

Sam Harries - Assignment 2

Final

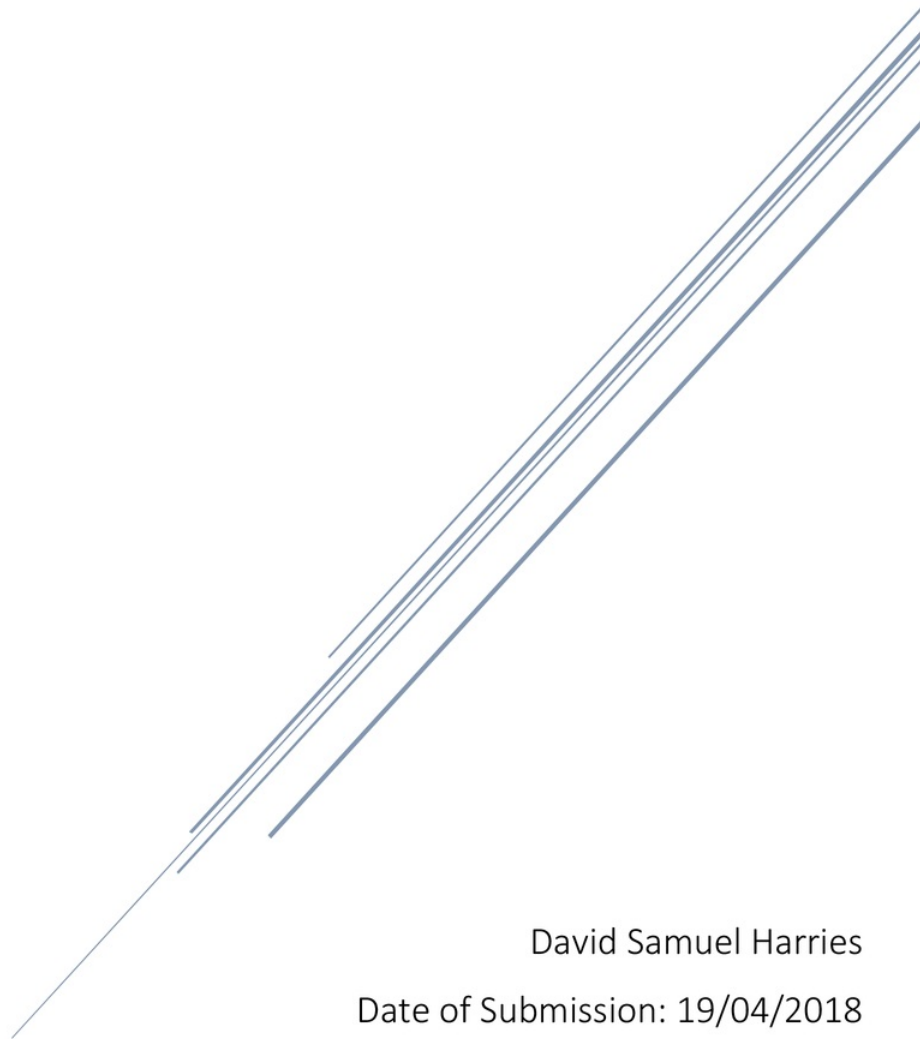
by David Harries

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HND Electrical and Electronic Engineering

PSDE5027

Assignment 1: Investigation into Single Quadrant DC Motor
Drive



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1 - RESEARCH

1.1 THYRISTORS AND THEIR USAGE AS CONTROLLED RECTIFIERS

"A thyristor is a four-layer semiconductor that is often used for handling large amounts of power. While a thyristor can be turned on or off, it can also regulate power using something called phase angle control. This allows the amount of power output to be controlled by adjusting the angle of the current input." (Techterms.com, 2018) There are a few types of thyristor:

- SCR (Silicon Controlled Rectifier)
- Triac
- GTO (Gate Turn off)
- MCT (MOSFET Controlled Thyristor)

1.1.1 SCR (Silicon Controlled Rectifiers)

Silicon Controlled Rectifiers are thyristors that block current in both directions. However, current can be allowed to pass through the SCR in the forward direction when triggered by a pulse on the 'gate'. This gives the SCR three 'modes' of operation; Forward Blocking, Forward Conducting and Reverse Blocking. **Figure 1-1** shows the physical diagram, equivalent schematic and the schematic symbol.

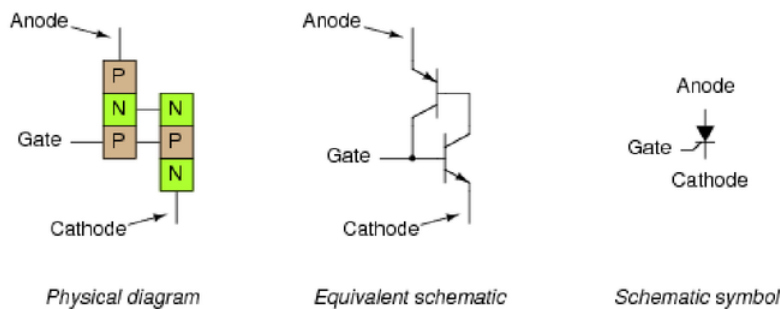


Figure 1-1

In forward blocking configuration, a positive potential is applied to the anode as a negative voltage is applied to the cathode. The gate is kept at zero potential. In this configuration the voltage is too low to break through the PN junction of the thyristor, so current is blocked.

In forward conduction configuration, the same potential is applied to the anode and cathode, however a voltage is also applied to the gate. This voltage on the gate allows the voltage to exceed the forward breakdown voltage, which allows current to flow through the thyristor. The thyristor acts as a closed switch in this configuration, however a small volt drop occurs due to the resistance in the PN junctions. As the gate current increases, the breakdown voltage is reduced, allowing the thyristor to operate in forward conduction at a lower forward voltage. This operation can be seen in **Figure 1-2**.

In reverse blocking configuration, the cathode is instead given a positive potential with respect to the anode. This means the thyristor is connected in reverse bias. This once again blocks current like a diode, and as such, has a reverse leakage current and an avalanche region. The thyristor operates in the avalanche region when a very large voltage is applied to the thyristor when

in this configuration. This can damage the thyristor as high temperatures are generated within the device. A SSCR in this configuration is generally used as an open switch. This operation can once again be seen in **Figure 1-2**.

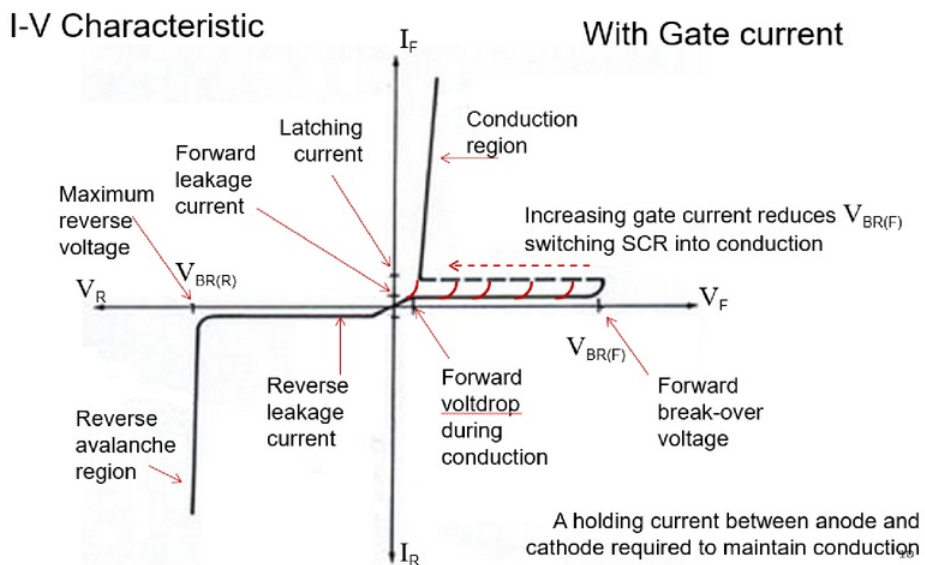


Figure 1-2

The SCR, like a diode, stores charge which means, it requires reverse recovery time. This makes SCR's slower at switching than a transistor. SCRs cannot be switched off by the gate, however a variation of the SCR is a GTO or (Gate Turn Off Thyristor). Even though it requires reverse recovery time, the SCR has the highest voltage rating of all control rectifying devices.

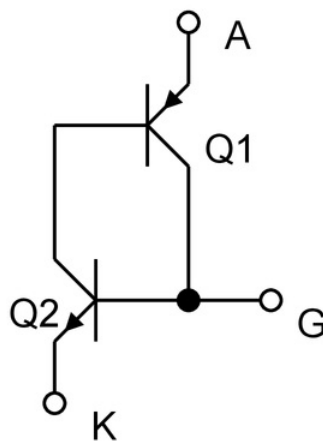


Figure 1-3

The equivalent schematic shows that a SCR can be equated to two BJT transistors connected as shown in **Figure 1-3**. The volt drop between the gate and the cathode switches Q2 into conduction mode. The base current then flows from the anode, through the collector on Q1 and into

the base of Q2. This keeps the current flowing when the signal on the gate is removed. For the SCR to turn off, a negative voltage must be applied between the anode and the cathode to turn off Q1, which would then turn off Q2.

(Allaboutcircuits.com, 2018), (Pantechsolutions.net, 2010), (Diffenderfer, 2005)

1.1.2 Triac

Since SRC's are only able to control current flowing in one direction, they are only useful for controlling DC systems. However, by connecting two SRC's together, a triac is created which allows for control in both positive and negative currents.

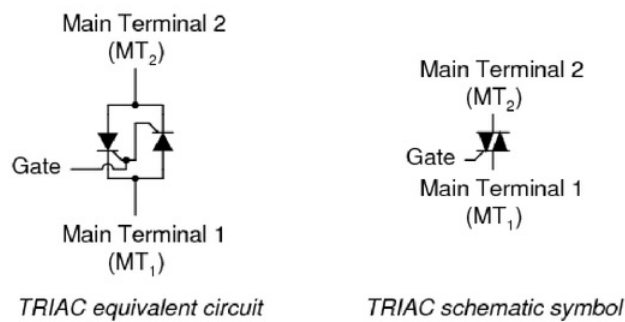


Figure 1-4

As shown above, the Triac device has two SCRs within it connected in anti-parallel, but they both share a gate. The Triac operates the same way as the SCR within the positive region, however due to the mirroring of the second SCR within the triac, the negative region also acts in the same manner rather than having leakage current and an avalanche region. This can be seen in **Figure 1-5**.

(Allaboutcircuits.com, 2018)

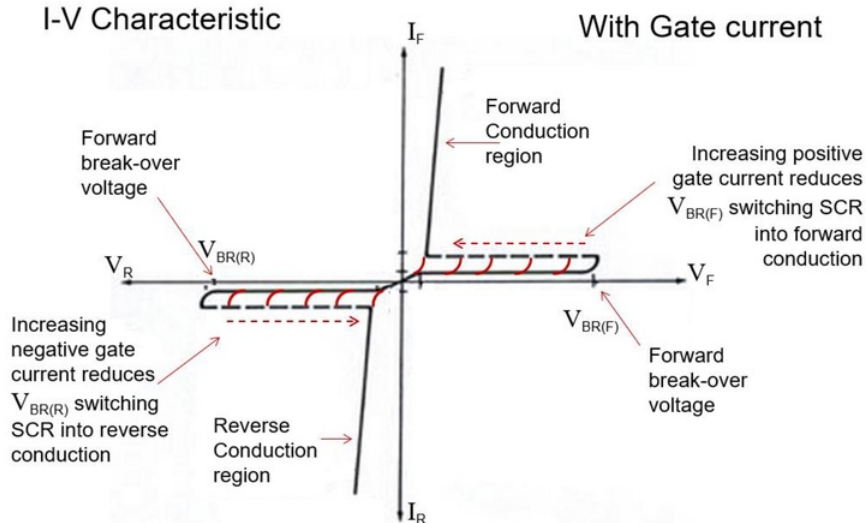


Figure 1-5

1.1.3 GTO (Gate Turn Off)

The GTO thyristor works just as the SCR does when it comes to blocking current flow in both directions when there is no current on the gate and allowing current flow when a positive pulse is applied to the gate. However, unlike the SCR, a negative pulse on the gate turns off the thyristor. Due to this feature, the voltage between the anode and cathode can be subject to very rapid changes. To counter these voltage changes a snubber circuit must be used.

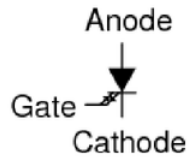


Figure 1-6

The I-V graph produced by the GTO thyristor is comparable to that of the SCR, however it has a slightly higher latching current than the SCR. The GTO also requires a longer pulse on its gate and a higher current than the SCR to turn the thyristor 'on'. Finally, the volt drop across the anode and the cathode can be reduced by maintaining a smaller gate current when the GTO is in its conduction mode. The I-V characteristic graph can be seen below.

(Allaboutcircuits.com, 2018), (Diffenderfer, 2005)

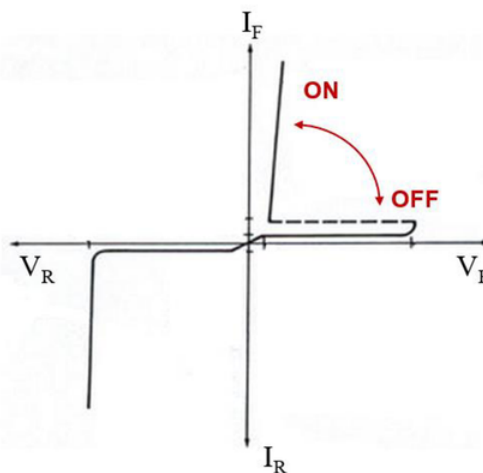


Figure 1-7

1.1.4 MCT (MOSFET Controlled Thyristor)

The MCT thyristor has similar operation to the GTO due to the fact it can be turned on and off by pulsing the gate. There are two types; P-MCT and N-MCT. The difference between these two types can be explained by looking at their equivalent circuits. The construction of both uses 2 built-in MOSFETs to control an SCR. **Figure 1-8** shows the P-MCT equivalent circuit which shows that it is switched on by the P-channel MOSFET, and the N-channel MOSFET is used for switching it off. The MOSFET controlled gate gives it high impedance and therefore a low gate drive current.

The N-MCT is also controlled by 2 built-in MOSFETs, however the MCT is switched on by the N-Channel MOSFET instead and is switched off by the P-Channel MOSFET. This can be seen in **Figure 1-9**.

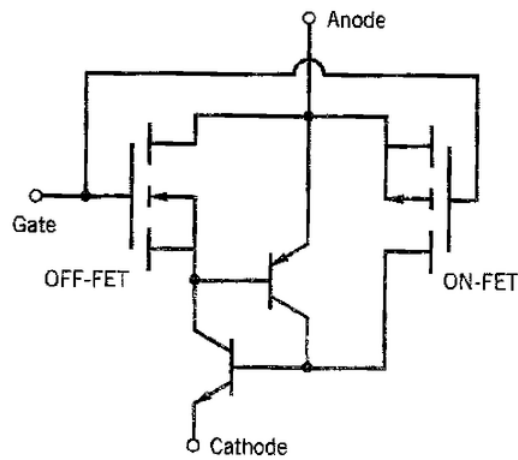


Figure 1-8

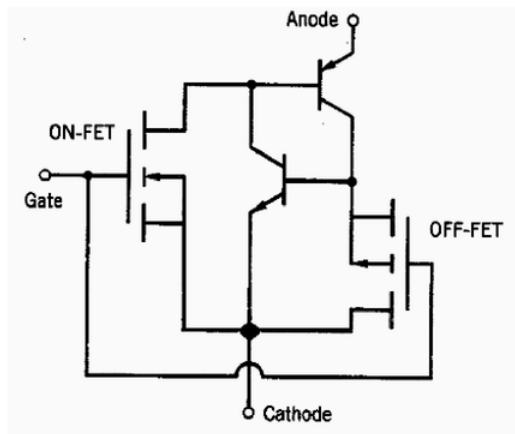


Figure 1-9

The MCT takes the low on-state losses and large current capacity of the SCR transistor and combines it with the low control current required and faster switching speed of the MOSFET. In addition to these features, it can switch on and off like a GTO.

When compared to the GTO, it has a faster switching speed due to the use of MOSFETs, and a lower on state volt drop.

1.1.5 Device Comparison

Each of the previously discussed devices has their pro's and con's. These can be seen in **Figure 1-10**.

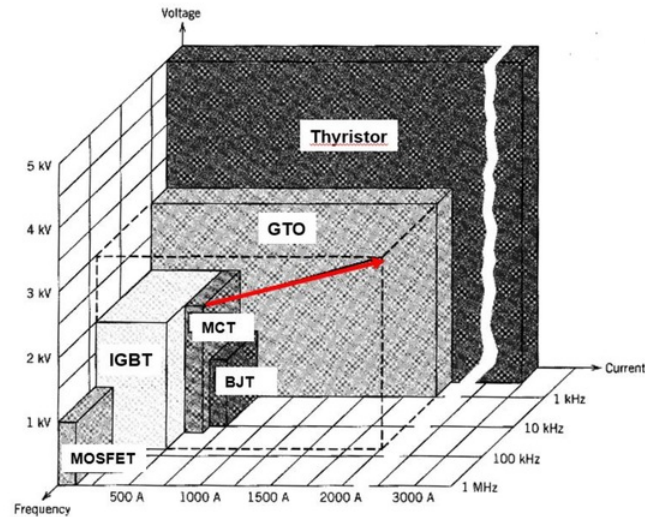


Figure 1-10

As shown above, each other various thyristor's have parameters that allow them to be suited to various applications. Firstly, the SCR thyristor has a much higher voltage rating than all the other types of thyristor. It also has a much higher current rating. However, due to its reverse recovery time, it is not suited to high frequency applications. It is much slower than the other types of thyristor.

The GTO thyristor has the second largest voltage and current rating compared to the rest. It is also capable of operating at higher frequencies than the SCR. However, it is still slower compared to the others.

The MCT is shown to have a lower voltage and current rating than the GTO and the SCR. However, it has an equal voltage rating, and a larger current rating than the IGBT. The MCT has a much faster frequency than that of the GTO and the SCR making it more suitable for faster applications, that do not require a high voltage or current rating.

The final switching device is the MOSFET which can be seen to have the highest frequency rating, but the lowest voltage and current rating of all the devices. This means that it can only be used in low power, fast applications.

1.1.6 Control Rectifiers

A rectifier that uses diodes is called an uncontrolled rectifier as the circuit has no control over the output voltage. However, when the diodes are replaced with thyristors, control over the output voltage is obtained. Thus, controlled rectifiers are created. Thyristors control the output voltage by changing their firing angle.

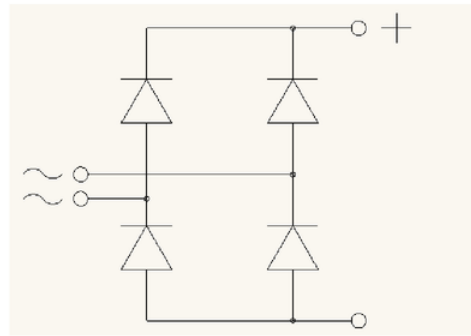


Figure 1-11

Figure 1-11 shows a single phase, full wave, uncontrolled rectifier. As shown it consists of four diodes in a bridge network. By replacing two or all four of the diodes with thyristors, the circuit gains half-control, or full-control of the output voltage respectively. These circuits can be seen in **Figure 1-12** and **Figure 1-13** respectively.

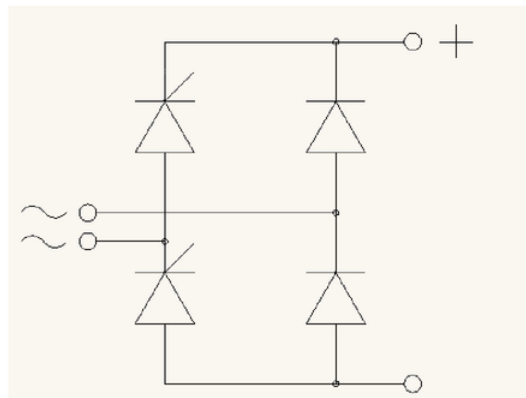


Figure 1-12 – Single Phase, Full-Wave, Half-Control Rectification Circuit

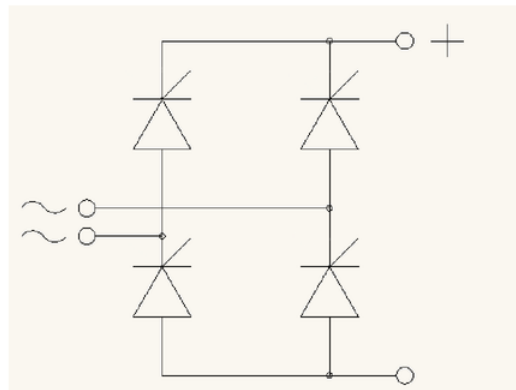


Figure 1-13 – Single Phase, Full-Wave, Full-Control Rectification Circuit

(Ppi-uk.com, 2018)

1.2 ANALYSIS OF A FULL-WAVE, HALF-CONTROLLED RECTIFIER CIRCUIT AND TYPICAL WAVEFORMS PRODUCED WHEN CONNECTED TO A DC MOTOR

As previously shown, a single phase, full-wave, half-controlled rectifier consists of two thyristors and two diodes. A Multisim circuit can be seen in **Figure 1-14**.

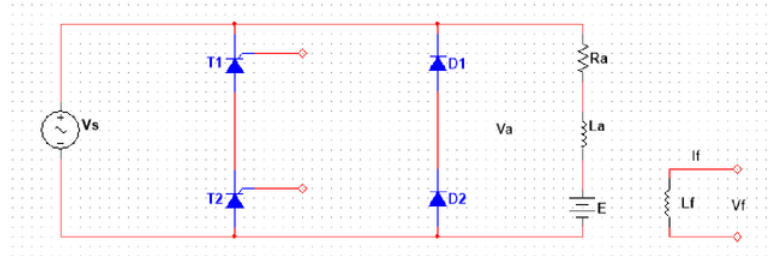


Figure 1-14

The waveform produced by a controller circuit like this when connected to a DC motor can be seen in **Figure 1-15**.

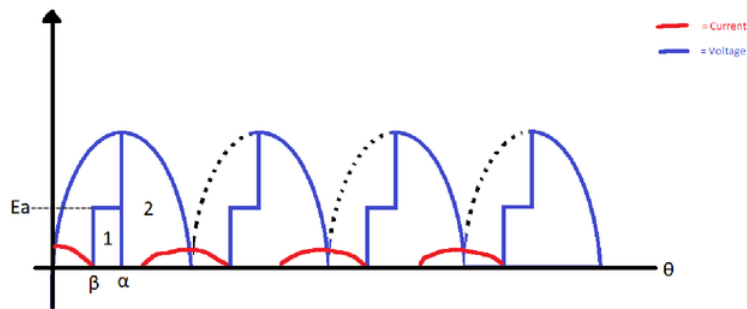


Figure 1-15

From the produced waveforms the average voltage can be calculated. The two sections of the waveform can be broken up into two areas; area 1 and area 2. This is seen clearly in **Figure 1-16**.

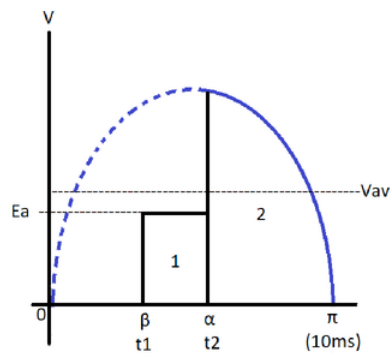


Figure 1-16

Area 1 represents the back emf from the motor and can be calculated as follows:

$$\text{Area 1} = E_a \times (\alpha - \beta)$$

Area 2 can be calculated as follows:

$$\int_0^\pi V_{pk} \sin(\theta) d\theta = V_{pk} (-\cos\theta) = V_{pk} (-\cos\pi - -\cos\alpha) = \sqrt{2} V_{rms} (1 + \cos\alpha)$$

To calculate the average voltage, the two areas must be added together and divided by pi.

$$V_{av} = \frac{E_a \times (\alpha - \beta) + \sqrt{2} V_{rms} (1 + \cos\alpha)}{\pi}$$

The final step is to calculate α and β . This can be done as shown below.

$$\alpha = \frac{t_2}{10ms} \times \pi$$

$$\beta = \frac{t_1}{10ms} \times \pi$$

Using these formula in conjunction with the waveform allows the calculation of average armature voltage.

(AC to DC Converters, 2018)

1.3 ANALYSIS OF A TYPICAL LOW POWER DC DRIVE

An example of a control rectifier drive is the Parker 512C DC controller. The 512C is a converter suited to control both permanent magnet DC motors, and shunt wound DC motors. It can operate within a range of 110Vac to 415Vac and at a frequency of either 50Hz or 60Hz. **Figure 1-17** shows the 512C DC controller.



Figure 1-17

The speed is controlled by a linear closed loop system where the feedback signal is obtained from either a tachogenerator or the armature voltage. "A current loop within the speed loop always

ensures that controlled levels of current are applied to the motor, actual levels being scaleable via programmable switches.” (Product Manual to support the Parker SSD 512C DC Controller, 2016)

A stall detection circuit is also contained within the controller which cuts off current from the motor after 60 seconds. **Figure 1-18** shows the block diagram of the controller.

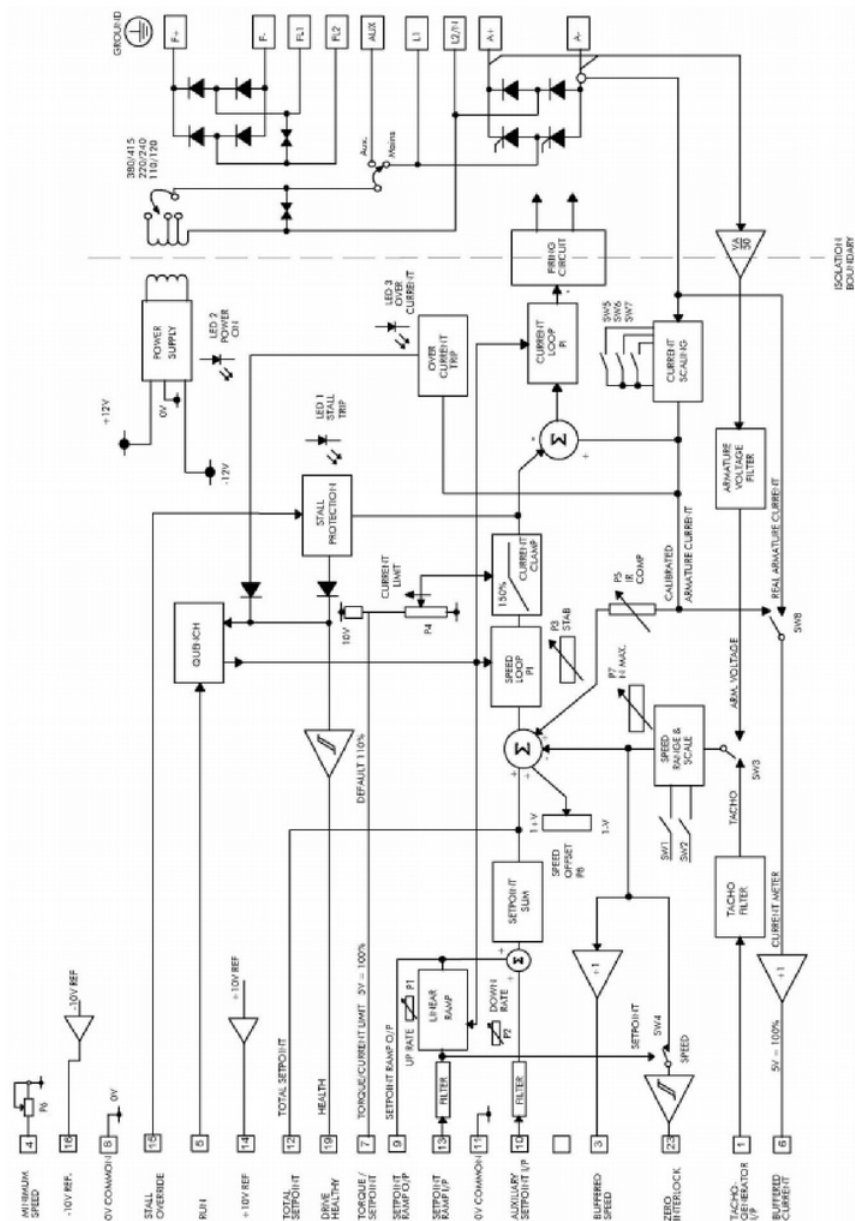


Figure 1-18

By looking at the block diagram there is a half-controlled rectifier which means that this controller only has half control. From page 2-2 of the datasheet the control features can be seen.

Control Features

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 (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
	Stall Override		+10	100Kohm
	Digital Outputs	Health	+24V	50mA Source
		Zero Speed or Setpoint	+24V	50mA Source

Figure 1-19

In the speed control section, its shown that when a tachogenerator is used in the feedback loop, the load regulation is much more accurate at 0.1% compared to 2% when armature voltage is used. The maximum torque / speed range ratio is also much larger.

1.4 APPLICATIONS OF DC DRIVES IN INDUSTRY

DC Drives have many applications in industry. As previously stated in **Section 1.1.5** each of the thyristors are suited to specific applications based on their voltage, current and frequency rating. For slower applications such as speed control of a DC motor for a conveyor belt, an SCR is a suitable

option. Applications for DC Drives in industry are almost limitless as DC motors are used countless systems. A list of applications includes:

- DC motor control in rolling mills such as steel, paper and textile mills.
- Elevators
- Conveyor belts
- Electric Cars

An MCT might be more suitable for an application such as an electric car as it requires higher frequency rating, and accuracy to vary speeds at a moment's notice. Controlled rectifiers have other applications other than DC drives. These include:

- Electric Traction
- Electromagnetic Power Supplies
- Battery Charging Systems
- Uninterruptible Power Supply Systems
- High Voltage DC Transmission

(Budimir, 2017)

2 - SIMULATION OF A HALF-CONTROLLED RECTIFIER CIRCUIT

To analyse the performance of a single-phase, full-wave, half-controlled rectifier circuit, a simulation can be made using Multisim. This simulation can be seen in **Figure 2-1**.

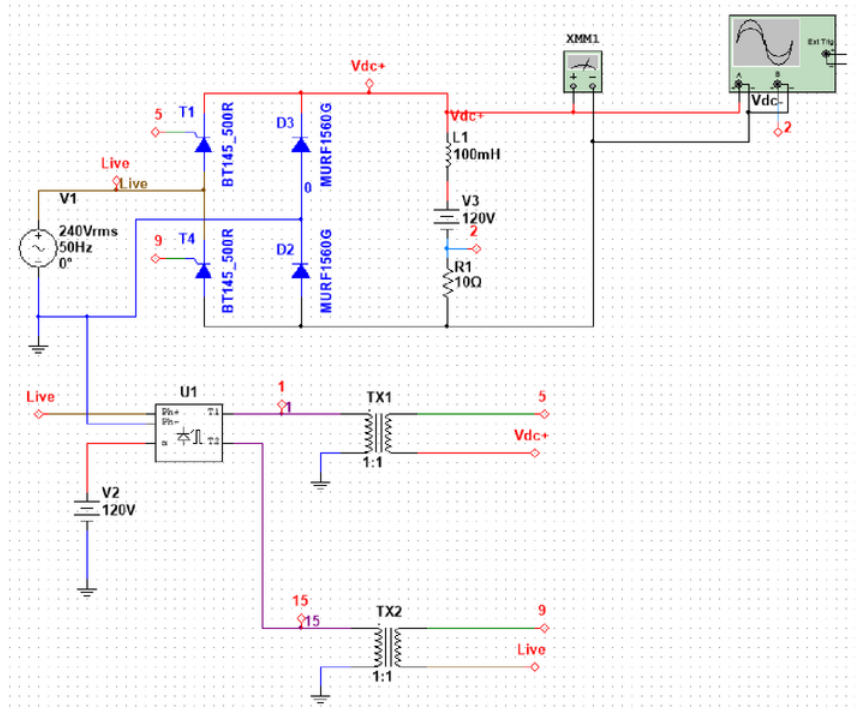


Figure 2-1

As shown, there are two thyristors connected to two diodes in a bridge configuration. This gives the circuit half-control. Connected to the bridge configuration is an inductor, DC source and a resistor. This network of components is used to emulate a DC motor. The resistor represents the armature resistance, the inductor represents the armature inductance and the DC power source represents the back EMF.

Connected to the thyristor gates is a phase angle controller. This controls the firing angle of the thyristors which is determined by the voltage of the DC source connected to the alpha pin of the controller.

During the positive half cycle of the supply voltage, the thyristor T1 and the diode D1 are connected in forward bias and do not conduct until a pulse is applied to the gate of T1. Once the pulse is applied the thyristor gets switched on and begins conducting current. During this period where T1 is switched on, the supply voltage is applied to the load. However, due to the presence of the inductor in the load, a current builds up within the load.

During the negative half cycle of the supply voltage, the thyristor T2 and the diode D2 are in forward bias whereas T1 and D1 are then reverse biased. The current changes its route through the circuit via D2 and T1 and flows through the load. When a pulse is applied to the gate of T2, the

thyristor gets switched on and begins conducting. During this period T2 and D2 are conducting and a current builds in the load once more.

During the following positive half cycle T1 and D1 are once again in forward bias, and T2 and D2 are in reverse. The current then changes its route via D1 and T2 and flows through the load. This operation rectifies the AC waveform so that it is DC, and both half cycles are received by the load. The average voltage is determined by the firing angle of the thyristors, which determines how far into the half cycle the thyristors are switched on. A small firing angle will yield a larger average voltage as the thyristor will be on for a larger part of the half cycle. Likewise, a large firing angle will yield a smaller average voltage as the thyristors will remain switched off for most of their respective half cycles.

D1 and D2 act as commutation diodes which form a flywheel that stops the current from going negative.

This principle of operation be proven through simulation. **Figure 2-2** shows the output waveform across the load from the above circuit. **Figure 2-4** shows the average voltage across the load.

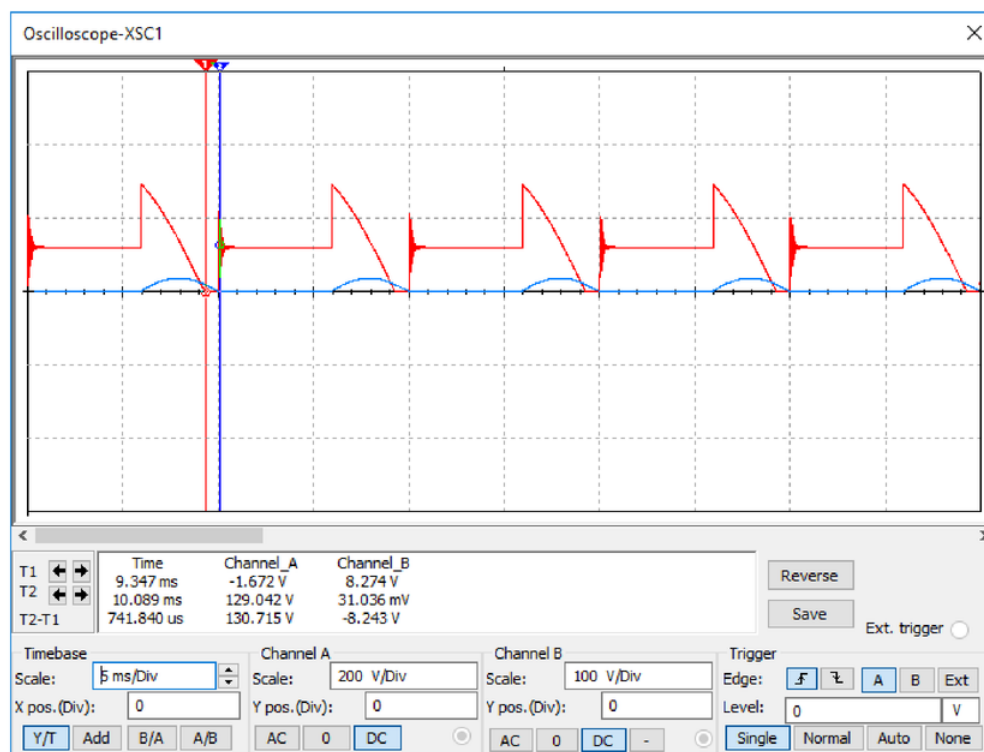


Figure 2-2



Figure 2-3

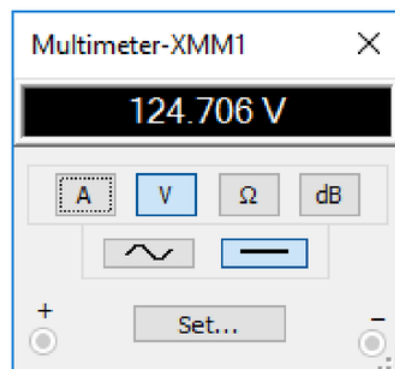


Figure 2-4

t1 can be taken from **Figure 2-2** and t2 can be taken from **Figure 2-3**. These values can be seen in table 1. To compare results, the firing angle is changed from 120° to 80°. The changes to the circuit can be seen in **Figure 2-5**.

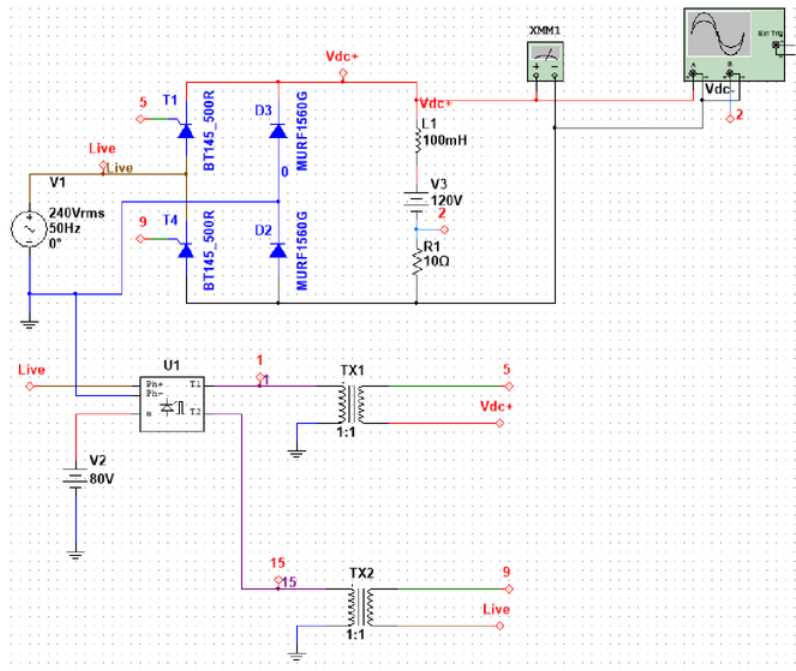


Figure 2-5

The output waveform can be seen in **Figure 2-6** and **Figure 2-7**.

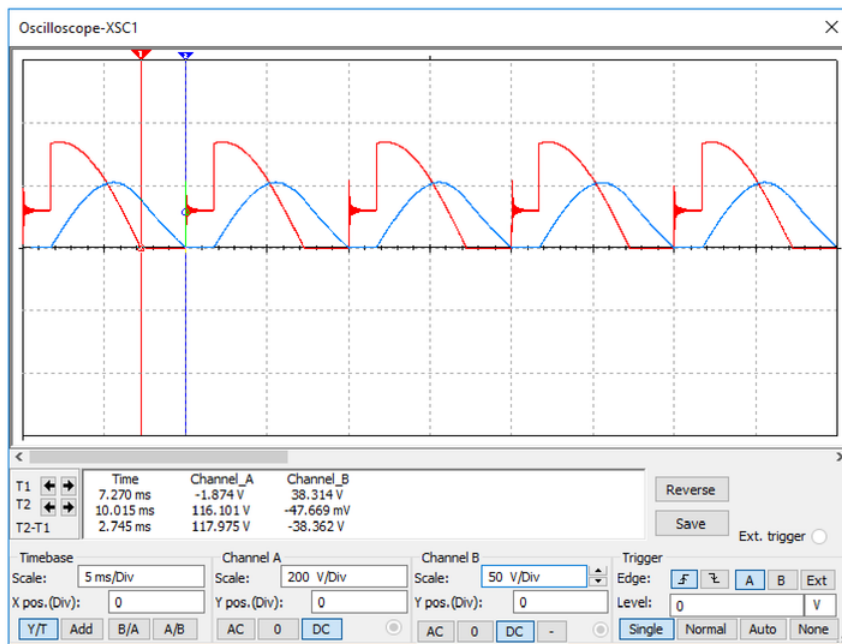


Figure 2-6

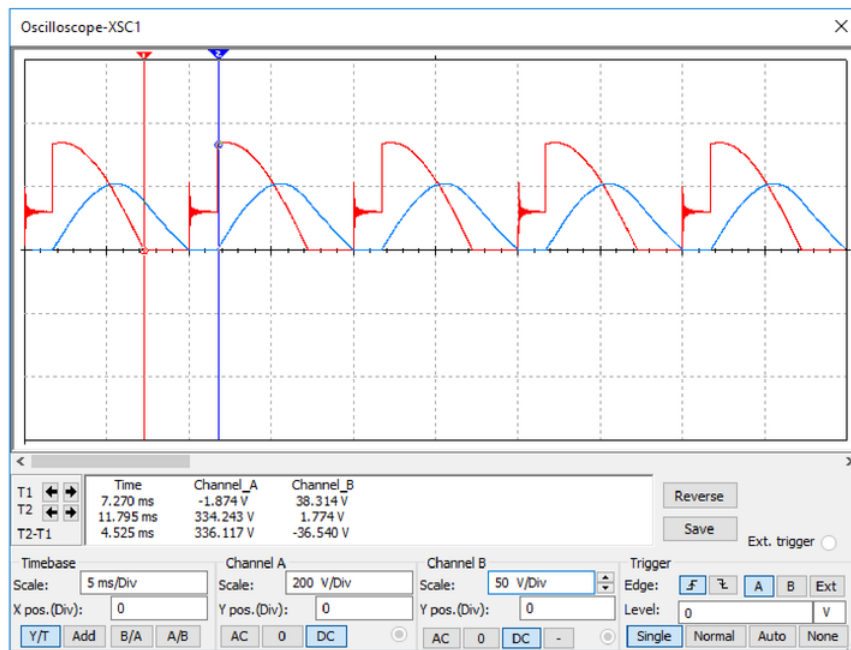


Figure 2-7

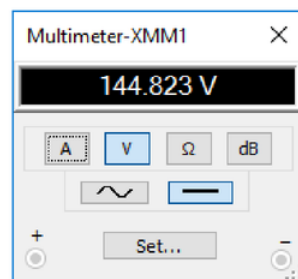


Figure 2-8

Firing Angle	E (V)	t1 (ms)	t2 (ms)	α (rad)	β (rad)	Measured (V)	Calculated (V)
120	120	0.741	6.677	2.097	0.232	124.706	125.01
80	120	2.745	4.525	1.421	0.862	144.823	145.47

Table 1

The calculations for both these firing angles can be found in the appendices. As the measured values from the simulations show, as the firing angle is reduced the average voltage across the load increases. This proves that the firing angle determines the average voltage going through the load. The variations between the calculated and simulated values are most likely created by rounding errors as all of the values were calculated and measured to 3 decimal places.

Another way to analyse this circuit is to change the back emf to see the effect of mechanical loading and armature inductance on the current. To do this a firing angle of 80° is used and kept constant while the DC supply in the armature circuit is altered.

The simulation in **Figure 2-9** shows the circuit set to have a back emf of 120V, and a firing angle of 80°. **Figure 2-10** shows the output waveform with discontinuous current.

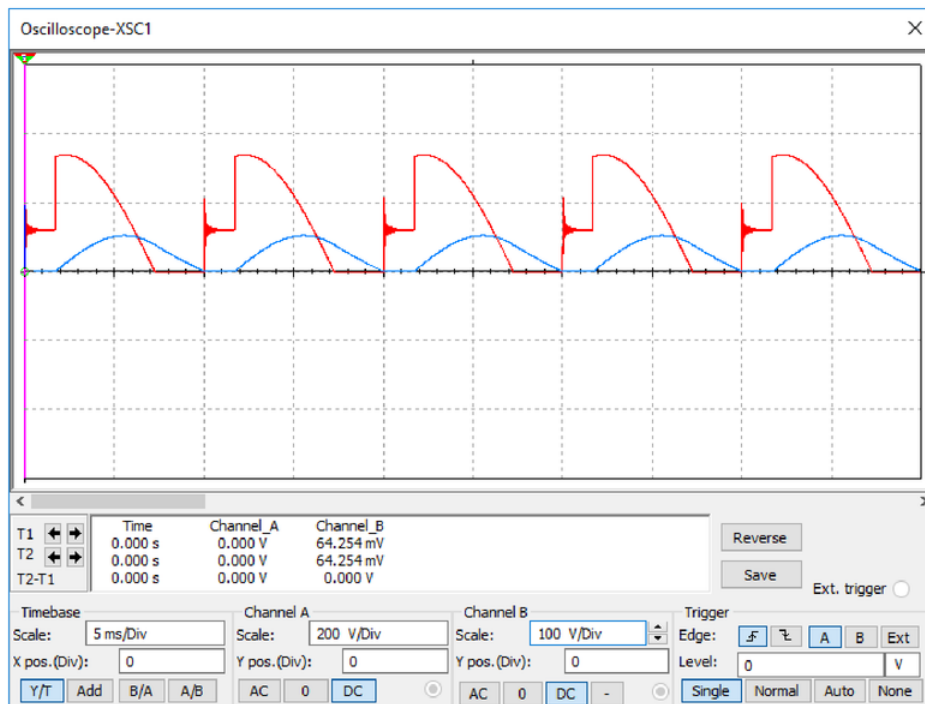


Figure 2-10

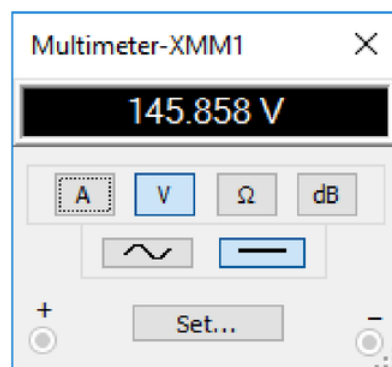


Figure 2-11

As previously stated, the above waveform shows discontinuous current as there is a short period where the current is not flowing through the load. Instead there is back emf opposing it. **Figure 2-12** shows the circuit with the same firing angle, however the back emf is reduced to 80V.

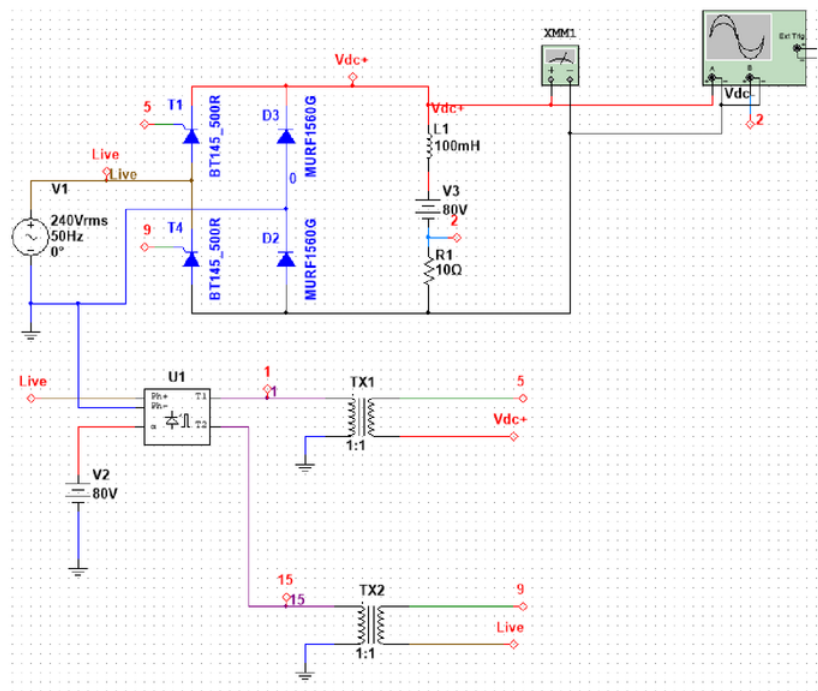


Figure 2-12

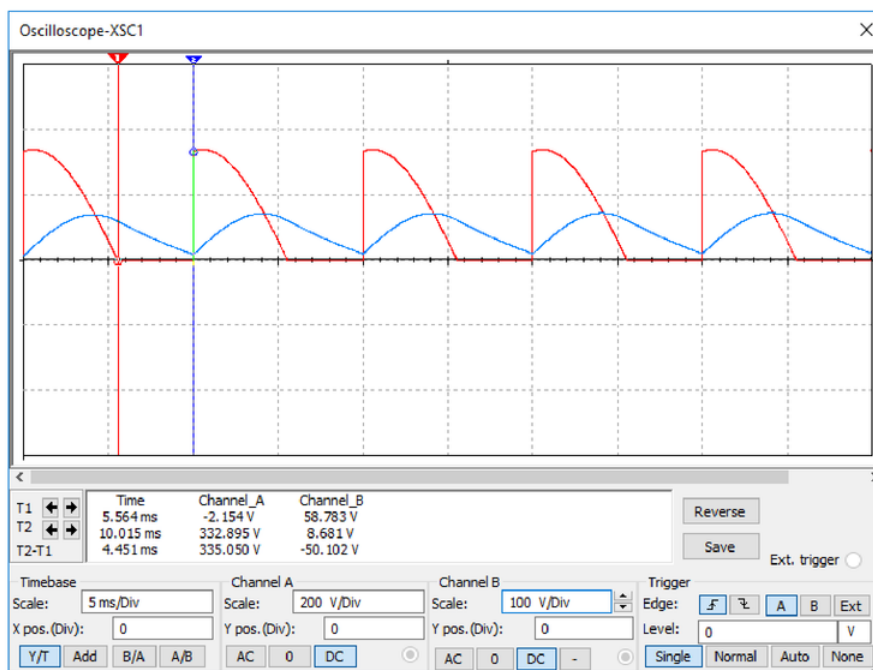


Figure 2-13

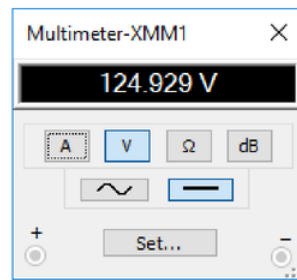


Figure 2-14

Figure 2-13 shows the output waveform for the circuit in **Figure 2-12**. Unlike the previous waveform, this waveform shows that the current is now continuous. This is because the back emf has gone low enough to allow a continuous flow of current into the armature which would increase the driving torque of the motor.

Firing Angle	E (V)	t1 (ms)	t2 (ms)	α (rad)	β (rad)	Measured (V)	Calculated (V)
80	120	2.745	4.525	1.421	0.862	144.823	145.47
80	80	0	4.451	1.398	0	124.856	126.614

The large current caused by the lower back emf allows for a bigger field build up in the inductor which takes longer to decay and allows current to become continuous

When the back emf is reduced the average voltage of the motor is initially reduced. This is because the back emf is removed from the equation.

Due to this simply being a simulation, there is no feedback loop for the speed of the motor, and no DC driver. Therefore, the waveform simply repeats over and over with no change. In order to see how a half-control rectifier works in a practical situation, an experiment must be done. This can be found in **Section 3**.

3 - PRACTICAL INVESTIGATION INTO A SINGLE QUADRANT DC DRIVE

This practical involves setting up an experiment as a group to analyse the performance of the Parker 512C drive. The experiment is set up as

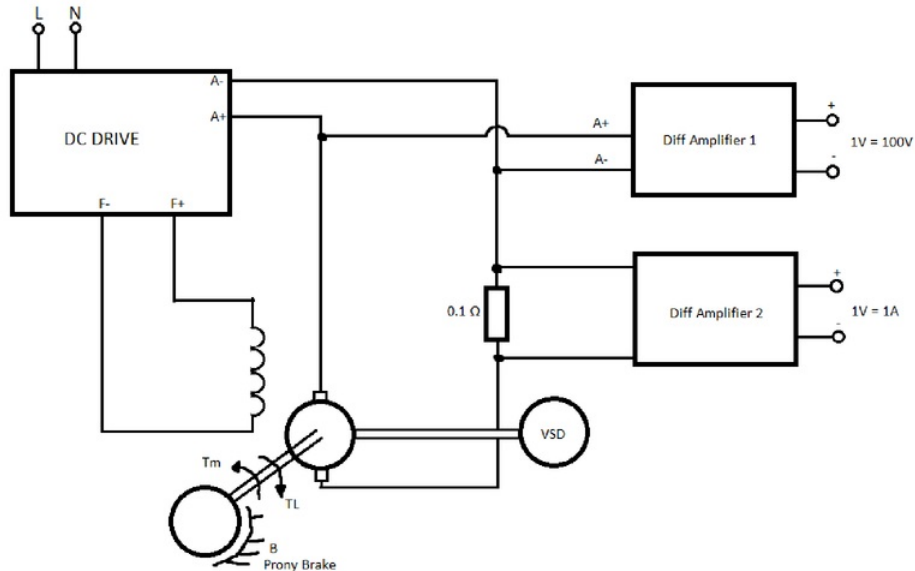


Figure 3-1

The Parker 512C drive is connected to a DC motor, which is also connected to a variable speed drive (VSD). A prony brake is connected to the motor in order to add load. Finally, two differential amplifiers are connected to the armature to measure voltage, and current across a 0.1Ω resistor. One amplifier scales the voltage so that it has a 100V:1V ratio making it safe to read on the oscilloscope. The other converts the current into voltage for the same reason. **Figure 3-2** shows the experiment after being set up.

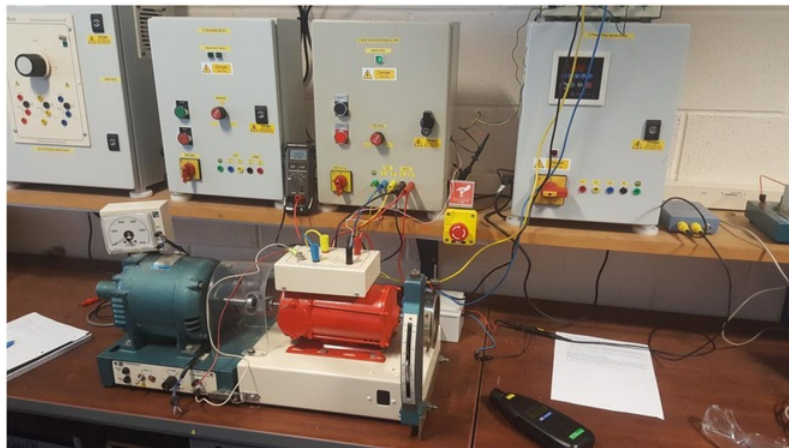


Figure 3-2

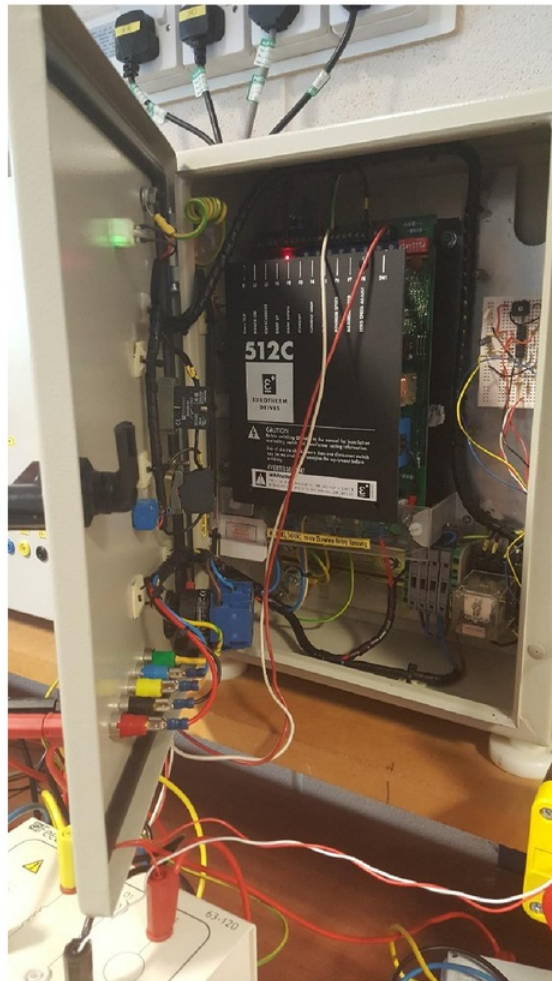


Figure 3-3

Figure 3-3 shows the Parker 512C drive within the control panel. This setup allows the speed of the motor to be fed back to the drive so that it can vary the average voltage to increase or decrease the speed. The first experiment is to see what happens when the drive is told to increase the speed of the motor when under no load. This is done at 3 speeds; 567rpm, 1178rpm, 1977rpm. For each of these speeds t_1 and t_2 are measured along with the average voltage output. These values can be seen in Table 2.

To measure the speed a tachometer is used. The following figures are picoscope measurements for 567 rpm. From these figures t_1 , t_2 , the back emf and average voltage can all be measured. These measurements are then scaled back to their original values using the conversions done by the differential amplifiers and can be found in Table 2.

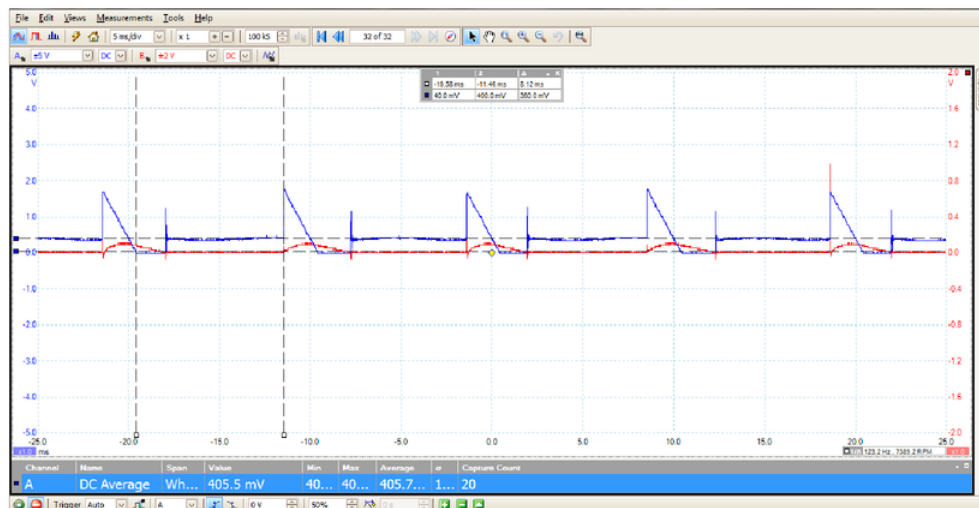


Figure 3-4

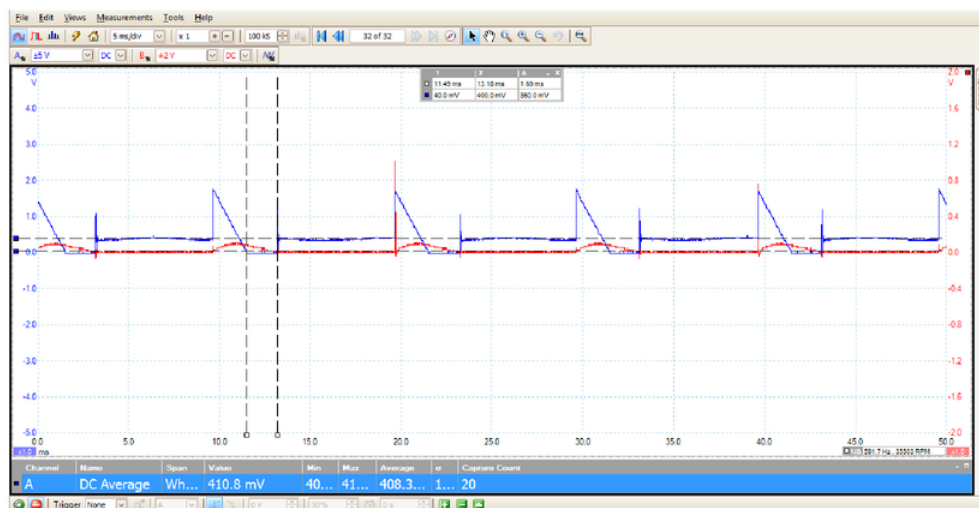


Figure 3-5

The next part of the experiment was to increase the speed to 1178rpm. An expected result of this would be to have a larger average voltage since to increase the speed of a motor, the armature voltage must be increased. This means that a smaller firing angle is also expected. The measurements for 1178rpm can be found as follows.

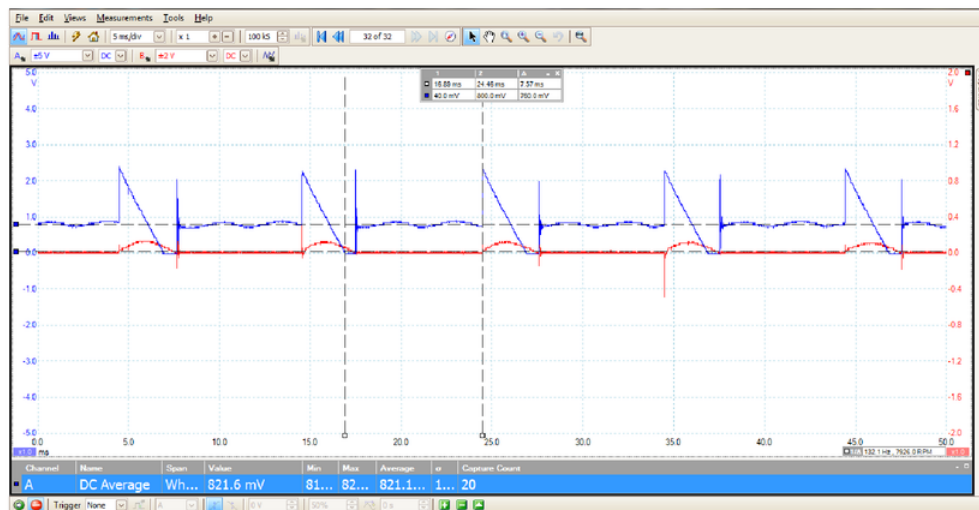


Figure 3-6

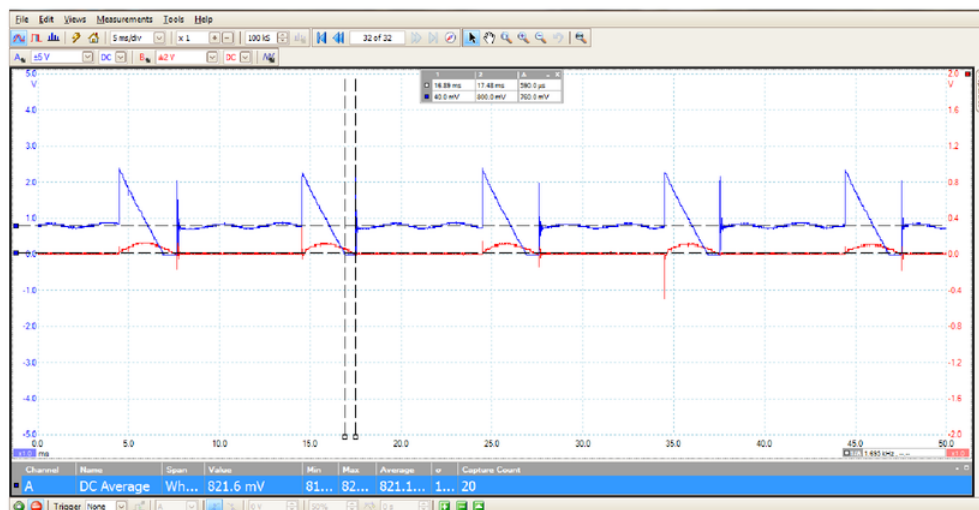
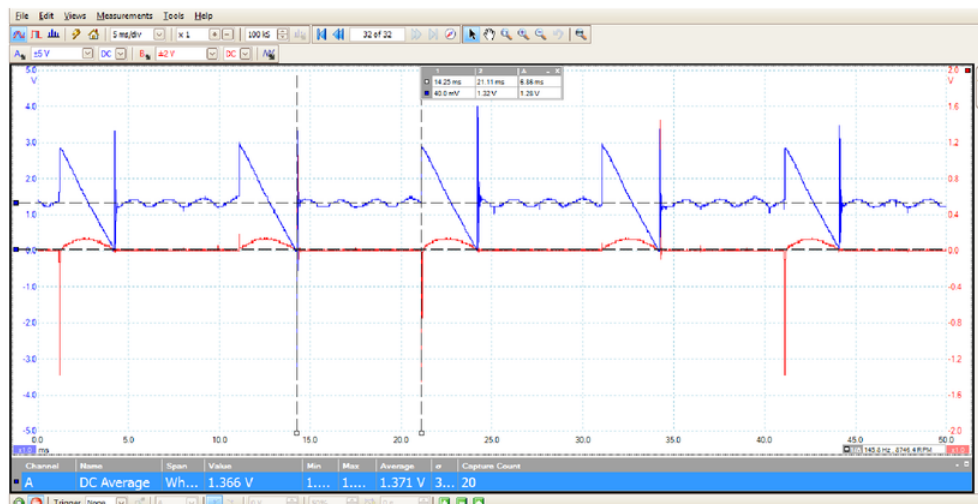


Figure 3-7

The measurements for 1178rpm can be found in Table 2. The final part of this experiment is to increase the speed again to 1977. The picoscope measurements can be found as follows.



With all three speed experiments completed and all measurements taken, an analysis of the performance of the system can be done. As expected, when the speed of the motor increased, the back emf also increased. This is due to the armature conductors cutting through the field faster. Another expected result was that as the set speed was increased, the average voltage in the armature would also increase. This can be seen to once again occur as each time the speed was increased, the average voltage also increased. This confirms that the firing angle also decreased as the firing angle of the thyristors in the DC drive determines the average voltage. As previously stated, a lower firing angle produces a higher average voltage. This is confirmed in the measurements as the values of t_2 and t_1 decrease as the speed is increased.

The next step of this experiment is to do calculations on this system and compare to the measured values. These calculations can once again be found in the appendices.

Speed (rpm)	E (V)	t_1 (ms)	t_2 (ms)	α (rad)	β (rad)	Measured (V)	Calculated (V)
567	40	1.69	8.12	2.551	0.531	41	43.89
1178	80	0.59	7.57	2.378	0.185	82	85.6
1977	137	0	6.86	2.155	0	132	142.083

Table 2 should be 132

When comparing the calculated values to the measured values, they replicated what was expected to decent degree of accuracy. Just like the simulation calculations, the discrepancies could be caused by a number of factors. These factors include; rounding errors in the measurements and calculations, supply variations, assuming the value of 337V for V_{peak} for the calculations, the accuracy of the differential amplifiers, and the precision of the cursor on the picoscope.

Despite the deviations, the calculated values are not far from the measured values and show the same trends as previously discussed.

An observation of the emf as the speed is increased is that while the magnitude increases, so does the ripple. This is known as torque ripple and is not a desirable thing to have in a system as it can potentially cause unsmooth rotations. the ripple is due to the commutator

The second experiment involves keeping the speed set but changing the torque. For this experiment a speed of 577rpm will be used, and loads of 0.2Nm, 0.4Nm and 0.6Nm will be applied

to the armature by the prony brake. This experiment will see how applying a load will affect the armature voltage, the armature current and the firing angle of the DC drive. Just like before the measurements can be found in Table 3. **Figure 3-8** shows the measurement from the 0.2Nm experiment.

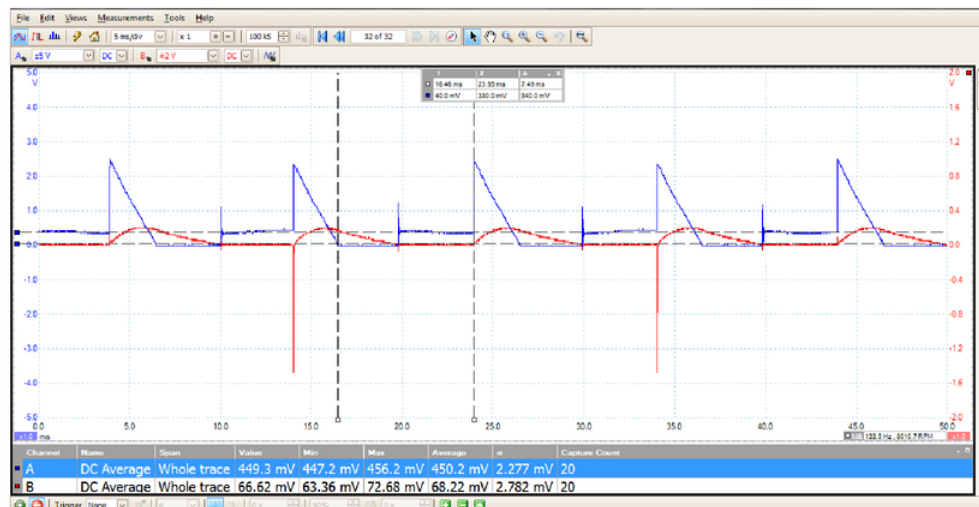


Figure 3-8

Figure 3-9 shows the measurements from the 0.4Nm experiment.

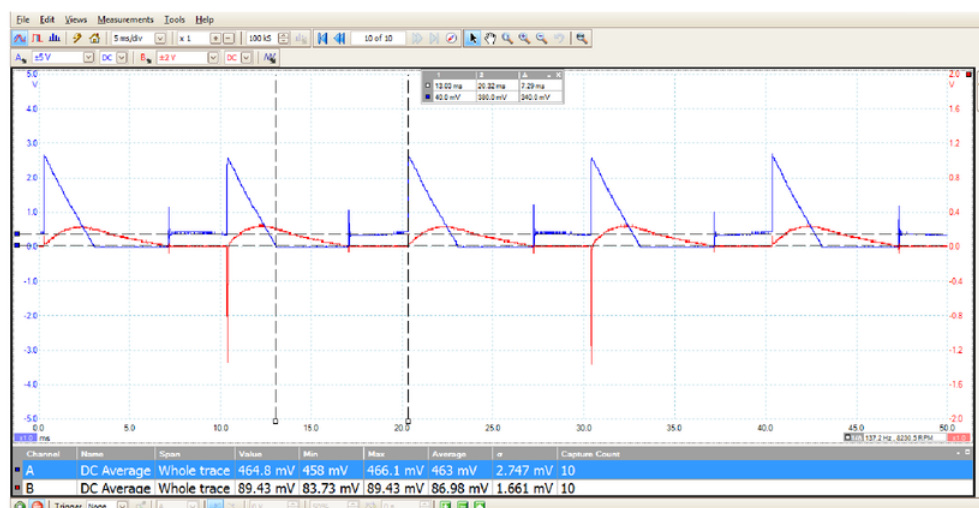


Figure 3-9

Figure 3-10 shows the measurement from the 0.6Nm experiment.

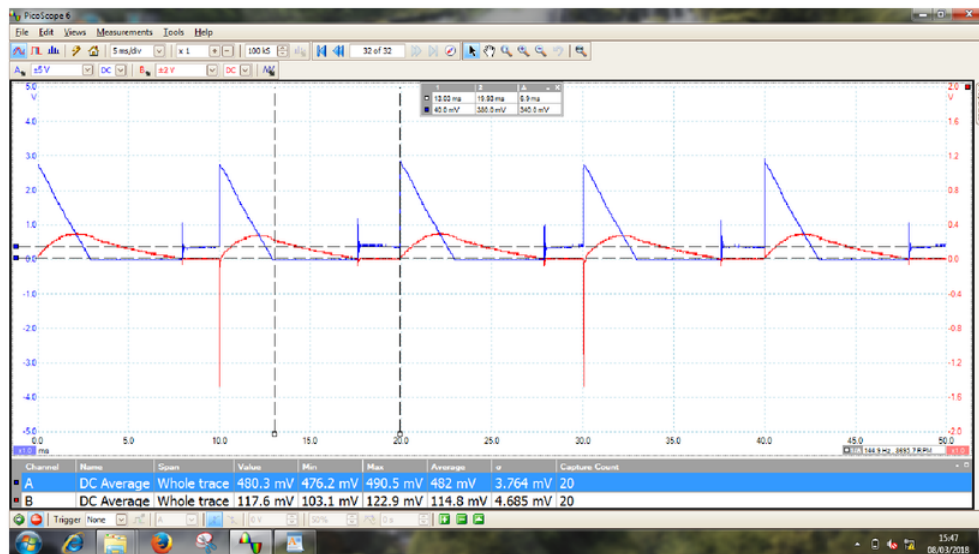


Figure 3-10

The calculations for this experiment can be found in the appendices. As expected, as the load is increased, the average voltage increases. This is because the load slows the motor initially, but the feedback loop tells the Parker 512C that the motor is running slower than it should. This causes the drive to decrease the firing angle of the thyristor to increase the voltage going to the armature of the motor. This increases the motor's speed until it gets back to 577 rpm. This speed remains constant as the load is increased. The armature current also increases as the load is increased. This is because as the load is put on, the motor slows down, which reduces the back emf. This allows more current to flow through the armature increasing the driving torque of the motor to compensate for the load.

Torque (Nm)	Speed (rpm)	E (V)	t2 (ms)	α	Measured (V)	Calculated (V)	Measured (mA)
0.2	577	38	7.49	2.35	45	60.31	68.22
0.4	577	38	7.29	2.29	46.3	64.3	86.98
0.6	577	38	6.9	2.17	48.2	73	114.8

The calculations have a very large deviation from the measured values in this experiment. This again could be because of; rounding errors in the measurements and calculations, supply variations, assuming the value of 337V for V_{peak} for the calculations, the accuracy of the differential amplifiers, and the precision of the cursor on the picoscope.

However, the calculations still follow the same trends as the measured values confirming the principle of operation for this system.

4 - CONCLUSIONS AND RECOMMENDATIONS

Thyristors and controlled rectifiers have countless applications in industry, from high power transmission to fast speed control for electric cars. When used in DC drives for motors thyristors are able to provide a high degree of control over the speed by varying its voltage output. This creates efficiency as no power is wasted and the device isn't constantly in an 'on' state.

By using a simulation to emulate a control rectifier connected to a DC motor, the core principles of operation for the control rectifier were able to be tested. The use of Multisim allowed for efficient and accurate simulation of a system without the cost of having to build it in the first place.

After simulating to test the theory behind the operation of the system, a practical was carried out allowing for first hand experience seeing the system work. As part of the group, I was the one changing the speed of the motor while Emyr took measurements from Picoscope, and Joe recorded them.

A possible recommendation for this practical would be to use a different DC drive to see the possible differences that much be present. A further improvement to the system could be to change it from a half-control rectifier to a full-control rectifier. This would open up many more opportunities for analysis of the system and allow for comparisons to be made between the two.

Furthermore, something that could have been done better would be to ensure the parameters that were worked with were accurate. This includes the assumption that V_{pk} is equal to 337V, the supply is accurate, and the measuring apparatus were properly calibrated.

5 - CITATION LIST

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6 - APPENDICES

6.1 SIMULATION CALCULATIONS

Firing angle 120° Calculations

$$E = 120V$$

$$t_1 = 0.741ms$$

$$t_2 = 6.677ms$$

$$\alpha = \frac{t_2}{10 \times 10^{-3}} \times \pi = \frac{6.677ms}{10 \times 10^{-3}} \times \pi = 2.097 \text{ rad}$$

$$\beta = \frac{t_1}{10 \times 10^{-3}} \times \pi = \frac{0.741ms}{10 \times 10^{-3}} \times \pi = 0.232 \text{ rad}$$

$$V_{av} = \frac{E(\alpha - \beta) + \sqrt{2} \times V_{rms}(1 + \cos \alpha)}{\pi}$$
$$= \frac{120(2.067 - 0.232) + \sqrt{2} \times 240(1 + \cos 2.097)}{\pi} = 125.01V$$

Firing angle 80° Calculations

$$E = 120V$$

$$t_1 = 2.745ms$$

$$t_2 = 4.525ms$$

$$\alpha = \frac{t_2}{10 \times 10^{-3}} \times \pi = \frac{4.525ms}{10 \times 10^{-3}} \times \pi = 1.421 \text{ rad}$$

$$\beta = \frac{t_1}{10 \times 10^{-3}} \times \pi = \frac{2.745ms}{10 \times 10^{-3}} \times \pi = 0.862 \text{ rad}$$

$$V_{av} = \frac{E(\alpha - \beta) + \sqrt{2} \times V_{rms}(1 + \cos \alpha)}{\pi}$$
$$= \frac{120(1.421 - 0.862) + \sqrt{2} \times 240(1 + \cos 1.421)}{\pi} = 145.47V$$

Emf 80V Calculations

$$E = 80V$$

$$t_1 = 0ms$$

$$t_2 = 4.451ms$$

$$\alpha = \frac{t_2}{10 \times 10^{-3}} \times \pi = \frac{4.451ms}{10 \times 10^{-3}} \times \pi = 1.398 \text{ rad}$$

$$\beta = \frac{t_1}{10 \times 10^{-3}} \times \pi = \frac{0ms}{10 \times 10^{-3}} \times \pi = 0 \text{ rad}$$

$$V_{av} = \frac{\sqrt{2} \times V_{rms}(1 + \cos \alpha)}{\pi}$$

$$= \frac{\sqrt{2} \times 240(1 + \cos 1.398)}{\pi} = 126.61V$$

6.2 PRACTICAL CALCULATIONS

No Load, 567rpm Calculations

$$V_{max} = 337V$$

$$E = 40V$$

$$t_1 = 1.69ms$$

$$t_2 = 8.12ms$$

$$\alpha = \frac{t_2}{10 \times 10^{-3}} \times \pi = \frac{8.12}{10 \times 10^{-3}} \times \pi = 2.551 \text{ rad}$$

$$\beta = \frac{t_1}{10 \times 10^{-3}} \times \pi = \frac{1.69}{10 \times 10^{-3}} \times \pi = 0.531 \text{ rad}$$

$$V_{av} = \frac{E(\alpha - \beta) + V_{max}(1 + \cos \alpha)}{\pi} = \frac{40(2.551 - 0.531) + 337(1 + \cos 2.551)}{\pi} = 43.89V$$

No Load, 1179rpm Calculations

$$V_{max} = 337V$$

$$E = 80V$$

$$t_1 = 0.59ms$$

$$t_2 = 7.57ms$$

$$\alpha = \frac{t_2}{10 \times 10^{-3}} \times \pi = \frac{7.57}{10 \times 10^{-3}} \times \pi = 2.378 \text{ rad}$$

$$\beta = \frac{t_1}{10 \times 10^{-3}} \times \pi = \frac{0.59}{10 \times 10^{-3}} \times \pi = 0.185 \text{ rad}$$

$$V_{av} = \frac{E(\alpha - \beta) + V_{max}(1 + \cos \alpha)}{\pi} = \frac{80(2.378 - 0.185) + 337(1 + \cos 2.378)}{\pi} = 85.61V$$

No Load 1977rpm Calculations

$$V_{max} = 337V$$

$$E = 137V$$

$$t_1 = 0ms$$

$$t_2 = 6.86ms$$

$$\alpha = \frac{t_2}{10 \times 10^{-3}} \times \pi = \frac{6.86}{10 \times 10^{-3}} \times \pi = 2.155 \text{ rad}$$

$$\beta = \frac{t_1}{10 \times 10^{-3}} \times \pi = \frac{0}{10 \times 10^{-3}} \times \pi = 0 \text{ rad}$$

$$V_{av} = \frac{E(\alpha - \beta) + V_{max}(1 + \cos \alpha)}{\pi} = \frac{137(2.155 - 0) + 337(1 + \cos 2.155)}{\pi} = 142.084V$$

Load 0.2Nm Calculations

$$V_{max} = 337V$$

$$E = 38V$$

$$t_1 = 0ms$$

$$t_2 = 7.49ms$$

$$\alpha = \frac{t_2}{10} \times \pi = \frac{7.49}{10} \times \pi = 2.35 \text{ rad}$$

$$\beta = \frac{t_1}{10} \times \pi = \frac{0}{10} \times \pi = 0 \text{ rad}$$

$$V_{av} = \frac{E(\alpha - \beta) + V_{max}(1 + \cos \alpha)}{\pi} = \frac{38(2.35 - 0) + 337(1 + \cos 2.35)}{\pi} = 60.31V$$

Load 0.4Nm Calculations

$$V_{max} = 337V$$

$$E = 38V$$

$$t_1 = 0ms$$

$$t_2 = 7.29ms$$

$$\alpha = \frac{t_2}{10} \times \pi = \frac{7.29}{10} \times \pi = 2.29 \text{ rad}$$

$$\beta = \frac{t_1}{10} \times \pi = \frac{0}{10} \times \pi = 0 \text{ rad}$$

$$V_{av} = \frac{E(\alpha - \beta) + V_{max}(1 + \cos \alpha)}{\pi} = \frac{38(2.29 - 0) + 337(1 + \cos 2.29)}{\pi} = 64.3V$$

Load 0.6Nm Calculations

$$V_{max} = 337V$$

$$E = 38V$$

$$t_1 = 0ms$$

$$t_2 = 6.9ms$$

$$\alpha = \frac{t_2}{10} \times \pi = \frac{6.9}{10} \times \pi = 2.17 \text{ rad}$$

$$\beta = \frac{t_1}{10} \times \pi = \frac{0}{10} \times \pi = 0 \text{ rad}$$

$$V_{av} = \frac{E(\alpha - \beta) + V_{max}(1 + \cos \alpha)}{\pi} = \frac{38(2.17 - 0) + 337(1 + \cos 2.17)}{\pi} = 73V$$

Sam Harries - Assignment 2 Final

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

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Text Comment. The large current caused by the lower back emf allows for a bigger field build up in the inductor which takes longer to decay and allows current to becomes continuous

PAGE 25

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Text Comment. should be 132

Text Comment. should be 137

Text Comment. the ripple is due to the commutator

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PAGE 31

Text Comment. these result are too far apart, explanation is incorrect.

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GRADING FORM: CSG-RUBIC

RESEARCH-INFORMED LITERATURE

-  Section 1: Your research - Excellent section on research with good use of sources covering all aspects of this task. However, some information has been drawn with no reference to published sources. (12/15) Section 5: Your use of Harvard for citing and listing - Wide range of sources cited and listed correctly. (4/5)

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KNOWLEDGE AND UNDERSTANDING

-  Section 2: Explanation of simulation circuit - you have shown a very good understanding of the circuit and its operation. (9/10) Section 3: Explanation of practical circuit. Very good explanation. (8/10)

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ANALYSIS

-  Section 2: Analysis of results from simulation – Excellent analysis and results presented in a table and explained. There is one point that needs clarifying for continuous current (9/10) Section 3: Analysis of results from practical experiment – Very good analysis with results tabulated and explanations given. However, there are errors in your last set of readings for experiment 1 and one misconception. For experiment 2, the results are too far apart and reasons given are not good enough. (7/10) Section 4: Overall conclusions and recommendations – Very

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good. (6/10)

PRACTICAL APPLICATION AND DEP.



Section 2: Simulation – Very good use of simulation software with good presentation of results. (8/10)
Section 3: Practical experiment – Very good use of equipment and picoscope with good presentation of results (8/10)

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SKILLS FOR PROFESSIONAL PRAC.



All sections – Well structured and presented and written. (4/5) Section 4: Team role – Briefly described (2/5)

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