

assignment 1 (1602826)

by Sean Jones

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1. Executive Summary

In some industries DC motors are used with an old method of speed and direction control which is proved to be inefficient with power and provides poor control. Modern DC motor drives can perform as good as an AC drive with efficiency and control as technology allows wave forms to be chopped to reduce average voltage instead of wasting energy into heat to reduce speed. Research is done to see how a modern DC drive works and it is compared to an equivalent AC drive. A 4 quadrant DC drive is simulated and tested with all its running values recorded to analyse. The drive performs really well in the control of speed and efficiency of power usage. The recommendation of this system would be, if there is an existing DC motor that doesn't need replacing upgrade the motor control to a modern 4quadrant DC drive. If the motor needs replacing also or a new system is going in, an AC motor and drive should be installed for less motor maintenance and an all-round simpler system.

2. Research

According to Siemens (2020) the DCM 4 quadrant DC drive's main components are, the Control unit, Power interface, Field module and Thyristor unit. Appendices 1 and 2 show the block diagram of the physical components of the DC drive. From this it can be said the control block is almost the face of the drive holding ethernet and serial comms whilst implementing the systems physical I/O. The motor feedback also is handled here (speed, temp, voltage and current). On a software level all the control loops are handled here. Appendix 3 shows such control loop. This is a closed control loop with high precision as speed, armature current and field current are fed back into the loop.

The power interface is for electrical control. Physical e-stop channels for safety are controlled here. Also, any instrumentation of monitoring systems takes place here for suitable analogue values to be used in the control unit. The electronic circuitry required to fire the thyristors are all in this unit. According to (1993) it is expected the AC supply is used for reference here along with feedback from the motor. The field module is very similar but it controls the strength of the motor field.

The Thyristor unit is where the AC is converted to DC for the field and armature. This is the biggest part of the drive as according to Rashid (2014) SCR's are likely to be used to control the power going to the motor and According to Lander (1993) the temperatures caused by these thyristors are high so heatsinks and cooling are needed. Wildi states "We use two converters that function simultaneously. They are connected back-to-back across the armature" (2005, p. 561). Figure 1 shows this.

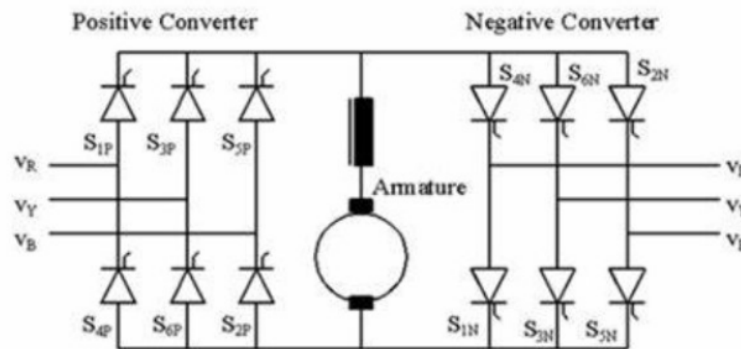


Figure 1 Thyristor layout according to tankonyvtar (2020)

The motor will be able to drive and generate in forward and reverse with this circuit. The method of controlling this is in Figure 2

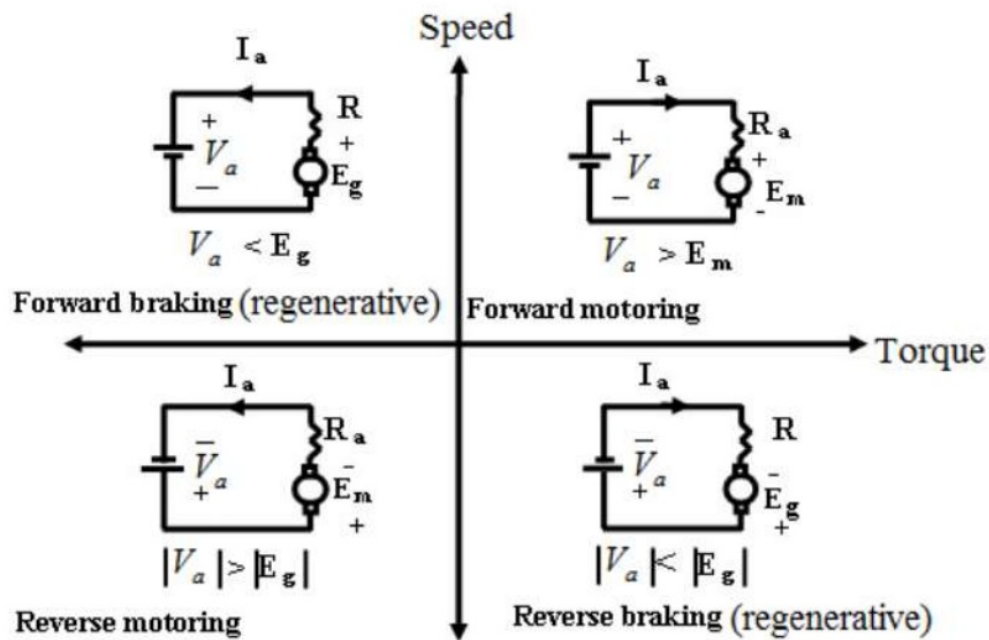


Figure 2 Motor running quadrants according to Antar (2018)

According to Wilamowski (2017) If $\alpha = 0^\circ$ V_{mean} will be at its highest increasing α up to 90° will reduce the average voltage where at 90° $V_{mean} = 0$. when α is taken beyond this it goes negative until it reaches max V_{mean} but inversed.

Electronics hub states “applications include electric traction systems, cranes and lifts” (2020). A crane is a good application for this 4-quadrant system as to crane items up and down high control is needed to stop the item falling and accelerating to the floor. Also, smooth operation is required to protect the goods being moved.

A vector variable drive controlling an AC motor can have a higher starting torque than a DC motor for a smaller cost. As well as being a cheaper to install an AC motor and drive as apposed to DC the AC system as a DC motor requires maintenance on the brushes and an additional motor to cool the DC motor which takes up more space. The DC drive is also a lot bigger for the 12 power thyristors, field thyristors and cooling for these. There’s a lot more availability for AC systems as most new installs use SC systems for price, compact size and performance. Using an AC system gives a smaller chance of an item being discontinued when a replacement is needed.

3. Practical Experiments

A DC motor controlled by a Siemens Three-Phase DCM drive is connected to an AC motor controlled by a Siemens S120 AC Drive via a Belt and pulley system. The Motors used are shown in Figure 4

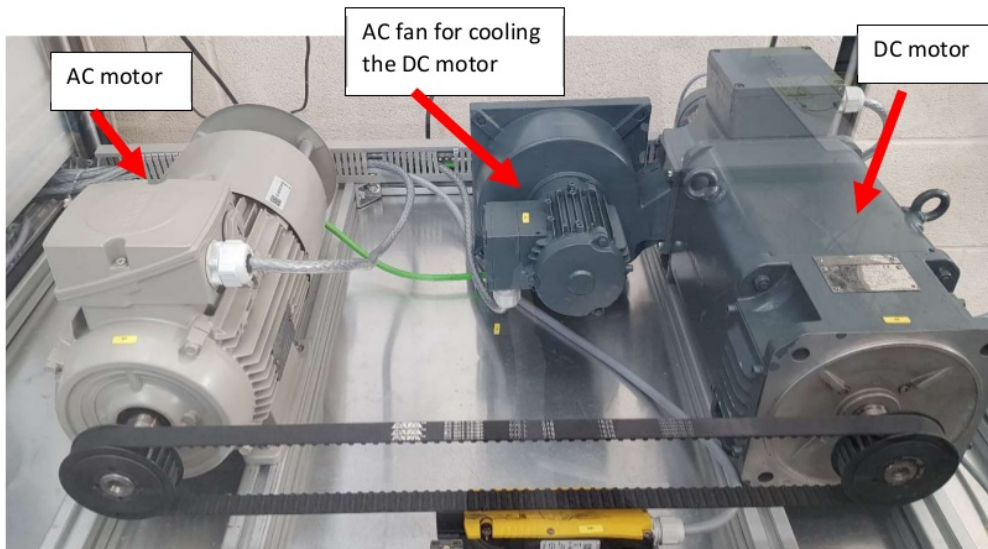


Figure 4 practical set up



Figure 3 electrical enclosure

The Drives are in the electrical enclosure shown in Figure 3. The drives have 2 main cables going to each motor, 1 being the power cable to run the motor and the other being a tachometer to have the speed feed back to the drives.

An HMI was used to adjust set points such as the target speed and the amount of torque put against the DC motor from AC motor. The motor variable values are monitored from this HMI screen. The Profinet connection between the PLC and motor drives allow this easy access to the motors feedback and drive outputs. This HMI screen is shown in Figure 5

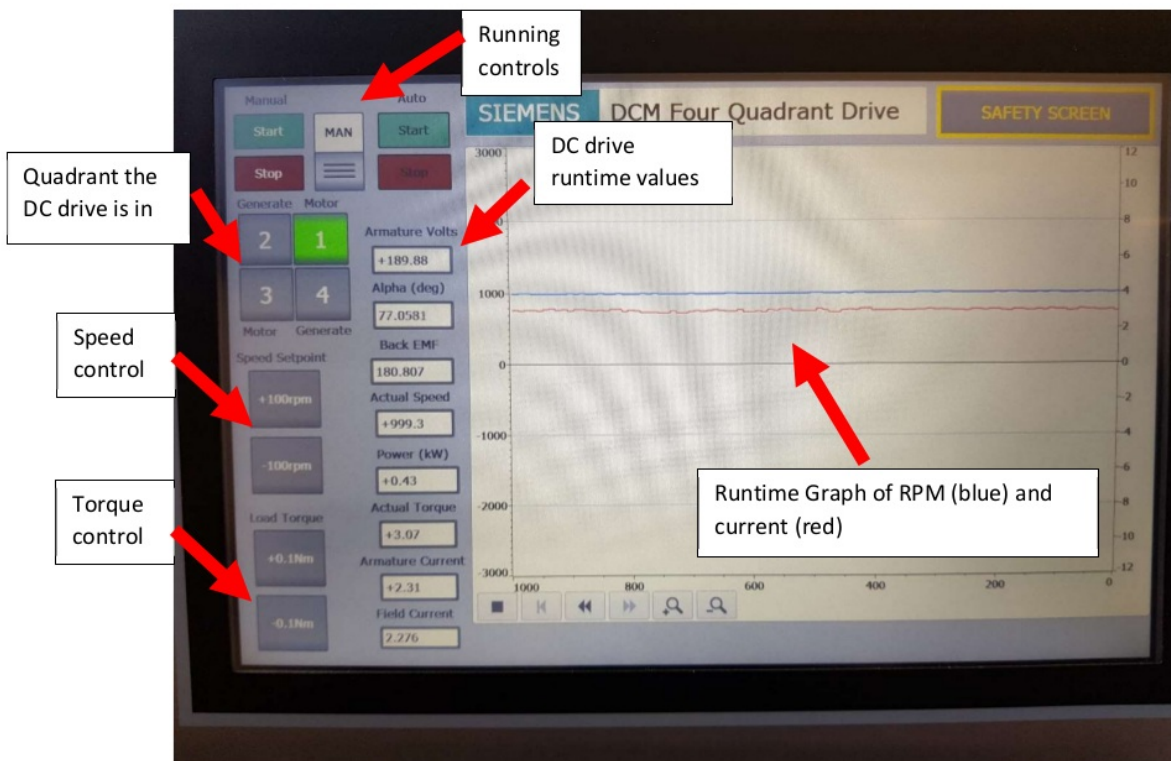


Figure 5 HMI screen

To study the waveforms of the output a Picoscope was attached to DC drive outputs. X100 leads were used on the Picoscope so all values recorded had to be multiplied by 100. The Picoscope was connected to a laptop for recording results. The colours of the Picoscope match Runtime HMI graph but blue is voltage instead of rpm. The settings for the Picoscope scaling are shown in Figure 6



Figure 6 Picoscope settings

The DC motor was run up whilst the AC motor drags against it to simulate the torque requirements that a DC motor may have in an industry application. The PLC is programmed to run the motors in 2 separate modes, manual and automatic. In manual mode the Quadrant that is the motor will run in is set on the HMI screen and it will run in that quadrant until another quadrant is selected or stop is pressed. In automatic mode the PLC will sequence through the quadrants entering each one for a limited time only.

The first part of these tests is done in manual mode to remain in one quadrant whilst altering the torque on the motor shaft. The test is done with continuous current. The motor is brought up to a 1800 rpm and the current is increased until it becomes continuous on the Picoscope graph. Shown in Figure 7. The values were recorded from this graph and the HMI screen. Figure 8 shows the values on the HMI screen

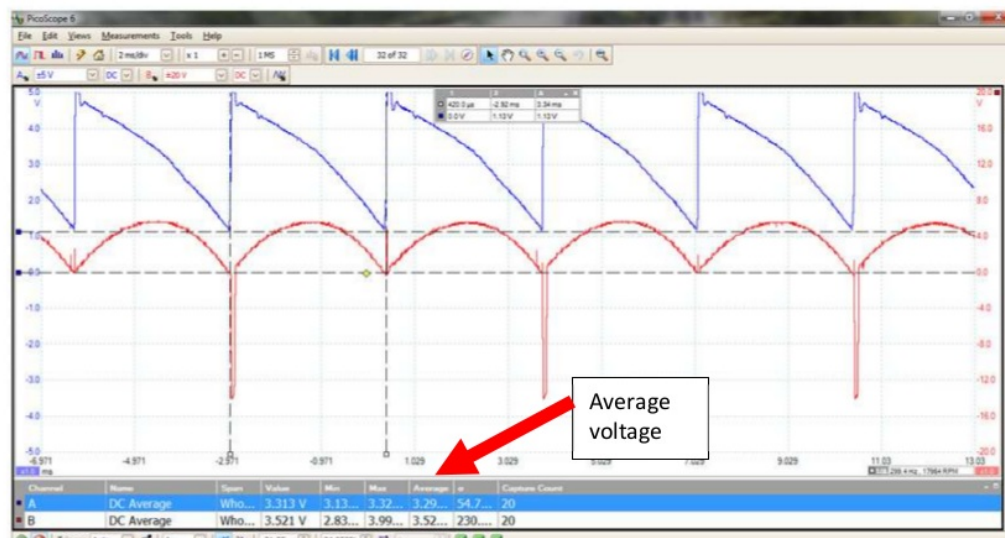


Figure 7 practical continuous current test 1 Picoscope

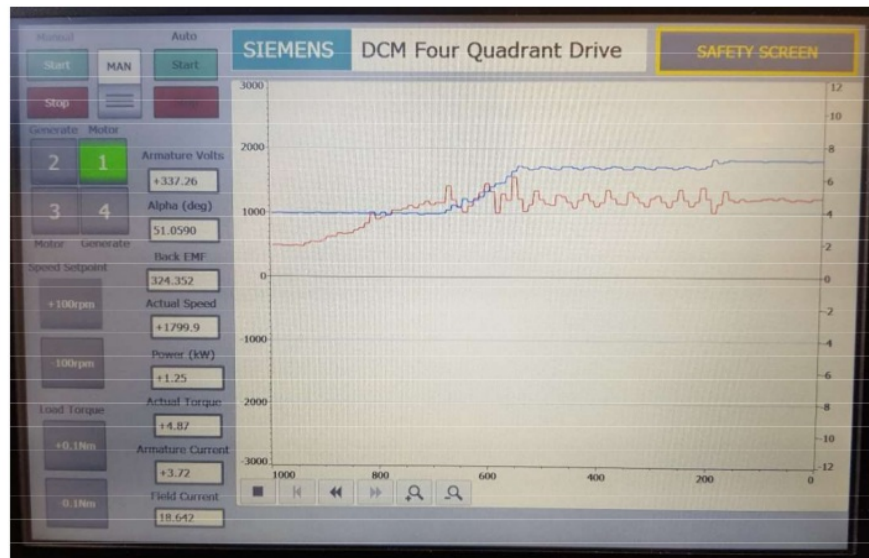


Figure 8 practical continuous current test 1 HMI

Another 2 tests of different torque settings are done. The graphs for these are shown in Figure 9 & Figure 10 for the 2nd test and Figure 11 & Figure 12 for the 3rd test.

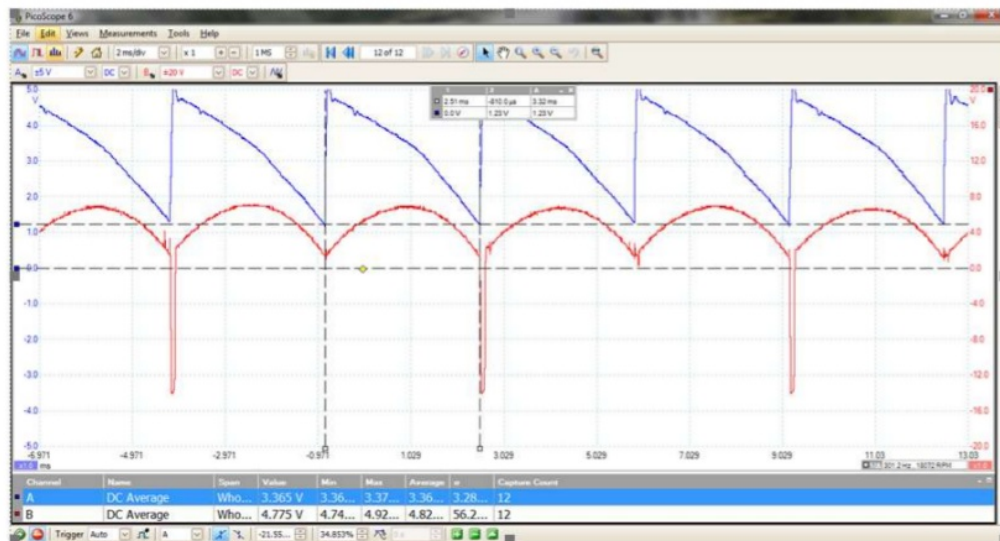


Figure 9 practical continuous current test 2 Picoscope

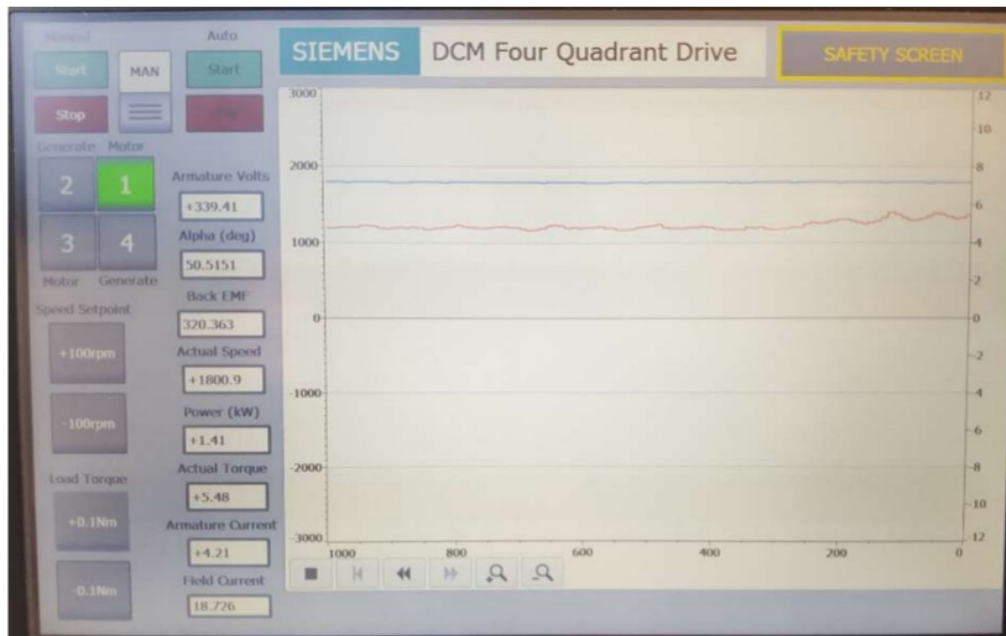


Figure 10 practical continuous current test 2 HMI

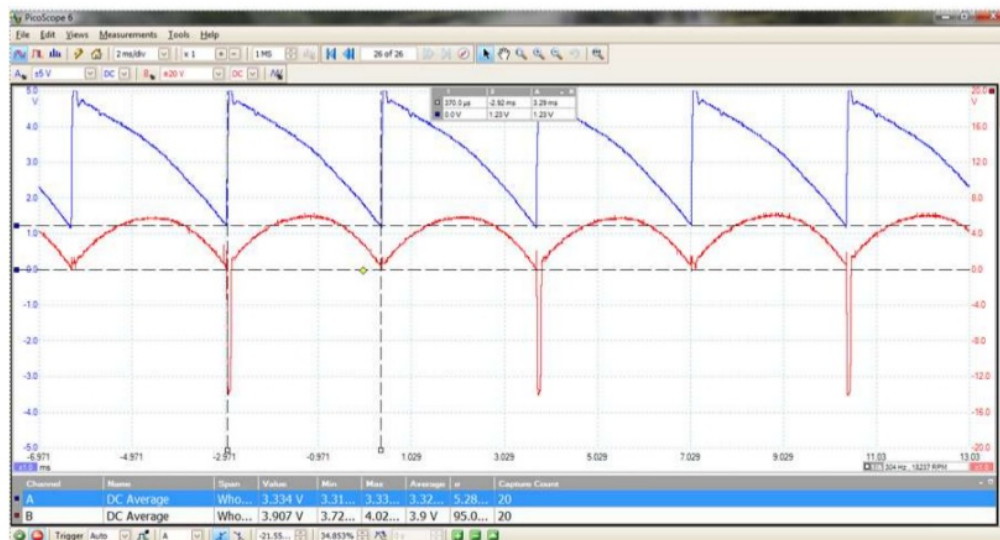


Figure 11 practical continuous current test 3 Picoscope



Figure 12 practical continuous current test 3 HMI

The error between average voltage on the DC drive and the Picoscope had no pattern. 2 being 8 Volts different and 1 being 3 Volts different. This is very close to the more reliable readings off the DC drive. The difference in voltage could be down to the loss of small voltage in the leads which is amplified by 100 when in the Picoscope. Slightly different reference points whilst measuring can be a big factor, the Picoscope was placed in the electrical enclosure with all the 3 phase systems so there was plenty of opportunity for noise to affect the recordings.

To calculate the average voltage a formula has to be derived to calculate the area under the curve of the waveform to give the average voltage. Alpha can be measured and calculated from taking measurements on the Picoscope graph so that can be used in the formula. The Vmax value will be a constant and the formula will need to calculate the average voltage is aspect of the maximum voltage. Pi is half of a single-phase wave form so each saw tooth on the waveform in Figure 13 is a 3rd of pi.

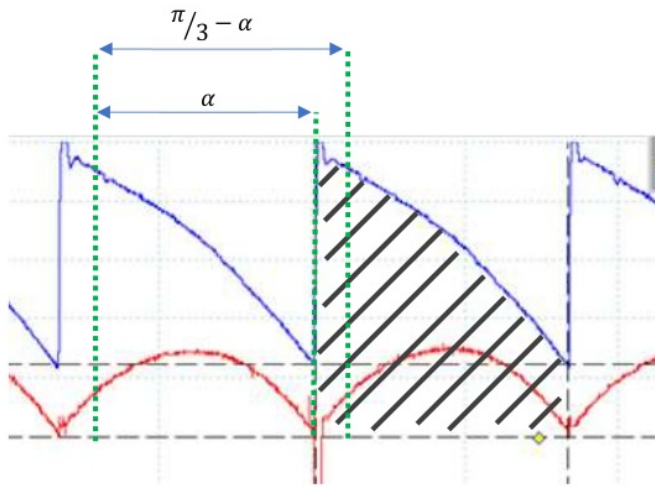


Figure 13 alpha measurement

$$area = \int_{\pi/3+\alpha}^{2\pi/3+\alpha} Vmax \sin \theta d\theta$$

$$= Vmax[-\cos \theta]_{\pi/3+\alpha}^{2\pi/3+\alpha}$$

$$= Vmax[-\cos(2\pi/3 + \alpha) - -\cos(\pi/3 + \alpha)]$$

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

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

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

$$area = V_{max} \cos \alpha$$

The derived formulae used is:

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

Where alpha can be used from the Picoscope graph the calculation is as below

$$\alpha = \frac{t \text{ of } \pi/3 \text{ (ms)}}{10} 180$$

This used in the calculation will have to be converted to radians

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

With the formulas required the values can be calculated.

Test 1 values

$$\alpha = \frac{3.34}{10} 180 = 60.12$$

This value is too far from the measured of 51.059 so for the accuracy the firing angle from the drive is used as it will be exact.

$$\alpha(rad) = \frac{\pi}{180} 51.059 = 0.891$$

$$V_{max} = \sqrt{2} 415 = 587$$

$$V_{mean} = \frac{3 \times 587}{\pi} \cos 0.891$$

$$V_{mean} = 352.33$$

Table 1 shows the comparison of all the measured and calculated values for test 1

Table 1 practical continuous current test 1

Continuous current torque increasing results	Test 1 Drive values	Picoscope	Continuous calculated
Armature Volts	337.26	329	352.33
Alpha	51.059(deg)	3.34ms	60.12(deg)
Back EMF	324.352	n/a	n/a
Actual Speed	1799.9	n/a	n/a
Power (KW)	1.25	n/a	n/a
Actual Torque	4.87	n/a	n/a
Armature Current	3.72	3.52	n/a
Field Current	18.642	n/a	n/a

Test 2 values

$$\alpha = \frac{3.32}{10} 180 = 59.76$$

Measured alpha is used.

$$\alpha(rad) = \frac{\pi}{180} 50.5151 = 0.882$$

$$V_{mean} = \frac{3 \times 587}{\pi} \cos 0.882$$

$$V_{mean} = 356.286$$

Table 2 shows the comparison of all the measured and calculated values for test 2

Table 2 practical continuous current test 2

Continuous current torque increasing results	Test 2 Drive values	Picoscope	Continuous calculated
Armature Volts	339.41	336	356.286
Alpha	50.5151(deg)	3.32ms	59.76(deg)
Back EMF	320.363	n/a	n/a
Actual Speed	1800.9	n/a	n/a
Power (KW)	1.41	n/a	n/a
Actual Torque	5.48	n/a	n/a
Armature Current	4.21	4.82	n/a
Field Current	18.726	n/a	n/a

Test 3 values

$$\alpha = \frac{3.29}{10} 180 = 59.22$$

Measured alpha is used.

$$\alpha(rad) = \frac{\pi}{180} 49.7076 = 0.868$$

$$V_{mean} = \frac{3 \times 587}{\pi} \cos 0.868$$

$$V_{mean} = 361.31$$

Table 3 shows the comparison of all the measured and calculated values for test 3

Table 3 practical continuous current test 3

Continuous current torque increasing results	Test 3 Drive values	Picoscope	Continuous calculated
Armature Volts	340.26	332	362.31
Alpha	49.7076(deg)	3.29ms	59.22(deg)
Back EMF	318.851	n/a	n/a
Actual Speed	1798.4	n/a	n/a
Power (KW)	1.77	n/a	n/a
Actual Torque	6.8	n/a	n/a
Armature Current	5.12	3.9	n/a
Field Current	18.668	n/a	n/a

The increase of torque appears to increase the voltage and current on the armature where field current changes a very small amount. There is discrepancies with the calculated values which may be down to the formula derived as they all have a patterned error of being too high. On the 3rd test the Picoscope has recorded a spurious value of 3.9 amps on the armature when the drive recorded 5.12. This is likely an error of the Picoscope and not the drive as 5.12 follows the pattern of increasing the torque.

Figure 14 shows the graph with measuring points to find the motor constants. The difference in voltage between the voltage at the point of maximum current and the emf. The difference between these are 16 volts. The maximum current is 4.88

$$E_{(r)} = Va - Ia_{(r)}R_a$$

$$Va - E_{(r)} = Ia_{(r)}R_a$$

$$\frac{Va - E_{(r)}}{Ia_{(r)}} = R_a$$

$$R_a = \frac{16}{4.88} = 3.28$$

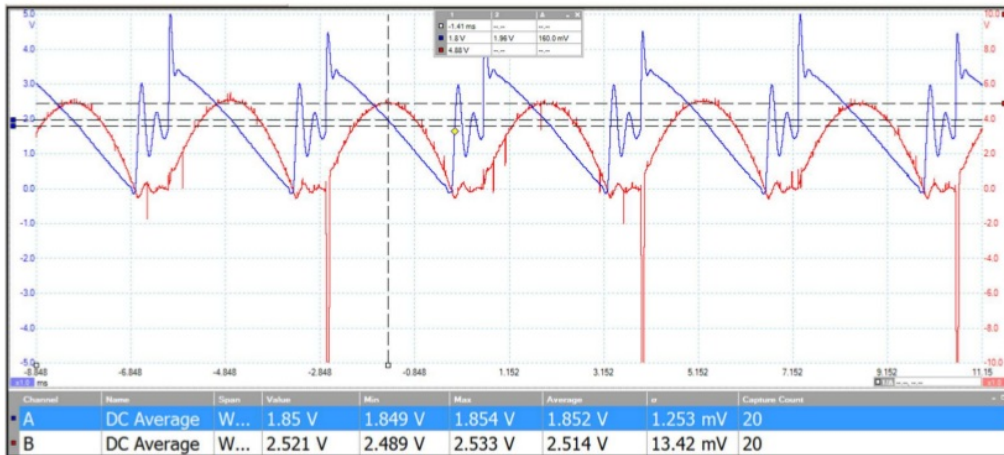


Figure 14 motor constants measurements

The values from test 2 are taken to calculate the motor constants.

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

$$Speed \text{ (Rad)} = \frac{1800\pi}{30} = 188.496$$

$$K_e = \frac{320.363}{188.496} = 1.6996$$

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

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

Table 4 motor constants

Motor constants	Ra	Ke	Kt
Value	3.28	1.6996	1.302

A similar test is carried out but with the motor in discontinuous current. The torque is constant and the speed is varied to show different speed setpoints. The test equipment is exactly the same apart from the speed is lower to start with is reduced. Figure 16 shows the first test Picoscope results and Figure 15 shows the HMI from test 1. Figure 18 shows the first test Picoscope results and Figure 17 shows the HMI from test 2. Figure 20 and Figure 19 shows the first test Picoscope results and Figure 21 shows the HMI from test 3.

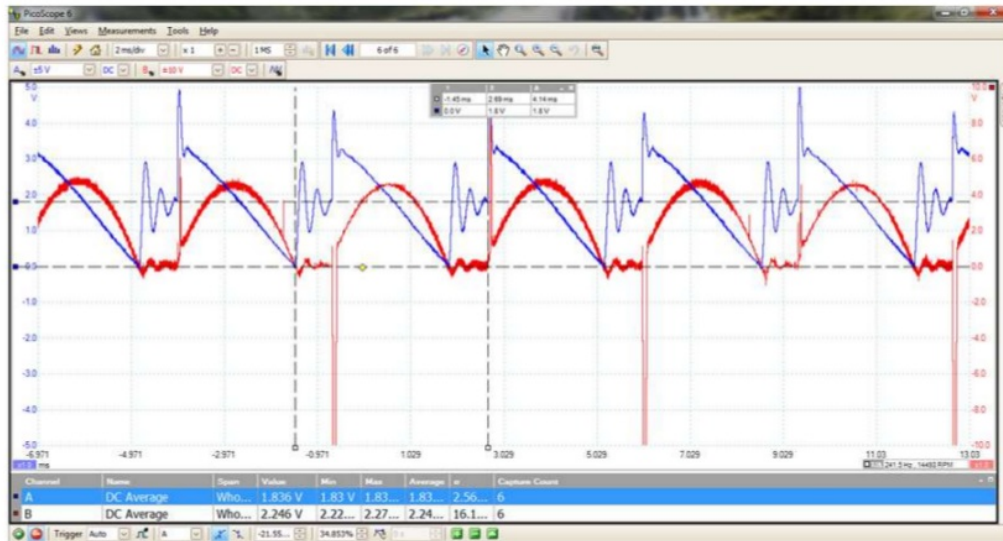


Figure 16 practical discontinuous current test 1 Picoscope

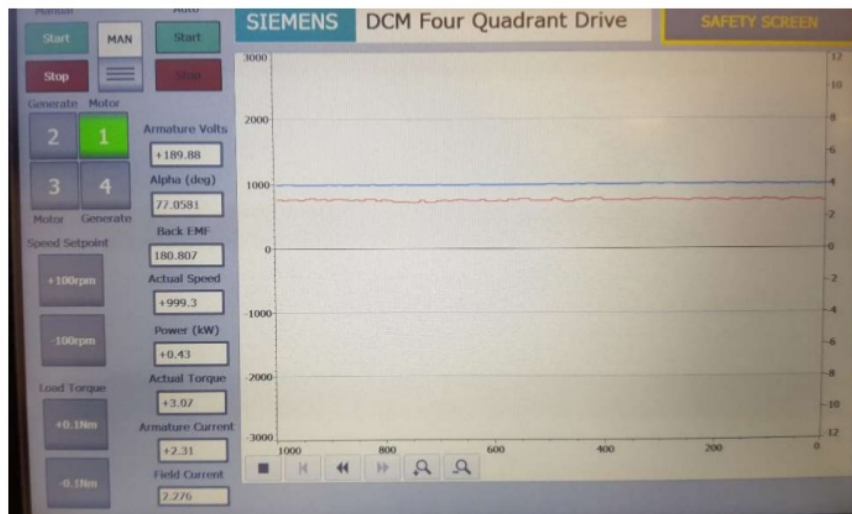


Figure 15 practical discontinuous current test 1 HMI

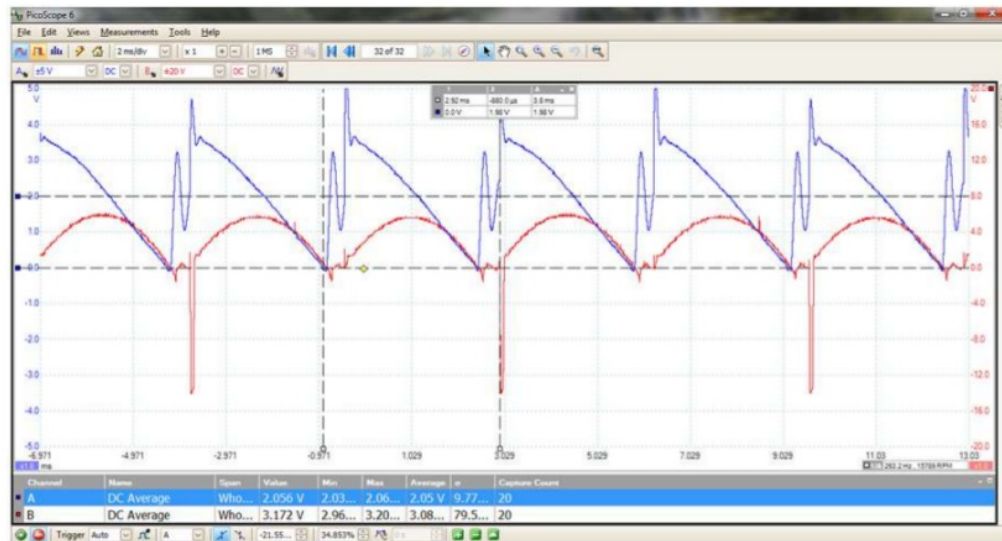


Figure 18 practical discontinuous current test 2 Picoscope

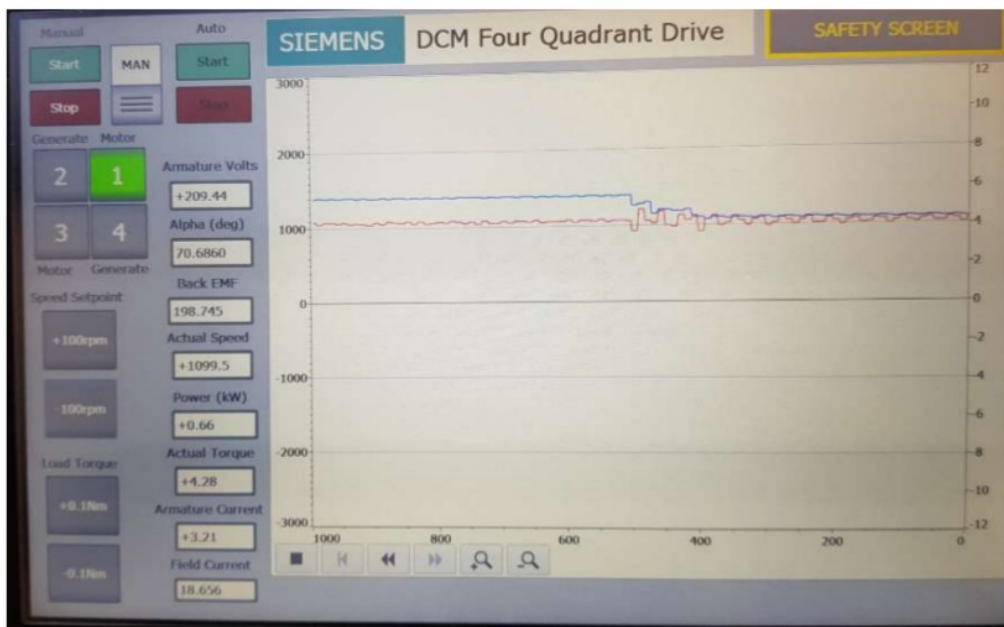


Figure 17 practical discontinuous current test 2 HMI

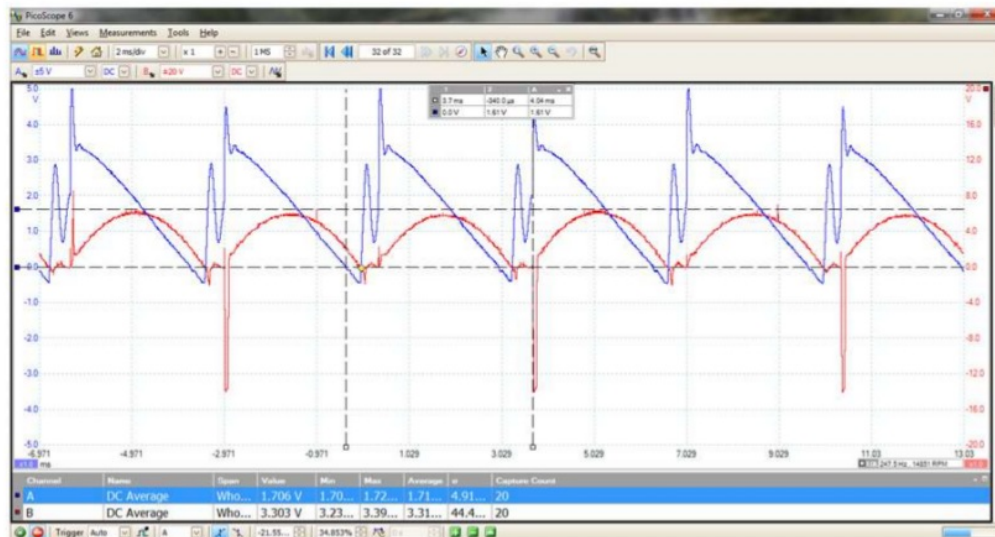


Figure 20 practical discontinuous current test 3 Picoscope

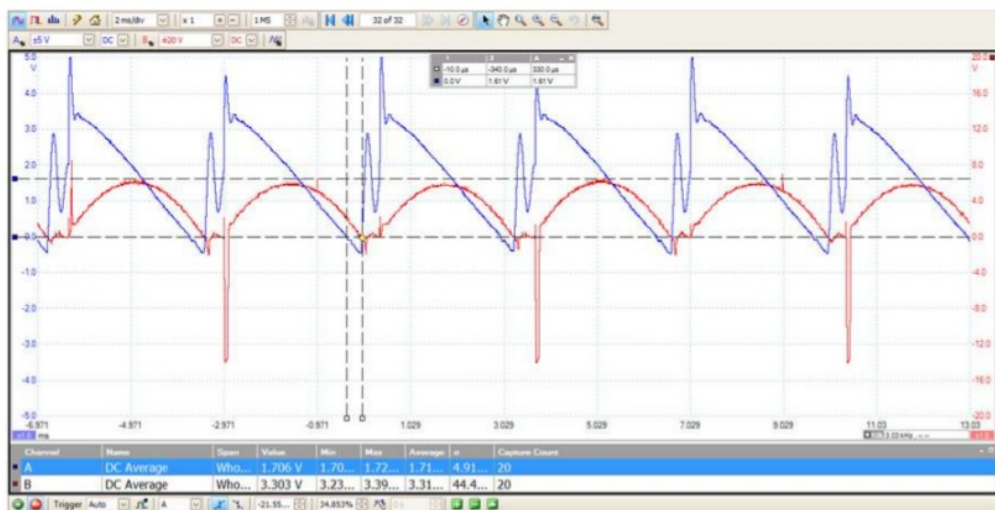


Figure 19 practical discontinuous current test 3 Picoscope BETA

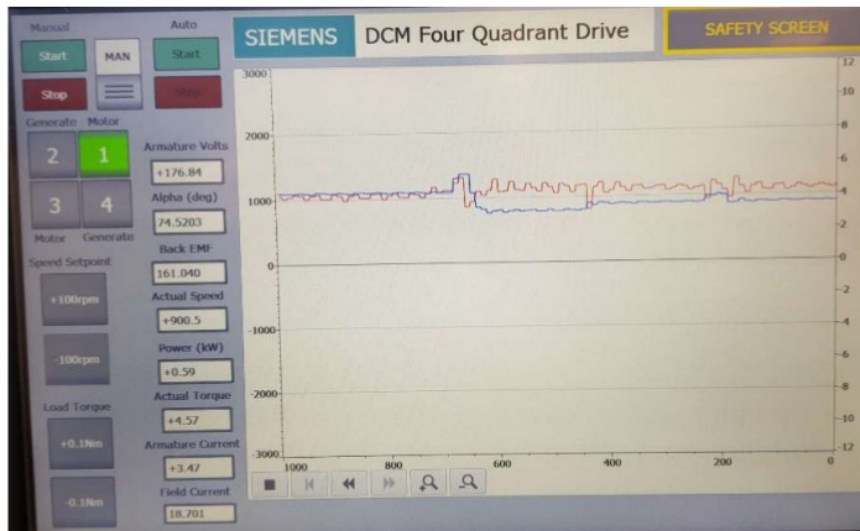


Figure 21 practical discontinuous current test 3 HMI

A formula is derived to calculate the running values. Figure 22 shows the area under the curve that needs its area to be calculated in order to find the average voltage. The drive doesn't use the traditional alpha value, it has a 60° offset.

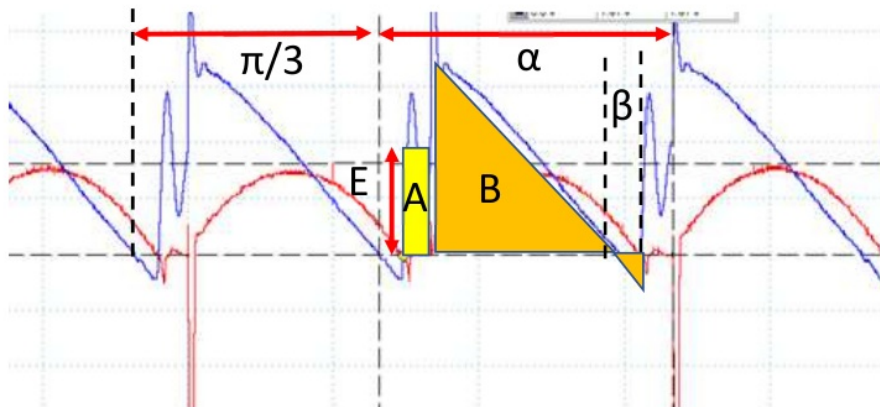


Figure 22 area under curve

Drive alpha:

$$\alpha = \alpha' + 60^\circ$$

Or it can be used as:

$$\alpha = \alpha' + \frac{\pi}{3}$$

Area "A" shown in Figure 22 is averaged as just a square so the calculation is below.

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

Area "B" shown in Figure 22 has a curve in it so it must be integrated.

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

Since

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

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

The total area will be these two areas added together.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

This formula is used to calculate the average armature voltage of a discontinuous current where the voltage goes to 0.

Test 1 values

$$\alpha = \frac{4.14}{10} 180 = 74.52$$

$$\beta = 0$$

This value of alphas is closer to the drive value than it was on the previous tests. Although it is only 3 degrees different the drive value will be used for a closer result.

$$\alpha(rad) = \frac{\pi}{180} 74.52 = 1.344$$

$$V_{mean} = \frac{180.807(1.344 - \pi/3 - 0) + 587 \left[\cos 0 + \frac{1}{2} \cos 1.344 - \frac{\sqrt{3}}{2} \sin 1.344 \right]}{\pi/3}$$

$$V_{mean} = 200.89$$

Table 5 shows the comparison of all the measured and calculated values for test 1

Table 5 practical discontinuous current test 1

Discontinuous current torque increasing results	Test 1 Drive values	Picoscope	Continuous calculated
Armature Volts	189.88	183	200.89
Alpha	77.0581(deg)	4.14ms	74.52(deg)
Beta	0	0	0
Back EMF	180.807	180	n/a
Actual Speed	999.3	n/a	n/a
Power (KW)	0.43	n/a	n/a

Actual Torque	3.07	n/a	n/a
Armature Current	2.31	2.26	n/a
Field Current	2.2176	n/a	n/a

Test 3 values

$$\alpha = \frac{3.8}{10} 180 = 68.4$$

$$\beta = \frac{3.8}{10} 180$$

Drive alpha used.

$$\alpha(\text{rad}) = \frac{\pi}{180} 70.686 = 1.234$$

$$V_{\text{mean}} = \frac{198.745(1.234 - \pi/3 - 0) + 587 \left[\cos 0 + \frac{1}{2} \cos 1.234 - \frac{\sqrt{3}}{2} \sin 1.234 \right]}{\pi/3}$$

$$V_{\text{mean}} = 230.33$$

Table 6 shows the comparison of all the measured and calculated values for test 2

Table 6 practical discontinuous current test 2

Discontinuous current torque increasing results	Test 2 Drive values	Picoscope	Continuous calculated
Armature Volts	209.44	205	230.33
Alpha	70.6860	3.8ms	68.4
Beta	0	0	0
Back EMF	198.745	198	n/a
Actual Speed	1099.5	n/a	n/a
Power (KW)	0.66	n/a	n/a
Actual Torque	4.28	n/a	n/a

Armature Current	3.21	3.08	n/a
Field Current	18.656	n/a	n/a

Test 3 values

$$\alpha = \frac{4.04}{10} 180 = 72.72$$

$$\beta = \frac{0.330}{10} 180 = 5.94$$

Drive alpha used.

$$\alpha(rad) = \frac{\pi}{180} 74.52 = 1.301$$

$$\beta(rad) = \frac{\pi}{180} 5.94 = 0.1037$$

$$V_{mean} = \frac{161.04(1.301 - \pi/3 - 0.1037) + 587 \left[\cos 0 + \frac{1}{2} \cos 1.301 - \frac{\sqrt{3}}{2} \sin 1.301 \right]}{\pi/3}$$

$$V_{mean} = 187.47$$

Table 7 shows the comparison of all the measured and calculated values for test 3

Table 7 practical discontinuous current test 3

Discontinuous current torque increasing results	Test 3 Drive values	Picoscope	Continuous calculated
Armature Volts	176.84	171	187.47
Alpha	74.5203	4.04ms	72.72
Beta	n/a	0.330 ms	5.94
Back EMF	161.040	161	n/a
Actual Speed	900.5	n/a	n/a
Power (KW)	0.59	n/a	n/a
Actual Torque	4.57	n/a	n/a

Armature Current	3.47	3.31	n/a
Field Current	18.701	n/a	n/a

The results from the speed test show a discrepancy that is proportional to the voltage on the armature. The V_{max} was calculated at 587v and when measured on the Picoscope it was also 587v eliminating that as the problem. The problem may lay on the back EMF part of the waveform in Figure 23. The formulae derived suggests a vertical start where there is a slight gradient which would cause too much area to be accounted for. The ringing on the Emf section may cause a loss in area which isn't accounted for, although this should balance out there may be slight affect on the result here. There is a delay in the ending of 1 wave form and the start of the emf on the Picoscope. This isn't below 0 so can be classified as beta. It could be possible that there is a delay of some sort on the drive and the formula doesn't account for. This would cause a large over estimation of area as the whole curve would move over. This might also explain the slight differences in alpha values. The Picoscope reads lower than the drive by about 4 to 6 volts. This may either be error in the Picoscope leads clamping on the wire or the calculations the drive makes for the average voltage may be different to the Picoscope.

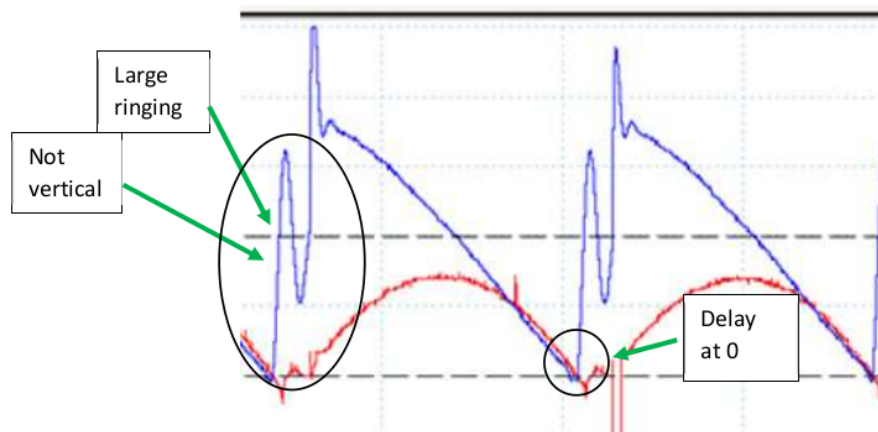


Figure 23 reasons for error

Automatic running

The system is switched into automatic mode.

When the DC motor is running in quadrant 1 the DC motor is driving forward with the AC dragging on it to simulate the mechanical torque fighting against the DC motor. When in quadrant 2 the AC motor will speed up faster than the set point causing the dc motor to brake to slow it back down to the set speed. In quadrant 3 and 4 the motor will do the same but in reverse to nominal direction.

Figure 24 shows the HMI screen graph that was produced after running a cycle through automatic mode. The speed of the drive is maintained smooth transitioning through the quadrants where the current is very very unstable to make the running of the motor smooth.

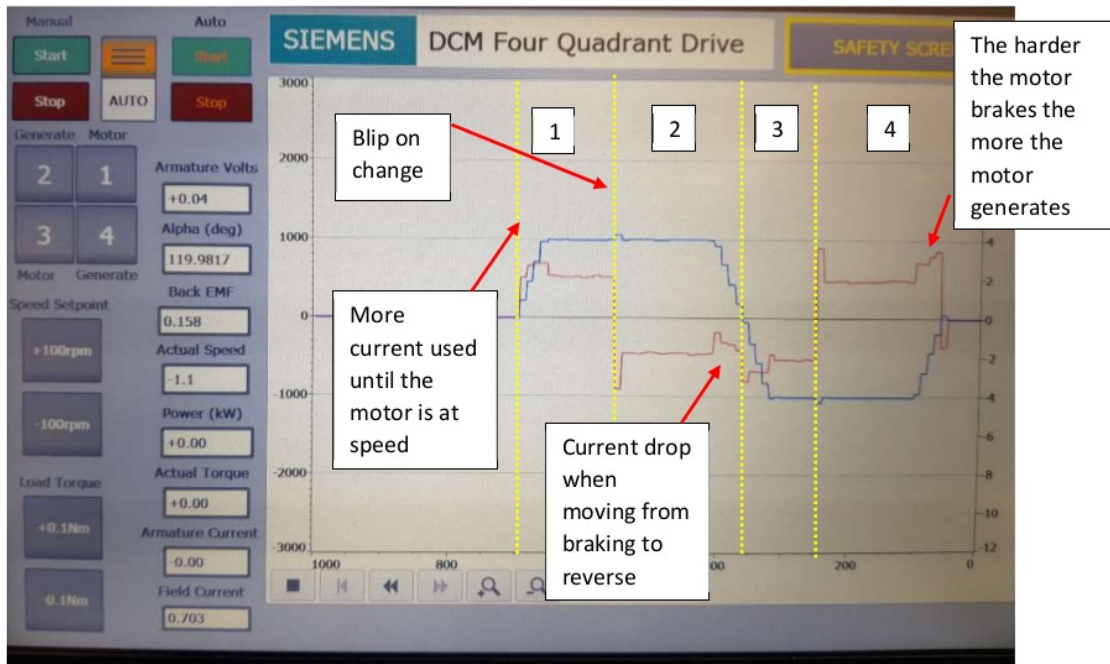


Figure 24 HMI in 4 quadrants

If it wasn't for the current acting unbalanced the speed of the motor would have been compromised. There is only a slight blip in increase of the motors speed where it transitions from motoring to braking but it's under 50rpm and is quickly acted upon by the drive. When the motor is braking quadrant 2 the current drops as it changes from braking to reversing. This is so the deacceleration is controlled as it can overheat the motor if continuous heavy braking occurs.

The Picoscope was used to record the waveforms in each quadrant of the motor running. Figure 25 shows quadrant 1. The drive is emitting positive voltage and positive current here so the drive should be using its forward bridge with alpha less than 90° . The motor still has a lot of back emf present so it's possible that it's not working very hard considering its only using 180V of its 587 potential.

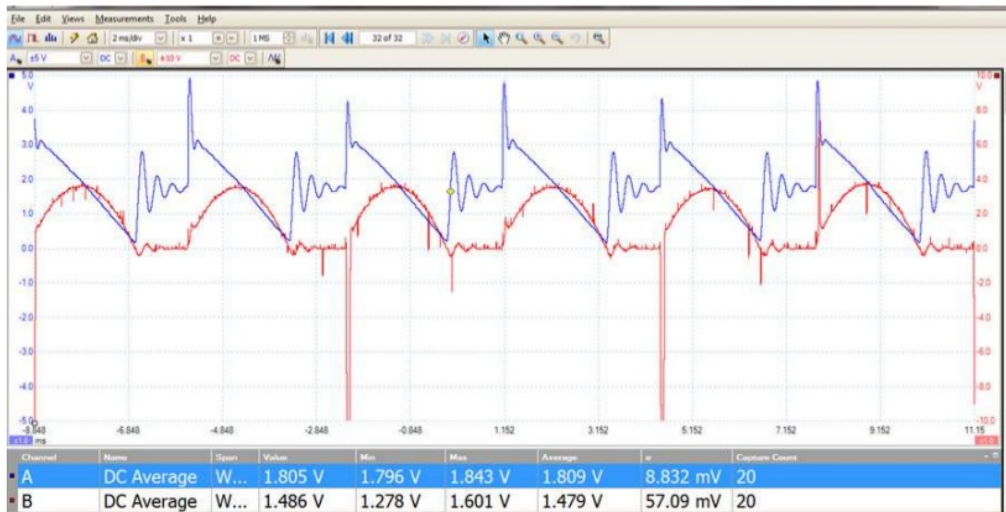


Figure 25 quadrant 1 Picoscope

Figure 26 shows the second quadrant being used. The current has flipped negative and positive voltage is still present. The second bridge will be used with alpha greater than 90°

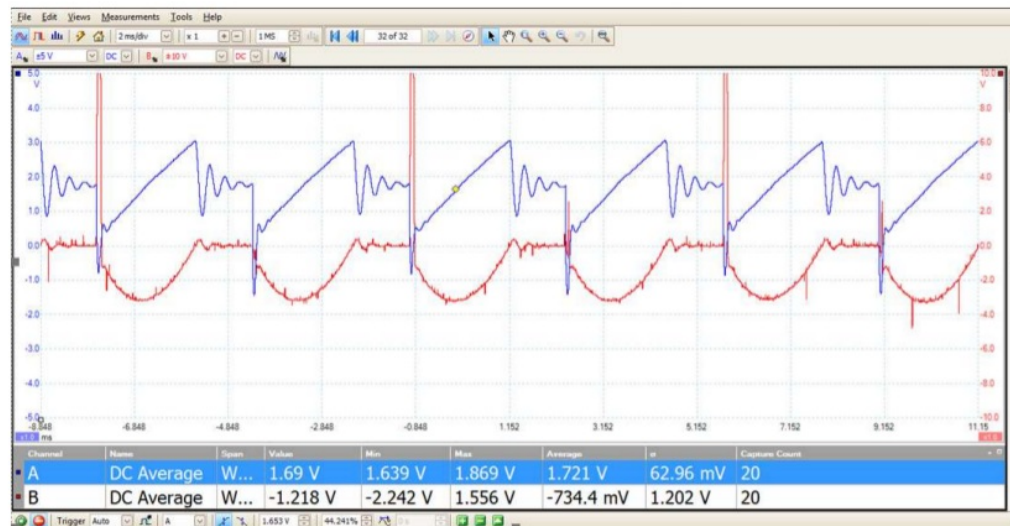


Figure 26 quadrant 2 Picoscope

Figure 27 shows quadrant 3. The voltage and current are both negative. The 2nd bridge will be in use with alpha less than 90° .

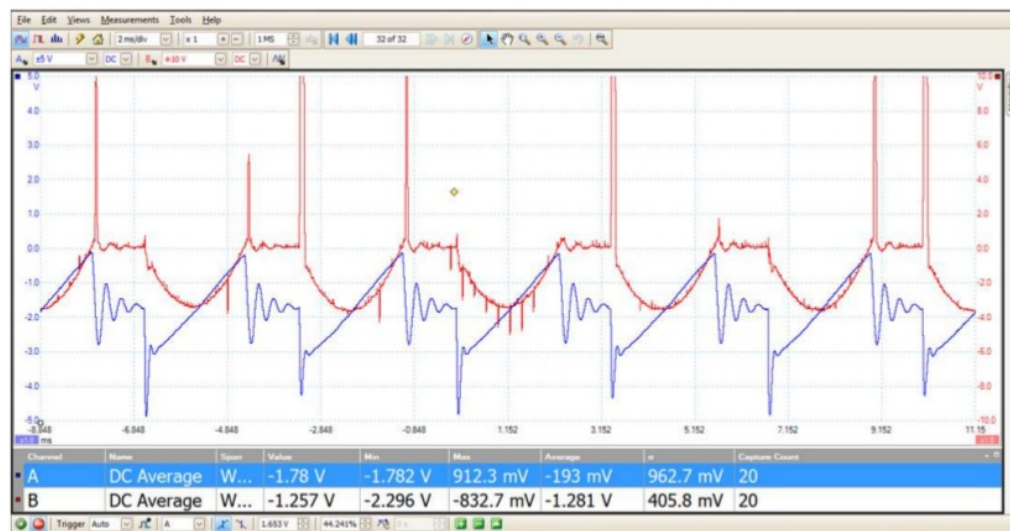


Figure 27 quadrant 3 Picoscope

Figure 28 shows quadrant 4. The voltage is negative and current is positive. The 1st bridge will be in use with alpha greater than 90°.

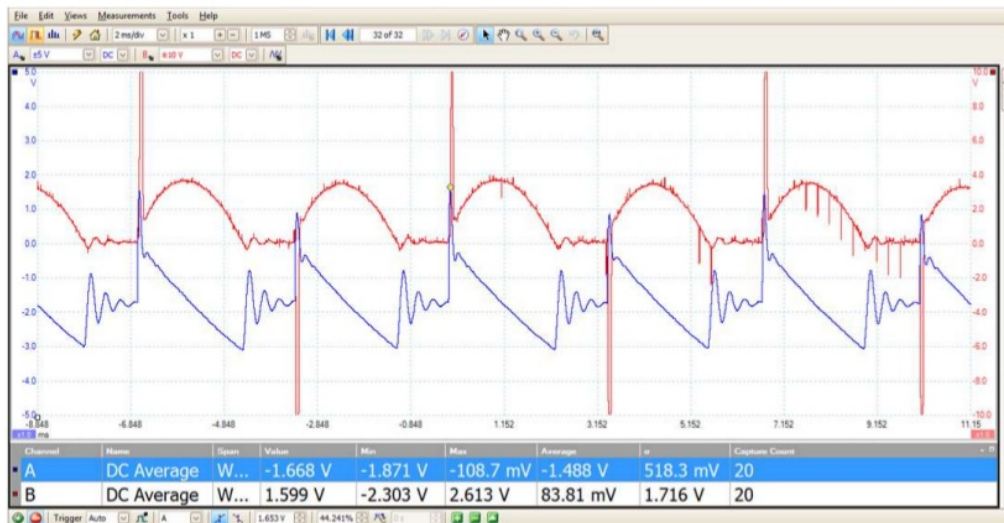


Figure 28 quadrant 4 Picoscope

The results from the practical tests show a very high performance from the drive. It deals with changing speeds and directions very smoothly with very little blips in rpm. It's also very efficient with power with the methods it uses to control its speed.

4. Simulation and Design Adaption

Multisim is used to simulate a DC motor and basic single quadrant drive Figure 29. 6 thyristors are used to rectify the wave form fully. These are controlled via a controller that gives a signal depending on where the alpha value is set. 60hz supply is used in this simulation as the controller assumes this frequency. The voltage inputted into the controller determines the firing angle. 60 degrees must be added on to the firing angle input. The inductor and resistor is used to simulate a purely inductive load on the output of the thyristor bank. An oscilloscope is placed across the resistor to measure volt drop across it for current and the other channel goes across the output of the thyristor circuit to measure the voltage. A battery is placed in series against the direction of the output to simulate the back emf in a circuit.

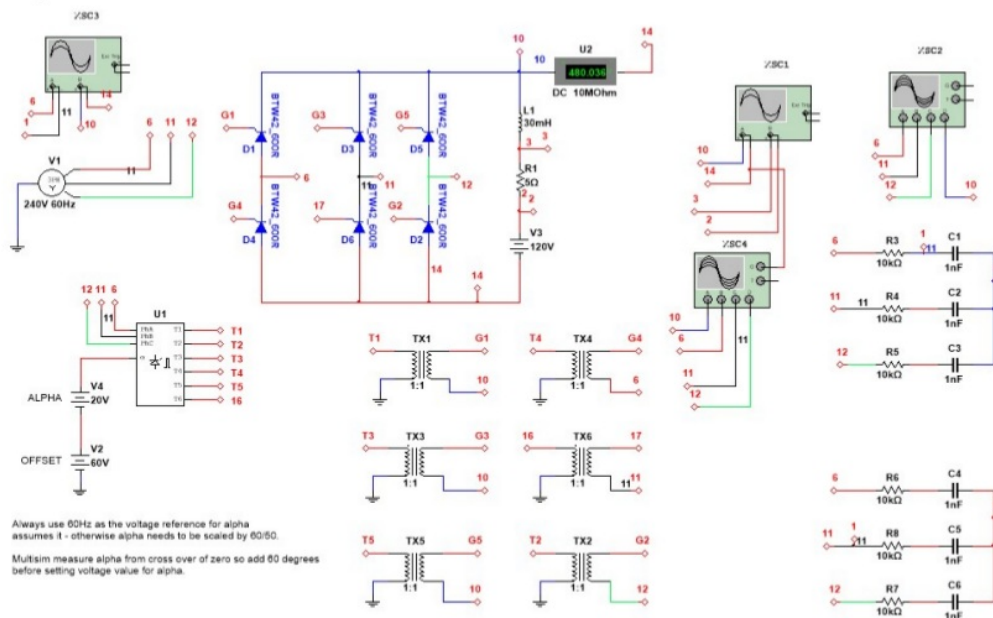


Figure 29 simulation circuit

3 tests were run to show the output at 3 different firing angles. Alpha will be measured on these tests to calculate the average voltage Figure 30 shows the first test at 15 degrees.

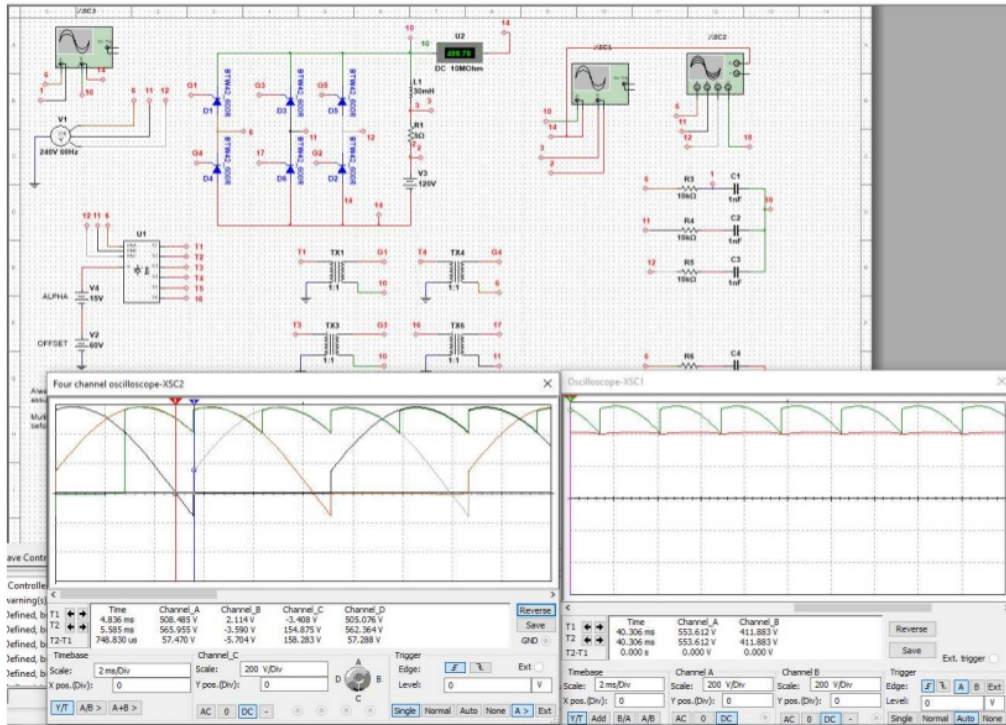


Figure 30 simulation alpha at 15 degrees

The calculation for the armature voltage is the same as the one for the practical test

$$\alpha = \frac{0.748}{10} 180 = 13.464$$

Measured alpha is used.

$$\alpha(\text{rad}) = \frac{\pi}{180} 15 = 0.262$$

$$V_{\text{mean}} = \frac{3 \times 587}{\pi} \cos 0.262$$

$$V_{\text{mean}} = 541.41$$

Table 8 simulation alpha at 15 degrees

Continuous current simulation	Test 1	Calculated
	Multisim values	

Armature Volts	498.78	541.41
Alpha	15	13.464

Figure 31 shows the same test with a 30-degree firing angle

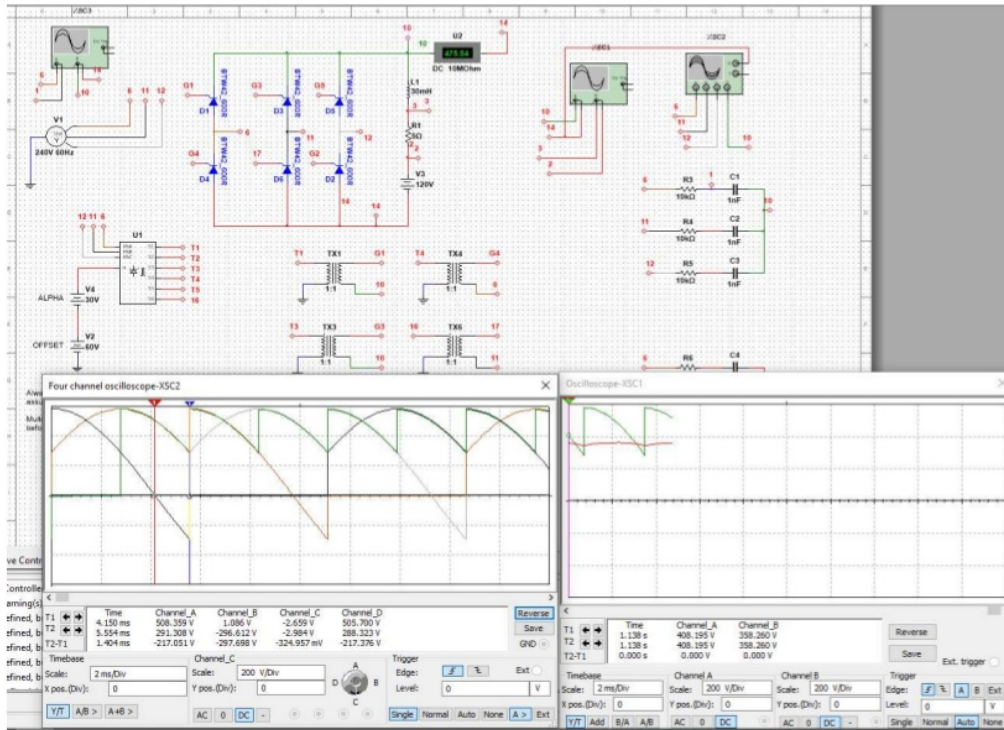


Figure 31 simulation alpha at 30 degrees

$$\alpha = \frac{1.404}{10} 180 = 25.272$$

Measured alpha is used.

$$\alpha(\text{rad}) = \frac{\pi}{180} 30 = 0.524$$

$$V_{\text{mean}} = \frac{3 \times 587}{\pi} \cos 0.524$$

$$V_{\text{mean}} = 485.33$$

Table 9 simulation alpha at 30 degrees

Continuous current simulation	Test 2 Multisim values	Calculated
Armature Volts	475.54	485.33
Alpha	30	25.272

Figure 32 shows the same test with a 45 degree firing angle

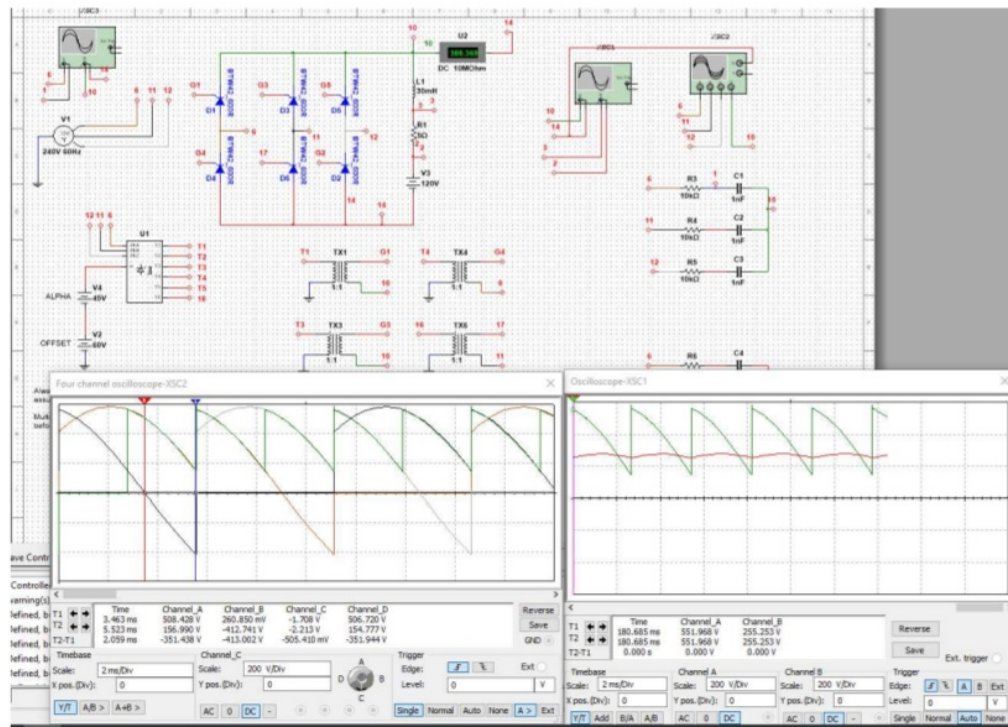


Figure 32 simulation alpha at 45 degrees

$$\alpha = \frac{2.059}{10} 180 = 37.062$$

Measured alpha is used.

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

$$V_{\text{mean}} = \frac{3 \times 587}{\pi} \cos 0.785$$

$$V_{\text{mean}} = 396.52$$

Table 10 simulation alpha at 45 degrees

Continuous current simulation	Test 3 Multisim values	Calculated
Armature Volts	388.37	396.52
Alpha	45	37.062

The results of the first test show a high value on the calculated and a 40 volts lower value on the measured. This is more than likely down to a simulation error as the other 2 results are fairly close and have a pattern of gap between them where this measured value is the odd one out. The alpha values are proportionally out. This was also the case on the practical continuous current tests. There is likely a difference in the alpha firing angle reference point from theory to the systems used in practical and simulation.

This circuit can be modified to run in 4 quadrant operation. Figure 34 an extra 6 thyristor bridge is added to the circuit in reverse polarity to the existing one allowing the reverse current output. The circuit can switch between bridges whilst running to change the quadrant it runs in. The simulation software used to run this setup would error out when alpha was taken beyond 90 degrees so this is the system running in 2 of the quadrants. Figure 34 is quadrant 1 and Figure 33 is quadrant 3.

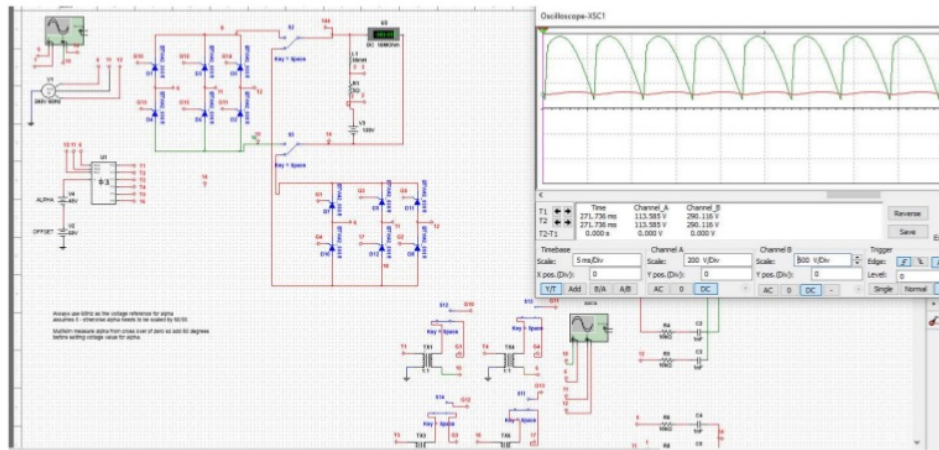


Figure 34 2 rectifier bridge circuit in quadrant 1

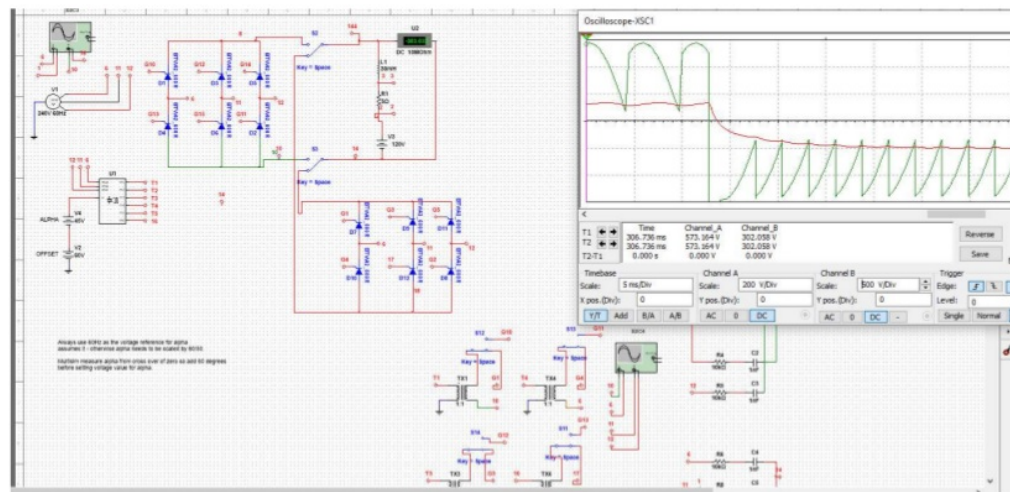


Figure 33 2 rectifier bridge circuit in quadrant 3

5. Conclusions and Recommendations

The research showed the working of the drive to give a greater understanding when testing the system. The research also made it possible to alter the simulation circuit to run in 4 quadrants.

The practical tests clearly showed the differences in waveforms produced by the DCM drive when setpoints were changed. The formulas derived needed more time spent on them to create a more accurate armature voltage as it wasn't quite close enough for accuracy. The Picoscope measurements proved a good method of understanding the behavioural characteristics of the DC drive and to get measurements that wouldn't otherwise be possible to obtain. Discrepancies were also found on the Picoscope measurements but every waveform matched what was expected from the research.

The simulation tests were effective to see the clear effect changing the firing angle has, although measurements taken for the alpha time were inaccurate causing large discrepancies. This could be due to unknown effects and behaviour on the thyristor controller. The mean voltages seemed to be pretty close to the measured value apart from one error which seemed to be down to the simulation package. Modifying the circuit was made easy on the simulation and clearly showed how easy it is to change a single quadrant drive into a 4-quadrant drive. Although simulation errors made it difficult to see the system working in all 4 quadrants.

As for overall, although the DC motor is outdated as apposed to such advanced AC Drives. Its still a very useable and controllable system to use in modern industry. Very few applications can't be done with an AC motor (with and advanced drive) but where some DC systems are used older industries upgrading from an outdated speed control system to a 4-quadrant drive would make processes a lot more energy efficient and controllable without having the heavy cost of a whole new AC motor and drive system. But if a new system was going to be installed an AC system would be a better option with cost and maintenance.

6. Team Working

My role in the team was recording the results on the Picoscope and moving them into a file. I contributed into discussions on what the values of setpoints would be for the best waveforms. I also contributed in the discussion over how the DC drive was working.

7. Citation List

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8. Appendix

SINAMICS DCM

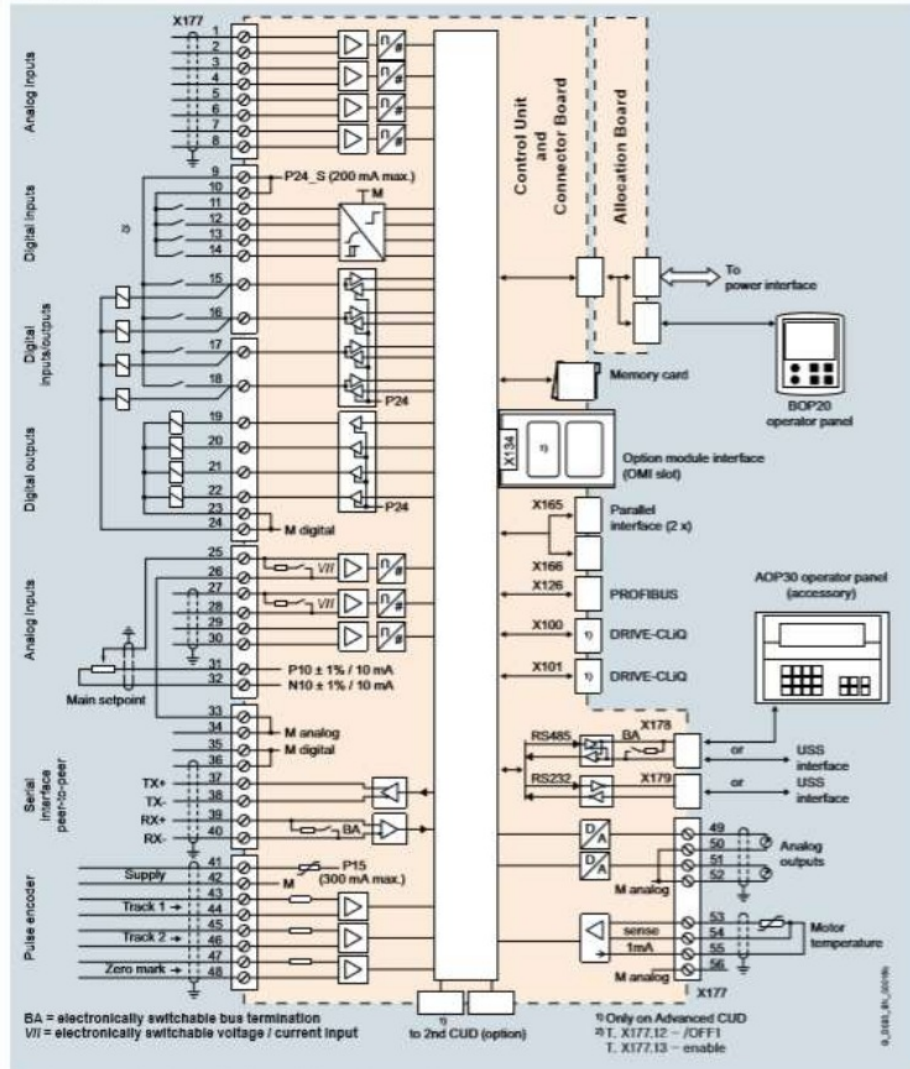
DC Converter and Control Module

DC Converter

Circuit diagrams

Control Units

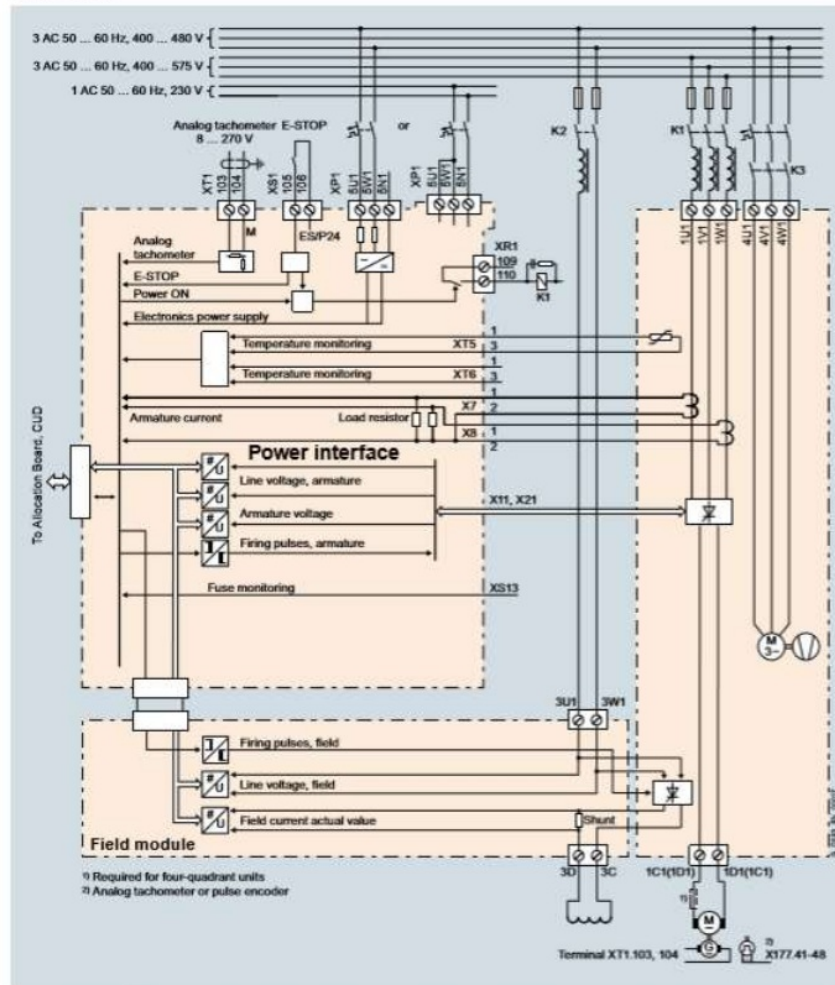
3



Connection diagram, Standard CUD/Advanced CUD with typical connections

Circuit diagrams (continued)

DC Converters

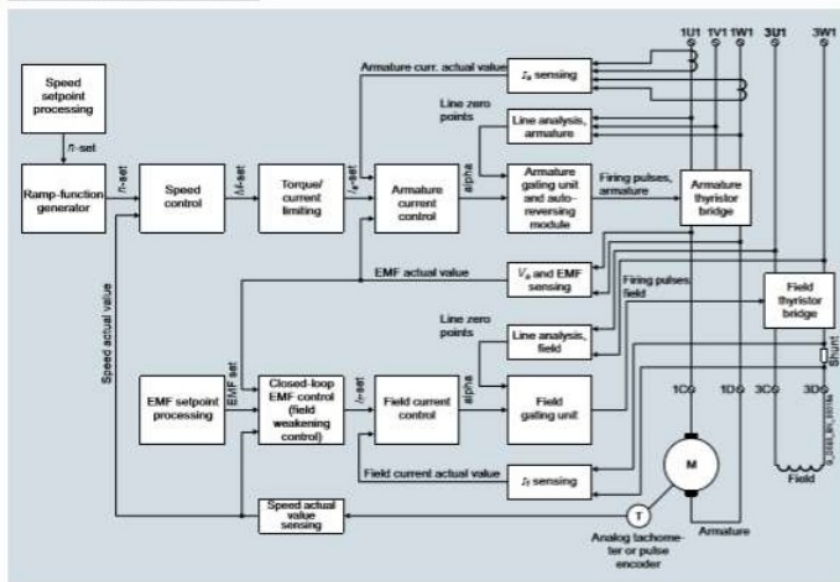


Connection diagram, DC Converters, 400 to 3000 A, electronics power supply 400 V or 230 V, with fan (standard version)

Function (continued)

Function	Description
Communication between drive components (continued)	
QALINK	QALINK (Open Application Link) allows two Control Units to exchange data directly. A higher-level master is not required. The following Control Units support the QALINK: • CU320-2 • Advanced CUD The communication system is based on DRIVE-CLIQ which means that no hardware components other than the DRIVE-CLIQ line are required. QALINK must be loaded as a technology package. A software license is required when it is installed on the CU320-2. The article number for the Certificate of License (CoL) is 6SL3077-QAA01-QAB0. No license is required on the Control Unit CUD of the SINAMICS DC MASTER. QALINK permits the cyclic transmission of a total of 120 words which can comprise the following data types: • Integer16 (1 word) • Integer32 (2 words) • FloatingPoint32 (2 words) For instance, QALINK can be used for the following applications: • Torque distribution for n drives • Setpoint cascading for n drives • Load distribution of drives coupled through a material web • Technology expansion for the SINAMICS DCM (CU320-2 as T400 substitute) • Couplings between SINAMICS units

Overview, closed-loop control structure



assignment 1 (1602826)

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

54/100

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GRADING FORM: NEW CSG-RUBRIC

**SEAN
JONES****54****1. ENGAGEMENT WITH LITERATURE**

Good evidence of reading with correct method of citing and list of sources. However, the range and number of sources is limited compared to what is expected at level 6. Some evidence of research into the actual Siemens DCM. (9/20)

9**2. KNOWLEDGE AND UNDERSTANDING**

Knowledge is reasonably detailed, accurate with a good systematic understanding of the field of study.

10**3. COGNITIVE AND INTELLECTUAL**

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

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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)

12

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)

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