

SGEE6001 Power Electronics and Drives

by Carl Jones

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Executive Summary

This assignment provides an analysis of the Siemens three phase DC four quadrant drive producing discontinuous and continuous Armature current. It also looks at the effect of the thyristor bridges firing in all four quadrants. The assignment provides research into DC drive construction and use within industry and compare with AC drive.

Methods of analysis included research using credible sources, practical experiment with a motor test rig and Electrical control panel, use of design software to build circuits and simulate. Calculation from derived formulae's to prove practical results.

Results and calculation showed how discontinuous and continuous armature currents are produces calculation to compare measure values show discrepancies. Computer simulation design of the thyristor bridges prove the circuits that can't be seen in the DC drive.

The assignment proves the effectiveness of the thyristor bridges within the drive and the different Armature voltages and currents that are generated with varying firing angles.

Research

There are a few manufactures of three phase DC drives, the focus of this researches is on the Siemens DCM converter which is going to be used for the practical experiment.

The Siemens DCM drive is very versatile in that it can used for basic and advanced control operations. It combines open loop, closed loop and power selection all in one device.

Siemens DCM drive internal construction is listed below

- Electronic Module with Control unit (CUD)
- Power selection with thyristors in a fully controlled three-phase bridge circuit configuration (two quadrant drive or four quadrant drive.
- Ventilation fan for self-cooling
- Single- quadrant field power selection with integrated free-wheel circuits,
- Electronic power supply
- Standard BOP20 operator panel.

Implementing these drives in to control systems has become a lot more advance as they can be connected via profibus as standard or an optional profinet card can be fitted.

In the Drive there is a power interface module, this is where the DC output armature voltage is controlled from and monitored fig1 schematic diagram. Within this module will be the dual three phase fully controlled converter made up to two 6 thyristor bridge circuits

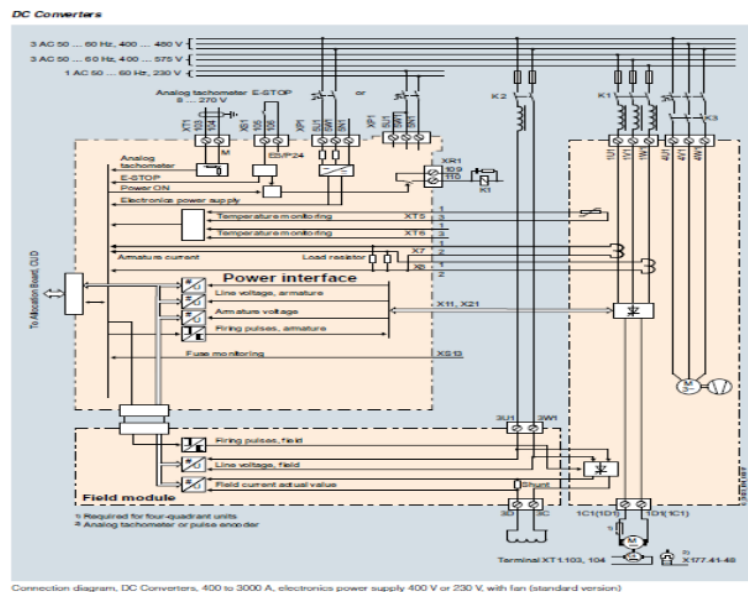


Figure 1 Diagram of power module in DCM drive. (Siemens, n.d.)

Within this module will be the dual three phase fully controlled converter made up to two 6 thyristor bridge circuits fig2 which will generate Armature voltage dependant on control signals sent to the power module from the control module.

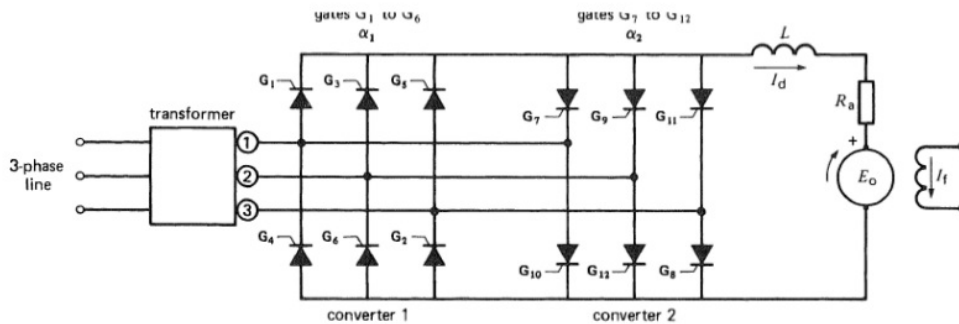
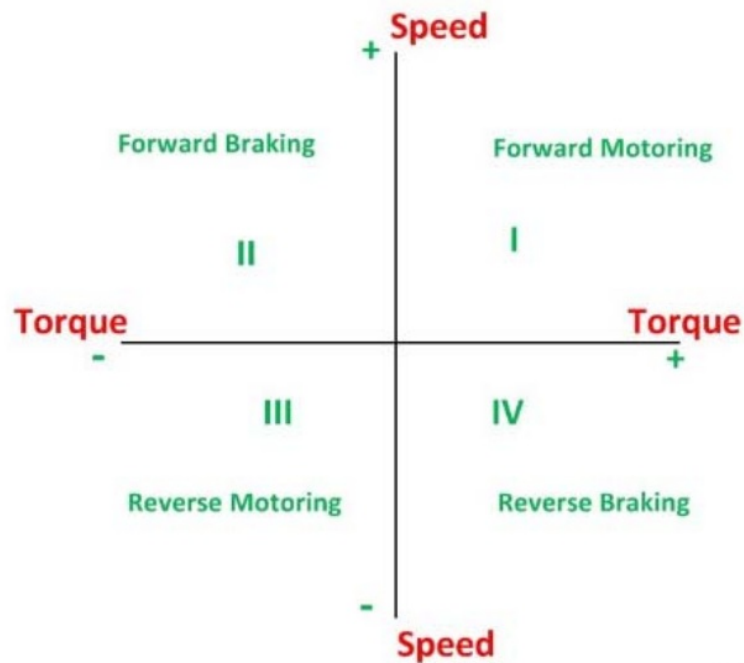


Figure 2 layout of a thyristors in a dual fully controlled circuit. (Wilder)

The Siemens DCM drive is able to do four quadrant motor control this makes it very useful for industrial application. Each of the thyristor bridges are used to produce different firing angles which will affect the armature voltage and current outputted from the drive to the motor, it can now be positive or negative. fig3 show the four quadrants.



Circuit Globe

Figure 3 shows are 4 quadrants in relation to speed and torque. (Circuitglobe)

Quadrant 1 produces forward motoring meaning that both armature voltage and current are positive which intern produces positive speed and torque.

Quadrant 2 produces forward breaking where armature voltage has become negative but current is still positive. This produce positive speed but negative torque.

Quadrant 3 produces reverse motoring, now both armature voltage and current are negative. This will produce both negative speed and torque.

Quadrant 4 produces reverse breaking where armature voltage has now become positive but current is negative, this produces negative speed but positive torque.

The Siemens DCM drive is able to be controlled, closed loop control, open loop control. Control is all done via the Control module (CUD) in the drive. Fig 4

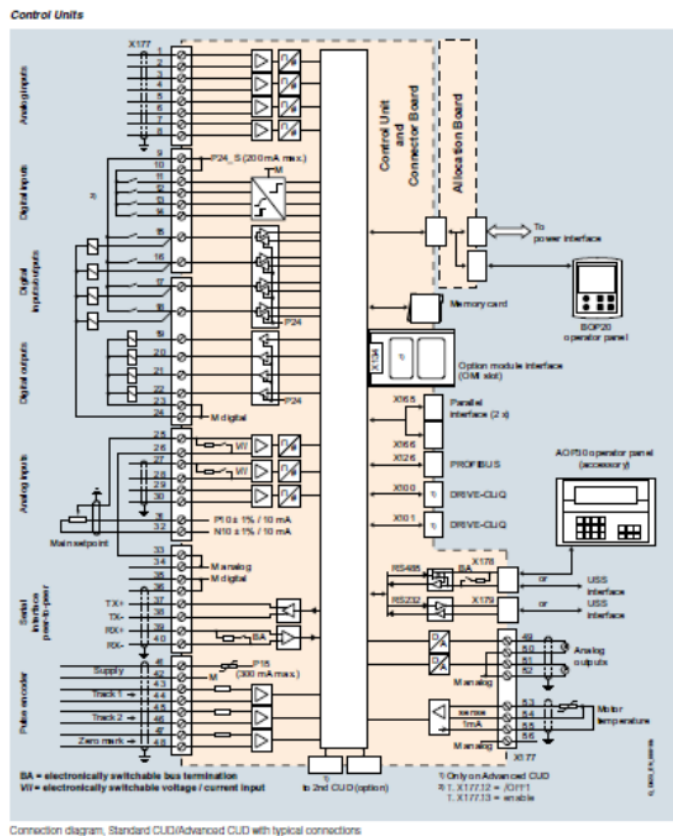


Figure 4 diagram of CUD connections. (Siemens, n.d.)

Closed loop control is used in many applications, it requires a control system with feedback and monitoring the drive can then vary the armature and field of the motor.

As seen in fig 4 DCM converter control module has connection terminals which allow for various digital inputs, analogue inputs, DC motor feedback from position encoders and tachogenerators, also within the drive its self are function blocks which read values from current and voltages being generated internally parameters can be selected to use these.

Open loop control is straight forward when a motor is required to run at speed the drive will output a voltage, armature current and the speed will be reached immediately. Fig 5 simple open loop diagram.

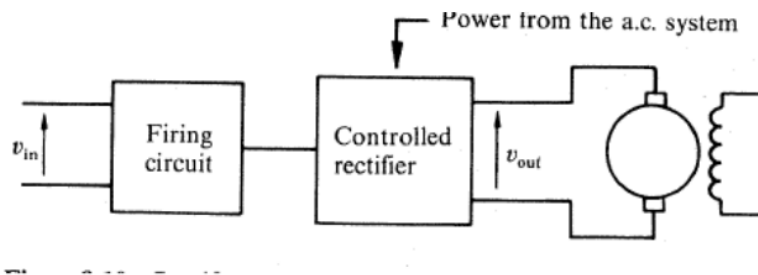


Figure 5 open loop drive system. (Lander)

A closed loop on the other hand requires feedback so if a motor is required to change speed.

A tachogenerator attached to the shaft of the motor will send voltage feedback into the Control module. The speed will then be compared with the reference speed, the Error value of speed will be applied to the speed controller and the armature Voltage will change to correct.

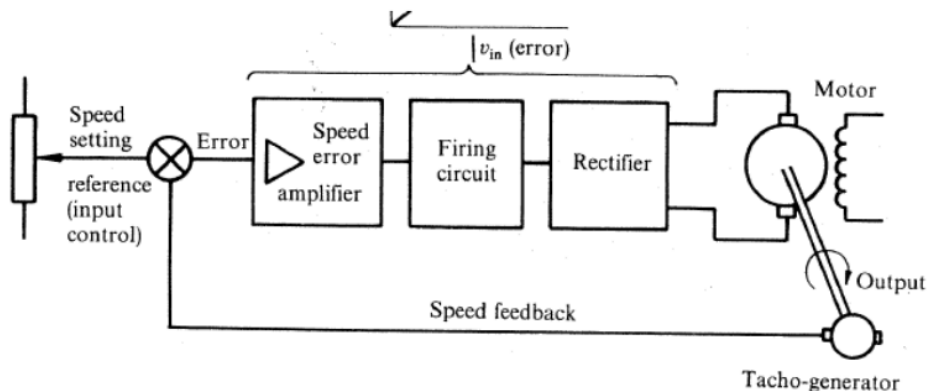


Figure 6 basic closed loop feedback control (Lander)

The closed loop ability of the Siemens DCM 4 quadrant Converter is much more advanced as of what can be feedback to reference. Fig 7 is the overview block diagram.

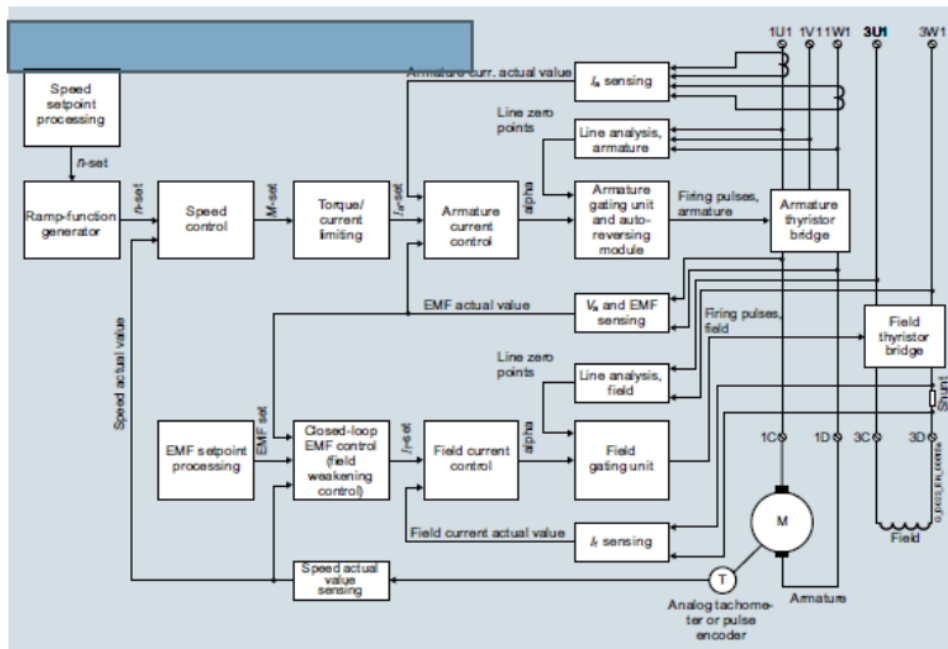


Figure 7 Siemens DCM drive closed loop overview (Siemens, n.d.)

DC drives Vs AC drives

Both AC and DC drives and motors have their place in industry. Advancements in AC drive technology as seen the flux vector drive created. This drive use a torque controlling method similar to the DC drive, it can control a wide range of speed and has a quick response. It uses a closed loop system like the DC drive but with a digital encoder that monitors real time.

The encoder allow accurate control of motor speed, torque and power. A typical application for a DC drive is a precision rolling machine where accurate starting and running torque is required. This application can now be carried out with the use of an AC flux vector drive it may be costly initially but more energy efficient in the long term. The 4 quadrant DC drive will remain on to where application which require braking in both direction of rotation, the DC drive can handle the energy created by the changing in quadrant. For an AC drive to carry out this operation it would need extra power bridges and this is costly plus the AC drive is large enough without adding on extras.

AC, DC drive advantages	AC, DC drive dis-advantages
DC drive have advanced closed loop operation with built in current and voltage sensor for current control. Without extra encoder.	AC drives are complex for basic closed loop operation, flux vector drive needs encoder
AC drives are more energy efficient	High cost in changing old systems from DC to AC drives
AC motor are large and robust and low maintenance	DC Motors are high maintenance at constant speed due to the commutator and brushes
DC motor can run at a wide range of speeds at constant torque due to attached cooling fans	

From the research it seems that there will always be a need for DC drives but the advances in AC control will probably surpass DC drives and new industrial machines will be close loop controlled AC drive system. As everyone is looking for a greener cleaner future AC drive system with more efficient motors will be used.

Practical Experiments

A purpose built test rig comprising of the follow is used to carry out this DC Drive Experiment Fig 8

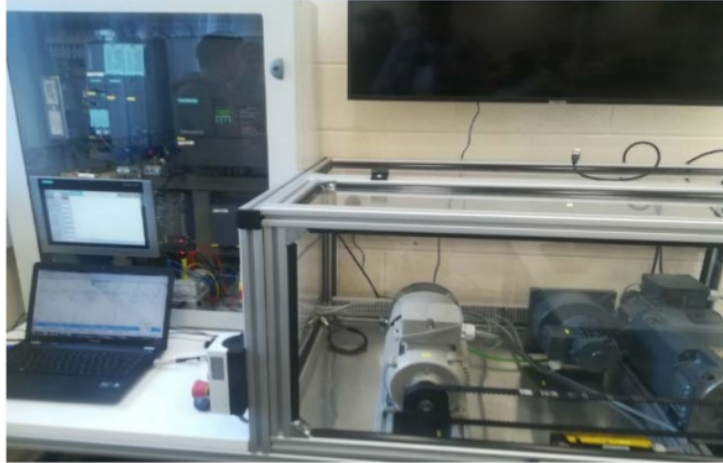


Figure 8 Experiment test rig

An Electrical three phase control panel wired with the following equipment.

1. Three phase Siemens S120 AC Drive
2. Three phase Siemens DCM Drive
3. Siemen S7 PLC with HMI
4. A couple of filters and a choke (to reduce harmonic effects on main supply)

A Motor Rig with the following.

1. Three phase AC induction Motor
2. DC Motor with External fan also attached a Tachogenerator and an Encoder

The drive shafts of the motors are connected via a drive belt, as in fig 9

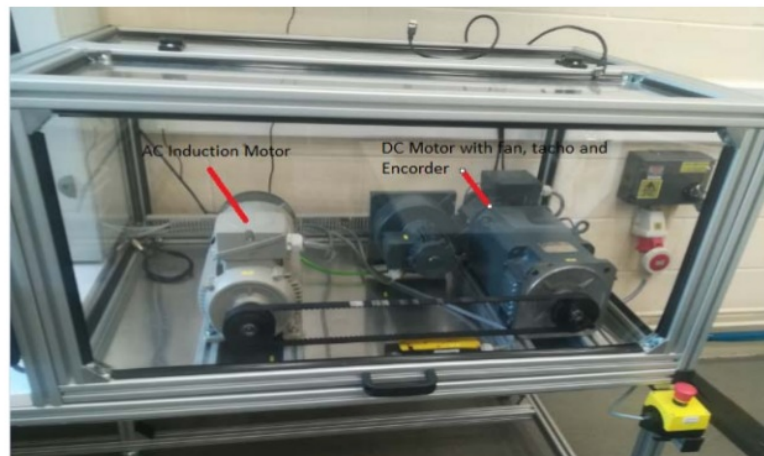


Figure 9 Motor rig with AC and DC motors

The AC induction motor is used to produce a loading effect on the DC motor so that torque can be measured. On the DC motor is the Tachogenerator this will generate feedback to the Siemens DCM drive to accurately measure speed.

To run this experiment the Siemens PLC and HMI have been pre-programmed with software to control the motors and display required measured values. Communication between the drives and PLC is via Profinet.

The PLC software has been programmed for 4 Quadrant running of the DC Motor. As shown in fig 10 of the HMI, the program allows Auto running of all Quadrants or manual running where individual Quadrants can be selected and adjustable speed/torque values. It also displays the required measured values of Armature voltage, current, back EMF, etc.

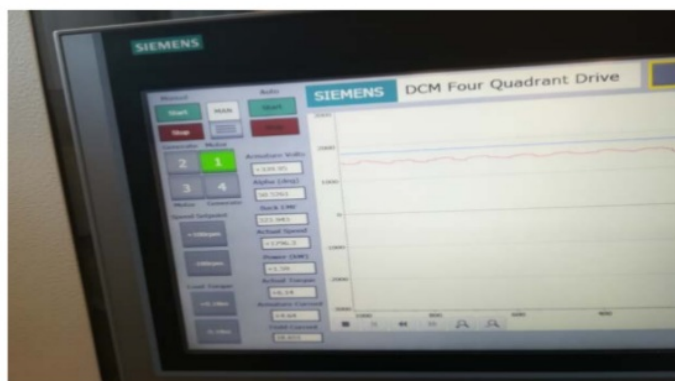


Figure 10 HMI Display for control and measured values.

A Picoscope is connected to a laptop to produce waveforms of Armature current and voltage of the DC motor running Fig 11. The probes are connected to the output cable of the DC drive, as shown in fig 12. As the Picoscope is not designed to read large voltages and currents that the drive could

produce, a current transducer amplifier is used to produce a 1 amp = 1 volt scale for armature current and a voltage transducer amplifier is used to produce a 100 volt = 1 volt scale for armature voltage.

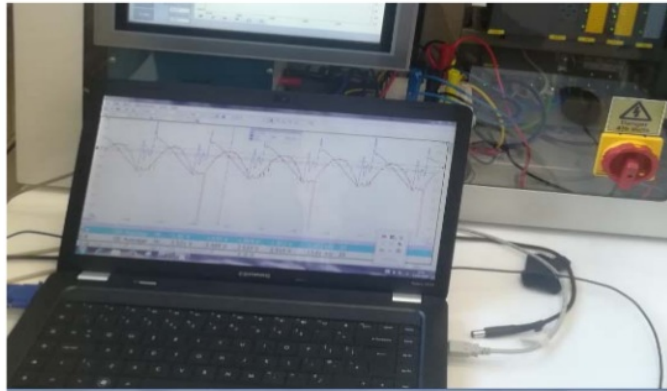


Figure 11 Laptop setup at Picoscope to produce waveforms

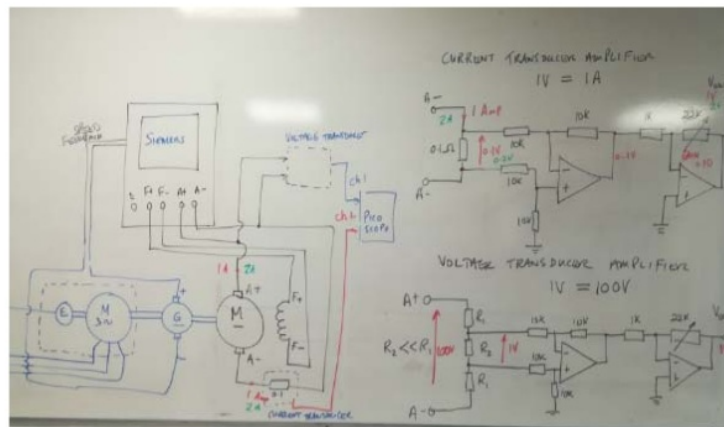


Figure 12 Voltage and current transducer amplifiers for Picoscope.

Experiment 1- produce continuous current waveform

Using the HMI to select and change control values, manual mode and quadrant 1 is selected.

DC Motor speed is set to 1800 rpm and the torque is increased to raise the Armature current until the continuous current waveform of the thyristors firing is produced. Inputting three different torque setting the below waveforms were produced and HMI measured values were recorded.

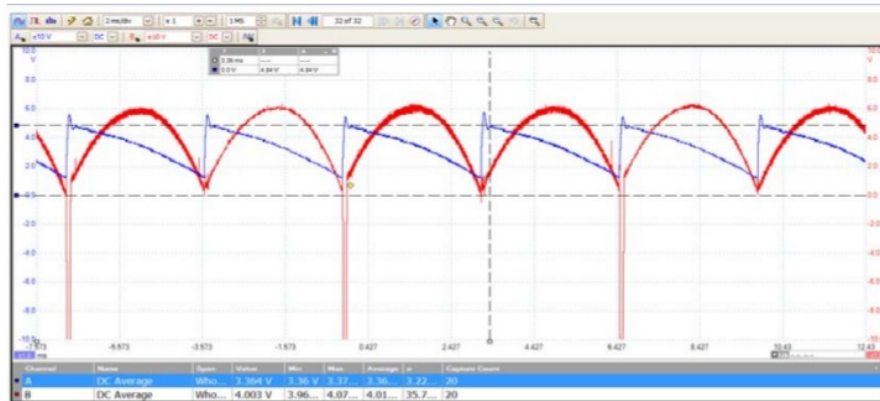
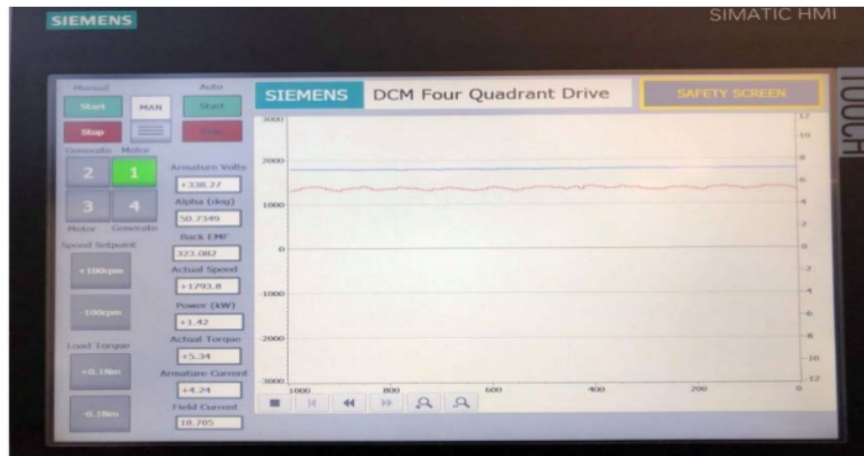
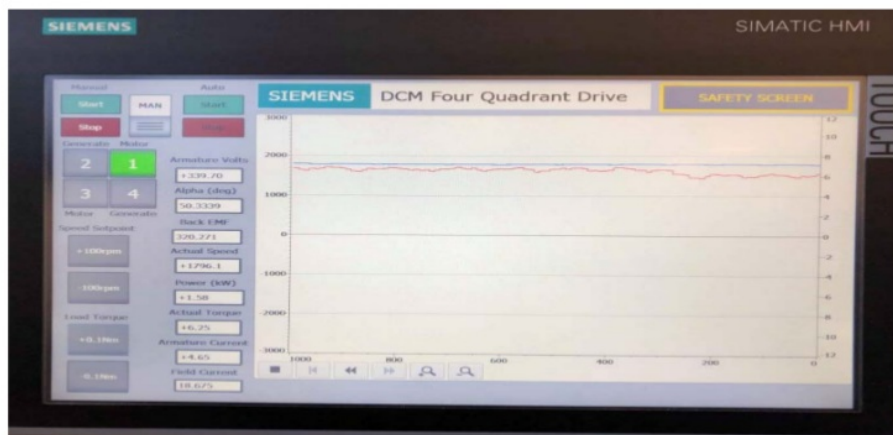
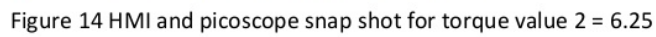


Figure 13 HMI and Picoscope snap shot for Torque value 1 = 5.34





The below table is of the values measured from the drive and displayed on the HMI

	HMI Values		
Torque	5.34	6.25	6.75
Armature voltage	338.27	339.7	341.4
Alpha(deg)	50.73	50.33	49.94
Back EMF	323.1	320.271	323.49
Actual speed	1794	1796	1803
Power	1.42	1.58	1.75
Armature Current	4.24	4.65	5.16
Field current	18.7	18.68	18.62

From analysis of the Picoscope waveform, it can be seen that a continuous current is being produced by the thyristors firing. The red waveform represents armature current and blue waveform armature voltage, the values on the Picoscope are 100th of the measured value off the HMI from the drive. The Waveform shows that armature voltage never hits zero or switches off before the next thyistor fires causing an overlap which produces a continuous current output to the armature.

Validation of armature voltage is required, to do this a formulae is derived from the waveforms produced on the Picoscope. Fig16

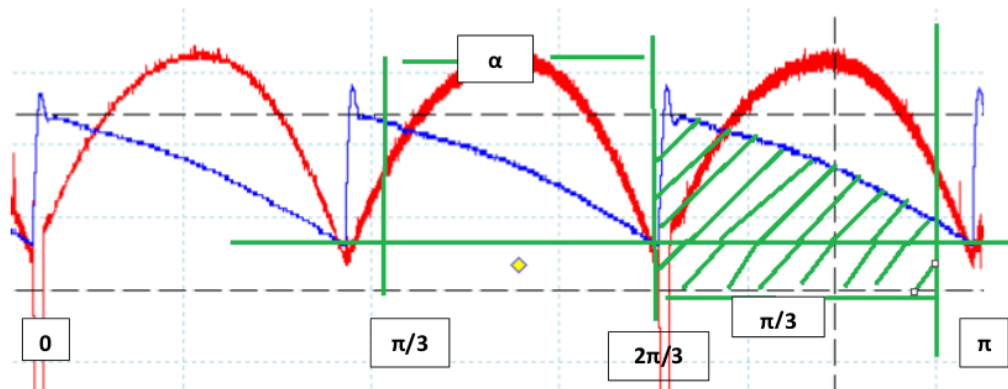


Figure 16 – waveform to derive formulae from.

The formulae is derived from the area of the single waveform.

$$\begin{aligned}
 \text{area} &= \int_{\pi/3 + \alpha}^{2\pi/3 + \alpha} V_{\max} \sin \theta \, d\theta \\
 &= V_{\max} [-\cos \theta]_{\pi/3 + \alpha}^{2\pi/3 + \alpha}
 \end{aligned}$$

$$= V_{max}[-\cos(2\pi/3 + \alpha) - -\cos(\pi/3 + \alpha)]$$

$$\cos(\pi/3 + \alpha) = \frac{1}{2} \cos \alpha - \sqrt{\frac{3}{2}} \sin \alpha$$

$$\cos(2\pi/3 + \alpha) = -\frac{1}{2} \cos \alpha - \sqrt{\frac{3}{2}} \sin \alpha$$

$$area = V_{max} \left[-\frac{1}{2} \cos \alpha - \sqrt{\frac{3}{2}} \sin \alpha + \frac{1}{2} \cos \alpha - \sqrt{\frac{3}{2}} \sin \alpha \right]$$

$$area = \frac{3V_{max}}{\pi} \cos \alpha$$

Final equation to calculate mean voltage (Armature dc voltage) is

$$V_{mean} = \frac{3V_{max}}{\pi} \cos \alpha$$

Values entered in the equation come from the measured values recorded from the HMI for each of the torque values entered.

Torque test 1 Calculations

	HMI Values		
Torque	5.34		
Armature voltage	338.27		
Alpha(deg)	50.73		
Back EMF	323.1		
Actual speed	1794		
Power	1.42		
Armature Current	4.24		
Field current	18.7		

The calculation needs to be carried out in Radians

$$\alpha = 50.73^\circ \quad \alpha(rad) = \frac{50.73}{180} \times \pi = 0.8854$$

$$V_{line} = 415V \quad V_{max} = \sqrt{2} \ 415 = 587$$

Due to voltage drop within the drive caused by the thyristors firing 5V is taken off Vmax for the calculation.

$$V_{max} = 583V$$

$$V_{mean} = \frac{3 \times 583}{\pi} \cos 0.8854$$

$$V_{mean} = 352.39$$

Torque test 2 calculations

	HMI Values		
Torque		6.25	
Armature voltage		339.7	
Alpha(deg)		50.33	
Back EMF		320.271	
Actual speed		1796	
Power		1.58	
Armature Current		4.65	
Field current		18.68	

The calculation needs to be carried out in Radians

$$\alpha = 50.33^\circ \quad \alpha(rad) = \frac{50.33}{180} \times \pi = 0.8784$$

$$V_{line} = 415V \quad V_{max} = \sqrt{2} \ 415 = 587$$

Due to voltage drop within the drive caused by the thyristors firing 5V is taken off Vmax for the calculation.

$$V_{max} = 583V$$

$$V_{mean} = \frac{3 \times 583}{\pi} \cos 0.8784$$

$$V_{mean} = 355.40$$

Torque test 3 calculations

	HMI Values		
Torque			6.75
Armature voltage			341.4
Alpha(deg)			49.94
Back EMF			323.49
Actual speed			1803
Power			1.75
Armature Current			5.16
Field current			18.62

The calculation needs to be carried out in Radians

$$\alpha = 49.94^\circ \quad \alpha(rad) = \frac{49.94}{180} \times \pi = 0.8716$$

$$V_{line} = 415V \quad V_{max} = \sqrt{2} \, 415 = 587$$

Due to voltage drop within the drive caused by the thyristors firing 5V is taken off V_{max} for the calculation.

$$V_{max} = 583V$$

$$V_{mean} = \frac{3 \times 583}{\pi} \cos 0.8716$$

$$V_{mean} = 358.30$$

Table of Comparison for the results of measurements and calculations

Torque value	Measured Armature Current	Calculated Armature Current	Voltage difference
5.34	338.27	352.39	14.12
6.25	339.7	355.4	15.7
6.75	341.4	358.3	16.9

From the results there seems to be a large difference between measured and calculated. It is unknown where such a large difference has come from it could be parameter settings within the Siemens drive and it may also be a scaling error in the way the PLC reads and displays the data. Part of a simple investigation is to check the three phase supply voltage, this is 412v meaning the Vmax value is going to be smaller

$$V_{line} = 412V \quad V_{max} = \sqrt{2} \ 412 = 582$$

Take off voltdrop from thyristors =5v $V_{max} = 577v$

Angle α is also easy to check by re-arranging the mean voltage formulae

$$\alpha = \cos^{-1}\left(\frac{V_{mean}}{3V_{max}/\pi}\right)$$

Calculate for torque test 1

$$V_{mean} = 338.27 \quad \text{keep } V_{max} = 583$$

Calculate in degs

$$\alpha = \cos^{-1}\left(\frac{338.27}{3 * 583/\pi}\right)$$

$$\alpha = 52.58^\circ \quad \text{convert to rads}$$

$$V_{mean} = \frac{3 \times 583}{\pi} \cos 0.9177$$

$V_{mean} = 338.29$ This value is almost exact of measured value on HMI, there seems to be approx.

3 % error occurring with the reading of angle α being read and displayed.

Calculating the motor constants.

Using measured values from test 3 the voltage constant (K_e) and torque constant (K_t) can be calculated

$$K_e = \frac{Emf}{\text{Speed Rad/s}}$$

$$Emf = 323.49$$

$$\text{Speed} = 1803 \text{ rpm} \quad \text{Speed (Rad)} = \frac{1803\pi}{30} = 188.81 \text{ rad/s}$$

$$K_e = \frac{323.49}{188.81} = 1.7133$$

$$K_t = \frac{T_m}{I_a}$$

$$K_t = \frac{5.48}{4.21} = 1.302$$

Armature resistance R_a

$$E_{(r)} = V_a - I_{a(r)} R_a$$

$$V_a - E_{(r)} = I_{a(r)} R_a$$

$$R_a = \frac{V_a - E_{(r)}}{I_{a(r)}}$$

Where $V_a - E_r$ is the difference in voltage between the EMF and armature voltage at the cross over point at the centre of the peak. Shown in the waveform fig17

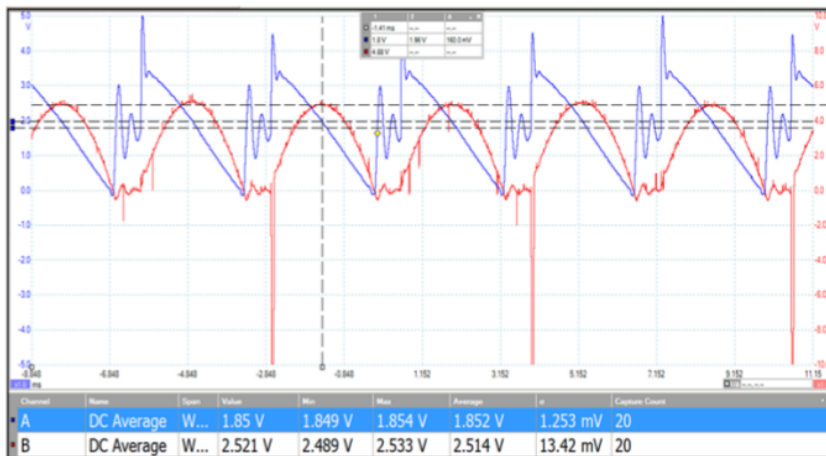


Figure 17 waveform with voltage lines on peak and crossover point.

$$R_a = \frac{17.91}{4.88} = 3.67 \text{ ohms}$$

Experiment 2- produce discontinuous current waveform

Using the HMI to select and change control values, manual mode and quadrant 1 is selected.

DC Motor torque is set to a constant value and the speed is low and increased to raise the Armature voltage, back EMf voltage is also produced until discontinuous current waveform of the thyristors

firing is produced. Inputting three different speed setting the below waveforms were produced and HMI measured values were recorded.

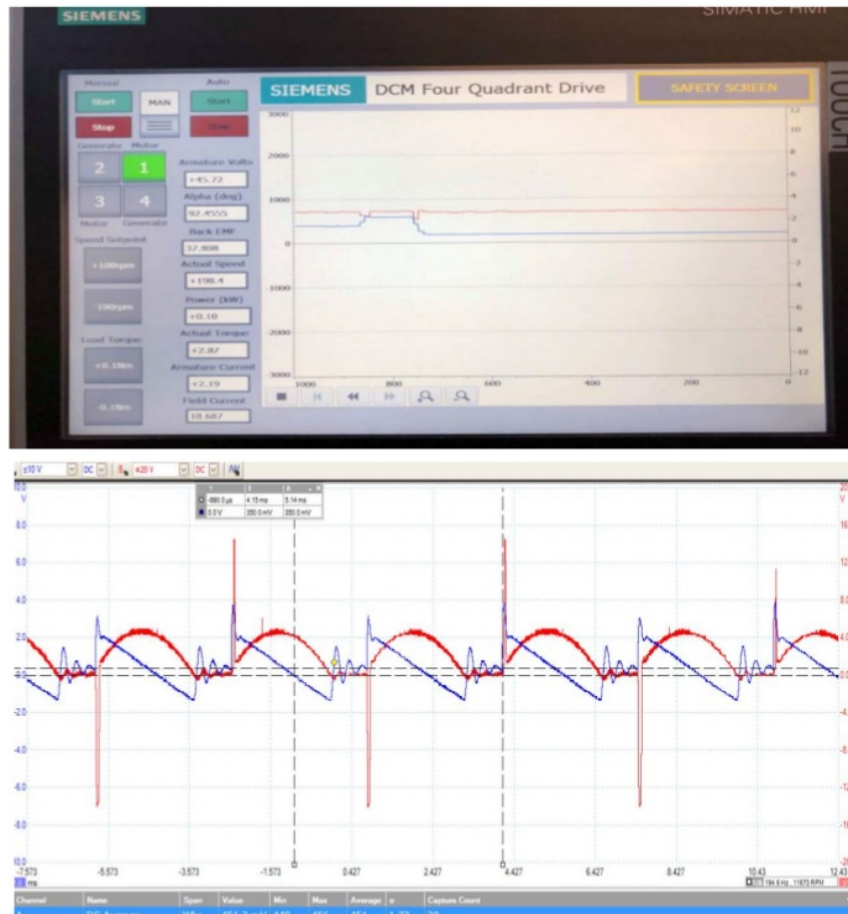
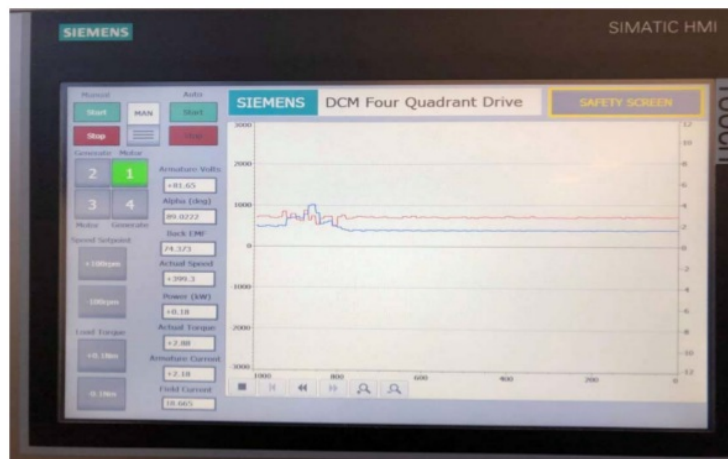


Figure 18 HMI and Picoscope waveform for speed 1.



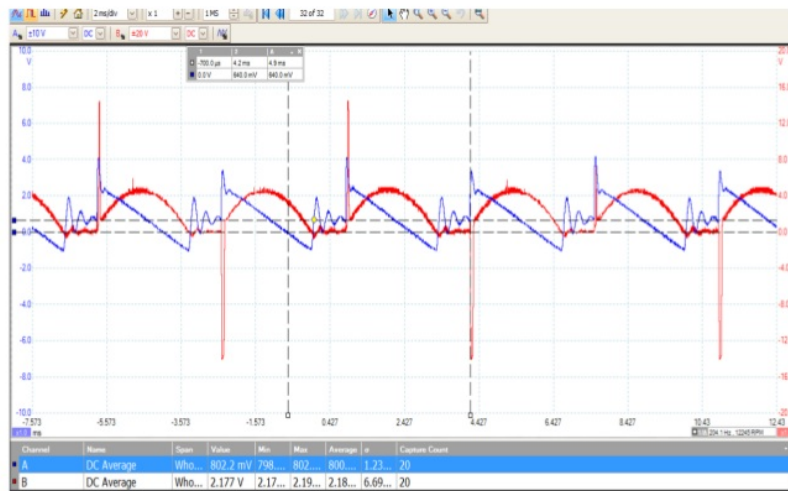


Figure 19 HMI and Picoscope waveform for speed 2.

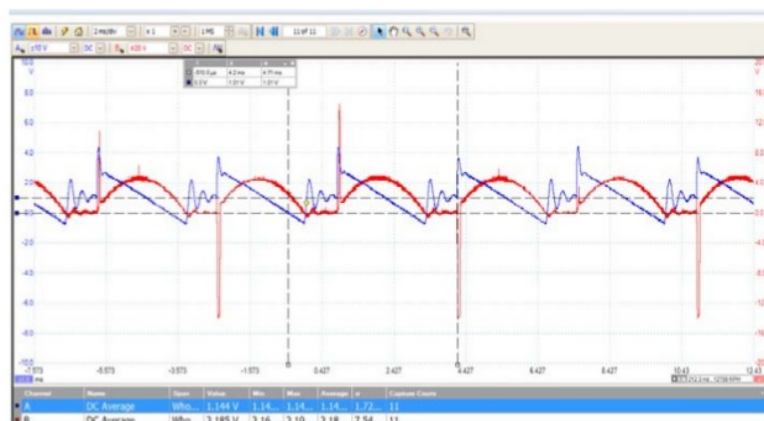
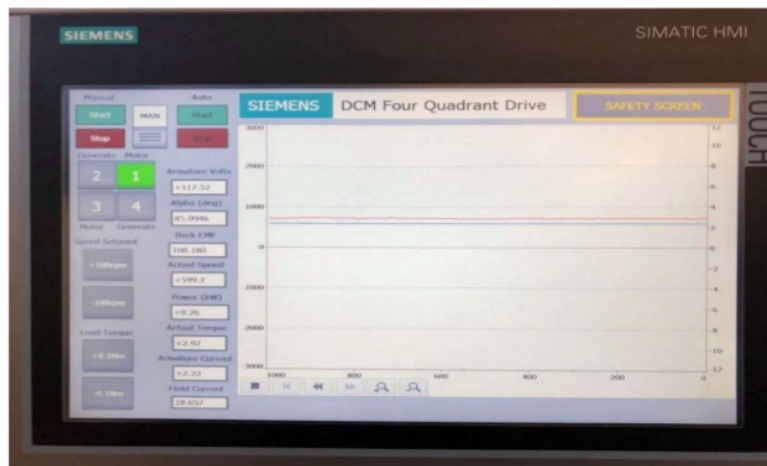


Figure 20 HMI and Picoscope waveform for speed 3

The below table is of the values measured from the drive and displayed on the HMI

	HMI Values		
Speed	198.4	399.3	599.7
Armature voltage	45.72	81.65	117.52
Alpha(deg)	92.455	89.022	85.09446
Back EMF	37.808	74.37	108.18
Torque	2.87	2.88	2.92
Power	0.1	0.18	0.26
Armature Current	2.19	2.18	2.23
Field current	18.68	18.66	18.66

From analysis of the Picoscope waveform, it can be seen that a discontinuous current is being produced by the thyristors firing. The red waveform represents armature current and blue waveform armature voltage, the values on the Picoscope are 100th of the measured value off the HMI from the drive. The

Waveform shows that armature voltage passes the zero line, switching off causing back emf before the next thyristor fires.

Validation of armature voltage is required, to do this a formulae is derived from the waveforms produced on the Picoscope. Fig21

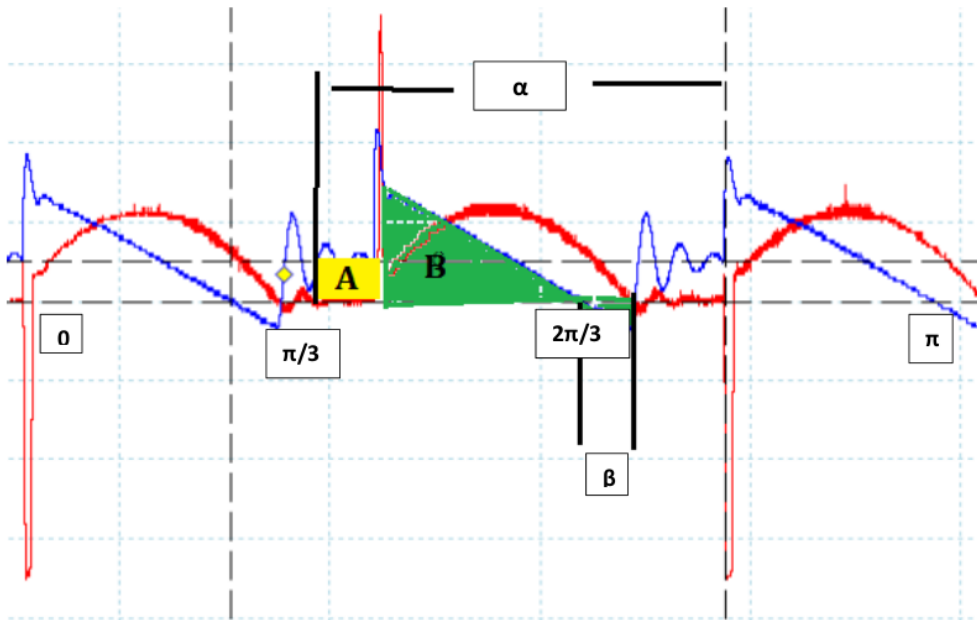


Figure 21– waveform to derive formulae from.

The formulae is derived from the area of back Emf (A) and the area of Armature voltage (B) of the single waveform.

Area a is a rectangle so it can be deriver as

$$area A = E(\alpha' - \beta) \pi/3 = E(\alpha - \pi/3 - \beta)$$

Area “B” is an integrated

$$area B = \int_{2\pi/3+\alpha'}^{\pi+\beta} Vmax \sin(\theta) d\theta$$

Since

$$\alpha' = \alpha - \pi/3$$

$$Vmean = (area A + area B) / \pi/3$$

$$area B = \int_{\pi/3+\alpha}^{\pi+\beta} Vmax \sin(\theta) d\theta$$

$$area B = Vmax [-\cos(\theta)]_{\pi/3+\alpha}^{\pi+\beta}$$

$$area B = Vmax [-\cos(\pi + \beta) - -\cos(\pi/3 + \alpha)]$$

$$\cos(A + B) = \cos A \cos B - \sin A \sin B$$

$$\cos(\pi + \beta) = \cos \pi \cos \beta - \sin \pi \sin \beta$$

$$\cos(\pi) = -1$$

$$\sin(\pi) = 0$$

$$\cos(\pi + \beta) = -\cos \beta$$

$$\cos(\pi/3 + \alpha) = \cos \pi/3 \cos \alpha - \sin \pi/3 \sin \alpha$$

$$\cos(\pi/3) = 1/2$$

$$\sin(\pi/3) = \frac{\sqrt{3}}{2}$$

$$\cos(\pi/3 + \alpha) = \frac{1}{2} \cos \alpha - \frac{\sqrt{3}}{2} \sin \alpha$$

$$area B = Vmax [- -\cos \beta + \frac{1}{2} \cos \alpha - \frac{\sqrt{3}}{2} \sin \alpha]$$

$$area B = Vmax [\cos \beta + \frac{1}{2} \cos \alpha - \frac{\sqrt{3}}{2} \sin \alpha]$$

$$V_{mean} = \frac{E(\alpha - \pi/3 - \beta) + V_{max} \left[\cos \beta + \frac{1}{2} \cos \alpha - \frac{\sqrt{3}}{2} \sin \alpha \right]}{\pi/3}$$

Values entered in the equation come from the measured values recorded from the HMI for each of the Speed values entered.

Speed test 1 Calculations

	HMI Values		
Speed	198.4		
Armature voltage	45.72		
Alpha(deg)	92.455		
Back EMF	37.808		
Torque	2.87		
Power	0.1		
Armature Current	2.19		
Field current	18.68		

The calculation needs to be carried out in Radians

$$\alpha = 92.455^\circ \quad \alpha(rad) = \frac{92.455}{180} \times \pi = 1.614$$

β is measured off the Picoscope as the time in which the Armature voltage is below zero

$$\beta = 0.92\text{ms} \quad \text{convert to rads} \quad \beta = \frac{0.92}{10} \times \pi = 0.289$$

$$V_{line} = 415\text{V} \quad V_{max} = \sqrt{2} \ 415 = 587$$

Due to voltage drop within the drive caused by the thyristors firing 5V is taken off V_{max} for the calculation.

$$V_{max} = 583\text{V}$$

$$V_{mean} = \frac{37.808(1.614 - \pi/3 - 0.289) + 583 \left[\cos 0.289 + \frac{1}{2} \cos 1.614 - \frac{\sqrt{3}}{2} \sin 1.614 \right]}{\pi/3}$$

$$V_{mean} = 49.95\text{v}$$

Speed test 2 Calculations

	HMI Values		
Speed		399.3	
Armature voltage		81.65	
Alpha(deg)		89.022	
Back EMF		74.37	
Torque		2.88	
Power		0.18	
Armature Current		2.18	
Field current		18.66	

The calculation needs to be carried out in Radians

$$\alpha = 89.022^\circ \quad \alpha(rad) = \frac{89.022}{180} \times \pi = 1.554$$

β is measured off the Picoscope as the time in which the Armature voltage is below zero

$$\beta = 0.7\text{ms} \quad \text{convert to rads} \quad \beta = \frac{0.7}{10} \times \pi = 0.2199$$

$$V_{\text{line}} = 415\text{V} \quad V_{\text{max}} = \sqrt{2} \, 415 = 587$$

Due to voltage drop within the drive caused by the thyristors firing 5V is taken off V_{max} for the calculation.

$$V_{\text{max}} = 583\text{V}$$

$$V_{\text{mean}} = \frac{74.34(1.554 - \pi/3 - 0.2199) + 583 \left[\cos 0.2199 + \frac{1}{2} \cos 1.554 - \frac{\sqrt{3}}{2} \sin 1.554 \right]}{\pi/3}$$

$$V_{\text{mean}} = 86.29\text{v}$$

Speed test 3 Calculations

	HMI Values		
Speed			599.7
Armature voltage			117.52
Alpha(deg)			85.09446
Back EMF			108.18
Torque			2.92
Power			0.26
Armature Current			2.23
Field current			18.66

The calculation needs to be carried out in Radians

$$\alpha = 85.094^\circ \quad \alpha(\text{rad}) = \frac{85.094}{180} \times \pi = 1.485$$

β is measured off the Picoscope as the time in which the Armature voltage is below zero

$$\beta = 0.475\text{ms} \quad \text{convert to rads} \quad \beta = \frac{0.475}{10} \times \pi = 0.149$$

$$V_{\text{line}} = 415\text{V} \quad V_{\text{max}} = \sqrt{2} \, 415 = 587$$

Due to voltage drop within the drive caused by the thyristors firing 5V is taken off V_{max} for the calculation.

$$V_{\text{max}} = 583\text{V}$$

$$V_{\text{mean}} = \frac{108.18(1.485 - \pi/3 - 0.149) + 583 \left[\cos 0.149 + \frac{1}{2} \cos 1.485 - \frac{\sqrt{3}}{2} \sin 1.485 \right]}{\pi/3}$$

$$V_{\text{mean}} = 123.88\text{v}$$

Table of Comparison for the results of measurements and calculations

Speed Value	Measured Armature Current	Calculated Armature Current	Voltage difference
198.4	45.72	49.95	4.23
399.3	81.65	86.29	4.64
599.7	117.52	123.88	6.36

From the results above there is again a difference between measured and calculated.

The voltage difference is a lot smaller in the results for discontinuous current than continuous, again the difference may be due to PLC scaling of data from the drive or drive parameters not set correctly. Value of β in mS maybe out as it is measured on the waveform at the crossing point of zero when the thyristors are switching off and on.

α maybe also be at error as in the continuous current calculations.

4 quadrant running Experiment.

The PLC program allow a 4 quadrant operation to be simulated. On the HMI Auto mode is selected and start is pressed. The DC motor speeds up and down as Armature current and voltage rise and fall. Fig22 shows the result of the switching of quadrants on the HMI.

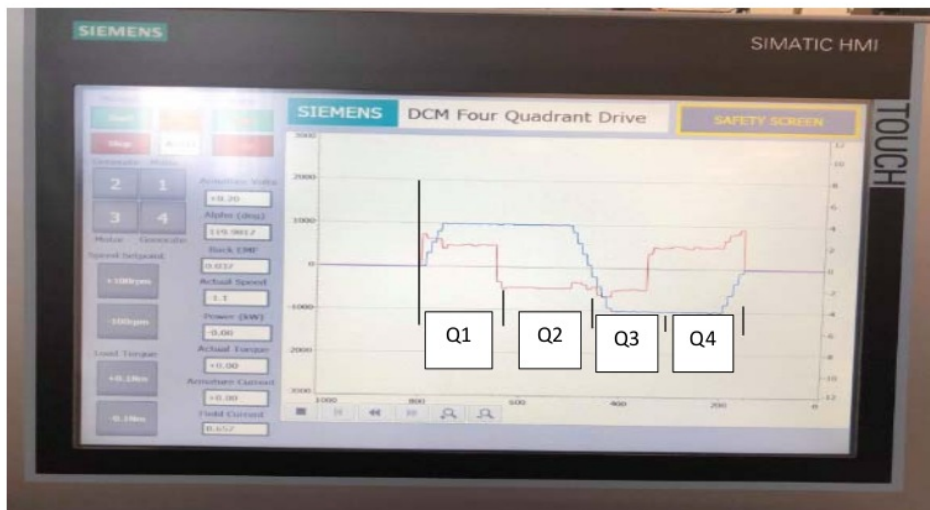


Figure 22 HMI with simulation of 4 quadrant running.

Using the Picoscope waveforms of the effect for each quadrant are recorded.

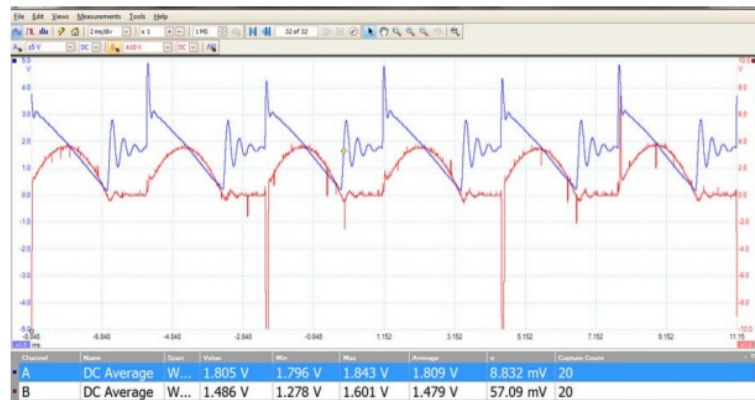


Figure 23 – Armature current and voltage quadrant 1

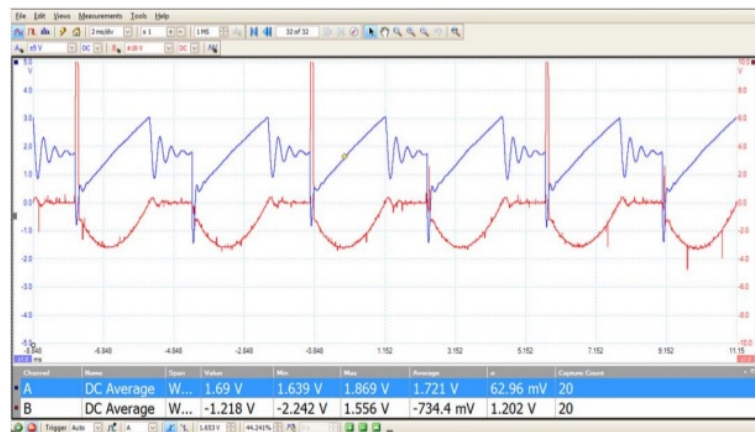


Figure 24- Armature current and voltage quadrant 2

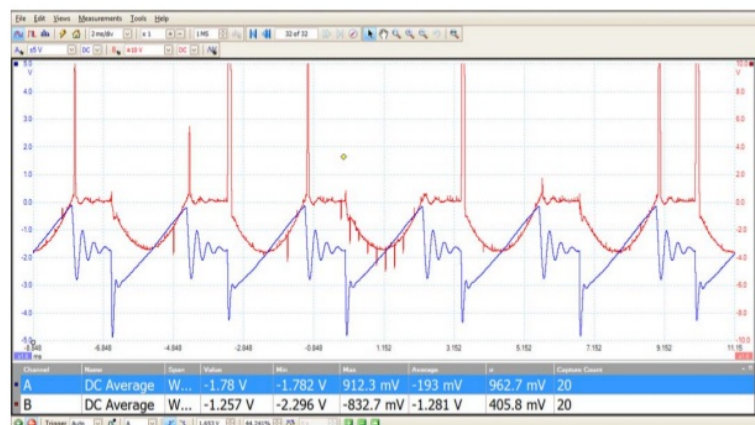


Figure 25- Armature current and voltage quadrant 3

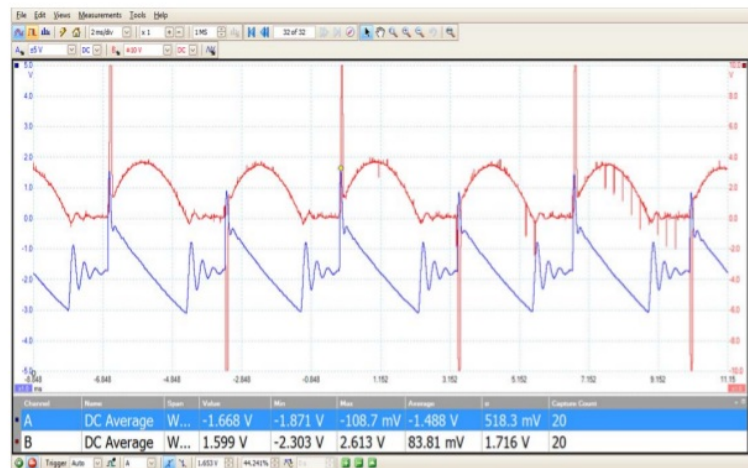


Figure 26 Armature current and voltage quadrant 4

From analysis of the result it can be accurately seen how armature voltage and current is changed between positive and negative as the two thyristor bridges switch changing the Alpha firing angle.

Quadrant 1 fig23. Both armature current and voltage are positive as the motor is forward motoring. The first thyristor bridge is producing an angle Alpha less than 90 degrees.

Quadrant 2 fig24. Armature voltage is still positive but now the armature current is negative. The drive has switched over to the second thyristor bridge to create an angle alpha larger than 90 degrees. The effects on the motor is now forward braking.

Quadrant 3 fig25. Both armature voltage and current are now negative as the second thyristor bridge is switched to produce an angle Alpha less than 90degrees. The motor is now running in reverse motoring.

Quadrant 4 fig26. Armature voltage is still driving negative but now the armature current has become positive as the drive switches to the first thyristor Bridge and produce an angle alpha greater than 90 degrees. The effect on the motor is now reverse braking.

The results show how easy the drive can change the thyristor bridge firing angles to produce each of the 4 quadrants. The changeover is smooth and effortless and the physical effects on the motor running are hardly seen. This shows that there are a lot of uses for 4 quadrant drive where dynamic braking maybe requires or hoisting a load up and down with easy stopping and reversing direction.

Simulation and design adaption.

Using simulation software called Multisim a single quadrant DC drive is designed using a full wave rectifier circuit made up of 6 thyristors.fig27.

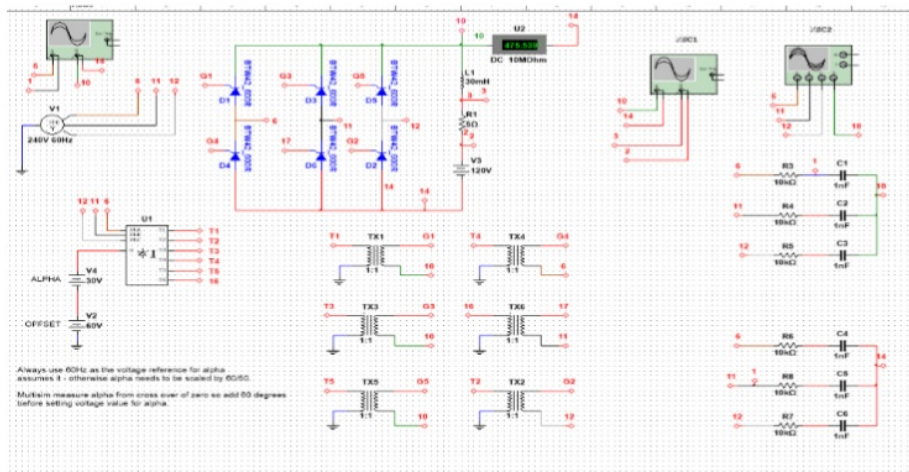


Figure 27 DC drive design for 1 quadrant.

Supply voltage in Multisim is always at 60 Hz and due to where the simulator reading from the zero crossover line an angle of 60 degrees is always added to the firing and Alpha.

The circuit design incorporates a resistor and inductor, this is to produce a load which represents the motor being attached to the output of the thyristor bridge. Two oscilloscopes are placed across the load so that waveforms of armature current and voltage can be shown.

To prove the circuit works, three tests of different Alpha angles are inputted and waveforms produced.

Test 1 Alpha = 25 degrees, this is represented as 25 v in Multisim

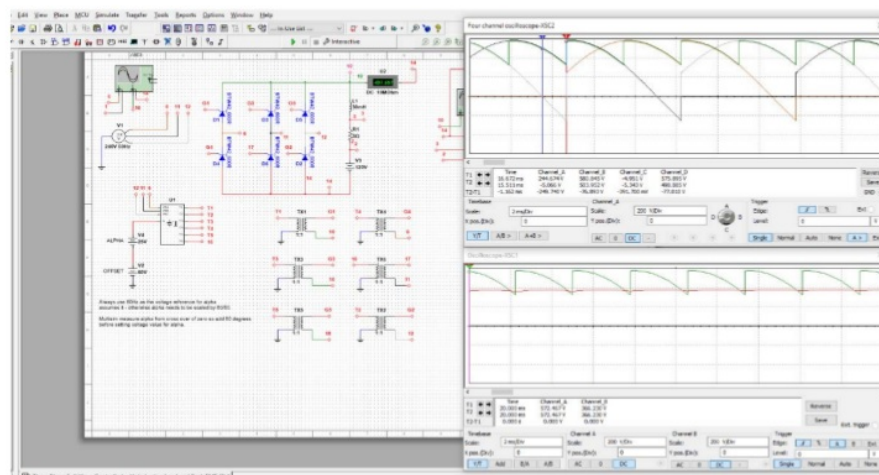


Figure 28 – Alpha simulation at 25 degrees

Test 2 Alpha = 35 degrees, this is represented as 35 v in Multisim

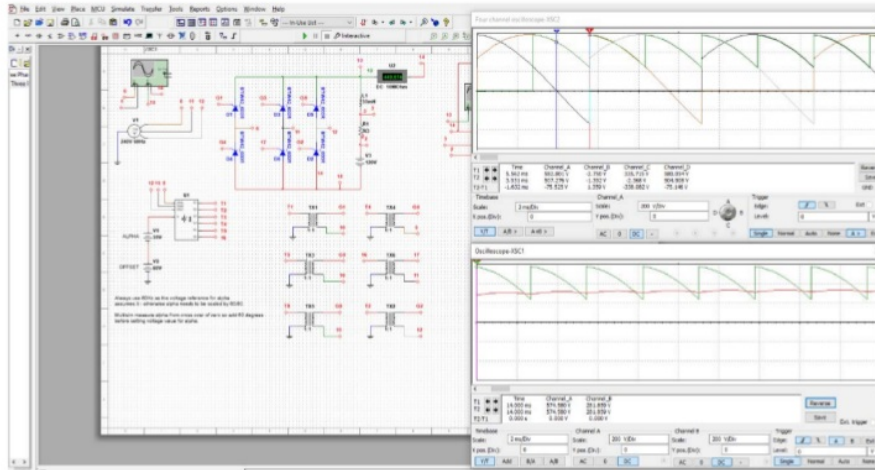


Figure 29– Alpha simulation at 35 degrees

Test 3 Alpha = 45 degrees, this is represented as 45 v in Multisim

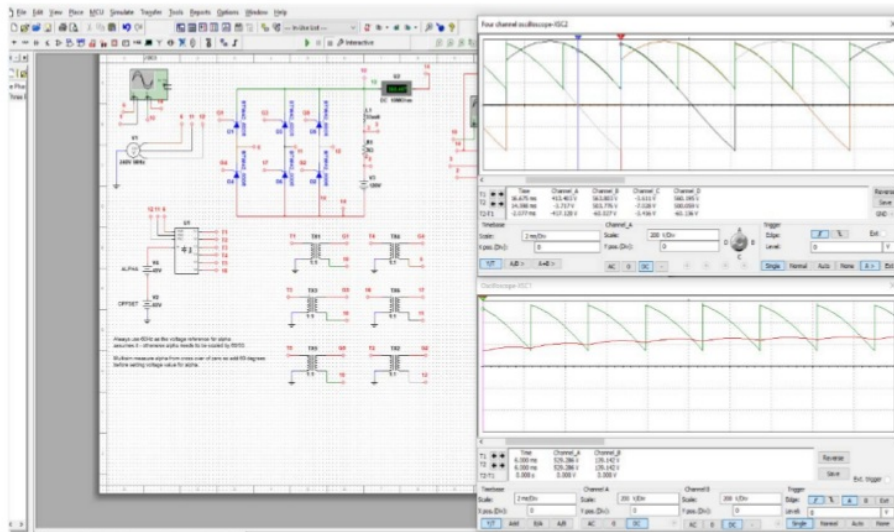


Figure 30– Alpha simulation at 45 degrees

Using the values obtained from the simulations, a calculation of armature current is carried out.

Test 1. Alpha = 25 degrees $V_{max} = 587 - 5v$ for losses in thyristor bridge

$$\alpha(rad) = \frac{25}{180} \times \pi = 0.4363$$

$$V_{mean} = \frac{3 \times 583}{\pi} \cos 0.4.363$$

$$V_{mean} = 504.57 \text{ vdc}$$

Test 2. Alpha = 35 degrees Vmax = 587 – 5v for losses in thyristor bridge

$$\alpha(\text{rad}) = \frac{35}{180} \times \pi = 0.611$$

$$V_{mean} = \frac{3 \times 583}{\pi} \cos 0.4.363$$

$$V_{mean} = 455.99 \text{ vdc}$$

Test 3. Alpha = 45 degrees Vmax = 587 – 5v for losses in thyristor bridge

$$\alpha(\text{rad}) = \frac{45}{180} \times \pi = 0.785$$

$$V_{mean} = \frac{3 \times 583}{\pi} \cos 0.785$$

$$V_{mean} = 393.82 \text{ vdc}$$

Comparison of values

	Test 1	Test 2	Test 3
Armature Volts measured	497.65	449.87	380.47
Armature Volts Calculated	504.57	455.99	393.82

There seems to be a voltage difference between the measured and calculated values of between 6-12 volts.

This maybe down to simulation voltage losses also it has been assumed that Vline is 415 v. from analysing the waveforms the Vmax readings are a lot low than 583v used in the calculation, if these simulated values are used than the voltage difference will be removed.

The above circuit is then modified to produce a 4 quadrant drive as below in fig31

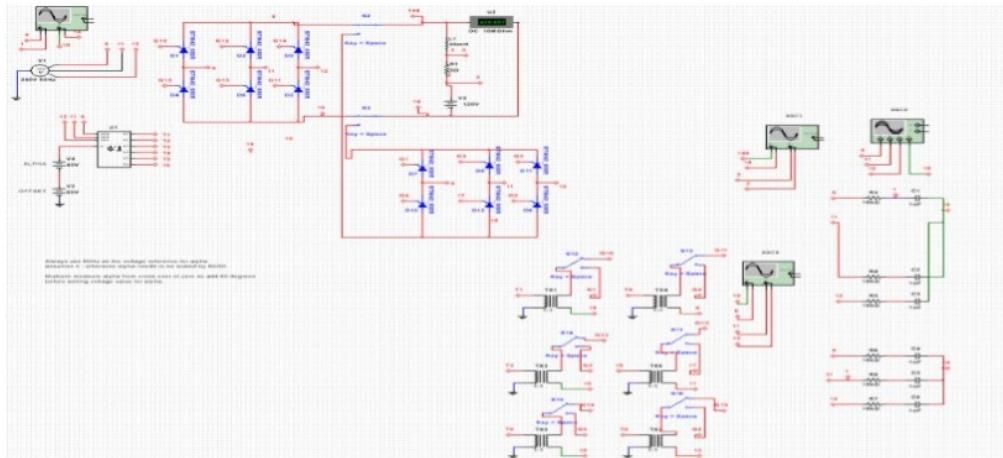


Figure 31 modified circuit to produce a 4 quadrant drive

The two rectifier thyristor bridges are connected via a manual switch. When the circuit is running, the switch is opened or closed via the space bar on the keyboard. Switching will cause the four quadrant change over.

Fig32 are the wave form results.

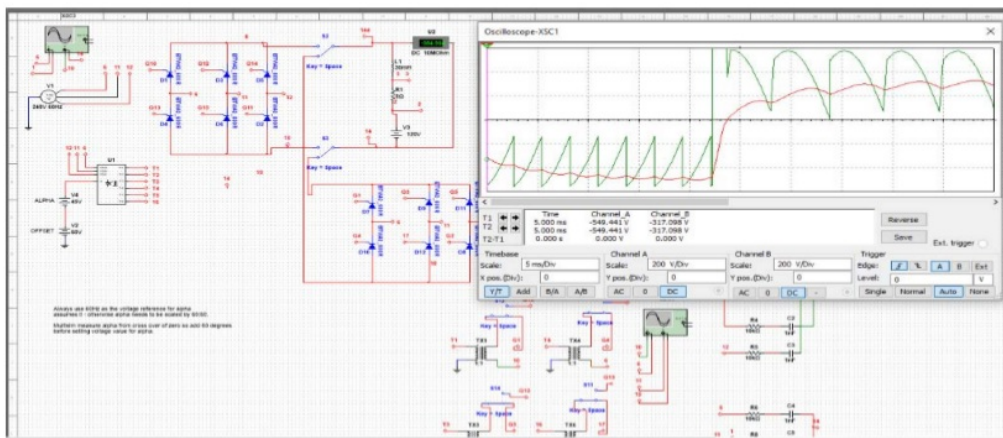


Figure 32 Simulation of Q1 & Q3 waveforms generated.

Unfortunately no waveform simulation could be produced for Q2 & Q4, the reason is unknown as the circuit seems to work ok. The way Multisim generates the waveform might be a reason as the simulation crashes. A test of other Alpha values had no effect.

Form the simulation wave form fig32 Q3 is on the bottom as the armature voltage and current are negative the motor is driving in reverse. Q2 is the top waveform as both armature current and voltage are positive and the motor is driving forward.

Conclusions and recommendations

To conclude the assignment, all objective set out in the assignment brief have been achieved.

Research into DC drive within industry and how the construction and features set them apart from AC drives. The finding also showed that AC drive technology is rapidly improving and machines that could only be run with DC drives and motors are changing, with this industry will become more energy efficient. Find also show that the 4 quadrant DC drive will still be used for a long time due to its versatility in forward and reverse braking. The four quadrant experiment proved the directional changes and braking by looking at the waveforms but also watch the DC motor physically stop and change direction. It proved the usefulness for this setup in application in industry.

A practical experiment into continuous and discontinuous proved the effectiveness of firing angles caused by the dual thyristor bridge. Measured and calculated values for Armature voltages were compared and differences were found. Discrepancies in Firing angle Alpha were proven but unable to find the cause. Waveforms produced by the picoscope make understanding the behaviour of the firing angles to the effects caused to Armature voltage and current.

Computer simulated design was good to show the circuit construction of the thyristor bridge and waveforms produced by increase firing angle alpha and the modification to change it to a dual bridge for 4 quadrant running. Unfortunately the simulation software wouldn't produce a full 4 quadrant simulated waveform, it would only simulate Q1 & Q3. Investigation in to causes was inconclusive all the wiring of the circuits work fine, it may be down to parameters in the program making it crash.

Overall this assignment proved DC drive technology and how useful the effects of thyristor firing angle causes motor control.

Recommendation for the assignment is to have more time to investigate errors between measured and calculation by simulating and testing voltages on the test rig, also may be looking at the read parameters on the drive operator screen and compare with PLC outputted values.

Citation List

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Appendix

SGEE6001 Power Electronics and Drives

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

40/100

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GRADING FORM: NEW CSG-RUBRIC

CARL

48

JONES

1. ENGAGEMENT WITH LITERATURE



Poor engagement with essential reading. No evidence of wider reading. Reliance on inappropriate sources, and/or indiscriminate use of sources. Heavily reliant on information gained through class contact. Inconsistent and weak use of referencing. No citations given for research in the text (only for images). List given isn't exactly in Harvard style. (7/20)

7

2. KNOWLEDGE AND UNDERSTANDING



Knowledge is reasonably extensive coherent and detailed. Exhibits very good understanding of the breadth and depth of established views, and the work is, at least in part, well-informed by current research and scholarship. (12/20)

12

3. COGNITIVE AND INTELLECTUAL



Sound critical thinking, analysis, synthesis and evaluation demonstrating critical thinking. Ability to devise and sustain persuasive arguments, and to review the reliability, validity and significance of evidence (that may be incomplete) to make mostly appropriate and valid judgements. (12/20)

12

4. PRACTICAL APPLICATION

 A very good application of a range of methods, materials, tools and/or techniques. Very good consideration of the context of the application, with perceptive insights. Can identify problems and propose appropriate solutions in complex and unpredictable contexts. Evidence of some innovation and creativity. (12/2)

12

5. TRANSFERABLE SKILLS

 Can communicate in a suitable medium but with some room for improvement. Mostly ordered presentation and structure in which relevant ideas / concepts are reasonably expressed. Work may lack coherence in places. Demonstrates the basic skills required in graduate employment, with some areas of minor weakness. Report contains several spelling and grammatical errors. No team working explained. Sections should be numbered. One inappropriate image included. Word count penalty applied (-5) (5/20) LATE SUBMISSION, CAPPED TO 40%

5