

1809800

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There is some evidence of understanding and good evidence of testing

However, there are many misconceptions and inaccuracies throughout particularly in your research

Simulations results are incorrect as the wrong value was recorded

Conclusions are rather vague

Recommendations are good.

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Executive Summary

Research was carried out into the operation and design of a DC converter, specifically the Parker DC9590+ series, the basic principle of operation and control methods were analysed and reviewed. This alongside an explanation of how a thyristor converter worked provided the theoretical understanding needed for the simulation and practical elements of the report. The DC contemporary DC drive was evaluated in relation to various industrial applications and the multiple variations of rectification available. All sources were credible in nature with little reliance on opinion pieces and a greater reliance on established literature and datasheets, any information collated from the web was up to date and from reputable sources.

A simulation of a three phase rectifier was analysed and converted into a DC drive with 4 quadrants in the second task. This simulation task allowed an analysis of the drive in all four quadrants in relation to established theory, this was further bolstered by an actual practical investigation where a DC motor with four quadrants was analysed under performance in all states as well at various speeds and torque values. What was found in this tasks tallied with established theory and research.

An overall conclusion of the results deemed the investigation a success, as the principal and understanding of DC drives was thoroughly explored and proven in both simulated and practical settings in relation to established theory.

Research

A typical three phase, four quadrant drive used in servo applications is the DC590+ Series DC Digital Drive manufactured by Parker. The specific AC supply voltage that can be accepted varies between the models, all of which are capable of powering a DC shunt field and permanent magnet motors, providing controlled DC output voltage and current for armature and field. The drive is designed to be modular by using standard spare parts in its design therefore reducing the variety of specialised components.

As an example of this, regardless of horsepower or bridge configuration, the control boards are the same standard among all the three phase armature controllers. Furthermore the control circuit is entirely isolated from the power circuit, making replacement connections easy and safe. The coding of the circuitry is such that it can adapt to accept supply frequencies between 45-65Hz with great immunity to interference and noise, furthermore the armature controllers are phase rotation insensitive.

In terms of control and communication, the drive is controlled by a 32bit microcontroller which provides features like; serial link communication with other drives or a PC, software-configurable control circuitry designed around the use of standard software blocks that contain complex control algorithms not normally attainable with other analogue techniques.

As is normal with most drives the keypad allows the access of parameters, diagnostic messages and setting of parameters such as trip values. (Parker, 2021)

Parker offers the motor armature controllers include in both regenerative and non-regenerative form:

In the regenerative controller, the use of two fully-controlled thyristor bridges and a field bridge allows for sophisticated control of speed, in regard to acceleration and deceleration and torque in both rotational directions. In the non-regenerative controller only one fully-controlled thyristor bridge is present with a field bridge and provide accurate speed and/or torque control in one selected direction of rotation. Furthermore the field bridge is designed to be fully transient, and overload protected in both models. (Invertek Drives, 2020)

As part of Parkers design the DC590+ Series DC digital drives come with a field regulator fitted as standard. Comprised of a full-wave half controlled single phase thyristor bridge with appropriate overload and transient protections.

A fixed current or fixed voltage source can be generated depending on the mode of operation and the specific constant torque application. A field current mode of operation can be used to alter the field strength for applications which require extended speed or constant horsepower control.

The two selectable control loops available are an inner current loop and outer speed loop. Selectable via the keypad on the drive.

Current control is achieved by feeding back an error signal to a PI control algorithm, providing the output current firing angle, the signal can be obtained in two forms.

1 - The average error is computed as the difference between demand and average value of feedback and fed into an Integral part of the P + I algorithm.

2 - The instantaneous error is computed as the difference between demand and instantaneous value of feedback and is fed into the Proportional part of the P + I algorithm. This gives higher transient performance since it does not contain any time lag, unlike the average which has a built-in lag of 1/6 of mains cycle. However, the average is the true measurement of torque which is the objective of the current control, and this is not affected by the small time lag in achieving zero steady-state error. (Parker, 2021)

The firing angle can be converted into a time delay function via a phase lock loop from the mains zero cross point, this results in a signal being sent to the thyristor stack every 1/6 of a mains cycle in steady state. Furthermore, as the gain of a thyristor 6 pulse converter drops exponentially at discontinuous value of an armature current, therefore within the current controller a gain boost is achieved. The algorithm is adaptive and as such allows the current to follow the demand and fire within the discontinuous region of operation.

The speed loop can be controlled via data from outside the loop e.g. a positional data or directly from the motor, the error signal is calculated as the difference between the demand and feedback values, this is input into a PI controller and produce the current demand signal.

The value of the integral is converted in a time constant value which set the function of the compensator against a certain load time constant. To reduce time lag and increase the bandwidth, the proportional part of the program is executed immediately before each run of the current loop. By utilising encoder feedback on an integral part of the PI program and analogue tacho feedback on the proportional part of the algorithm, the drive achieves maximum transient response with the increased steady state accuracy of the digital feedback.

Within the design of the parker drives, current sensors are integrated parts of the design, and speed feedback is achieved by encoders, tachogenerators or the armature sensing circuit. If the speed control loop is chosen, the performance can be further altered by weakening the field current, this allows the motor to be run at a speed greater than is permitted by the rated armature voltage of the DC motor. (Parker, 2021) In DC motors that possess a separately excited field winding, the motor can be run at higher than the rated speed with a proportional reduction of the field flux. Many high power rating motor drives use wound fields, using a line frequency phase controlled converter that will be explored in detail later in this section, can be used to control I_f through the field winding. The current is modulated in magnitude but only flows unidirectionally. Using a thyristor converter the output voltage is reversible and the field current can be decreased rapidly. (Mohan/Undeland/Robbins, 1995)

The advantages of regenerative drives are of course the ability to brake the motor, there are several ways the regeneration of the load can be dissipated instead of flowing into the DC link of the drive. Several designs are available to mitigate this phenomenon. One such way is DC chopper drives, in which a resistor is placed across the DC drive to dissipate energy.

The resistor is controlled by the IGBT and the accompanying software to monitor the DC voltage and switch the resistor accordingly. This has the effect of chopping the voltage, the system is also known as resistive braking or dynamic braking. The schematic of this can be seen in Fig.1

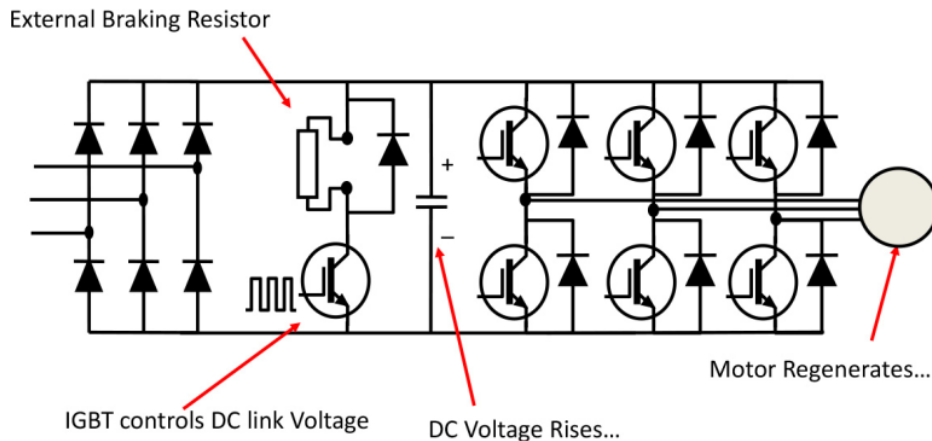


Fig.1 – Chopper DC Drive - (Invertek Drives, 2020)

This setup allows full load currents to be returned to the drive and dissipated safely. This means the drive can now function for applications involving controlled lowering and rapid deceleration.

This method is having its drawbacks, firstly the resistor normally will not be included with the drive package, it must be selected carefully at the required high DC voltage and fused appropriately. It must also have a minimum ohmic value to limit the current in the IGBT. It must be capable of handling the full power over the duty cycle of the machine. There is also the safety and aesthetic aspect of the resistor normally being mounted outside the unit with appropriate shielding due to the heat they hold as well as being ingress protected against debris.

This design is optimal for medium to low power application and occasional braking. If there is a lot of power required to be dissipated or a constant need of braking, then a fully regenerative drive will be needed as otherwise an inordinate amount of energy will be wasted instead fed back to the supply to mitigate this, we need to replace the input rectifier with a fully functioning inverter as shown in Fig.2. Ideal applications include battery operated vehicles, switched mode power supplies, trolleys and hoists and can be used to control the speed of wound rotor induction motors. (ElectricalWorkbook, 2021)

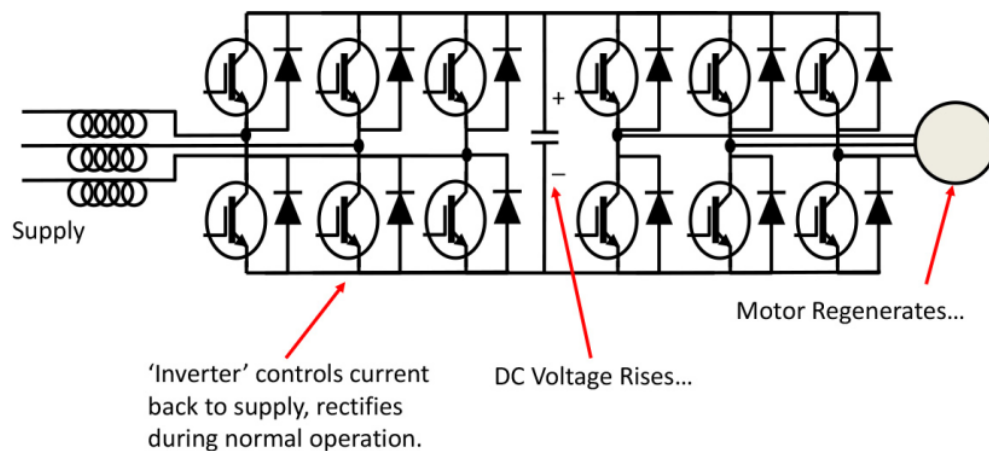


Fig.2 – Regenerative DC Drive - (Invertek Drives, 2020)

As power can flow through both way through an inverter, therefore the regenerated power can be fed along the DC link and back through the inverter to the mains supply. A great advantage of this design is the control of the input harmonics under normal operation which is vital at high power applications. The relative cost of the drive electronics used in this design as well as the associated electronics and inductors can be justified by any system that can regenerate 200kW or greater. A specific feature of this design is that with system with several drives is to connect the DC links together so when one motor is regenerating it supplies power to the other drives that are motoring.

A typical range of DC drives are as follows, DEC 1Q speed controller. This type of controller only operates in the first quadrant, meaning speed and torque can only be controlled in one direction, meaning current only flows in one direction. A module such as this does not possess braking capabilities and must rely on friction. This simple speed control model would be useful for blowers, pumps and cutting drives. (Maxon Motor Control, 2018)

Four quadrant controllers such as the ESCON, EPOS and MAXPOS means we can operate in all four quadrants, meaning with quadrants 2 and 4 the motor speed and torque can be in reverse to 1 and 3. With this functionality we can maintain speed under changing load in both directions, acceleration, and braking, with the ability to actively break down the motor speed as torque and speed can be applied in opposition to the direction of rotation. This braking means energy is back fed and saved and mis dynamic in response to speed control, these types of modules are vital for any sort of positional control application.

In further detail the ESCON module has dynamic current control, in which the actual motor current is compared to a set value with the ability for dynamic readjustment. Furthermore it can also operate in a closed loop speed control method as well as open loop. In the case of the closed loop speed control the actual speed is compared to a set value and dynamically adjusted, in the open loop system a voltage is applied to the motor which is proportional to the set value. Because of this the ESCON module is best suited for conveyor drives, hand tools and scanners. (MAXON, 2022)

The EPOS2/EPOS4 module is more suited for positional control, and can be used in application such as actuators, lab automation and door drives. Whereas the more sophisticated MAXPOS modules are highly dynamic drives and can be used in complex robotics, pick and place and on the fly processes. (Drive.Tech, 2022)

To conclude, this section has given an overview of DC drives and their relative and comparative uses between different methods of positional control. An analysis of the Parker DC590+ Series DC Digital Drive, the basic principles of operation and how it achieves speed control. The 1Q and 4Q drives were looked at extensively in both their advantages and disadvantages which is ultimately up to the engineer to decide which of the two is more appropriate for the project. We can summarise that if the application is dynamic in its deceleration a four quadrant drive is required. For instances where only speed is controlled a 1Q or 2Q drive may be applicable and more cost effective, and if regeneration is not an issue a chopper drive could be used, though compared to these modern controllers is a fairly archaic method. A range of devices have been explored and give a broad overview of how different drives are applicable for different design specifications.

Simulation and Design Adaption

Using Multisim software, a separately excited DC motor can be modelled. This is seen in Fig.3, comprised of an inductive, resistive load with accompanying back EMF. Using this model waveforms for a full wave fully controlled three phase rectifier can be produced for current and armature voltage. Three firing angles will be chosen, and the simulation will be run alongside accompanying calculation so that the two methodologies can be compared in relation to average armature voltage.

As can be observed from Fig.3, a three phase full wave controlled rectifier can be seen, including an inductive load can be seen in the simulation software. A 240V three phase supply is fed into a PFC, or phase controller, alongside DC offset and the alpha firing angle. The six outputs are fed into isolation transformers, these 1:1 transformers serve as an isolation between the AC power line and the electronics, meaning there is no DC path between the two windings. They provide galvanic isolation from the two sides and reduce line noises being transmitted from the primary side to the secondary side and vice versa. (Stull, 2019) The supply is fed into the thyristor bridge and produces DC current via modulating the voltage signal. Using a DC power supply to simulate back EMF and feedback, the signal is parsed across a snubbing capacitor circuit to smooth out voltage and current spikes, limiting dV/dt or di/dt and reducing overall noise and interference to prevent damage to IGBTs and thyristors. In power converters these capacitors are subject to high dV/dt changes and high values of peak and rms current. Meaning ceramic and polypropylene film capacitors are suitable for said applications. (Passive Components, 2019) The resulting waveform is presented on the oscilloscope and will be used in the simulation phase.

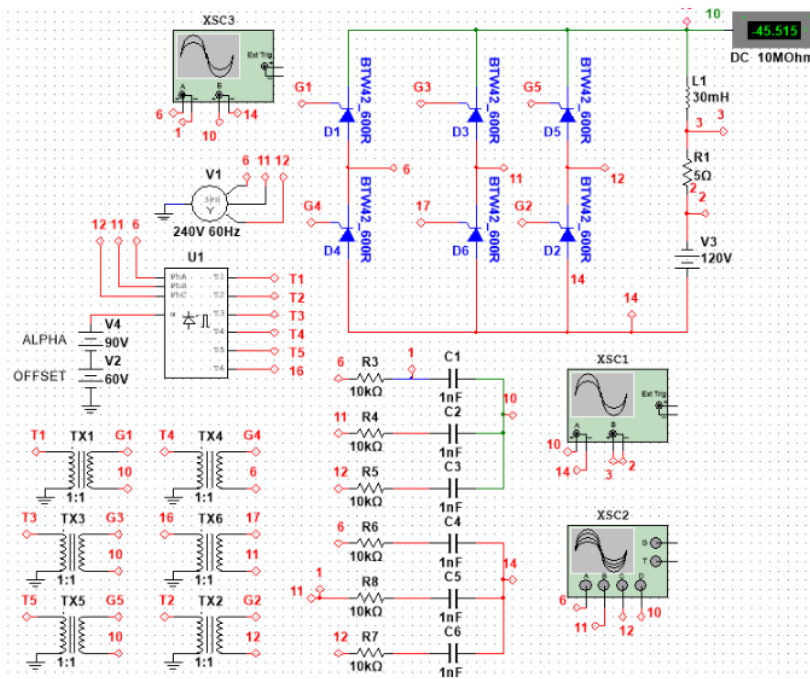


Fig.3 – Three Phase Full Wave Rectifier

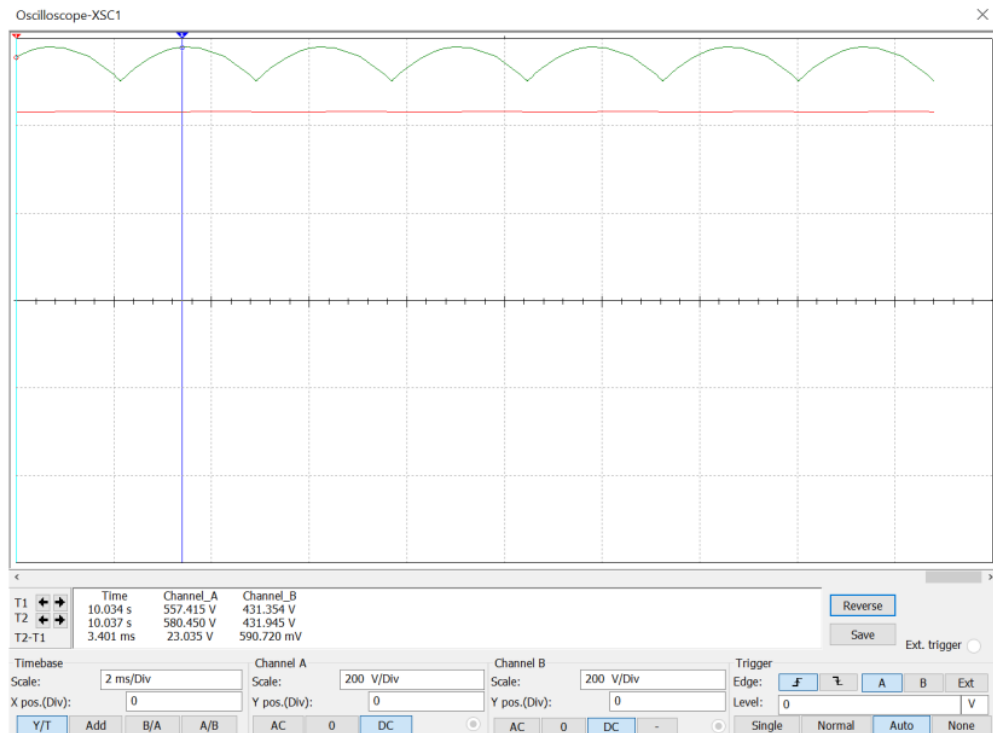


Fig.4 – Vmax Acquisition

Fig.4 shows how Vmax was obtained to carry out the calculations, furthermore, running the simulation at three different firing angles gives us the following simulated and accompanying calculated results. The Multisim results are obtained from the screen shots in appendix 1.

Firing Angle	Multisim Result	Calculated Result
10	541.145	541.133V
20	516.278	516.343V
30	475.876	475.864V

It can be observed that the simulated and calculated results are extremely close to the simulated results, this means that they are indeed correct with discrepancies attributing to limitation of simulation software in relation to losses.

To modify the design to run as a DC motor with all four quadrants, another thyristor bridge will be required as we have already seen from the research, this bridge allows the motor to run in revers polarity in terms of regenerating. The DC power supply that acts as back EMF has to be reversed and a switching array is made to alternate the two modes. Fig.5 shows the completed design. The design was then run in all four quadrants with accompanying waveforms captured.

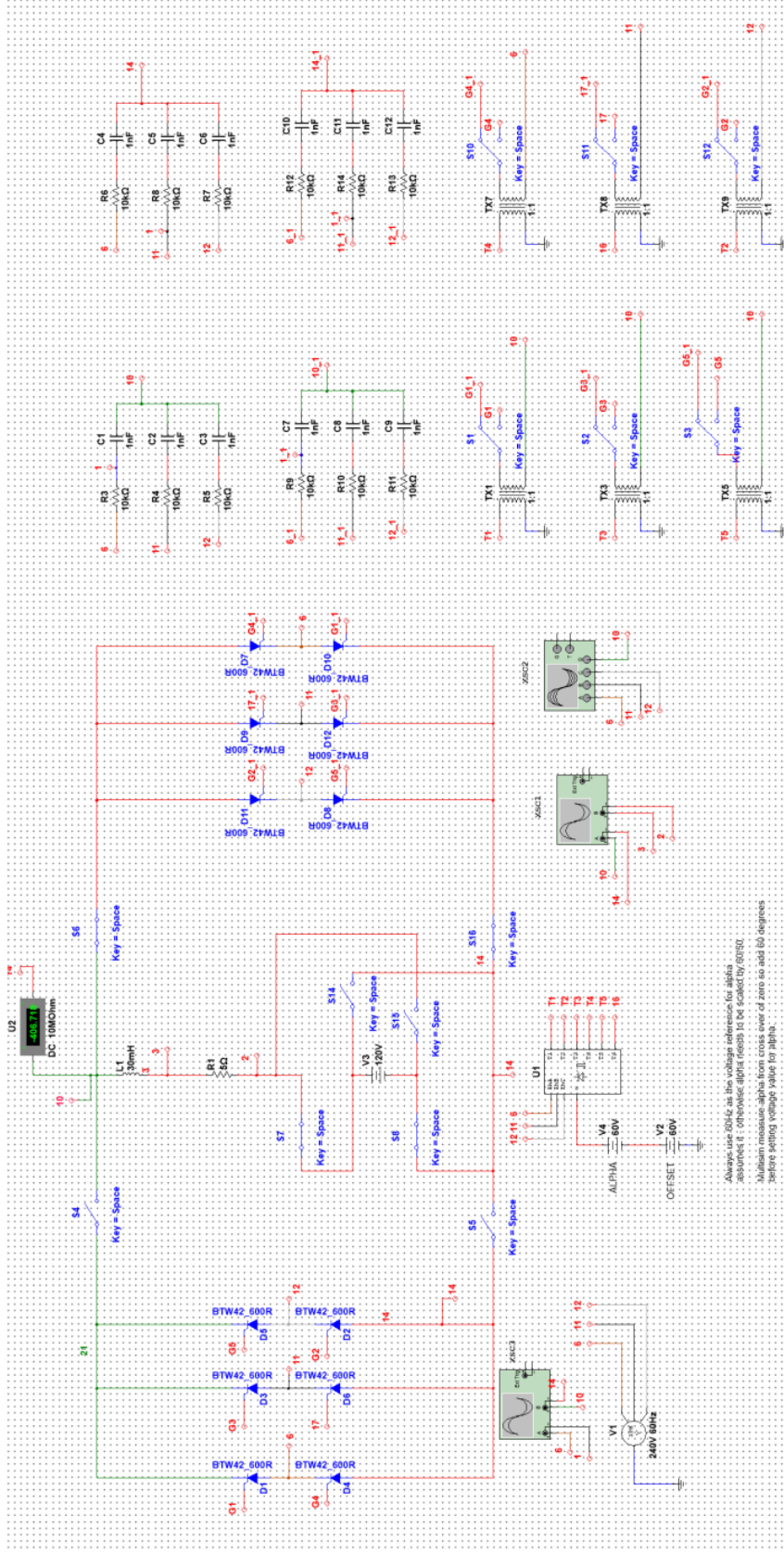


Fig.5 – Rectifier 4 Quadrant DC Drive Modification

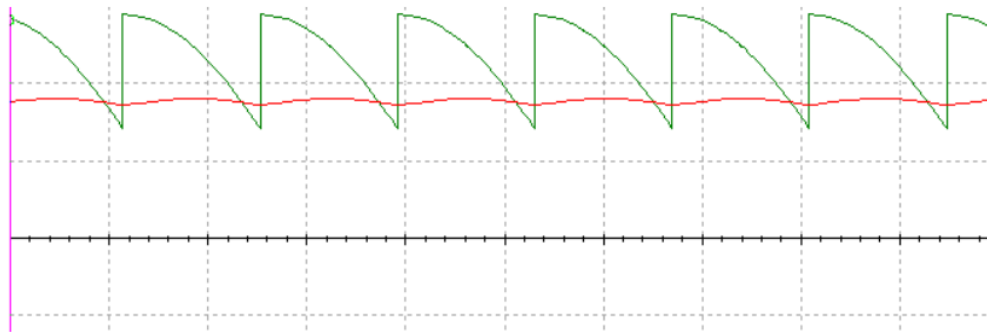


Fig.6 – Quadrant 1 Operation Waveform

Fig.6 above is a waveform capture of the motor operating in quadrant 1, this can be proven as both the voltage and current are positive. The firing angle is set to 30, in this mode the motor will run at a steady speed in the forward quadrant.

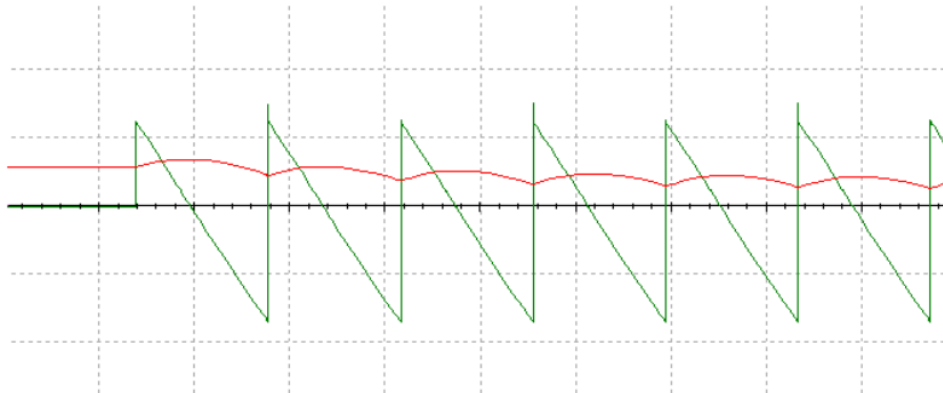


Fig.7 – Quadrant 2 Operation Waveform

Fig.7 above is a waveform capture of the quadrant 2 operation where the polarity of the DC power supply, or back EMF is reversed and alpha is set above 90 to cause the average voltage to invert, this operation is known as regenerative forward braking, and will eventually stop in this state.

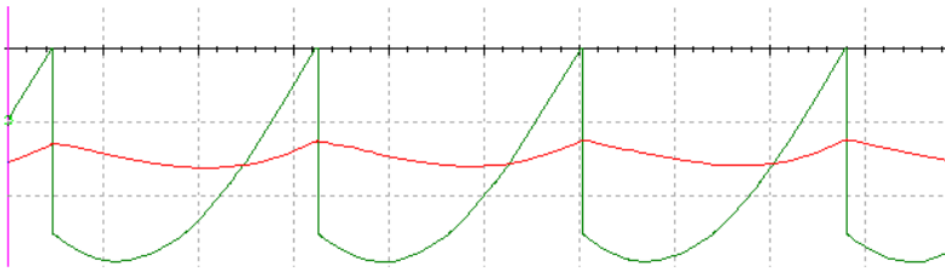


Fig.8 – Quadrant 3 Operation Waveform

Fig.8 above demonstrates the waveform of quadrant 3 in operation, in this state both voltage and current are negative, the back EMF is still in reverse polarity and alpha is less than 90. In this switched configuration the thyristor network is reversed and thus so is the voltage. This means the motor will run in reverse but not regenerate.

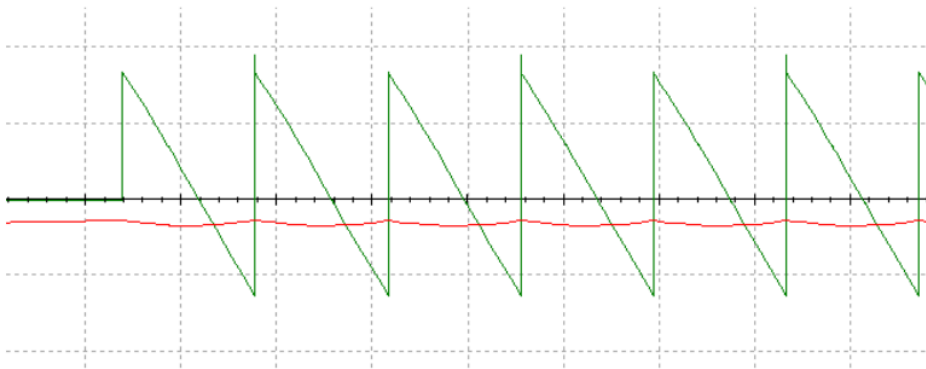


Fig.9 – Quadrant 4 Operation Waveform

Fig.9 above demonstrate the waveform of a quadrant 4 response. The back EMF is not inverted, and alpha is greater than 90, this results in a positive voltage with negative current. This means the motor will act as in regenerative reverse braking.

Practical Investigation

In this section an investigation into the operation of a Siemens three-phase DCM drive connected to a Siemens s120 AC drive acting as a load. Using an integrated HMI to control the drive, and an accompanying Pico scope and power quality analyser to record data. The setup of the system can be seen below in Fig.10. The Siemens Sinamics DC Master Series converter is our four quadrant controller for the variable speed DC motor in the accompanying photo. It regulates the field and armature current to achieve 4 quadrant control. The Sinamics S120 6SL3040-1MA01-0AA0 is controlling the AC motor that is acting as the load, the HMI can set the resistance met by the DC motor from the AC motor as well as the input to the DC motor. The two clamp meters below the DC drive monitor input current and the field current of the DC motor. The three clamp meters connected to the transformer are run back to Pico scope software monitored by the team.

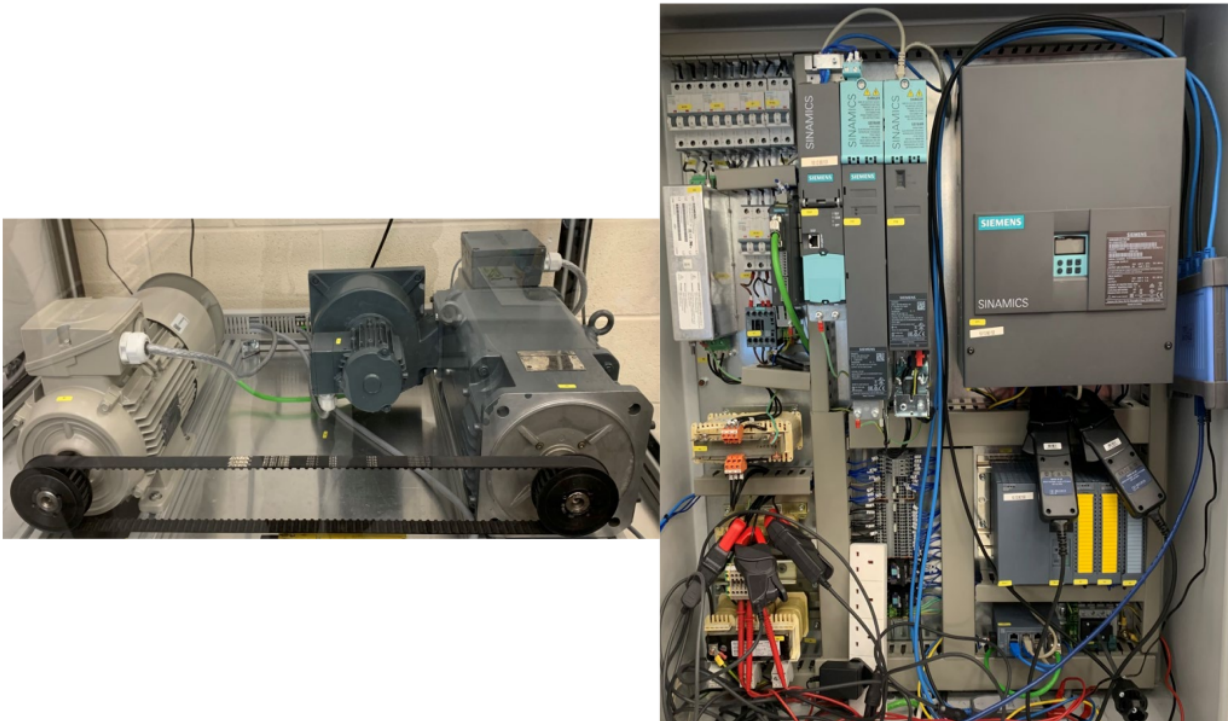


Fig.10 – Practical Setup Connection and Layout

The Pico scope software is used to monitor the drive performance, Fig.11 shows an example waveform. The green waveform represents one phase of the AC input to the DC converter, the yellow waveform is the supply current. The blue waveform is the firing response for each thyristor for each input phase, the ripple after the pulse is the back EMF settling. There is also an accompanying drop in the mains voltage as can be observed on the AC supply waveform. Each time a thyristor fires it will sync with one of the three phases, between either 90-180 degrees for the positive half cycle or 270-360 for a negative half cycle. The negative half cycle is rectified by the thyristor bridge to DC voltage. The red waveform represents the current in the DC motor's armature. This peaks lower than the yellow waveform which is the supply current due to heat losses in resistance in the converter, in an ideal system the rate of change of current being $D_i D_t$ would equal zero making the yellow and red waveforms overlap perfectly. The current rises during a state when;

$$\text{Thyristor voltage } (V_a) > I_a R_a$$

And then when

$$V_a \leq \alpha$$

The current waveform will decrease to zero until the thyristor fires again, from Fig.11 we can see that the armature and line current peak at the thyristor decline, where it should ideally match up, however because of the voltage drop in the motor, the decline will not meet the alpha point at that precise time. Now that we have examined the

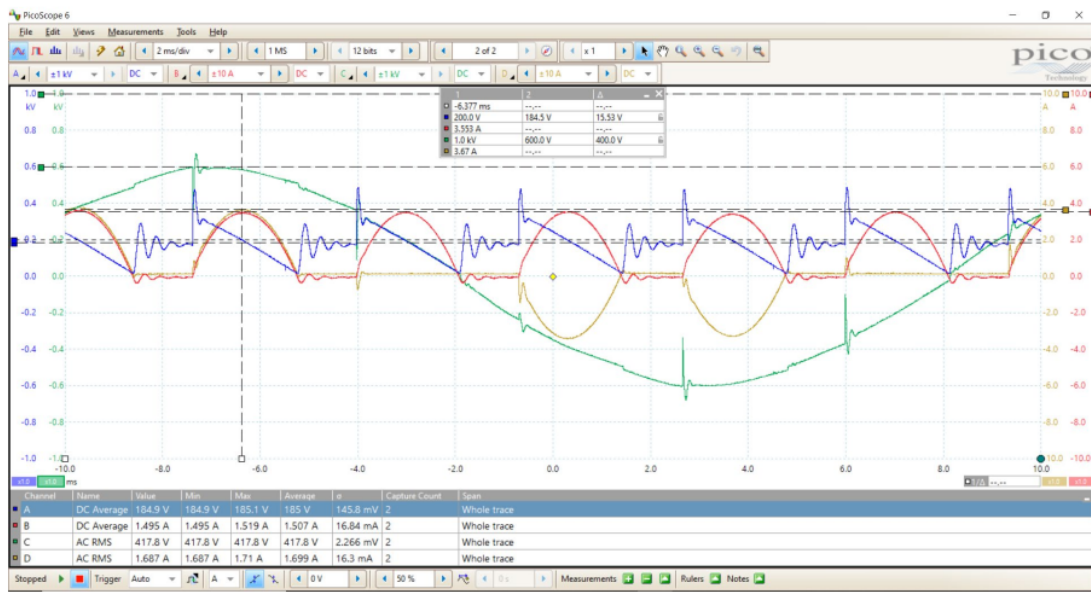


Fig.11 – Pico scope Waveform

From this capture the dynamic resistance can be found.

$$V_a = E + I_a R_a + L \frac{di}{dt}, \text{ at peak current } L \frac{di}{dt} = 0$$

Therefore,

$$R_a = (V_a - E) / I_a = 15.53 / 3.553 = 4.371$$

Fig.12 show a quadrant 1 operation of the DC converter, as seen with simulated results for this quadrant, both the current and voltage in the armature are positive. The motor is at a steady rpm and torque in the motoring operation where $\alpha < 90$.

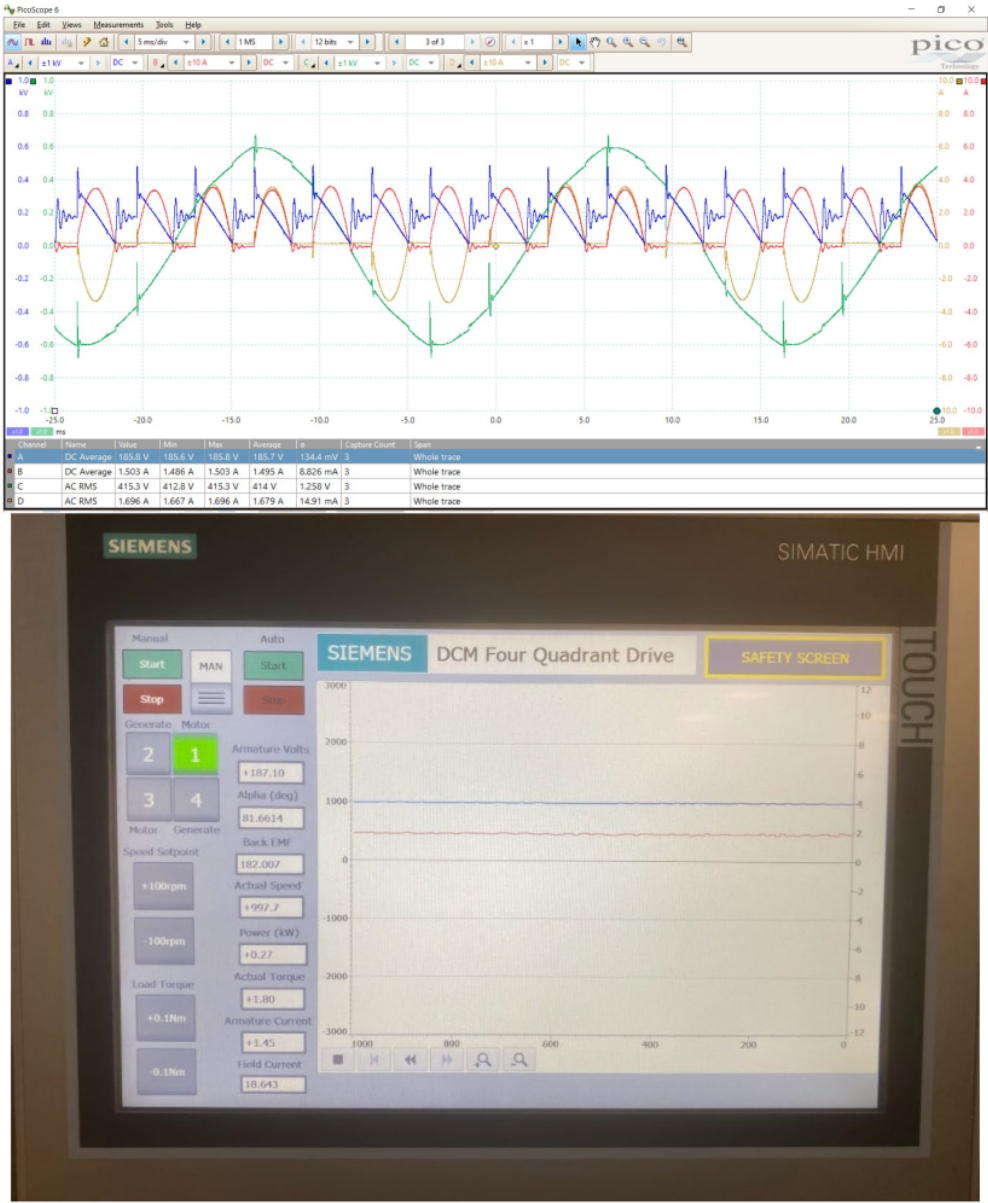


Fig.12 – Practical Quadrant 1 Operation Waveform

Fig.13 shows the practical operation of the second quadrant where the armature voltage is positive and the armature current is negative, the motor acts in regenerative forward braking where $\alpha > 90$. The rpm stays steady but the torque can be observed to reverse which will eventually stop the motor.

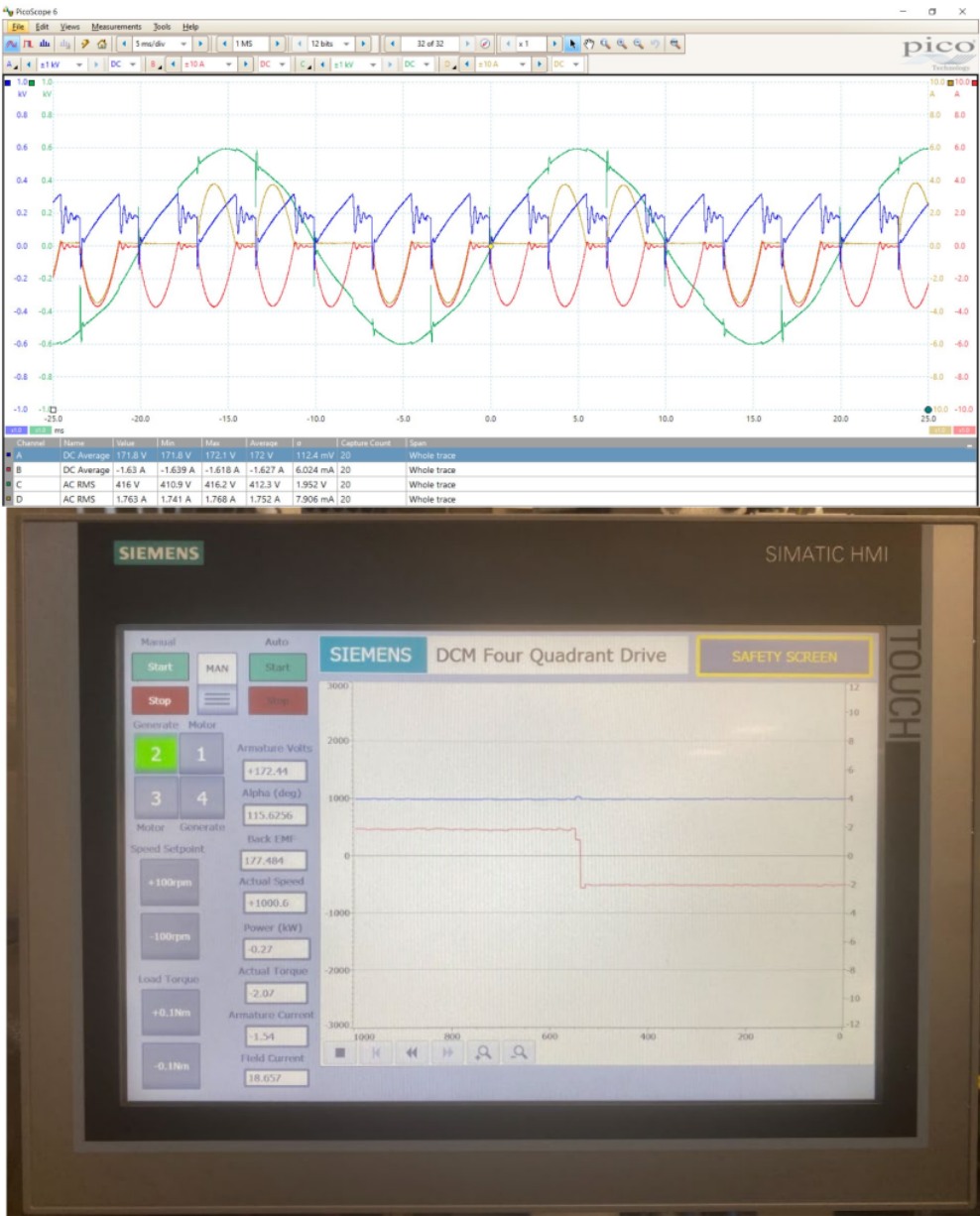


Fig.13 – Practical Quadrant 2 Operation Waveform

Fig.14 shows the quadrant 3 operation, both speed and torque are negative, meaning current and voltage are negative. This means the motor is operating in reverse motoring with $\alpha < 90$.

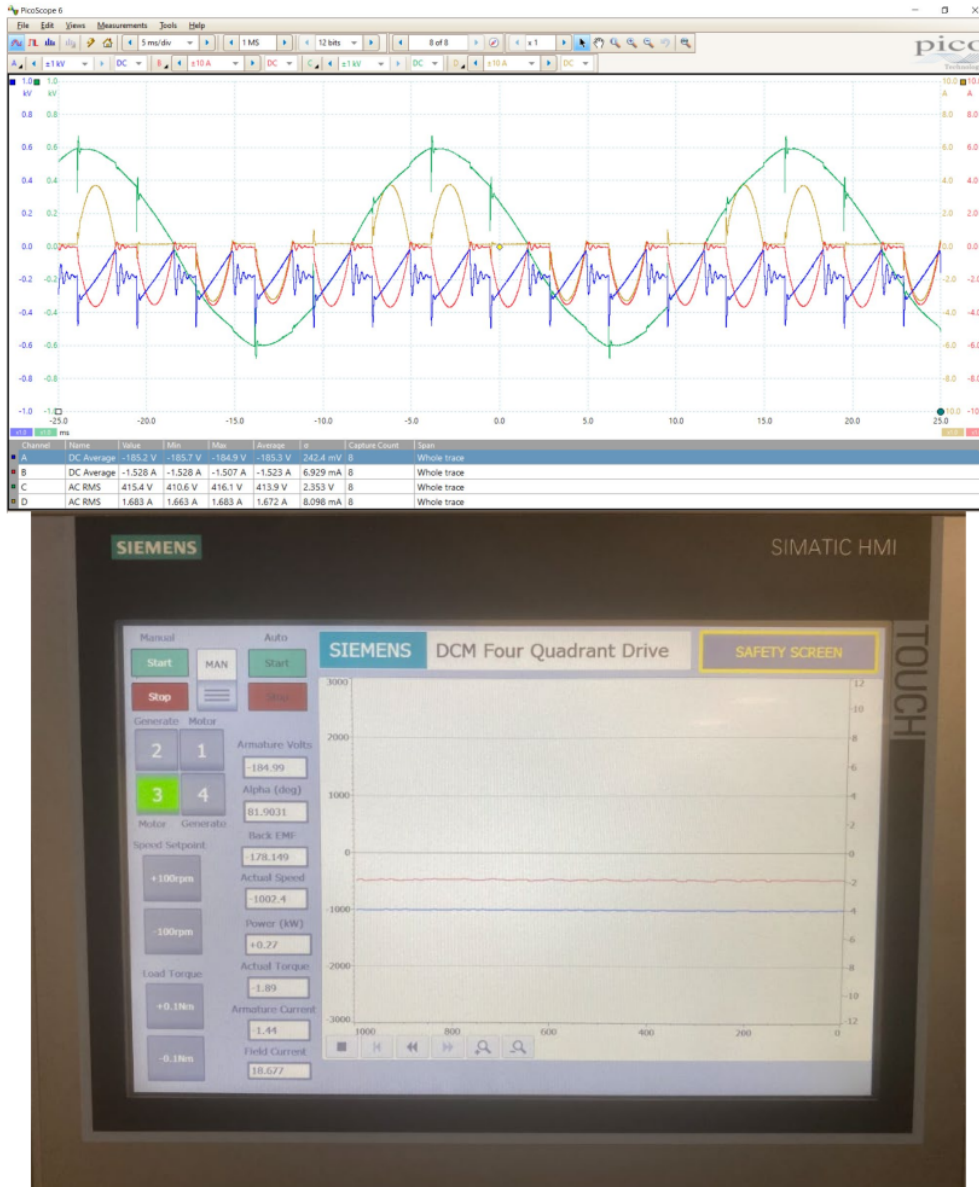


Fig.14 – Practical Quadrant 3 Operation Waveform

Fig.15 shows the motor operating in the quadrant 4 mode, where speed is negative and torque is positive, with armature voltage being negative and armature current being positive. This signifies regenerative braking in reverse, with $\alpha > 90$.

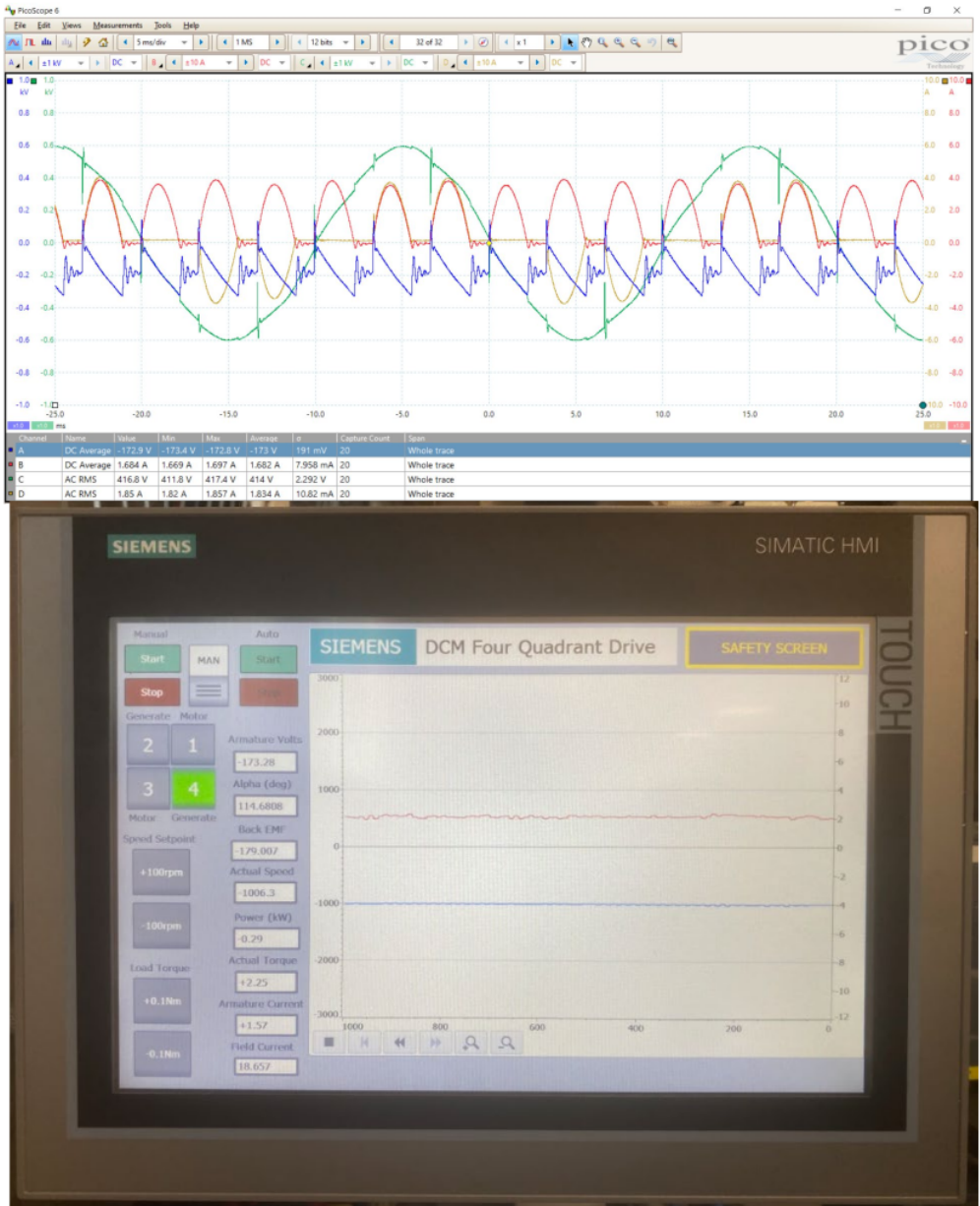


Fig.15 – Practical Quadrant 4 Operation Waveform

The motor setup was also run in quadrant 1 with constant torque whilst varying speed, the resultant waveforms can be found in appendix 2. What was observed is that as the speed decreased so did the armature volts, back emf and power as well as the firing angle this is to be expected. The motor was also run in quadrant 1 with an increase in torque over three set points, what was observed is that the increase in load also caused an increase in back EMF and power. This can also be seen in appendix 2.

Overall the drive performed as expected from the research and simulated theory, the principle established of 4 quadrant operation can be viewed practically in relation to theory and an overview analysis of the characteristics of all four quadrants.

Overall Conclusions and Recommendations

To conclude, the research element provided the fundamental understanding of DC converters in relation to their relative use and application in various industrial applications and multiple variations of the DC drive. The Parker DC drive was looked at in detail to provide an understanding of how a general DC drive works. The thyristor bridge design was also investigated to comprehend the fundamental operation of how modern converters work. This knowledge was bolstered by both the simulated and practical tasks that demonstrate the technical workings of the converter in a practical and simulated environment where the explored theoretical principle could be demonstrated to an engineering layman. Overall the investigation and report were a success, the information gathered and then explored correlated with what was expected and a semi thorough analysis of the modern DC drive was undertaken. To further improve the investigation of the DC converter, is an analysis of harmonic variation on the supply by variation of the thyristor firing angle. A further analysis could be made upon the chopper drive in relation to regenerative braking.

Team Working and Health & Safety Precautions

The teamworking element of the assignment can be deemed a success as the practical experiment yielded all the necessary evidence needed to evaluate the performance of the drive in relation to the research and simulated tasks. The authors role in the team was to gather all pictorial evidence and set the Pico scope software to capture the waveforms. Gareth Wilkins recorded all data needed and Thomas Grennan collated the waveform screenshots as well as oversaw the Pico scope analysis. All Covid restrictions were followed during the task, as well as health and safety considerations as the task was undertaken on live electrical equipment and moving mechanical apparatus.

Harvard Citation List

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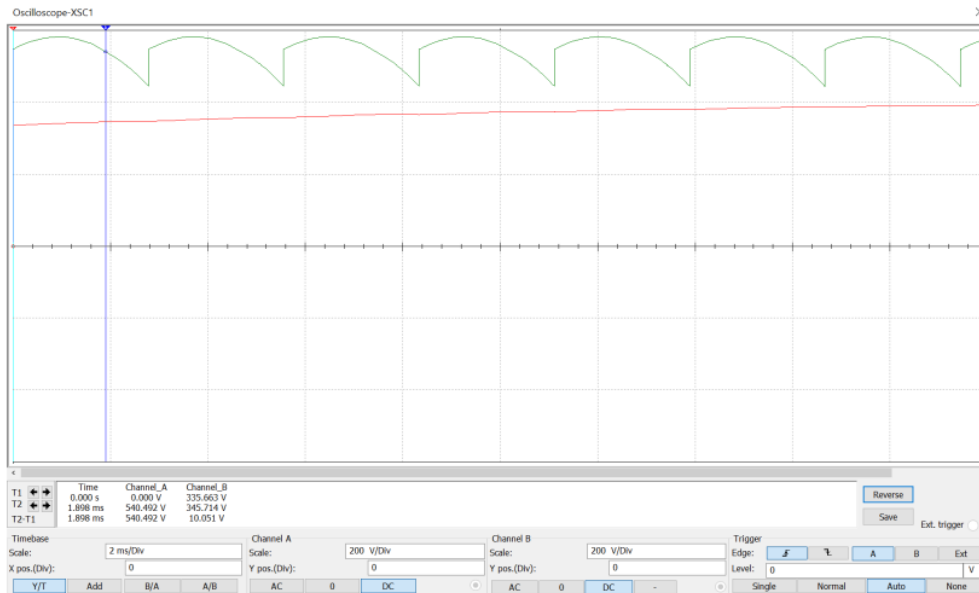
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[Accessed 10 January 2022].

Appendix

Appendix 1 – 3 Firing Angles



$$V_{mean} = \frac{3(575.415)}{\pi} \cos(10)$$

$$V_{mean} = 541.133V$$

Multisim simulated result = 540.492V

$$V_{mean} = \frac{3(575.415)}{\pi} \cos(20)$$

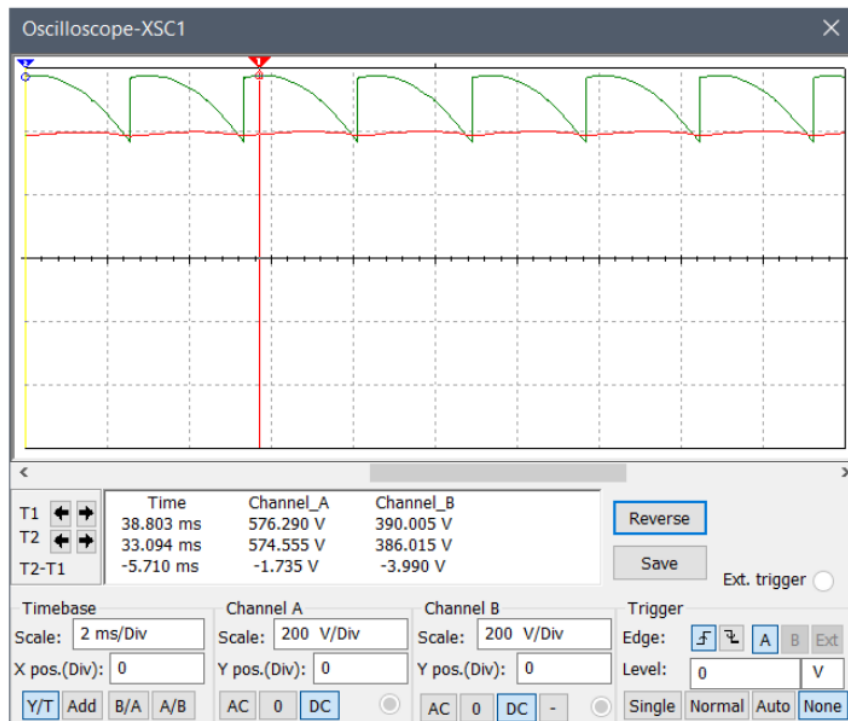
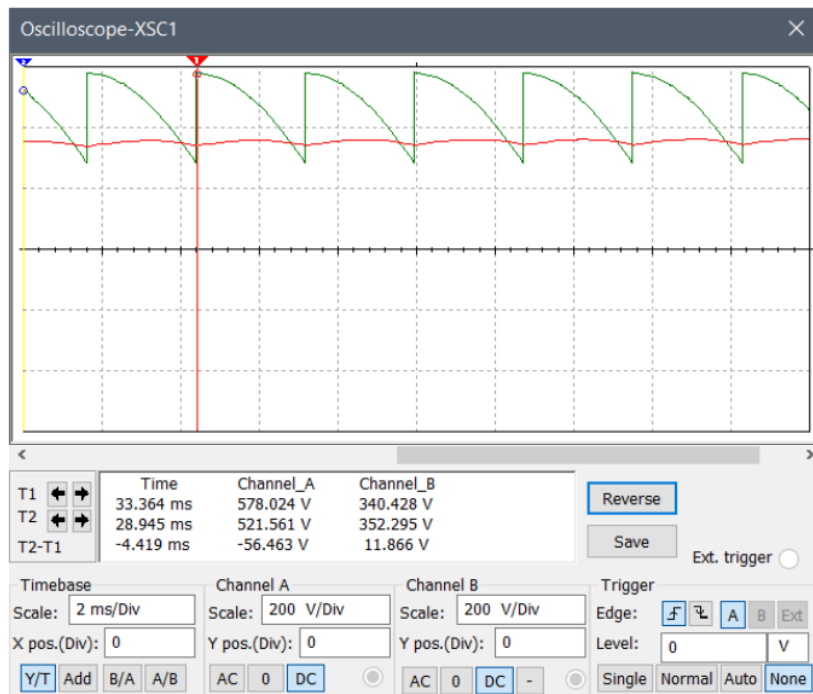
$$V_{mean} = 516.343V$$

Multisim simulated result = 516.343V

$$V_{mean} = \frac{3(575.057)}{\pi} \cos(30)$$

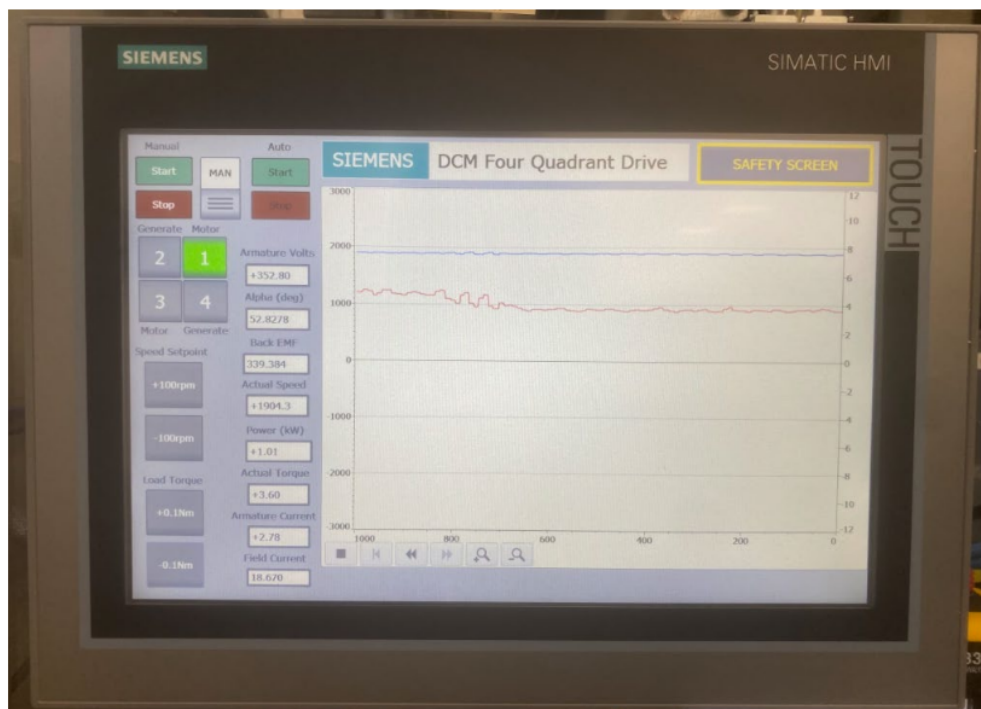
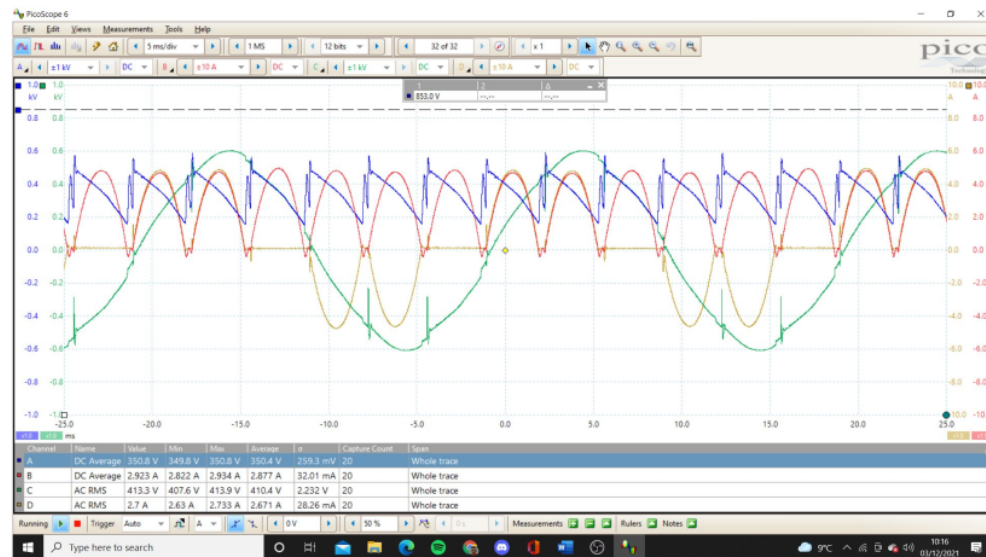
$$V_{mean} = 475.864V$$

Multisim simulated result = 475.864V



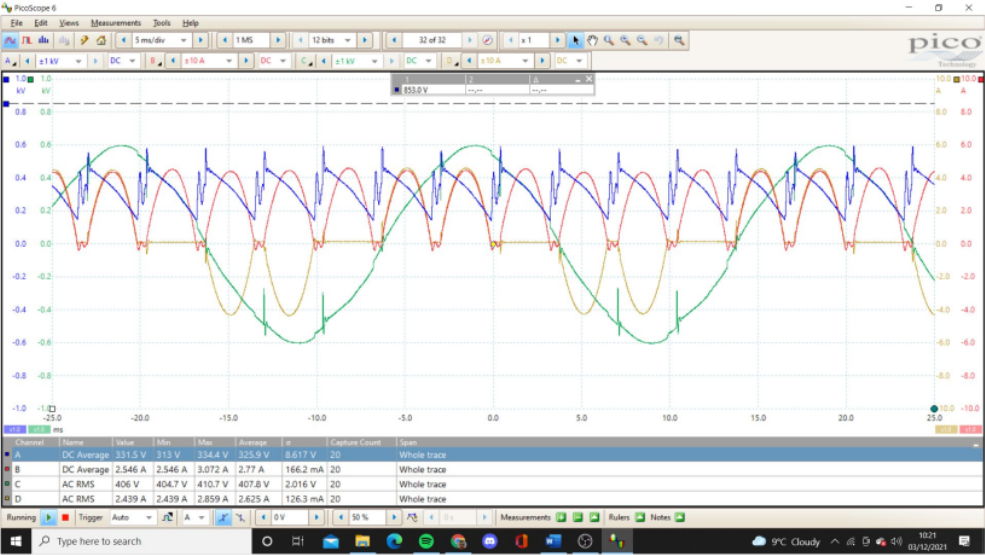
Appendix 2 - 3 Different Speed Set-points

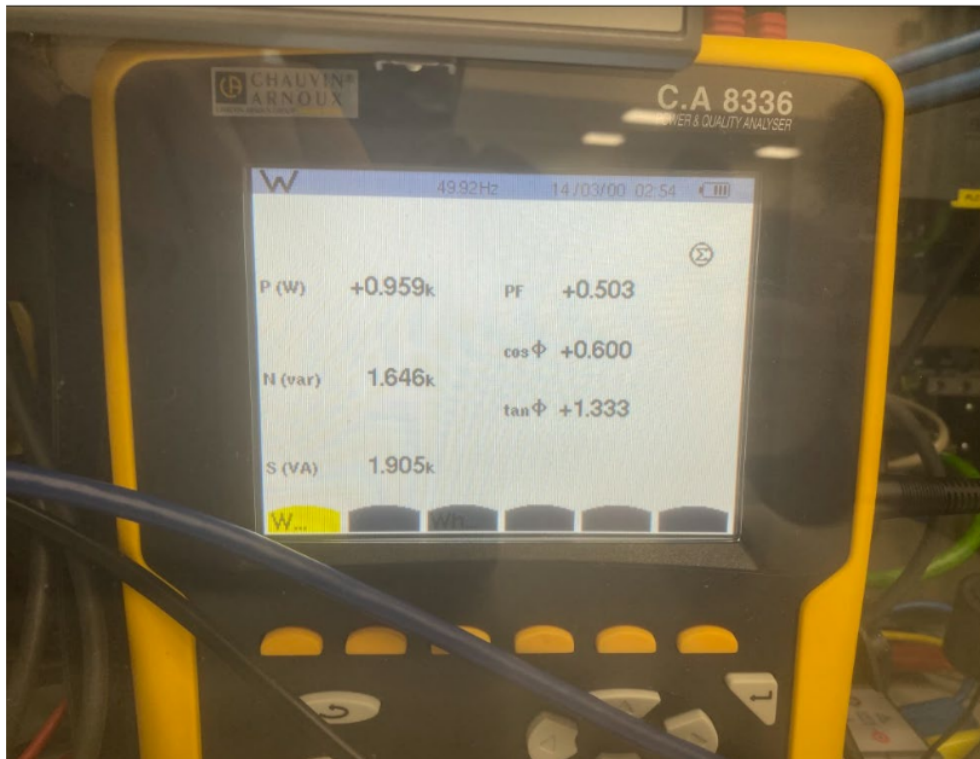
SP1



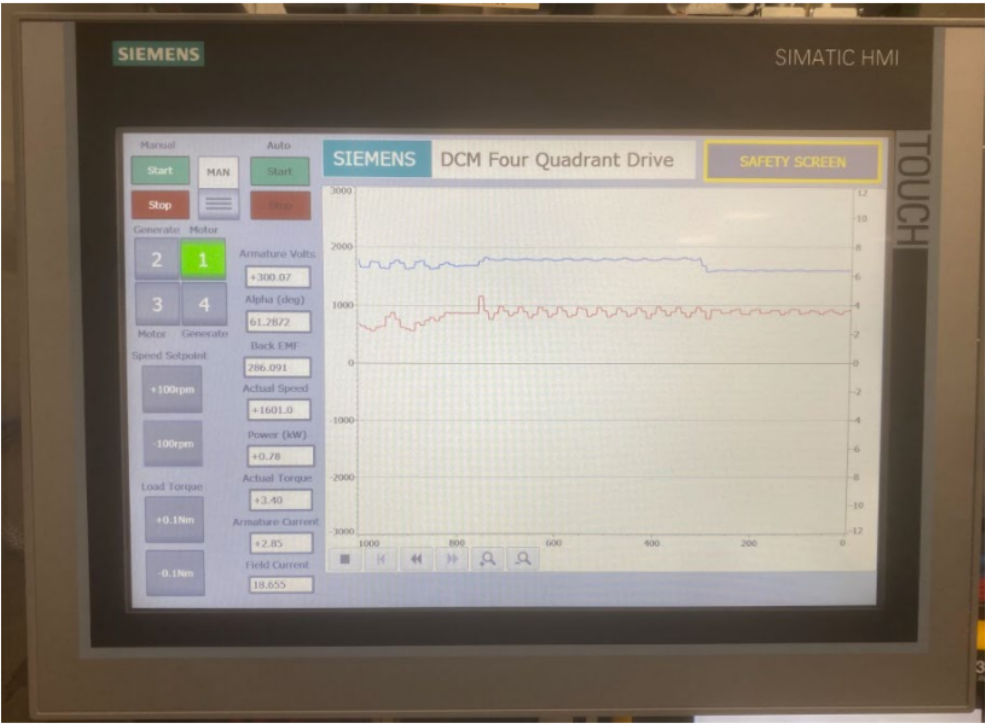
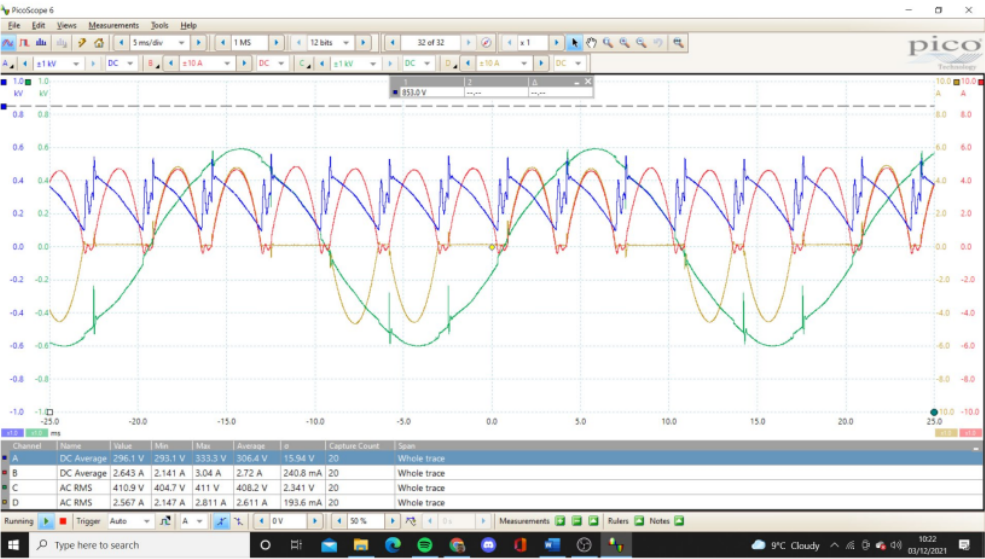


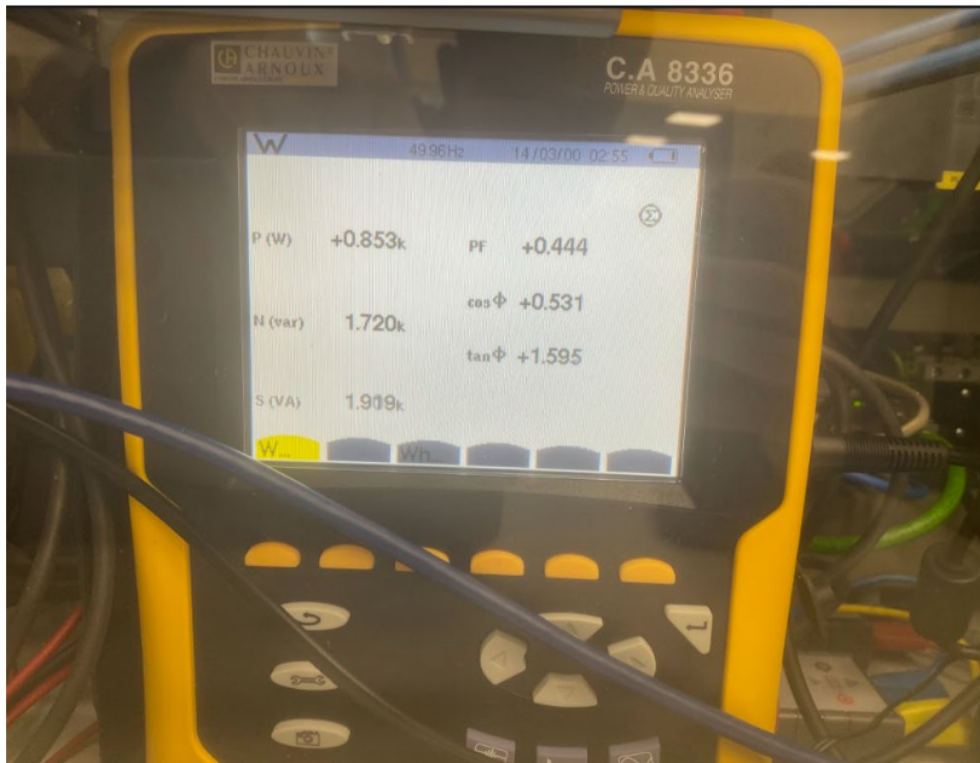
Speed SP2 2 –





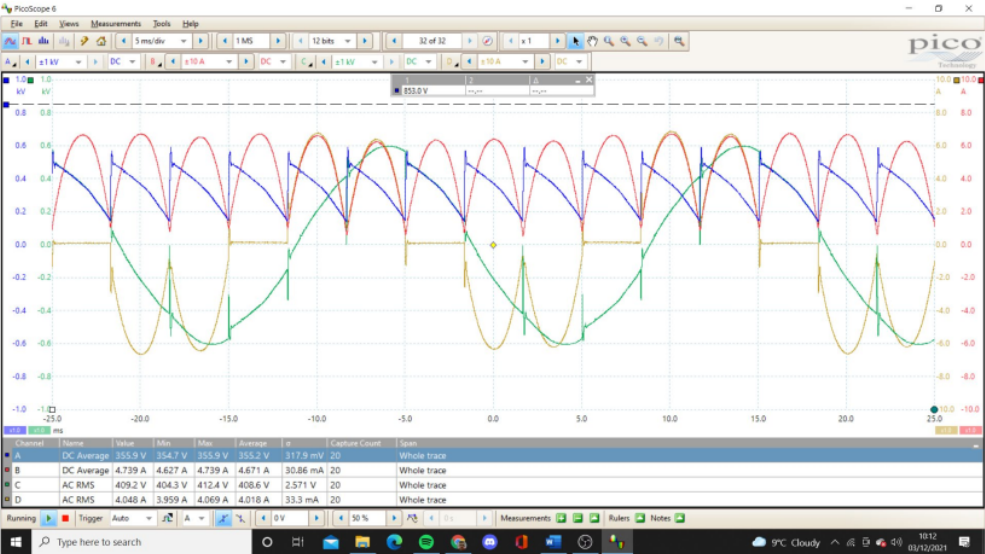
Speed SP3

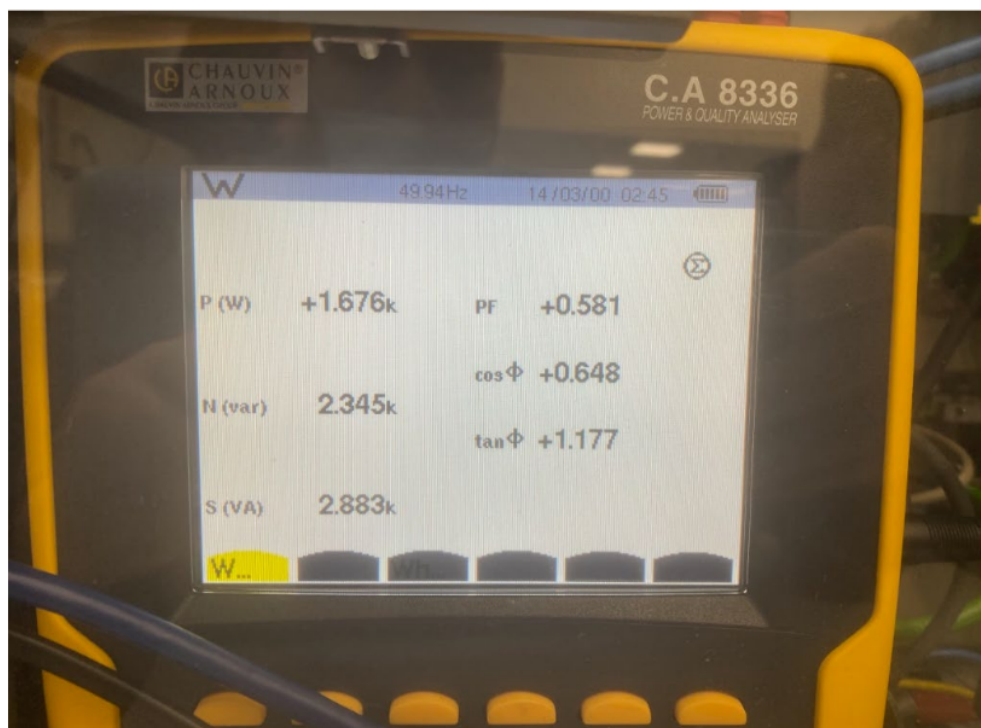




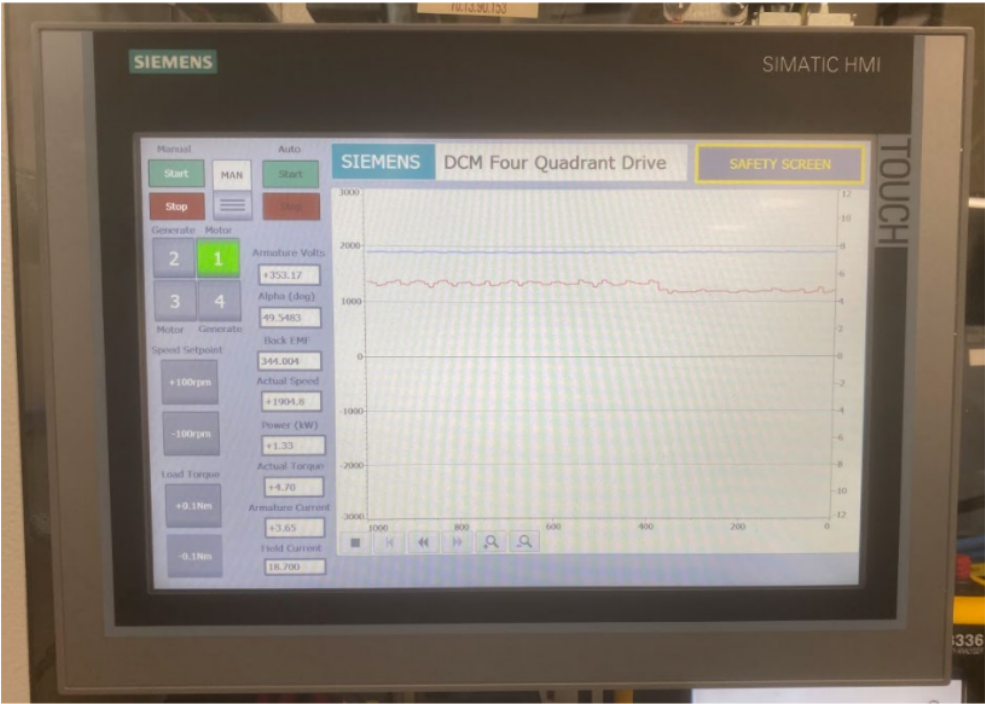
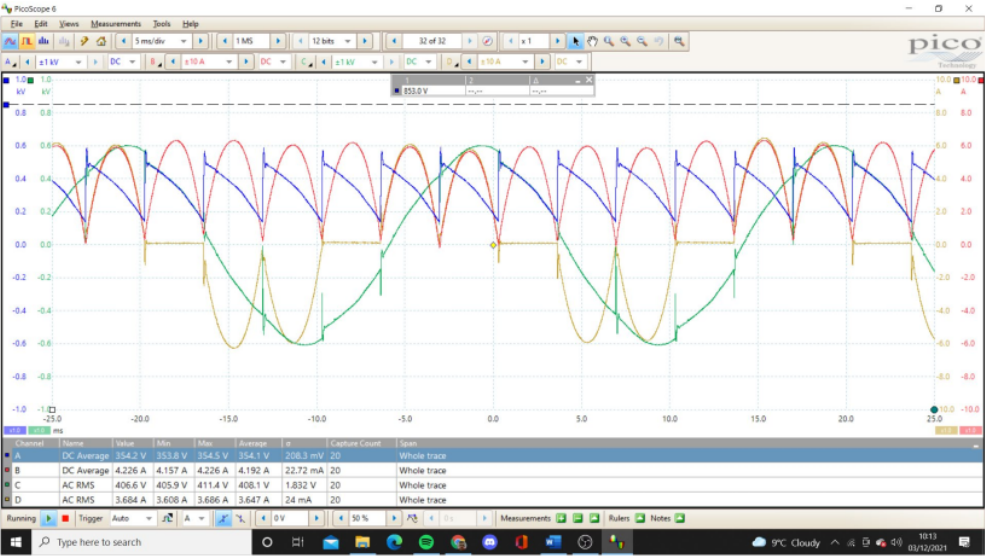
3 Different Torque Values

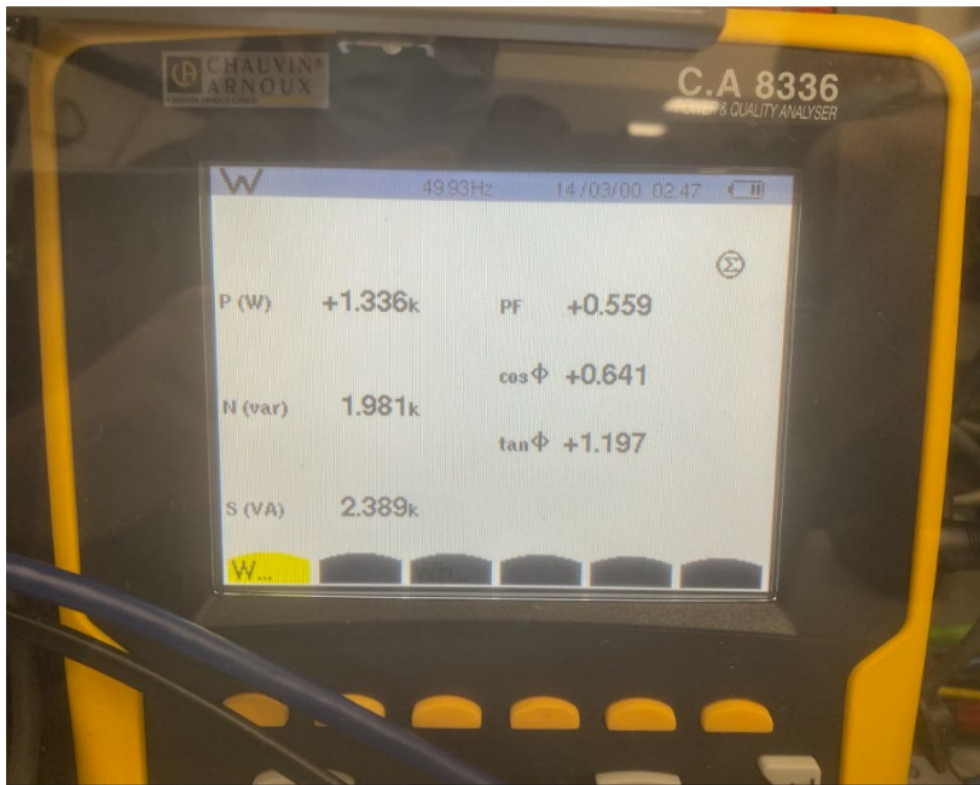
Torque SP1



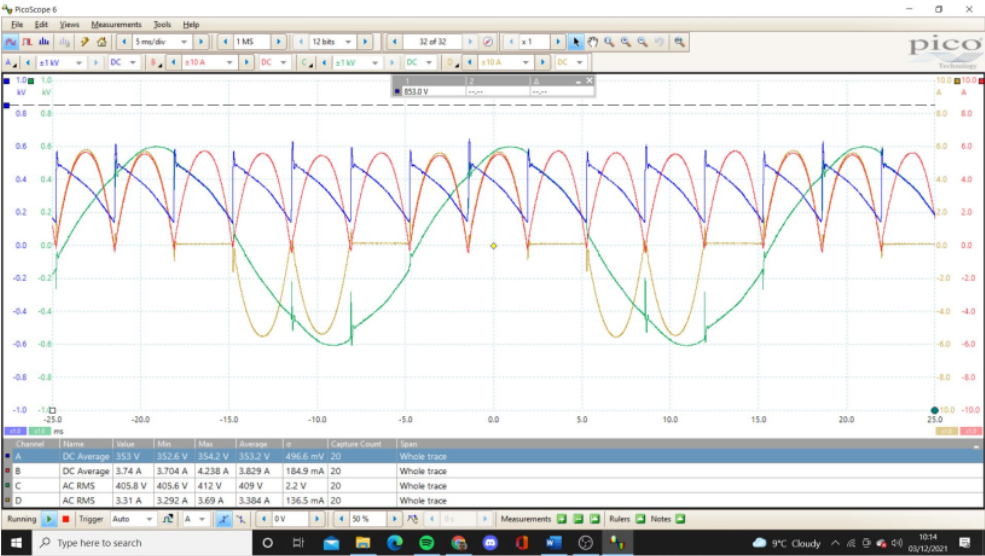


SP2





Sp3





Instructor

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PAGE 1

Text Comment. Word count exceeded

Text Comment. There is some evidence of understanding and good evidence of testing

Text Comment. However, there are many misconceptions and inaccuracies throughout particularly in your research

Text Comment. Simulations results are incorrect as the wrong value was recorded

Text Comment. Conclusions are rather vague

Text Comment. Recommendations are good.

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GRADING FORM: NEW CSG-RUBRIC

IWAN COSTELLODOWNS

52

1. ENGAGEMENT WITH LITERATURE



Engagement with a limited range of mostly relevant and credible sources. Some omissions and minor errors. Referencing conventions evident though not always applied accurately or consistently (9/20)

9

2. KNOWLEDGE AND UNDERSTANDING



Knowledge is reasonably detailed, accurate with a good systematic understanding of the field of study and to some extent, current research and scholarship (11/20)

11

3. COGNITIVE AND INTELLECTUAL



Some critical thinking, analysis, synthesis and evaluation. Can analyse new and/or abstract concepts and data without guidance. An emerging awareness of different stances and ability to use evidence (that may be incomplete) to support the argument. Mostly valid arguments and logical judgements. Some tendency to assert/state opinion rather than argue on the basis of reason and evidence. (10/20)

10

4. PRACTICAL APPLICATION



A good and appropriate application of standard methods, materials, tools and/or techniques. Clear appreciation of the context of the application. Mainly consistent, accurate and logical application of theory to practice, making appropriate links between the two Can identify problems and propose mostly appropriate solutions in complex and unpredictable contexts (11/20)

11

5. TRANSFERABLE SKILLS



Can communicate effectively in a suitable format, but may have minor errors. Mostly coherent, organised work, in a suitable structure and is for the most part clearly expressed. Can work effectively independently and/or as part of a team, with clear contribution to group activities. Demonstrates the skills required in graduate employment, with some areas of strength and some of minor weakness (11/20)

11