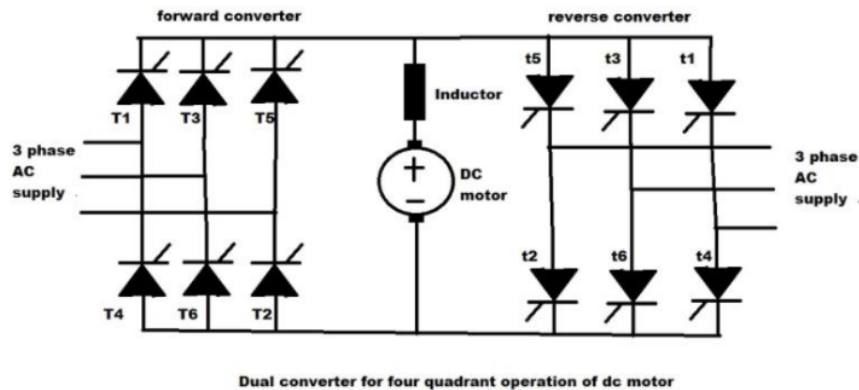


Figure 9 – Three-Phase Four Quadrant Converter (ElProCus, 2021)

The focus should be a single quadrant drive at this level as suggested by the next topic of research. You have done more than was required and exceeded the word count as a result. Please read the question more carefully in future..

The four-quadrant drive operates in four quadrants, these being: forward motoring, forward braking, reverse motoring and reverse braking as seen by the four-quadrant diagram in figure 10. Motoring mode is when the machine works as a motor by converting electrical energy into mechanical energy, however, in braking mode the machine works like a generator converting mechanical energy into electrical energy (circuitglobe, 2020).

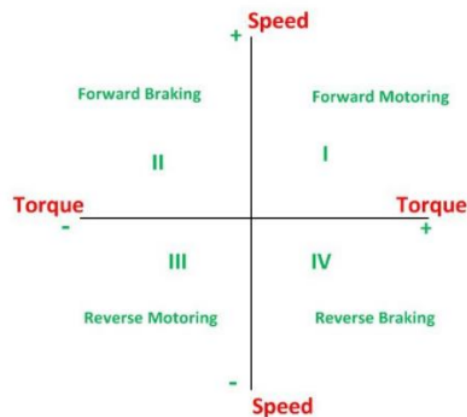


Figure 10 – Diagram showing four quadrants of a four quadrant drive (circuitglobe, 2020)

In the first quadrant known as the forward motoring quadrant, the power that is developed is positive and the motor is in its motoring mode producing mechanical energy. The second quadrant is the braking quadrant, in this quadrant the rotational direction is positive but the torque is negative, therefore the machine operates as a generator developing a negative torque which opposes the motion, the kinetic energy produced by the motor is available electrical energy which will be sent back to the supply. Quadrant 3 is the reverse motoring quadrant, here the motor works in the reverse direction and the torque and speed are negative whilst the power is positive. The reverse braking quadrant is quadrant 4, here the torque is positive whilst the speed is negative. Hoist drives are common applications where four-quadrant operation (circuitglobe, 2020).

The Parker 512C is a single-quadrant drive. Single-quadrant drives can be constructed using a half-wave or full-wave controlled rectifier circuit, for efficiency purposes it is better to use a full-wave rectifier.

Figure 11 displays the block diagram of the Parker 512C single-quadrant drive, the block diagram of the Parker 512C displays the speed control method, either using the tachogenerator feedback which is most accurate or the armature voltage method which is most cost-effective. Signals from these feed into the speed range & scale control block, these then feed into the summing point for the speed loop control in order to control the speed of the motor. It is seen that the converter offers stall protection and internal overcurrent protection which has a dual purpose in the form of torque limiting. On the left-hand side of the block diagram the control terminals are seen, these are explained in figure 12, these include digital inputs whereby a PLC can be used to send a run signal or stall-override signal, analog inputs to send a set-point signal or a tachogenerator input to set the speed of the motor. Digital outputs are used to send indication signals of the converter's health and zero speed or set-point from the drive to a PLC and analog outputs are used for speed, current, set-point ramp and +/- 10V reference for analog control.

You should have quoted from this datasheet and cited it as a source not included an image of it.

Inputs/ Outputs	Analogue Inputs		
	Setpoint Ramp	0 to +10V	100Kohm
	Auxiliary Speed Setpoint	0 to +10V	100Kohm
	Current Limit	0 to +7.5V	50Kohm
	Tachogenerator Input	0 to +350Vdc	110Kohm
Analogue Outputs	Speed	0 to +10V	5mA
	Current (SW8 Off)	0 to +5V (0 to Idc)	5mA
	Current (SW8 On)	0 to +5V (0 to Ical)	5mA
	Setpoint Ramp	0 to +10V	5mA
	Total Setpoint	0 to +10V	5mA
	+10V Reference	+10V	5mA
	-10V Reference	-10V	5mA
Digital Inputs	Run	+10 to +24V	100Kohm
	Stall Override	+10	100Kohm
Digital Outputs	Health	+24V	50mA Source
	Zero Speed or Setpoint	+24V	50mA Source

Figure 12 – Parker 512C Control Terminals (Parker, 2016)

Figure 13 shows the Power and Field terminals of the Parker 512C converter. The supply voltage is connected to the power terminals on terminal L1 and L2/N, the armature connections to A+ and A-. F+ and F- are the field terminals for the field connections, FL1 and FL2 are for the field rectifier and Aux L1 is for the auxiliary supply for the control transformer.

You should have quoted from this datasheet and cited it as a source not included an image of it.

Power Terminals

TERMINAL	FUNCTION	DESCRIPTION	NOTES
L1	AC Input Line 1	Mains Supply Line1 Input	
L2/N	AC Input Line2/ Neutral	Mains Supply Line2 Input or Neutral	Must also be used as Auxiliary Supply Return when Auxiliary Supply Input used.
A+	Armature Positive	Motor Armature Positive Output.	
A-	Armature Negative	Motor Armature Negative Output.	

Field Terminals (Auxiliary Supply)

TERMINAL	FUNCTION	DESCRIPTION	NOTES
F+	Field Positive	Motor Field positive DC Output	
F-	Field Negative	Motor Field negative DC Output	
FL1	Field Rectifier Supply	Mains Supply Input Field Rectifier	
FL2	Field Rectifier Supply	Mains Supply Input Field Rectifier	
* Aux L1	Auxiliary Supply	Auxiliary Supply Input to Control Transformer.	Auxiliary Supply Return via L2/N
* The signal applied to Aux L1 must be in phase with L1 in order to provide the correct coding for the controller.			

Figure 13 – Parker 512C Power and Field Terminals (Parker, 2016)

The Parker 512C also offers pre-wired potentiometers for various uses, these are useful as fine tuning can be performed to use the converter to its full potential, explanations of all 8 potentiometers are seen in figure 14.

P1	Ramp Up Rate	Rotate Clockwise for Faster Acceleration to Set Speed. (Linear :- 1 to 40 seconds)	Same as 512
P2	Ramp Down Rate	Rotate Clockwise for Faster Deceleration to Set Speed. (Linear :- 1 to 40 seconds)	Same as 512
P3	Speed Loop Stability	Optimises Speed Loop Stability. (Excessive adjustment may lead to instability)	Same as 512
P4	I Limit	Rotate Clockwise to increase Maximum Output Current. With no additional connection to Torque / Current Limit Terminal T7, the Upper Limit is 110%. To achieve the 150% maximum connect T7 to +7.5V.	Same as 512
P5	IR Compensation	Optimises speed regulation against load change when using Armature Voltage Feedback. Rotate Clockwise to increase compensation and reduce regulation.(Excess adjustment may lead to instability) Turn Anti-clockwise when Tachogenerator Feedback used.	Same as 512
P6	Minimum Speed	Controls Minimum Motor Speed /Setpoint when Speed Setpoint Potentiometer connected to Terminal 4. Rotate Clockwise to increase Minimum Speed / Setpoint. (Approximately 30% adjustment when using 10K ohm Speed Setpoint Potentiometer.)	Same as 512
P7	Maximum Speed	Controls Maximum Motor Speed. Rotate clockwise to increase maximum speed.	Same as 512
P8	Zero Speed Offset	Adjusts Zero or Minimum Speed for Zero Speed Setpoint.	New Feature

Figure 14 – Parker 512C Potentiometers (Parker, 2016)

You should have quoted from this datasheet and cited it as a source not included an image of it.

As the Parker 512C is a single-quadrant DC drive, the driven motor will only have the capabilities of operating in one specific direction under the action of developed torque. When the output from the drive is connected to the motor, the machine will operate in its forward motoring mode. In this mode the armature current flows in the opposing direction of the induced EMF in the armature, the direction of the EMF also opposes the applied voltage direction. The internal circuitry of a typical single-quadrant drive is explained in section 2.2.

The system's electromagnetic torque is developed by the rotation of the armature. Single-Quadrant drives such as the Parker 512C operate when the applied motor voltage is positive and greater than the back EMF, therefore allowing the motor to draw current, as both the current and voltage are both positive the power is positive, also the torque and speed are positive allowing for motor rotation in the forward direction. In order for the Parker 512C to drive the motor in reverse, the polarity of the motor leads must be swapped, this can be utilised through relays or contactors.

As the Parker 512C is a single-quadrant drive it does not offer any regulated braking or deceleration, this means that current or torque cannot be applied in the opposing direction to slow down the rotation of the motor, therefore requires the help of friction in the form of an external brake in order to decelerate (drive.tech, 2021).

3. Simulation of a Half-Controlled Rectifier Circuit

3.1 Explanation of the Simulation Circuit

A single-phase full-wave half-controlled rectifier was designed within Multisim as seen in figure 15, A supply voltage of 240Vrms at 50Hz is applied to a rectifier circuit which consists of two silicon-controlled rectifiers (SCR) connected in parallel with two commutating diodes. During the positive half-cycle, current will flow from SCR T1 through the load and then back through Diode D2, whilst during the negative half-cycle current will flow from Diode D3 back through to SCR T4, with the diode set-up ensuring that no polarity inversion is possible due to their commutating effects.

The SCRs are controlled by the phase-angle controller, A DC voltage is applied to the controllers α terminal, this terminal sets the firing delay with the DC voltage being directly proportional to the firing angle ($80\text{VDC} = 80^\circ$). The phase-angle controllers output terminals 'T1' and 'T2' are connected to transformers, with Transformer 1 (TX1) providing an output voltage of 5VDC and Transformer 2 (TX2) providing a 9VDC voltage. TX1 supplies SCR T1 with 5VDC which fires the thyristor allowing it to conduct current and TX2 supplies SCR T4 with 9VDC to fire it and allow it to conduct current. An imitation of a DC motor armature is connected across the output, this is imitated by a resistive-inductive load with a battery which simulates back EMF. The battery is connected in series between these passive components, this EMF can be altered to simulate various types of loads. A voltmeter and oscilloscope are connected in parallel, with the voltmeter measuring the output voltage and the oscilloscope will measure voltage and current waveforms across the armature.

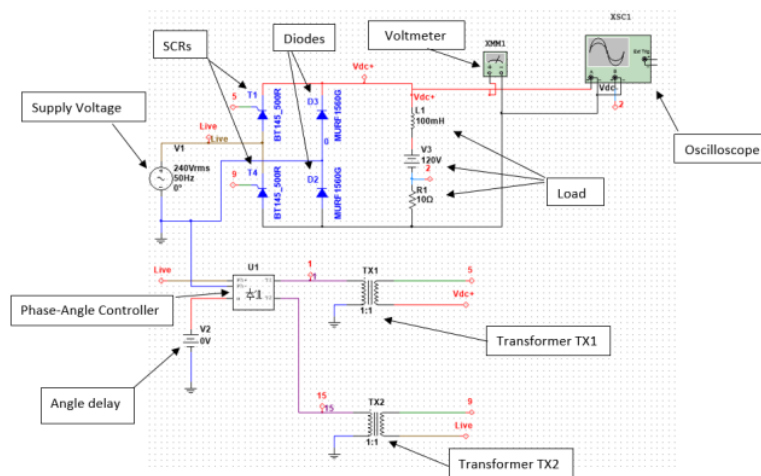


Figure 15 – Annotated Diagram of Multisim Half-Controlled Rectifier Circuit

3.2 The Effect of changing the firing angle at a fixed load

The modelled half-controlled rectifier circuit as seen in figure 15 is kept at a constant load consisting of an inductance of 100mH, a resistance of 10Ω with a back EMF set at 120V. The firing angle of the phase-angle controller is altered to provide analysis of how the system performs at three different firing angles, this is performed by altering the voltage connected to the angle terminal of the controller. Three angles were chosen, these being 80°, 100° and 120°. The process of obtaining the results for each angle along with the calculations are seen in appendix 9.1.1, the values obtained from the simulations and calculations are seen in table 3.

The effect of changing the firing angle at a fixed load									Good results
Angle°	T_1	T_2	E_A	V_{max}	α	β	Simulated V_A	Calculated V_A	Error of Simulation vs Calculation
80°	2.829ms	4.455ms	120V	337.06V	1.399rad	0.888rad	145.847V	145.14V	0.707V
100°	1.768ms	5.587ms	120V	337.06V	1.755rad	0.555rad	133.479V	133.47V	0.009V
120°	0.628ms	6.69ms	120V	337.06V	2.10rad	0.197rad	125.338V	125.75V	0.412V

Table 3 – Results for the effect of changing the firing angle at a fixed load

As seen in table 3, the results from altering the firing angle were highly successful from an analysis perspective. From looking at the error column it is clearly seen that there are very small differences between the simulated value and the calculated values using mathematical formulas, in turn proving that both methods are accurate approaches when calculating the armature voltage of a DC motor.

The largest measured error was recorded at 0.707V for a firing angle of 80°, the 100° firing angle produced the lowest error of 9mV which is negligible, the 120° firing angle produced a small error of 412mV between simulation and calculation. These errors are likely due to accuracy with the cursor on Multisim when finding values for T_1 and T_2 as these are key figures in the calculation of the armature voltage and due to the rounding of calculations. It can also be seen that the firing angle has a direct impact on the armature voltage, it is seen that every time the angle was increased by 20° there is a volt drop of around 10V, this is due to the fact that regulating the firing angle also regulates the voltage.

3.3 The effect of changing the load at a fixed firing angle

In order to simulate a mechanical load on the motor various values for back EMF were applied across the motors output. As seen when altering the firing angle at a fixed load when the armature voltage increases so does the current, as the current waveform increases the period of back EMF decreases. Under a load where continuous current is drawn the back EMF period disappears, this is seen in appendix 9.1.2. This will be proven through the use of Multisim whereby the firing angle will be kept at a constant with the back EMF being a variable, the values used for this experiment are seen in table 4.

The effect of changing the Load – Simulation Values			
Firing Angle	Back EMF	Value of t2	Current Type
80	90	4.322	Discontinuous
80	80	4.322	Continuous
80	70	4.247	Continuous
80	60	4.396	Continuous

Table 4 – Results for the effect of changing the Load – Simulation Values

From the values seen in table 4 it is clear to see that at a back EMF of 80V and below the current becomes continuous. Calculations were then performed on the circuit with a back EMF of 60V whereby the phase angle and armature voltage were calculated to prove the reliability as seen in appendix 9.1.2, the comparison results and calculated values are seen in table 5. As seen in table 5, the results show that the methods for calculating armature voltage and phase angle are highly accurate with miniscule errors of 2.1% between phase-angle values and 0.05% between armature voltage values, these errors are due to cursor accuracy in Multisim and rounding errors in calculations. It is seen at continuous current, the back EMF has disappeared, therefore it is not reducing the armature voltage which now stays at a steady value during the period of continuous current, this is seen in figures 28 to 30.

The effect of changing the Load – Comparison of Back EMF Values		
	Phase Angle	Armature Voltage
Simulated	80°	127.586
Calculated	79.128°	127.526V
Difference	0.872	0.06

Table 5 – Results for the effect of changing the Load – Comparison of Back EMF Values

4. Practical Investigation into a Single Quadrant DC Drive

The Parker 512C drive was connected to a DC motor with a Prony brake connected to the shaft. Suitable measuring equipment in the form of Picoscope current and voltage meters were connected to the armature connections in order to measure voltage and current waveforms.

4.1 Investigation into the Off Load Performance of a Single Quadrant DC Drive

For the off-load analysis of the single quadrant DC drive, the Prony brake was disconnected from the motors shaft. Using the Potentiometer on the control panel, three different analog signals were sent to the drive to set the drives output at three different speeds in order to monitor the affect this had on the armature voltage and current waveforms. The calculations and Picoscope screenshots of the current and voltage waveforms are seen in appendix 9.2.1, with the results seen in table 6.

Off Load Performance of a Single Quadrant DC Drive Results						
Speed	Measured V_{AVG}	Calculated V_{AVG}	Armature Current	$t\alpha$	$t\beta$	Back EMF
502 RPM	35.92V	39.31V	114mA	8.218ms	1.796ms	35.76V
1003 RPM	70.32V	74.02V	151mA	7.619ms	0.816ms	66.8V
1500 RPM	105.8V	107.38	347mA	6.88ms	0.756ms	97.89V

Table 6 – Results for the off-Load Performance of a Single Quadrant DC Drive

As seen in the results table it clearly shows there are errors between the measured V_{AVG} and calculated V_{AVG} , this is due to the user accuracy when placing the data points on the Picoscope graphs as it is difficult to place the cursors at the exact points for measurements, this is common for all three measured speeds. Other potential errors that could cause this discrepancy is due to inaccurately measuring the firing angles, and the rounding of calculations will cause errors in comparison. It is seen from figures 33 to 38 that the current waveforms do not change greatly, they only increase at a minuscule amplitude as the speed increases. As expected, as the speed increases, so does the average armature voltage, this is expected as within DC motors speed is proportional to voltage. It is seen in figures 33 to 38 that as the speed increases, the firing angle does not vary much, however, the back EMF waveform is much more prominent, this is because EMF and speed are proportional to each other, as the speed increases so does the EMF, this is seen in table 6 as the back EMF increases by around 30V per 500 RPM increase.

4.2 Investigation into the Under-Load Performance of a Single Quadrant DC Drive

The DC motor's brake was connected to the shaft in order to monitor its performance under three various mechanical loads, these loads were chosen at 0.5Nm, 1.0Nm and 1.5Nm. The current waveforms were monitored through the use of the Picoscope application. The results are seen in figures 16 to 18.

0.5Nm Load

At 0.5Nm it is seen that the armature current drawn is discontinuously, as seen when it falls to 0 Amps for a short period before increasing again as the thyristor is fired.

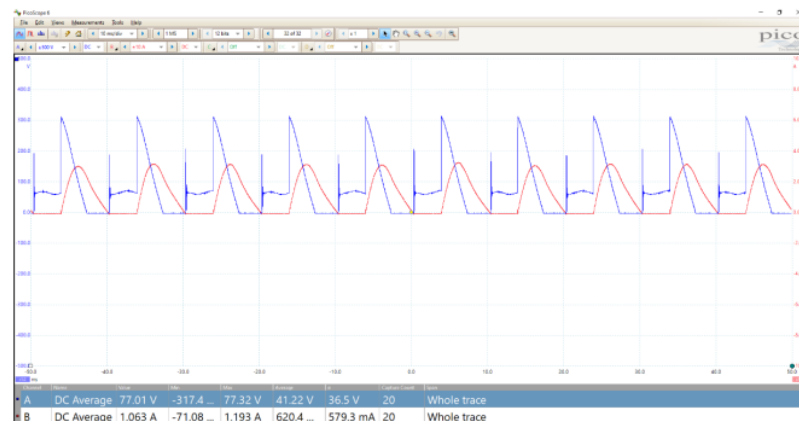


Figure 16 – Armature voltage and current waveform at 0.5NM

1.0Nm Load

At 1.0Nm of torque it is seen that the firing angle has become much larger, the back EMF period has drastically reduced and the period of discontinuous current has vastly shortened compared to the 0.5Nm load, at this load it is on the peak of producing a waveform with continuous current.

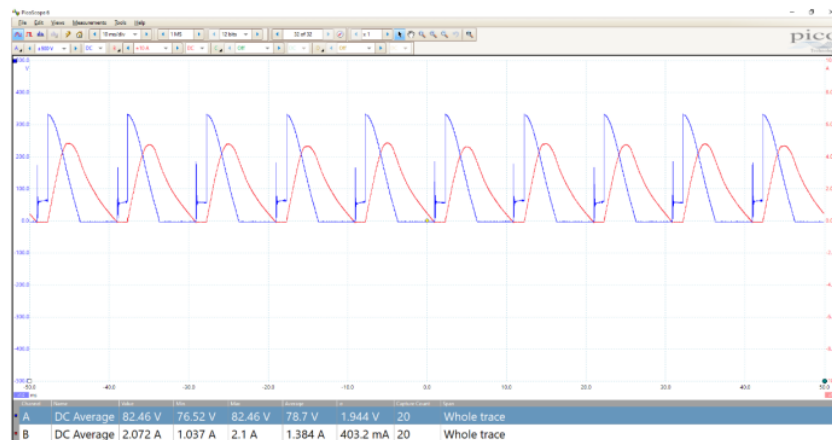


Figure 17 Armature voltage and current waveform at 1.0NM

1.5Nm Load

At a torque of 1.5Nm it is seen that the period of back EMF has disappeared, the firing angle is much bigger and the current is now drawn continuously.

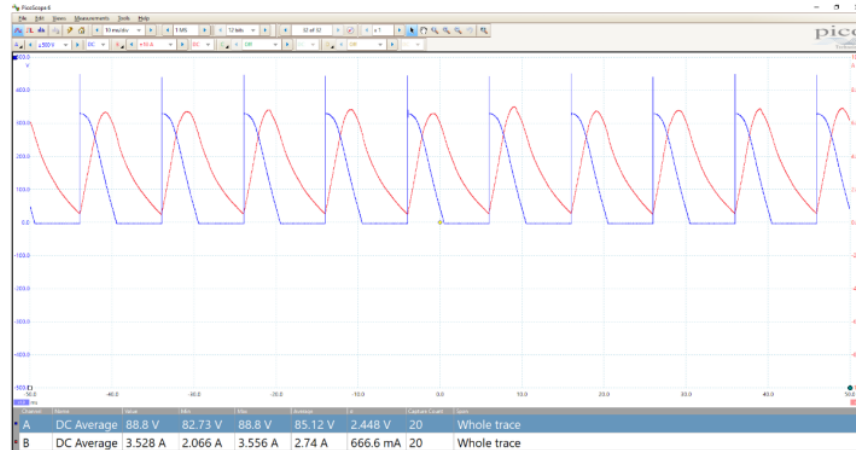


Figure 18 - Armature voltage and current waveform at 1.5NM

It is seen from the performance results in table 7 that the DC motor performed as expected when looking at the Picoscope results. It is seen from the results that the increase in load torque results in a linear increase in the armature current drawn, proving that the armature current has a proportional relationship to torque. The feedback loop of the DC drive is seen to be operating, as the load torque increases so does the armature voltage, this control loop functions to keep a constant speed when the load increases by reducing the value of alpha. At 1.5Nm the current is continuously drawn and the back EMF is not seen.

Under Load Performance of a Single Quadrant DC Drive Results			
Load Torque	Measured V_{AVG}	Measured Current	Current Type
0.5Nm	41.2V	580mA	Discontinuous
1.0Nm	78.7V	1.38A	Discontinuous
1.5Nm	88.8V	2.74A	Continuous

Table 7 – Results for the Under Load Performance of a Single Quadrant DC Drive

5. Simulation of a Medium Length Transmission Line

Figure 19 displays the nominal π Multisim circuit for the medium length transmission line. An explanation about this experiment along with the calculations used to derive the values is seen in appendix 9.3. As seen in figure 19 Voltmeters, Ammeters and Wattmeter's have been used in order to measure key points of the system.

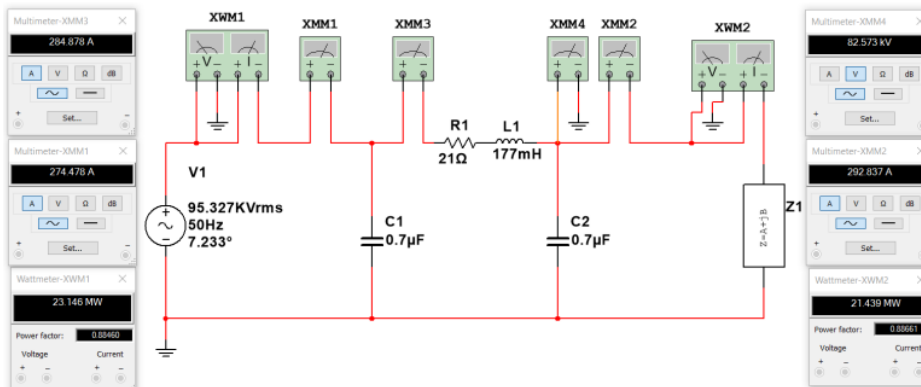


Figure 19 – Nominal π circuit for a medium length transmission line with results

Table 8 displays a comparison between calculated values from appendix 9.3 and simulated values. It is clearly seen that both the calculated method and simulated method are highly accurate methods when determining key values within this system, this is solidified by the fact that the largest error between calculation and simulation is negligible at 0.19%. It is also noted that every value calculated is slightly larger than the simulated value, this is likely due to rounding errors when calculating or due to Multisim method of calculation.

Medium Length Transmission Line – Comparison of Calculation vs Simulation				
	Calculation	Simulation	Error	% Accuracy
Sending End Voltage (VSN)	95.327 KV	95.327 KV	0	100%
Sending End Current (ISN)	274.844 A	274.478 A	0.366	99.87
Sending End Power Factor	0.88511 P.F	0.88460 P.F	0.00051	99.94%
Sending End Power	23.19 MW	23.146 MW	0.044	99.81%
Receiving End Voltage (VRN)	82.596 KV	82.573 KV	0.023	99.97%
Receiving End Current (IRN)	293.124 A	292.838 A	0.286	99.90%
Receiving End Power Factor	0.88722 P.F	0.88661 P.F	0.00061	99.93%
Receiving End Power	21.48 MW	21.439 MW	0.041	99.81%
Current (I1)	285.2138 A	284.876 A	0.3378	99.88%

Table 8 - Comparison of Calculation vs Simulation for the medium length transmission line

Another key aspect of a transmission line is its efficiency, this is the relationship between the power at the sending-end compared to the receiving-end, with the lower the error between these meaning the more efficient the system is due to less power being lost due to heat and line impedance. The efficiency comparison is seen in table 9.

Medium Length Transmission Line – Comparison of Efficiency				
	Sending End	Receiving End	Error	Efficiency %
Calculated Power (MW)	23.19 MW	21.48 MW	1.71MW	92.626%
Simulated Power (MW)	23.146 MW	21.439 MW	1.707MW	92.625%

Table 9 - Comparison of efficiency for the medium length transmission line

As seen in table 9, there is a negligible error of 0.01% between the simulation and calculation, this is due to rounding errors or Multisims calculation method, again proving that both the calculations and Multisim simulation are highly accurate methods of analysing the systems performance.

6. Overall Conclusions and Recommendations

Too much of this reads like a summary of what you did.

From an overall point of view in terms of the calculations, results and observations undertaken, this report has been highly successful. The comprehensive research undertaken based around DC machines set a solid basis for the following tasks due to the key information learned in this element of the report. The industrial DC machine application task was useful as the various types of DC motor were researched, these being the Series-Wound DC motor, Shunt-Wound DC motor and the Separately-Excited DC motor, from this their characteristics and best suited applications were understood. Research was then undertaken on methods of control of DC machines from AC supplies, this research element was undertaken into the electronic components that are used in DC drives, such as key components like the thyristor and how they operate within a DC drive. Research was undertaken on the single-pulse rectifier, single-phase half-controlled converter, single-phase fully-controlled converter and the three-phase four quadrant converter, from this their principles of construction and operation were understood, it was found that the three-phase four quadrant drive is the most efficient and eloquent method of controlling a DC motor due to the four quadrants of operation it performs under offering forward motoring, reverse motoring, forward braking and reverse braking. The final area of research was specific to the construction and operation of the single-quadrant Parker 512C DC drive, this was highly useful as it provided extensive information about the DC drive used in the practical.

This reads more like a reflection on what you did.

The practical elements were performed with great success. The simulation of the half-controlled rectifier circuit provided a safe environment to understand the testing element of the experiments. Software skills were improved through using Multisim to simulate a circuit of a half-controlled rectifier circuit with a load consisting of a resistor, inductor and battery to represent a DC motor with back EMF, from this waveform analysis skills were developed as the waveforms were analysed for armature voltage and current for three different firing angles, from this it was found that as the firing angle increased the armature voltage

This is useful

decreased, this was found to be due to an increase in the firing angle delay causing the thyristor to miss a large section of the input waveform, therefore the output voltage decreases, it was also found that the power factor decreases due to the delay of current flow, therefore the current lags voltage much like an inductive load, the greater the SCR turn on delay the greater the current lags voltage. The second simulation was to observe the effect that three different mechanical loads had on the current waveform, this was performed by altering the back EMF to show continuous current, it was found that as the back EMF acts against the armature voltage it reduces the current flow in the armature, this was proven as when the value of back EMF was reduced it is seen that more current flows, eventually drawing continuous current as the back EMF disappeared.

The practical investigation provided hands on experience needed to compare simulation to practical. The Parker 512C drive was connected to a DC motor and Picoscope clamp meters were connected to observe armature voltage and current waveforms for three different speeds under no load and three different loads at one speed. In the no-load test it was found that as the speed increases so does the voltage across the armature, due to the proportional relationship between speed and voltage, whereas, the loading test the theory that torque and armature current are proportional was proven, as the load increased so did the current, eventually drawing continuous current. The feedback loop of the Parker 512C as discussed in the research section was seen to be working, this is because as the load torque increased so does the armature voltage in order to keep a constant speed, this is due to the proportional relationship between torque and voltage.

The drive controls the voltage to maintain speed via feedback and armature voltage adjustment

The practical into the simulation of a transmission line also proved successful, from these important principles of high-voltage systems were understood, the results obtained from the calculation were highly accurate to the Multisim, proving that both methods are accurate when calculating the characteristics of a transmission line.

As a recommendation, for the practical load test it would be beneficial to measure the speed over the various torque ranges, from this the efficiency of the speed control-loop in the DC drive could be analysed and how the firing angle is altered to compensate for the increased load, this could be done by measuring the motor shaft with a tachometer and measuring the speed over various loads. Another useful practical would be to use a single-phase fully-controlled DC drive to compare the operation, characteristics and efficiency.

such as?

7. Team Working

Due to the global pandemic team working was limited to only necessary tasks whilst all government and HSE guidelines were followed. A safe working environment was provided by the lecturer in terms of both the pandemic and practical experiment where all PPE was supplied. The authors role was to note down all readings from the Picoscope application and note them down in tabulated format. As the local lockdown was eased, classroom learning recommenced allowing these practical's to take place.

8. Citation List

- Cavallo, C., 2018. *All About Shunt DC Motors - What They Are and How They Work*. [Online]
Available at: <https://www.thomasnet.com/articles/machinery-tools-supplies/shunt-dc-motors/>
[Accessed 01 05 2021].
- circuitglobe, 2020. *Four Quadrant Operation of DC Motor*. [Online]
Available at: <https://circuitglobe.com/four-quadrant-operation-of-dc-motor.html#:~:text=Four%20Quadrant%20Operation%20of%20any,Reverse%20motoring%20and%20Reverse%20braking.>
[Accessed 02 05 2021].
- Collins, D., 2015. *FAQ: What are DC shunt motors and where are they used?*. [Online]
Available at: [2021](#)
[Accessed 01 05 2021].
- Daware, K., 2018. *Speed Control Methods Of DC Motor*. [Online]
Available at: <https://www.electrical4u.com/2014/01/speed-control-methods-of-dc-motor.html#:~:text=Armature%20control%20method-Speed%20of%20a%20dc%20motor%20is%20directly%20proportional%20to%20the,to%20armature%20current%20Ia.>
[Accessed 01 05 2021].
- Dostal, F., 2020. *Voltage Conversion in Four Quadrants*. [Online]
Available at: <https://www.electronicdesign.com/resources/ideas-for-design/whitepaper/21146380/analog-devices-voltage-conversion-in-four-quadrants>
[Accessed 02 05 2021].
- drive.tech, 2021. *1-Q vs. 4-Q controllers*. [Online]
Available at: <https://drive.tech/en/stream-content/id-1-q-vs-4-q-controllers>
[Accessed 02 05 2021].
- Electrical4U, 2020. *DC Shunt Motor: Speed Control, Characteristics & Theory*. [Online]
Available at: <https://www.electrical4u.com/shunt-wound-dc-motor-dc-shunt-motor/>
[Accessed 02 05 2021].
- Electrical4U, 2020. *Series Wound DC Motor or DC Series Motor*. [Online]
Available at: <https://www.electrical4u.com/series-wound-dc-motor-or-dc-series-motor/>
[Accessed 01 05 2021].
- Electrical4U, 2020. *Types of DC Motors And Their Applications*. [Online]
Available at: <https://www.electrical4u.com/types-of-dc-motor-separately-excited-shunt-series-compound-dc-motor/>
[Accessed 02 05 2021].
- electrical4u, 2018. *Speed Control of Shunt Motor*. [Online]
Available at: <https://www.electrical4u.com/2014/01/speed-control-methods-of-dc-motor.html#:~:text=Armature%20control%20method-Speed%20of%20a%20dc%20motor%20is%20directly%20proportional%20to%20the,to%20armature%20current%20Ia.>
[Accessed 02 05 2021].

electronics-tutorials, 2017. *Separately Excited DC Motor*. [Online]
Available at: <https://www.electronics-tutorial.net/electronic-systems/separately-excited-dc-motor/>
[Accessed 02 05 2021].

ElectronicsTutorials, 2018. *Fully-controlled Bridge Rectifier*. [Online]
Available at: <https://www.electronics-tutorials.ws/power/single-phase-rectification.html>
[Accessed 02 05 2021].

ElectronicsTutorials, 2019. *Thyristor Tutorial*. [Online]
Available at: <https://www.electronics-tutorials.ws/power/thyristor.html>
[Accessed 02 05 2021].

ElProCus, 2019. *What is a DC Shunt Motor : Construction, Working Principle, Circuit Diagram*. [Online]
Available at: <https://www.elprocus.com/dc-shunt-motor-construction-working-principle-circuit-diagram/>
[Accessed 01 05 2021].

ElProCus, 2021. *Power Electronic Converters*. [Online]
Available at: <https://www.elprocus.com/power-electronic-converters/>
[Accessed 02 05 2021].

Hughes, A., 2013. Conventional DC Motors. In: *Electric motors and drives: Fundamentals, Types, and Applications*. s.l.:Newnes, p. 437.

Kharagpur, 2015. *Module 2: AC to DC Converters*, s.l.: EE ITT.

Linquip, 2020. *How does a Series DC Motor work?*. [Online]
Available at: <https://www.linquip.com/blog/series-dc-motors/#:~:text=Series%20DC%20motors%20are%20a,one%20based%20on%20electromagnetic%20law.>
[Accessed 01 05 2021].

Linquip, 2020. *Series DC Motors: A Comprehensive Guide*. [Online]
Available at: <https://www.linquip.com/blog/series-dc-motors/#:~:text=Series%20DC%20motors%20are%20a,one%20based%20on%20electromagnetic%20law.>
[Accessed 01 05 2021].

Mawdsleys, 2019. *Types of DC Motors*. [Online]
Available at: <https://www.mawdsleysber.co.uk/types-dc-motors/>
[Accessed 01 05 2021].

Parker, 2016. *512C DC Controller*. [Online]
Available at: <https://www.parker.com/Literature/SSD%20Drives/DC%20Drives/HA389196.pdf>
[Accessed 02 05 2021].

Rashid, M. H., 2013. Power electronics: devices, circuits and applications.. In: s.l.:Pearson Education, p. 1014.

S., N., 2014. *Single phase half controlled bridge converter*, s.l.: iitb.

Sharma, A., 2016. *Speed Control of DC Shunt Motor*. [Online]
Available at: <https://www.yourelectricalguide.com/2017/09/speed-control-of-dc-shunt-motor.html>
[Accessed 02 05 2021].

TeX, 2018. *SCR (aka thyristor) symbol in TikZ circuit*. [Online]
Available at: <https://tex.stackexchange.com/questions/430193/scr-aka-thyristor-symbol-in-tikz-circuit>
[Accessed 02 05 2021].

Vyas, S., 2019. *Why is the DC series motor used for a heavy load?*. [Online]
Available at: <https://www.quora.com/Why-is-the-DC-series-motor-used-for-a-heavy-load>
[Accessed 01 05 2021].

9. Appendix

9.1 Simulation of a Half-Controlled Rectifier Circuit

Using the Multisim package, a model was created of a single-phase full wave half-controlled rectifier circuit, this circuit is connected to a DC motor modelled armature load, this load consists of an inductor, resistor and a battery.

9.1.1 Changing the firing angle

The first area of analysis is monitoring the performance of this circuit by altering the firing angle, the firing angle is changed by altering the voltage supplied to the circuits phase angle controller, within this system the voltage supplied to the controller is directly proportional to phase angle e.g., 120V = 120°. Firstly, the time period was calculated:

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

The half period was calculated by halving the time period:

$$Half\ Time\ Period = \frac{20}{2} = 10ms$$

Values for α and β are calculated using the equations:

$$\alpha = \frac{t_2}{10} \times \pi \quad and \quad \beta = \frac{t_1}{10} \times \pi$$

In order to measure the average armature voltage, the equations below were derived:

Area 1 is calculated as:

$$area\ 1 = \int_{\alpha}^{\pi} V_{max} \sin(\sigma) \, d\sigma = V_{max}[-\cos\sigma]_{\alpha}^{\pi}$$

This is simplified as:

$$area\ 1 = V_{max}[-\cos\pi - -\cos\alpha]$$

Further simplified:

$$area\ 1 = V_{max}(1 + \cos\alpha)$$

Area 2 is calculated as:

$$Area\ 2 = E \times (\alpha - \beta)$$

From this, the average armature voltage is calculated using the equation:

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

Or:

$$V_{av} = \frac{Area\ 1 + Area\ 2}{\pi}$$

Before the various firing angles can be applied to the circuit, V_{max} needs to be calculated. The voltage drops across the SCRs and Diodes. These were found to be 1.1V across the SCR and 1.25V across the diodes, therefore V_{max} is calculated as:

$$V_{max} = 240 \times \sqrt{2} - (1.1 + 1.25) = 337.06V$$

This was further confirmed through Multisim by applying a small firing angle to the phase-angle controller and placing the probe at the voltage peak. A voltage of 337.02 was obtained which coincides with the calculation proving the accuracy, this is seen in figure 20.

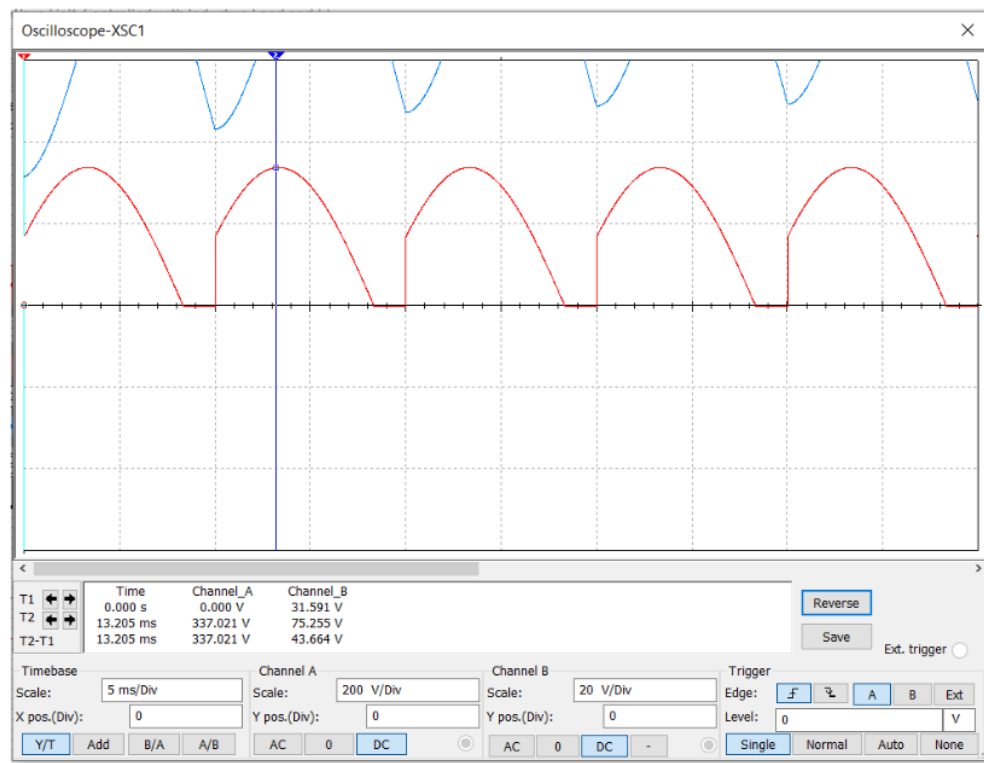


Figure 20 – Average Voltage measurement for Half-Controlled rectifier on Multisim

With all calculations for the system derived, the firing angle can now be altered.

80 Degree Firing Angle

At a firing angle of 80 degrees the Multisim average voltage is 145.847

T1 = 2.829

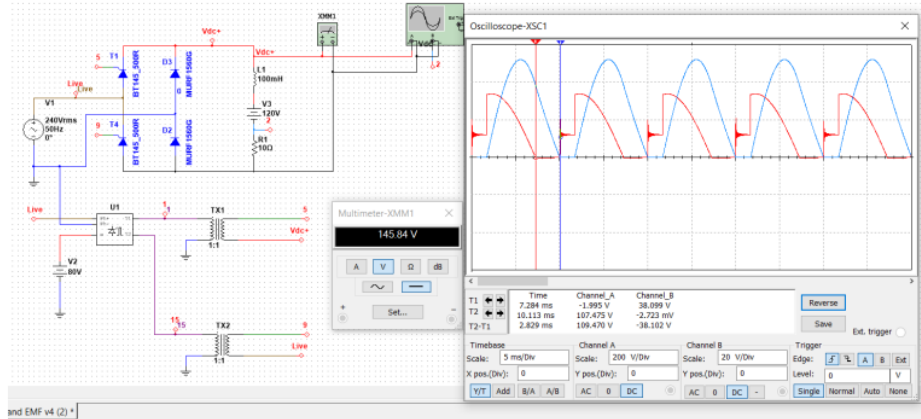


Figure 21 – 80 degree firing angle T1

T2 = 4.455

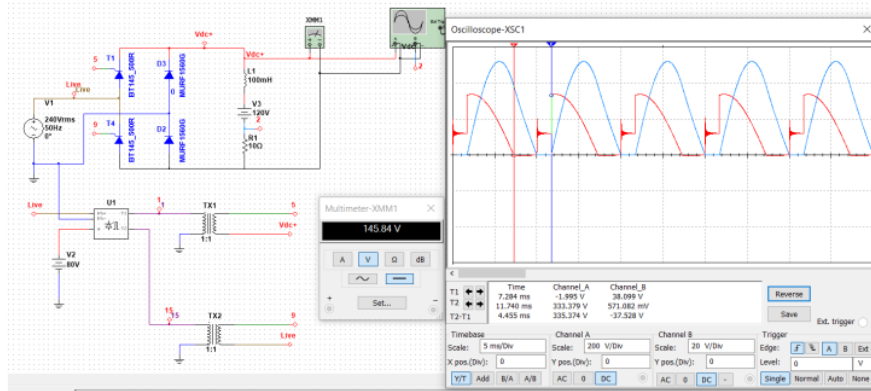


Figure 22 - 80 degree firing angle T2

The average armature voltage can then be mathematically calculated.

$$\alpha = \frac{T2}{10} \times \pi = \frac{4.455}{10} \times \pi = 1.399 \text{ rad}$$

$$\beta = \frac{T1}{10} \times \pi = \frac{2.829}{10} \times \pi = 0.888 \text{ rad}$$

With values for α and β the average armature voltage can be calculated:

$$V_{av} = \frac{V_{max}(1 + \cos(\alpha)) + E(\alpha - \beta)}{\pi} = \frac{337.06(1 + \cos(1.399)) + 120(1.399 - 0.888)}{\pi} = 145.14V$$

100 Degree Firing Angle

At a firing angle of 100 degrees the Multisim average voltage is 133.479

T1 = 1.768

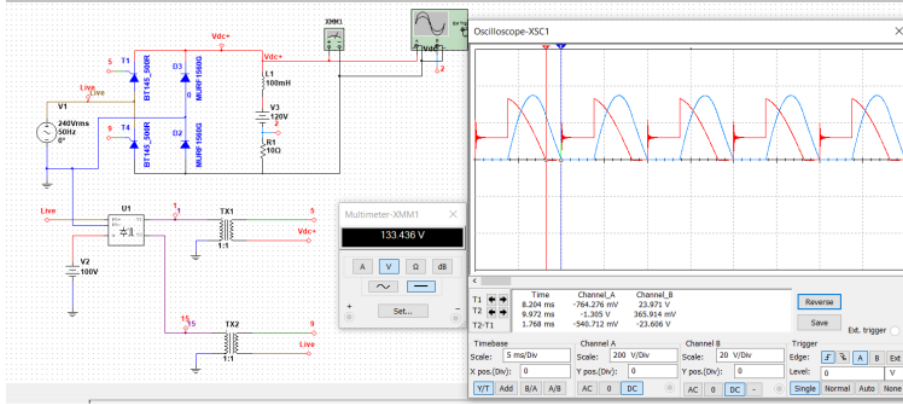


Figure 23 - 100 degree firing angle T1

T2 = 5.587

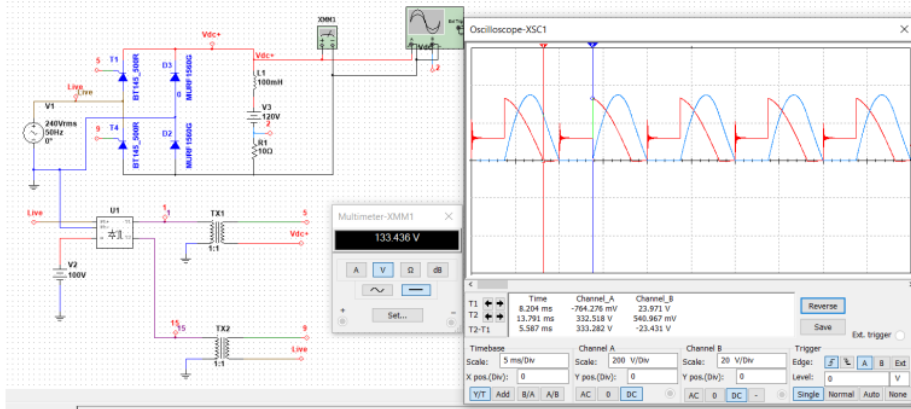


Figure 24 - 100 degree firing angle T2

The average armature voltage can then be mathematically calculated.

$$\alpha = \frac{T2}{10} \times \pi = \frac{5.587}{10} \times \pi = 1.755 \text{ rad}$$

$$\beta = \frac{T1}{10} \times \pi = \frac{1.768}{10} \times \pi = 0.555 \text{ rad}$$

With values for α and β the average armature voltage can be calculated:

$$V_{av} = \frac{V_{max}(1 + \cos(\alpha)) + E(\alpha - \beta)}{\pi} = \frac{337.06(1 + \cos(1.755)) + 120(1.755 - 0.555)}{\pi} = 133.47V$$

120 Degree Firing Angle

At a firing angle of 120 degrees the Multisim average voltage is 125.338V.

$T1 = 0.628$

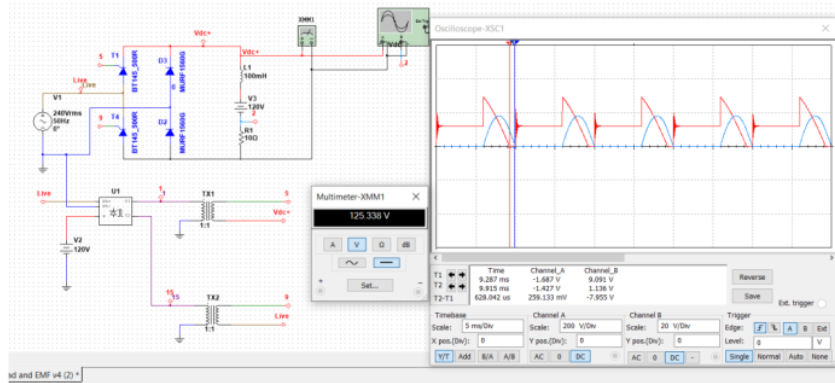


Figure 25 - 120 degree firing angle T1

$T2 = 6.69$

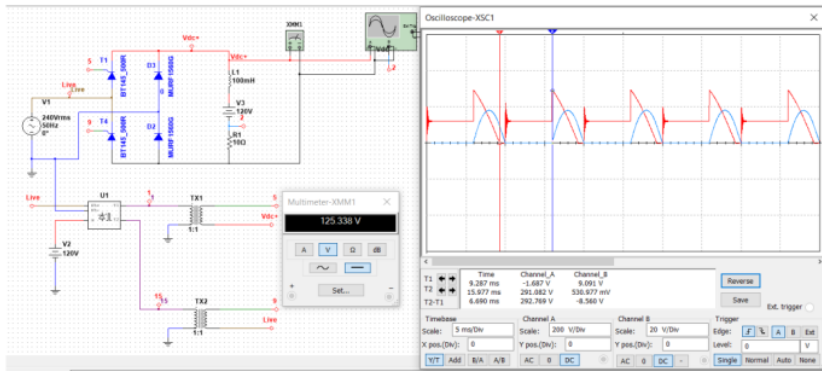


Figure 26 - 120 degree firing angle T2

The average armature voltage can then be mathematically calculated.

$$\alpha = \frac{T2}{10} \times \pi = \frac{6.69}{10} \times \pi = 2.101 \text{ rad}$$

$$\beta = \frac{T1}{10} \times \pi = \frac{2.656}{10} \times \pi = 0.197 \text{ rad}$$

With values for α and β the average armature voltage can be calculated:

$$V_{av} = \frac{V_{max}(1 + \cos(\alpha)) + E(\alpha - \beta)}{\pi} = \frac{337.06(1 + \cos(2.101)) + 120(2.101 - 0.197)}{\pi} = 125.75V$$

9.1.2 Changing the back EMF

Figure 27 shows the back EMF of 90V at a firing angle of 80° showing a discontinuous current. The firing angle will be kept as a constant with the back EMF being the variable.

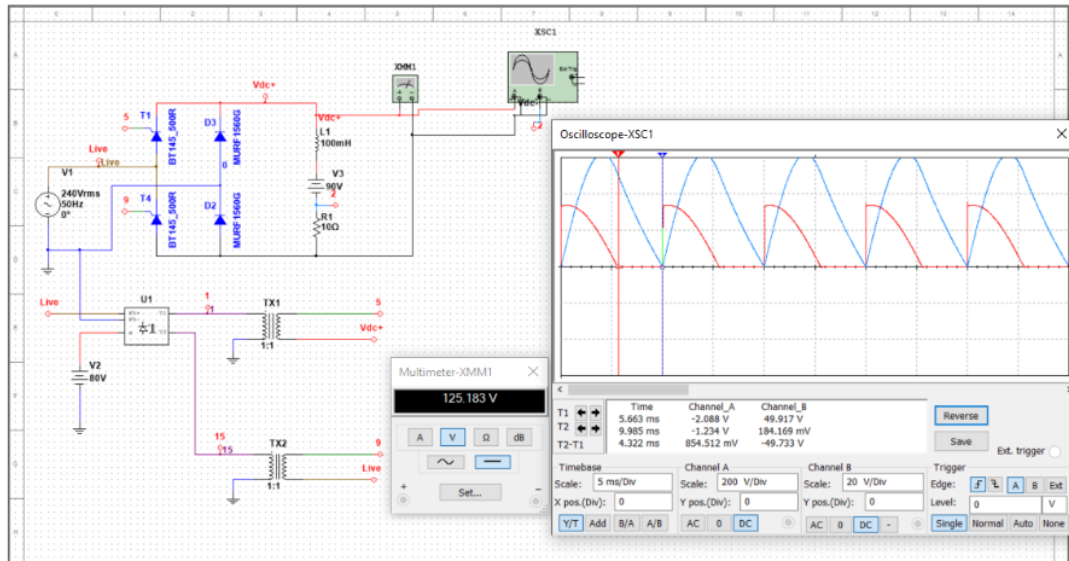


Figure 27 – Changing the back EMF, 90V EMF at 80°

The back EMF is reduced until continuous current is visible, this is first seen at 80V.

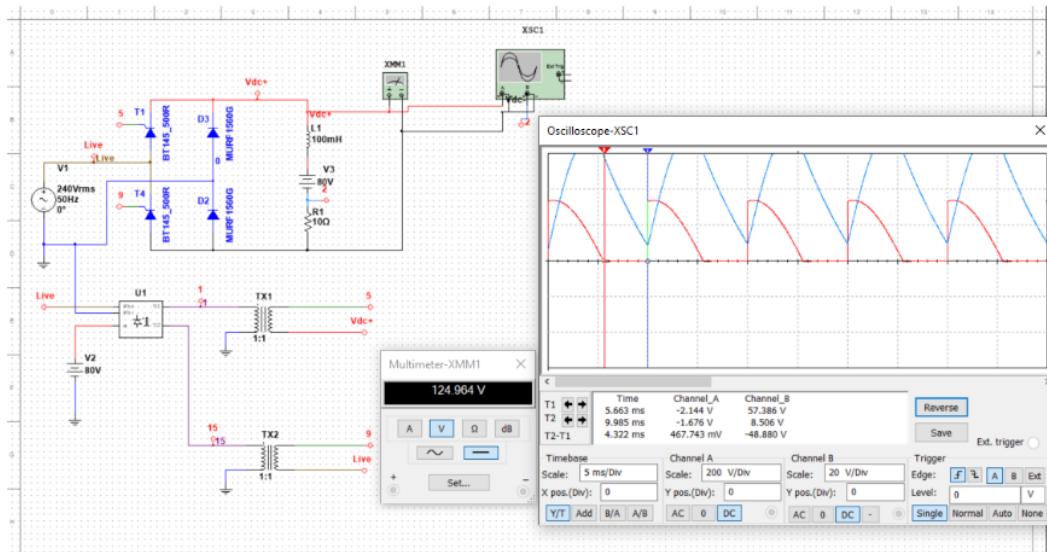


Figure 28 - Changing the back EMF, 80V EMF at 80°

The back EMF is further reduced with continuous current still being visible, the second back EMF value is at 70V.

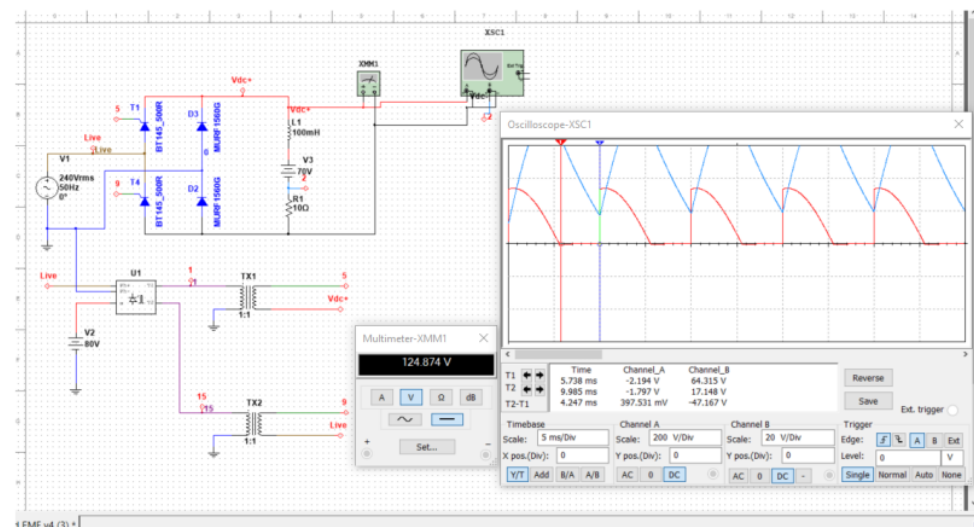


Figure 29 - Changing the back EMF, 70V EMF at 80°

The final back EMF value was 60V, continuous current is still seen on the scope response.

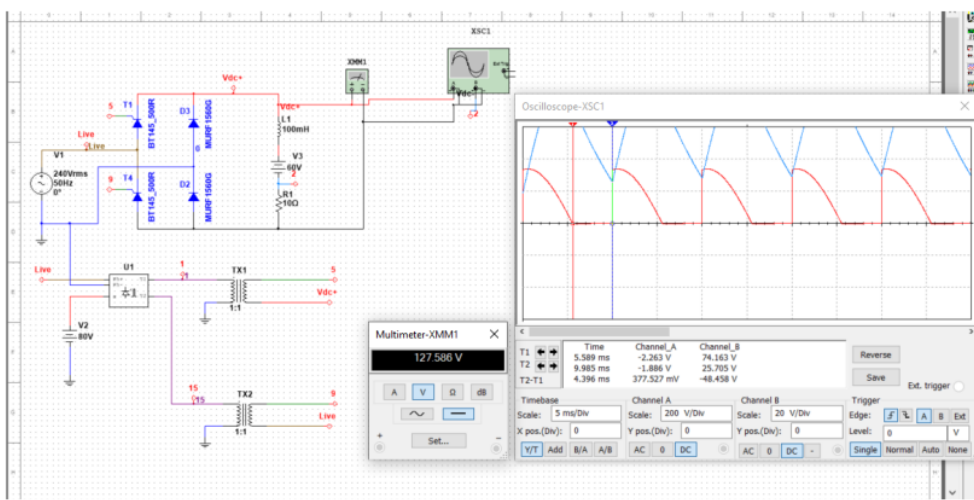


Figure 30 - Changing the back EMF, 60V EMF at 80°

9.1.3 Calculations for changing the back EMF at a fixed load

The chosen back EMF value for the calculation is 60V, the calculations for this are seen below:

The first equation needed to be calculated is the Half-cycle time:

$$\begin{aligned} Full\ Cycle &= \frac{1}{f} = \frac{1}{50} = 20ms \\ Half\ Cycle &= 20 / 2 = 10ms \end{aligned}$$

The value of α is then calculated:

$$\alpha = \left(\frac{t2}{Half\ Cycle} \right) \times \pi = \left(\frac{4.396 \times 10^{-3}}{10} \right) \times \pi = 1.38104\ rad$$

The average voltage is then calculated, the value for V_{pk} is the same value from the firing angle tests:

$$v_{av} = \frac{V_{pk}}{\pi} (1 + \cos(\alpha)) = \frac{337.06}{\pi} (1 + \cos(1.38104)) = 127.526\ v$$

The Phase Angle is then calculated:

$$t2 \times 180^\circ = 0.4396 \times 180 = 79.128^\circ$$

9.2 Practical investigation into a Single Quadrant DC Drive

A Parker 512C DC drive was connected to a DC motor, A brake was connected for the load test, this brake allowed for the analysis of how the motor performs under a specified load, this was disconnected for the off-load test. A Picoscope clamp meter was connected to the DC motor's armature in order to measure the voltage and current waveforms for analysis. Figure 31 shows the motor connections to the panel for the field and armature, push buttons are used to control the drives operation.

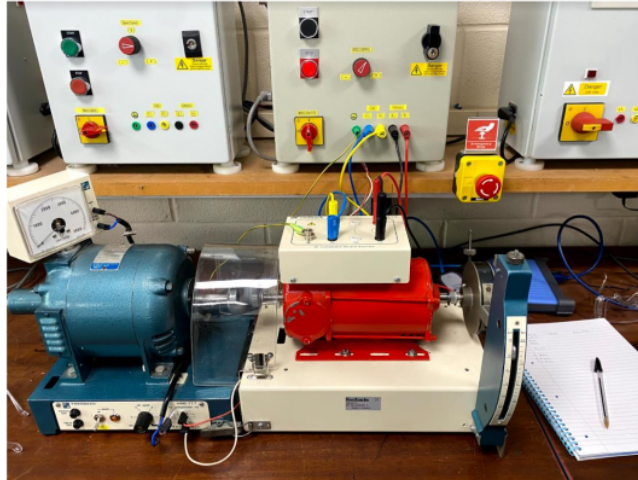


Figure 31 – Practical Set-up

As seen in figure 32, the peak voltage of the waveform is found at 336.3V as it is $672.6\text{V}/2$.

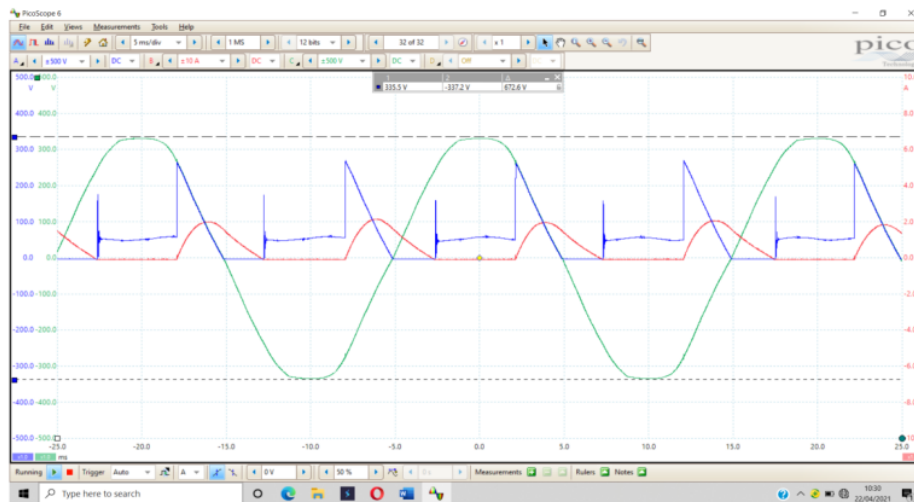


Figure 32 – Vpk for Armature voltage

9.2.1 Off Load Performance of a Single Quadrant DC Drive

The DC motor’s brake was disconnected in order to monitor the off-load performance of the DC motor over three different set-points. As this speed was controlled through the use of a potentiometer it was found difficult to accurately find readings at a round number, due to this, speeds were chosen as close to a round number as possible. These speeds are 502 RPM, 1003 RPM and 1500 RPM.

502 RPM

T1 – 1.796ms

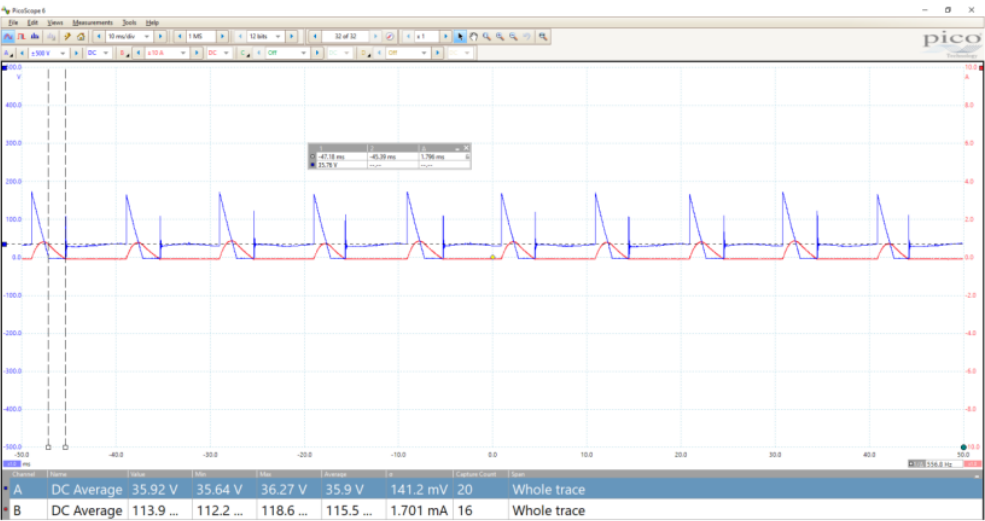


Figure 33 – Off-Load Practical, T1 at 502 RPM

T2 – 8.218ms

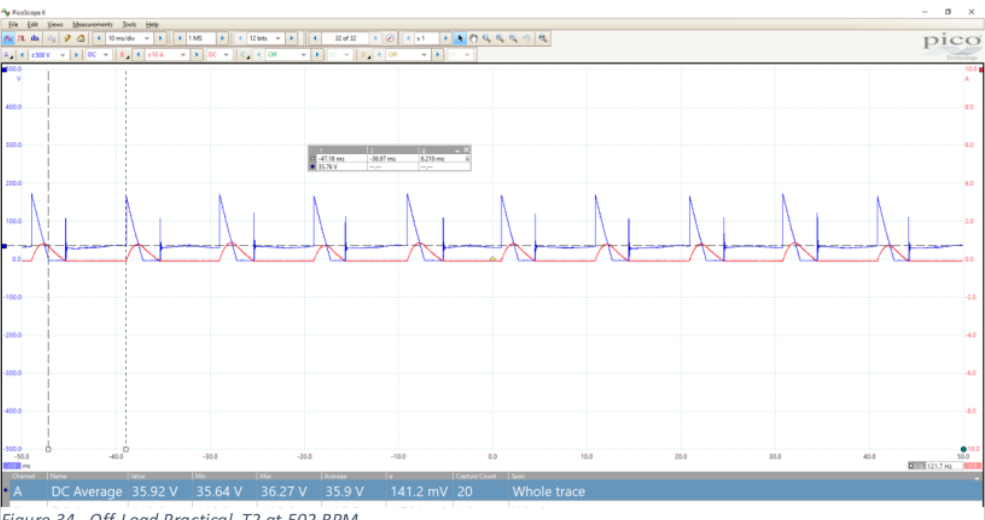


Figure 34 - Off-Load Practical, T2 at 502 RPM

The average armature voltage at 502 RPM can then be mathematically calculated.

$$\alpha = \frac{T2}{10} \times \pi = \frac{8.218}{10} \times \pi = 2.5817 \text{ rad}$$

$$\beta = \frac{T1}{10} \times \pi = \frac{1.796}{10} \times \pi = 0.5642 \text{ rad}$$

With values for α and β the average armature voltage can be calculated:

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

$$V_{av} = \frac{E}{\pi}(\alpha - \beta) + \frac{V_{pk}}{\pi}(1 + \cos(\alpha)) = \frac{35.76}{\pi}(2.5817 - 0.5642) + \frac{336.3}{\pi}(1 + \cos(2.5817)) = 39.31V$$

1003 RPM

T1-0.816ms

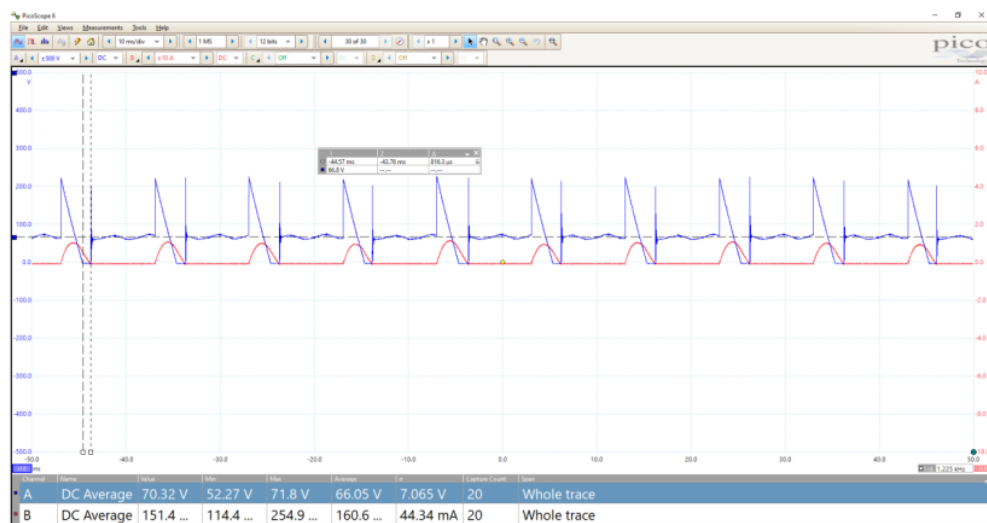


Figure 35 - Off-Load Practical, T1 at 1003 RPM

T2 – 7.619ms

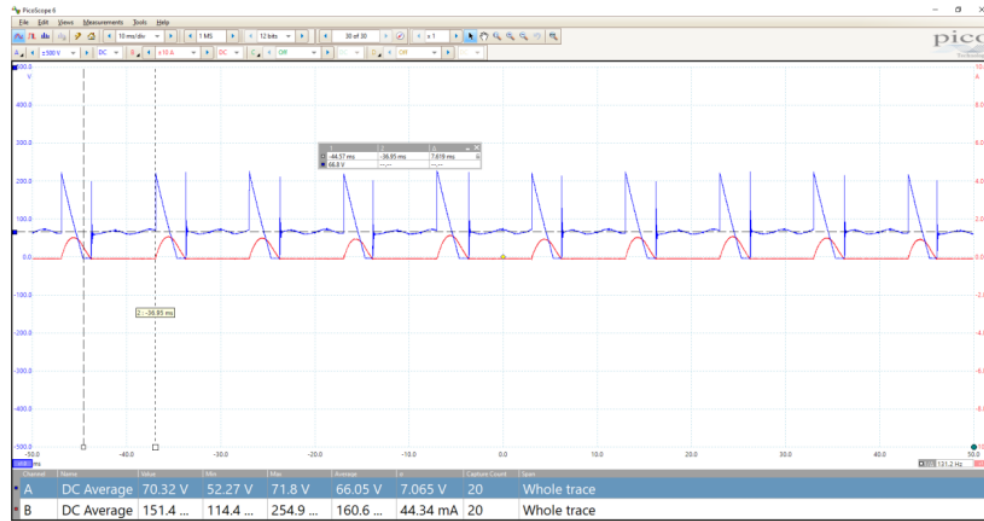


Figure 36 - Off-Load Practical, T2 at 1003 RPM

The average armature voltage at 1003 RPM can then be mathematically calculated:

$$\alpha = \frac{T2}{10} \times \pi = \frac{7.619}{10} \times \pi = 2.3936 \text{ rad}$$

$$\beta = \frac{T1}{10} \times \pi = \frac{0.816}{10} \times \pi = 0.25635 \text{ rad}$$

With values for α and β the average armature voltage can be calculated:

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

$$V_{av} = \frac{E}{\pi} (\alpha - \beta) + \frac{V_{pk}}{\pi} (1 + \cos(\alpha)) = \frac{66.8}{\pi} (2.3936 - 0.25635) + \frac{336.3}{\pi} (1 + \cos(2.3936)) = 74.02V$$

1500 RPM

T1 – 0.756ms

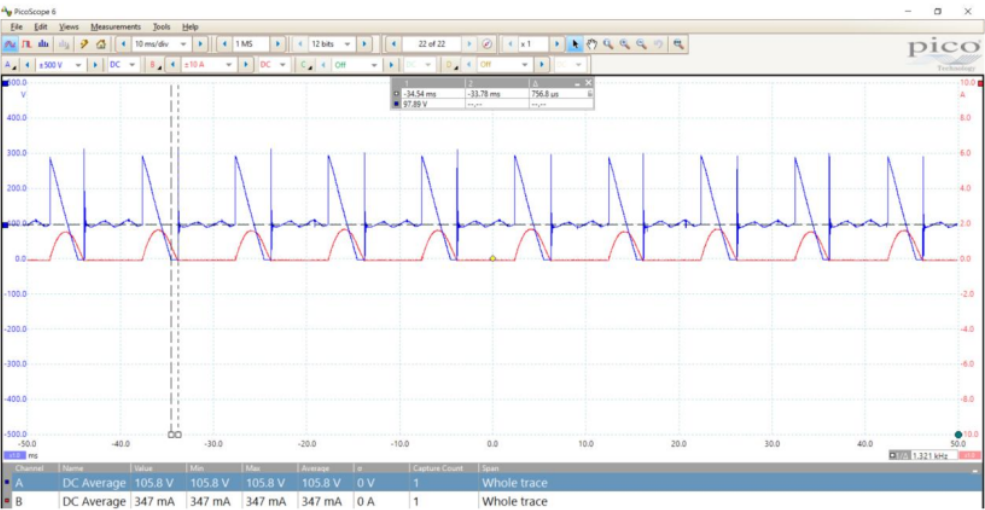


Figure 37 - Off-Load Practical, T1 at 1500 RPM

T2 – 6.88ms

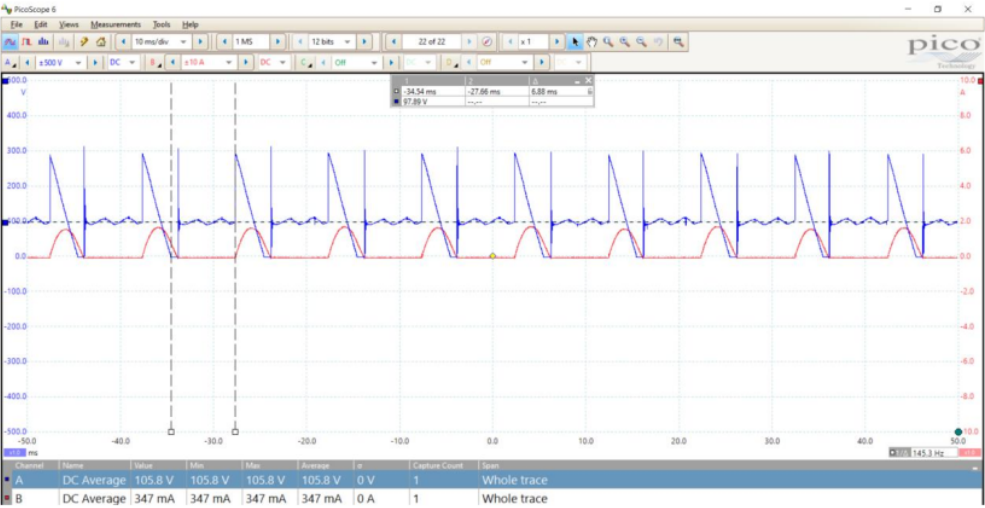


Figure 38 - Off-Load Practical, T2 at 1500 RPM

The average armature voltage at 1500 RPM can then be mathematically calculated.

$$\alpha = \frac{T2}{10} \times \pi = \frac{6.88}{10} \times \pi = 2.1614 \text{ rad}$$

$$\beta = \frac{T1}{10} \times \pi = \frac{0.756}{10} \times \pi = 0.2375 \text{ rad}$$

With values for α and β the average armature voltage can be calculated:

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

$$V_{av} = \frac{E}{\pi} (\alpha - \beta) + \frac{V_{pk}}{\pi} (1 + \cos(\alpha)) = \frac{97.89}{\pi} (2.1614 - 0.2375) + \frac{336.3}{\pi} (1 + \cos(2.1614)) = 107.38V$$

9.3 Calculations for the simulation of a medium length transmission line

A single-phase 50Hz transmission line has a resistance of 21Ω , an inductance of 177mH and a capacitance of $1.4\mu\text{F}$, this transmission line has a load impedance of $250 + j130$. A Multisim model of this circuit is seen in figure 39. Calculations will be undertaken to calculate the series impedance, shunt admittance and the sending-end Voltage, Current and Power Factor when the receiving end has 293.124A at 82.596KV with a lagging power factor of 0.88722 . The sending-end Voltage, Current and Power Factor will then be applied as the supply values, Suitable Multisim values will be taken and compared to the calculations to prove the validity of this method.

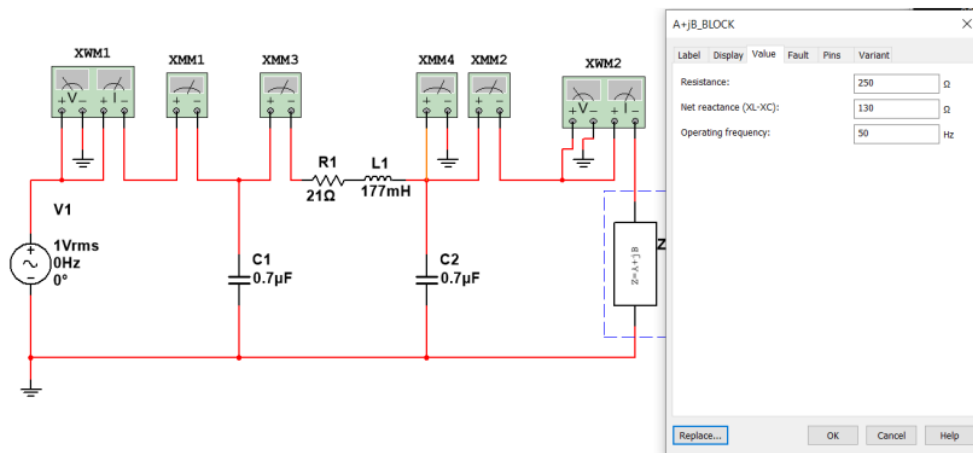


Figure 39 – Nominal π circuit for a medium length transmission line complex load values

The first calculation is the systems Series Impedance:

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

This is then converted into polar form:

$$Z_s = \sqrt{21^2 + 55.606^2} = 59.4393$$

$$\tan^{-1}\left(\frac{55.606}{21}\right) = 69.311^\circ$$

$\therefore$

$$Z_s = 59.4393 \angle 69.311^\circ$$

The Shunt Admittance is calculated:

$$Y = j\omega \times C = j \times 2\pi \times 50 \times 1.4 \times 10^{-6} = j4.398 \times 10^{-4}$$

This is converted to polar form:

$$4.39 \times 10^{-4} \angle 90^\circ$$

Values at the receiving end for Voltage, Current and Power Factor are:

$$\begin{aligned} \text{Voltage} &= 82.596 \text{ kV} \\ \text{Current} &= 293.124 \text{ A} \\ \text{Power Factor} &= 0.88722 \end{aligned}$$

Therefore, the Voltage at the receiving end is:

$$V_{RN} = 82596 \text{ V} \angle 0^\circ$$

The current at the receiving end is calculated:

$$I_{RN} = 293.124 \angle \cos^{-1}(0.88722) = 293.124 \angle -27.474^\circ$$

Using a nominal π circuit:

$$I_1 = I_{RN} + V_{RN} \times \frac{Y}{2}$$

$\therefore$

$$I_1 = 293.124 \angle -27.474^\circ + 82596 \angle 0^\circ \times \frac{4.39 \times 10^{-4}}{2} \angle 90^\circ$$

$$I_1 = 293.124 \angle -27.474^\circ + 18.1298 \angle 90^\circ$$

I_1 is converted to Cartesian:

$$293.124 \cos(27.474) = 260.0655$$

$$293.124 \sin(27.474) = 135.2316 = 260.0655 - j135.2316$$

$$260.0655 - j135.2316 + j18.1298 = 260.066 - j117.1018 \text{ A}$$

I_1 is converted to Polar:

$$\sqrt{260.0655^2 + 117.1018^2} = 285.2138$$

$$\tan^{-1}\left(\frac{117.102}{260.066}\right) = 24.241^\circ$$

I1 in Polar form:

$$285.2138 \angle -24.241^\circ A$$

The voltage at the sending end is calculated (VSN):

$$V_{SN} = V_{RN} + I_1 Z_s$$

$$V_{SN} = 82596 \angle 0^\circ + 285.2138 \angle -24.241^\circ \times 59.4393 \angle 69.311^\circ$$

$$V_{SN} = 82596 \angle 0^\circ + 16952.91.12 \angle 45.07^\circ$$

The VSN is converted to Cartesian:

$$16953.12 \cos(45.07) = 11973.01$$

$$16953.12 \sin(45.07) = 12002.30 = 11973.01 + j12002.30$$

$$82596 + 11973.01 + j12002.30 = 94569.01 + j12002.30$$

The VSN is then converted to Polar:

$$\sqrt{94569.01^2 + 12002.30^2} = 95327.608$$

$$\tan^{-1}\left(\frac{12002.30}{94569.01}\right) = 7.233^\circ$$

$$95327.61 \angle 7.233^\circ \text{ volts}$$

The current at the sending end (ISN) is calculated:

$$I_{SN} = I_1 + V_{SN} \times \frac{y}{2}$$

$$I_{SN} = 260.066 - j117.02^\circ + 95327.608 \angle 7.233^\circ \times \frac{4.39 \times 10^{-4}}{2} \angle 90^\circ$$

$$I_{SN} = 260.066 - j117.02^\circ + 20.924 \angle 97.223^\circ$$

The ISN is converted to Cartesian:

$$20.924 \cos(97.223) = -2.631$$

$$20.924 \sin(97.223) = 20.758 = -2.631 + j20.758$$

$$260.066 - j117.02^\circ - 2.631 + j20.758^\circ = 257.435 - j96.262$$

The ISN is converted to Polar:

$$\sqrt{257.435^2 + 96.262^2} = 274.844$$

$$\tan^{-1}\left(\frac{96.262}{257.435}\right) = 20.502^\circ = 274.844 \angle -20.502^\circ A$$

The angle between the VSN and ISN is calculated:

$$VSN(\emptyset) - ISN(\emptyset) = 7.233^\circ - (-20.502^\circ) = 27.735^\circ$$

The Sending end power factor can be calculated:

$$\cos(VSN\emptyset - ISN\emptyset) = \cos(7.233^\circ - (-20.502^\circ)) = \cos(27.735^\circ) = 0.88511$$

The final calculation is to calculate the power lines efficiency:

Sending End:

$$\begin{aligned} P &= IxVxP.F \\ P &= 274.844 \times 95327.61 \times 0.88511 \\ P &= 23.19 \times 10^6 W \end{aligned}$$

Receiving end:

$$\begin{aligned} P &= IxVxP.F \\ P &= 293.124 \times 82586 \times 0.88722 \\ P &= 21.48 \times 10^6 W \end{aligned}$$

FINAL GRADE

GENERAL COMMENTS

71 /100**Instructor**

PAGE 1

Text Comment. Your word count is excessive because you didn't read and interpret the research question carefully enough.

PAGE 2**Good Structure**

Report is structured exactly as stated in the assignment brief.

PAGE 3

PAGE 4

PAGE 5

Text Comment. Too long, should be around 300 words

Text Comment. Two unnecessary sentences

Text Comment. this clause says nothing to your reader

PAGE 6

Text Comment. You have spent too much time explaining the operation of a DC motor from a DC supply. Only the applications were required. You should have read the question more carefully.

**Correctly cited**

Citation method conforms to Harvard standard, well done.

**Correctly cited**

Citation method conforms to Harvard standard, well done.



Correctly cited

Citation method conforms to Harvard standard, well done.



Correctly cited

Citation method conforms to Harvard standard, well done.

PAGE 7



Correctly cited

Citation method conforms to Harvard standard, well done.

PAGE 8

PAGE 9

PAGE 10



Punctuation Error

Punctuation error



Wrong choice of word/s

You could have chosen a better word to express your thought here



Correctly cited

Citation method conforms to Harvard standard, well done.

Text Comment. An inappropriately large image that could be seen from 50 feet away. I am reading your report no more than 2 feet away.

PAGE 11



Correctly cited

Citation method conforms to Harvard standard, well done.

PAGE 12

PAGE 13

PAGE 14

Text Comment. The focus should be a single quadrant drive at this level as suggested by the next topic of research. You have done more then was required and exceeded the word count as a result. Please read the question more carefully in future..

PAGE 15

PAGE 16

Text Comment. You should have quoted from this datasheet and cited it as a source not included an image of it.

PAGE 17

Text Comment. You should have quoted from this datasheet and cited it as a source not included an image of it.

Text Comment. You should have quoted from this datasheet and cited it as a source not included an image of it.

PAGE 18



Punctuation Error

Punctuation error

PAGE 19

PAGE 20

Text Comment. Good results

PAGE 21

PAGE 22

PAGE 23

PAGE 24

PAGE 25

PAGE 26

PAGE 27

Text Comment. Too much of this reads like a summary of what you did.

Text Comment. This reads more like a reflection on what you did.

Text Comment. This is useful

PAGE 28

Text Comment. The drive controls the voltage to maintain speed via feedback and armature voltage adjustment

Text Comment. Good

Text Comment. such as?

PAGE 29



Punctuation Error

Punctuation error

PAGE 30

PAGE 31

PAGE 32

PAGE 33

PAGE 34

PAGE 35

PAGE 36

PAGE 37

PAGE 38

PAGE 39

PAGE 40

PAGE 41

PAGE 42

PAGE 43

PAGE 44

GRADING FORM: NEW CSG-RUBRIC

THOMAS GRENNAN

71

1. ENGAGEMENT WITH LITERATURE



Engagement with an extensive range of relevant and credible literature. Consistently accurate application of referencing. However, not all research was requested, a closer look at the question would have revealed this. (14/20)

14

2. KNOWLEDGE AND UNDERSTANDING



Excellent, detailed knowledge and highly critical understanding of the well-established concepts and principles of the subject and the main methods of enquiry. (15/20)

15

3. COGNITIVE AND INTELLECTUAL

-  Excellent critical evaluation and analysis of concepts and principles leading to logical, evidence-based, reasoned arguments and judgements. Explicit recognition of other stances and a strong awareness of the limits of their knowledge. A capacity for independent thought and ability to 'see beyond the question', suggesting some grasp of the broader field and wider concepts. (16/20)

16

4. PRACTICAL APPLICATION

-  An advanced application of a range of established methods, materials, tools and/or techniques. The context of the application is well considered, and insightful. Consistent, accurate and logical application of theory to practice, making well-developed links between the two. Can identify problems and propose excellent, creative solutions outside the context in which they were first studied. (16/20)

16

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

10

good skills for employment requiring the exercise of personal responsibility and decision-making, with just occasional minor weakness. There is repetition and additional information not request that increased your word count. Read the question more carefully next time. Word count penalty applied (-5) (10/20)