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by Matthew Perry

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Good detailed table of contents

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Good extensive list of figures with good relevant identification

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Good use of tables

1. Executive Summary

This assignment focused on understanding and applying four-quadrant drives in DC motor systems, considering their suitability for specific requirements and diverse applications. Theoretical insights into DC motor operation in different quadrants were practically tested through simulations.

The simulation involved designing a comprehensive circuit with a full-bridge converter, incorporating firing angles and waveforms. To enable four-quadrant functionality, the circuit was transformed into a dual converter, involving additional components for isolation and protection. *Good point with dual converter*

Oscilloscope analysis provided a detailed understanding of the four quadrants, depicting variations in power and current under different conditions. The simulation results aligned accurately with the theoretical framework.*Good point*

Practical investigations validated theoretical concepts by identifying quadrants through HMI and Pico-scope tools. Motor constants were derived and verified, demonstrating a direct relationship between increased speed or torque setpoints and corresponding changes in armature voltage and current.*Good work here*

The success of the assignment can be confirmed through the comparisons of theoretical and practical values, reinforcing the alignment of simulations with real-world outcomes.

The summary demonstrates an understanding of requirements for the tasks

2. Work plan for Life-long Learning & Risk Assessment

This assignment will be approached methodically, where each section will be divided and carried out. Firstly, the student will research design features and control techniques employed in 3-phase, 4 quadrant DC drives and analysing the advantages and limitations of various design approaches. Specifications of a DC drive from manufacturers will be analysed and evaluating whether a drive is suitable for specific applications. Lastly, DC drives will be investigated in where they will be applied and comparing them with other options such as single-phase converters, chopper drives and modern ac drives.

Secondly, the student will utilise simulation software to model armature voltage and current wave forms for a full wave, fully controlled 3 phase rectifiers with different firing angles. From the simulation results will be gathered and compared with theoretical calculations while identifying any differences. The rectifier design will be explained down to a degree of each component and then modifying the circuit for operation in all 4 quadrants and discussing the results.

Thirdly, a detailed experiment using a siemens 3-phase DCM drive connected to a Siemens S120 AC drive as a load will be used for a practical investigation. Using test equipment such as a pico-scope and a power quality analyser will be used for monitoring and waveform recording. The drive will be analysed in all 4 quadrants including discontinuous current situations and increasing the load. All scenarios will be analysed and compared with results.

A risk assessment has been carried out for the practical tasks which can be seen in Figure 1.

Lastly, from the research, simulation and practical investigations a conclusion will be carried out to state the findings. From this, recommendations may be made on the system.

Now that the assignment is complete, the student has learned the importance of researching relevant theoretical concepts to then compare to simulations and practical investigations.

A very detailed work plan. Good work

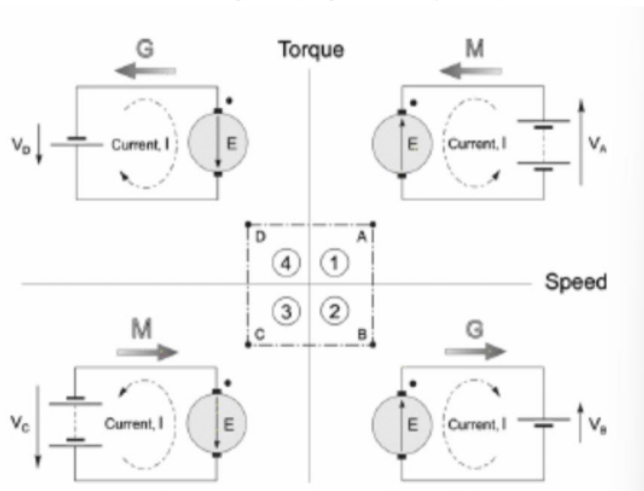
3. Research

3.1 Design Features and Control Techniques

4 Quadrant Operation

The use of 3-phase, 4 quadrant drives are essential within industry. These systems allow precision and efficiency within motor control. Design features within these systems can consist of motion control, regenerative braking, high frequency pulse width modulation and fault diagnostics *Good points covered here*

An armature voltage controlled direct current machine is capable of 'four quadrant' operation. This is because the steady state speed is determined by the applied voltage so the motor can run in either direction by applying the appropriate amount and polarity of the armature current. This depends on the difference between applied voltage and back electromagnetic flux. Therefore, an engineer can make the machine create positive (motoring) or negative (generating) torque by controlling the extent the applied voltage is more than or less than the back e.m.f as shown in Figure 1 (Hughes & Drury, 2013).



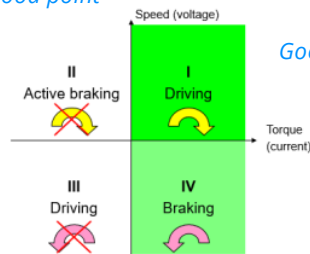
Good explanation and good relevant diagram

FIGURE 1; 4 QUADRANT OPERATION DIAGRAM

Analysing the figure further, it can be shown that quadrants 1 and 3 are known as motoring which means speed and torque are in the same direction whether that is both positive or both negative. Quadrants 2 and 4 are defined as generating which means speed and torque are opposite directions. This regenerative energy can be fed back to mains voltage, transferred to heat in a brake resistor or stored in capacitors (Kollmorgen, 2013) *Good explanation with key points included*

2 Quadrant Operation

A 2-quadrant drive can be implemented however it can apply a negative torque but only when the velocity is negative for example accelerating in reverse, meaning it is turned manually. Negative current and active braking is not possible (ABB, 2024). *Good point*



Good explanation with good supporting diagram

FIGURE 2; 2 QUADRANT OPERATION

A 3-phase, 4 quadrant rectifier DC drive can be made up of thyristors. This drive can have a closed loop speed control with two anti-parallel three phase thyristor rectifiers. The anti-parallel rectifiers operate in *The need for dual converters is identified* circulating current mode with aid of circulating current inductors. A speed control loop outputs the reference armature current of the machine. Then implementing the PI current controller, the thyristor firing angles for the two rectifiers in relation to the command armature current are derived. The firing angles are then used to receive the required gate signals for the rectifier through a thyristor bridge firing unit. Although the addition of the 2 anti-parallel converters in addition to the circulating current inductors create a more complex system, through this configuration, the drive can operate in all 4 quadrants which are:

- Forward motoring
- Reverse regeneration
- Reverse motoring
- Forward regeneration

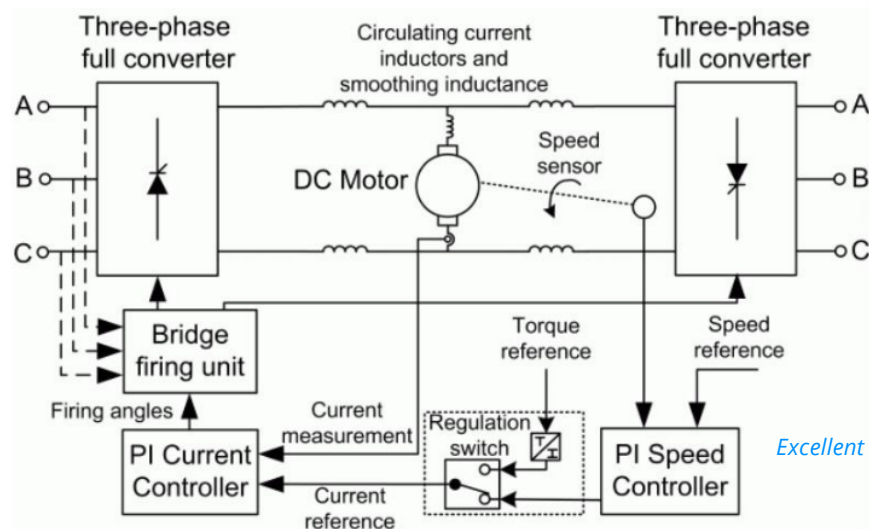


FIGURE 3; DC DRIVE CONFIGURATION DIAGRAM

(MathWorks, 2023)

3.2 Suitable DC drive with Specifications

Siemens DCM

An appropriate drive to be implemented is a Sinamics DCM DC Converter (6RA8013-6DV62-0AA0) manufactured by Siemens. This drive is designed to supply the field and armature of variable speed DC motors using 4 quadrant thyristor drive for a supply of 400V with 230V or 400V control supply.

The power units for the armature and field include an electrically insulated thyristor modules, this means that the heat sink is at ground potential. In the higher rated DC current units, the power unit for the armature control circuit includes disc-type thyristors are heatsinks at voltage potential. Additionally, this unit is autonomous because of the integrated parametrizing device and don't require any further equipment for parametrization (Siemens , 2018). *Key points identified*

Fig 4 Shows the configuration for the power circuit, it consists of 6 pairs of thyristors utilised in dual 3-phase fully controlled converters, in addition to the connecting terminals for the SCR's gate. RC snubber circuits are *Good key point here* implemented by connecting them parallel with the thyristors. This snubber operates by the resistor absorbing voltage spikes while the capacitors provide short term storage for the energy, preventing electrical flow damages to the circuit (Marshall, 2021)

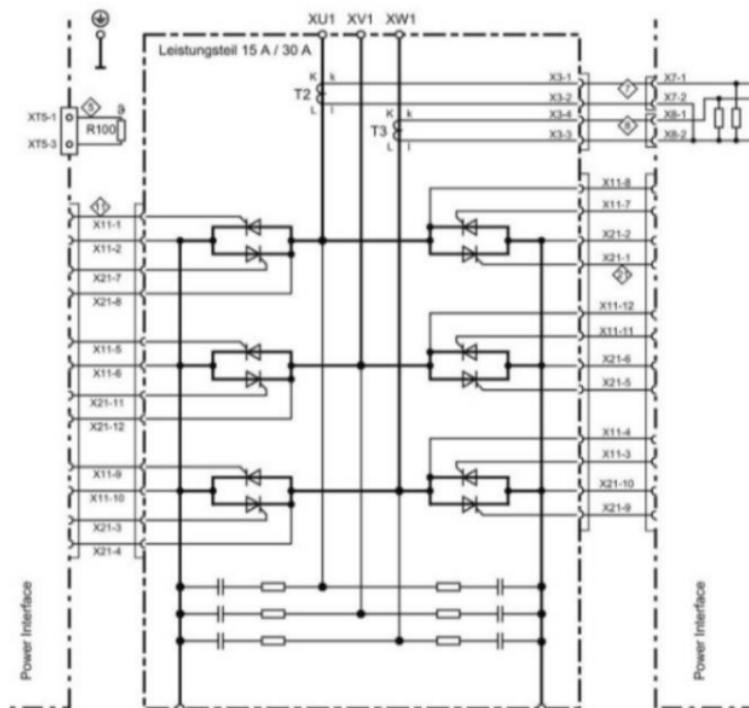


FIGURE 4; SINAMICS 6RA8013-6DV62-0AA0 POWER DIAGRAM

Good explanation with relevant diagram

Parker DC590+

The DC590+ Integrator Series DC drive is applicable to process line control with dedicated function blocks which simplify the implementation of applications. This drive uses internal controlled field supply programming including open and closed loop winder control as standard.

The power configuration consists of 4-quadrant regenerative with 2 fully controlled 3-phase thyristor bridges with a microprocessor implemented phase control extending the firing range. It has ratings up to 1950A and supply voltages up to 690V. Below shows the connection diagram for the power board and terminal board, but within this the bridges are shown including a field bridge that comes standard (Parker , 2022).

Good key parameters from spec covered.

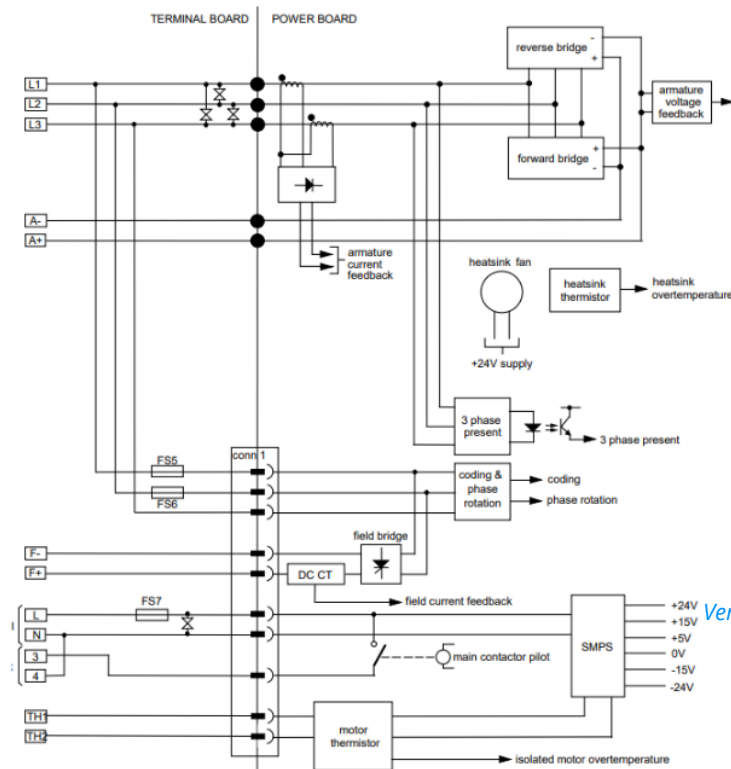


FIGURE 5; DC590 CONNECTION DIAGRAM (PARKER , 2022)

The feedback options that are available are the most common feedback devices enabling simple motor control. Armature feedback is standard without the need for any interface option and additionally an analogue tachogenerator or encoder can be used. Shows further technical data such as protection and IO specifications.

Good explanation

Eurotherm ER-PL / ER-PLX

Eurotherm offer digital DC-drives that are available in both 2-quadrant and 4-quadrant versions, however the 4-quadrant will be focused on due to the application. Its supply armature input can be 3-phase 12V ac-480V ac at 50-60Hz and the field input can be 3-phase 100V ac-240V ac 50-60Hz. The speed feedback used is standard for armature voltage, an analogue tachometer and encoder. A speed setpoint can be determined by using a 10K ohm potentiometer and has a full software package that consists of:

- 2 x PID free programmable
- 2 x Summers free programmable
- 2 x Filters
- Self-auto-tune for current loop

Good key points included

(Eurotherm, 2009)

Figure 6 shows basic arrangement of a control loop for speed control using the ER-PLX. Using the 3-phase controlled rectifier, which delivers power to the motor armature. The armature current is sensed to provide feedback to the inner current loop. After being scaled, this is compared to the current demand. The current error amplifier is able to detect any difference, and then act in such a way that the current feedback remains identical to the current demand during normal operation. This inner loop monitors the armature current and delivers more current or less current as required. The outer speed loop works in the same way as the inner current loop but uses different parameters (Sprint Electrics, n.d.).

Good explanation of control loops with good relevant diagram

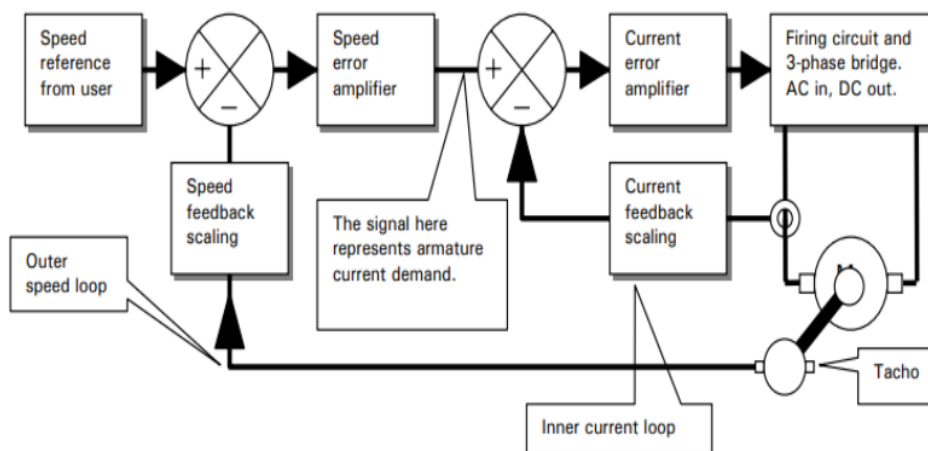


FIGURE 6; SPEED CONTROL EUROTHERM CONFIGURATION

3.3 Typical applications of four quadrant DC drives

Four quadrant DC drives are versatile systems that can operate using motoring and regenerative braking modes in both forward and reverse directions. This allows the drive to be implemented in many applications.

Compressors, pumps, and fan applications require operation in the first quadrant only. This is due to their operation being unidirectional and can be known as one quadrant drive systems. *Good identification of application*

Transportation drives require operation in both directions, the motor still operates in a forward direction but also acts as a generator, converting mechanical power back into electrical power. This means the speed is positive but the torque negative. Applications such where regenerative braking is essential such as downhill conveyors where the load is being slowed down or elevators descending then converts the excess energy into electrical power.

Using the third quadrant the motor operates in reverse direction, converting electrical power into mechanical power. The speed is negative, and the torque is negative. Applications where the motor is required to run in reverse such as reserving a conveyor belt. *Good points covered*

If regeneration is necessary in the application all four quadrants may be required such as in applications in crane and hoists. This is because precise control of lifting and lowering motion is required, the ability of smoothly accelerating and decelerating in addition to controlled braking is paramount in these applications. The motor operates in the reverse direction and can act as a generator converting mechanical power into electrical power, speed and torque are negative (Hughes & Drury, 2013).

In aid to determine how many quadrants are needed for an application, the table below can specify the function.

Function	Quadrant	Speed	Torque	Power Output
Forward Motoring	I	+	+	+
Forward Braking	II	+	-	-
Reverse Motoring	III	-	-	+
Reverse Braking	IV	-	+	-

Good relevant diagram

TABLE 1; FUNCTION OF QUADRANTS

The applications are very good, however, the comparisons are not included. The chopper fed drive and single phase converters should be included for comparison

4. Simulation and Design Adaption

4.1 Original Circuit

Using NI software Multisim, a simulated model of the design was configured. The modelled load is a separately excited motor which is made up of an inductor, resistor, and back EMF. This load is then controlled by a single converter which is a 3-phase rectifier. *Good key points identified here*

A 6-pulse phase angle controller directs the angle of alpha, which is dependent on the input voltage specified, in addition there is an offset of 30V (30 degrees) due to Multisim's configuration.

60V 60 degrees due to the NI multisim software. In practice this would not be necessary

From the controller, the pulses are connected to isolating transformers to trigger the SCR gate. The 6 silicon-controlled rectifiers are configured in a bridge arrangement with 3 pairs in series are all connected to a common point across the load. *Good key points*

An RC snubber circuit is used, although this is not necessary for the Simulation, it would be used in a real-world application to prevent voltage spikes.

Oscilloscopes are used as measurement devices that will record line voltage, armature voltage and armature current waveforms.

The design of the circuit has been labelled appropriately by the student. *Good explanation of test circuit*

Single Converter

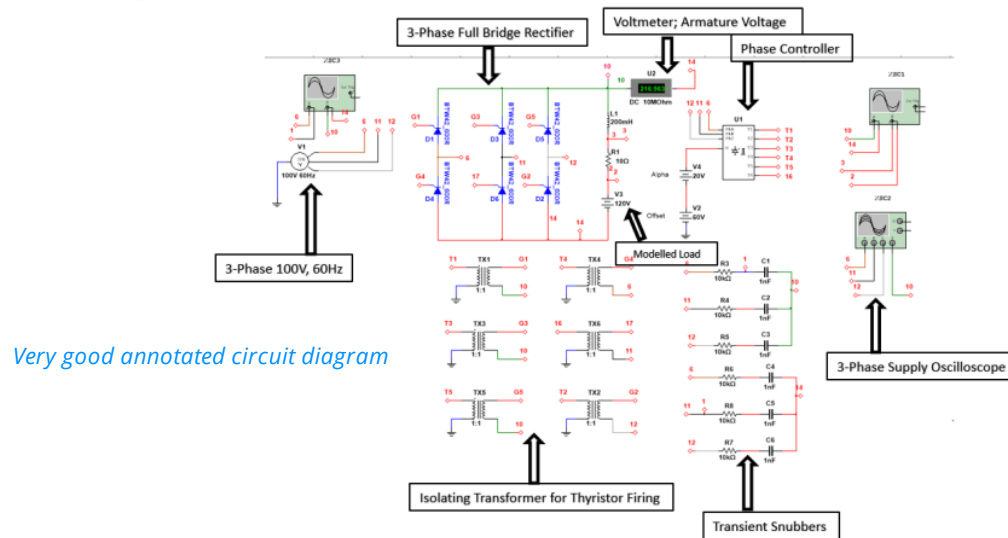


FIGURE 7; FULL BRIDGE SINGLE CONVERTER

Good work here

4.2 Vmean Calculations

Setting the firing angle to 0, with an offset of 30V, the Vmax value was measured using an oscilloscope as shown in *60V*

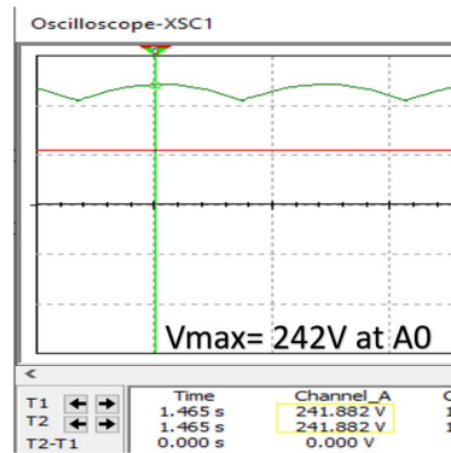


FIGURE 8; OBTAINING VMAX SIMULATION

By obtaining the Vmax value, the mean voltage can be calculated by:

$$V_{mean} = \left[\frac{3 \times V_{max}}{\pi} \right] \times \cos(\alpha) \quad \text{Formula is identified}$$

Using 5 firing angles, the vmean was calculated and compared with the simulation measurements.

At $\alpha = 10$

$$V_{mean} = \left[\frac{3 \times 242}{\pi} \right] \times \cos(10) = 227.58V$$

At $\alpha = 20$

$$V_{mean} = \left[\frac{3 \times 242}{\pi} \right] \times \cos(20) = 217.16V$$

At $\alpha = 30$

$$V_{mean} = \left[\frac{3 \times 242}{\pi} \right] \times \cos(30) = 200.13V$$

At $\alpha = 40$

$$V_{mean} = \left[\frac{3 \times 242}{\pi} \right] \times \cos(40) = 177V$$

At $\alpha = 50$

$$V_{mean} = \left[\frac{3 \times 242}{\pi} \right] \times \cos(50) = 148.54V$$

Excellent work

Compiling the values for calculated and simulated armature mean voltage in a table the errors can be shown.

Alpha α	Armature Mean Voltage (V)		Error	Evidence
	Simulated Voltage	Calculated Voltage		
10	227.27	227.58V	0.31	Figure 21
20	216.96	217.16V	0.80	Figure 22
30	199.9	200.13V	0.77	Figure 23
40	176.7	177V	0.7	Figure 24
50	148.38	148.54	0.16	Figure 25

TABLE 2; ARMATURE MEAN VOLTAGE SIMULATED VERSUS CALCULATED

Analysing the table, there is little error in simulated versus calculated and the simulation operates as expected.

Good use of table of results to evaluate outcomes and good ref to evidence figures

Some of these value do not quite match the results in the evidence in the appendix, but the errors are relatively small

4.3 Adapted Circuit

The circuit in Figure 9 was amended to a dual converter. An additional 6 thyristors were implemented to make a second bridge of the DC drive. The polarity of this bridge is in reverse to the original and placed across the opposite side of the load. Switches were implemented and connected between the two converters to isolate them preventing circulating currents. Additional RC Snubber circuits and additional isolating transformers were implemented for the same reasons as the original circuit.

The design of the configuration was appropriately labelled by the student below

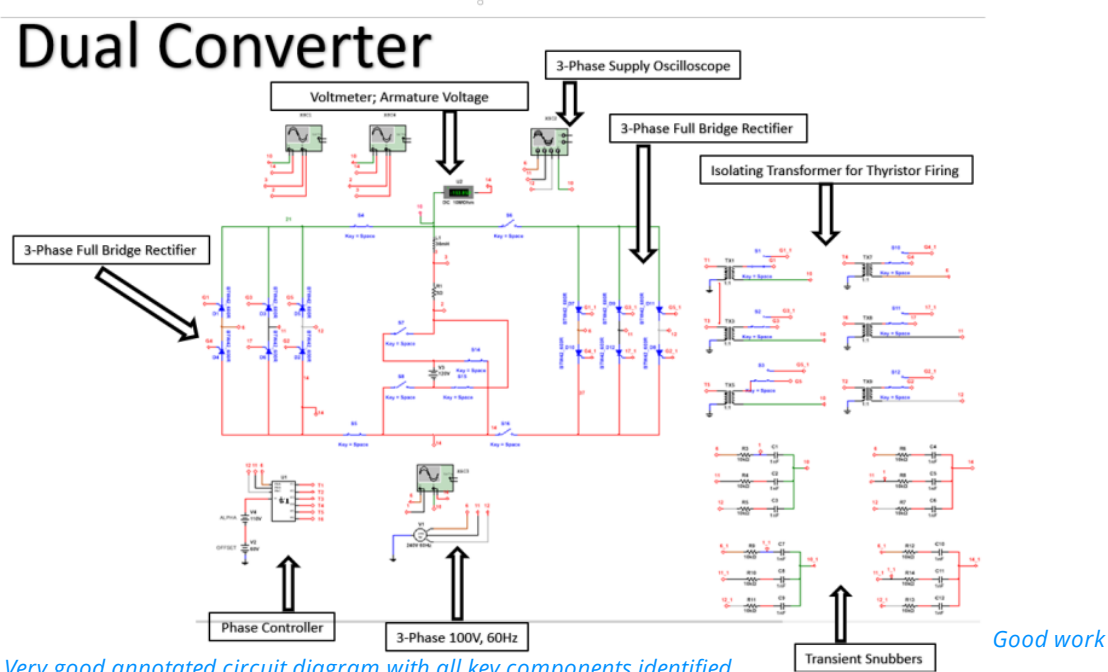


FIGURE 9; DUAL CONVERTER SIMULATION

Using the oscilloscopes, the circuit was energised using different variations of α to observe the four quadrants. Following the research the expected result was compared with the simulation results.

4 Quadrant Operation Theory & Simulation				
Quadrant	Expected Result	Simulation Result	Evidence	Correct Operation?
1	Forward Motoring ; Positive Voltage & Positive Current	Forward Motoring ; Positive Voltage & Positive Current	Figure 26	Yes
2	Forward Generating ; Positive Voltage & Negative Current	Forward Generating ; Positive Voltage & Negative Current	Figure 27	Yes
3	Reverse Motoring ; Negative Voltage & Negative Current	Reverse Motoring ; Negative Voltage & Negative Current	Figure 28	Yes
4	Reverse Generating; Negative Voltage & Positive Current	Reverse Generating; Negative Voltage & Positive Current	Figure 29	Yes

TABLE 3; 4-QUADRANT OPERATION COMPARISON

Excellent work here with ref to test evidence in appendix

5. Practical Investigations

5.1 Practical Configuration

The practical set up is made up of a Siemens DC motor controlled by a 3-Phase Sinamics DCM DC converter for four quadrant operation. The DC motor is connected to the AC induction motor via a belt and pulley system that acts as a variable load. The ac motor can vary the load by being controlled by a Siemens S120 AC drive. Using a PLC as a controller for the converters, the relevant information and controls are supplied by a T1200 comfort panel HMI, additionally a Pico-Scope was used externally from the system for values of armature voltage, line voltage, armature current and line current *Good explanation that includes good key points*

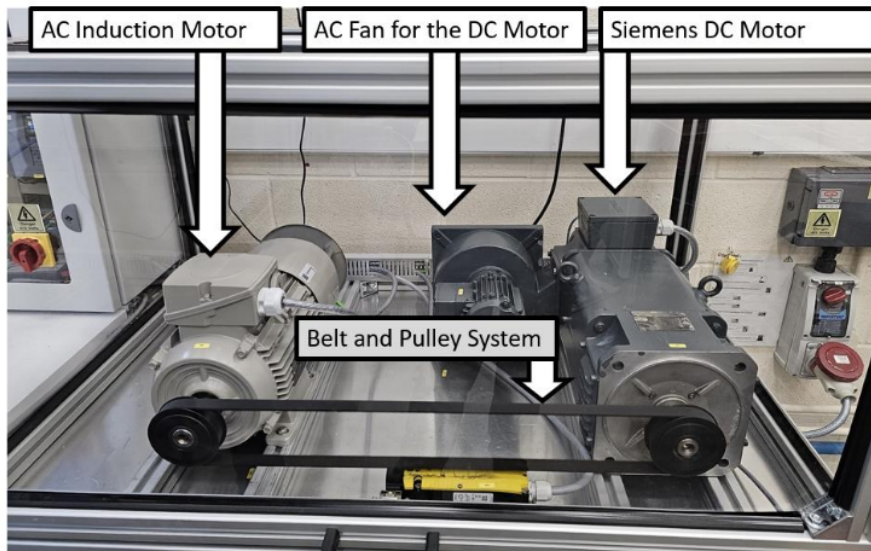


FIGURE 11; PRACTICAL SET UP

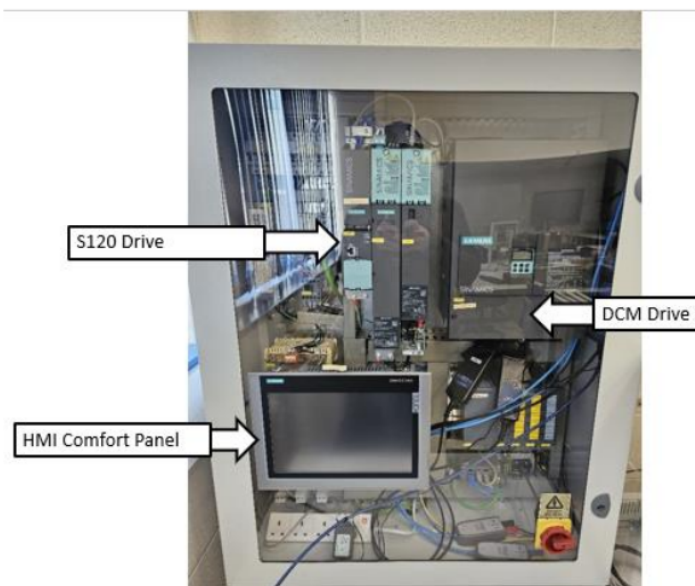


FIGURE 10; PRACTICAL PANEL SET UP

Good annotated images of test setup

Good evidence of test configuration

Using the auto function on the HMI, the quadrants were cycled through 1 to 4 with results being recorded on the Pico-Scope and HMI graph.

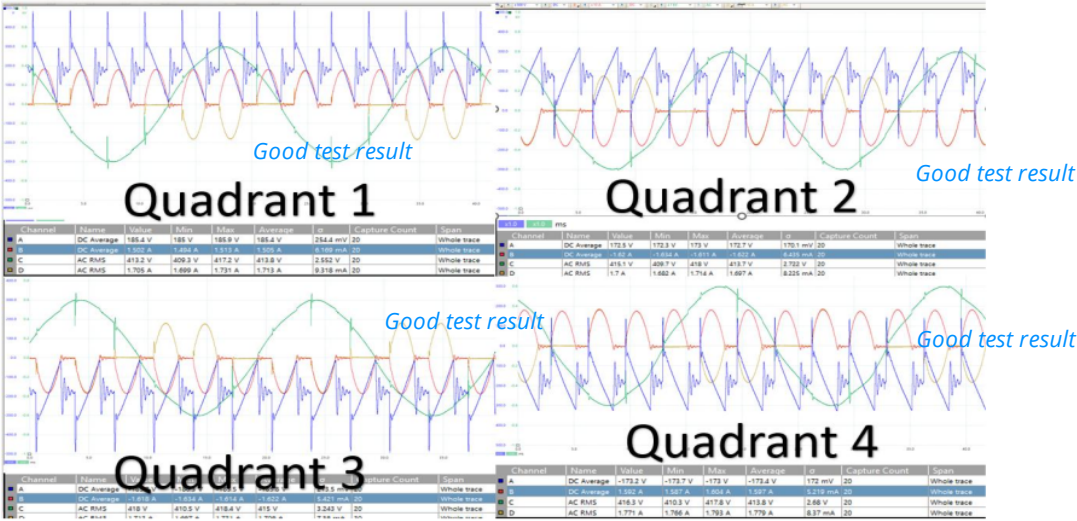


FIGURE 13; PICO-SCOPE 4 QUADRANTS

All 4 quadrants tested practically

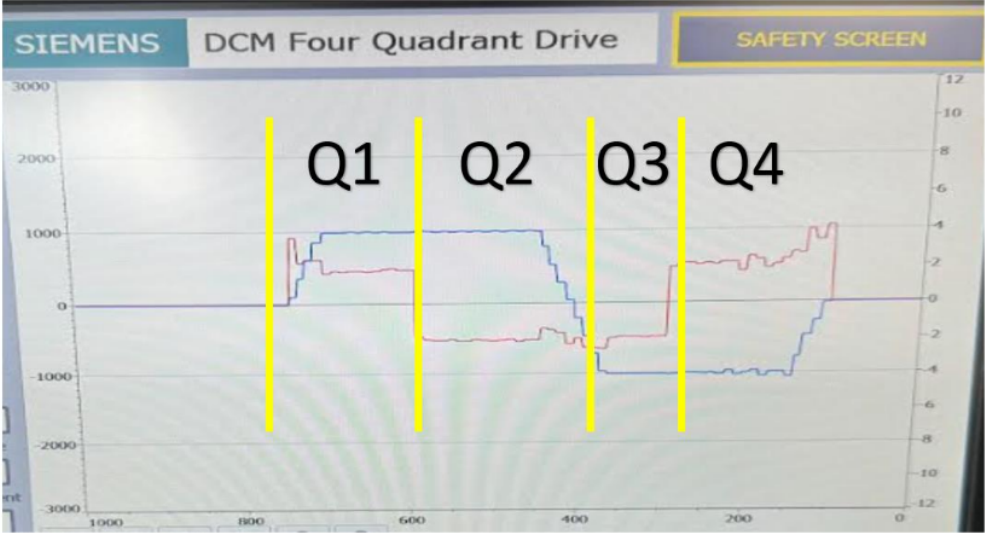


FIGURE 12; HMI 4 QUADRANTS

Excellent work here

Key		
Trace	Pico-Scope	HMI
Armature Voltage		
Armature Current		

TABLE 4; PICO-SCOPE & HMI KEY TRACE

Following practical task, results of specific values from each quadrant were recorded and compiled into the tables below.

4-Quadrant Operation		
Pico-Scope		
Quadrant	Armature Voltage (V)	Armature Current (A)
1	185.4	1.5
2	172.5	-1.62
3	-185.7	-1.6
4	-173.2	1.592

Good table of test results

TABLE 5; 4-QUADRANT OPERATION PICO-SCOPE RESULTS

4-Quadrant Operation						
HMI						
Quadrant	Armature Voltage (V)	Armature Current (A)	Firing Angle	EMF	Torque (Nm)	Speed (Rpm)
1	185.74	1.52	81	179.553V	2.09	999
2	172.86	-1.49	115	177.730V	-1.88	999
3	-185.72	-1.5	81	-179.38	-1.94	-1000
4	-172.87	1.57	115	-178	2.05	-1002

TABLE 6; 4-QUADRANT OPERATION HMI RESULTS

Good detailed tables of results

In quadrant 1, the Pico-scope and HMI shows both armature voltage and current positive which indicates that the motor is forward motoring. Additionally, the firing angle is less than 90 degrees with positive torque and positive speed.

In quadrant 2 the Pico-scope and HMI shows that armature voltage is positive but armature current is now negative, which means the DC motor is forward braking. Additionally, the firing angle is more than 90 degrees with negative torque and positive speed.

In quadrant 3 the Pico-scope and HMI show that both armature voltage and armature current are negative, meaning that the system is reverse motoring. Additionally, the firing angle is less than 90 degrees with negative torque and negative speed.

In quadrant 4 the Pico-Scope and HMI show that armature voltage is negative and armature current is positive, indicating the system is reverse generating. Additionally, the firing angle is more than 90 degrees with positive torque and negative speed.

Good explanations of results

Error Between Measurements (Pico-Scope Versus HMI)		
Quadrant	Armature Voltage (V)	Armature Current (A)
1	0.34	0.2
2	0.36	0.13
3	0.2	0.1
4	0.33	0.02

Good attention to detail here

TABLE 7; ERROR BETWEEN MEASUREMENTS

It can be seen that there is little error between the two measurements, however the Pico-Scope provides less information due to the amount of measuring instruments implemented. *Good point*

5.2 Motor Constants

Using the cursors on the Pico-Scope armature voltage and current can be measured to calculate motor constants.

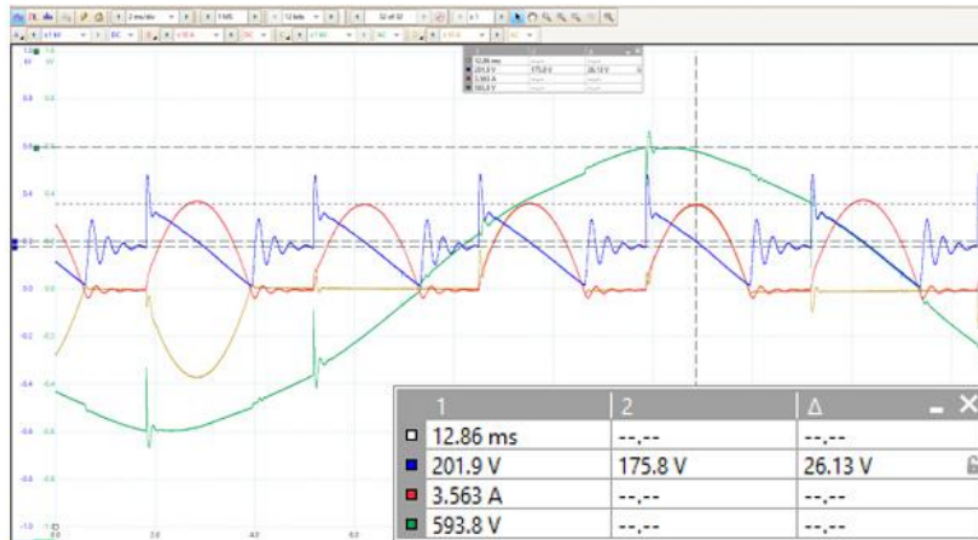


FIGURE 14; PICO-SCOPE MOTOR CONSTANT

Good test evidence with test results needed for calculations

Dynamic Resistance:

$$V_a = E + I_a R_a + L \frac{Di}{Dt}$$

Formula is identified

$$\text{Using Peak Current, } L \frac{Di}{Dt} = 0$$

Good work here

Re-arranging the equation to find armature resistance:

$$R_a = \frac{V_a - E}{I_a} = \frac{185.74 - 179.5}{1.52} = 4.1 \text{ Ohms}$$

Ra value is identified through calc

This equation can be proved by substituting Ra into the original equation to confirm the armature voltage 185V

$$V_a = 179.8 + (1.52 \times 17.19) = 186V$$

Good work

Using the values from the HMI seen in Figure 15, other constants can be calculated.

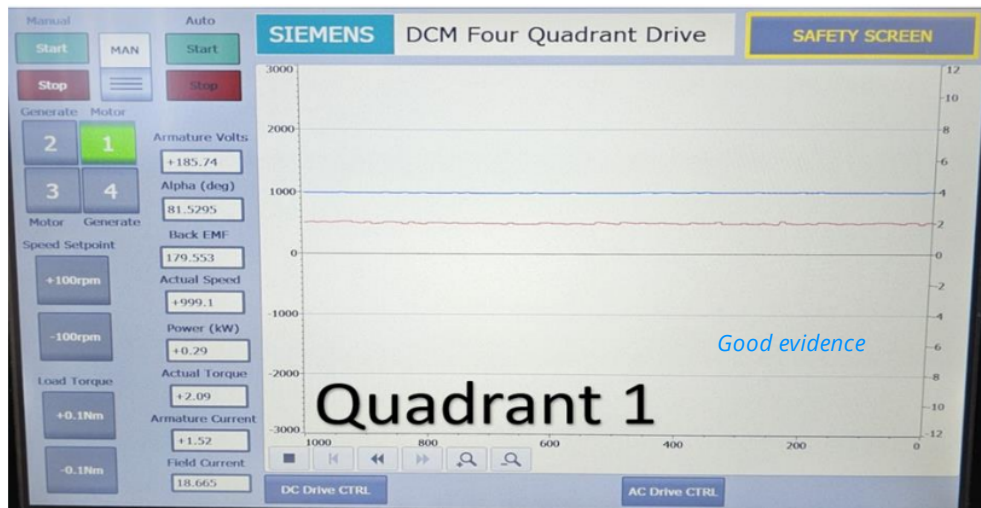


FIGURE 15; HMI MOTOR CONSTANT

Motor torque constant:

$$K_t = \frac{T}{I_a} = \frac{2.09}{1.52}$$

Motor Back EMF:

$$K_e = \frac{E_a}{w}$$

Where w:

$$w = \frac{Rpm}{2\pi} = \frac{999.1}{2\pi} = 159$$

Therefore Ke:

$$K_e = \frac{E_a}{w} = \frac{999.1}{159} = 6.28V/Krpm \quad \text{Good work}$$

5.2 3 Setpoint Speed at Constant Torque
Discontinuous

Further experimentations were carried out by setting 3 setpoints of speed at constant torque. The 3 setpoints that determined were 1200, 1600 and 2000rpm. The speed setpoints were controlled by the HMI by increasing the setpoint in steps of +100rpm. This will provide data from the HMI and Pico-scope to see the relationships between characteristics.

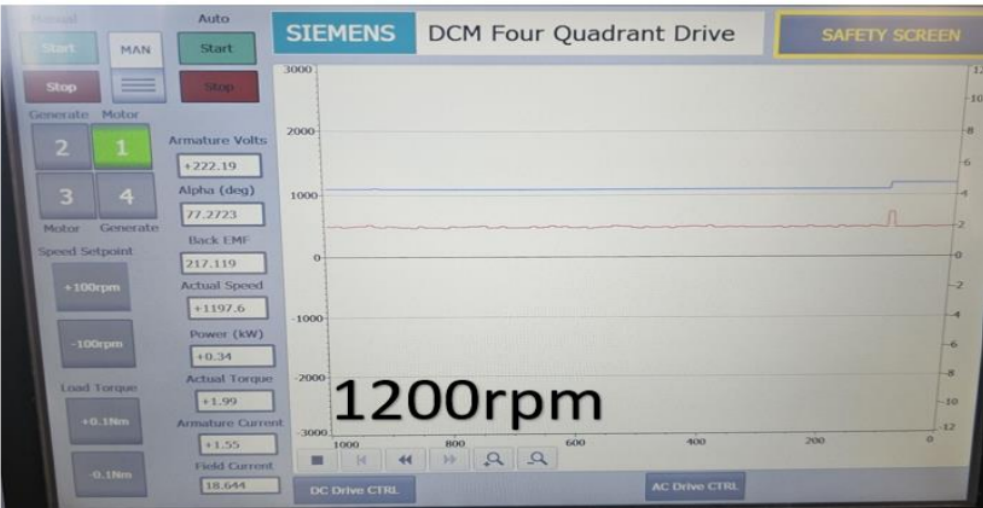


FIGURE 16; SPEED 1200RPM HMI

Good test result

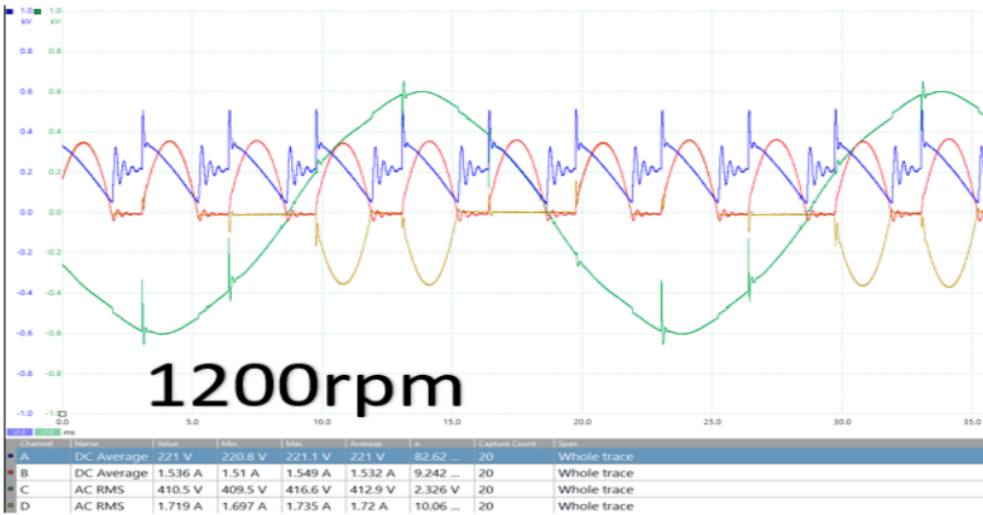


FIGURE 17; SPEED 1200RPM PICO-SCOPE

Further images of the HMI and Pico-Scope for setpoints 2 and 3 can be seen in Figure 36, Figure 37, Figure 38 and Figure 39

Good ref to evidence in appendix

From carrying out the three tests, the results were compiled into the table below.

3 Speed Setpoints at Constant Torque						
Motor Parameters	Speed Test 1 1200		Speed Test 2 1600		Speed Test 3 2000	
Recorder	HMI	PicoScope	HMI	PicoScope	HMI	PicoScope
Armature Voltage (Va)	222.19V	221V	294.78V	296.V	363.89V	365.3V
Firing Angle	77.27		63.11		53.14	
Back EMF E	217.12		236.87		357.64	
Speed (RPM)	1197.6		1598.7		2002	
Power (kW)	0.34		0.55		0.56	
Actual Torque (Nm)	1.99		2.03		1.62	
Armature Current (Ia)	1.55	1.54	1.21	1.31	1.47	1.5
Field Current (If)	18.644		18.66		18.647	

TABLE 8; 3 SPEED SETPOINTS AT CONSTANT TORQUE RESULTS

Excellent detailed table of results

Analysing the table, it can be seen that when the speed was increased, the armature voltage increased. This is important because the voltage needs to overcome the back EMF generated by the armature and maintain the setpoint. *Good key point*

It can be seen that the firing angle decreases with each increased setpoint, this allows more power to be delivered to the motor, thus increasing the speed. The power is directly proportional to the armature voltage and armature current, meaning as the speed increased the voltage increases, leading to more power consumption. *Good point*

*Firing angle
relevance is
identified*

The armature current and field current remained consistent with each setpoint change, and is influenced by the torque, from this it can be seen that due to the constant torque, there was little increase meaning current was not needed to generate more torque. The variation of the current is due to the loading effect which is representative of a dc motor. *Excellent point made*

Lastly, it can be said that the system was in forward motoring (quadrant 1) with positive armature voltage and positive armature current with a firing angle less than 90 degrees.

Good detailed explanation

5.3 Discontinuous Calculations

$$V_{mean} = \frac{\text{Area A} + \text{Area B}}{\frac{\pi}{3}}$$

Formula derived from waveforms

Area A:

$$\text{Area A} = E \times Y = \left[\alpha - \frac{\pi}{3} \right]$$

$$\text{Area B} = V_{max} \int_{\frac{\pi}{3} + \alpha}^{\pi} \sin(\theta) d\theta$$

$$V_{max} = [-\cos(\theta)]_{\frac{\pi}{3} + \alpha}^{\pi}$$

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

Using the rule $\cos(A + B) = \cos A \cdot \cos B - \sin A \cdot \sin B$

$$\text{If, } \cos \pi = -1$$

$$\sin \pi = 0$$

$$\cos \frac{\pi}{3} = \frac{1}{2}$$

$$\sin \frac{\pi}{3} = \frac{\sqrt{3}}{2}$$

$$\text{Therefore : } \cos\left(\frac{\pi}{3} + \alpha\right) = \cos\left(\frac{\pi}{3}\right) \cdot \cos \alpha - \sin\left(\frac{\pi}{3}\right) \sin \alpha$$

$$= \frac{1}{2} \cos \alpha - \frac{\sqrt{3}}{2} \sin \alpha$$

$$V_{max} [(-1) - (-\frac{1}{2} \cos \alpha - \frac{\sqrt{3}}{2} \sin \alpha)]$$

Area B:

$$\text{Area B} = V_{max} [1 + \frac{1}{2} \cos \alpha - \frac{\sqrt{3}}{2} \sin \alpha]$$

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

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

Good work

Setpoint 1, Armature voltage = 222.19V

E = 217.12V

Alpha = 77.27

Converting degrees to radians = $77.27 \times \frac{\pi}{180} = 1.35 \text{ rad}$

Vmax = 591V

$$V_{mean} = \frac{3}{\pi} \{217.12 \times (1.35 - \frac{\pi}{3})\} + 591[1 + \frac{1}{2} \cos(1.35) - \frac{\sqrt{3}}{2} \sin(1.35)]$$

$$V_{mean} = 232.54V$$

Good work

Setpoint 2, Armature voltage = 294.78V

E = 236.87V

Alpha = 63.11

Converting degrees to radians = $63.11 \times \frac{\pi}{180} = 1.1 \text{ rad}$

Vmax = 591V

$$V_{mean} = \frac{3}{\pi} \{236.87 \times (1.1 - \frac{\pi}{3})\} + 591[1 + \frac{1}{2} \cos(1.1) - \frac{\sqrt{3}}{2} \sin(1.1)]$$

$$V_{mean} = 294.68V$$

Good work

Setpoint 3, Armature voltage = 363.89V

E = 357.64

Alpha = 53.14

Converting degrees to radians = $53.14 \times \frac{\pi}{180} = 0.92 \text{ rad}$

Vmax = 591V

$$V_{mean} = \frac{3}{\pi} \{357.64 \times (0.92 - \frac{\pi}{3})\} + 591[1 + \frac{1}{2} \cos(0.92) - \frac{\sqrt{3}}{2} \sin(0.92)]$$

$$V_{mean} = 336.27V$$

Good work

5.3 Torque Setpoints at Constant Speed

The system was then ran at 3 different setpoints of torque at a constant speed. The setpoints that were chosen were 2.5, 4 and 5.5Nm. Using the HMI and Pico-Scope values and wave forms were recorded as shown below. *Good explanation of test*



FIGURE 18; TORQUE 2.5Nm HMI



FIGURE 19; TORQUE 2.5 PICO-SCOPE

Setpoints 2 and 3 can be seen in the appendix under Figure 40, Figure 41, Figure 42 and Figure 43

Good test result and ref to test evidence in appendix

The results gathered from the 3 setpoints were compiled into a table.

3 Torque Setpoints at Constant Speed						
Motor Parameters	Torque Test 1 2.5Nm		Torque Test 2 4Nm		Torque Test 3 5.5Nm	
Recorder	HMI	PicoScope	HMI	PicoScope	HMI	Picoscope
Armature Voltage (Va)	366.37V	363.9V	370.1V	368.3V	373.1V	370.9
Firing Angle α	55.28		50.84		47.1	
Back EMF E_b	357.27		356.77		353.894	
Speed (RPM)	1909.7		2002		2002	
Power (kW)	0.59		1.1		1.58	
Actual Torque (Nm)	2.48		4.05		5.42	
Armature Current (Ia)	1.99	1.923	3.08	3	4.13	4.17
Field Current (If)	18.76		18.03		18.639	

TABLE 9; 3 TORQUE SETPOINTS AT CONSTANT SPEED RESULTS

Excellent work here

Analysing the table, it can be seen that when the torque setpoints were increased, the armature current increased. The armature voltage increased slightly to provide the additional torque, this increased not to increase the torque specifically but to maintain the constant speed setpoint while the torque is increased. The back emf increased slightly, this is due to the speed setpoint overshooting. In an absolute situation the back emf, armature voltage and speed would stay consistent. *Good point*

Excellent work here

6. Conclusions and Recommendations

This assignment has researched four quadrant drives, suitable drives in relation to specification and drives that can be used for different applications. By compiling theory of how a DC drive operates within 4 quadrants, it was then applied to a simulation.

Creating the design of the simulation allowed the student to demonstrate the operation of a full bridge converter, firing angles and waveforms. Adapting the circuit to be able of operating as a four-quadrant device meant that it had to be converted to a dual converter. This was done by adding an additional bridge with transformers to isolate the circuits and an RC snubber circuit to prevent voltage spikes. *Good work here. The key elements in the tasks have been identified*

Using the oscilloscopes allowed the student to analyse and comment on the 4-Quadrants, where the following summary can be made:

- Quadrant 1- Forward Motoring ; Positive Voltage & Positive Current
- Quadrant 2 – Forward Generating ; Positive Voltage & Negative Current
- Quadrant 3 – Reverse Motoring ; Negative Voltage & Negative Current
- Quadrant 4 – Reverse Generating; Negative Voltage & Positive Current *Good work*

It was established that the design was accurate in relation to the research.

Using a firing angle of 0, the V_{mean} of each firing angle increase of the setpoint could be calculated. This showed that as the firing angle increased, the V_{mean} decreased *Good key point*

A practical investigation was carried out on the system. Firstly, the 4 quadrants were identified by using the HMI and Pico-scope. Using values from this test, motor constants were calculated and proved. By determining 3 setpoints of speed and showed the relationship between the characteristics. It can be said that when the speed was increased, armature voltage increased while the firing angle decreased applying more power to the motor. Whereas in the 3 setpoints of torque, when increased the armature current increased. *Good points identified*

Additionally, discontinuous current calculations were carried out from the data on the HMI and Pico-Scope for the setpoints of speed. It resulted in showing the relationship between speed and V_{mean} voltage. From this it can be said that as the speed increased, the V_{mean} voltage increases.

In conclusion, it can be seen that the research simulation and practical investigation were successful. This is determined by comparing theory to the simulation and practical where values were compared within tables.

The recommendations could for further learning in the future, could be calculations in relation to the torque setpoints. By carrying out a further analysis of the torque would allow the system to be compared to theoretical values. *This is further investigation using same methods*

Integrating a power meter, further measurements such as a could allow the student to analyse the power consumption during speed and torque setpoints. This would allow the student to gain an insight into the systems efficiency, losses and how it could be optimised. Additionally, these practical results could be compared to theoretical values. *This is a good recommendation*

Lastly, using field current manipulation to test and control the motor speed. This would be done by adjusting the field resistance and observing the motors characteristics which could further investigate into the motor's relationship between field current, speed and torque. *This is another good recommendation to further parameter manipulation for speed control*

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Good number of ref sources

8. Appendix

Risk Assessment for Practical Investigation

Facility / Activity	Identify the hazards	Who/what may be harmed	Risk likelihood	Severity of harm	Overall risk	Existing control measures	Recommendations/ further action required
Engineering Classroom / Practical Investigation/ Siemens Three-Phase DCM drive; Siemens S120 AC Drive	Electrical Shock	Students; Lecturers	Low	High	Low	Electrical Panel is locked with no access for students or Lecturers, appropriate safety circuits are in place & grounding.	Inspect equipment before testing and report any damages of defects.
	Trips, Slips & Falls	Students; Lecturers	Medium	Low	Low	Signs for keeping a clean work place.	Inspect walk ways before entering the area.
	Flying Objects	Students; Lecturers	Low	Medium	Low	Motors and belt are contained behind clear plastic guards and have interlocks to prevent them being opened while system is active.	//

Good work here with colour coded levels of risk

FIGURE 20; RISK ASSESSMENTS FOR PRACTICAL INVESTIGATION

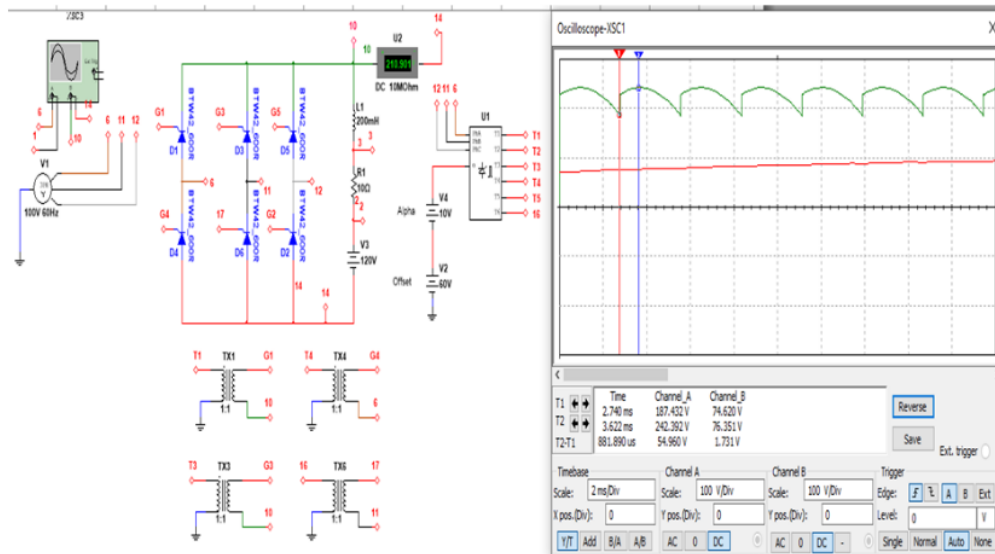


FIGURE 21; ARMATURE MEAN VOLTAGE SIMULATED (V) A = 10

Good evidence

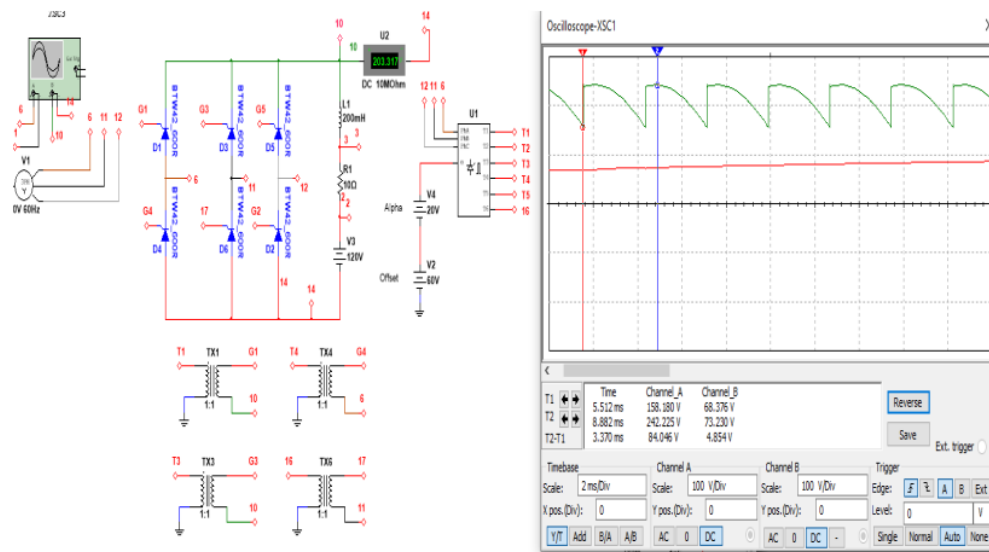


FIGURE 22; ARMATURE MEAN VOLTAGE SIMULATED (V) A =20

Good evidence

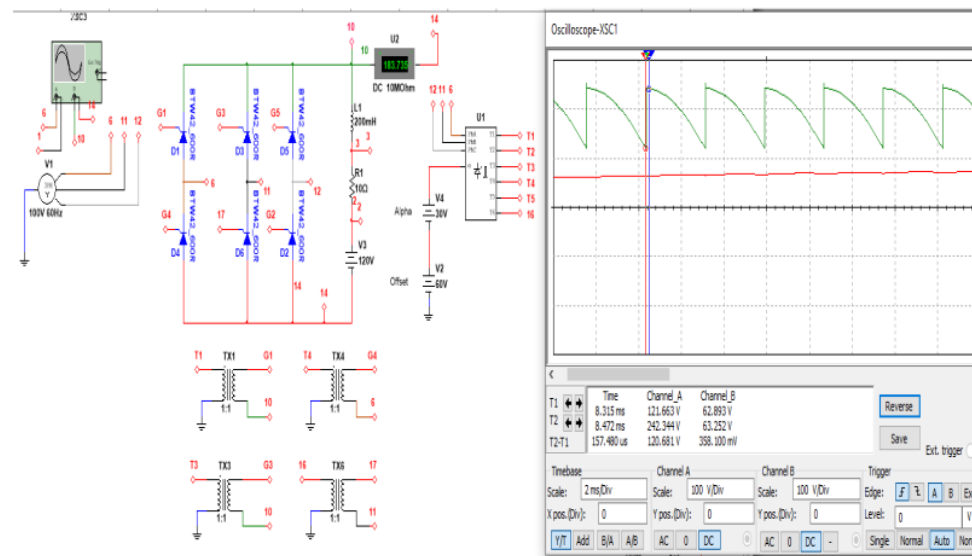


FIGURE 23; ARMATURE MEAN VOLTAGE SIMULATED (V) A =30

Good evidence

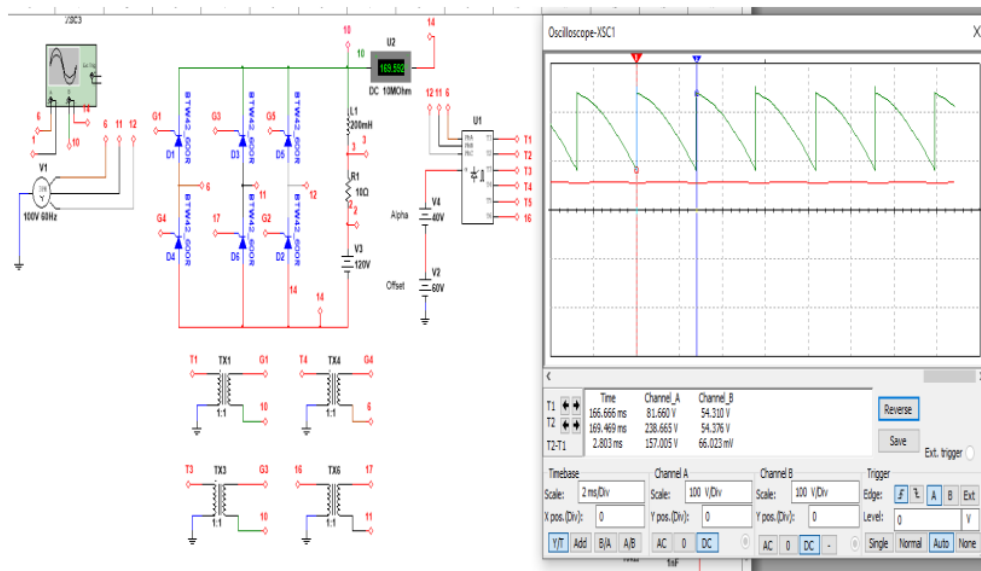


FIGURE 24; ARMATURE MEAN VOLTAGE SIMULATED (V) A =40

Good evidence

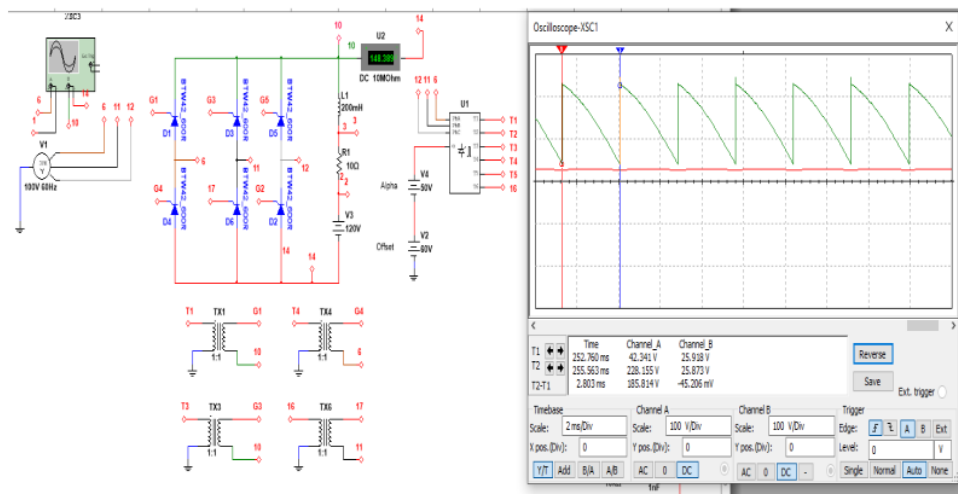


FIGURE 25; ARMATURE MEAN VOLTAGE SIMULATED (V) A =50

Good evidence

Some of the value for armature voltages are not consistent with results in table, however, this can be due to timing of the screen shot

There should be a heading here



FIGURE 26; DUAL CONVERTOR QUADRANT 1



FIGURE 27; DUAL CONVERTOR QUADRANT 2

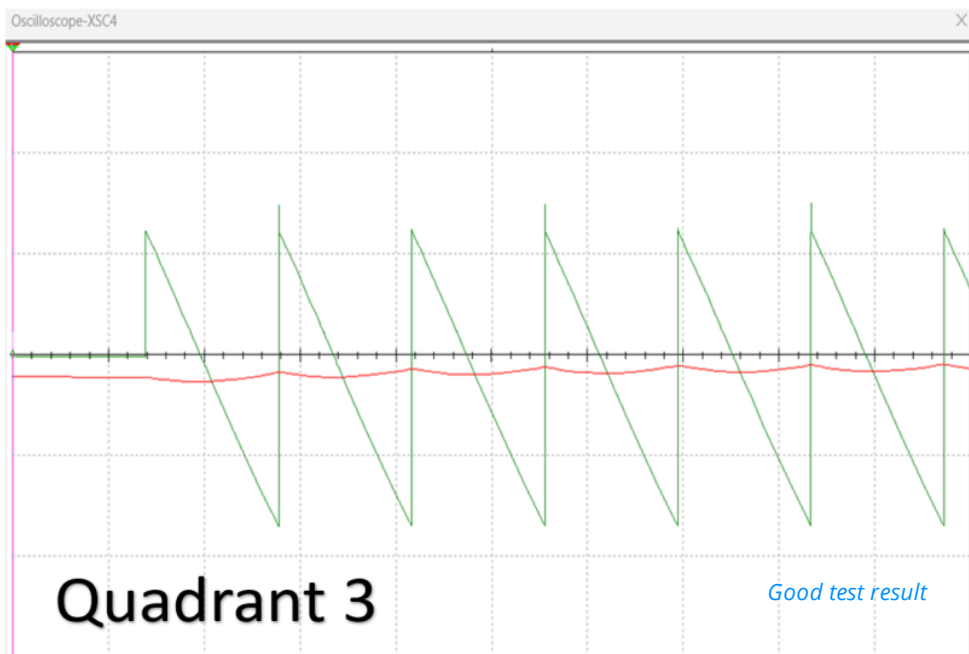


FIGURE 28; DUAL CONVERTOR QUADRANT 3



FIGURE 29; DUAL CONVERTOR QUADRANT 4

All 4 quadrants are tested

Heading needed

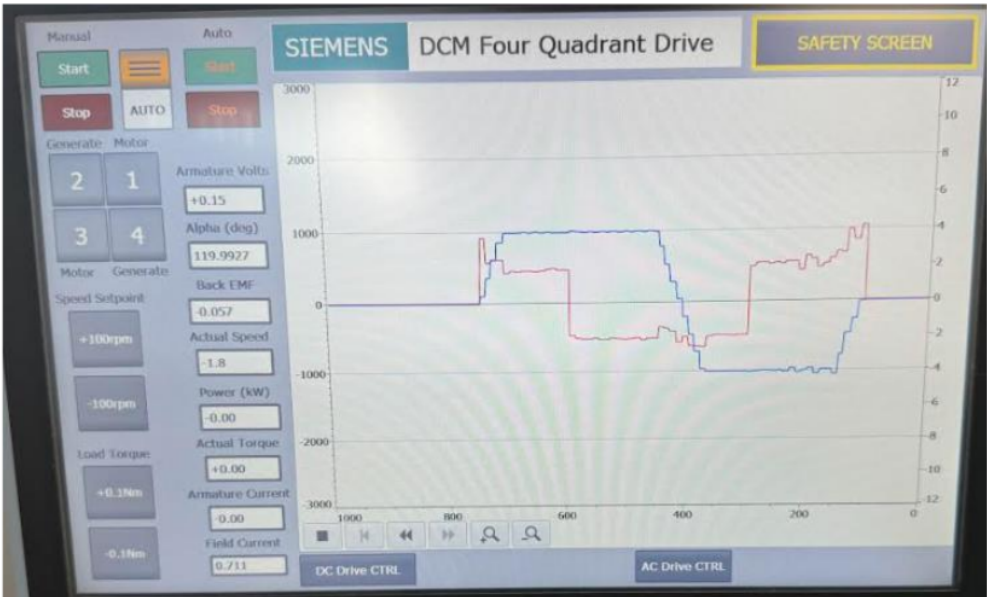


FIGURE 31; 4 QUADRANT OPERATION PRACTICAL AUTO

Technical Data

Protection	High energy MOV's Heatsink overtemperature Instantaneous overcurrent Thyristor trigger failure Inverse time overcurrent Interline snubber network Field Failure Zero speed detection Speed feedback failure Stall protection Motor overtemperature
Inputs/Outputs	
Analogue inputs	(5 Total - 1 x 12 bit plus sign, 4 x 10 bit plus sign) 1 - Speed demand setpoint (-10/0/+10 V) 4 - Configurable
Analogue outputs	(3 Total - 10 bit) 1 - Armature current output (-10/0/+10 V or 0-10 V) 2 - Configurable
Digital inputs	(9 Total - 24 V, max 15 mA) 1 - Program stop 1 - Coast stop 1 - External stop 1 - Start/Run 5 - Configurable
Digital outputs	(3 Total - 24 V (max 30 V) 100 mA) 3 - Configurable
Reference supplies	1 - +10 VDC 1 - -10 VDC 1 - +24 VDC

This is good, but in the wrong place. This belongs with the research content.

FIGURE 30; DC590 TECHNICAL DATA

Heading needed here

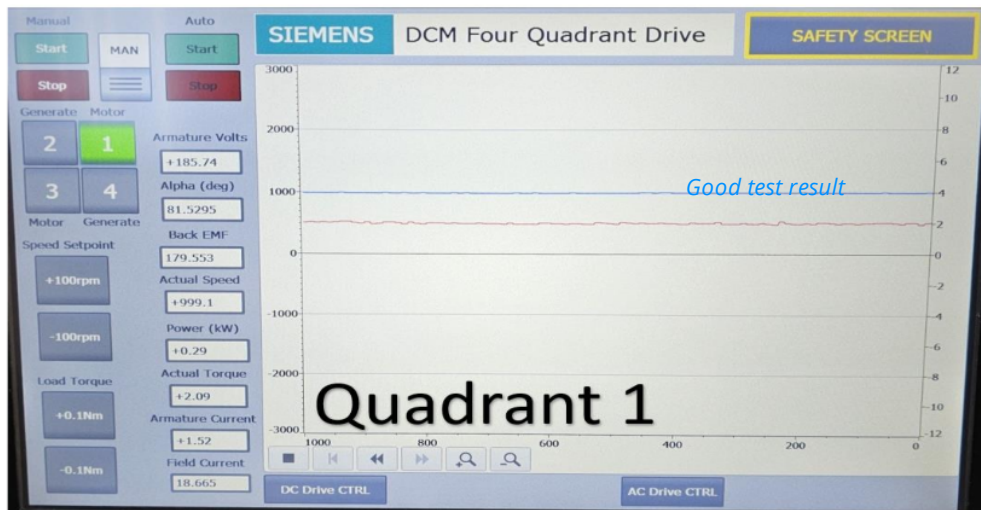


FIGURE 32; PRACTICAL INVESTIGATION QUADRANT 1

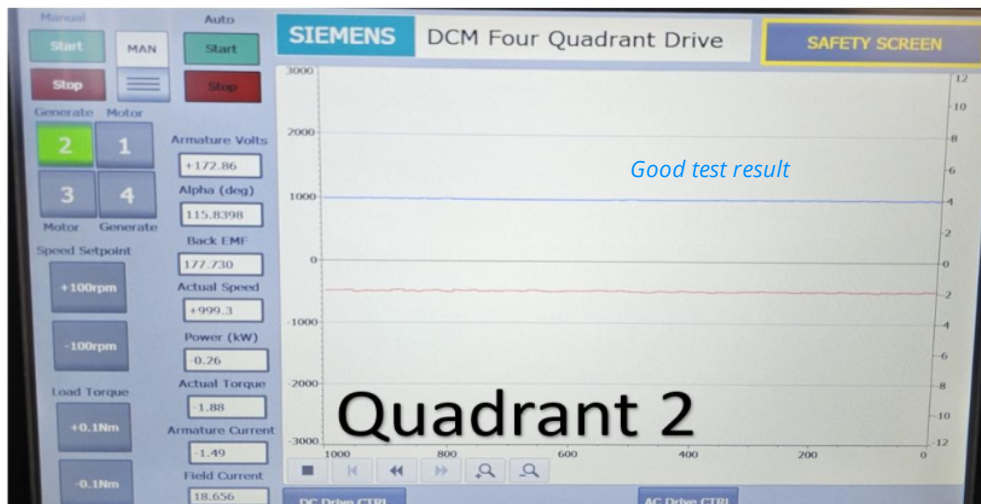


FIGURE 33; PRACTICAL INVESTIGATION QUADRANT 2

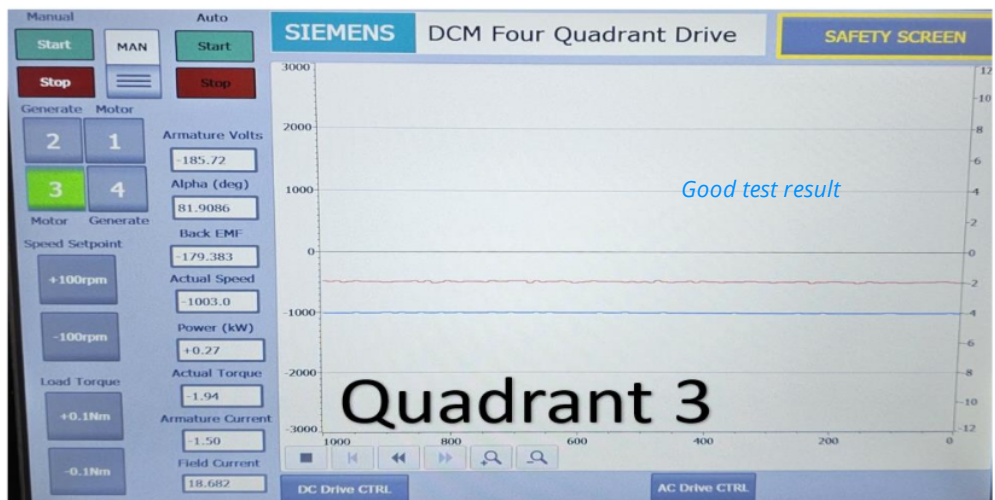


FIGURE 34; PRACTICAL INVESTIGATION QUADRANT 3

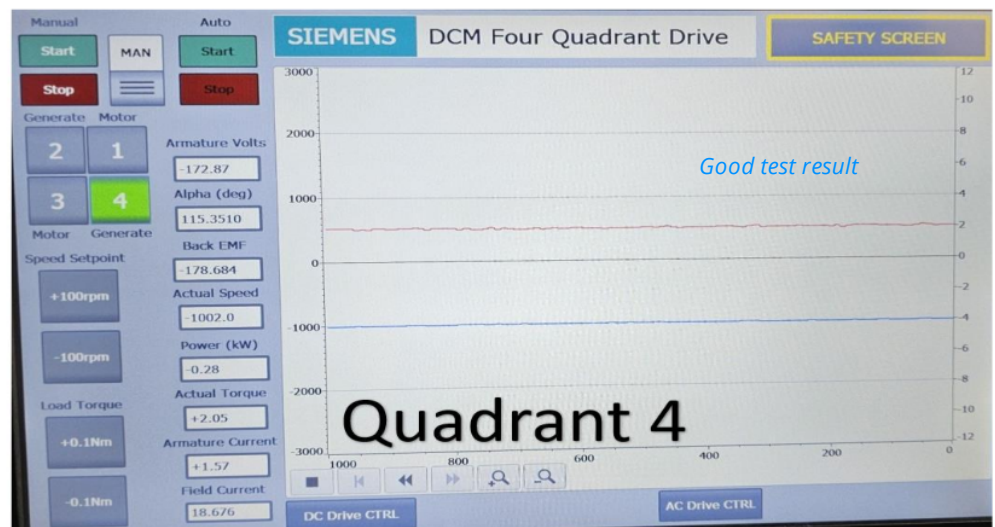


FIGURE 35; PRACTICAL INVESTIGATION QUADRANT 4

Good individual test evidence for all 4 quadrants

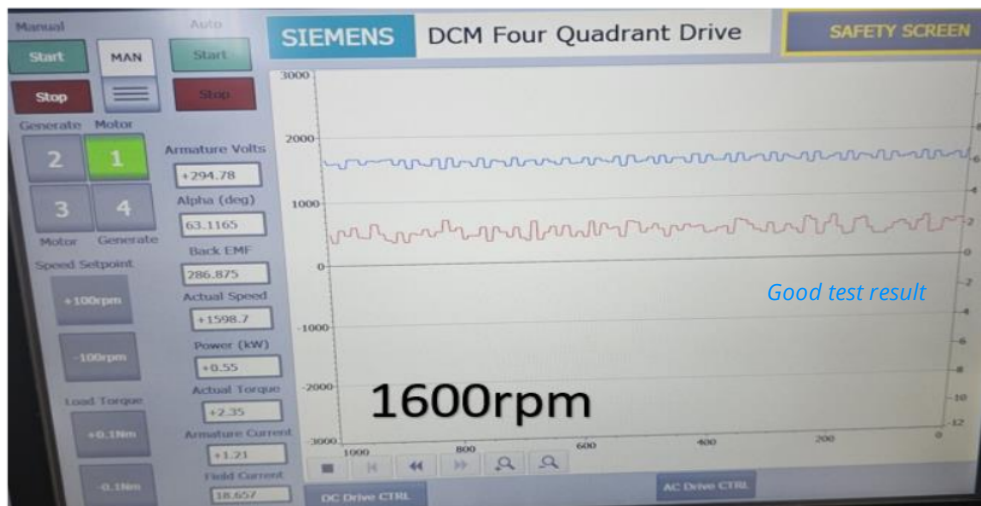


FIGURE 36; SPEED SETPOINT 1600 HMI

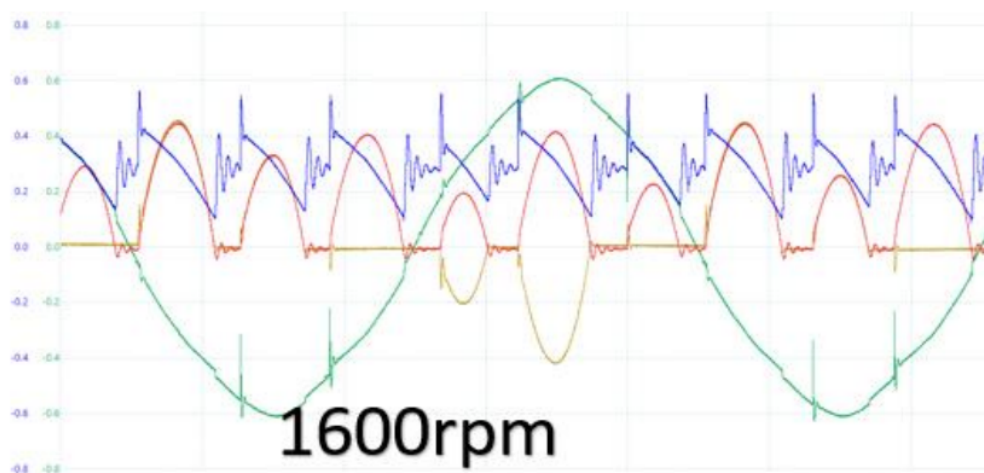


FIGURE 37; SPEED SETPOINT 1600 PICO-SCOPE

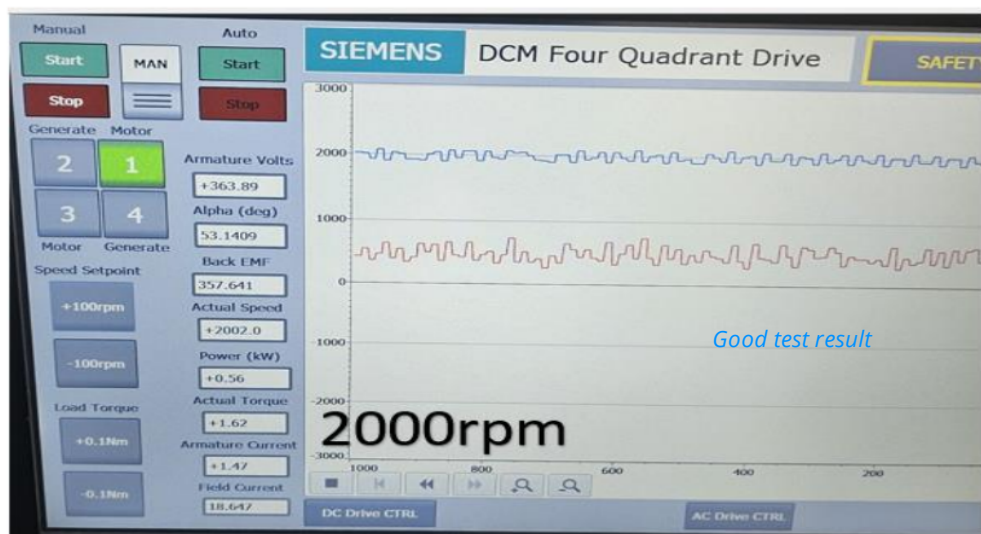


FIGURE 38; SPEED SETPOINT 2000 HMI

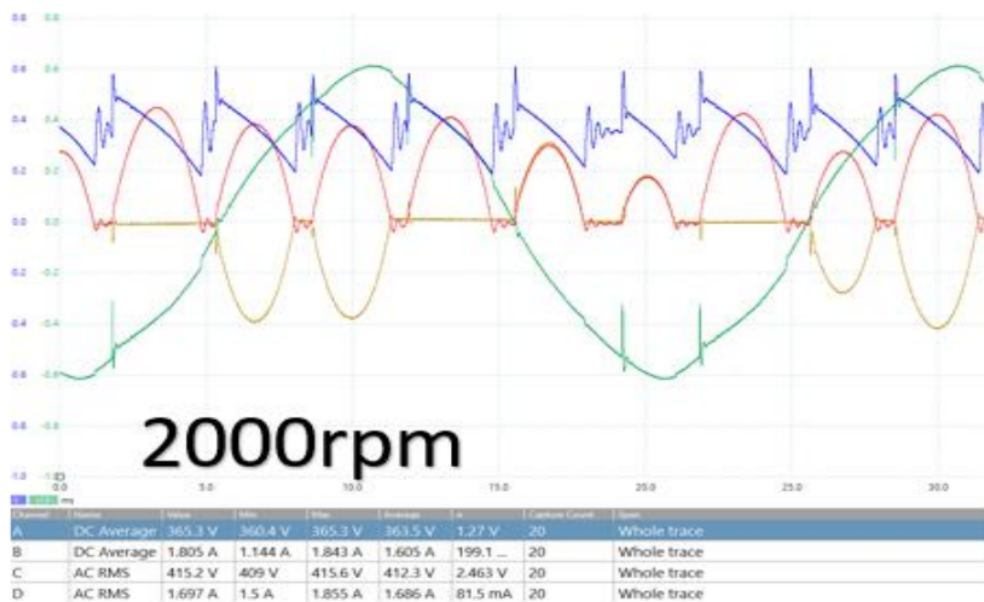


FIGURE 39; SPEED SETPOINT 2000 PICO-SCOPE

Heading needed here

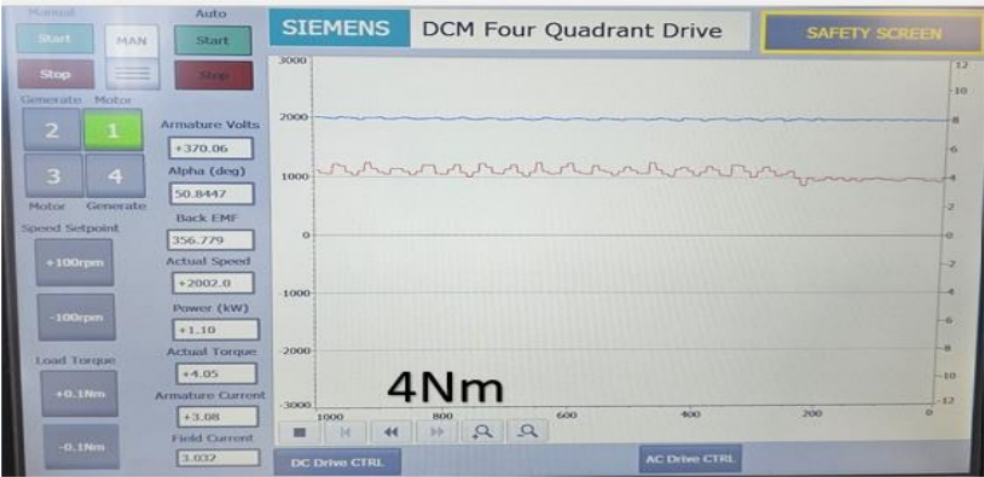


FIGURE 40; TORQUE SETPOINT 4NM HMI

Good test result

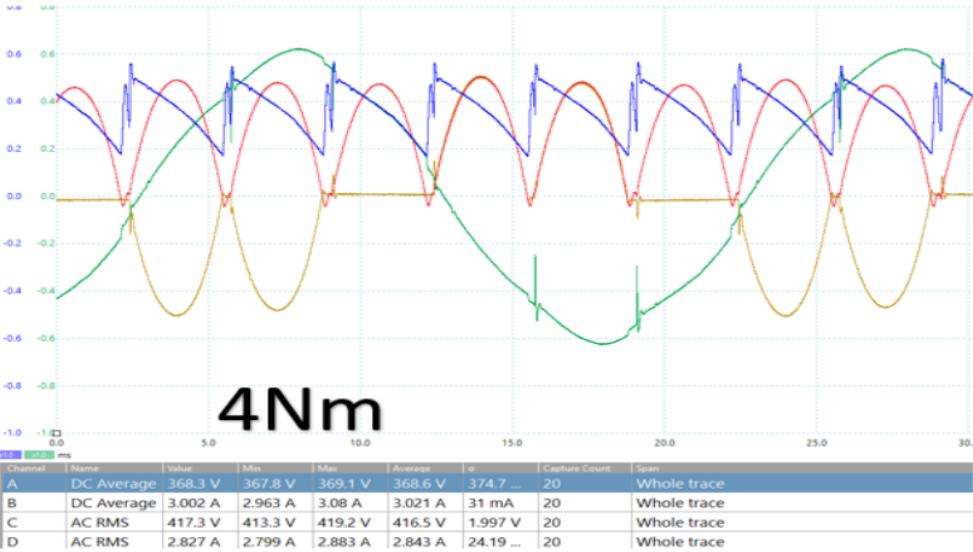


FIGURE 41; TORQUE SETPOINT 4NM PICO-SCOPE

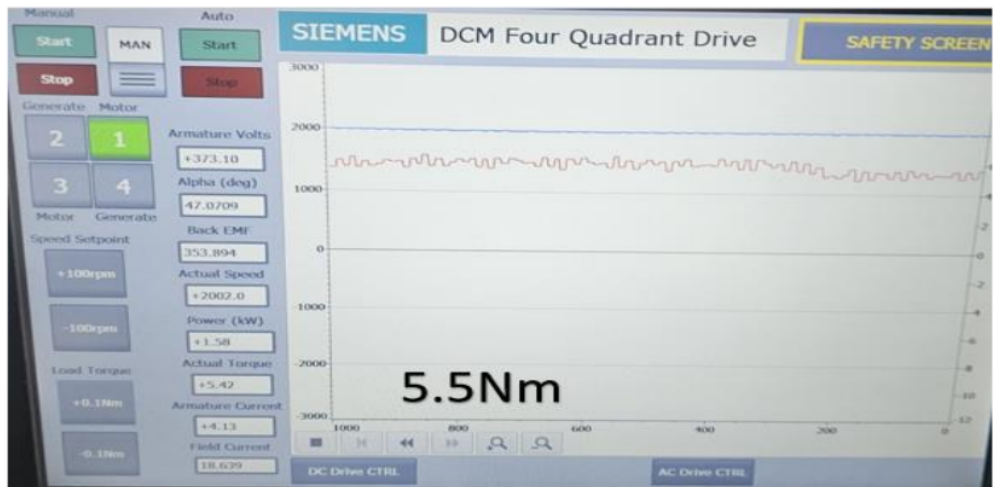


FIGURE 42; TORQUE SETPOINT 5.5Nm HMI

Good test result

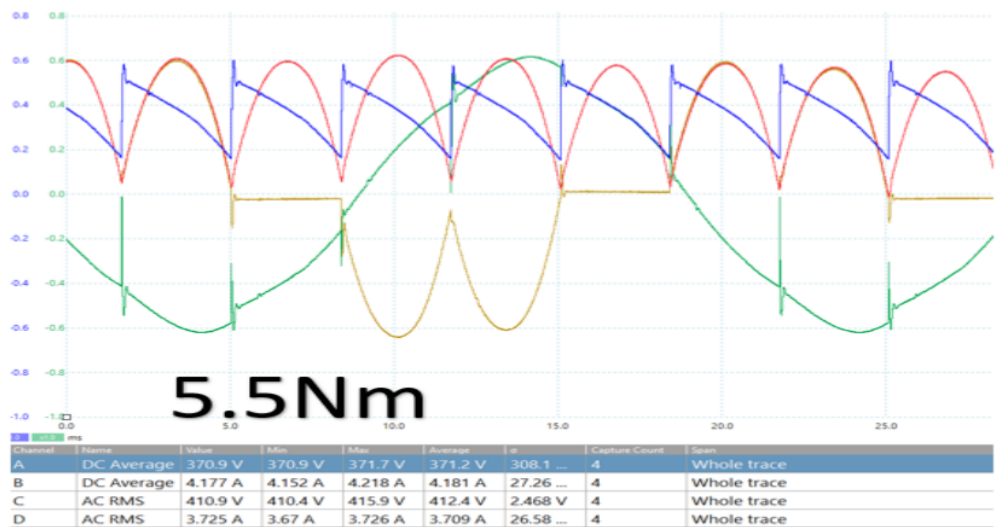


FIGURE 43; TORQUE SETPOINT 5.5Nm PICO-SCOPE

79/100

PAGE 1

PAGE 2

Text Comment. Good detailed table of contents

PAGE 3

Text Comment. Good extensive list of figures with good relevant identification

PAGE 4

Text Comment. Good use of tables

PAGE 5

Text Comment. Good point with dual converter

Text Comment. Good point

Text Comment. Good work here

Text Comment. The summary demonstrates an understanding of requirements for the tasks

PAGE 6

Text Comment. A very detailed work plan. Good work

Text Comment. Good points covered here

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Text Comment. Good explanation and good relevant diagram

Text Comment. Good explanation with key points included

Text Comment. Good point

Text Comment. Good explanation with good supporting diagram

Text Comment. The need for dual converters is identified

Text Comment. Excellent work here

Text Comment. Key points identified

Text Comment. Fig 4

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Text Comment. Good key parameters from spec covered.

Text Comment. Very good relevant diagram

Text Comment. Good explanation

Text Comment. Good key points included

Text Comment. Good explanation of control loops with good relevant diagram

PAGE 12

Text Comment. Good identification of application

Text Comment. Good points covered

Text Comment. Good relevant diagram

Text Comment. The applications are very good, however, the comparisons are not included. The chopper fed drive and single phase converters should be included for comparison

PAGE 13

Text Comment. Good key points identified here

Text Comment. 60V 60 degrees due to the NI multisim software. In practice this would not be necessary

Text Comment. Good key points

Text Comment. Good explanation of test circuit

Text Comment. Very good annotated circuit diagram

Text Comment. Good work here

PAGE 14

Text Comment. 60V

Text Comment. Formula is identified

Text Comment. Excellent work

PAGE 15

Text Comment. Good use of table of results to evaluate outcomes and good ref to evidence figures

Text Comment. Some of these value do not quite match the results in the evidence in the appendix, but the errors are relatively small

PAGE 16

Text Comment. Key point identified

Text Comment. Statement not needed

Text Comment. Good work

Text Comment. Very good annotated circuit diagram with all key components identified

Text Comment. Excellent work here with ref to test evidence in appendix

PAGE 17

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Text Comment. Good evidence of test configuration

PAGE 18

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Text Comment. Excellent work here

PAGE 19

Text Comment. Good table of test results

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PAGE 20

Text Comment. Good test evidence with test results needed for calculations

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PAGE 21

Text Comment. Good evidence

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PAGE 22

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PAGE 23

Text Comment. Excellent detailed table of results

Text Comment. Good key point

Text Comment. Firing angle relevance is identified

Text Comment. Good point

Text Comment. Excellent point made

Text Comment. Good detailed explanation

PAGE 24

Text Comment. Formula derived from waveforms

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PAGE 25

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Text Comment. Good work

PAGE 26

Text Comment. run

Text Comment. Good explanation of test

Text Comment. Good test result

Text Comment. Good test result and ref to test evidence in appendix

PAGE 27

Text Comment. Excellent work here

Text Comment. Good point

Text Comment. Excellent work here

PAGE 28

Text Comment. Good work here. The key elements in the tasks have been identified

Text Comment. Good work

Text Comment. Good key point

Text Comment. Good points identified

Text Comment. This is further investigation using same methods

Text Comment. This is a good recommendation

Text Comment. This is another good recommendation to further parameter manipulation for speed control

PAGE 29

Text Comment. Good number of ref sources

PAGE 30

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PAGE 31

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PAGE 33

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Text Comment. Good individual test evidence for all 4 quadrants

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GRADING FORM: NEW CSG-RUBRIC

MATTHEW PERRY

0

1. ENGAGEMENT WITH LITERATURE

 Research is extensive with good quality ref sources used. The level of detail is excellent and demonstrates an understanding of requirements. There are excellent key technical features included with relevant diagrams.
The comparison part is missing

14/20

2. KNOWLEDGE AND UNDERSTANDING

 Good comparison to theory used in the explanations. Implementation methods are fully explained and excellent order.
Good comparison methods using tables are used for evaluation purposes. Simulated methods have been carried out successfully with very good technical explanations relating to theory.
Practical tasks have been carried out methodically and using detailed tables of results for evaluation.

17/20

Thorough testing has been carried out with an abundance of well presented evidence that is clearly referenced in appendix. The only criticism here is that there are sections that needed headings to identify some of the content in appendix.
An excellent level of understanding demonstrated.

3. COGNITIVE AND INTELLECTUAL



Simulation of full wave controlled rectification has been achieved and tests have been carried out. Tables of results have been presented in good order and results have been evaluated. The test evidence in appendix values were slightly different from the tabled results, this could have been explained.
Adapted sim cct test for 4 quadrant operation has been carried out and results evaluated against research findings.
All practical test requirements have been carried out, constant speed with discontinuous current and constant torque with continuous current. Results are presented using tables and explained in detail.
A very good conclusion that points out key features of the tasks carried out and the results. Good relevant recommendations are included. Results for sim and prac were compared to calculated values and tables used to present findings.

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4. PRACTICAL APPLICATION



Practical application of simulated ccts has been carried out using very good methods and real problems solved during implementation. Practical application showed initiative and evidence included demonstrates the initiatives with the tasks. Explanations are detailed for all practical tasks. Results were taken from a wide range of tests carried out for speed and torque.

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5. TRANSFERABLE SKILLS



A very good report with high level quality content. Some headings missing in appendix to identify content is the only criticism of the report layout. Very good use of tables and figures to support the report structure.

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