

1809806

by Richard Harrison

RESEARCH WAS OK, BUT CITATIONS SHOULD BE MORE
CONSISTENT AT THIS POINT OF YOUR STUDIES.
ADEQUATE KNOWLEDGE WAS DEMONSTRATED AND THERE
WAS SOME EVIDENCE OF CRITICAL ANALYSIS IN THE
CONCLUSIONS.

MARK AGREED



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1. Executive summary

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This report focuses on DC machines and their applications. Research was done, looking into different applications of DC machines such as motors and generators along with how they can be powered using an AC supply. Specifically, AC to DC conversion using simple diode bridge rectifier circuits which are then integrated into other devices such as motor drives.

Methods of DC machine control was researched which included H-bridge circuits, the use of variable resistors and three/single phase dual converters and their operation.

Two experimental circuits were constructed and tested within Multisim and their results were compared each time against calculated values. One was a half-controlled rectifier circuit which was used to simulate a single quadrant DC drive such as the Parker 512C and compare its performance against calculated values. The second circuit simulated a medium length transmission line which was used to prove calculations done were correct.

Lastly, a practical experiment was carried out to investigate the behaviour of a single quadrant DC drive under both load and no-load conditions.

2. Research

2.1 Industrial DC machine applications

Applications of DC machines (also called commutating machines) which can be categorised as either DC motors or DC generators have uses which include variable speed motor drives, welding processes and electrolytic processes. DC motors are mostly used as variable speed drives where the application requires something that can cope with large torque differences because regulation of these two factors is easy to control. A very common application of larger DC motors is their use in locomotives which transport large quantities of heavy material/products over long distances.

For this to work without a DC generator to produce current, the AC supply from the mains needs to be rectified to create usable direct current. Within DC power supplies there are Silicone Controlled Rectifiers (SCRs) which each consist of four layers of p-n-p-n (Also called thyristors or 4-layer diodes). These were developed by Tanenbaum, Goldey, Holonyak and Moll working for Bell laboratories (1956). They are used since they only allow the flow of current in one direction.

DC motor/generator types:

- | | |
|-----------------------|-------------------|
| 1. Separately excited | 4. Series wound |
| 2. Self-excited | 5. Compound wound |
| 3. Shunt wound | |

The DC series motor are used in applications where a high starting torque (since the starting torque is up to five times the full load torque) and variable speed is needed such as cranes and air compressors. [Citation Needed](#)

Compound DC motors are also used for high starting torque applications, but the speed control is important in that important since many uses of this motor have pulsating loads. Used in conveyors, presses, and elevators.

DC Shunt motors do not have as high a starting torque and are instead used where a constant speed is needed. They are used in Lathes, lifts, and centrifugal pumps. [Citation Needed](#)

Separately excited DC generators have a large voltage output range which is ideal for controlling DC motors.

The DC series wound generator can be used for regenerative braking in locomotives as well as heavy power supply systems and arc welding.

"Whenever the application of any machine is considered, its operating characteristics along with its economic and technical viability as compared to its competitors are the essential criteria. For a dc machine, of course, the main attraction lies in its flexibility, versatility, and ease of control. This explains why in spite of its rather heavy initial investment it still retains its charm in strong competitive industrial applications. In the world, today, around 25% of the motors manufactured are dc motors." (EEEGUIDE, 2014)

Wrongly cited. You should have said: EEGuide state that "....." (2014, Page ?)

2.2 Methods of control of DC machines from an AC supply

2.2.1 How a diode bridge rectifier works

A bridge rectifier works by allowing the positive half of an AC waveform through and preventing any of the negative waveform from passing. When DC is being produced with a single-phase AC supply a bigger smoothing capacitor is needed since the product of the Diode bridge is positive halves of the waveform spaced apart. The capacitor is charged by the positive half waveform and slowly discharges to bridge the gap between the positive waveform halves. In systems which require a DC supply as smooth as possible more smoothing capacitors are used to create a DC output which is as smooth as possible. This simple circuit is used in a wide variety of devices including the Parker 512C drive and other DC output control devices.

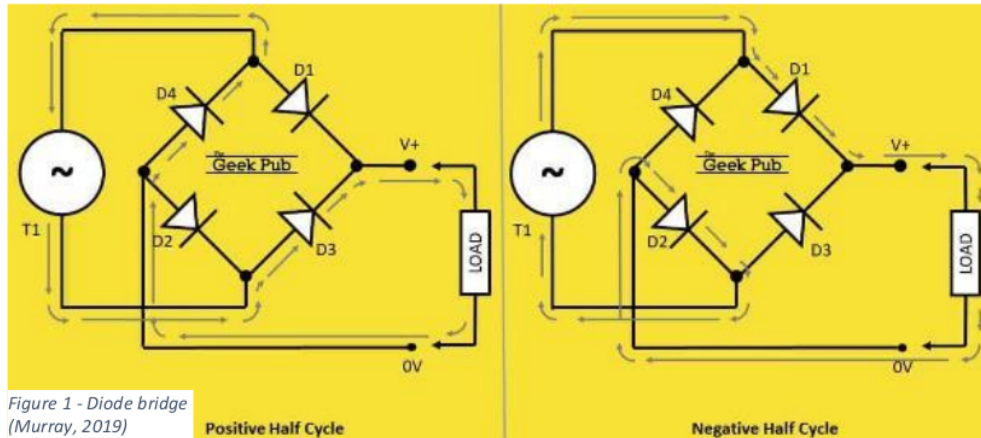


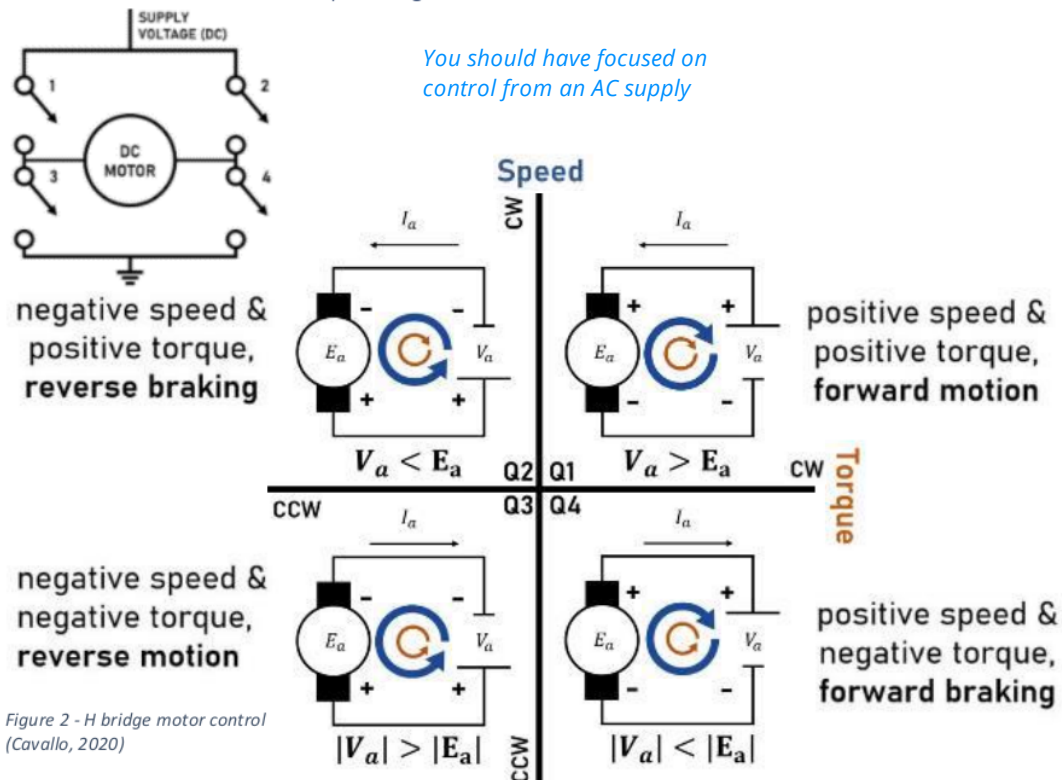
Figure 1 - Diode bridge
(Murray, 2019)

The common DC motor can easily be controlled simply by varying the voltage supplied to it. It can even be reversed by switching the input leads. Also, since the torque/speed relationship is linear in nature, it is easy to find the correct input voltage to apply.

"To briefly summarize, the speed/torque curve of DC motors are inversely linear, meaning their torque proportionally decreases as the motor RPMs increase. This allows for easy control, as lowering the speed will increase the torque, and vice versa." (Cavallo, 2020)

Incorrectly cited, this is not the Harvard Method

2.2.2 DC machine control by H bridge



Following a bridge rectifier producing DC, this control method uses switch pairs to change the polarity of the supply to the motor, changing its direction of rotation. The switches are paired as (1-4) and (2-3) which creates a four-quadrant DC motor. This layout can also be used to control a non-regenerative DC drive but will need to be added to control speed as well. With reference to figure 2, quadrants one and three are the motoring quadrants since both the speed (blue, larger arrow) and torque (orange, smaller arrow) are in the same direction which can be controlled by a non-regenerative drive. However, a regenerative drive can use the braking quadrants (Q2 and Q4) to slow the motor down rather than just cutting the power and produce a small amount of power to send back to the supply. Increasing efficiency by using the mechanical energy contained within the load since the voltage being produced by the motor is more than the supplied voltage.

2.2.3 DC machine control by PWM or variable resistors

DC motor speed control factors	
Factors	Control method
Speed is directly proportional to voltage supply	Vary supply voltage
Speed is inversely proportional to armature voltage drop	Vary the armature voltage and thus, resistance
Speed is inversely proportional to the flux in the field windings	Vary the flux and thus, the field winding current

Table 1 - DC motor control factors Citation Needed

The H bridge is great for direction and braking control. However, it requires the addition of a PWM circuit to control the speed. Depending upon the length of the pulse, the motor will run at different speeds. If for instance a 24Vdc motor is given a 24V PWM signal that is in its high state for half of each duty cycle and low (0V) for the rest, it will run at half speed since it effectively is being supplied with 12V because the coil inductance of the motor smooths the gap between pulses.

The speed of the motor can also be controlled by changing the resistance of the armature (Armature controlled resistance and shunted armature control techniques) and field (Field diverter and Tapped field control techniques) coils. The magnetic field strength is controlled by the resistance of the coils and the stronger armatures magnetic field the slower the motor will run. Therefore, the stronger the stators magnetic field the faster the motor will turn. The PWM method is used instead of Variable Resistance in almost every application because increasing the resistance of the coils produces more heat and drastically decreases the efficiency of the motor.

2.2.4 Three phase Dual voltage converter

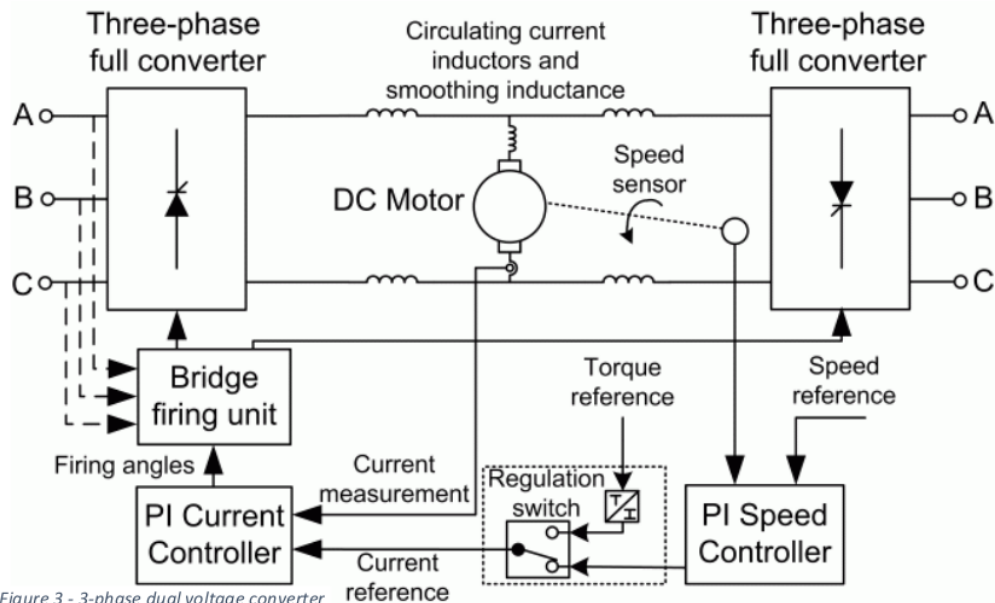


Figure 3 - 3-phase dual voltage converter
- (MathWorks, 2021)

A dual voltage converter can run off a single or three phase source and is both a rectifier and an inverter since it converts AC to DC and then back to AC. As shown in figure 3. This converter has four quadrants, uses three phase and is thyristor based. However, a similar setup can be used for single phase AC supply.

Incorrectly cited, this is not the Harvard Method

"The main advantage of this drive, compared with other DC drives, is that it can operate in all four quadrants (forward motoring, reverse regeneration, reverse motoring, and forward regeneration). However, two anti-parallelled converters along with circulating current inductors are required, which increases the complexity of the drive system." - (MathWorks, 2021)

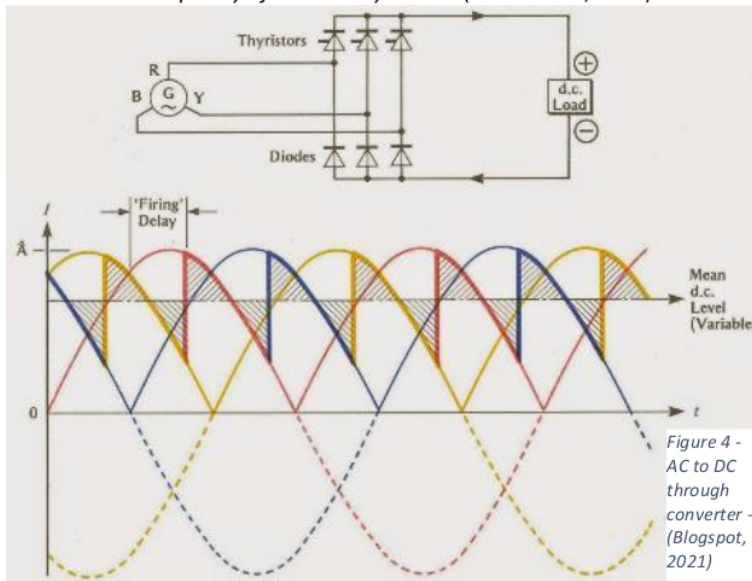


Figure 4 -
AC to DC
through
converter -
(Blogspot,
2021)

As shown in figure 4, the AC waveform is converted to DC for the motors use.

This type of converter has four quadrants of operation which are 90° apart. Converters 1 and 2 each create a firing angle from 0-90 degrees.

Quadrant 1: Forward motoring (current and voltage positive)

Quadrant 2: Regenerative braking (voltage positive, current negative)

Quadrant 3: Reverse motoring (current and voltage are negative)

Quadrant 4: regenerative braking (current positive, voltage negative)

The converters work in two modes, non-circulating and Circulating mode. Non-circulating means only one converter is active at a time so converter 1 fires and voltage/current are positive, followed by converter 2 and voltage/current are negative. Whereas in circulating mode the current flows through both as they are active at the same time. Meaning the firing angles of both are added to make 180 degrees. Circulating mode has two conditions in a full cycle:

1. Voltage and current are positive in this condition. Converter 1 operates as a rectifier to create DC when the firing angle is 0-90 degrees and converter 2 becomes an inverter from 90-180 degrees.
2. Voltage and current are negative in this condition. Converter 2 operates as a rectifier to create DC when the firing angle is 0-90 degrees and converter 1 becomes an inverter from 90-180 degrees.

However, in the real world the voltages produced by the two converters contain ripples which destabilise the system. Therefore, a time delay of approximately 10ms is needed between the switching of the two converters to keep the system stable.

2.2.5 single phase dual voltage converter

The architecture of this converter is like the three-phase Dual converter. The method is different. A single-phase AC supply is sent to converter 1 and DC is produced using thyristors and the DC is then filtered into pure DC before it reaches the motor to remove ripples. Once the DC is used by the motor, it travels to converter to which inverts it back into AC

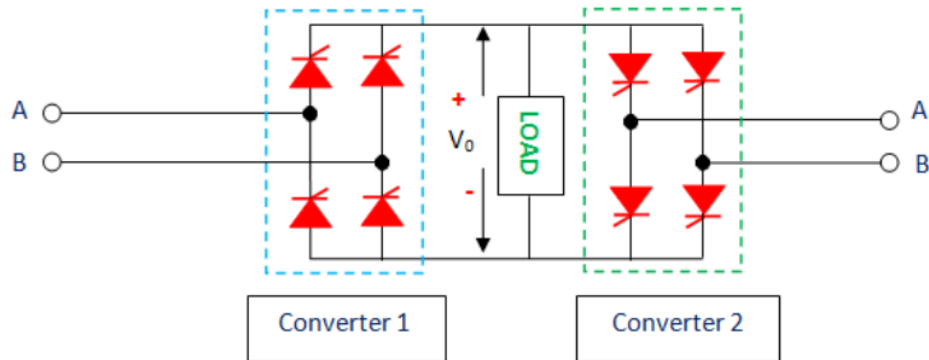


Figure 5 - Single phase dual converter - (Electrical4U, 2020)

Using SCR sets in each converter arranged to create a thyristor bridge allows the motors polarity to be reversed for both the single phase and three phase dual converters. Microcontroller triggering can be used with opto-isolators to control the speed by changing the SCR bank output to the DC motor.

"The dual converter is a power electronics control system to get either polarity DC from AC rectification by the forward converter and reverse converter." - (Elprocus, 2020)

Incorrectly cited, this is not the Harvard Method

2.3 Construction and operation of a typical single quadrant DC drive such as the Parker 512Cⁱ

A single quadrant drive only operates in the forward motion. It cannot forward brake, reverse brake, or reverse motion. Meaning the motor will rely on natural friction to stop. The drive offers 4-32A output with isolated control circuits for torque and speed. Manufactured for low-power applications such as controlling a centrifugal pump that uses a wound field DC motor.



DC Motor Speed Controller - DC512C Series

Where To Buy

You should have quoted from the datasheet and cited instead of including it here

Technical Specifications

Brand:	Parker	Product Type:	DC Drive
Drive Axis Type:	Single Axis Technology	Product Series:	DC51n
Input Voltage:	1*110VAC 1*230VAC 1*380-415VAC	Continuous Output Current Rating:	4 - 32A
Output Power:	0.3 - 7.5 HP	Compatible Motor Type:	DC Brushed Servo
Compatible Feedback Device:	Armature Voltage Tachometer	Modes of Control:	Non-Regenerative
Communication Interface:	n/a	Operating Temperature:	0 - 40 °C, 32 - 104 °F
Operating Altitude:	Up to 1000m ASL	Overload Rating:	150% for 60s
Specifications Met:	CE (EMC & LVD) UL Listed cUL Listed		

Figure 6 - Parker 512C drive

Consult Appendix figures 35-37 for more drive information.

The Parker 512C is an AC to DC non-regenerative single axis drive specifically for Brushed DC servo motors. Figure 7 shows a block diagram of the inner workings of the drive circuit board where key parts of the speed control can be found like the speed range & scale, armature voltage filter, speed loop PI, setpoint sum and two diode bridges. One being used for the incoming AC supply which is used to create 12Vdc.

The 512 is not suitable for servo motion as it can only work in one quadrant

This diagram belongs in the appendix and should be cited

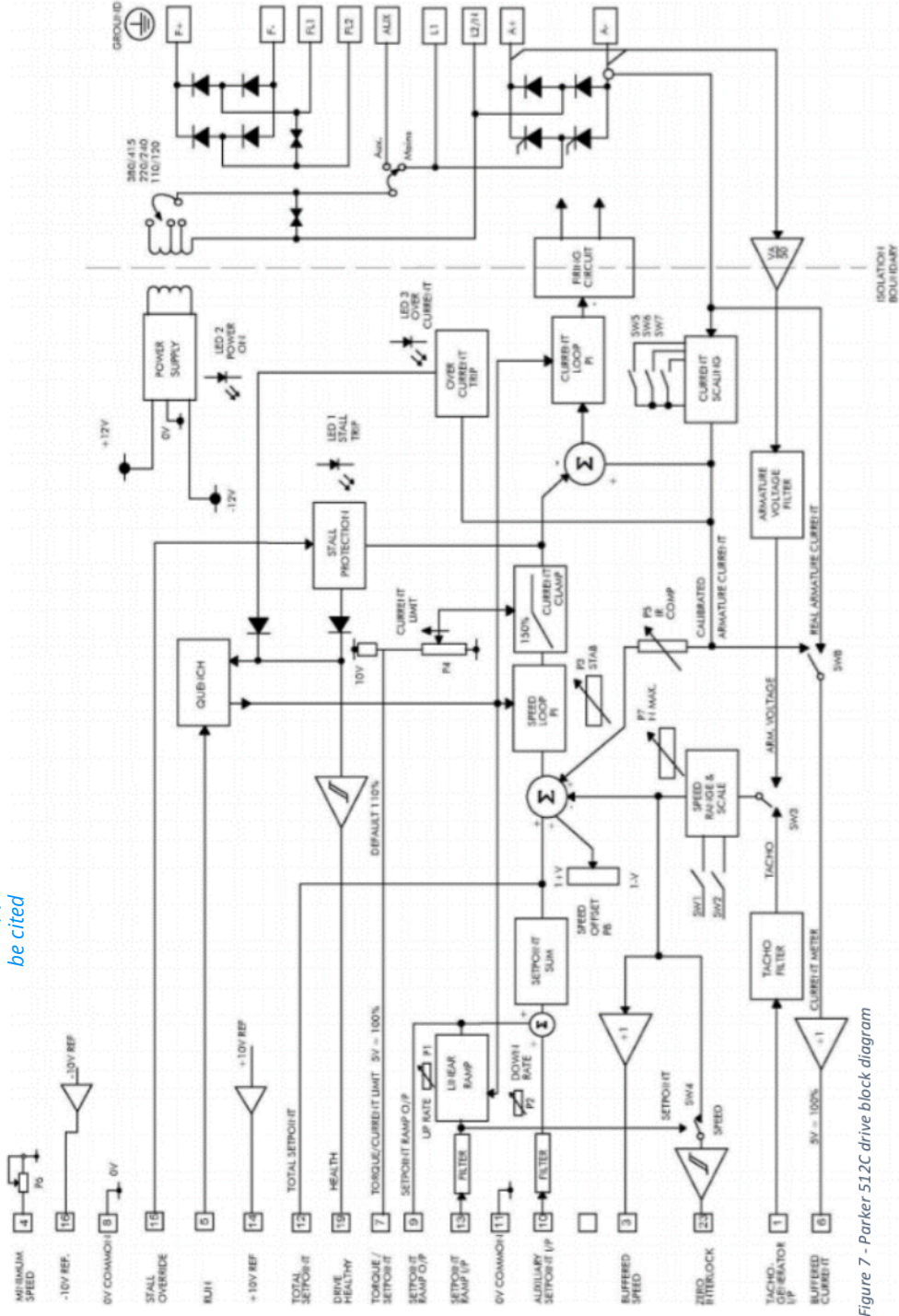


Figure 7 - Parker 512C drive block diagram

3. Simulation of a Half-Controlled Rectifier Circuit

Using the Multi-sim program, a single phase, full wave half-controlled rectifier was built (simulating a parker 512 DC drive). Shown below in figure 8. The constructed circuit represents a single quadrant drive and is made up of 2 diodes (D2+D3), 2 thyristors (T1+T4), 1 AC supply (V1), 1 resistor (R1), 1 inductor (L1), 2 transformers (TX1+TX2), 2 DC supplies (V2+V3), 4 grounds and a phase angle controller (U1).

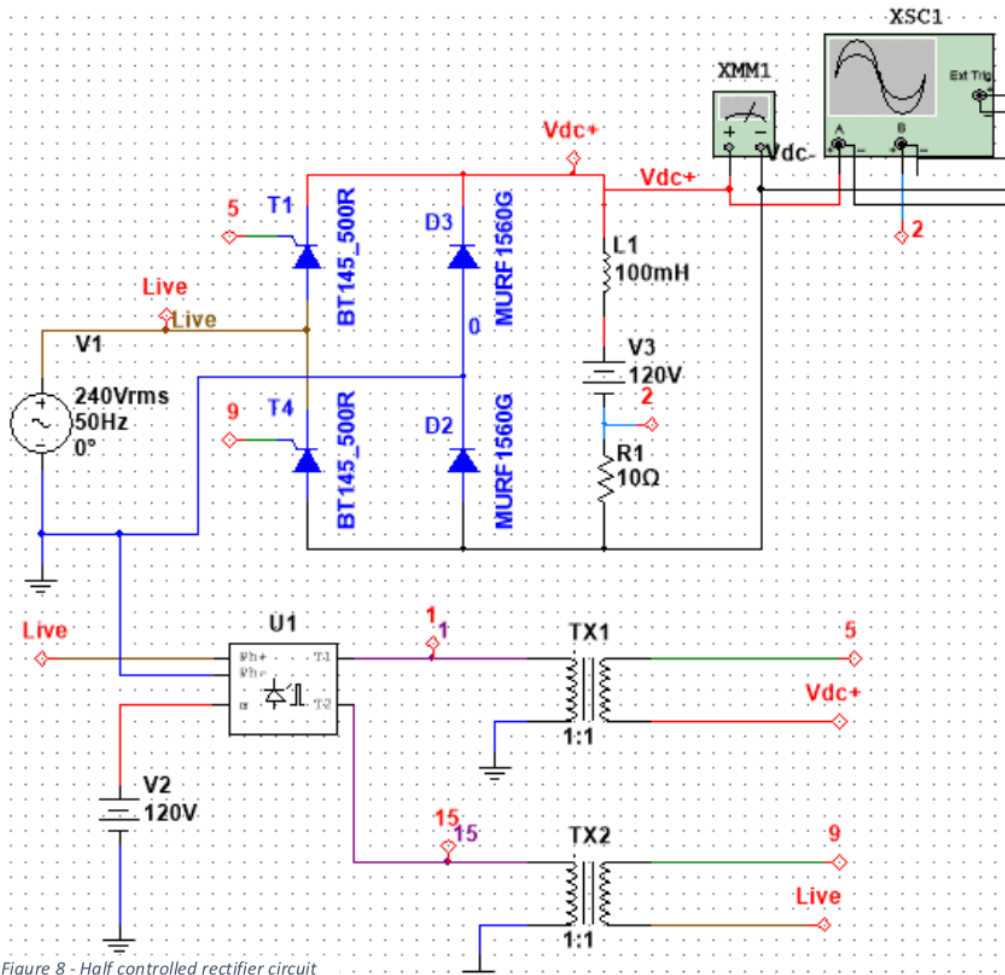


Figure 8 - Half controlled rectifier circuit

D2 and D3 are the commutators where there is no negative voltage which allows the thyristors to switch off. The positive half cycle is done by T1 and D2. Then the negative cycle is sorted by D3 and T4. To simulate a motor within the circuit, L1 and R1 are placed with a DC supply (V3) between the two for back EMF. Whereas V2 supplies the phase angle controller (U1) with a firing angle. The phase angle controller is used to create a pulse for each phase. The two transformers (TX1+TX2) are used as isolation transformers. In practical use they will isolate the pulses that are created by the controller (possibly >300V).

Using the Multisim software to simulate and experiment with the circuit, a built-in oscilloscope and voltmeter was used to measure and present the output of the circuit. The phase angle used by the controller can be changed by altering the value of the DC (battery) supply V2. For this experiment, three phase angles were chosen. 120, 90 and 60 degrees giving a large spectrum of testing within the wave cycle. For each of the three experiment runs, the values of t1 and t2 are measured on the oscilloscope using two cursers and setting them on the cross-over point for T1 and T2 is set to show the thyristors firing point.

The values recorded for T1 will be used to calculate β and the values recorded for T2 will be used to calculate the value of α . Then, the average voltage and the phase angle can be calculated. The result of each of the three calculated phase angles should match the voltage of the DC power supply/battery marked as V2.

3.1 120-degree phase angle

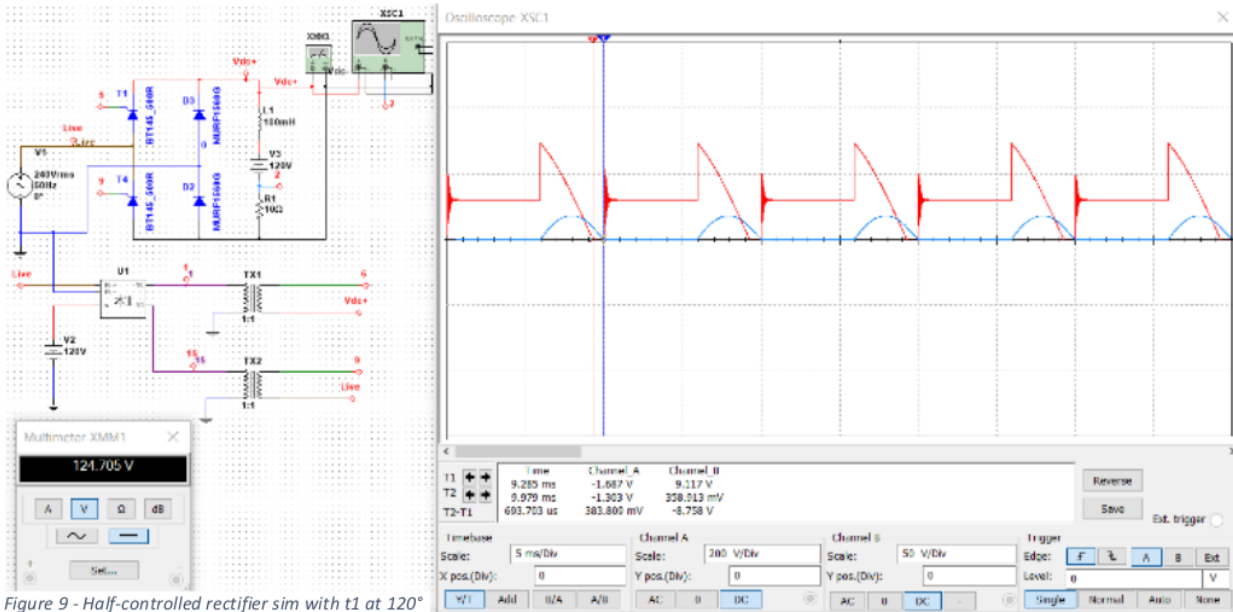


Figure 9 - Half-controlled rectifier sim with t1 at 120°

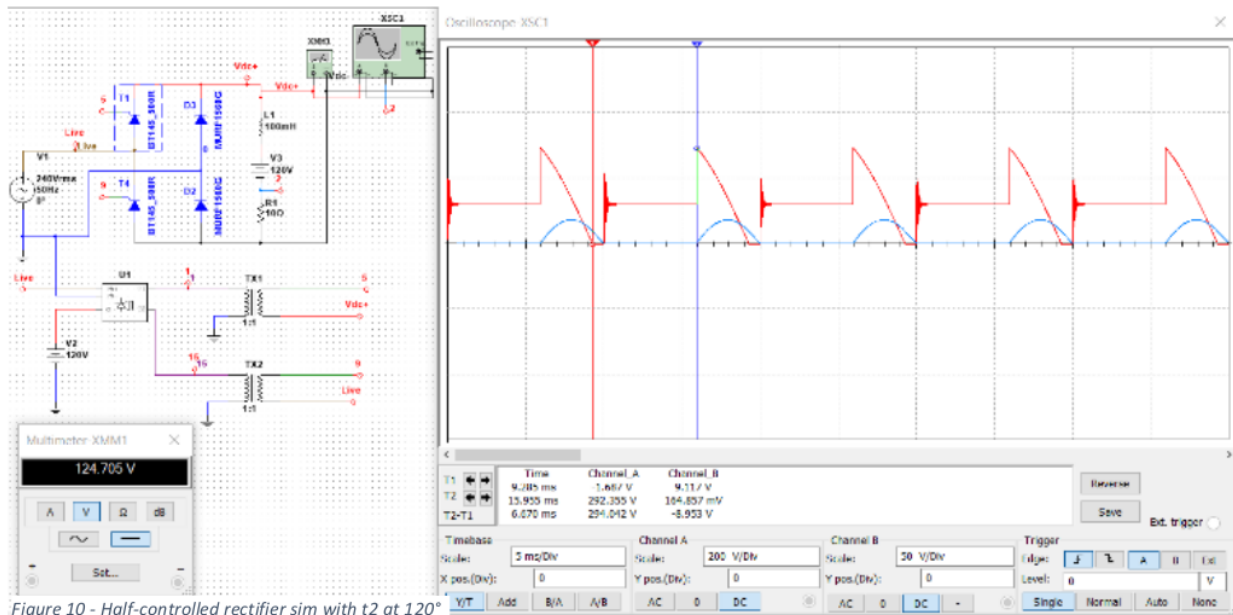


Figure 10 - Half-controlled rectifier sim with t2 at 120°

3.2 120-degree calculations

At 120 degrees:

$$\text{Full period} = \frac{1}{f} = \frac{1}{50\text{Hz}} = 20\text{ms}$$

For a half period the length is 10ms which relates to π rad.

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

$$\beta = \frac{t_1}{10\text{ms}} \times \pi = \frac{0.693 \times 10^{-3}}{10} \times \pi = 0.2177 \text{ rads}$$

$$\alpha = \frac{t_2}{10\text{ms}} \times \pi = \frac{6.670 \times 10^{-3}}{10} \times \pi = 2.095 \text{ rads}$$

To calculate the average voltage with back EMF:

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

$$\text{Voltage average} = \frac{120}{\pi}(2.095 - 0.2177) + \frac{292.335}{\pi}(1 + \cos(2.095))$$

V_{max} is always 337 V

$$\text{Voltage average} = 71.70757792 + 46.4778223 = 118.185\text{v}$$

For phase angle:

$$t_2 \times 180^\circ = 0.667 \times 180^\circ = 120.06^\circ$$

3.3 90-degree phase angle

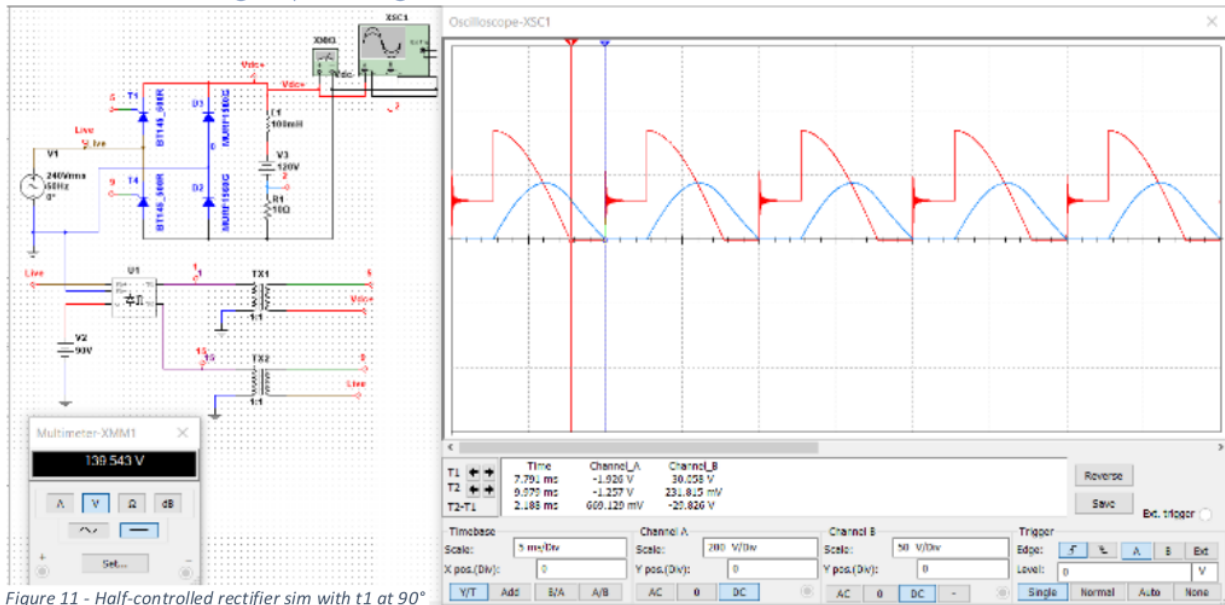


Figure 11 - Half-controlled rectifier sim with t1 at 90°

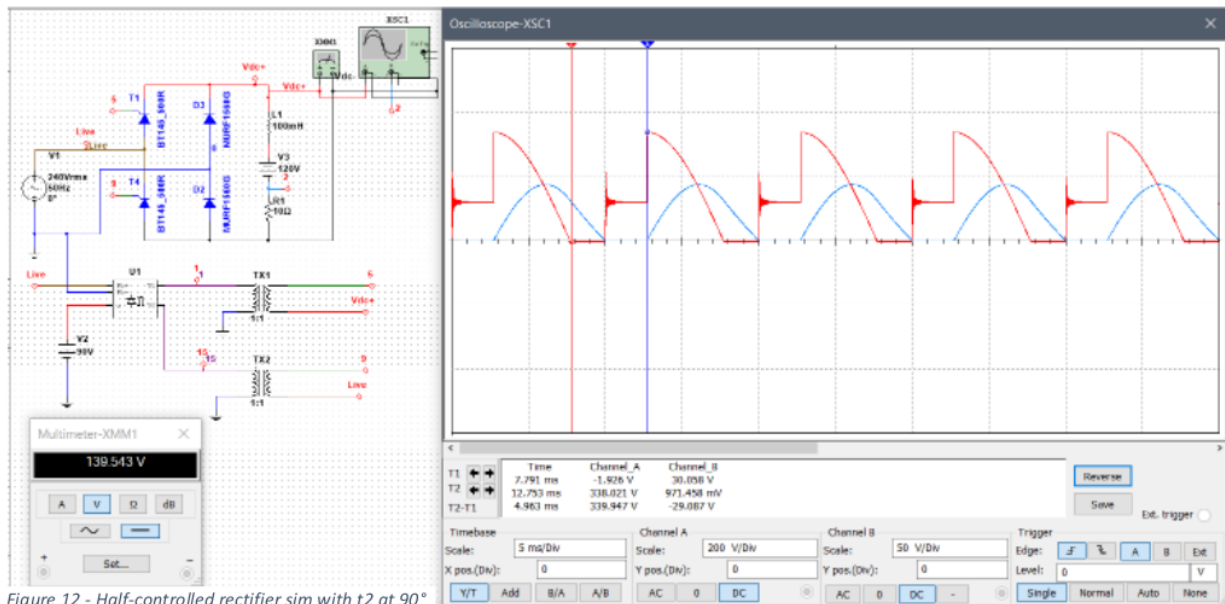


Figure 12 - Half-controlled rectifier sim with t2 at 90°

3.4 90-degree phase angle calculations

Using the same 10ms half period:

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

$$\beta = \frac{t_1}{10ms} \times \pi = \frac{2.188 \times 10^{-3}}{10} \times \pi = 0.6874 \text{ rads}$$

$$\alpha = \frac{t_2}{10ms} \times \pi = \frac{4.963 \times 10^{-3}}{10} \times \pi = 1.559 \text{ rads}$$

To calculate the average voltage with back EMF:

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

$$\text{Voltage average} = \frac{120}{\pi} (1.559 - 0.6874) + \frac{338.021}{\pi} (1 + \cos(1.559))$$

$$\text{Voltage average} = 33.29266762 + 108.8646274 = 142.157v$$

For phase angle:

$$t_2 \times 180^\circ = 0.4963 \times 180^\circ = 89.33^\circ$$

3.5 60-degree phase angle

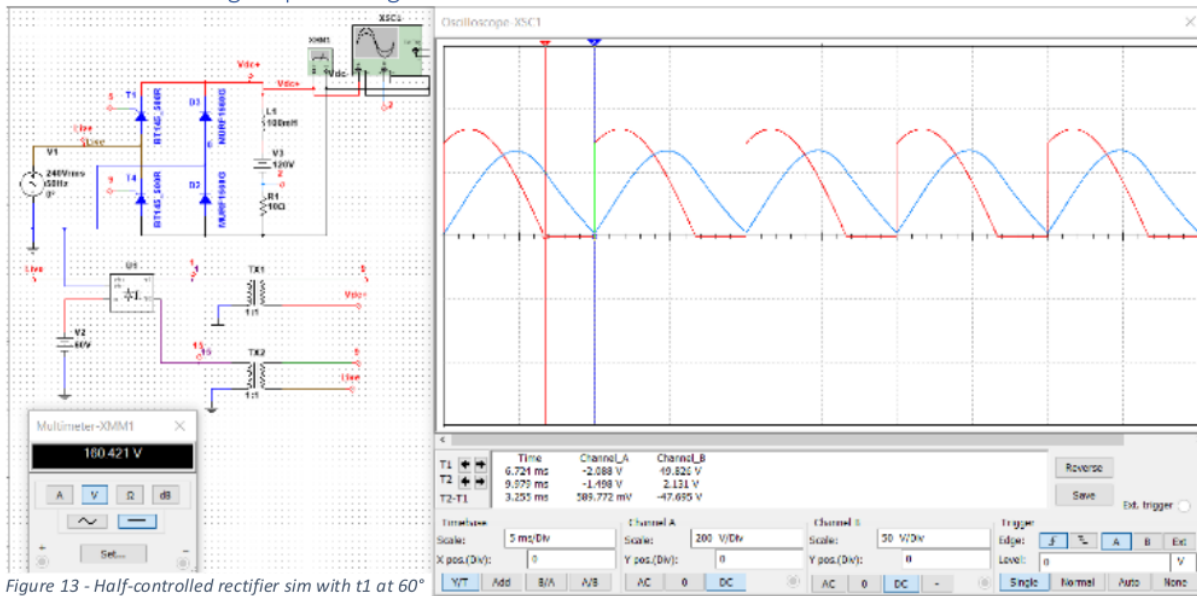


Figure 13 - Half-controlled rectifier sim with t1 at 60°

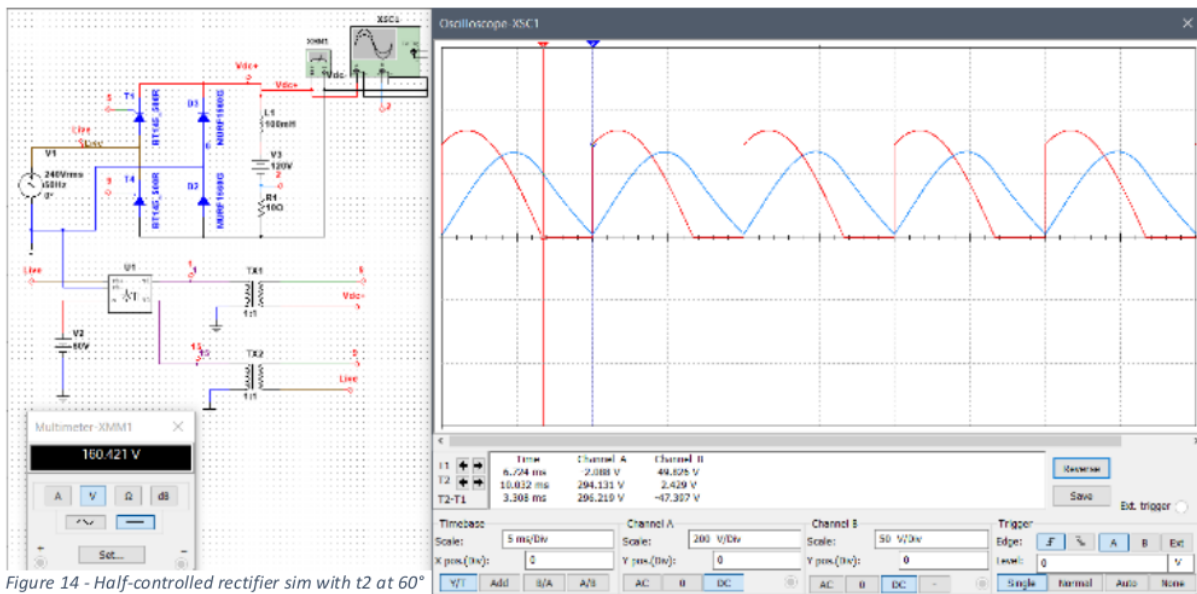


Figure 14 - Half-controlled rectifier sim with t2 at 60°

3.6 60-degree phase angle calculations

Using the same 10ms half period:

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

$$\beta = \frac{t_1}{10ms} \times \pi = \frac{3.255 \times 10^{-3}}{10} \times \pi = 1.0226 \text{ rads}$$

$$\alpha = \frac{t_2}{10ms} \times \pi = \frac{3.308 \times 10^{-3}}{10} \times \pi = 1.0392 \text{ rads}$$

To calculate the average voltage with back EMF:

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

$$\text{Voltage average} = \frac{120}{\pi} (1.0392 - 1.0226) + \frac{294.131}{\pi} (1 + \cos(1.0392))$$

$$\text{Voltage average} = 0.6340732933 + 141.0841568 = 141.72 \text{ v}$$

For phase angle:

$$t_2 \times 180^\circ = 0.3308 \times 180^\circ = 59.54^\circ$$

3.7 Half controlled rectifier results and comparisons

Half-controlled rectifier Multisim results		
Chosen phase angle (degrees)	Measured T1 value (milliseconds)	Measured T2 Value (milliseconds)
120	0.693	6.67
90	2.188	4.963
60	3.255	3.308

Table 2 - Phase angle Multisim results

Figures 15-17 Pages 23 and 24 show the Multisim results when testing a 120V back EMF, checking the circuits peak voltage and demonstrating the half-cycle of 10milliseconds. The results shown in table 2 along with their calculations done earlier and these allow for a more in depth set of results to be compiled and compared.

Half-controlled rectifier phase comparison table		
Multisim result (degrees)	Calculated result (degrees)	Difference (degrees)
120	120.06	0.06
90	89.33	0.67
60	59.54	0.46

Table 3 - Phase angle comparison

Half-controlled rectifier Voltage comparison table		
Multisim result (Volts)	Calculated result (Volts)	Difference (Volts)
124.705	118.185	6.52
139.543	142.157	2.614
160.421	141.72	18.701

Table 4 - Voltage comparison table

The differences are large
because V_{max} is always
337V means that your
calculations are
incorrect

3.7.1 Half cycle of 10ms

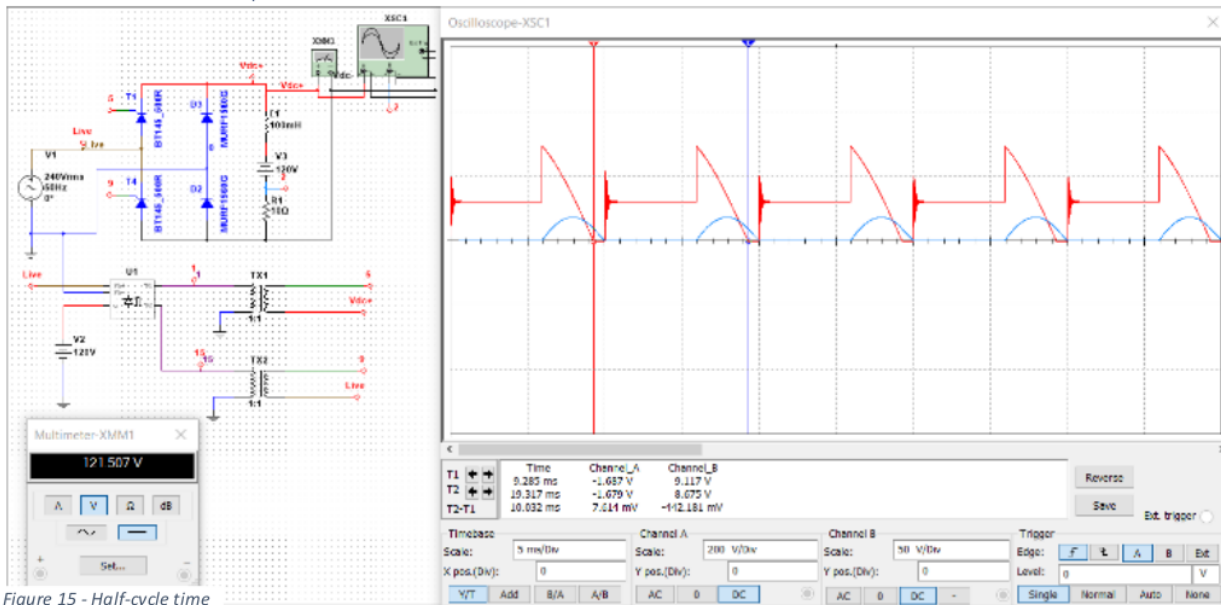


Figure 15 - Half-cycle time

3.7.2 Back EMF at 120V

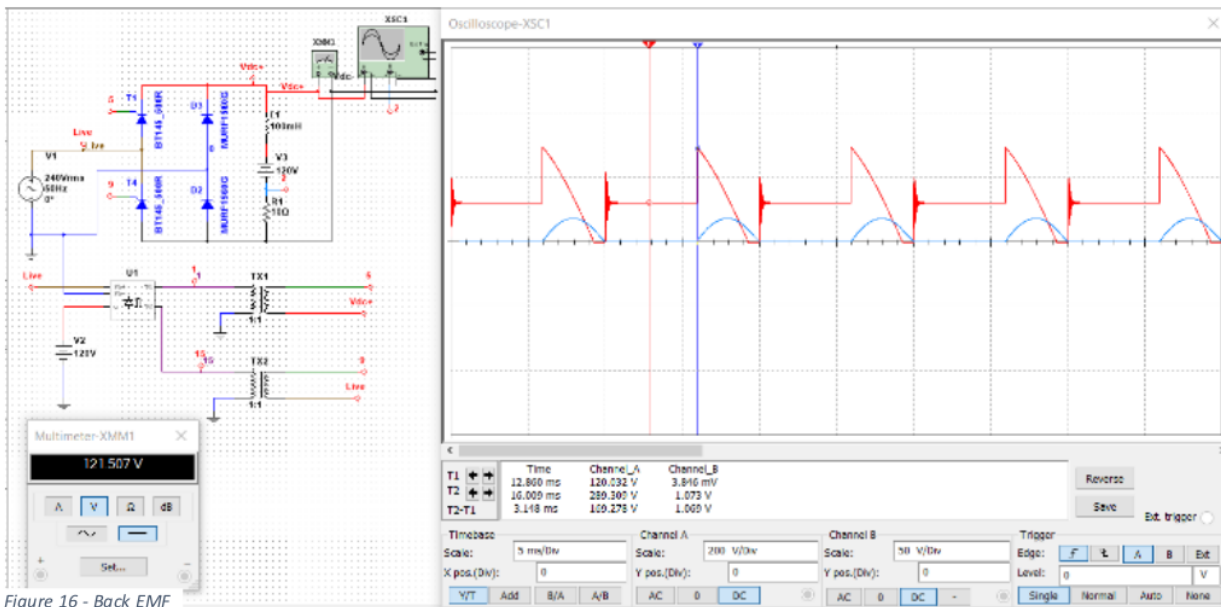


Figure 16 - Back EMF

3.7.3 Voltage peak at 337.230V

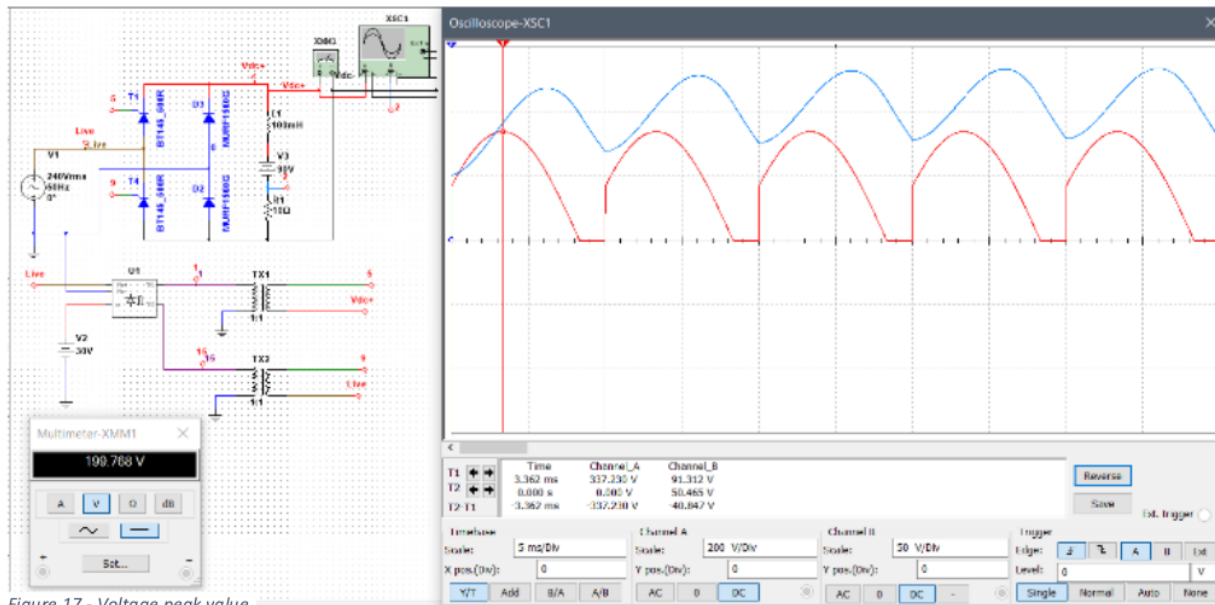


Figure 17 - Voltage peak value

From the calculations and Multisim screenshots, values for the average voltage and the phase angle could be compared. Comparisons between the calculated and simulated phase angle were minor and the results of each matched to within 0.7 of a degree. However, the average voltage has much larger discrepancies ranging from 1.84-11.65%. The differences in results could be because of poor/inaccurate placement of the cursers in the oscilloscope. It could also be because of the level of voltage drop within the thyristors in the simulation. The possibility of inaccuracy due to rounding answers is not applicable since the values used in the calculation were not rounded.

3.8 Simulating mechanical load on the circuit

To simulate having a mechanical load applied to a hypothetical motor connected to the circuit the firing angle was set to 80° and three values for backwards EMF was used. This is done by changing the value of the DC power supply V3. The three voltages chosen are 120, 100 and 80 volts. The Multisim results are shown in 3.8.1, 3.8.2, and 3.8.3 (figures 18, 19 and 20). Of the three, the only simulated value that did not allow the current to fall back to zero is the one with an 80V backwards EMF. This means that the output current of the circuit in that instance is constant. Whereas the other two values let the current fall back to zero on the output before the thyristor would fire again. Shown in figure 20.

3.8.1 120V back EMF and 80 degree firing angle

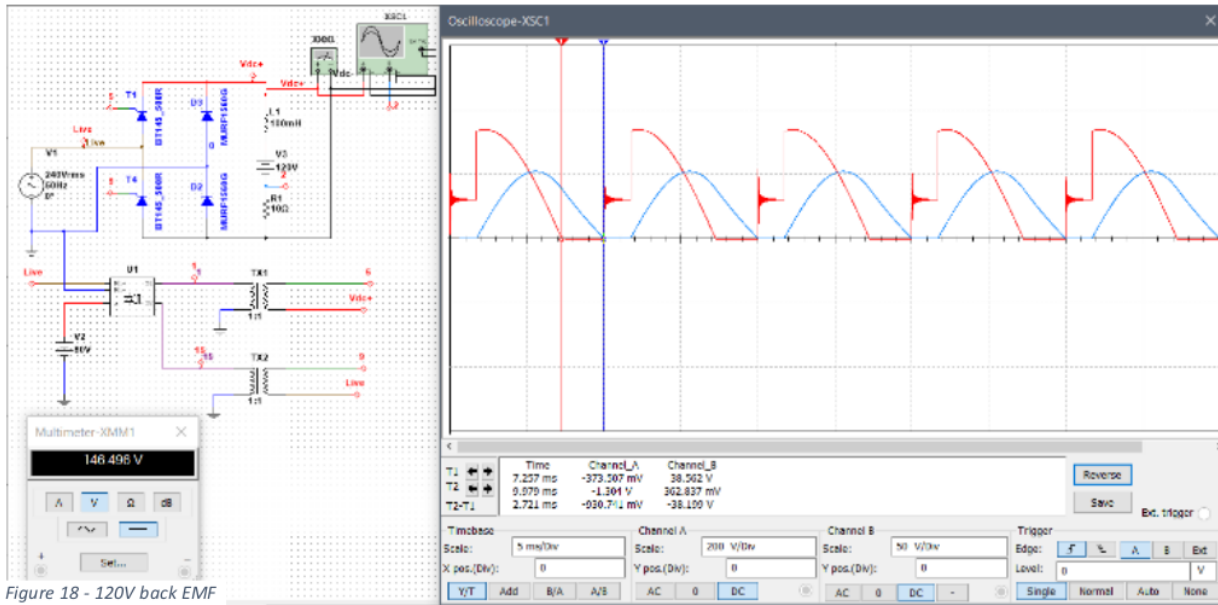


Figure 18 - 120V back EMF

Using a 10ms Half cycle:

$$\alpha = \frac{t_2}{10ms} \times \pi = \frac{2.721 \times 10^{-3}}{10} \times \pi = 0.8548 \text{ rads}$$

For average voltage:

$$\text{Voltage average} = \frac{337.230}{\pi} (1 + \cos(0.8548)) = 177.8V$$

For phase angle:

$$t_2 \times 180^\circ = 0.2721 \times 180^\circ = 48.98^\circ$$

3.8.2 100V back EMF and 80 degree firing angle

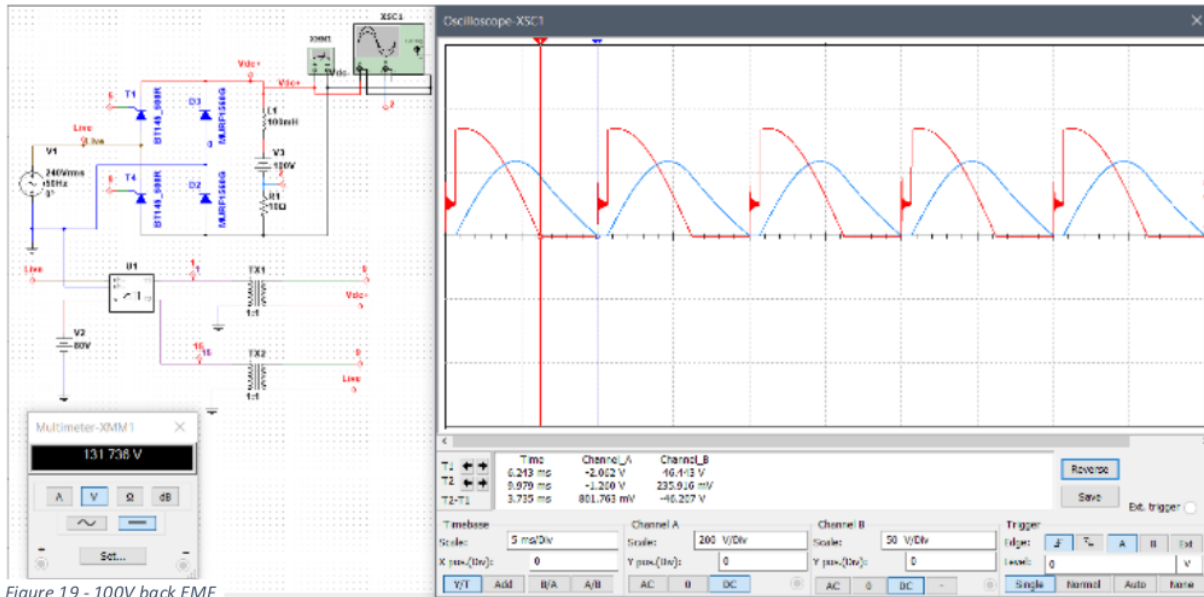


Figure 19 - 100V back EMF

Using a 10ms Half cycle:

$$\alpha = \frac{t_2}{10ms} \times \pi = \frac{3.735 \times 10^{-3}}{10} \times \pi = 1.06 \text{ rads}$$

For average voltage:

$$\text{Voltage average} = \frac{337.230}{\pi} (1 + \cos(1.06)) = 159.821V$$

For phase angle:

$$t_2 \times 180^\circ = 0.3735 \times 180^\circ = 67.23^\circ$$

3.8.3 80V back EMF and 80 degree firing angle

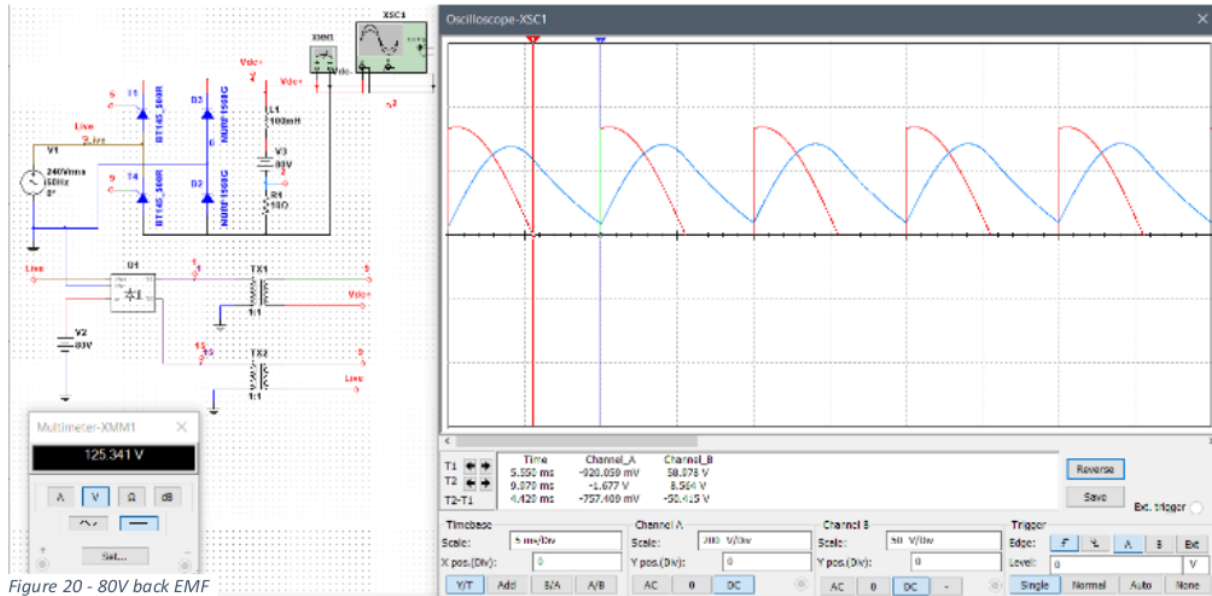


Figure 20 - 80V back EMF

Using a 10ms Half cycle:

$$\alpha = \frac{t_2}{10ms} \times \pi = \frac{4.429 \times 10^{-3}}{10} \times \pi = 1.391 \text{ rads}$$

For average voltage:

$$\text{Voltage average} = \frac{337.230}{\pi} (1 + \cos(1.391)) = 126.540V$$

For phase angle:

$$t_2 \times 180^\circ = 0.4429 \times 180^\circ = 79.72^\circ$$

Only when the backwards EMF value is set to match that of the firing angle will the calculations match the Multisim simulation, and this is the only time where the output current is continuous (see figure 20). When the phase angle and the backwards EMF voltage match there are only very minor differences in the results.

Backwards EMF phase comparison table		
Multisim result (degrees)	Calculated result (degrees)	Difference (degrees)
120	48.98	71.02
100	67.23	32.77
80	79.72	0.28

Table 5 - Backwards EMF phase comparison table

*There is something wrong either with your
measurements or your calculations*

Backwards EMF voltage comparison table			
Set voltage value (Volts)	Multisim result (Volts)	Calculated result (Volts)	Difference (Volts)
120	146.496	177.8	31.304
100	131.736	159.821	28.085
80	125.341	126.54	1.199

Table 6 - Backwards EMF voltage comparison table

Tables 4 and 5 show the phase angle and average voltage results from the Multisim simulator against the calculated values. There are large differences in phase and voltage results for 120 and 100 values. Since the output current is non-continuous for these two values, the results are disregarded. The third set of results at a voltage value of 80 give results which closely match with only a very small difference. The slight error may be because the placing of the curser on the oscilloscope is done by hand which can cause inaccuracy.

4. Practical investigation into a single quadrant DC drive

4.1 Speed at 554.7rpm

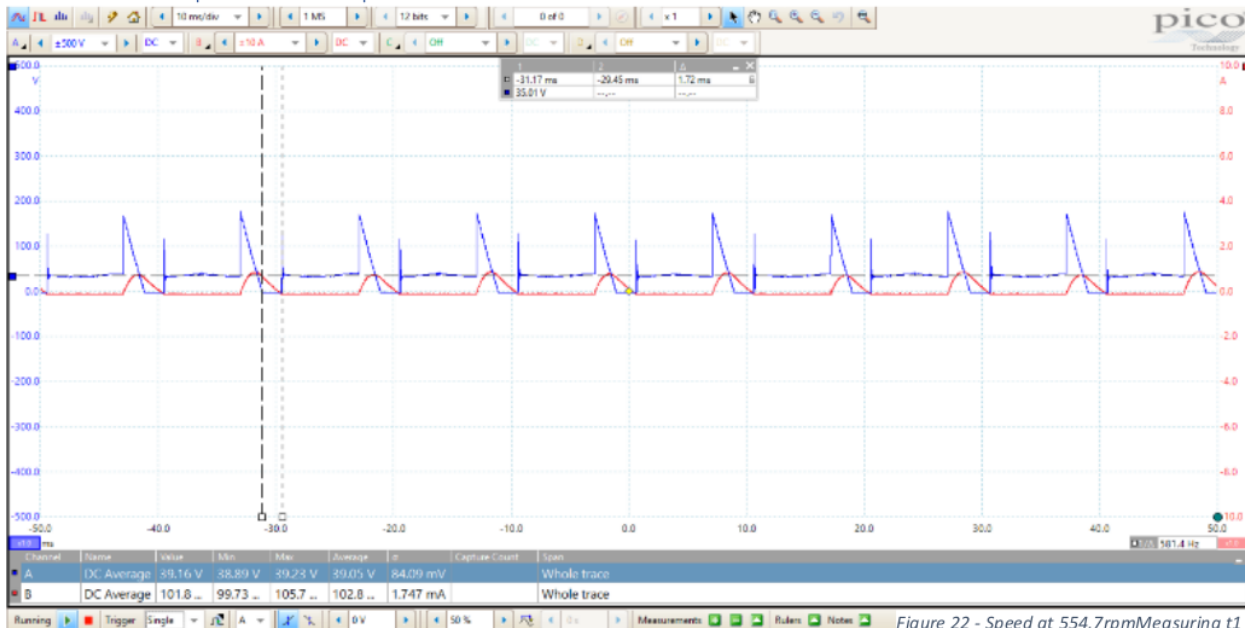


Figure 22 - Speed at 554.7rpmMeasuring t1

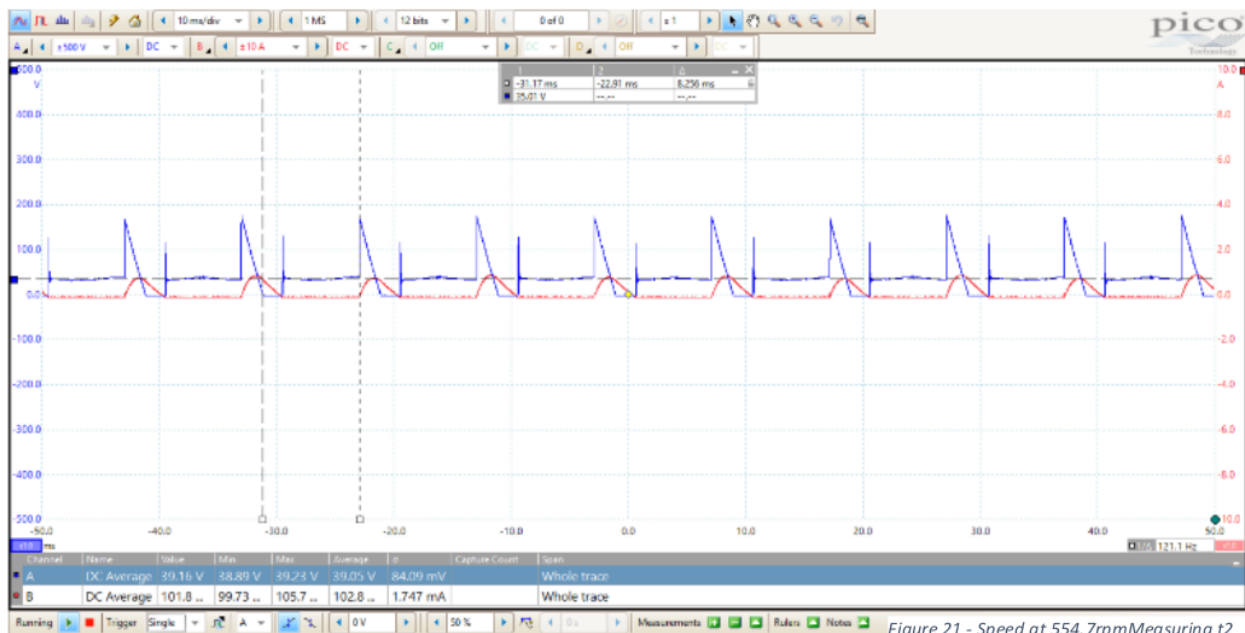


Figure 21 - Speed at 554.7rpmMeasuring t2

$$\beta = \frac{t_1}{10ms} \times \pi = \frac{1.72 \times 10^{-3}}{10} \times \pi = 0.54 \text{ rads}$$

$$\alpha = \frac{t_2}{10ms} \times \pi = \frac{8.256 \times 10^{-3}}{10} \times \pi = 2.594 \text{ rads}$$

Average armature voltage according to experiment: 39.05V

Calculated average armature voltage:

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

$$\begin{aligned} \text{Voltage average} &= \frac{35.01}{\pi}(2.594 - 0.54) + \frac{337.230}{\pi}(1 + \cos(2.594)) \\ &= 22.89 + 15.7 \end{aligned}$$

$$\text{Voltage average} = 38.59v$$

4.2 Speed at 1042rpm

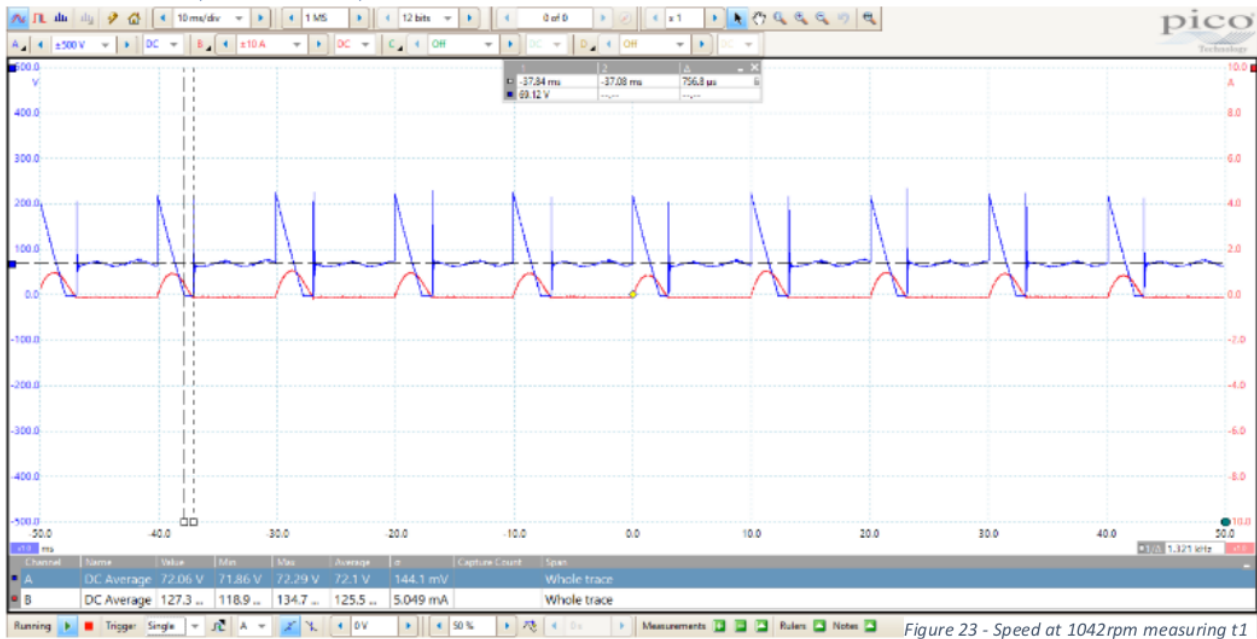


Figure 23 - Speed at 1042rpm measuring t1

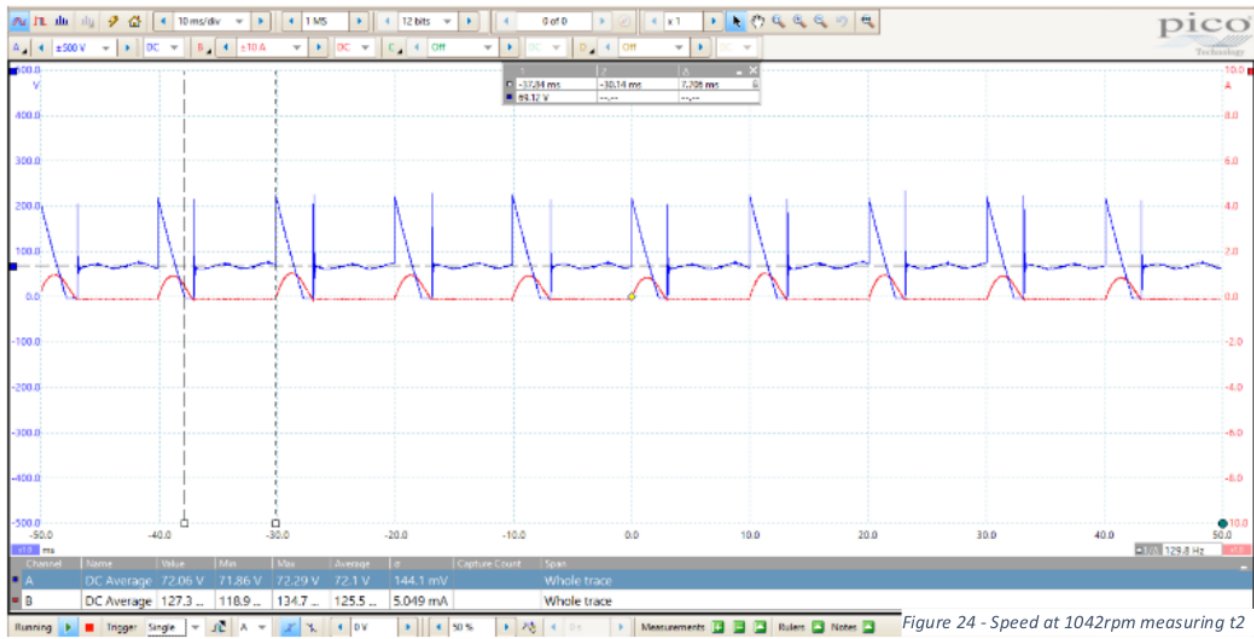


Figure 24 - Speed at 1042rpm measuring t2

$$\beta = \frac{t_1}{10ms} \times \pi = \frac{756.8 \times 10^{-6}}{10} \times \pi = 0.238 \text{ rads}$$

$$\alpha = \frac{t_2}{10ms} \times \pi = \frac{7.706 \times 10^{-3}}{10} \times \pi = 2.421 \text{ rads}$$

Average armature voltage according to experiment: 72.1V

Calculated average armature voltage:

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

$$\begin{aligned} \text{Voltage average} &= \frac{69.12}{\pi}(2.421 - 0.238) + \frac{337.230}{\pi}(1 + \cos(2.421)) \\ &= 48.03 + 26.68 \end{aligned}$$

$$\text{Voltage average} = 74.71v$$

4.3 Speed at 2020rpm

T1=0. Only T2 could be measured.

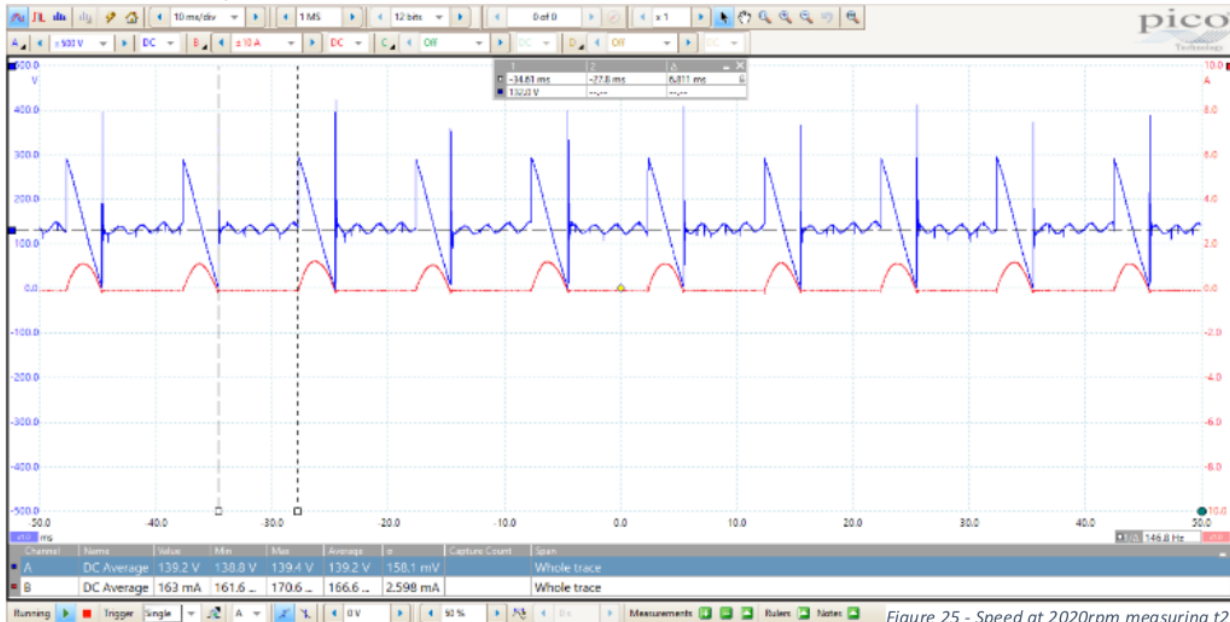


Figure 25 - Speed at 2020rpm measuring t2

$$\alpha = \frac{t_2}{10ms} \times \pi = \frac{6.811 \times 10^{-3}}{10} \times \pi = 2.14 \text{ rads}$$

Average armature voltage according to experiment: 139.2V

Calculated average armature voltage:

$$\begin{aligned} \text{Voltage average} &= \frac{E}{\pi} (\alpha - \beta) + \frac{V_{pk}}{\pi} (1 + \cos(\alpha)) \\ \text{Voltage average} &= \frac{132}{\pi} (2.14 - 0) + \frac{337.230}{\pi} (1 + \cos(2.14)) \\ &= 89.92 + 49.49 \\ \text{Voltage average} &= 139.41v \end{aligned}$$

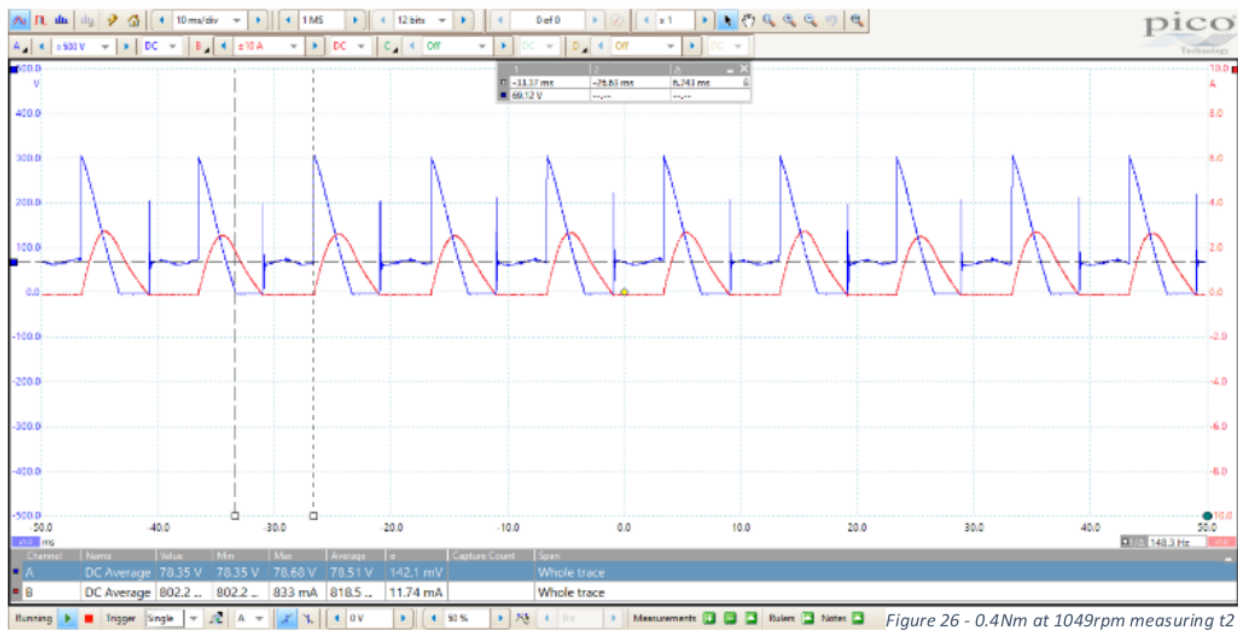
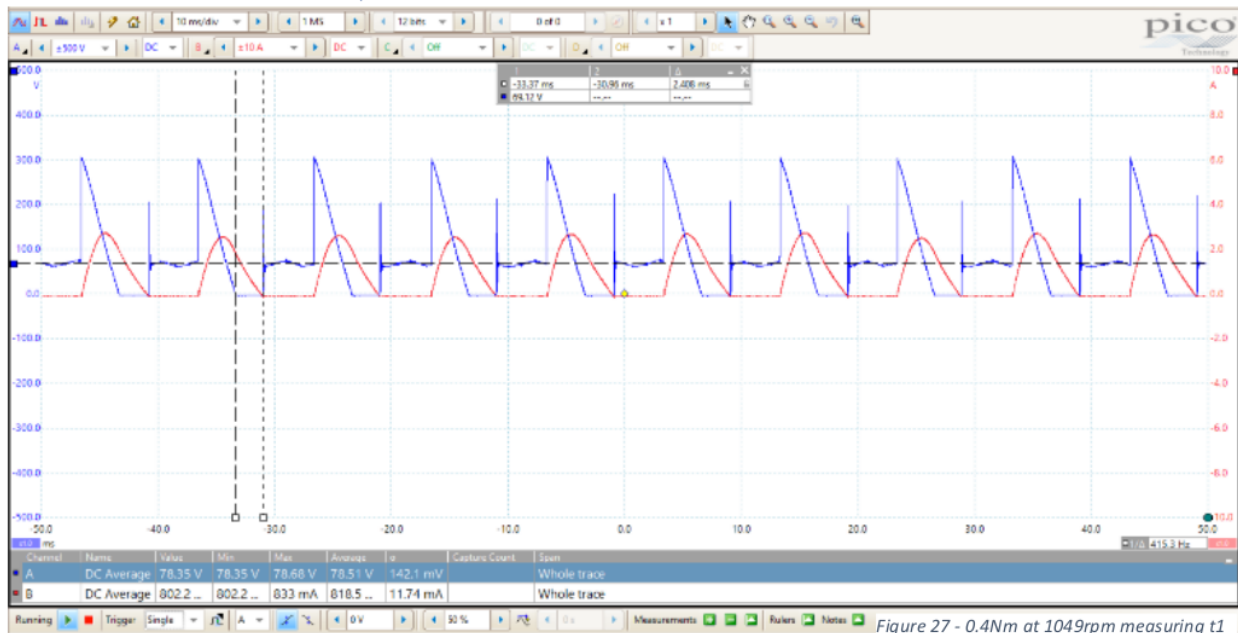
4.1.1 Table of comparison

Criteria	Zero load, varying speeds		
	554.7rpm	1042rpm	2020rpm
Average voltage	39.05V	72.1V	139.2V
Calculated voltage	38.59	74.71	139.41
Peak voltage	175V	220V	290V
voltage when current=0	35.01V	69.12V	132V
t1 value	1.72mV	0.757mV	0V
t2 value	8.256mV	7.706mV	6.811mV

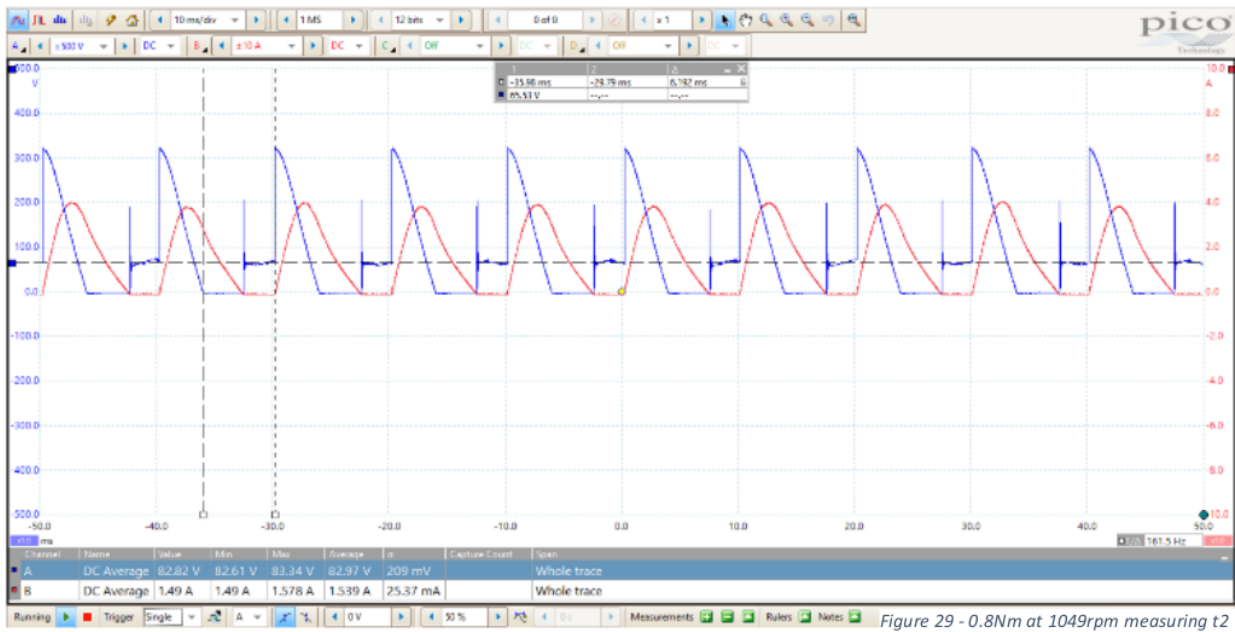
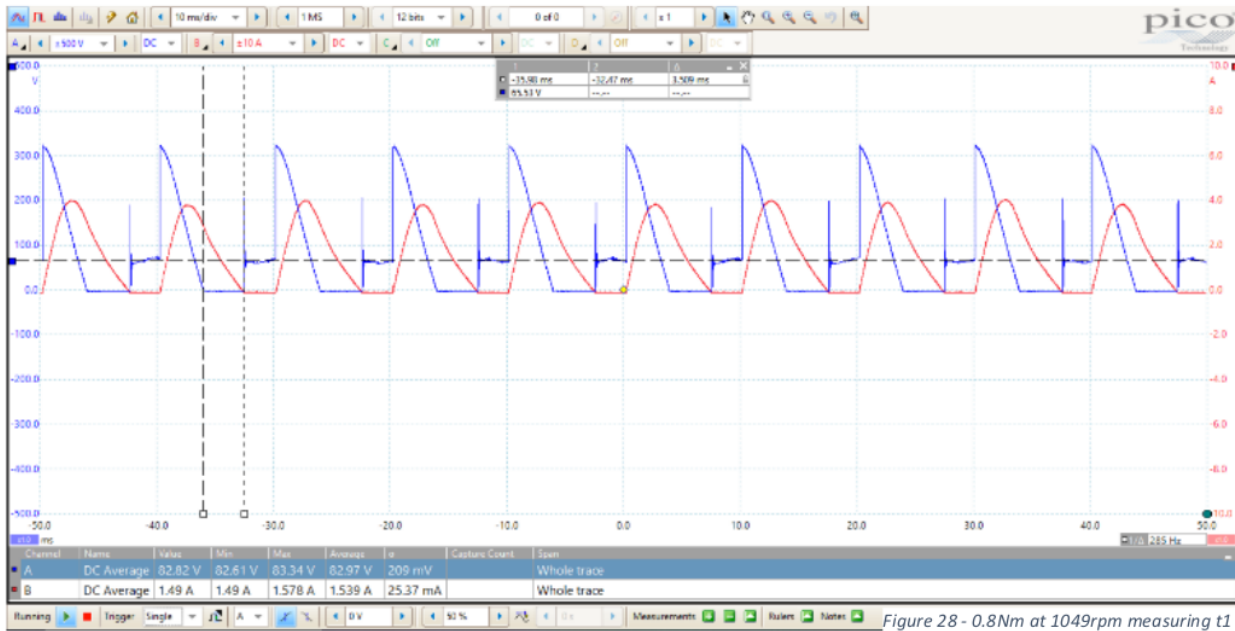
Table 7 - no load, varying speeds

Table 7 shows that as the speed increases all voltage readings increase with it except for the values of t1 and t2. Which decrease because the duty cycle reduces with the increasing load.

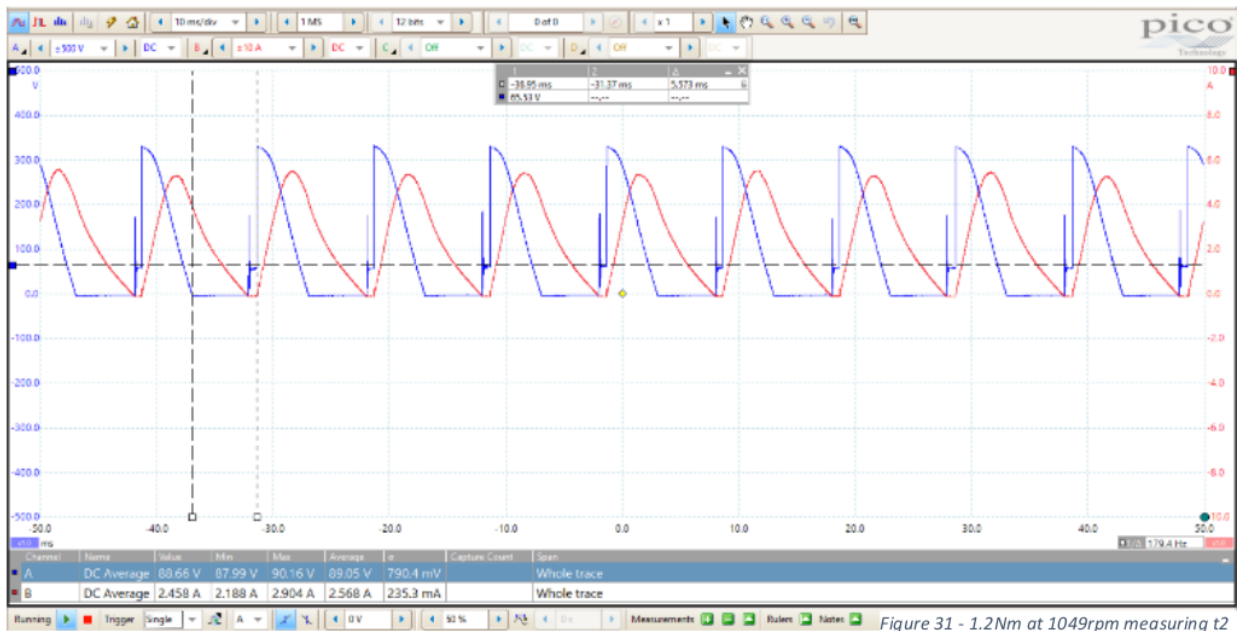
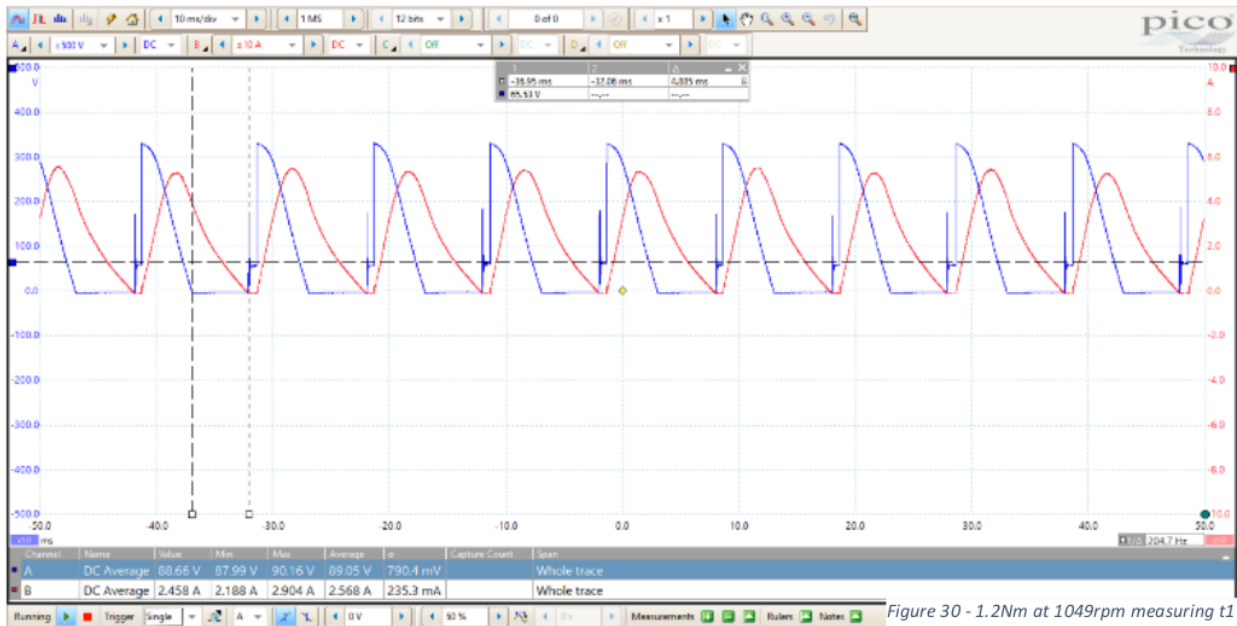
4.4 0.4Nm at 1049rpm



4.5 0.8Nm at 1049rpm



4.6 1.2Nm at 1049rpm



The term duty cycle belongs to PWM drive, this is a controlled rectifier, you should be talking about phase angle

4.7 The experiment

The experiment involved driving a DC motor with a Parker 512C drive, attaching a Pico-scope module to the motor, and using a laptop to display the readings. The motor was tested under load and no-load conditions. Figures 38-42 pages 53-57 in appendix show photos of the practical experiment being undertaken.

4.8 How the drive performance changes with the load

Figures 26-31 on pages 35-37 and table 8 show the performance of the drive when set at a constant speed with different loads applied. (0.4, 0.8 and 1.2Nm of force) The biggest visible change on the Pico-scope waveform shows that as the load increases the duty cycle or time between the voltage dropping and the thyristor firing gets smaller. The current steadily increases with the load showing to be directly proportional. See appendix for photos.

Criteria	Constant speed of 1049rpm		
	0.4Nm	0.8Nm	1.2Nm
Average voltage	78.51V	82.97V	89.05V
Peak voltage	300V	315V	325V
voltage when current=0	69.12V	65.53V	65.53
t2 value	6.743ms	6.192ms	5.573ms
Average current	818.5mA	1.539A	2.568A
Peak current	2.8A	3.9A	5.3A

Table 8 - Set speed, varying loads

Increasing the load on the motor increases the average and peak voltage levels. But not in direct proportion. The load value will double but the voltage levels only increase slightly in comparison. However, the voltage when current falls to zero stays relatively the same and the t2 value decreases as the load increases and the current progresses towards a constant level.

5. Simulation of a medium length transmission line

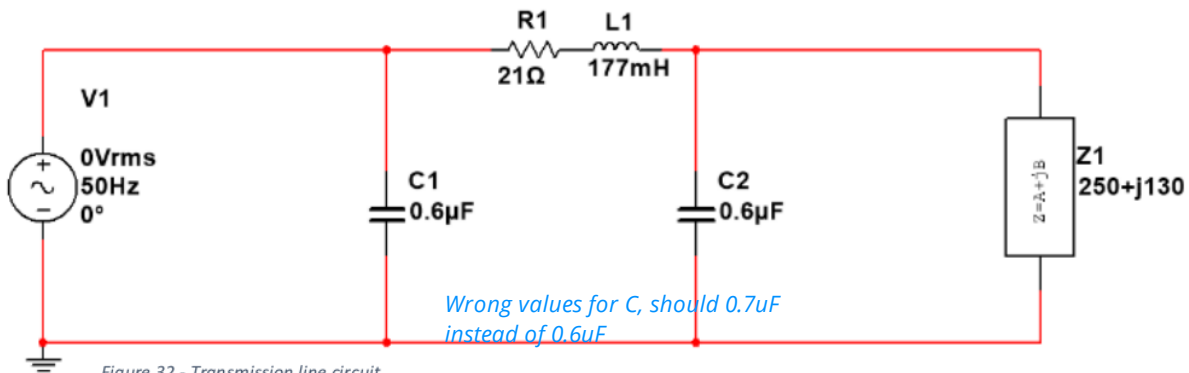


Figure 32 - Transmission line circuit

5.1 Calculations:

Read the question again !

Single-phase 50Hz transmission line. 21Ω Resistance, 177mH Inductance, 1.4μF Capacitance

Impedance:

$$Z_s = 21 + j\omega \times 177mH$$

$$Z_s = 21 + j \times 2\pi \times 50 \times 177 \times 10^{-3}$$

$$Z_s = 21 + j55.606\Omega$$

To convert to polar form:

$$\sqrt{21^2 + 55.606^2} \angle \tan^{-1} \left(\frac{55.606}{21} \right)$$

$$= 59.44 \angle 69.31^\circ$$

Shunt admittance:

You should be using 1.4 for C not 1.4uF

$$Y = j \times 2 \times \pi \times 50 \times 1.4 \times 10^{-6}$$

$$Y = j0.439 \times 10^{-3}$$

Or

$$Y = j0.439 \times 10^{-3} \angle 90^\circ$$

Given that the receiving end load is 82.596KV(VRN) at 293.124A(IRN) with a 0.88722 lagging power factor:

$$\text{Receiving current} = 293.124 \angle \cos^{-1}(0.88722)$$

$$\text{Receiving current} = 293.124 \angle -27.47^\circ$$

Using the nominal π circuit:

$$\begin{aligned} 293.124 \angle -27.47^\circ + 82.596 \times 10^3 \angle 0^\circ \times \frac{0.439 \times 10^{-3}}{2} \angle 90^\circ \\ = 293.124 \angle -27.47^\circ + 18.13 \angle 90^\circ \end{aligned}$$

Then into cartesian form:

$$293.124 \cos(27.47) = 260.075 \text{ and } 293.124 \sin(27.47) = 135.213$$

$$260.075 \text{ and } 135.213 = 260.075 - j135.213$$

$$\text{adding the } 18.13 \angle 90^\circ$$

$$260.075 - j135.213 + j18.13$$

$$= 260.075 - j117.083A$$

Then back to polar form:

$$\begin{aligned} \sqrt{260.075^2 + 117.083^2} \angle \tan^{-1}\left(\frac{117.083}{260.075}\right) \\ = 285.215A \angle -24.24^\circ \end{aligned}$$

At Sending end:

$$\begin{aligned} \text{Sending voltage} &= 82.596 \times 10^3 \angle 0^\circ + 285.215 \angle -24.24^\circ \times 59.44 \angle 69.31^\circ \\ &= 82.596 \times 10^3 \angle 0^\circ + 16953.18 \angle 45.07^\circ \end{aligned}$$

Into cartesian:

$$16953.18 \cos(45.07) = 11973.05$$

$$16953.18 \sin(45.07) = 12002.35$$

Therefore:

$$11973.05 + j12002.35$$

$$82.596 \times 10^3 + 11973.05 + j12002.35$$

$$= 94569.05 + j12002.35$$

Back into polar:

$$\sqrt{94569.05^2 + 12002.35^2} = 95327.65$$

$$\tan^{-1}\left(\frac{12002.35}{94569.05}\right) = 7.23^\circ$$

$$= 95327.65V \angle 7.23^\circ$$

At Sending end:

$$\begin{aligned} \text{Sending current} &= 260.075 - j117.083 + 95327.65 \angle 7.23^\circ \times \frac{0.439 \times 10^{-3}}{2} \angle 90^\circ \\ &= 260.075 - j117.083 + 20.924 \angle 97.23^\circ \end{aligned}$$

Into cartesian:

$$20.924 \cos(97.23) = -2.633$$

$$20.924 \sin(97.23) = 20.758$$

$$\begin{aligned} 260.075 - j117.083 - 2.633 + j20.758 \\ = 257.442 - j96.325 \end{aligned}$$

Back into polar:

$$\sqrt{257.442^2 + 96.325^2} = 274.873$$

$$\tan^{-1}\left(\frac{96.325}{257.442}\right) = 20.51^\circ$$

$$= 274.873A \angle 20.51^\circ$$

Sending current/voltage angle:

$$\text{Sending angle} = 7.23^\circ - (-20.51^\circ) = 27.74^\circ$$

Sending power factor:

$$\text{Sending power factor} = \cos(27.74^\circ) = 0.8851 \text{ Lagging}$$

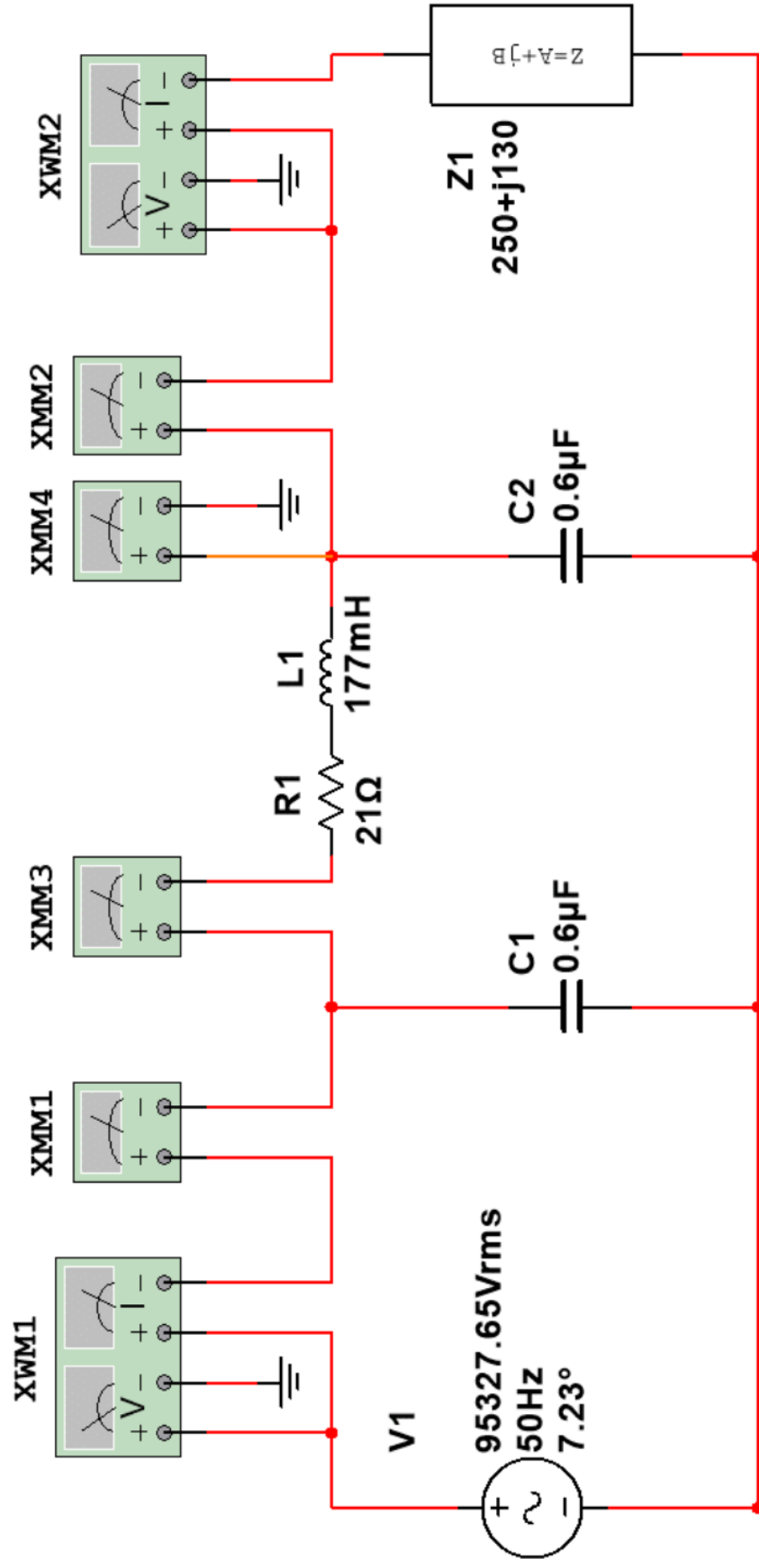


Figure 33 - Transmission line circuit with calculated values

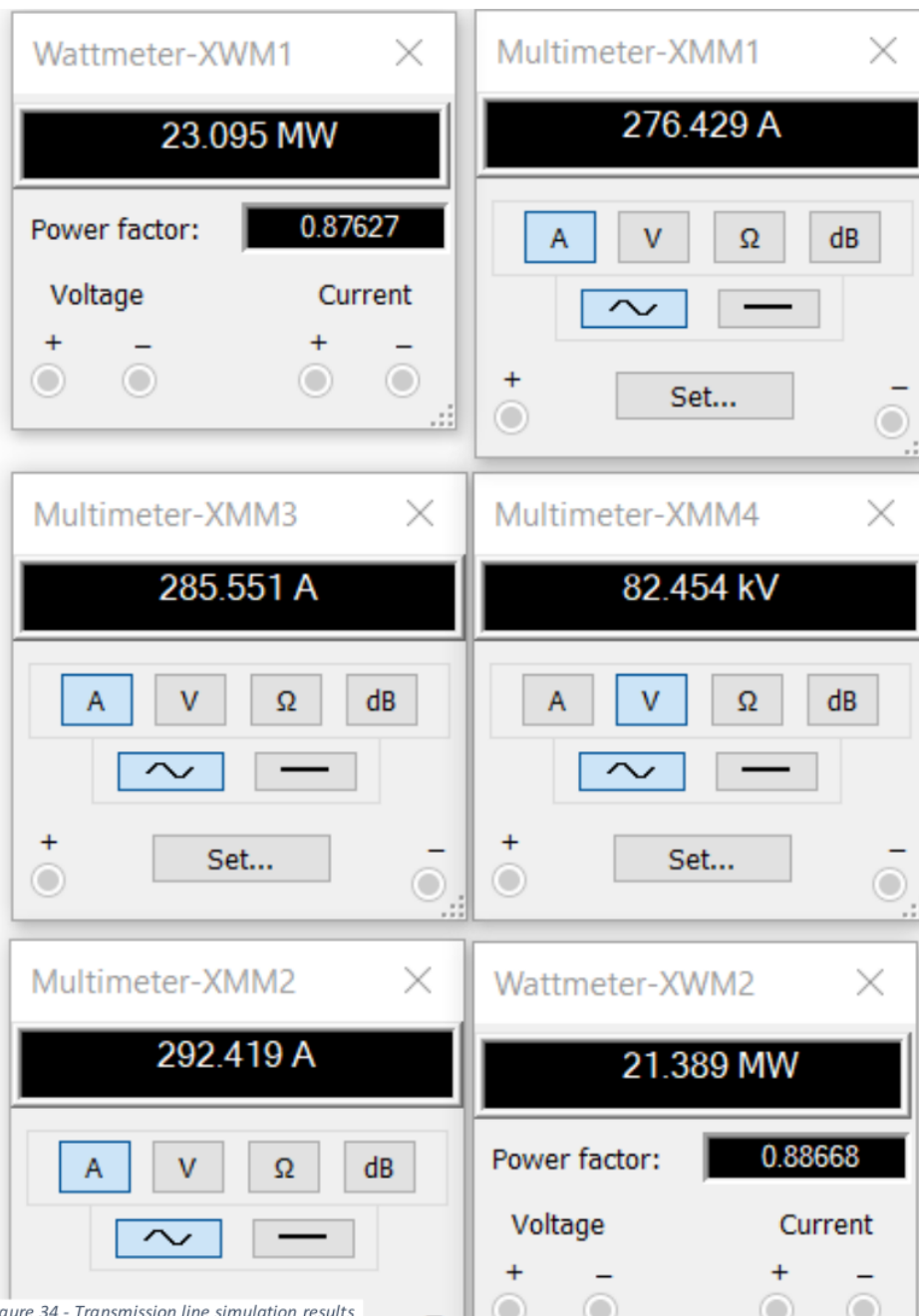


Figure 34 - Transmission line simulation results

Power line efficiency

Sending:

$$274.873 \times 95327.65 \times 0.8851 = 23.19MW$$

Receiving:

$$293.124 \times 82.596 \times 10^3 \times 0.88722 = 21.48MW$$

*Where is your comparison table to see the differences
between simulated and calculated results?*

6. Conclusions and recommendations

There are many types of DC motor and an even larger range of uses for all types. However, given that power is mainly distributed in the form of AC, methods of rectification of the waveform into DC for use by these motors/generators is vital. These include a diode bridge rectifier used in conjunction with PWM/variable resistor control, machine control via H-bridge or control through a three/single-phase dual voltage converter.

All results obtained from simulations and tests closely matched the calculated results with only minor discrepancies which could be a result of human error in placing the cursors on the simulator graph. Only when comparing voltage levels in task three did any differences occur that were too big to be discrepancies.

The errors are in your calculations or measurements, when they don't match up, you need to investigate more closely

Applying load to the motor had the effect of reducing the duty cycle on the motor and if enough load were applied, the current would then remain constant and at a larger value since it is proportional to the load. An example of this could be excessive load on a motor, giving continuous current which will cause it to overheat eventually. While the voltage levels did increase but not nearly as much as the current did in proportion to the load.

Duty cycle is not the relevant term, you should be writing about phase angle

7. Team working

During the experiment looking at a single quadrant DC drive we all worked as a team while making sure to follow social distancing guidelines. My personal role in the experiment involved setting up the pico-scope on the computer. Making sure the data was correctly recorded and the correct parameters used to present the waveform in a usable manner. Good communication within the team meant the experiment was finished quickly.

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9. Appendix

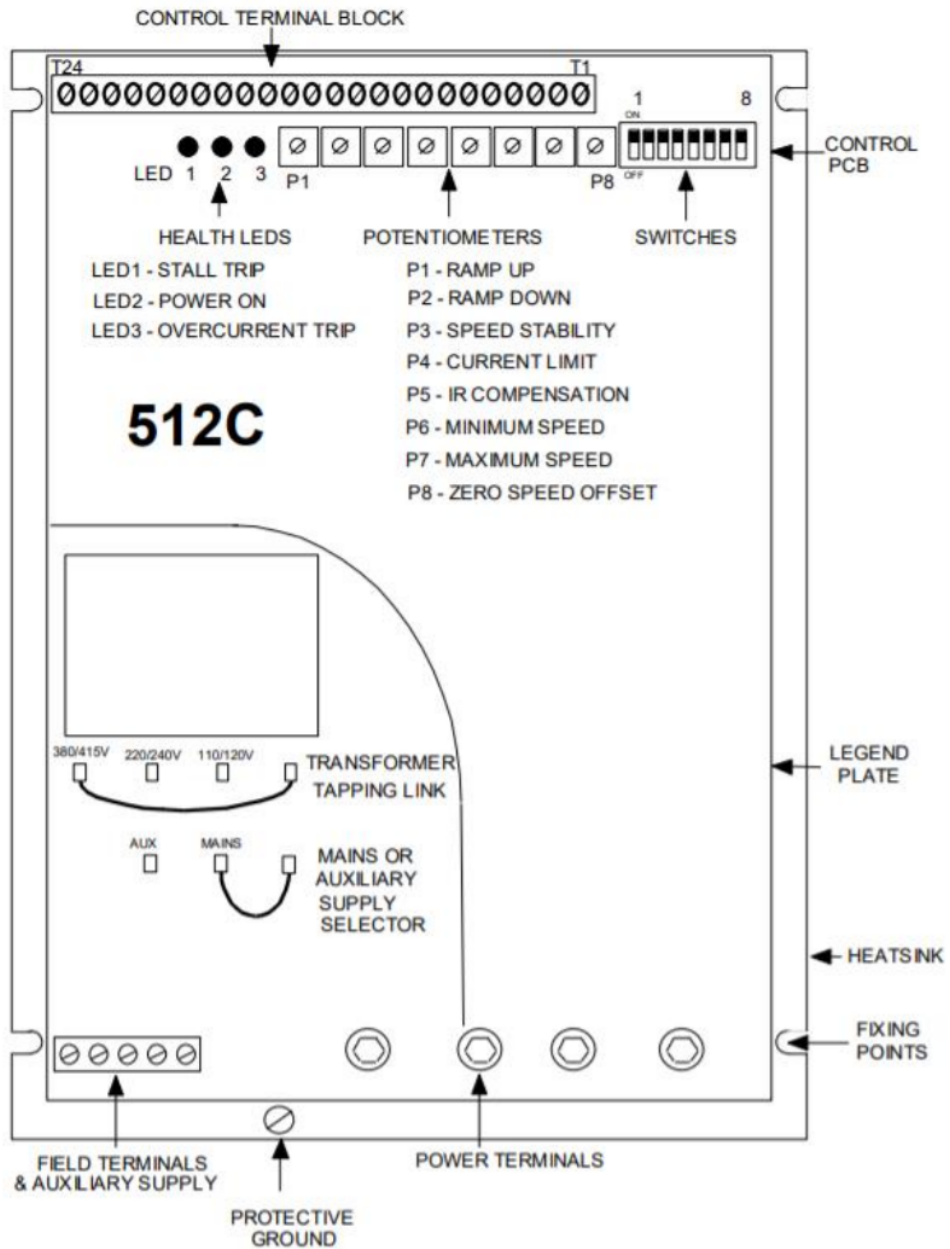
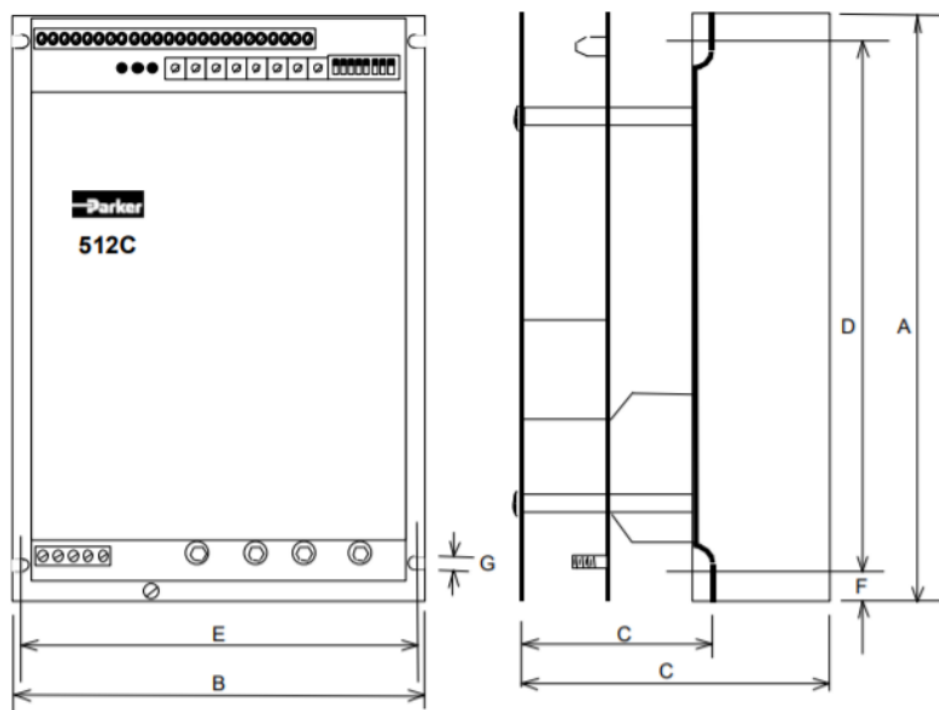


Figure 35 - 512C facer

Speed Control	Control Action	Closed Loop with Proportional Integral Control and Adjustable Stability		
	Speed Feedback	Armature Voltage	Tachogenerator	
	100% Load Regulation	2 % Typical	0.1 % Typical	
	Maximum Torque/Speed Range	20:1	100:1	
	Overload	150% for 60 seconds.		
Torque Control	Control Action	Closed Loop with Proportional Integral Control		
	Accuracy	2 %		
	Overspeed	Inherent		
	Overload	None 100% Continuous (consideration must be given to motor when operating at low speed)		
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 (SWB Off)	0 to +5V (0 to Idc)	5mA
		Current (SWB 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
	Stall Override		+10	100Kohm
	Digital Outputs	Health	+24V	50mA Source
		Zero Speed or Setpoint	+24V	50mA Source

Figure 36 - 512C technical data



PRODUCT	OVERALL DIMENSIONS			FIXING CENTRES		SIZE	SLOT DETAIL	
	A	B	C	D	E		F	G
512C-04	240mm	160mm	90mm	210mm	148mm	M6	15mm	7mm
512C-08	240mm	160mm	90mm	210mm	148mm	M6	15mm	7mm
512C-16	240mm	160mm	90mm	210mm	148mm	M6	15mm	7mm
512C-32	240mm	160mm	130mm	210mm	148mm	M6	15mm	7mm

Table 3.1 Product Dimensions

Figure 37 - 512C Dimensions



Figure 38 - Motor control panel

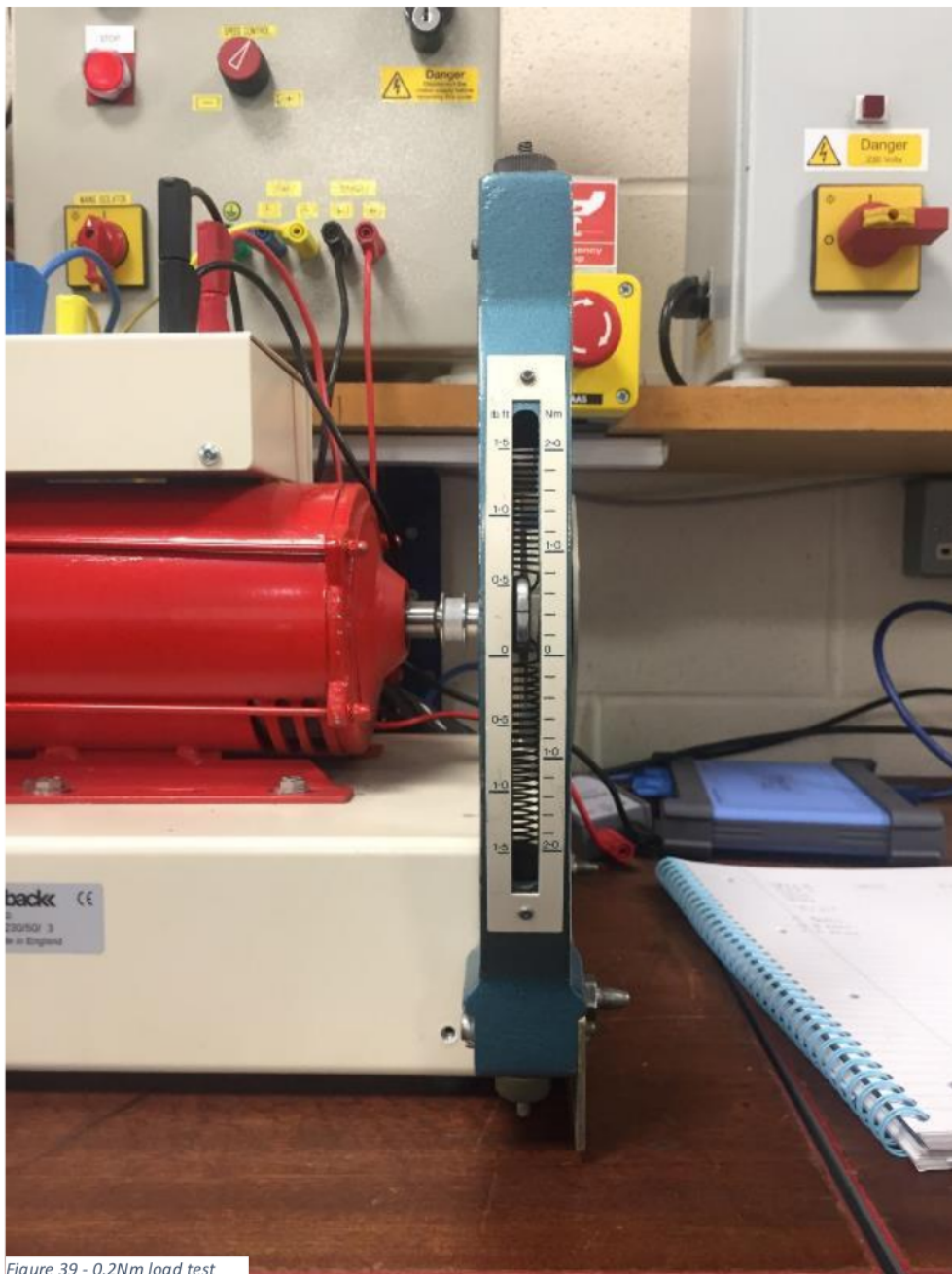


Figure 39 - 0.2Nm load test

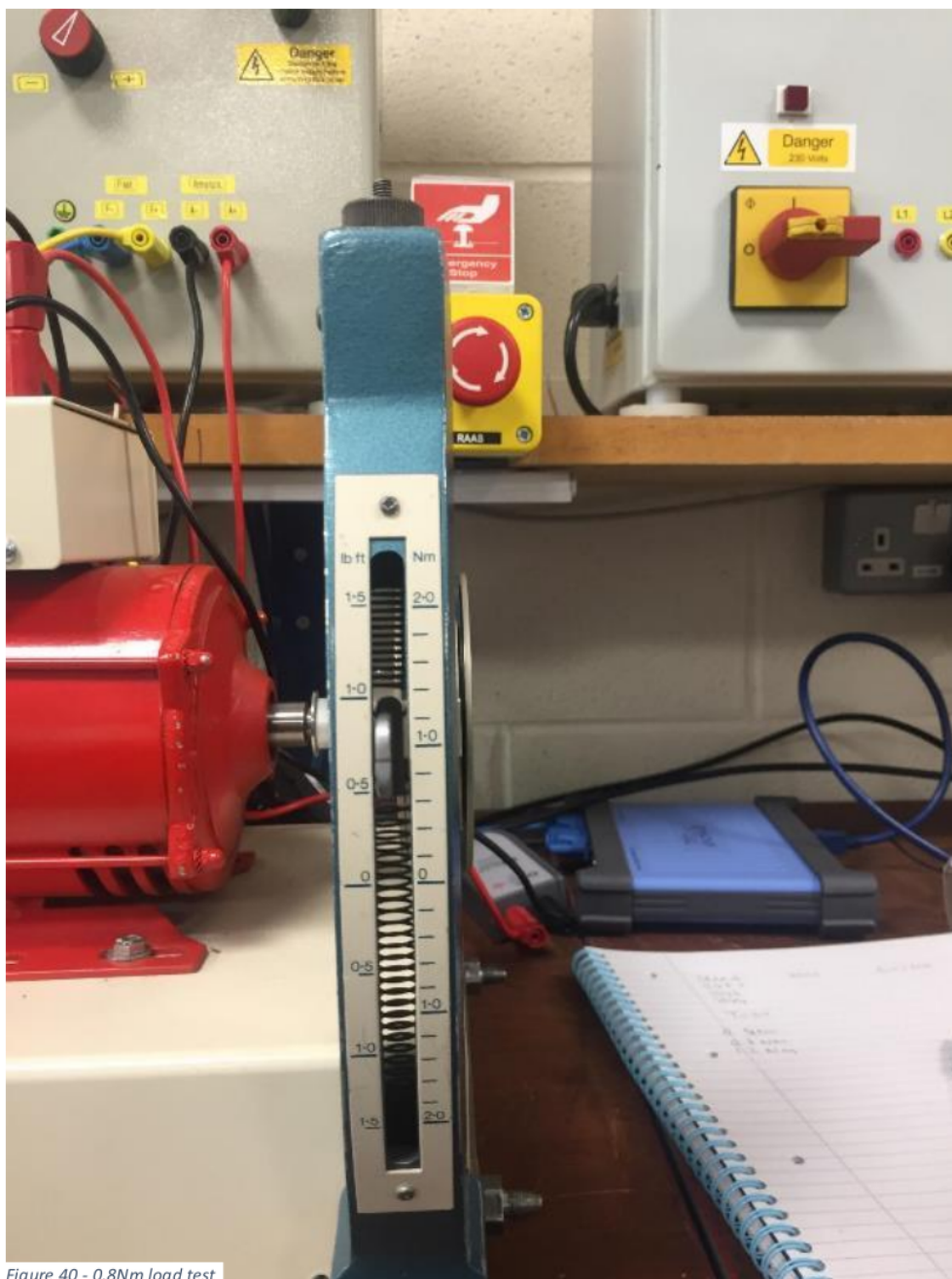


Figure 40 - 0.8Nm load test

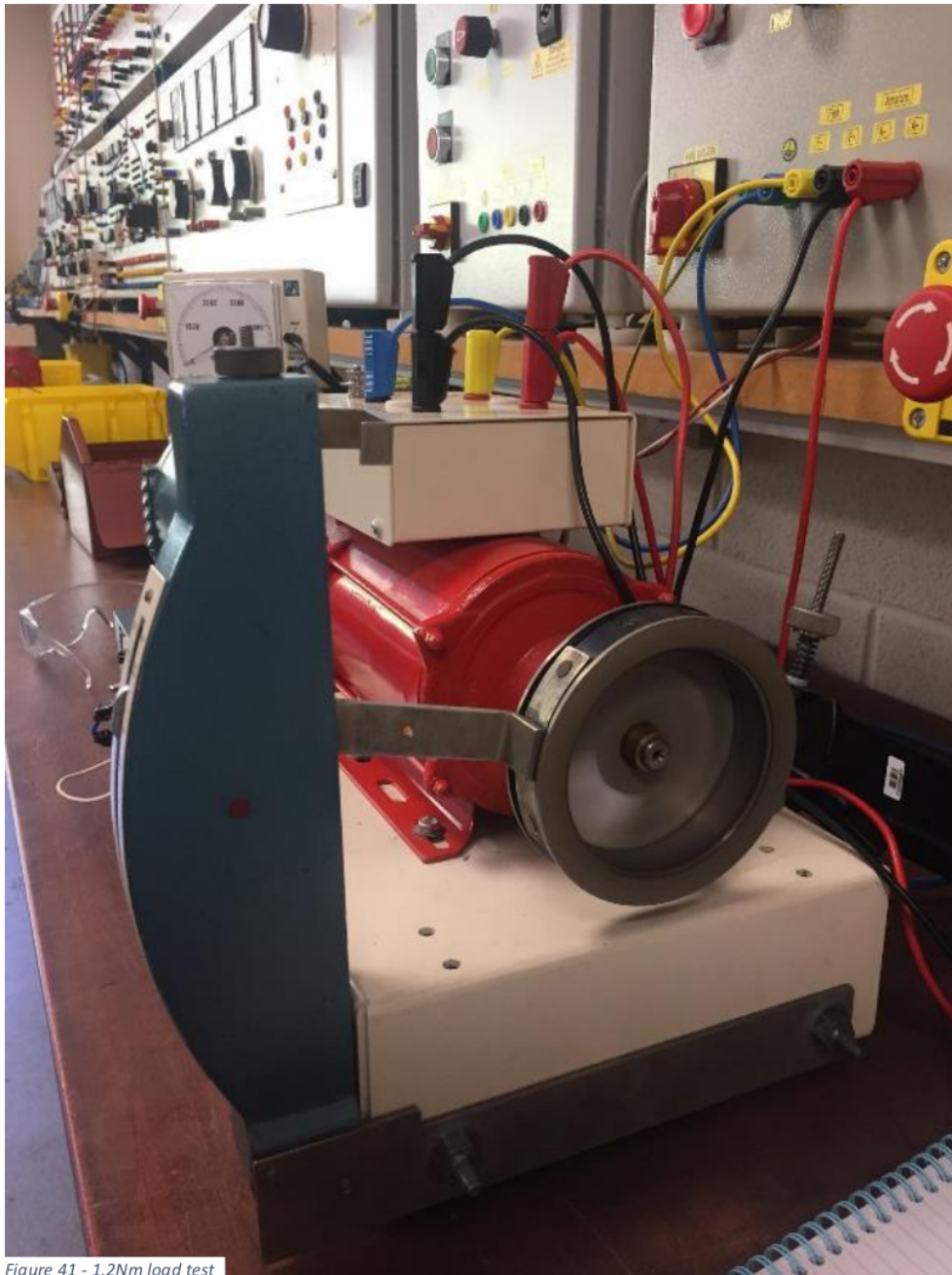


Figure 41 - 1.2Nm load test



Figure 42 - Motor experiment setup

Instructor

52/100

PAGE 1

Text Comment. word count exceeded

PAGE 2

QM

Good Structure

Report is structured exactly as stated in the assignment brief.

PAGE 3

PAGE 4

PAGE 5

QM

Use of 11pt Arial, full justification with 1.5 line spacing allows easier reading and marking

Your presentation could be improved making the text easier to read and mark. Your tutor will then be able to add comments between lines

PAGE 6

QM

Spelling

Spelling error

QM

Citation Needed

Cite Source:

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

QM

Citation Needed

Cite Source:

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

Text Comment. Wrongly cited. You should have said: EEEGuide state that "
....." (2014, Page ?)

PAGE 7

Text Comment. This is too simple for level 5, you should have focused on thyristor controlled rectification

QM

Incorrectly cited, this is not the Harvard Method

PAGE 8

Text Comment. You should have focused on control from an AC supply

PAGE 9

QM

Citation Needed

Cite Source:

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http://www.plagiarism.org/plag_article_citation_styles.html

PAGE 10

QM

Incorrectly cited, this is not the Harvard Method

PAGE 11

PAGE 12

QM

Incorrectly cited, this is not the Harvard Method

PAGE 13

Text Comment. You should have quoted from the datasheet and cited instead of including it here

Text Comment. The 512 is not suitable for servo motion as it can only work in one quadrant

PAGE 14

Text Comment. This diagram belongs in the appendix and should be cited

PAGE 15

PAGE 16

PAGE 17

PAGE 18

Text Comment. V_{max} is always 337 V

PAGE 19

PAGE 20

Text Comment. V_{max} is always 337 V

PAGE 21

PAGE 22

Text Comment. V_{max} is always 337 V

PAGE 23

Text Comment. The differences are large because V_{max} is always 337 V

Text Comment. This means that your calculations are incorrect

PAGE 24

PAGE 25

PAGE 26

PAGE 27

PAGE 28

PAGE 29

Text Comment. There is something wrong either with your measurements or your calculations

PAGE 30

PAGE 31

PAGE 32

PAGE 33

PAGE 34

PAGE 35

PAGE 36

PAGE 37

PAGE 38

Text Comment. The term duty cycle belongs to PWM drive, this is a controlled rectifier, you should be talking about phase angle

PAGE 39

Text Comment. Wrong values for C, should 0.7uF instead of 0.6uF

Text Comment. Read the question again !

Text Comment. You should be using 0.7 uF for C not 1.4uF

PAGE 40

PAGE 41

PAGE 42

PAGE 43

PAGE 44

Text Comment. Where is your comparison table to see the differences between simulated and calculated results?

PAGE 45

Text Comment. not always, it is important that you critically evaluate your results

Text Comment. The errors are in your calculations or measurements, when they don't match up, you need to investigate more closely

Text Comment. Duty cycle is not the relevant term, you should be writing about phase angle

PAGE 46

PAGE 47

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PAGE 57

GRADING FORM: NEW CSG-RUBRIC

RICHARD HARRISON

52

1. ENGAGEMENT WITH LITERATURE



Engagement with a wide range of literature, including sources retrieved independently. Selection of relevant and credible sources. However, your referencing is not always correct and not all source have been cited. (12/20)

12

2. KNOWLEDGE AND UNDERSTANDING



Knowledge is reasonably detailed and accurate. A good critical understanding of the well-established concepts and principles and the main methods of enquiry, with minor gaps in the selection of material. However, there are some misconceptions and confusion between duty cycle and phase angle. (10/20)

10

3. COGNITIVE AND INTELLECTUAL



Some critical evaluation and analysis of concepts and principles, though descriptive in parts. An emerging awareness the limits of their knowledge and ability to use evidence to support the argument though with some tendency to assert/state opinion rather than argue on the basis of reason and evidence. Mostly valid arguments and logical judgements. However, when results do not match up, you should investigate further and be more critical of your findings. (10/20)

10

4. PRACTICAL APPLICATION



A good and appropriate application of established methods, materials, tools and/or techniques. Clear appreciation of the context of the application. Mainly consistent, accurate and logical application of theory to practice, making appropriate links between the two. Can identify problems and propose mostly appropriate solutions outside the context in which they were first studied. (11/20)

11

5. TRANSFERABLE SKILLS



Can communicate effectively in a suitable medium for the audience, but may have minor errors.

9

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 exceeded. (9/20)