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Generally good, well structured and presented

Research shows understanding

Good simulations and practical work

Analysis and calculations are mostly good except for the value of V_{max} chosen

Good conclusions and recommendations

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1. Executive Summary

Research was conducted into the ABB DCS800 DC drive, where not only the design features of the drive was elaborated upon, but also the ancillary components needed for a DC drive operate in a safe, reliable and environmentally friendly manner. Understanding of the drive hardware and software packages, as well as communication protocols utilised indicated that the DCS800 is a robust and versatile asset for any prospective users.

Further research carried out showed that 4-quadrant operation can be achieved by using chopper drives when the supply voltage is DC. Single phase AC converters were found to be restricted to 15kW applications, due to susceptibility to ripple currents and harmonics.

Simulations were carried out using Multisim, where a DC drive was modelled utilising Thyristors coupled to a firing controller via pulse transformers and snubber circuits, whilst the system was supplied by a three-phase supply. Three different firing angles, which were 10°, 20° and 30° were chosen, to enable performance analysis whilst producing continuous current. Average armature voltage for the different phase angles were measured, where comparisons were carried out to calculated values.

The simulation circuit was modified by adding a second thyristor bridge in anti-parallel to the original bridge, which enabled simulations to be carried out in all four quadrants. Additionally, a back EMF polarity switch was constructed to enable negative EMF during operation in the 2nd and 3rd quadrants.

The practical experiment setup was elaborated upon, which concluded that the basic components required for 3-phase DC drive is universal, regardless of manufacturer. AC supply conditioning was present as well as DC motor protection, which protects the motor and control circuits, especially during regenerative operation.

Practical tests carried out with the drive operating in quadrant 1 with constant torque and varied speed as well as constant speed and varied torque enabled performance analysis to be carried out on the drive whilst producing continuous and discontinuous current.

Finally, conclusions were ascertained as well as an elaboration into how the team carried out the practical measurements on the system.

A good summary should made up of around 300 words. This is far in excess of that.

2. Research

2.1 Design Features and Control Techniques

The DCS800 drive is an AC/DC converter utilising controlled thyristors to achieve the required DC output characteristics and can be customised through the use of a “type designation” (appendix figure 1), which is used to select the correct drive for the intended application and whether 2 or 4-quadrant operation is required. The drive itself is called a power converter module and can be supplied as a fully assembled package, which is a complete pre-wired and pre-tested DC drive solution, with contactor, control transformer, fuses and power converter module installed on a panel, ready to be installed in a suitable enclosure. (ABB, 2016).

2.1.1 Ancillary System overview

Appendix figure 2 shows the system overview, including auxiliaries such as supply voltage conditioning and contactors illustrated. The DCS800 power converter modules are supplied in frame sizes D1 to D4 and D5 to D7, where D1 - D4 require separately mounted AC line fuses and D5 – D7 have internally mounted AC line fuses. Supply AC fuses, EMC filters and line reactor are a requirement for the safe and reliable operation of the drive. DC armature fuses are needed for all 4-quadrant drives (ABB, 2016).

AC and DC Contactor

Appendix figure 2 shows the AC and DC contactors controlled by the DCS800, both breakers can be forced to trip and provide feedback on whether in the open or closed position, which is utilised to generate fault signals in the event of issues with either breaker (ABB, 2016).

Contactors are electronic switching devices used to switch circuits on or off through the use of a relay. DC contactors have no inductance and can accommodate higher resistances, therefore functions as a magnetic arc extinguishing device, whereas AC contactors are designed to work at lower resistances and function as grid arc extinguishing devices (Electric, 2022).

DC Fusing

DC fusing, usually fast semiconductor fuses will melt in fractions of a second in the event of an over current situation which could be caused by a short circuit. The drive thyristors will have a very low tolerance to overcurrent situations, certain specified overloads can be tolerated for very short periods and only occasionally (Nicolai, 2018). Appendix figure 4 shows the meting characteristics of a semiconductor fuse. From this image it is clear that the arc integral, or arcing time, in addition to the melting time has to be noted and accounted for when selecting a suitable fuse (Nicolai, 2018).

EMC Filter

Where a larger horsepower drive is connected to a domestic supply (<500v) an EMC (electromagnetic compatibility) filter has to be installed between the supply and drive to ensure no unwanted disturbances or harmonics are injected back onto the grid (ABB, 2002). Product manufacturers intending to supply products to the UK market need to comply with the EMC regulations 2016 (Standards, 2021).

AC Line Reactor

Line reactors are inductors wired in series with the phase supply. Reactors are constructed with copper wound coils around electrical grade steel laminations and act as current limiters, usually with impedance ratings of 3% or 5%. As a device's full load rated current increases, or spikes, the line reactor impedance will increase, thereby slowing the rate of current changes in the supply line, inversely, in the event of a reduction in rated supply current, the reactor impedance will decrease (Haase, 2018). Correctly cited

2.1.2 DCS800 Power Converter Module Design Features

The power converter modules are rated to IP00, therefore has to be mounted in a suitable, rated enclosure and can be supplied as 2 or 4-quadrant operation (ABB, 2016).

Field excitation is provided, either onboard in the case of the D1 to D4 converters, where external exciters are required for the D5 to D7 models. External field excitation can be achieved through the use of a dedicated DCS800-Sox which is controlled by the armature converter through a serial interface board (ABB, 2016).

DriveOPC is a software package which enables read access to the DCS800 controller for data acquisition, such as fault logging, run status, drive information as well as write access for parameter updates, start / stop and directional commands. Additionally, DriveWindow

software enables adaptive programming, where the speed/torque reference can be modified amongst others, through the use of 16 programmable function blocks and 31 available functions. PID tuning blocks are utilised to enable current or voltage tuning through the use (ABB, 2016).*seems like an unfinished sentence?*

Commissioning Macros are stored within the DriveOPC software, which are factory pre-programmed parameter sub-sets, used to define parameters such as if speed or torque control is being used, whether the motor inputs are maintained or pulsed, whether a DC contactor is being used or field weakening is needed (ABB, 2016). *Correctly cited*

Field excitation is controlled independently from the armature circuit and is utilised to increase motor speed beyond base speed (field weakening), which will cause a reduction in torque (H.Rashid, 2014). *Useful comments*

Communication with field exciters or other drives are achieved through the use of DCSLink serial communication, which is based on the CAN Bus system. Additional communications modules can be added to enable fieldbus communications through fibre-optics (Vinz, 2020). *Useful comments*

Power and firing circuit isolation is achieved through the use of two SDCS-PIN-H41 pulse transformer boards (Vinz, 2020).

Four-quadrant operation is achieved through a second Thyristor bridge, as shown in appendix figure 4. DC fusing, rated the same as the AC fuses need to be utilised between the drive and motor when 4-quadrant operation is required (ABB, 2016).

Four quadrant operation is summarised in table 1 below, with the four quadrants shown in appendix figure 5.

4-Quadrant Characteristics				
Operation	Quadrant	Speed	Torque	Power
Forward Motoring	1	Positive	Positive	Positive
Forward Regeneration	4	Positive	Negative	Negative
Reverse Motoring	3	Negative	Negative	Positive
Reverse Regeneration	2	Negative	Positive	Negative

This is a useful table

Table 1 - 4-Quadrant Operation (Krishnan, 2001)

Four quadrant operation enables the DC motor to be started and stopped in a controlled manner as well as enable reverse operation. To enable controlled reduction of speed to zero the motor can function as a DC generator and transfer the stored energy back to the source,

thereby increasing efficiency. For the purpose of forward generating, the armature current has to be reversed, which is achieved by reducing the DC supply voltage to a value less than the induced back EMF. The power will flow in the reverse direction of which the motor is operating, resulting in negative torque, also known as regenerative braking (Krishnan, 2001).

It is clear that in quadrant 1 and 4 the motor will be operating forward and in quadrant 2 and 3 it will operate in reverse. Whilst the speed is negative (reverse) in quadrant 2 the torque will be positive with negative power, therefore generating in reverse, whereas in the third quadrant the torque will be negative with positive power.

2.1.3 Applications of 4-Quadrant DC Drives and Comparisons

Various industrial processes require the constant torque characteristics of DC motors which enables high torque to be applied even at low speeds or from standstill. This is particularly useful in stop / start operation or where tensioning is required in a production line. Less inertia, due to the smaller sizes that DC motors occupy, enables rapid acceleration and de-acceleration (Kimbrell, 2016).

Typical applications of a DC drive, operating in 4-quadrant operation is strip mill for instance, where upwards of 10 DC motors are arranged in succession, coupled to individual gearboxes and roller sets, are used to shape and manipulate steel that passes through the coupled rollers. In this application there is a need for accurate tension control to ensure the product is formed correctly. As the steel passes from one roller set to another there is a reduction in speed, which has to recover very fast. Controlled braking, as well as an emergency stop capability is required in this application, in which case four quadrant operation will be required. Start / stop demands require large amounts of power and torque in both directions, which is another requirement for 4-quadrant operation (Thorstenson, 2020).

Chopper Drives

Spelling

Chopper drives are utilised where the supply is in the form of AC voltage, for instance electric vehicles, here the armature voltage is varied to enable motor control. Regenerative braking is utilised in this instance to recharge the vehicle's battery. Four quadrant operation is achieved through controlling the armature and field currents as well as voltages (Rashid, 2011)

Single-Phase Converters

Single phase converters are subdivided into four categories. Single phase, half-wave converters aren't widely used, therefore have been excluded from this section. The three main single-phase converters are shown in table 2.

Single Phase Converters			
Single phase	Circuit Arrangement	Quadrant Operation	Applications
Semiconverter		1st Quadrant	Up to 15kW
Full Converter		1st and 4th Quadrant	Up to 15kW
Dual Converter		All four Quadrants	Up to 15kW

Table 2 - Single-Phase Converters (H.Rashid, 2014)

Single phase converters are limited to 4 SCRs in a single converter, with a switching arrangement to achieve armature and field reversal. These drives are more susceptible to harmonic interferences than 3-phase drives and utilise a smoothing inductor to reduce ripple current to acceptable standards (H.Rashid, 2014)

[Useful comments](#)

2.1.4 Drive Selection for Industry

The selection of motor drives for industry will depend on its intended application and existing infrastructure. AC motor drives are more expensive than DC drives, whereas DC motors are more expensive than AC motors. Maintenance on ^{AC} DC motors are reduced due to their construction. Environmental requirements need to be considered, not only for business ethics, but for the reliable operation of equipment.

3. Simulation and Design Adaption

3.1 Simulation Circuit - Full-wave, fully controlled three-phase rectifier

The circuit shown in figure 1 represents a separately excited DC motor in the form of an inductance, resistance and back EMF, controlled by a full wave, fully controlled rectifier. The circuit was created to enable behavioural simulation to ascertain the effects of varying the firing angle on the armature voltage, whilst producing continuous current.

Appendix figures 6, 8 & 10 show the simulation circuits with firing angles 10° , 20° and 30° . The circuit is supplied by a three phase 100v, 60Hz supply. The Thyristor (SCR) firing circuit (U1) delays the SCR commutation by the firing delay angle (alpha), to ensure the desired response is achieved (Lander, 1993).

The resultant waveforms (appendix figures 7, 9 & 11) showed that the simulated motor is motoring forward with positive speed, torque and armature current, thus using quadrant 1.

The Vmax simulated value was ascertained by reducing alpha to 10° and running the simulation, which resulted in 242.12V being observed, as shown in appendix figure 7.

By calculating the Vmax value, the armature voltage could be calculated. The calculations are shown in appendix 8.2.2, with the results tabulated in table 3, compared to the measured values. The simulated wave was measured using graph cursors, which produced a V_{Max} value of 244.97V, which is a negligible difference of 0.02V.

Simulation Results			
Firing Angle	Calculated	Measured	Deviation
10°	230.36V	227.68V	2.68V
20°	219.80V	217.00V	2.80V
30°	202.57V	199.90V	2.67V
Vmax	244.95V	242.13V	2.82V
Averaged deviation			2.74V

You should have used the measured Vmax in your calculations in the appendix - includes the voltage drop across the thyristors Table 3 - Simulated Circuit Results

From table 3, it is clear to see that the measured voltages are consistently lower, by an average of 2.74V across the three different firing angles, including the Vmax values. The reduction in armature voltage with the increase in firing angle gradient is consistent.

3.2 Simulation Design Adaption

3.2.1 Circuit Design Explanation

The simulation circuit was constructed using Multisim. Table 4 lists, with brief descriptions, which components were utilised to construct the circuit

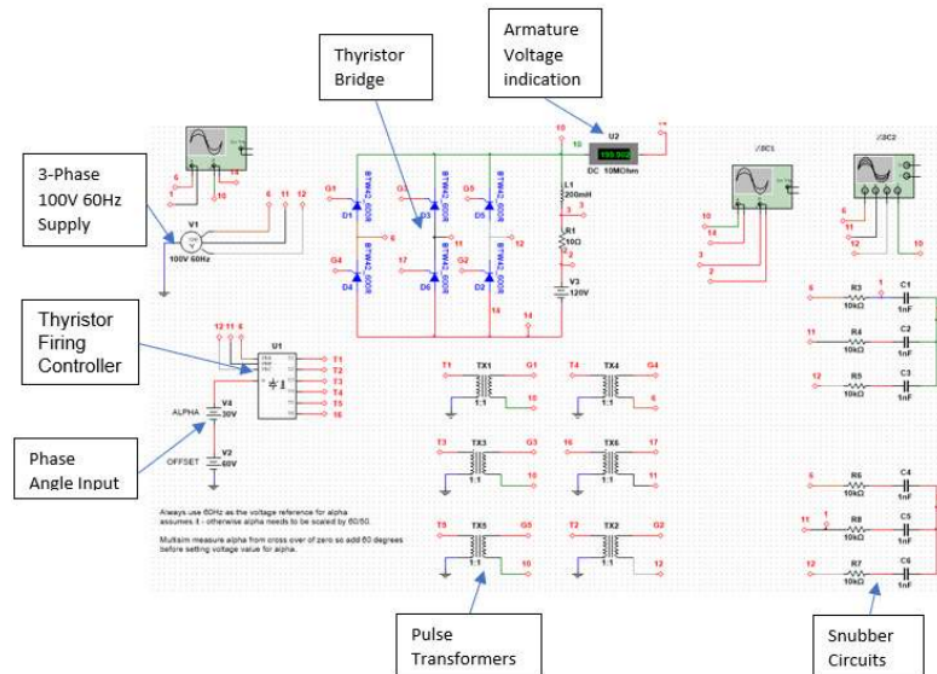


Figure 1 - Multisim Simulated Circuit

The simulated rectifying circuit comprise of a 3-phase AC supply voltage which is fed to the Thyristor bridge as well as to the firing controller. The Thyristor bridge supply is fed via the snubber circuits, which protect against voltage and current spikes (dv/dt & di/dt), as well as to the secondary windings on the pulse transformers, which provide isolation between the power circuit and firing circuit. Phase angle is set as a DC voltage supply to the firing controller in series with the 60V zero-crossover offset. An internal stepdown transformer and rectifier conditions line input AC voltage for use in the firing controller. Voltage and current measurements are achieved through the use of multimeters and four-channel oscilloscopes connected accordingly.

Simulation Circuit	
Identifier	Description
V1	Three phase, 100v, 60 Hz supply
U1	Thyristor Firing controller – Utilised to control the commutation voltage to the thyristors.
U2	Armature Voltage Indication
V2	Offset due to Multisim measuring alpha from cross-over from zero, hence the 60v offset
V4	Phase angle, set by DC voltage representing 10, 20 & 30 Degree firing angle
L1	200mH Inductor - Part of DC motor simulation
V3	120V Back EMF voltage - Part of DC motor simulation
R1	10 Ohm Resistor - Part of DC motor simulation
Tx1 - Tx6	Pulse transformers
Snubber Circuits	10KΩ Resistor and 1nF Capacitors utilised to form series resonance to reduce voltage spikes to low amplitude, dampened oscillations
Thyristor Bridge	BTW42_600R Thyristors controlled by U1 via Pulse Transformers

Table 4 - Simulated Circuit Components

good evidence of research

The datasheet for the BTW42-600R SCR states the maximum voltage before reverse direction breakdown to be 600V and the rated on-state current to be 10A. The SCR can briefly withstand 150A surge current and is limited to a maximum of 1.5V @ 50mA gate trigger voltage and current (Arrow, 2022).

Snubber circuits are constructed using resistors and capacitors and are used to protect the Thyristors from high dv/dt (voltage rise over time) & di/dt (current rise over time) and can be classified as reverse and forward polarised. Snubber circuits employed in 4-quadrant operation need to function in both directions, i.e., unpolarised (H.Rashid, 2014).

Isolation is required between the power circuit and the gate circuit for each individual Thyristor in the firing circuit, where the power circuit usually operates at voltages higher than 100V and the gate circuit usually operates at lower voltages of between 12V and 30V. Opto-couplers (i.e., phototransistors) or pulse transformers can be utilised to achieve isolation. Opto-coupling circuits require a separate power supply at a cost, whereas pulse transformers are simple and more cost-effective. The pulsed voltage applied to the transformer primary from the firing circuit induces a pulsed voltage on the secondary, which is then applied to the Thyristor, which enables forward conduction (H.Rashid, 2014).

3.2.2 Circuit Design Adaptation

To enable 4-Quadrant operation of the simulated circuit, an additional bridge needs to be added. Back EMF voltage polarity needs to be reversed for quadrant 2 & 3 operation as well as advancing the phase angle past 90° . Appendix figure 12 shows the modified circuit. The switch arrangement enabled simple switching between either bridge as well as simulated EMF polarity reversal.

You could have provided figures for waveforms in different quadrants

4. Practical Investigations

4.1 Experimental Setup

The practical experimental setup was constructed using a Siemens Sinamics DC drive controlling a DC motor coupled to an S120 AC drive, which acted as a load. The

Figure 2 shows the Simatic HMI screen which provides live data captured from the system, displayed as; Armature voltage and current, phase angle, back EMF, speed and torque which was utilised to analyse drive and motor performance. The HMI enables the user to select which quadrant the drive should operate in, whether the drive cycles through quadrants automatically or by operator command in manual, as well as what the speed and torque settings are.

Figure 2 illustrates a simplified view of the 3-phase supply distribution via a line filter as well as how data acquisition and control is accomplished through the system.

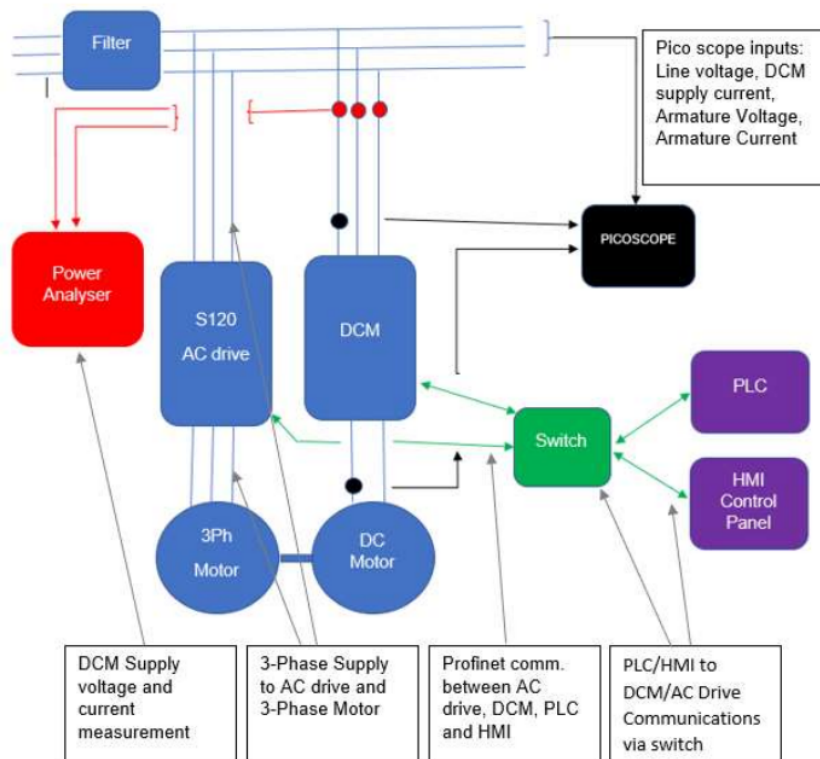


Figure 2 - 3-Phase Supply Distribution, Data Acquisition and Control

Appendix figures 13 to 17 show the practical components which is needed to complete the drive system.

The power analyser was utilised throughout the practical to measure active power (kW), apparent power (kVA), reactive power (kVAR) & power factor.

4.2 Four Quadrant Operation

Motor parameters were measured using the Picoscope and HMI diagnostic display, whilst operating the drive in each of the four quadrants.

As seen in figure 3, the motor was driven in all four quadrants, in this case with auto selected. The graph shows the motor speed as the blue line and the actual measured torque as the red line. Whilst in quadrant 1 the speed and torque are positive, whereas during quadrant two the speed stays positive with negative torque. In quadrant 3 the speed reduces past zero to approximately -1000rpm with the torque still negative. Quadrant 4 shows positive torque and negative speed indicating reverse generation. Operation in each quadrant along with quadrant and performance analysis as well as Thyristor bridge utilisation will be conducted below.

you could have annotated the trace to show the quadrants

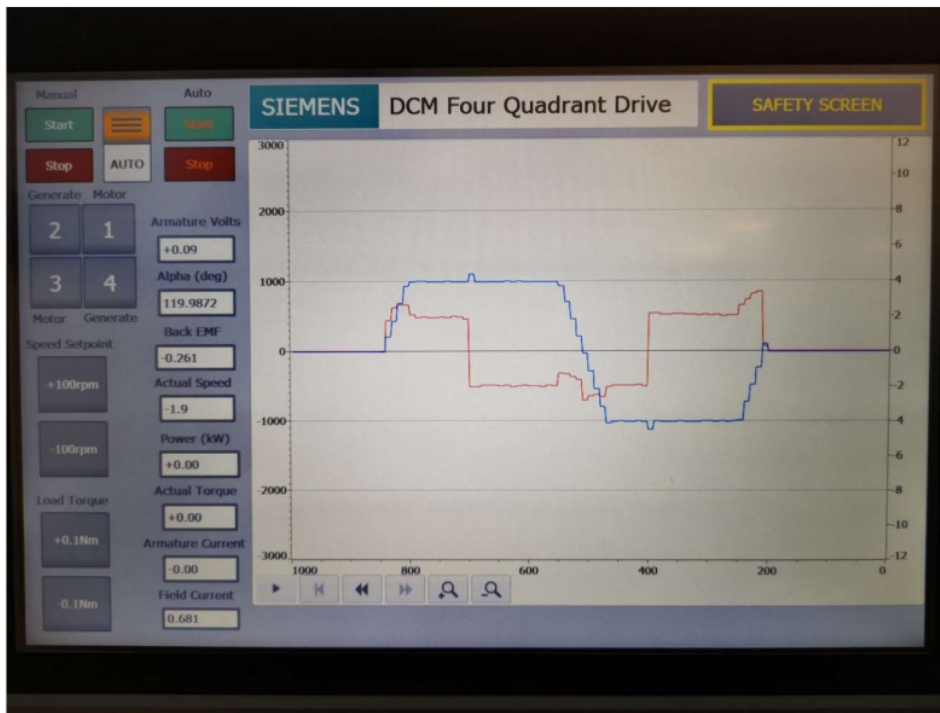


Figure 3 - 4-Quadrant Operation - HMI Results

Dynamic Resistance Calculation:

$$R = \frac{(V_a - E)}{I_a} = \frac{12.96}{3.693} = 3.509\Omega$$

Table 5 shows the four parameters measured with corresponding colour key; this is valid for the rest of the practical experiment PicoScope graphs.

Key		
Colour	Measurement	Abbreviation
Blue	Armature Voltage	V _a
Red	Armature Current	I _a
Green	Mains Line Voltage	V _s
Brown	Mains Line Current	I _s

Table 5 - PicoScope Colour Key

Figure 4 shows the Picoscope graphs of parameters measured, with cursors used to extract the required information.

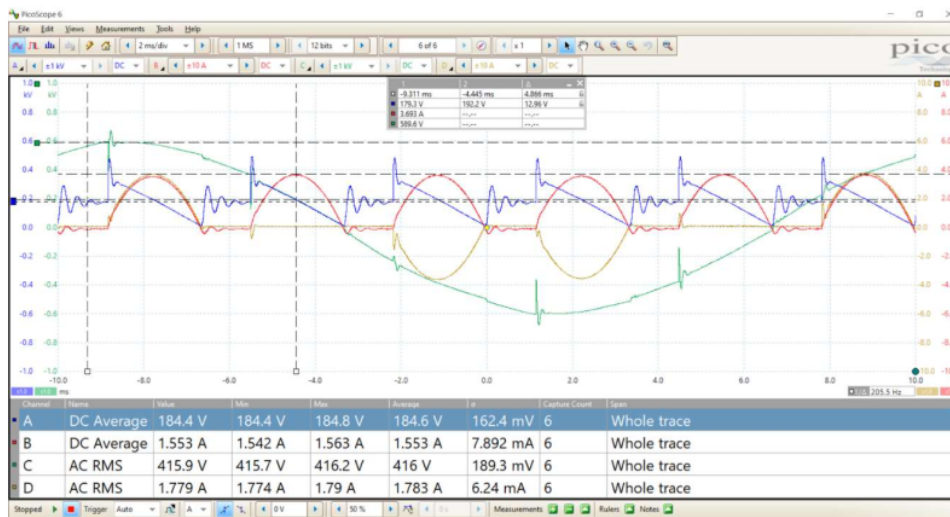


Figure 4 - PicoScope Graph for 1st Quadrant Analysis

Table 6 Shows the HMI and PicoScope results obtained by running the motor in each of the four quadrants in turn. (Appendix figures 18-25 show the HMI & PicoScope screenshots for reference).

Measured Motor Parameters								
	Quadrant 1		Quadrant 2		Quadrant 3		Quadrant 4	
	HMI	PicoScope	HMI	PicoScope	HMI	PicoScope	HMI	PicoScope
Va (V)	185.38V	185.3V	173.20V	172.3V	-184.47V	-185.6V	-173.28V	-173.4V
Ia (A)	1.56A	+1.51A	-1.54A	-1.64A	-1.48A	-1.62A	+1.63A	+1.61A
Torque (Nm)	2.02Nm	n/a	-1.99Nm	n/a	-1.99Nm	n/a	+2.02Nm	n/a
Speed (rpm)	997.6rpm	n/a	+998.9rpm	n/a	-1003rpm	n/a	-986.6rpm	n/a
Phase Angle (°)	81.15°	n/a	115.68°	n/a	81.77°	n/a	116.43°	n/a
Back EMF (V)	179.51V	n/a	179.10V	n/a	-179.97V	n/a	-178.62V	n/a
Power (kW)	+0.29kW	n/a	-0.26kW	n/a	+0.27kW	n/a	-0.27kW	n/a

Table 6 - Practical Results for all 4 Quadrants

excellent results

The following analyses refer to the data in table 6.

Quadrant 1

The positive armature voltage, current and torque indicates that the motor is motoring forward, which is confirmed by the speed and power being positive. The phase angle is less than 90° with positive back EMF and armature current, therefore a conclusion can be made that quadrant 1 and bridge 1 is being utilised.

Quadrant 2

Positive armature voltage and positive speed indicates that the motor is operating forward, whilst the negative armature current, phase angle more than 90° and the negative torque indicates generation taking place. Additionally, positive back EMF (larger than armature current) and negative armature current (bridge 2) confirms that quadrant 2 is being utilised. The positive speed and negative power further confirm quadrant 2 operation.

Quadrant 3

Negative armature voltage and current as well as negative torque and speed indicates the motor is now motoring in reverse. The negative back EMF, which is smaller than the armature voltage, in addition to the negative armature current, confirms bridge 2 is still being utilised. Therefore, a conclusion can be made that quadrant 3 is being utilised.

Quadrant 4

Negative armature voltage, positive armature current and negative power indicates that reverse generation is taking place in quadrant 4, utilising Thyristor bridge 1. This is confirmed with a phase angle that is more than 90° with negative back EMF and negative speed.

4.3 Discontinuous Current in Quadrant 1 – Constant Torque / Variable Speed

By keeping the torque constant and running the motor in quadrant 1 at three different speeds, discontinuous current was achieved, as shown on the PicoScope graph in appendix figures 26, 27, 28. The initial speed of 1000rpm resulted in discontinuous armature current being measured with a phase angle of 81.13° , with 1.46 Nm torque.

Constant Torque / Variable Speed				
HMI	Speed setpoint	1001.2rpm	1501rpm	2046.4rpm
	Torque	1.93Nm	1.8Nm	1.86Nm
	Va	185.95V	273.13V	362.26V
	Ia	1.46A	1.48A	1.71A
	Phase Angle	81.13°	71.14°	52.64°
	Back EMF	178.75V	270.96V	361.52V
	Power	0.27kW	0.41kW	0.60kW
	If	18.63A	18.77A	18.69A
Power Anl.	Power	0.305kW	0.461kW	0.595kW
	Power Factor	0.256	0.379	0.491
	Nvar	1.154kVAr	1.162kVAr	1.056kVAr
	Sva	1.194kVA	1.216kVA	1.213kVA

Table 7 – Practical - Quadrant 1 – Constant Torque / Variable Speed

It is clear to see that there are slight variations in torque through the speed range, these variations have been deemed acceptable.

As the speed increases the armature voltage increases by an average of 88V, this is true for the back EMF as well, confirming that armature voltage is proportional to speed and that an increase in speed will also result in an increase in back EMF. The power factor increases with an increase in speed, resulting in better efficiency. The relationship between firing angle and armature voltage can be seen, where an increase in α results in a decrease in armature voltage and therefore speed, which is consistent with the simulated results.

The mean voltage was calculated, to enable a comparison to be made with the simulation measured mean voltage (calculations are in appendix 8.3.5)

The calculated V_{mean} value was 187.29V whereas the measured value was 185.95V, thus a discrepancy of 1.34V, which can be attributed to simulation measurement cursor and rounding errors.

Motor constants were calculated to be: $K_v = 0.071V/A/rad/s$ & $K_b = 1.322 Nm/A$ – Calculations can be seen in appendix 8.3.5.

4.4 Continuous Current in Quadrant 1 – Constant Speed / Variable Torque

Constant Speed / Variable Torque				
HMI	Torque	5.31Nm	6.03Nm	6.66Nm
	Speed	1998.0rpm	1999.0rpm	2000.6rpm
	Va	373.81V	371.67V	372.53V
	Ia	4.21A	4.61A	5.22A
	Phase Angle	46.44°	46.16°	45.79°
	Back EMF	355.28V	355.05V	355.41V
	Power	1.56kW	1.76kW	1.89kW
	If	18.67A	18.65A	18.79A
Power Ani.	Power	1.61kW	1.79kW	1.98kW
	Power Factor	0.60	0.607	0.614
	Nvar	2.15kVAR	2.348kVAR	2.55kVAR
	Sva	2.68kVA	2.96kVA	3.22kVA

Table 8 - Quadrant 1 – Constant Speed / Variable Torque

Continuous current was achieved in quadrant 1 through varying the torque applied and keeping the speed constant. The power factor increased as the load increased, which also resulted in an increase in power. The speed and phase angle relationship in this instance showed that the phase angle did not really change with an increase in torque, once again confirming the that only speed / armature voltages are affected by the phase angle. Back EMF measured showed a relatively consistent voltage of 355V, which would be correct, as the armature voltage hardly changed.

It is clear from that data collected that the armature current is proportional to the load under which the motor is operating and that in this case that the motor was not affected, as the power factor remained at approximately 0.6.

Referring to appendix figure 29 there is no visible back EMF, this is due to the continuous current.

4.5 Drive Performance Analysis

During discontinuous current operation in quadrant 1, the drive results confirmed that whilst keeping the load constant and increasing the speed, the Va and subsequently the EMF increase at a similar rate. Whilst producing continuous current in quadrant 1 the torque

increases only affected the armature current and power. A conclusion can be made that speed control under constant load conditions results in the drive being more efficient.

you would need to calculate the output power to prove this

5. Conclusions and Recommendations

Research conducted in the DC800 DC drive by ABB enabled a thorough understanding of how a DC drive operates and what components are required to ensure the drive operates safely and as intended. Applications of DC drives are varied and range from small stepper ^{not a dc drive} motors, to electric car motors as well as heavy industry applications, where the motors and drives are subjected to large loads and varying speeds.

The simulations provided a platform to conduct performance analysis as well as mathematical modelling of DC drives, where simulated results were found to match calculated results and theory closely, thereby confirming correct operation and enabling a deeper understanding of principles and components used.

The addition of a second thyristor bridge to the simulated circuit seemed possible in theory, but did not function correctly in practice. A recommendation would be to re-attempt the ant-parallel bridge using more powerful simulation software, like PSpice for instance.

Practical tests that were carried out enabled a fairly clear understanding of how a DC drive ad motor performs in the first quadrant when subjected to changes in torque whilst maintaining constant speed, as well as variations in speed under constant torque.

3180

6. Team Working and Health & Safety Precautions

The practical part of this assignment was carried out as a team, where measurements were taken from the Siemens DC drive, utilising aforementioned test equipment. Whilst conforming to Covid-19 regulations of wearing a three-ply mask and ensuring social distancing was maintained at all times, the team discussed what information was required. Once a clear understanding of the requirements was ascertained, a plan was formed, which involved individuals firstly familiarising themselves with the system safety implementations and interlocks as well as PPE requirements. The individual members of the team took turns to control the motor utilising the HMI, as well as documenting the data. By ensuring all members participated in the control and data recording, a thorough understanding of the system could be achieved.

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[0DCS800%20Hardware%20Manual%20e%20h.pdf](#)

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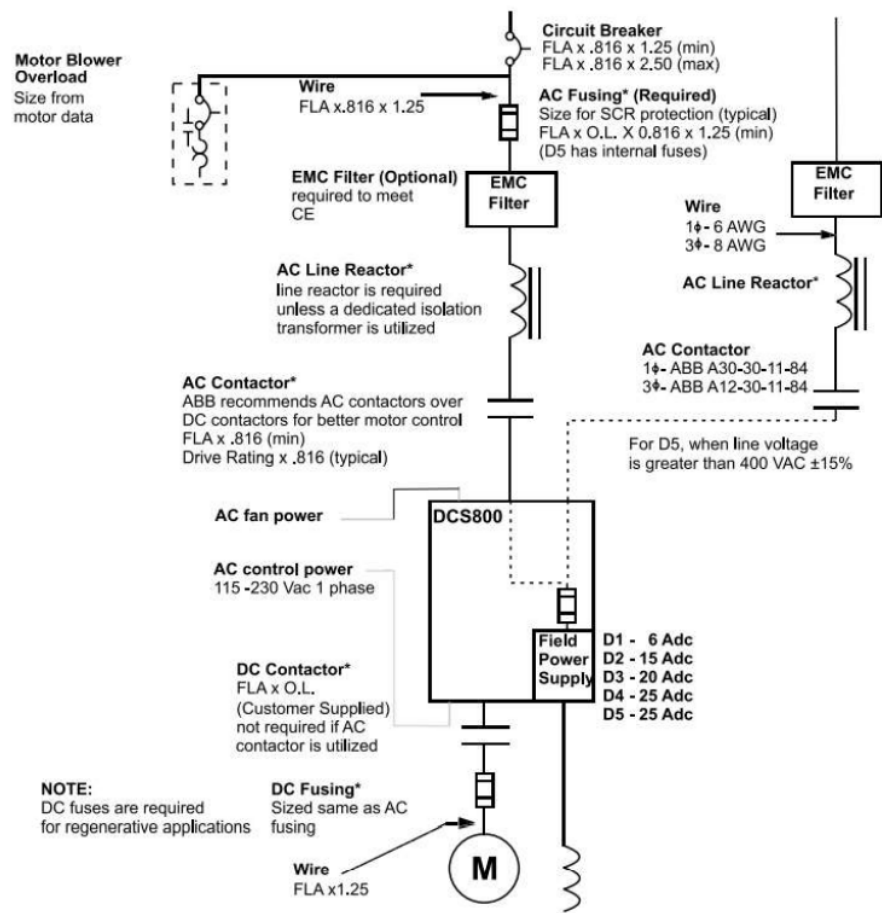
8. Appendix

8.1 Research

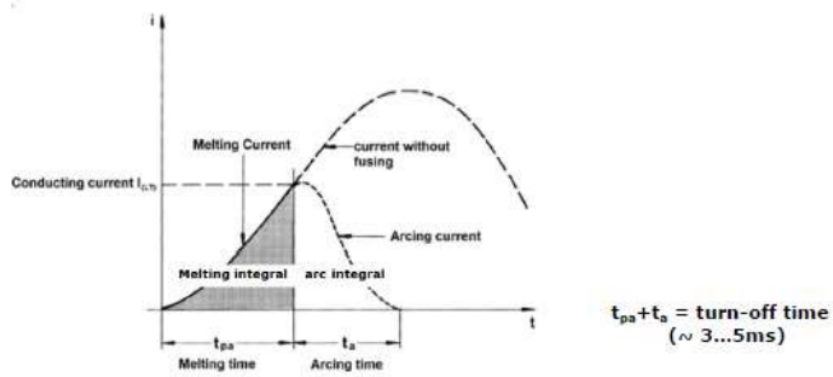
The drive's basic type code: DCS800-AAX-YYYY-ZZ-B + plus code			
Product family	DCS800		
Type:	AA	= S0 = R0 = E0 = A0	Standard converter module Rebuild kit Panel solution Enclosed converter
Bridge type:	X	= 1 = 2	Single bridge (2-Q) 2 anti-parallel bridges (4-Q)
Module type:	YYYY	=	Rated DC current
Rated AC voltage:	ZZ	= 04 = 05 = 06 = 07 = 08 = 10 = 12	230 V _{AC} - 400 V _{AC} 230 V _{AC} - 525 V _{AC} 270 V _{AC} - 600 V _{AC} 315 V _{AC} - 690 V _{AC} 360 V _{AC} - 800 V _{AC} 450 V _{AC} - 990 V _{AC} 540 V _{AC} - 1200 V _{AC}
Power connection:	-	= = L = R	Standard D1 - D6 Left side D7 Right side D7
Revision code:	B	= = a = b	Standard Second thyristor type D5, D6 ErP compliant cooling fan D5, D6, D7 and second thyristor type
Field exciter configuration:		+0S163 +S164	D1 - D4 without OnBoard field exciter D4+ and D5 with internal field exciter, supply external (D4+ and D5: 25 A, Rebuild kit: 16 A / 25 A)
Fan voltage:		Standard +S171	Size D4 Fan voltage: 230 V / 1-ph Fan voltage: 115 V / 1-ph
Current measurement:		+S175	SDCS-CMA-2 (D5 - D7)
Voltage measurement:		+S186 +S185 +S180 +S181 +S182 +S183 +S189 +P905 +P906	120 V SDCS-SUB-4 (D1 - D4+) SDCS-PIN-51 configured to 120 V (D5 - D7) SDCS-PIN-51 configured to 600 V (D5 - D7), 12-pulse serial / serial sequential SDCS-PIN-51 configured to 690 V (D5 - D7), 12-pulse serial / serial sequential SDCS-PIN-51 configured to 800 V (D6, D7), 12-pulse serial / serial sequential SDCS-PIN-51 configured to 990 V (D6, D7), 12-pulse serial / serial sequential SDCS-PIN-51 configured to galvanic isolation (D6, D7) Electronic boards are located in the D7 module Electronic boards are in an external control unit (outside the D7 module)
SDCS-DSL-4:		+S199 +0S199	With SDCS-DSL-4 Without SDCS-DSL-4
DCS Control Panel:		+0J404 +J409	Without DCS Control Panel Door mounting kit, including 3 m cable
Fieldbus:		+K454 +K451 +K457 +K466 +K458	Profibus RPBA-01 DeviceNet RDNA-01 CANopen RCAN-01 Ethernet/IP, Modbus/TCP RETA-01 Modbus (RTU) RMBA-01
I/O and DDCS:		+L500 +L501 +L508 +L509	Analog Extension RAIO-01 Digital Extension RDIO-01 DDCS communication board (10 Mbaud CH0) SDCS-COM-81 DDCS communication board (5 Mbaud CH0) SDCS-COM-82

Appendix Figure 1 - DCS800 Type Designation (ABB, 2016)

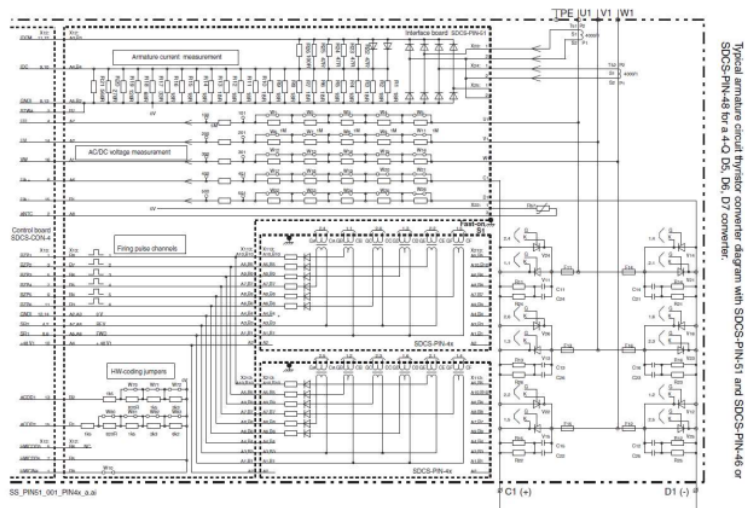
DCS800 System overview



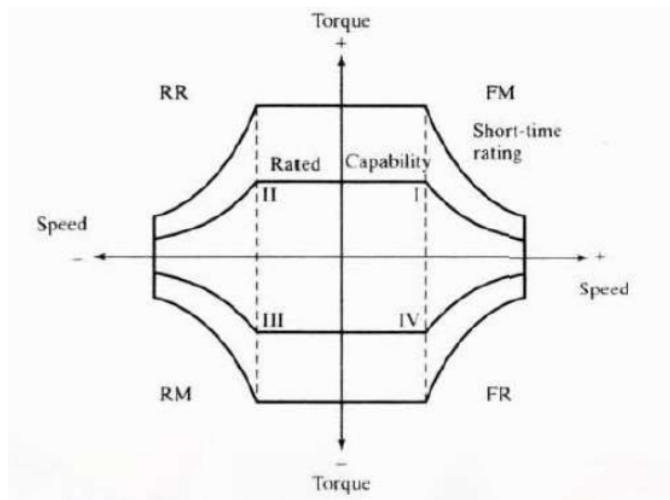
Appendix Figure 2 - System Overview (ABB, 2016)



Appendix Figure 3 - DC Fuse Turn-off Time Characteristic (Nicolai, 2018)



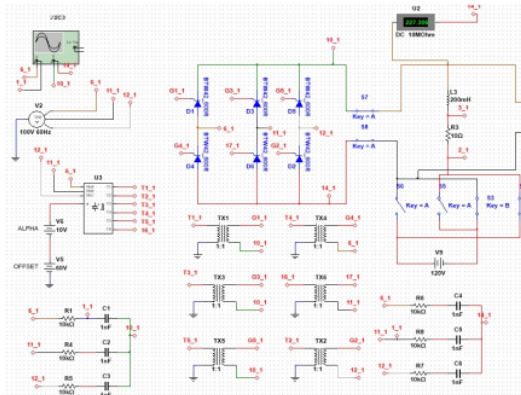
Appendix Figure 4 - DCS800 Anti-Parallel Bridges (4-Q Operation) (Vinz, 2020)



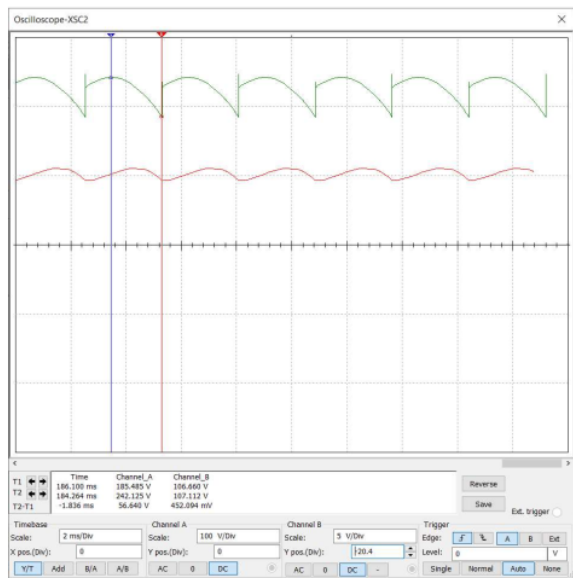
Appendix Figure 5 - 4-Quadrant Diagram (Krishnan, 2001)

8.2 Simulation and Design Adaption

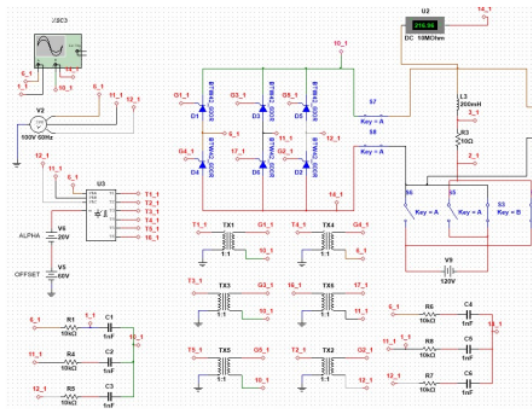
8.2.1 Firing Angles 10°, 20°, 30°



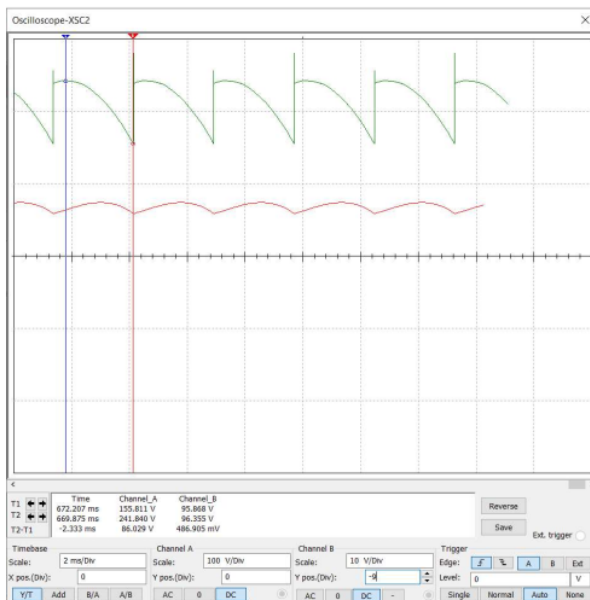
Appendix Figure 6 - Simulated Circuit 10 Degree Firing Angle



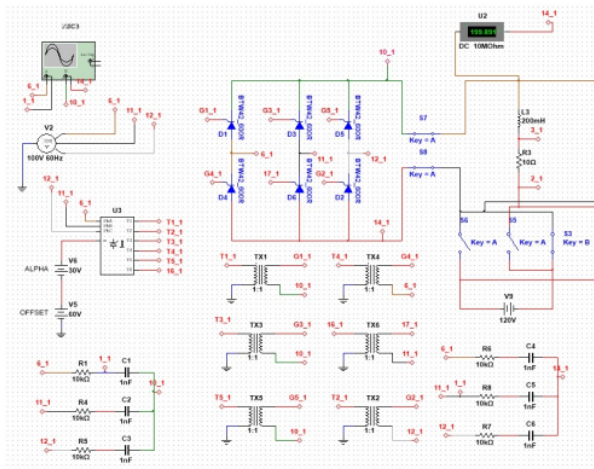
Appendix Figure 7 - Simulated Circuit 10 Degree Firing Angle Graph



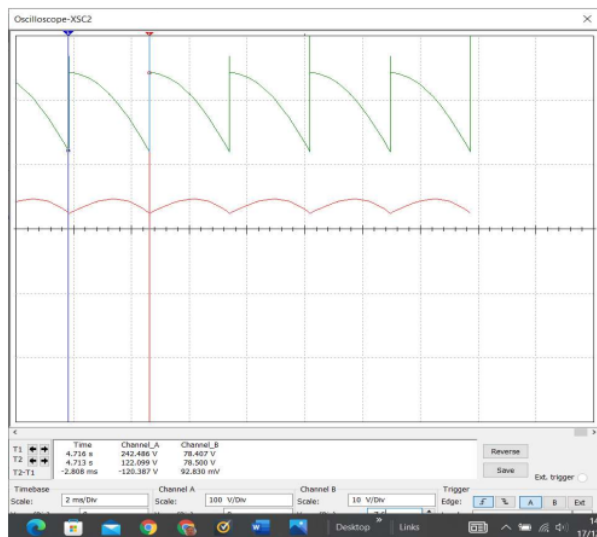
Appendix Figure 8 - Simulated Circuit 20 Degree Firing Angle



Appendix Figure 9 - Simulated Circuit 20 Degree Firing Angle Graph



Appendix Figure 10 - Simulated Circuit 30 Degree Firing Angle



Appendix Figure 11 - Simulated Circuit 30 Degree Firing Angle Graph

8.2.2 Simulation Equations

10° Firing angle

should have used measured Vmax instead, results would then be closer

$$V_{Mean} = \frac{3V_{\max(line)}}{\pi} \cos(10) = \frac{3(244.95)}{\pi} \cos(10) = 230.36V$$

20° Firing angle

$$V_{Mean} = \frac{3V_{\max(line)}}{\pi} \cos(20) = \frac{3(244.95)}{\pi} \cos(20) = 219.80V$$

30° Firing angle

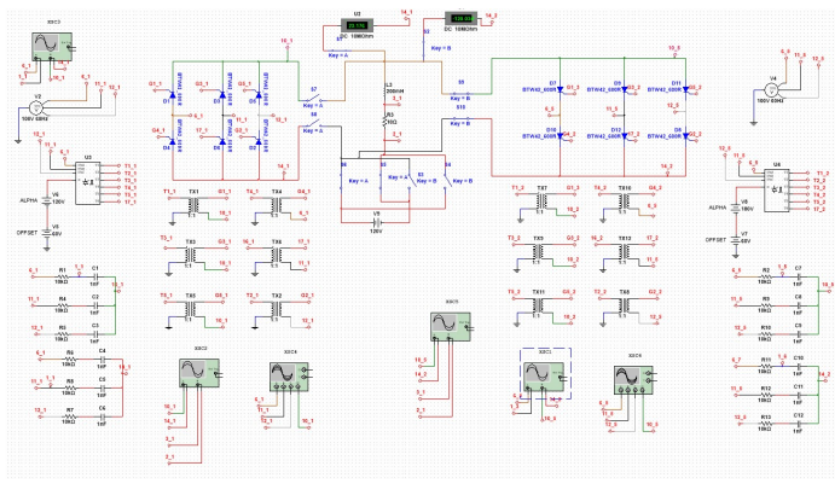
$$V_{Mean} = \frac{3V_{\max(line)}}{\pi} \cos(30) = \frac{3(244.95)}{\pi} \cos(30) = 202.57V$$

Vmax calculated value

$$V_{\max(line)} = V_{RMS} \times \sqrt{2} \times \sqrt{3}$$

$$V_{\max(line)} = 100V \times \sqrt{2} = 141.42 \text{ } V_{RMS} \times \sqrt{3} = 244.94V$$

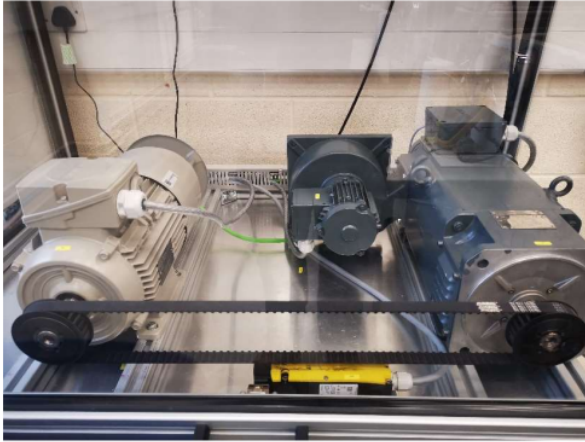
8.2.3 Simulation Design Adaptation for 4-Quadrant operation



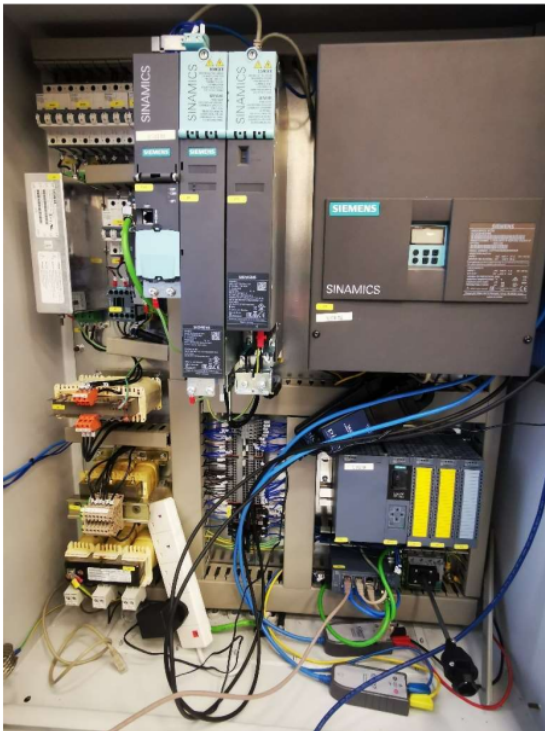
Appendix Figure 12 - Simulated Circuit - Both Thyristor Bridges

8.3 Practical Investigation

8.3.1 Experimental Setup



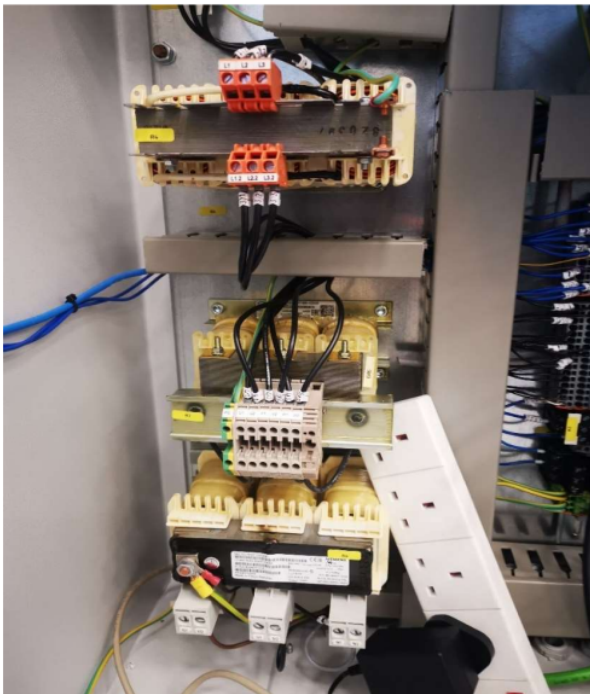
Appendix Figure 13 - Practical - DC Motor Coupled to S120 AC Drive



Appendix Figure 14 - Siemens Sinamics CU230-2 & Braking and Control Module



Appendix Figure 15 - Siemens Simatic S7-1500 PLC



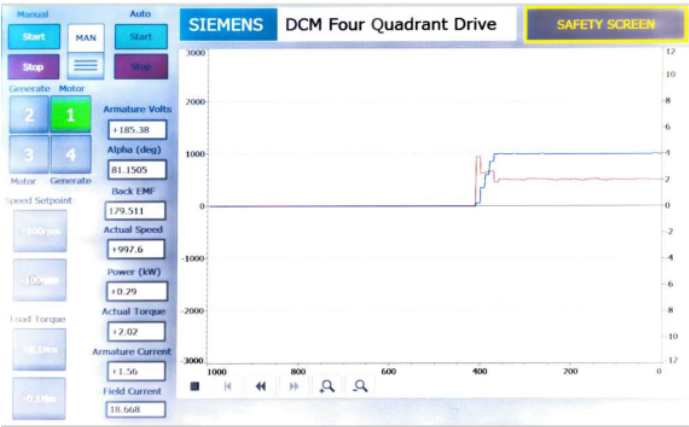
Appendix Figure 16 - Practical AC Supply Conditioning as well as DC Motor Supply Filter / Reactor



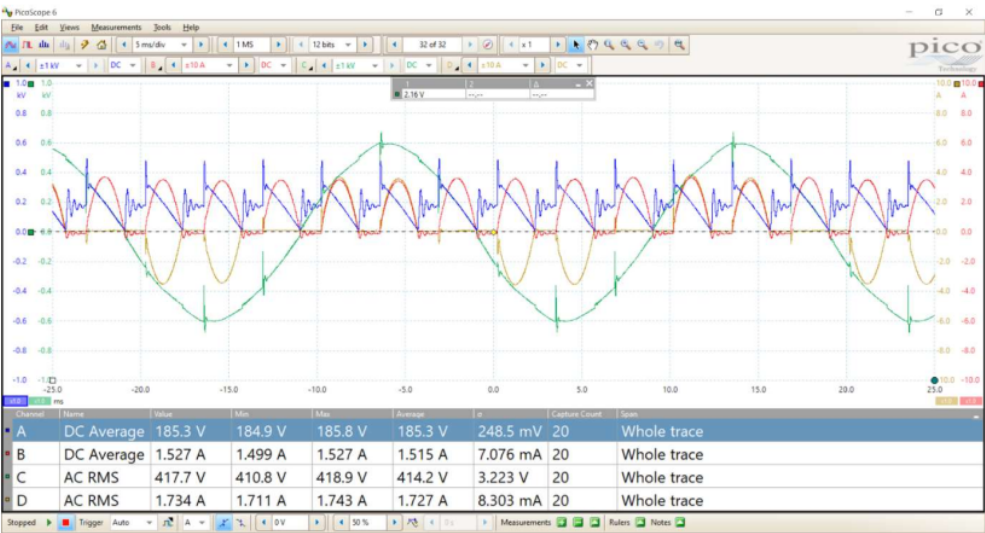
Appendix Figure 17 - Siemens 3-PH DCM Drive

8.3.2 4-Quadrant Operation

Quadrant 1

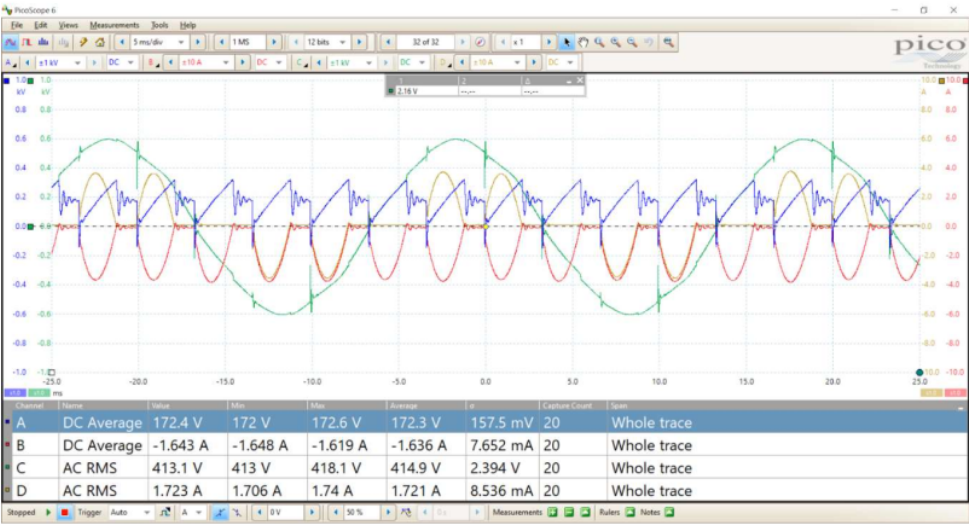


Appendix Figure 18 - 4-Quadrant Operation - 1st Quadrant HMI

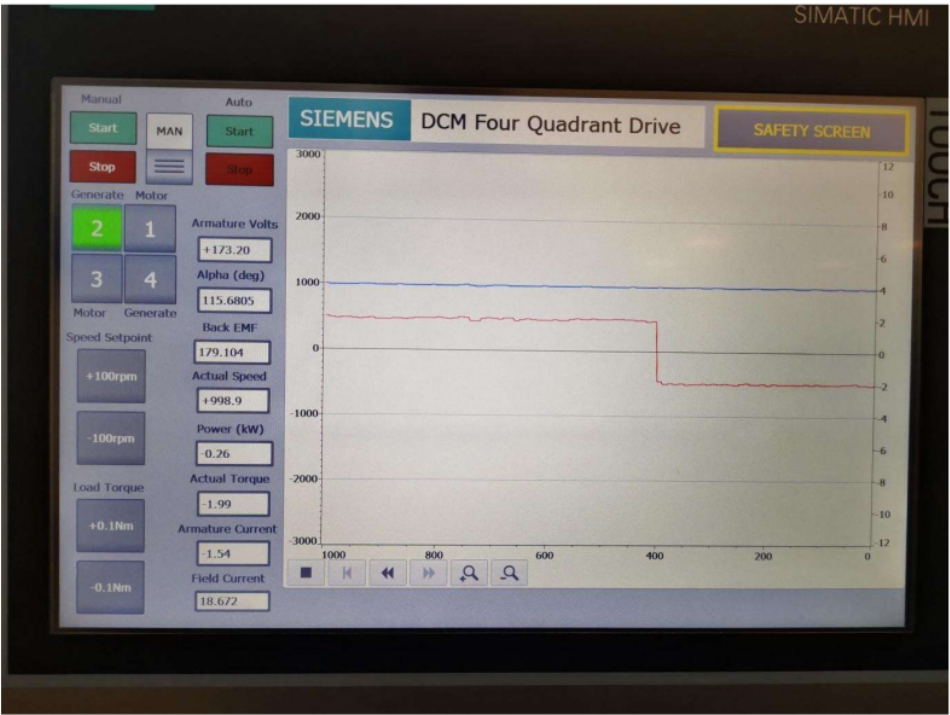


Appendix Figure 19 - 4-Quadrant Operation - 1st Quadrant Picoscope Graph

Quadrant 2



Appendix Figure 20 - 4-Quadrant Operation - 2nd Quadrant Picoscope Graph

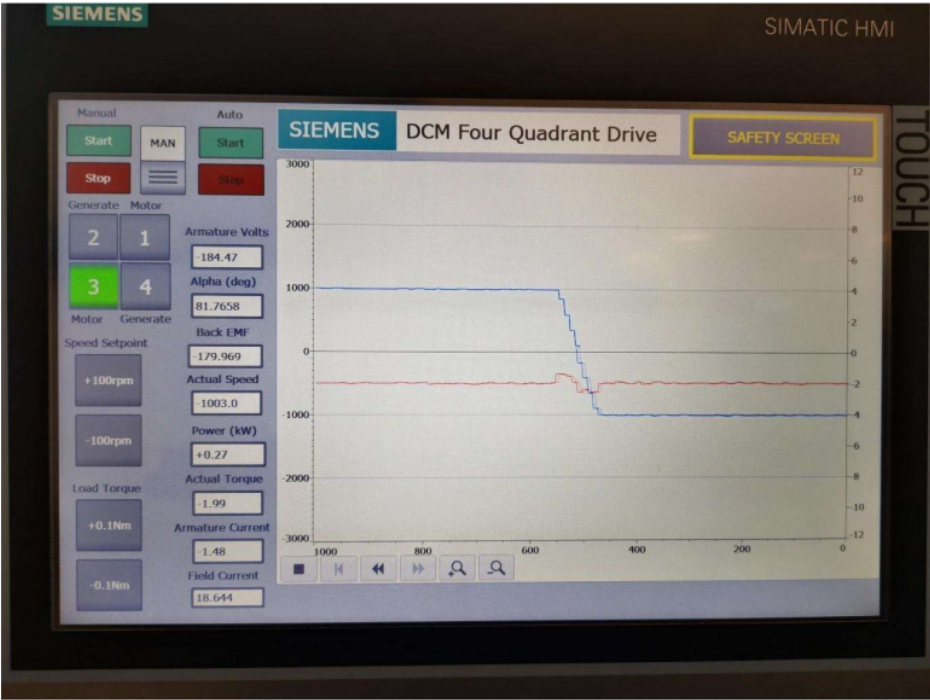


Appendix Figure 21 - 4-Quadrant Operation - 2nd Quadrant HMI

Quadrant 3

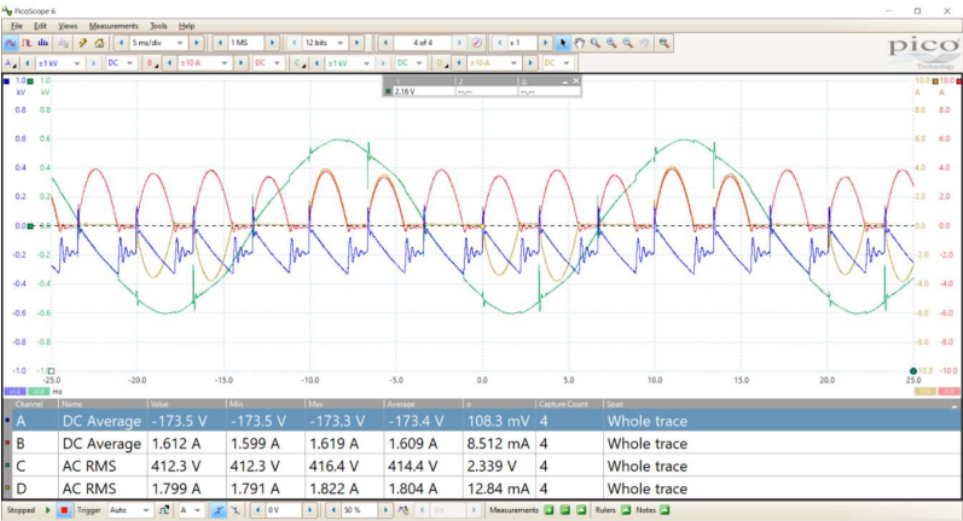


Appendix Figure 22 - 4-Quadrant Operation - 3rd Quadrant Picoscope Graph

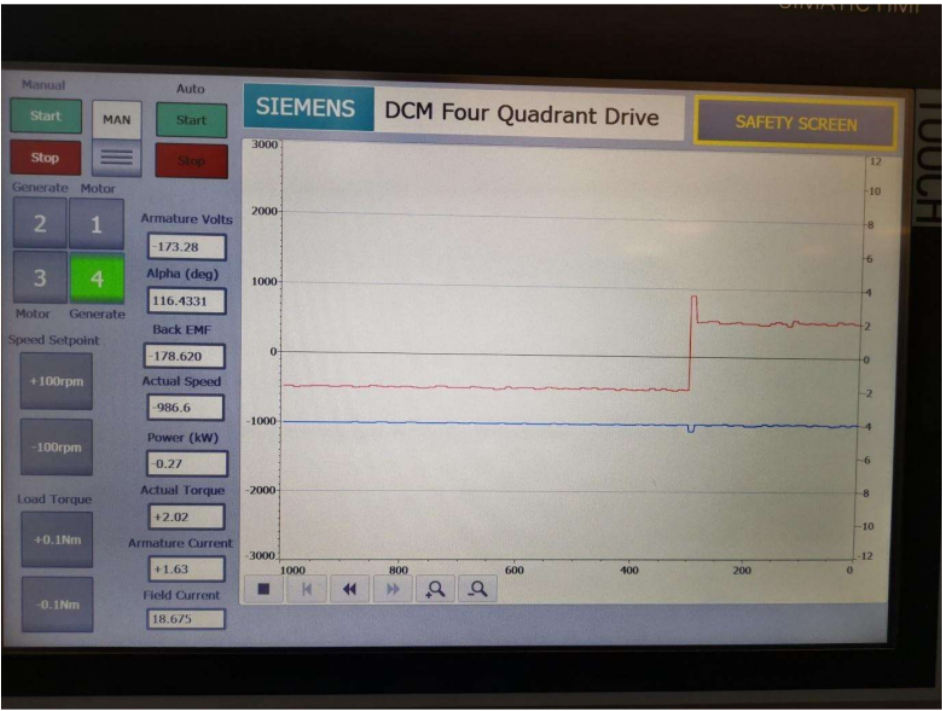


Appendix Figure 23 - 4-Quadrant Operation - 3rd Quadrant HMI

Quadrant 4

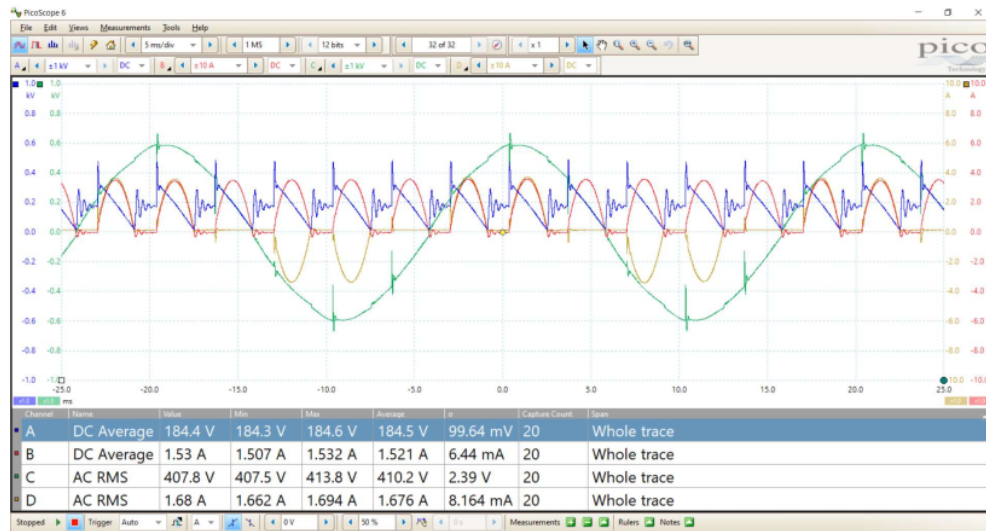


Appendix Figure 24 - 4-Quadrant Operation - 4th Quadrant Picoscope Graph

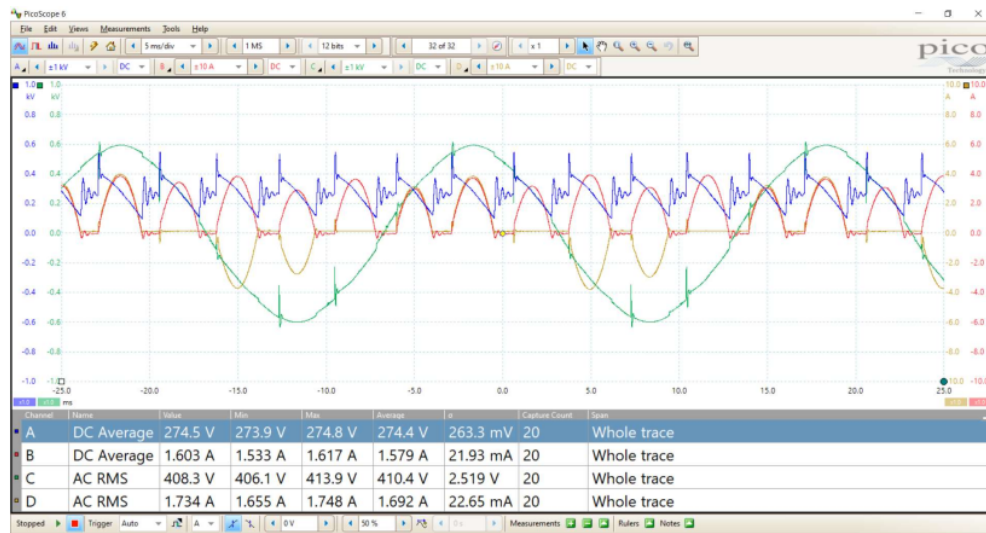


Appendix Figure 25 - 4-Quadrant Operation - 4th Quadrant HMI

8.3.3 Constant Torque / Variable Speed / Discontinuous Current in Quadrant 1



Appendix Figure 26 - Constant Torque / Variable Speed in Quadrant 1 – 1000rpm

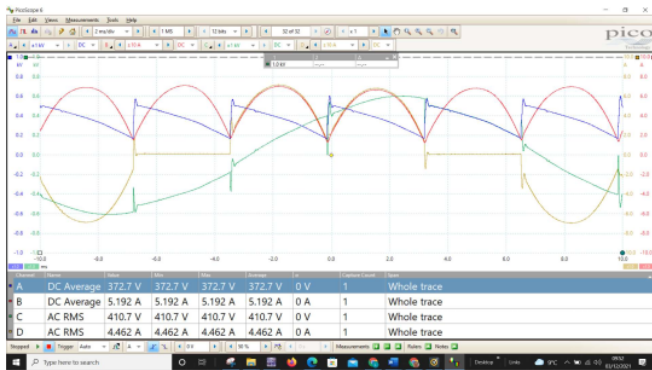


Appendix Figure 27 - Constant Torque / Variable Speed in Quadrant 1 – 1500rpm



Appendix Figure 28 - Constant Torque / Variable Speed in Quadrant 1 – 2000rpm

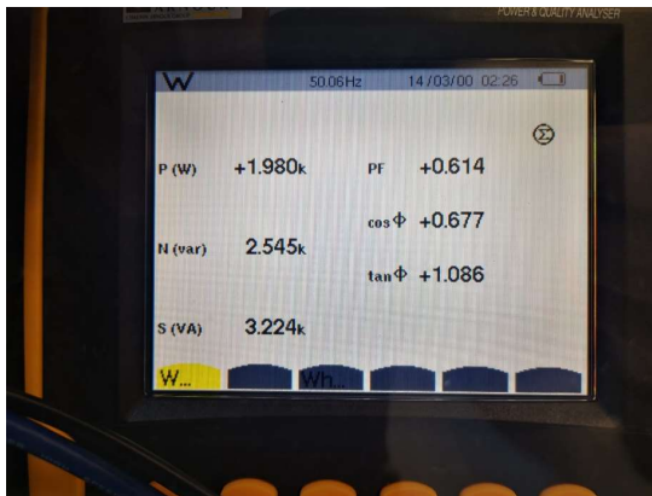
8.3.4 Varying Torque / Constant Speed / Continuous Current in Quadrant 1



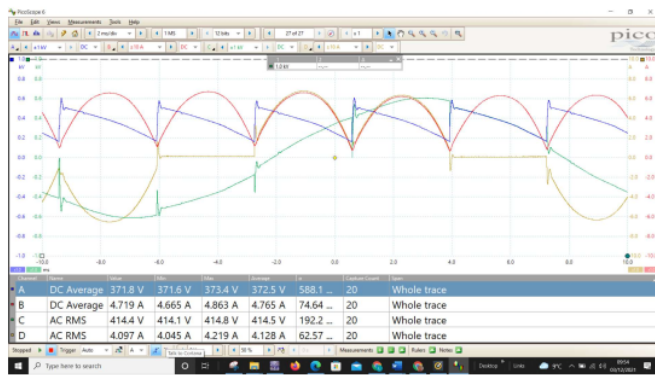
Appendix Figure 29 - Practical - Varying Torque / Constant Speed 2000rpm/6.66Nm



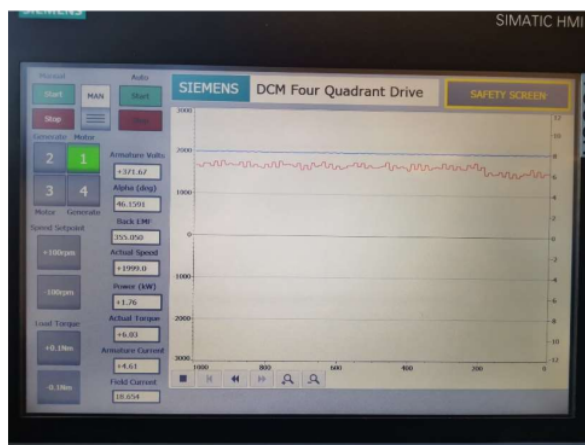
Appendix Figure 30 - Practical - Varying Torque / Constant Speed 2000rpm/6.66Nm HMI



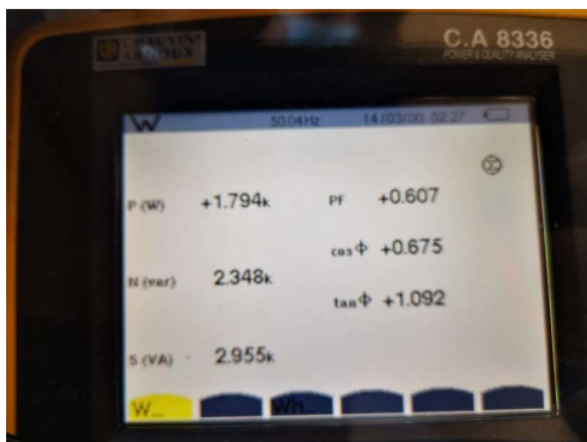
Appendix Figure 31 - Practical - Varying Torque / Constant Speed 2000rpm/6.66Nm Power Anl.



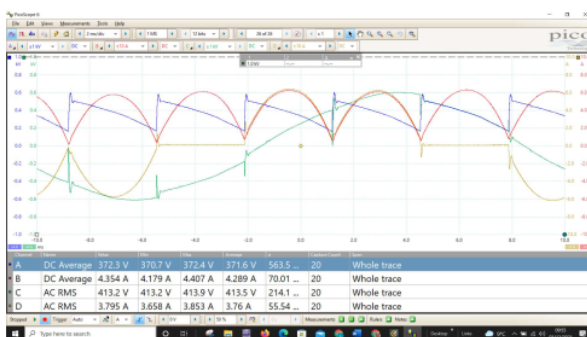
Appendix Figure 32 - Practical - Varying Torque / Constant Speed 2000rpm/6.03Nm



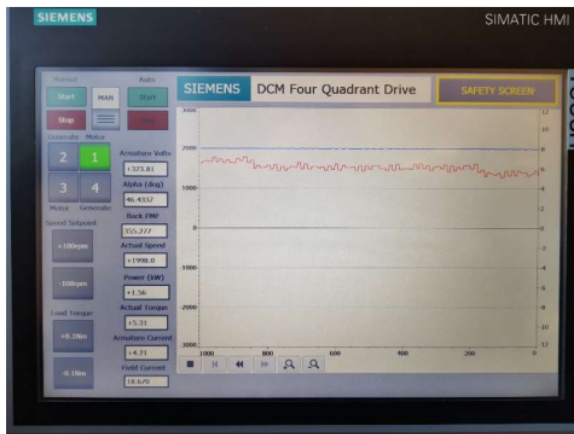
Appendix Figure 33 - Practical - Varying Torque / Constant Speed 2000rpm/6.03Nm HMI



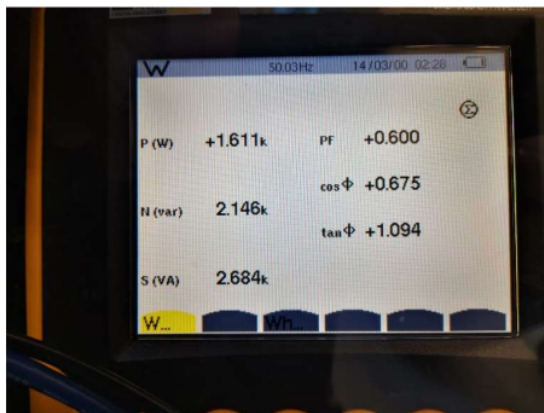
Appendix Figure 34 - Practical - Varying Torque / Constant Speed 2000rpm/6.03Nm Power Anl.



Appendix Figure 35 - Practical - Varying Torque / Constant Speed 2000rpm/5.31Nm



Appendix Figure 36 - Practical - Varying Torque / Constant Speed 2000rpm/5.31Nm HMI



Appendix Figure 37 - Practical - Varying Torque / Constant Speed 2000rpm/5.31Nm Power Anl.

8.3.5 Vmax & Vmean Calculations & Motor Constants

Discontinuous current

Area A & Area B

$$\text{Area A} = E \times y = E \left(\alpha - \frac{\pi}{3} \right)$$

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

Vmax

$$\begin{aligned} & V_{max}(-\cos \theta) \frac{\pi}{3} + \alpha \\ &= V_{max} \{ -\cos \pi - -\cos(\frac{\pi}{3} + \alpha) \} \\ &= V_{max} \left\{ 1 + \frac{1}{2} \cos \alpha - \frac{\sqrt{3}}{2} \sin \alpha \right\} \end{aligned}$$

Vmean

$$\begin{aligned} V_{mean} &= \frac{\text{Area A} + \text{Area B}}{\frac{\pi}{3}} \\ V_{mean} &= \frac{3}{\pi} \left\{ 178.75(1.416 - 1.047) + 589.6 \left(1 + \frac{1}{2} \times 0.154 - 0.866 \times 0.988 \right) \right\} \\ V_{mean} &= \frac{3}{\pi} \{ 65.959 + 589(1 + (0.077) - (0.856)) \} \\ \frac{3}{\pi} (65.959 + 130.169) &= 187.29V \end{aligned}$$

Motor Constants:

$$\begin{aligned} T &= K_v I_f I_a \\ 1.93 &= K_v (18.63)(1.46) \\ K_v &= \frac{1.93}{(18.63)(1.46)} = 0.071 V/A/rad/s \end{aligned}$$

$$T = K_b I_a$$

$$1.93 = K_b I_a$$

$$K_b = \frac{1.93}{1.46} = 1.322 Nm/A$$

Instructor

65/100

PAGE 1

Text Comment. unnecessary image

Text Comment. Generally good, well structured and presented

Text Comment. Research shows understanding

Text Comment. Good simulations and practical work

Text Comment. Analysis and calculations are mostly good except for the value of V_{max} chosen

Text Comment. Good conclusions and recommendations

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

Text Comment. A good summary should made up of around 300 words. This is far in excess of that.

PAGE 7



Correctly cited

Citation method conforms to Harvard standard, well done.

Text Comment. seems like an unfinished sentence?



Correctly cited

Citation method conforms to Harvard standard, well done.



Useful comments

This statement is helpful and shows a good understanding of the material presented



Useful comments

This statement is helpful and shows a good understanding of the material presented

Text Comment. This is a usweful table



Spelling

Spelling error



Useful comments

This statement is helpful and shows a good understanding of the material presented

Text Comment. AC

Text Comment. You should have used the measured V_{max} in your calculations in the appendix - includes the voltage drop across the thyristors

PAGE 15

Text Comment. good evidence of research

PAGE 16

Text Comment. You could have provided figures for waveforms in different quadrants

PAGE 17

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PAGE 19

Text Comment. you could have annotated the trace to show the quadrants

PAGE 20

Text Comment. excellent results

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Text Comment. you would need to calculate the output power to prove this

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GRADING FORM: NEW CSG-RUBRIC

LOURENS BRITS**65****1. ENGAGEMENT WITH LITERATURE**

There is excellent evidence of research and good use of Harvard referencing throughout from a wide range of sources. However, though the first 2 research questions have been covered in extensively, the 3rd question is rather brief. (14/20)

14**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. (13/20)

13**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

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evidence (that may be incomplete) to make mostly appropriate and valid judgements. (12/20)

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. (12/20)

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5. TRANSFERABLE SKILLS



An advanced application of a range of methods, materials, tools and/or techniques. The context of the application is well considered, and insightful. Word count maintained. Application and deployment extend beyond established conventions. Can identify complex problems and propose excellent solutions. Innovation and creativity evident. (14/20)

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