

1809802

by Mason Morgan

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Assignment: Investigation into DC Drives & Control Methods
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A wide range of sources have been used in the research. However, the questions have not been understood completely and no manufacturer was selected.

Executive summary is a series of lists and comments covering 3 pages. It should be 1 paragraph of 300 words

There is little evidence of understanding and knowledge is incomplete. Much has not been explained.

Analysis is generally weak, waveforms have not been explained. Most results should be in the appendix.

Conclusions show however, that something has been learnt.

CONTENTS

1. Executive summary	4
2. Research.....	7
2.1. The design features & control techniques in a three-phase, four quadrant DC drive.....	7
2.2. Applications of four quadrant DC drives, whilst making comparisons	8
2.3. Selection of motor drives for industrial applications.....	9
3. Simulation & Design Adaption	11
3.1. Calculations behind 3 different firing angles	11
4. Practical Investigations.....	18
4.1. Experimental setup, drive connections & the measuring equipment used.	18
4.2. How the drive acts in all 4 quadrants	20
4.3. Gaining 3 different values of speed for the same torque point	28
4.4. Applied continuous current in quadrant 1 by increasing the load torque.	35
5. Conclusions and Recommendations	38
6. Team Working and Health & Safety Precautions	39
Bibliography.....	40
Appendix	42

TABLE OF FIGURES

Figure 1: Firing angle value 1 @ 20V	11
Figure 2: Firing angle value 2 @ 35V	12
Figure 3: Firing angle value 3 @ 50V	13
Figure 4: Quadrant 1 w/ waveform results	14
Figure 5: Quadrant 2 w/ waveform results	15
Figure 6: Quadrant 3 w/ waveform results	16
Figure 7: Quadrant 4 w/ waveform results	17
Figure 8: Control Panel Setup	18
Figure 9: MOTOR setup	19
Figure 10: Pico Scope data for quadrant 1	20
Figure 11: Live HMI data of activity in quadrant 1	21
Figure 12: Pico scope data for quadrant 2	22
Figure 13: Live HMI data of activity in quadrant 2	23
Figure 14: Pico scope data for quadrant 3	24
Figure 15: Live HMI data of activity in quadrant 3	25
Figure 16: Pico scope data for quadrant 4	26
Figure 17: Live HMI data of activity in quadrant 4	27
Figure 18: Live HMI data of different speed values. Torque & speed value 1.	28
Figure 19: Power Factor reading at 1572rpm	28
Figure 20: Pico scope reading of speed value 1572rpm.....	29
Figure 21: Live HMI data of different speed values. Torque & speed value 2.	30
Figure 22: Power Factor at a speed of 1833rpm	31
Figure 23: Pico scope reading of speed value 1833rpm.....	31
Figure 24 : Pico Scope data with changed torque value of 5.41	35
Figure 25: Pico Scope data with changed torque value of 6	36
Figure 26: Pico Scope data with changed torque value of 6.5	37
Figure 27: Normalised characteristics of a variable-speed dc motor	42
Figure 28: Three-phase controlled convertor	43
Figure 29: Rectification in the three-phase convertor in steady state (first quadrant operation)	44
Figure 30: A for-quadrant dc motor drive	45

1. Executive summary

During this project, extensive research was carried out into the following topics:

Research

Simulation and Design Adaption

Practical Investigation

Overall Conclusions and Recommendations

Team Working and Health & Safety Precautions

Research

To elaborate on the research, the following information was provided:

1. Designing features and control techniques employed in a three-phase; four quadrant DC drive currently available from one DC drive manufacturer.
2. Exploring typical applications of four quadrant DC drives, making comparisons with other DC drives.
3. Selection of a motor drive for industrial applications based on multiple factors.

After the following points had been researched and key information had been placed in the report a summary of the research and conclusion must be constructed based on the overall research task to identify what had been found.

Simulation & Design Adaption

During this stage of the report the following tasks must be carried out:

1. Produce a Multisim circuit of a Separately excited DC motor and obtain values for armature voltage and current waveforms.
2. Producing three suitable firing angles for continuous current only for a full wave, fully controlled three-phase rectifier with average armature voltage readings recorded.
3. The designing of the rectifying circuit which included components selection

4. Discussing how the circuit design could be adapted to run a DC motor in all four quadrants.

After the above points have been discussed and answered suitable results can be gathered & recorded.

Practical Investigation

During the practical task I worked in a team of 2 to carry out the experiment. The practical consisted of a three-phase DCM drive which was paired up to another drive which acted as the load. A Pico scope program was implemented to capture all live waveform data.

It was essential that the following information was recorded during this practical, this consisted of:

1. Explaining the experimental setup, drive connections and all measuring equipment used.
2. The operation of the drive in all four quadrants
3. Continuous current for 3 different values of speed for the same torque setpoint was recorded.
4. Determining the average armature voltage from the Pico scope waveform.
5. Explaining the actions of the drive with continuous current in quadrant 1
6. Analysing the results and producing a conclusion about the performance of the drive.

After the experiment had been carried out an overall conclusion and recommendation list had to be recorded with detail explaining exactly what had been discovered and what could be done in the future to improve what was carried out.

Overall Conclusion & Recommendations

At this stage of the assignment, it was critical to capture all data collected throughout the report to make comparisons & understand how to improve in the future.

Team Working and Health & Safety Precautions

During the Practical stage of the report teamwork was critical to complete the tasks thus, to carry out a successful task teamwork and communication was essential.

Health & Safety was critical because of the moving parts during the, although there were safeguards in place it was important to understand what risks available & much of a danger were, they presented to the individual.

2. Research

2.1. The design features & control techniques in a three-phase, four quadrant DC drive

About the Four Quadrant Drive Operation

A Three-phase, four quadrant DC drive can run through 4 separate quadrants, a representation of these 4 different states can be shown in the appendix marked as figure 1 The drive requires start and stop of the DC motor. There are two ways to bring the steady speed W_m to zero, these are by:

1. Cutting off the armature supply to the machine and let the rotor come to zero speed.
2. The machine can be made to work as a DC generator, therefore stored kinetic energy can be effectively transferred to the source. This saves energy and brings the machine rapidly to zero speed.

It's found that cutting the supply creates a haphazard speed response; second method provides a controlled braking of the dc machine. (ZIKODRIVE, 2022)

To make the DC machine operating in the motoring mode go to the generating mode, all that needs to be done is to reverse the armature current flow in the DC machine.

As speed reduces, induced emf decreases, creating a continued corresponding reduction in the source voltage to keep the armature current constant. Power flows from machine armature to the DC source. This mode of operation is called regenerative braking.

First and fourth quadrants are for one direction of forward or backwards.

Functionality of the circuit

Studying the circuit in figure 2 in the appendix, assuming that the current is continuous, it can be said that at a given instance, two thyristors are conducting. Assuming that the voltage between phases a & b is maximum, then the thyristors T1 & T6 are conducting. The next line voltage to become positive than ab is ac. At that time, triggering signal for T6 will be disabled and that of T2 will be enabled. The anode of T2 is more negative than the cathode of T6, because line voltage ac is greater than the line voltage ab. That will turn off T6 and transfer the current from T6 to T2. (Caratron, 2021)

The delay in current transfer from T6 to T2 is dependent on the source inductance. During this current transfer, T1, T6, and T2 are all conducting, and the load voltage is the average of the line voltages v_{ab} and v_{ac} . The load current will remain the same during commutation of T6. The current in T6 declines by the same proportion as current in T2 rises. It is to be observed that the current transfer is affected by the source voltages: voltage v_{ac} becoming greater than the voltage. The rectification in the three-phase convertor in steady state can be easily explained using waveforms by figure 3 which can be found in the appendix below.

How the thyristors work in pairs

The four-quadrant dc motor drive has a set of dual three-phase convertors for the power stage. Convertors must be energised depending on the quadrant of operation. Convertors 1 & 2 are for forward & reverse directions of rotation of the motor, respectively. (Power Products International Ltd. , 2021)

The changeover from the convertor to another is safely handled by monitoring speed, current-command, zero-crossing current signals. These signals form the inputs to the selector blocks, which assigns the pulse-control signals to the appropriate convertor. The convertor shares the same current and speed loops. In the appendix figure 4 shows a control schematic of the four-quadrant dc motor drive is shown. The selector block will switch the convertors over only when the current in the outgoing convertor has come to zero.

2.2. Applications of four quadrant DC drives, whilst making comparisons

Such applications for a Four-Quadrant DC Drive include flying-shear systems, a schematic of this has been displayed by figure 5 in the appendix. Fling shears are used in the metal-rolling industry for cutting materials to desired lengths to suit customer needs. A flying shear consists of two blades rotating in opposite directions from their initial positions of c' at a velocity of V_b m/s, reference for this piece of text can be found in the appendix by figure 5. (QUANTUM, 2021)

CHOPPER DRIVES

An image of the four-quadrant chopper circuit can be seen below in the appendix as figure 34.

Each transistor has a freewheeling diode across it and a snubber circuit to limit the rate of rise of the voltage.

The load consists of a resistance, an inductance, and an induced emf. The source is dc, and a capacitor is connected across it to maintain a constant voltage. The base drive circuits of the transistors are isolated, and they reproduce and amplify the control signals at the output. For the sake of simplicity, it is assumed that the switches are ideal and hence, the base drive signals can be used to draw the load voltage. (R.Krishnan, 2022)

SINGLE-PHASE CONVERTORS

Modern AC drives can be divided into:

- 1) Variable Frequency Drive (VFD)
- 2) Variable Speed Drive (VSD)
- 3) Adjustable Speed Drive (ASD)

(SHAH, 2022)

Some applications which integrate VFD's into their system are paper making machines, centrifugal pumps, and fan Control, other applications include Pumping systems, Heating, Ventilating & Air Conditioning (HVAC) systems and Air Compressor systems. (Engineering360, 2022)

2.3. Selection of motor drives for industrial applications

The most common used motor drives used in industry today are AC Motors more commonly known synchronous and Asynchronous motors, DC Motors which include the common Servo and Stepper Motors, Universal Motors which produce high starting torque which find their use in various appliances like vacuum cleaners & drills. (SIEMENS, 2021)

VFD's or Variable Speed Drives which vary the Voltage & Frequency supplied to the motor, they can also change the speed over a designated speed range while providing constant or variable torque as the application requires. (SEMIKRON, 2022)

Most often in industry if an AC motor needs to be used then its most often to replace an existing motor or is used for selection of a new application. The following options are most often considered when selecting a motor drive for industry application purposes, Horsepower & speed rating, Duty cycle which is the fixed repetitive load pattern over a given period, the Voltage & Frequency, the Enclosure, the Frame size, insulation, and the Altitude. (Kathuria, 2022)

There are some motor load types which are frequently used in industry, these being:

- 1) Variable horsepower & constant torque.
- 2) Variable torque & constant horsepower.
- 3) Variable horsepower & variable torque.
- 4) Positional control or torque control.

(SISLER, 2022)

3. Simulation & Design Adaption

3.1. Calculations behind 3 different firing angles

Firing angle value 1 @ 20V

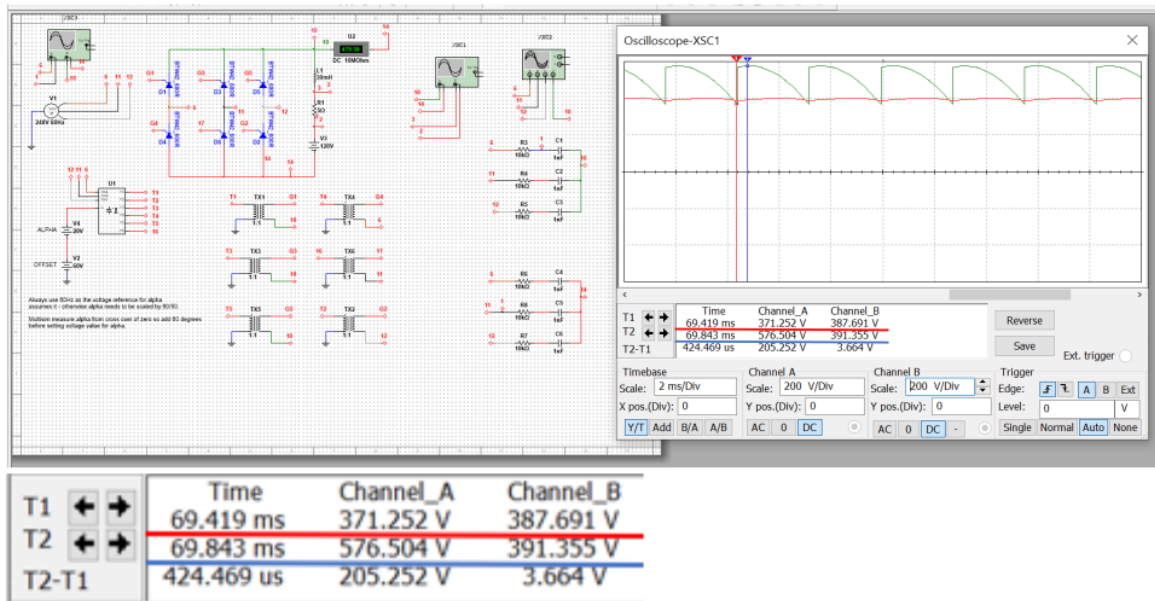


Figure 1: Firing angle value 1 @ 20V

Figure 1 shows a constant reading for current and voltage. The current is displayed by the red waveform and the voltage is shown off by the green waveform. Two data tips have been recorded and placed on the minimum and maximum points of the voltage waveform.

These values have been derived with a value set at 20V for Alpha. This will be the only value that will change as three separate values will be recorded.

With the V_{max} determined and a value for Alpha selected an equation for the average armature voltage can be derived, this can be seen below.

Average Armature Voltage Calculations for equation 1

$$\alpha = 20^\circ$$

$$V_{max} = 576.313 \text{ V}$$

$$V_{mean} = 3V_{max} \cos(20^\circ)\pi$$

$$V_{mean} = 3 * 576.067 * \cos(35^\circ)\pi$$

$$V_{mean} = 517.1372457 \text{ V}$$

Firing angle value 2 @ 35V

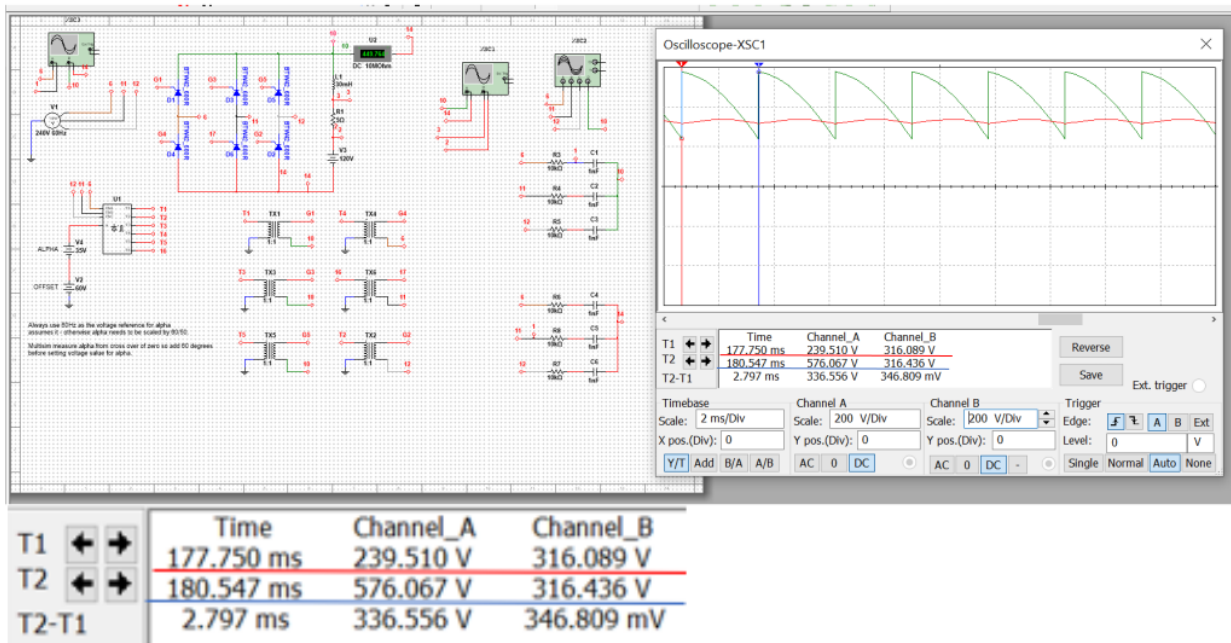


Figure 2: Firing angle value 2 @ 35V

The firing angle has now been increased to 35V for Alpha. Comparing the voltage and current waveforms to the first value of 20V, the maximum voltage is recorded as practically the same as the firing angle of 35V. Visually the shapes of the waveforms are different when increasing the Alpha value, it can be said that the voltage and current have much smaller minimum values.

Average Armature Voltage Calculations for equation 2

$$\alpha = 35^\circ$$

$$V_{max} = 576.067 \text{ V}$$

$$V_{mean} = 3V_{max} \cos(35^\circ)\pi$$

$$V_{mean} = 3 * 576.067 * \cos(35^\circ)\pi$$

$$V_{mean} = 450.6183768 \text{ V}$$

Firing angle value 3 @ 50V

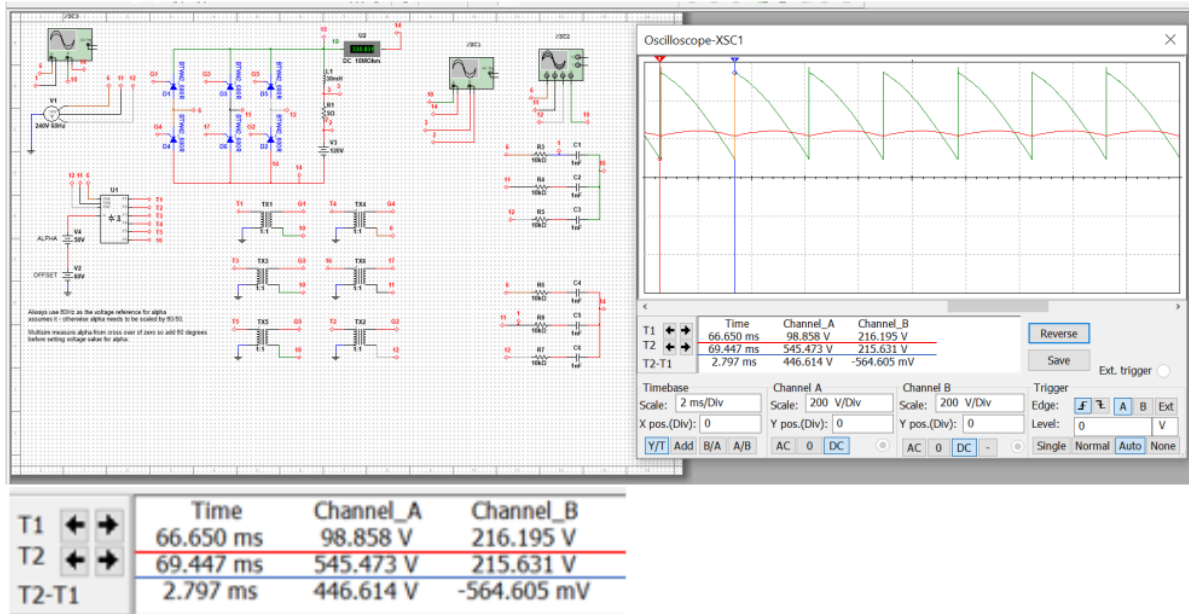


Figure 3: Firing angle value 3 @ 50V

The Alpha value has now been raised to 50V and continues the pattern before in which both voltage and current values have a much lower minimum value, however this time the maximum value has been reduced in comparison to the previous values.

Average Armature Voltage Calculations for equation 3

$$\alpha = 50^\circ$$

$$V_{max} = 545.473 \text{ V}$$

$$V_{mean} = 3V_{max} \cos(50^\circ)\pi$$

$$V_{mean} = 3 * 545.473 * \cos(50^\circ)\pi$$

$$V_{mean} = 334.8205746 \text{ V}$$

A data table can be shown which compares all three separate firing angles with mean voltages together.

Firing Angle	20V	35V	50V
Maximum Voltage	576.313 V	576.067 V	545.473 V
Mean Voltage	517.1372457 V	450.6183768 V	334.8205746 V

3.3. Adapting the circuit

The circuit can indeed be modified from its current setup. Currently the multisim circuit shows a Full-wave bridge rectifier circuit which shows the operation and waveforms in quadrant 1. It can now be shown that the circuit can be re-designed to show the other 3 quadrants.

Quadrant 1

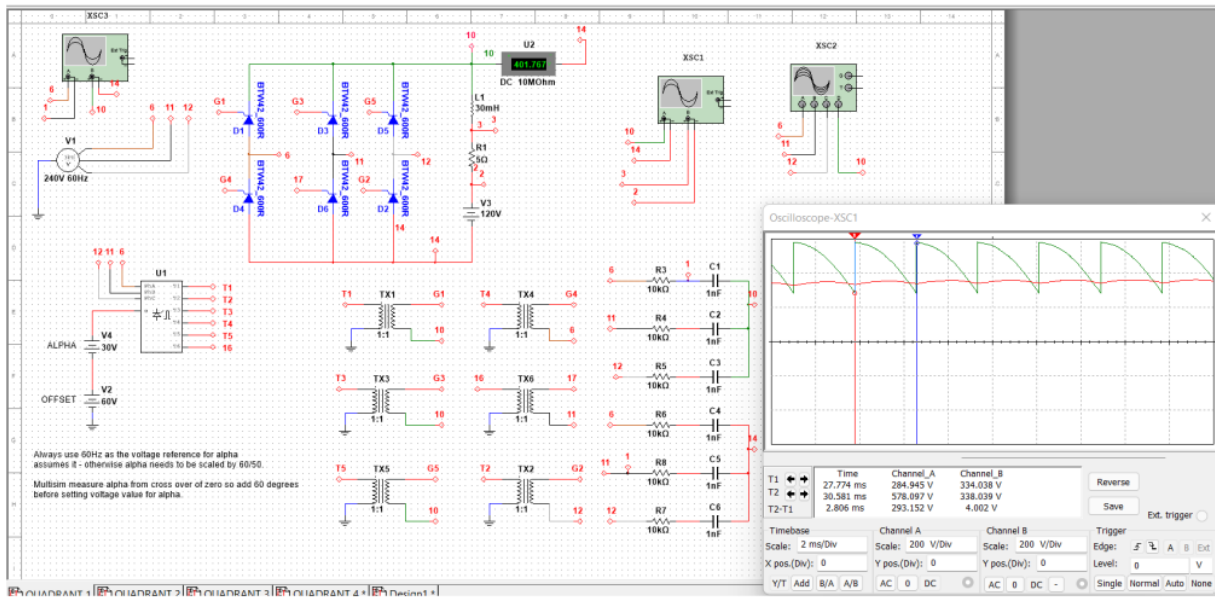


Figure 4: Quadrant 1 w/ waveform results

Quadrant 2

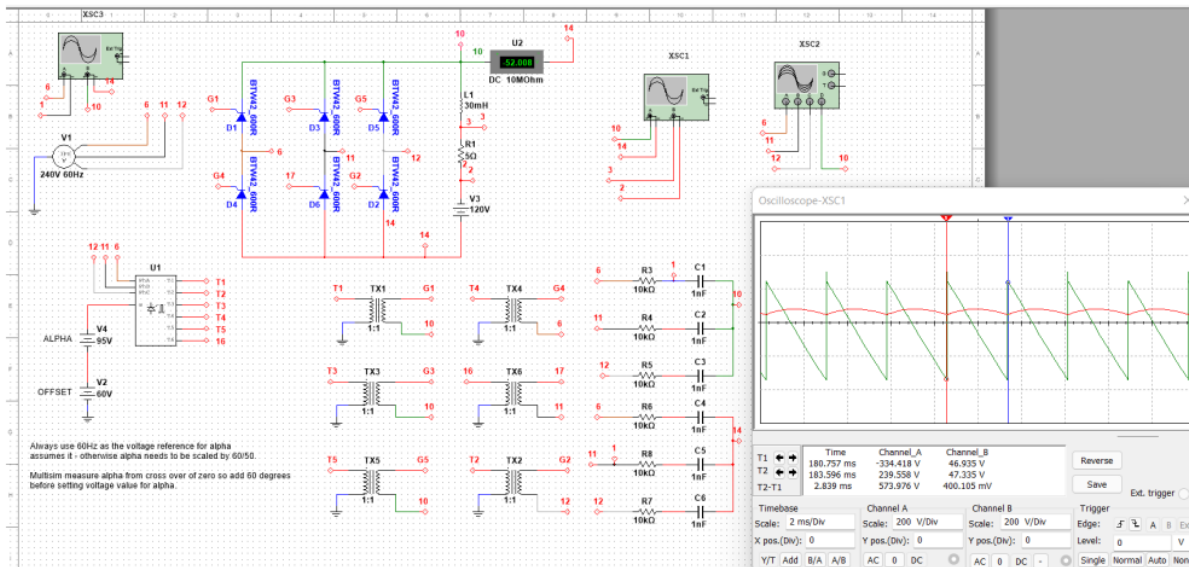


Figure 5: Quadrant 2 w/ waveform results

The modifications that have been made for the circuit to operate in the quadrant 2 are swapping the polarity of the 120V power supply, adjusting the firing angle to 30V.

Quadrant 3

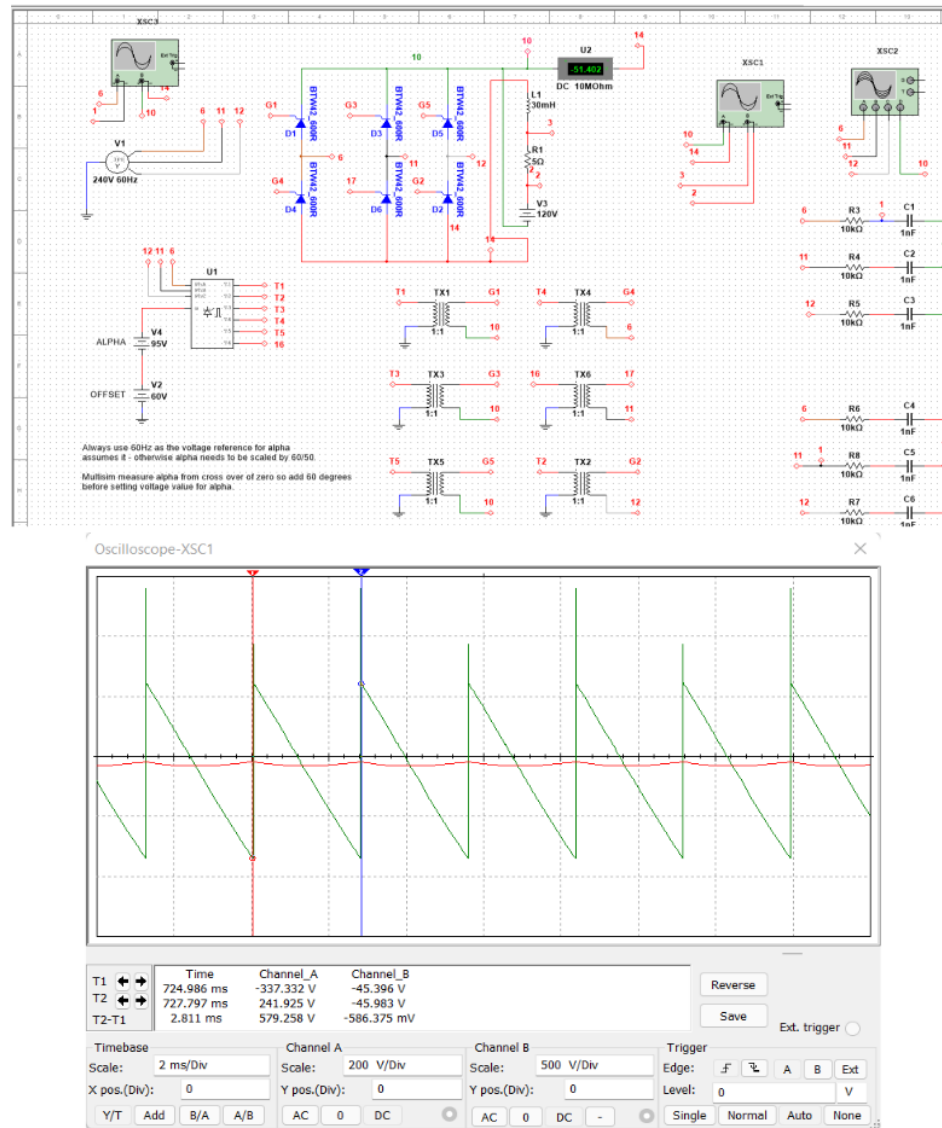


Figure 6: Quadrant 3 w/ waveform results

To operate in quadrant 3 the changes that have been are swapping the polarity between the input of the inductor and the output of the power supply. The firing angle has now been taken to 95V which then leaves the following waveforms shown above. The current has gone negative, and the average voltage is negative.

Quadrant 4

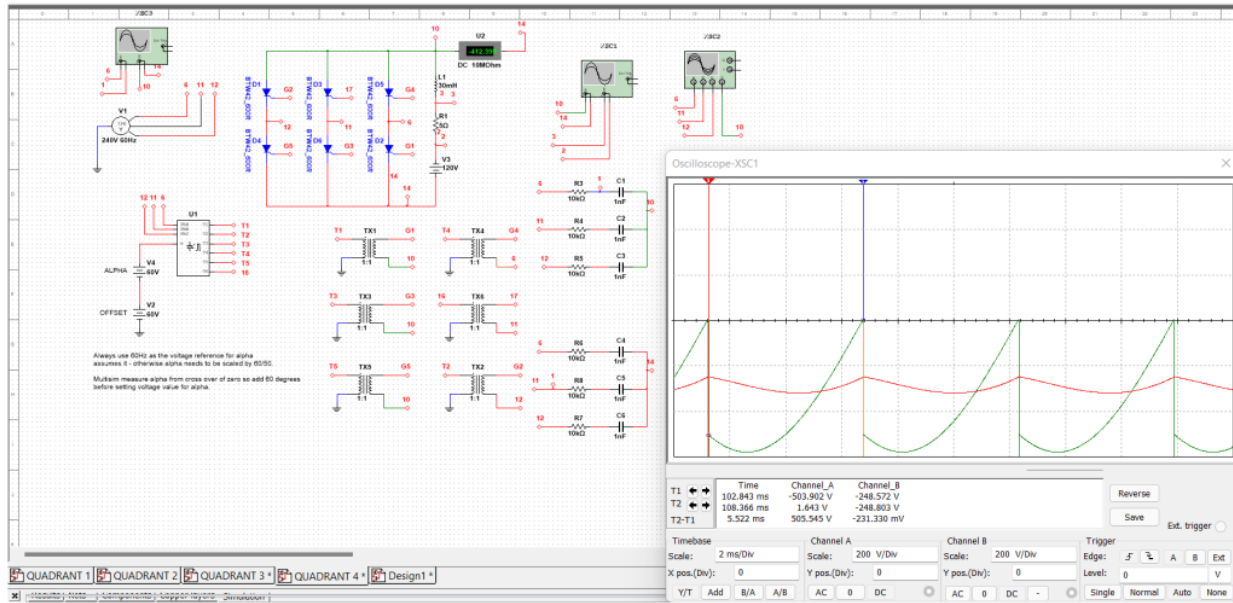


Figure 7: Quadrant 4 w/ waveform results

To operate in quadrant 4 all 6 thyristors need to be rotated 180 degrees, along with this all the connectors need to follow the thyristors, also the connection to the power supply needs to be reversed again.

The waveform is now operating in the negative half cycle, and it can be seen both the voltage and the current are indeed negative.

4. Practical Investigations

4.1. Experimental setup, drive connections & the measuring equipment used.

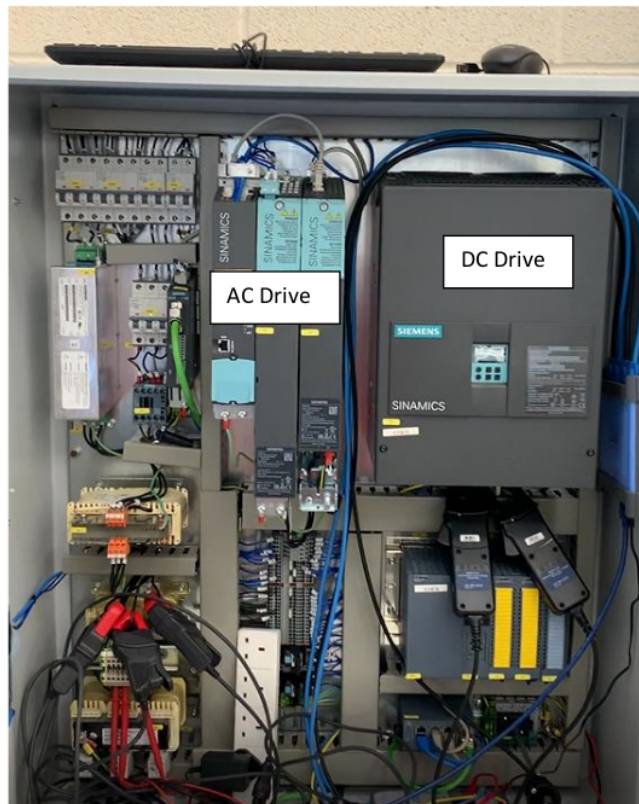


Figure 8: Control Panel Setup

The experimental setup involves the following equipment, a Siemens Sinamics DC Master Convertor, the DC Drive was used to handle/regulate the supply of power to the variable DC motor field and armature, there is also an AC drive which manages the AC induction motor.

The idea of this system is to compile sufficient power for 4-quadrant operation. The Sinamics 120 control unit is used for operation of the AC drive and is used to act like a load. The AC drive in fact acts like a break so that the DC drive can motor so that it can generate.

Inside the control panel there is a 4-channel Pico scope which extracts all live data which can then be converted into live waveforms which can be displayed on the Pico scope software. There are also 2 current transformers along with 2 current probes which measure armature current and mains current along with 2 voltage probes.

An HMI has been installed into the panel so that the operator can operate the entire system from the touch of a button. Images of the HMI screen can be seen in such images like figure 11. From the HMI the operator can select each individual quadrant and all torque and speed values can be adjusted.

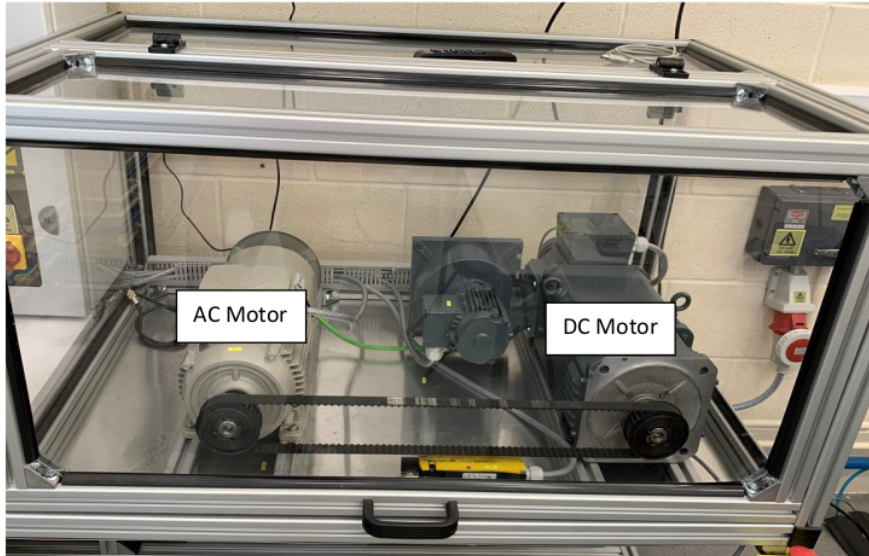


Figure 9: MOTOR setup

4.2. How the drive acts in all 4 quadrants

Quadrant 1

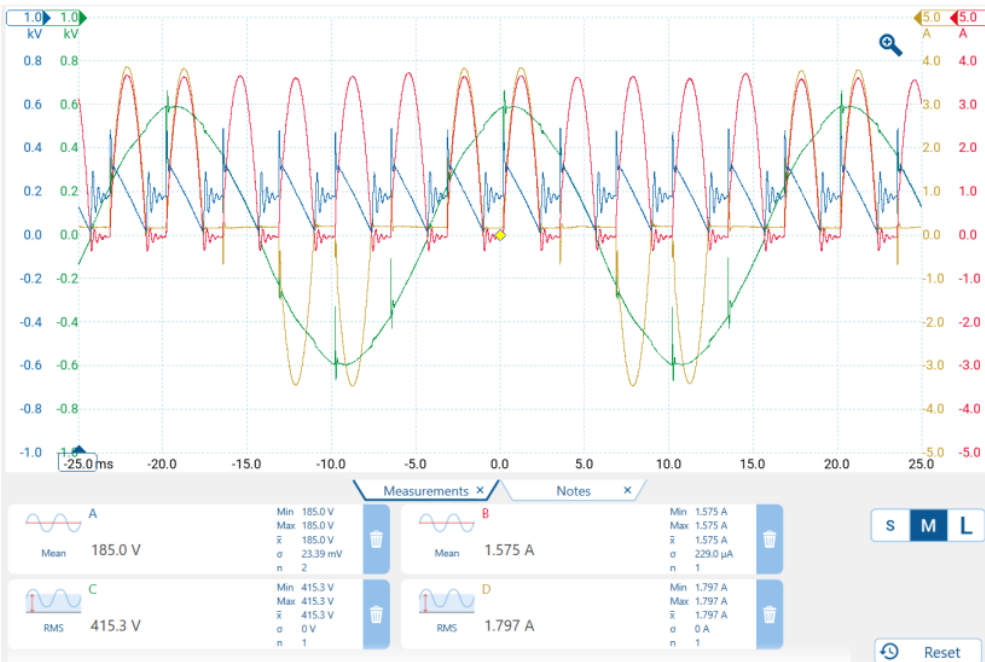


Figure 10: Pico Scope data for quadrant 1

Figure 10 shows the live Pico scope data of the DC and AC drive under operation in quadrant 1. The mean voltage has been recorded, along with the RMS voltage, also the mean current and RMS Current.

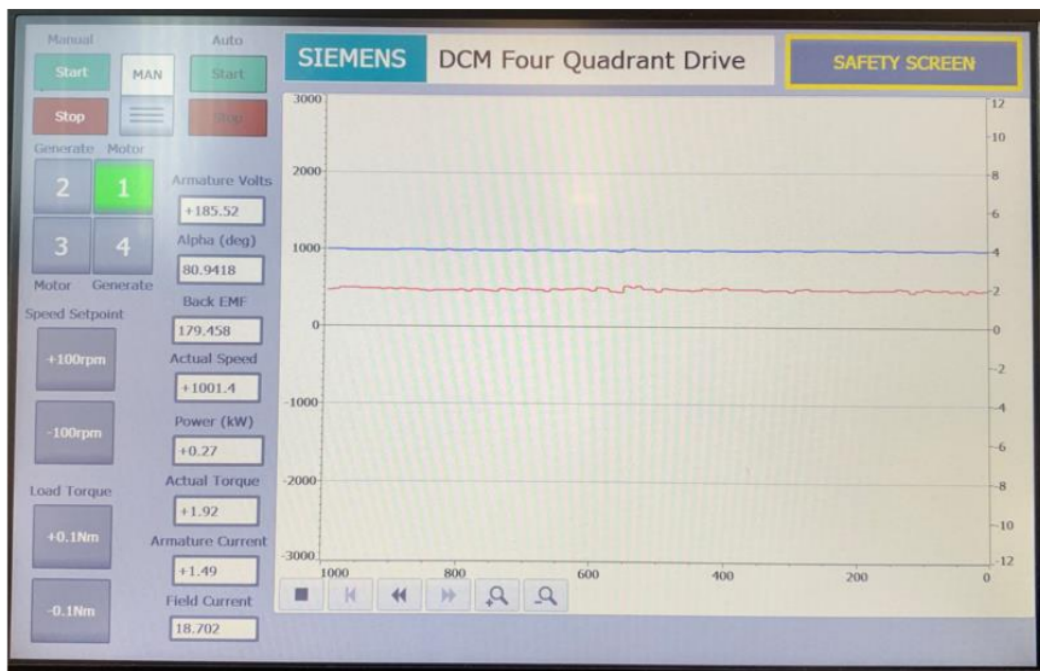


Figure 11: Live HMI data of activity in quadrant 1

Quadrant 2

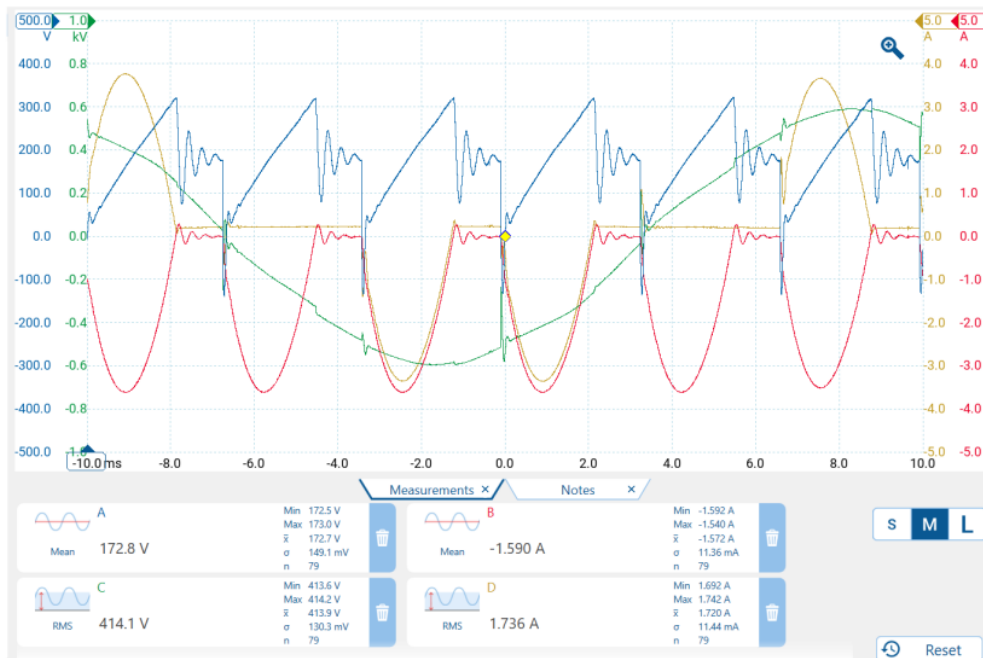


Figure 12: Pico scope data for quadrant 2

Figure 12 presents the live Pico Scope data in quadrant 2. The mean Voltage and RMS Voltage has been gathered along with the Mean Current and RMS Current.

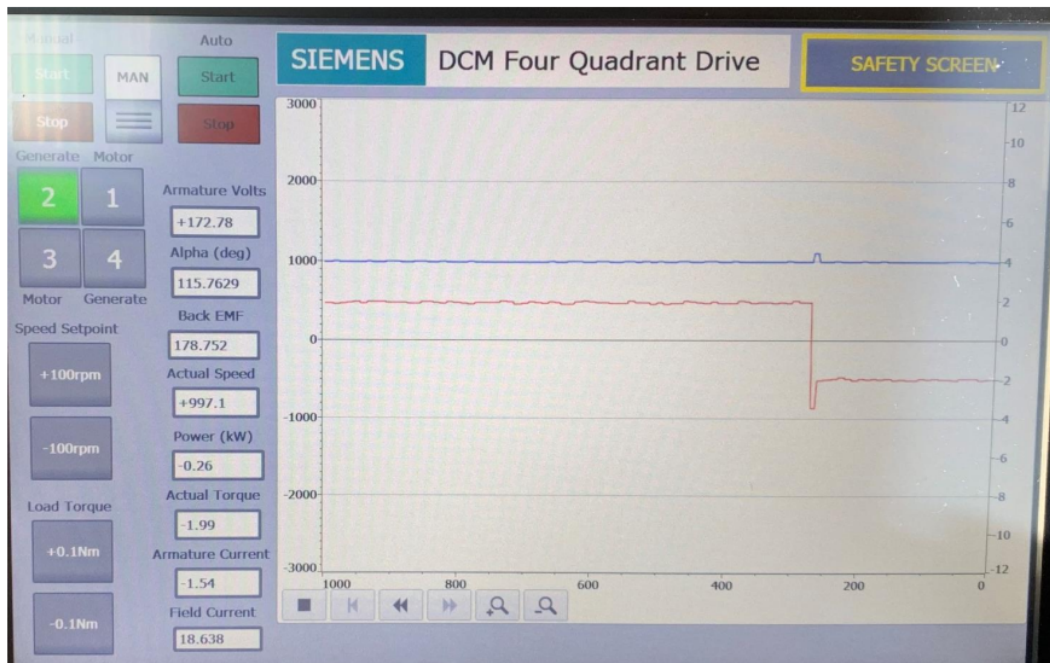


Figure 13: Live HMI data of activity in quadrant 2

Quadrant 3

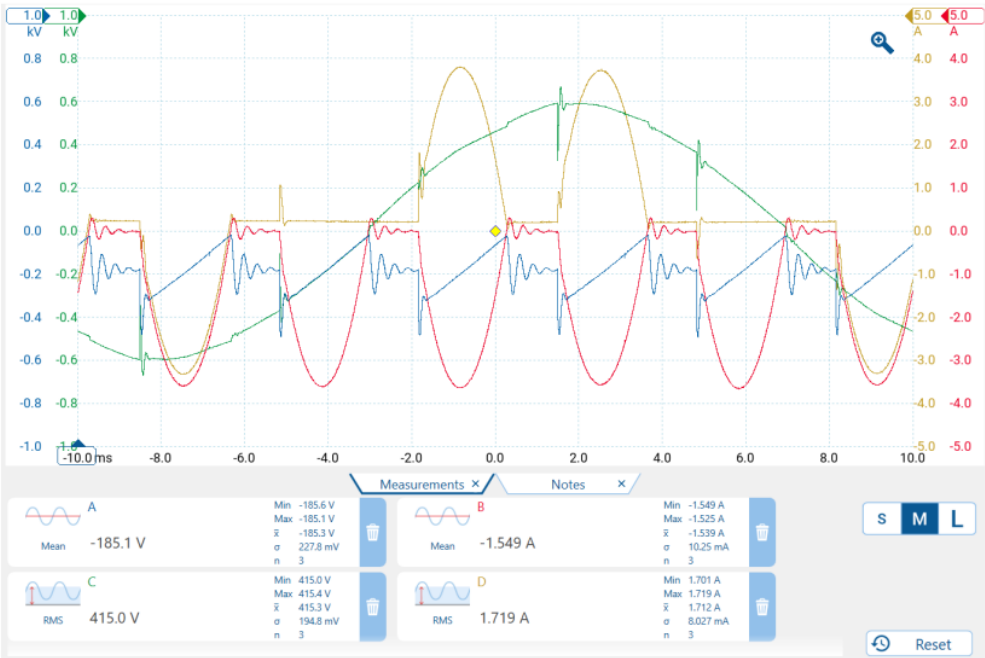


Figure 14: Pico scope data for quadrant 3

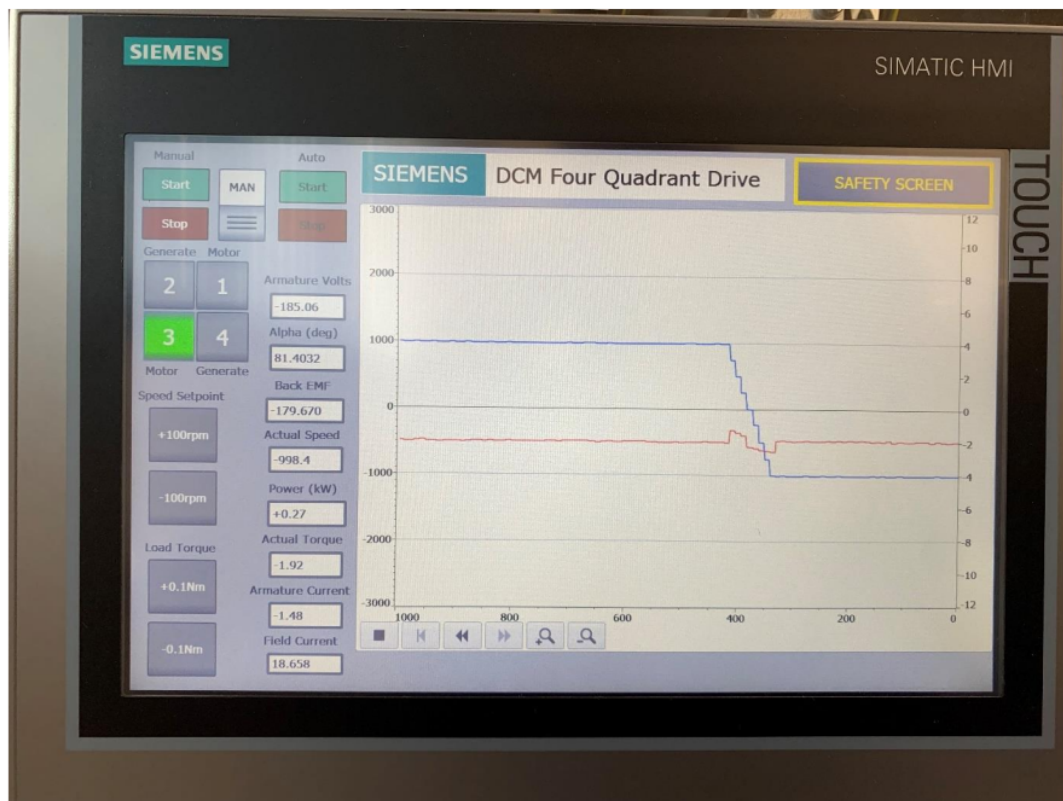


Figure 15: Live HMI data of activity in quadrant 3

Quadrant 4

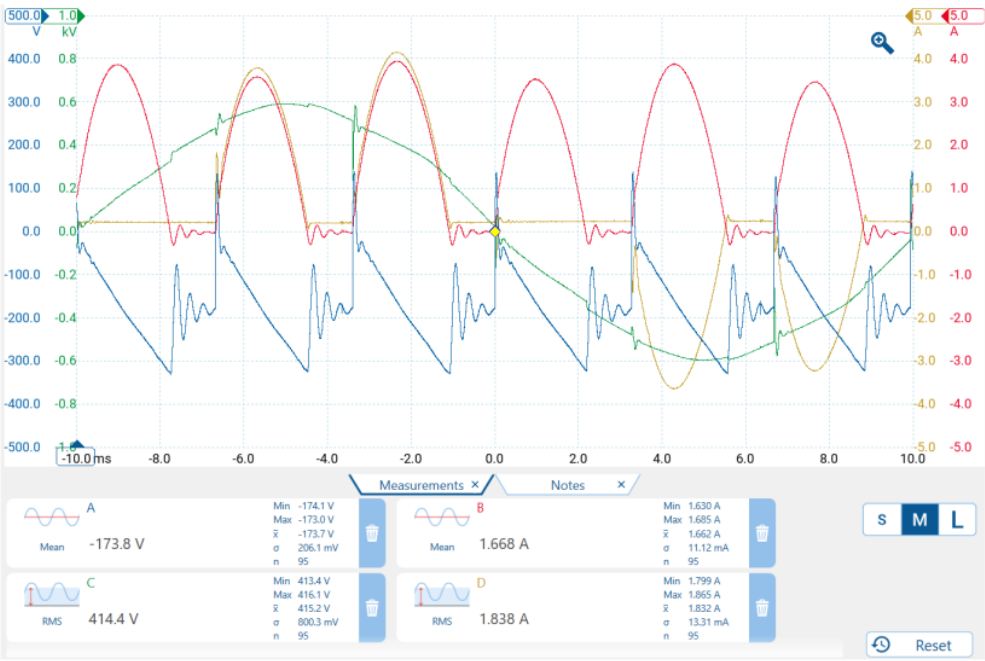


Figure 16: Pico scope data for quadrant 4

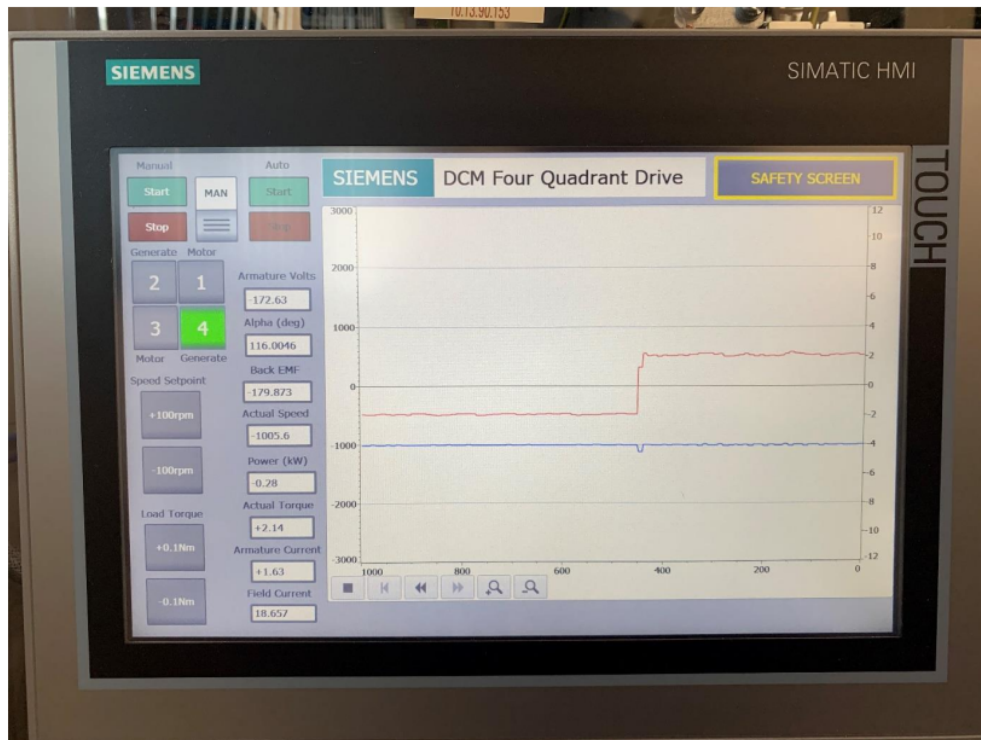


Figure 17: Live HMI data of activity in quadrant 4

Measurements	Quadrant 1	Quadrant 2	Quadrant 3	Quadrant 4
Mean Voltage	185.0 V	172.8 V	-185.1 V	-173.8 V
Mean Current	1.575 A	-1.590 A	-1.549 A	1.668 A
RMS Voltage	415.3 V	414.1 V	415.0 V	414.4V
RMS Current	1.797 A	1.736 A	1.719 A	1.838 A

Above shows the compiled data for all four-quadrant data recording from the Pico scope program.

This data will later be used as a comparison against the simulated data to prove accuracy.

4.3. Gaining 3 different values of speed for the same torque point

Test 1 - Discontinuous current measurement at 1572rpm

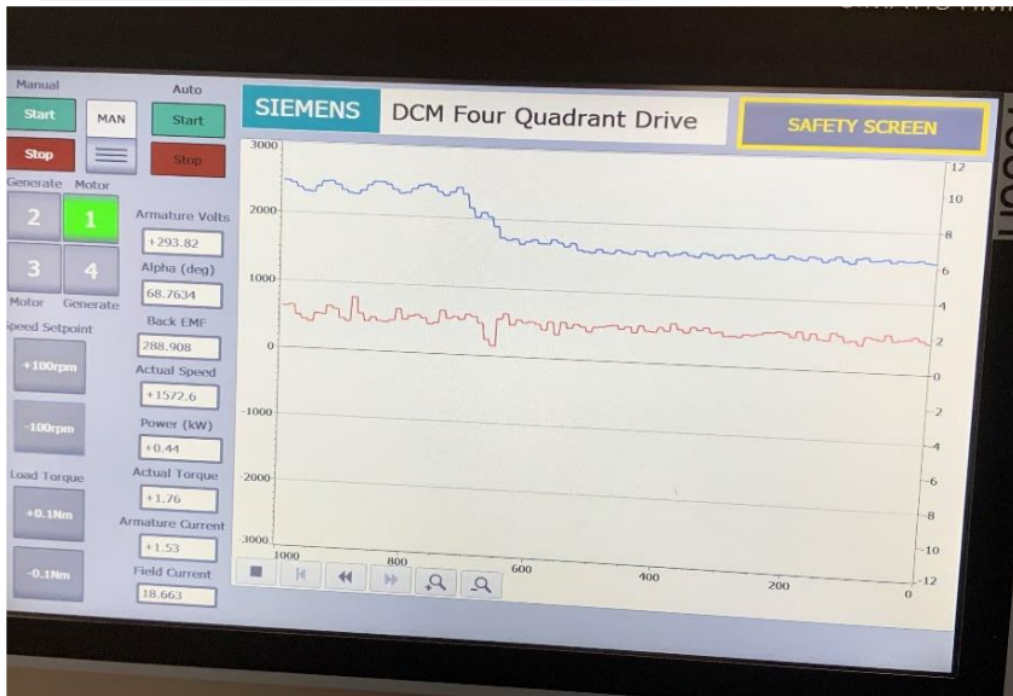


Figure 18: Live HMI data of different speed values. Torque & speed value 1.

Figure 18 shows the 2 unique values which have been altered. The Actual Speed has been set to 1572rpm, whereas the Torque actual has been set to 1.76. A resultant waveform for voltage and current can then be shown.

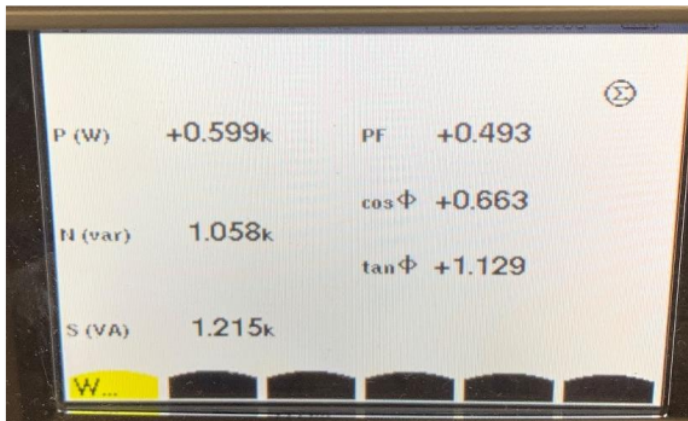


Figure 19: Power Factor reading at 1572rpm

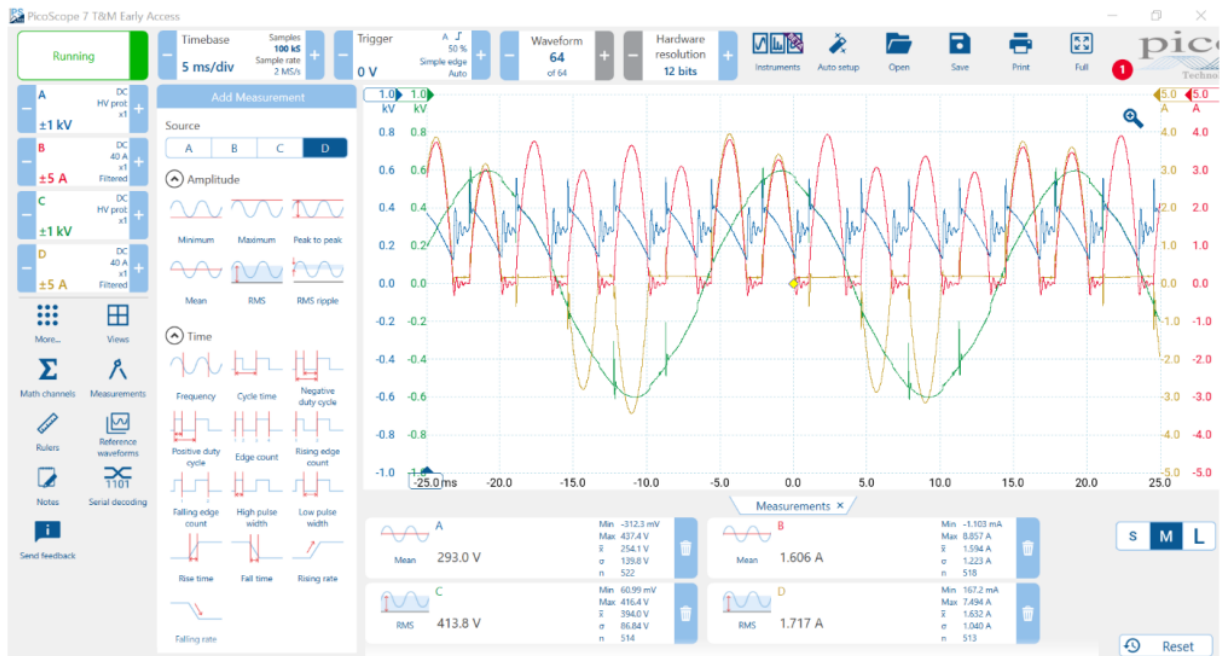


Figure 20: Pico scope reading of speed value 1572rpm

Test 2 - Discontinuous current measurement at 1833rpm

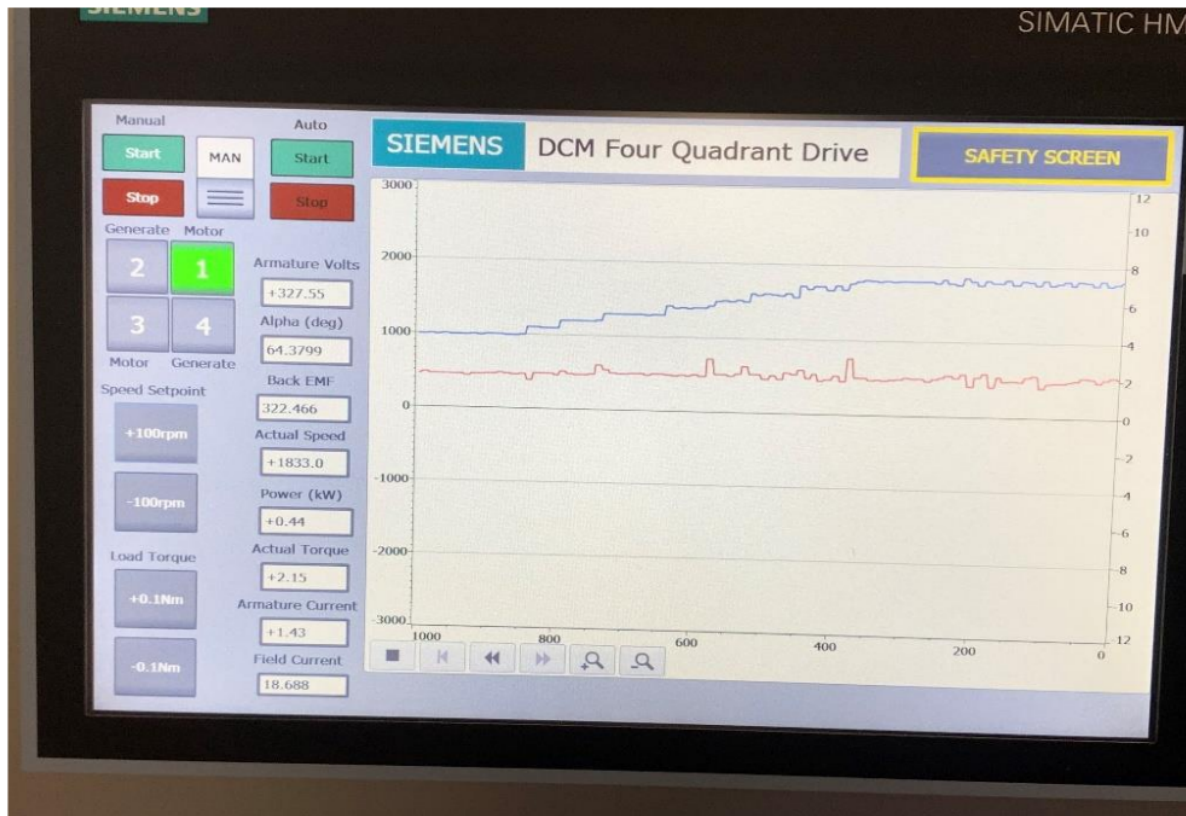


Figure 21: Live HMI data of different speed values. Torque & speed value 2.

Figure 21 has been increased to a total Speed value of 1833rpm, this has also been matched with a Torque actual value of 2.15 which provides the most stable values and waveforms.

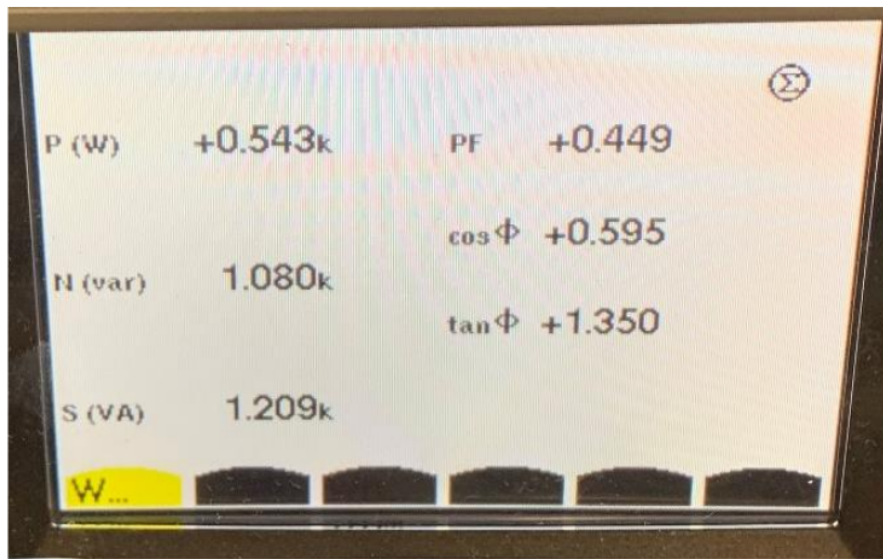


Figure 22: Power Factor at a speed of 1833rpm



Figure 23: Pico scope reading of speed value 1833rpm

Test 3 - Discontinuous current measurement at 2000rpm

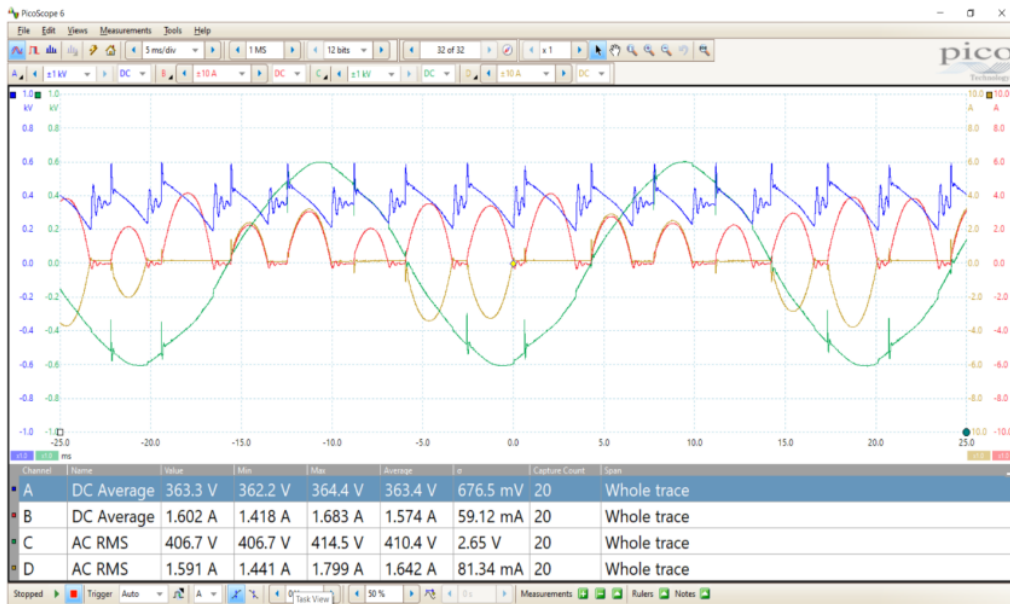


Figure 31 - Practical - Pico Scope Discontinuous Current 2000rpm

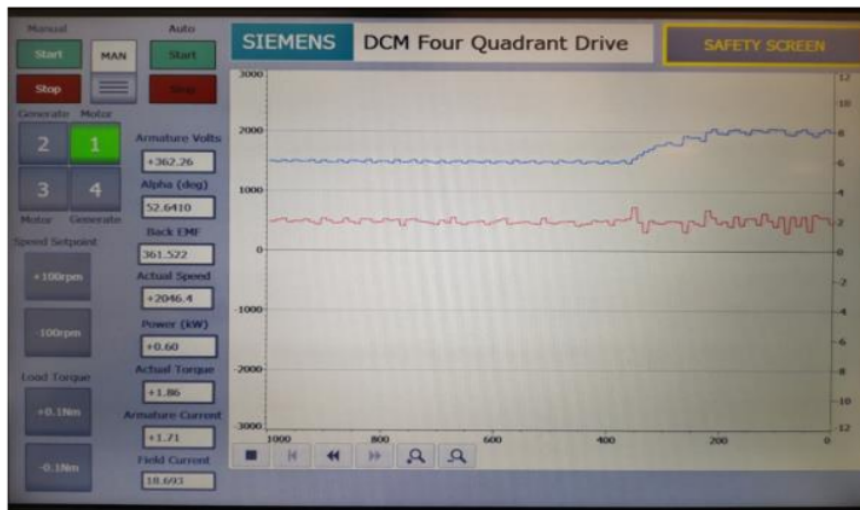


Figure 32 - Practical - Pico Scope Discontinuous Current 2000rpm

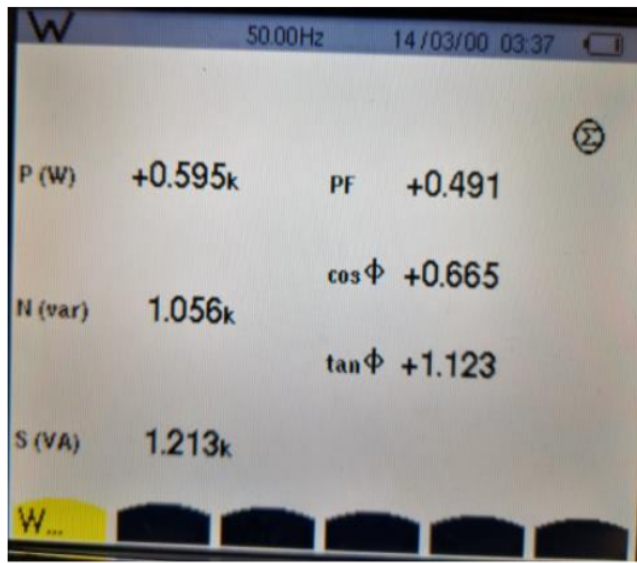


Figure 33 - Practical - Power Analyser Discontinuous Current 2000rpm

Test 3 - Discontinuous current measurement at 2046rpm

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

Equation 1 - Calculation for V-mean Discontinuous Current Area A

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

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

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

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

Equation 2 - Calculation for V-mean Discontinuous Current Area B

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

$$V_{\text{mean}} = \frac{3}{\pi} \left[361.522(0.9187 - 1.0472) + 589.6 \left(1 + \frac{1}{2} \times 0.6069 - 0.866 \times 0.7948 \right) \right]$$

$$= \frac{3}{\pi} [46.4547 + 362.662] = 390.6777$$

Equation 3 - Calculation for V-mean

Continuous Current Test Data	
	Test 3
VMAX	589.6 V
Back EMF	361.522 E
Alpha	52.64 α
Radians	0.9187 Rad/s

Continuous Current Test Data			
	Armature Voltage (simulated)	Armature Voltage (calculated)	Difference
Test 3	361.522	390.6777	29.1557v

4.4. Applied continuous current in quadrant 1 by increasing the load torque.

Set torque value of 5.41

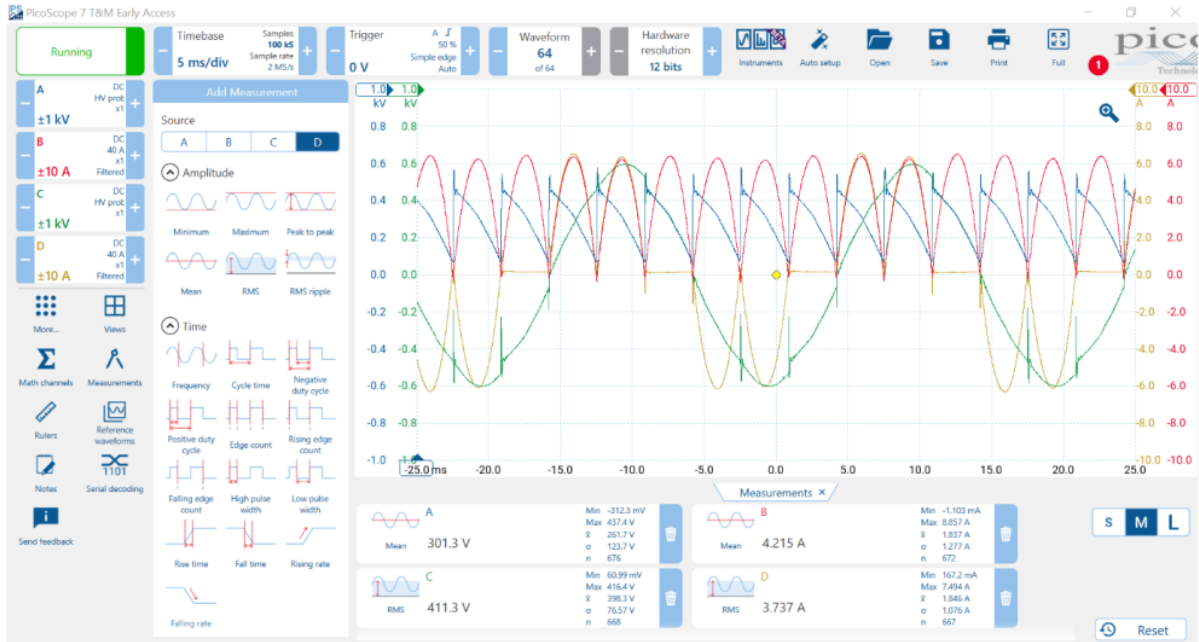


Figure 24 : Pico Scope data with changed torque value of 5.41

Set Torque value of 6



Figure 25: Pico Scope data with changed torque value of 6

With an increase in actual torque value the waveforms show continuous current in the red marked line. In comparison to the previous torque value of 5.41 the mean voltage, mean current and RMS current have all increased apart from the Voltage RMS which has dropped ever so slightly, these results are expected seeming as when you apply a larger torque value to the DC motor it is being loaded thus increasing the current values.

Set torque value of 6.5



Figure 26: Pico Scope data with changed torque value of 6.5

As expected, the current values have again increased as soon as more load is applied to the DC motor.

5. Conclusions and Recommendations

To conclude, in the simulation task 3 different firing angles were used on the multisim program, these being 20V, 35V, and 50V. From these 3 separate values, waveforms could be provided on the oscilloscope, it was clear that when the firing angle increased the Channel A and channel B voltage Min and Max values decreased. It was also clear that the current waveform also decreased because of the firing angle being increased.

At this stage the mean voltage could be calculated for each firing angle.

To compare results against the practical assessment at a later stage each of the four operation quadrants were constructed on multisim. Quadrant 1 had no alterations made apart from the firing angle being set at 30V which produced waveforms showing positive current and voltage like that above.

At quadrant 2 the polarity of the battery supply was switched, and the firing angle was increased to 95V which drastically reduced the current average and made the average voltage negative.

At Quadrant 3 the firing angle was lowered to 60V, and the battery supply was switched back around however this time the negative side was connected to the positive side and the inductor was then joined to the negative side rather than the positive, this resulted in a negative voltage and a negative current.

Finally at quadrant 4 all 6 thyristors have been switched 180 degrees whilst the battery supply was switched back to the same state as quadrant 2, this produced the lowest rated waveforms which meant that again the current and voltage negative but constant.

Once all the data was collected from multisim waveforms were gathered for all 4 quadrants whilst again calculating a mean voltage to compare against the simulated results.

Later 3 different values for speed were calculated for the same torque point, although there was a slight increase in torque as the speed was increased but this was only to increase the accuracy of the waveform data. It was gathered that as the speed was increased the Power Factor decreased furthermore, the current increased which was displayed on the Pico Scope software.

6. Team Working and Health & Safety Precautions

It was essential to work as part of a team during this report. Throughout every task it was paramount that all work was done as efficiently and effectively as possible as we were working against a time constraint. The quality of work needed to be as good as possible to ensure accuracy of values wasn't an issue.

During the practical task we worked in groups of 2. A laptop was used and connected to the Pico scope program which allowed us to analyse live data being recorded by the system.

It was important that the brief was read beforehand so that we knew exactly what tasks we were carrying out and what information we needed to collect, because of these jobs were assigned to each other. Whilst one person was setting up and analysing data on the Pico Scope software the other was in control of adjusting the HMI, such adjustments included speed and torque adjustments to the motors.

Whilst team working was very important it was crucial that safety was the main concern. As displayed in such images in this report evidence of interlocks can be seen ensuring that nobody can access any moving or live parts whilst the machine is operating.

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Appendix

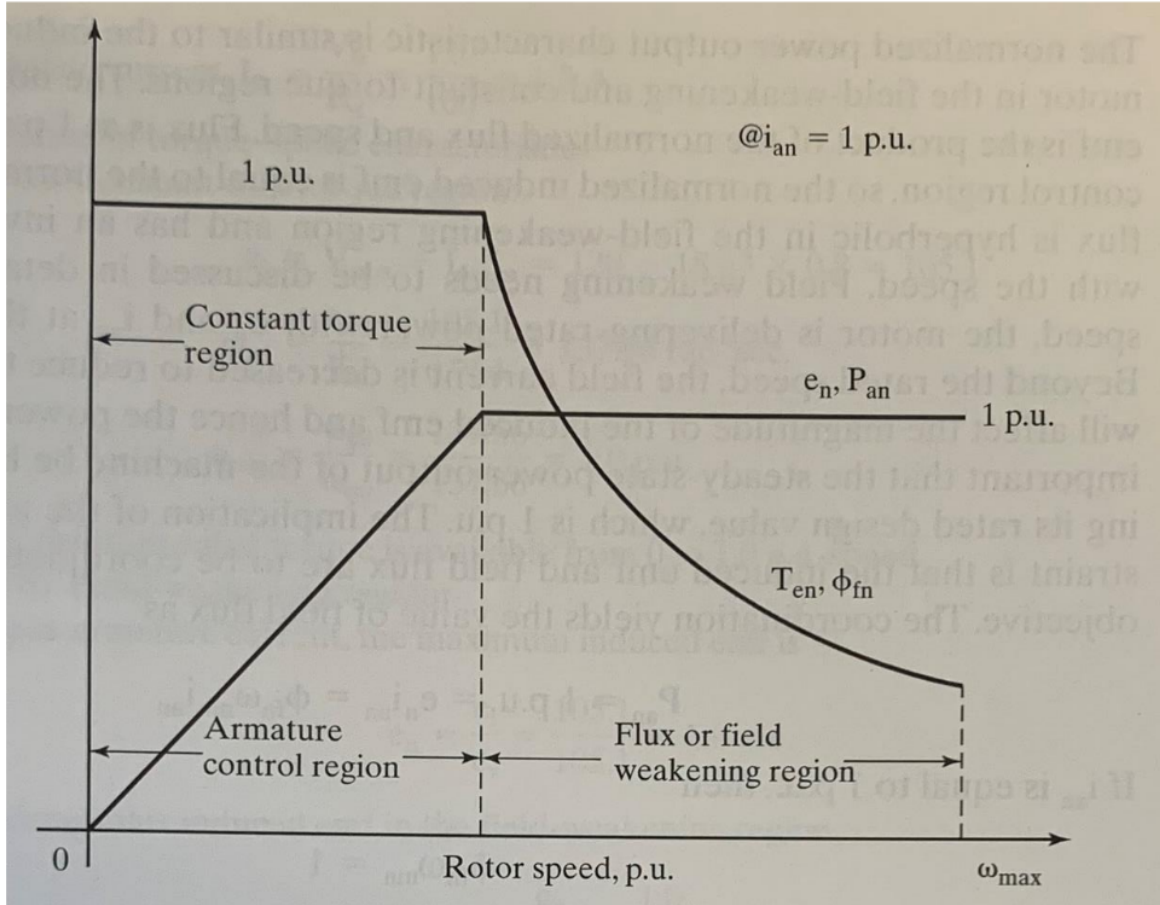


Figure 27: Normalised characteristics of a variable-speed dc motor

(KRISHNAN, 2021)

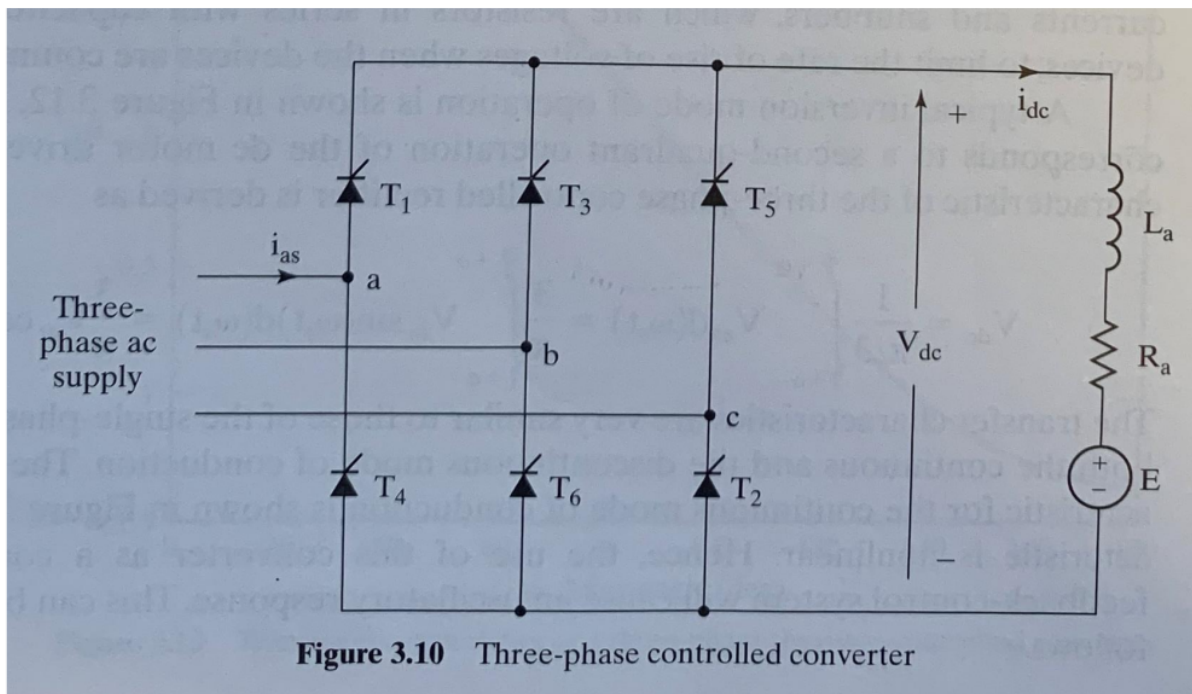


Figure 3.10 Three-phase controlled converter

Figure 28: Three-phase controlled convertor

(KRISHNAN, 2021)

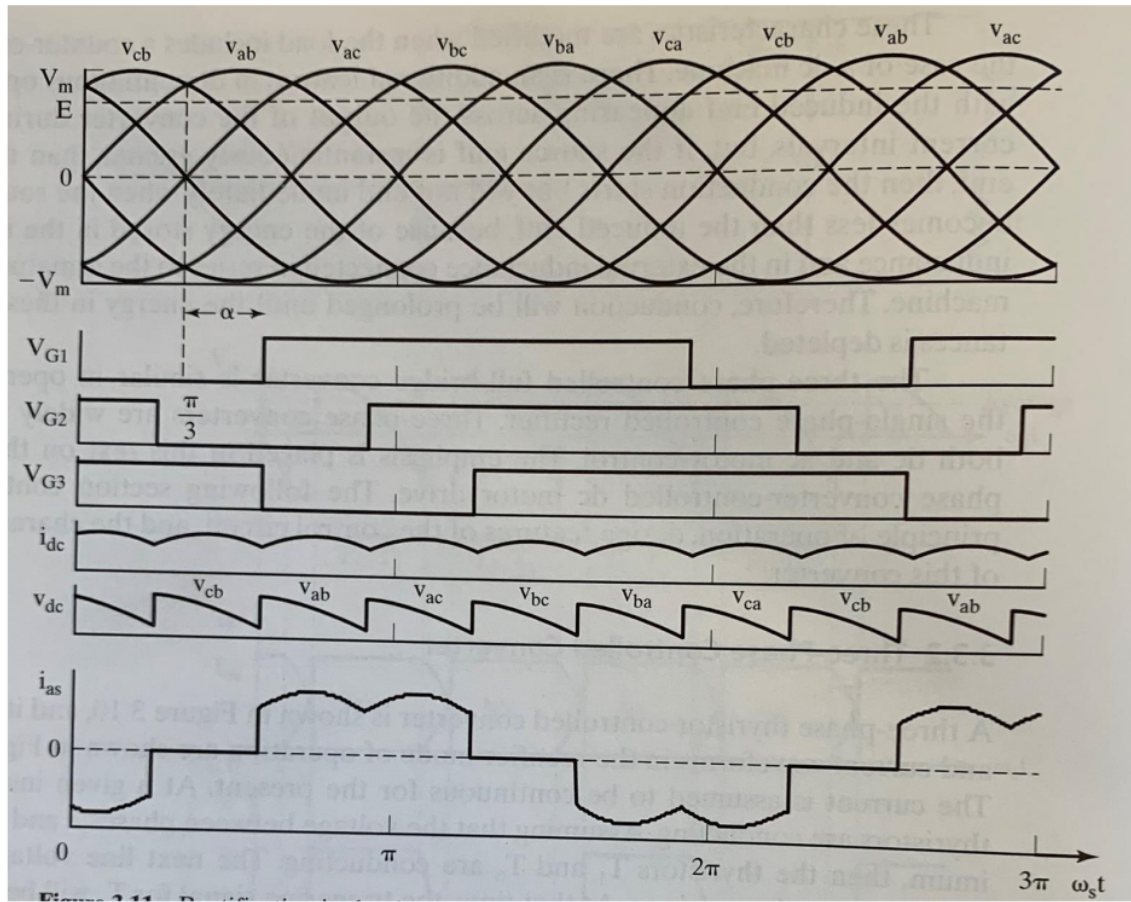


Figure 29: Rectification in the three-phase convertor in steady state (first quadrant operation)

(KRISHNAN, 2021)

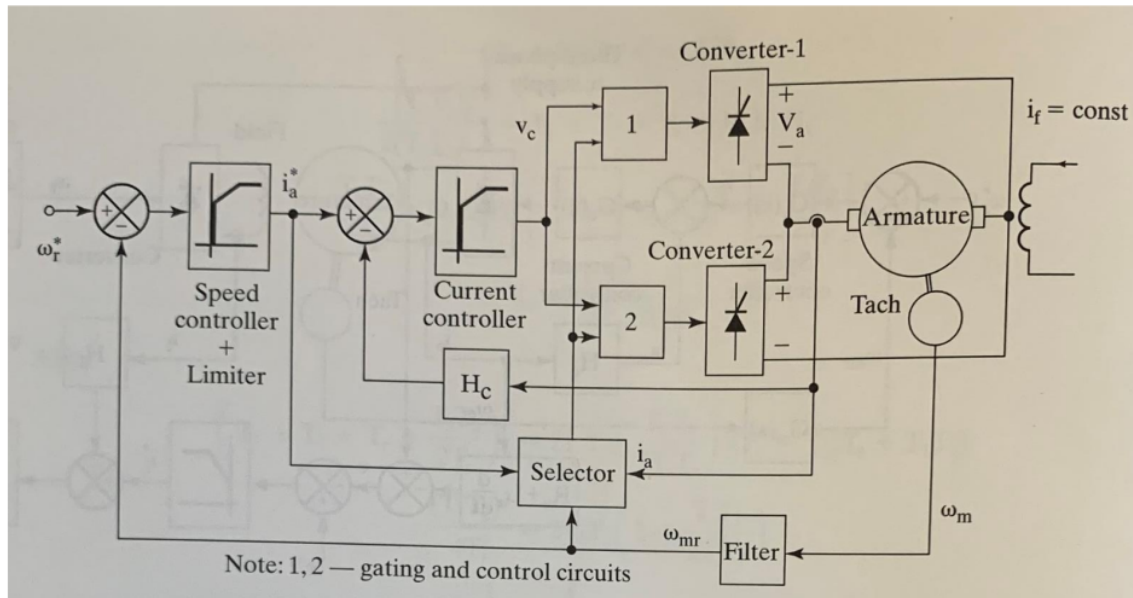


Figure 30: A four-quadrant dc motor drive

(R.KRISHNAN, 2021)

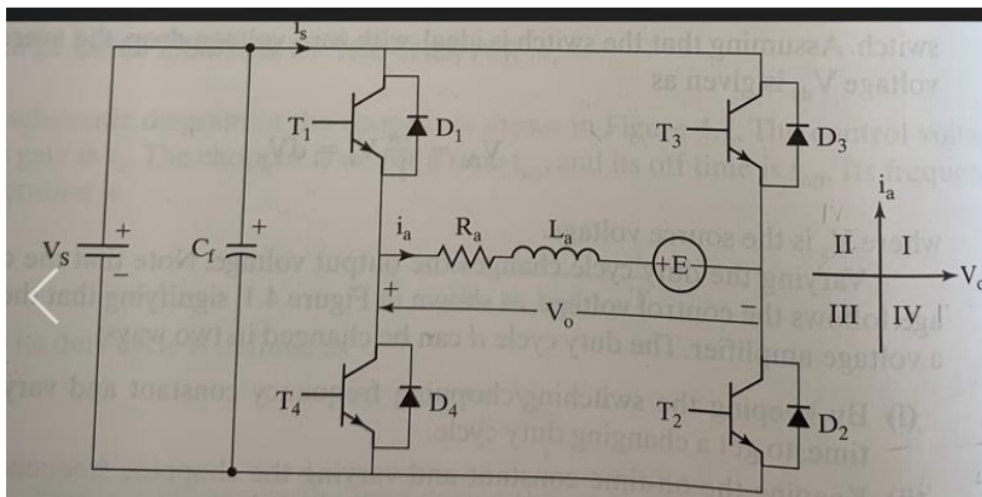


Figure 31: Chopper circuit diagram

FINAL GRADE

GENERAL COMMENTS

Instructor

47 / 100

PAGE 1

Text Comment. Word count exceeded

Text Comment. A wide range of sources have been used in the research. However, the questions have not been understood completely and no manufacturer was selected.

Text Comment. Executive summary is a series of lists and comments covering 3 pages. It should be 1 paragraph of 300 words

Text Comment. There is little evidence of understanding and knowledge is incomplete. Much has not been explained.

Text Comment. Analysis is generally weak, waveforms have not been explained. Most results should be in the appendix.

Text Comment. Conclusions show however, that something has been learnt.

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9

PAGE 10

PAGE 11

PAGE 12

PAGE 13

PAGE 14

PAGE 15

PAGE 16

PAGE 17

PAGE 18

PAGE 19

PAGE 20

PAGE 21

PAGE 22

PAGE 23

PAGE 24

PAGE 25

PAGE 26

PAGE 27

PAGE 28

PAGE 29

PAGE 30

PAGE 31

PAGE 32

PAGE 33

PAGE 34

PAGE 35

PAGE 36

PAGE 37

PAGE 38

PAGE 39

PAGE 40

PAGE 41

PAGE 42

PAGE 43

PAGE 44

PAGE 45

GRADING FORM: NEW CSG-RUBRIC

MASON MORGAN

47

1. ENGAGEMENT WITH LITERATURE



Engagement with an appropriate range of research-informed literature, including sources retrieved independently. Some over-reliance on texts. Referencing may show minor inaccuracies or inconsistencies. (10/20)

10

2. KNOWLEDGE AND UNDERSTANDING



Limited knowledge and systematic understanding of the relevant concepts and principles within the subject area which to some limited extent, is informed by current research and scholarship. (8/20)

8

3. COGNITIVE AND INTELLECTUAL



Limited attempt at critical thinking, analysis, synthesis and evaluation, tending towards description. Some evidence to support emerging arguments and judgements but these may be underdeveloped or with a little inconsistency / mis-interpretation. Asserts rather than argues a case. (8/20)

8

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

10

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. Word count exceeded
(10/20)