

assignment 1

by Liesel Williams

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PSDE 6016

Power and Machines

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Assignment 1

Investigation into Converters

Liesel Williams

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1. Introduction

The outcome aim of the report is to investigate DC motor drives and look for improved control design techniques for better operating stability.

Initially background research into various single and three-phase rectifying circuits for AC and DC conversion was carried out, further developed for configuration and control techniques used in commercial DC drives and design methods applied for improved stability when controlling a DC motor.

punctuation The Parker 514C single-phase four-quadrant DC drive, its control functions and power circuit were included in the theoretical and practical tasks. Included in the report is mathematical analysis of the motors armature voltage waveform, comparison with measured averages and detailed analysis of the current and voltage waveforms in a highly inductive DC motor at differing speeds and loads.



Figure 1 - Practical test apparatus

Good evidence of research but this task also asked for the following: Review of single and three phase full-wave rectifying circuits for controlled rectification when connected to a load containing low resistance, high inductance and a back EMF. Explain the shape of the expected output waveforms of voltage and current. Consider continuous and discontinuous current. Review of suitable formulae and performance parameters for analysing the behaviour of controlled rectifiers with suitable comparisons made between types of rectifier

2. Research and Theory

2.1 Motor Theory

Four quadrant operation of a DC motor allows reversible rotation and reversible torque, this is achieved with a dual converter i.e. two converters linked back to back shown in fig 2.

The forward converter (C1) produces both positive and negative dc output voltages with positive current output, this allows operation in the first and fourth quadrants respectively. The reverse converter (C2) produces negative current to the motor with positive and negative dc output voltages which gives operation in the second and third quadrants respectively. Refer to fig 3 for the four quadrants of operation. (Electronics, Converter and Converter, 2018)

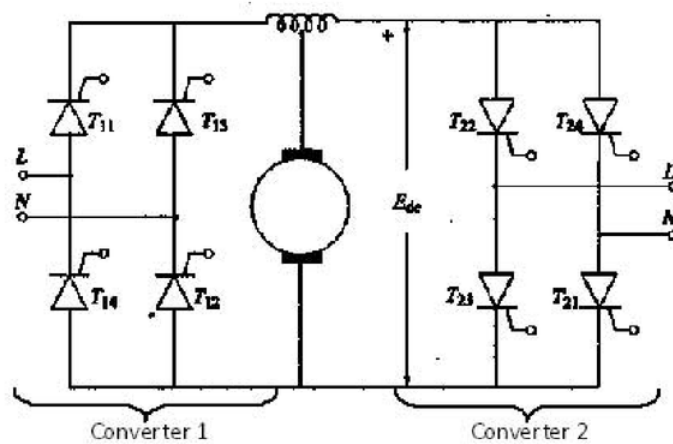


Fig.5: Single Phase Dual Converter

Figure 2 - Single phase dual converter

Speed is proportional to armature voltage so positive is clockwise and negative is anti-clockwise. Torque is proportional to current and so if the torque and speed have the same sign the machine is motoring ($P=T\omega$), when torque and speed have different signs the machine is a generator i.e. braking torque. Also, when armature voltage and current have the same sign the electrical power ($P_{IN}=V_a I_a$) is positive and the machine is motoring and when their signs differ, it is negative, machine is a generator. *a good way of explaining it*

Considering the back emf and since $I_a = \frac{V_a - E}{R}$ in steady state, the direction of I_a depends on whether V_a or E is largest in magnitude.

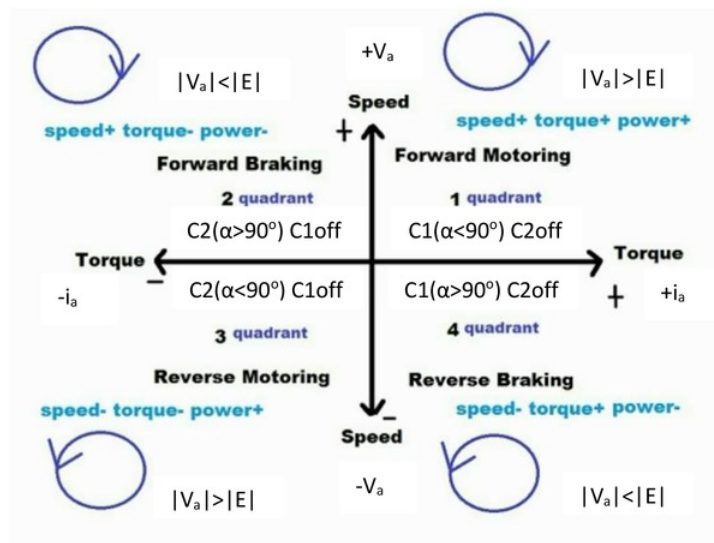
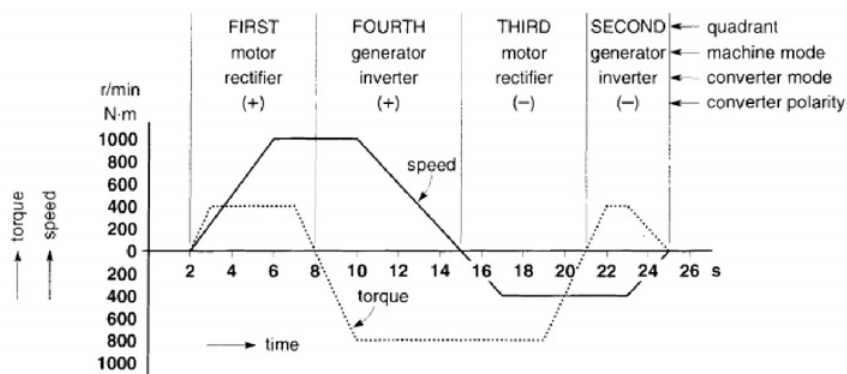


Figure 3 - DC motor four quadrant operation

Since V_a is proportional to $\cos(\alpha)$ when $\alpha > 90^\circ$ in quadrant 2 then V_a is positive but I_a is negative and electrically the machine is generating and mechanically it is braking. (YouTube, 2018)

Referring to section 4 experiment 5, the picoscope has been used as a data logger allowing analysis to be simplified. Looking at the result similar to that shown below, the times when either speed or torque pass through zero correlate with the transfer between quadrants. (Wildi 2002 p.550)



note that this author is using 4th quadrant for 2nd and 2nd quadrant for 4th.

In the figure overleaf the torque/speed possibilities of the drive are shown. In quadrant 2 the electric torque sign is negative but speed is positive which provides forward braking seeing that torque is of opposite sign to direction of rotation. This drive braking can either be used as a form of dynamic braking also called plug braking which either dissipates the power through a resistor or in the armature in the form of heat and is very inefficient, alternatively bi-directional power flow (regenerative braking) can be used. (Hughes and Drury, 2013)

Each quadrant has a constant torque region up to base speed and a region where the torque is inversely proportional to the speed from base speed to max speed i.e. a constant power region.

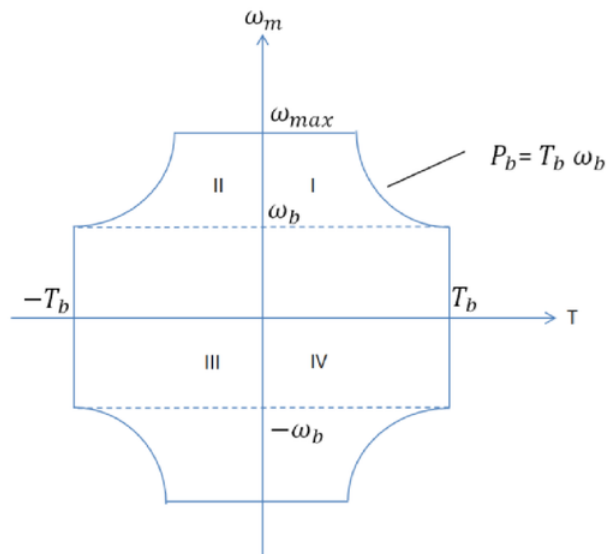


Figure 4 - Four Quadrant operating regions

This needs clarifying; do you mean that the control signals to the thyristors are in milliwatts?

Control Feedback Loops

Theory shows speed can be controlled by the average output from the rectifier which acts as a power amplifier, V_{av} being determined by firing angle. The input to the rectifier can be milliwatts but the output can be Megawatts.

Closed loop speed control is obtained with a feedback signal and amplifier, measuring the output speed by a tacho-generator and the difference between set speed and that measured gives a speed error. (Lander, 1981 p343-347)

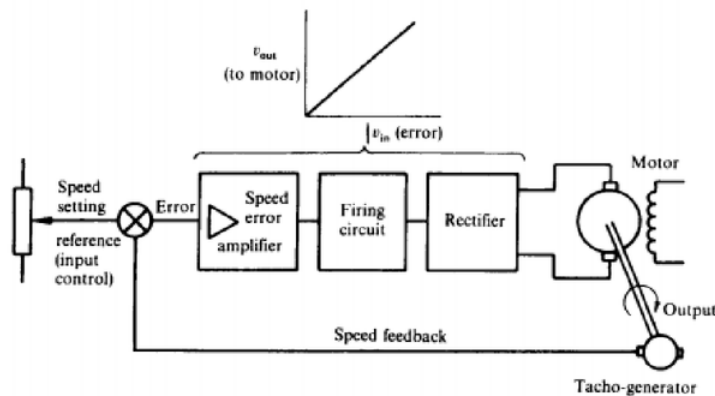


Figure 5 - Closed loop speed control

This is not always true since PI controller could be used. PI would be true for a very long time.

For this systems operation an error must always be present but also a change in motor speed causes large motor and thyristor currents, these must be limited to avoid damage. To obtain current limiting a second feedback loop as shown below is employed.

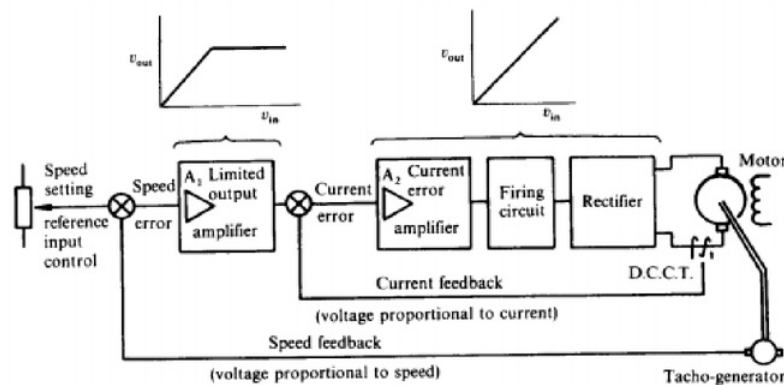


Figure 6 - Current limiting system

Here current limiting involves two amplifiers, the first A1, has limited output, A2 must receive an input i.e. the difference between A1 output and the current feedback, in order for the rectifier to provide output. Thus, this feedback current from the load is limited by A1 maximum level and any rise will lead to error reduction, rectifier output reduction and so load current reduction.

IR compensation is another, cheaper, less accurate method used for speed control, measure V_a , measure the volt drop across a small resistor in the armature circuit, subtracting gives the internal back EMF voltage error which is proportional to speed.

By feeding back signals related to torque, power, such as current feedback the drive can be used for constant torque or tension control.

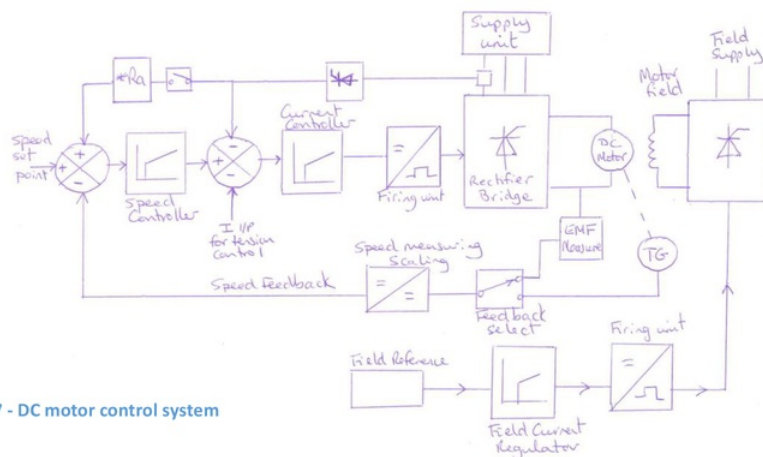


Figure 7 - DC motor control system

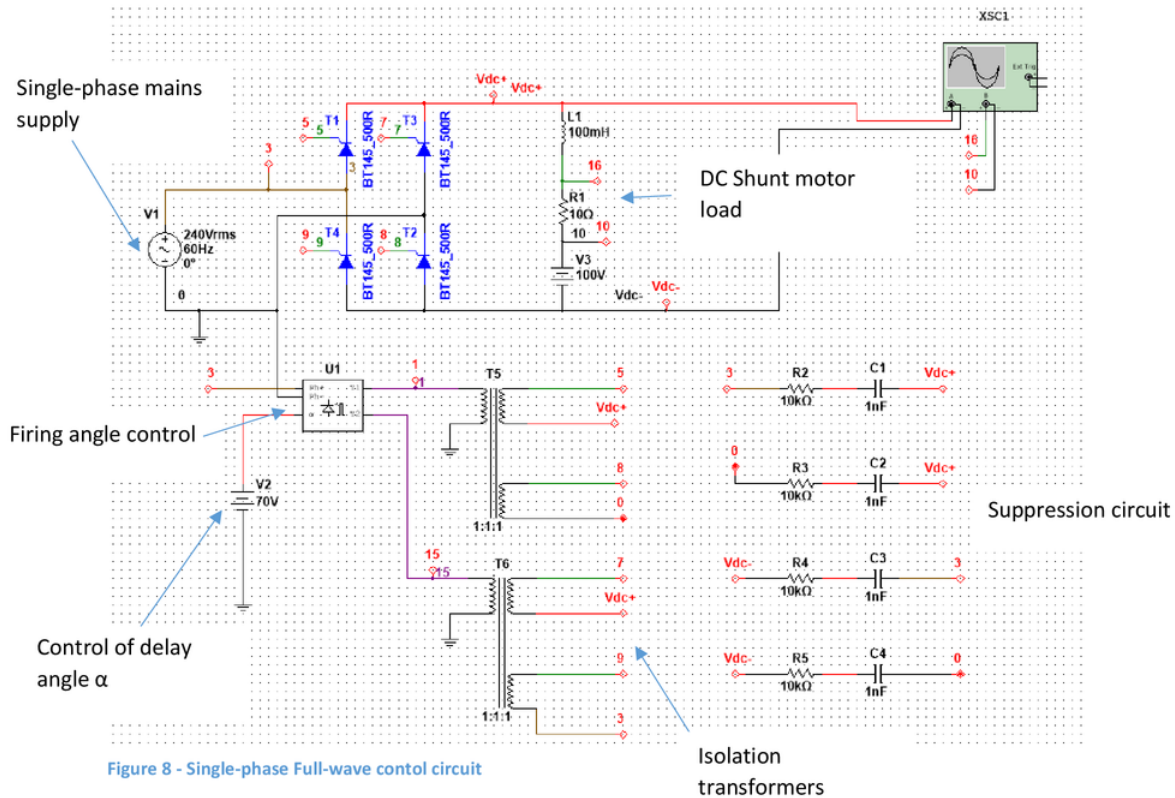
This control circuit has switch selectable feedback between armature voltage sensing or speed sensing via the tacho. The current control loop with current limiting and PI control also has switchable IR compensation which produces a voltage error into the summing circuit.

Refer to section 2.2.3 for the Parker 514C block diagram where these elements are identified.

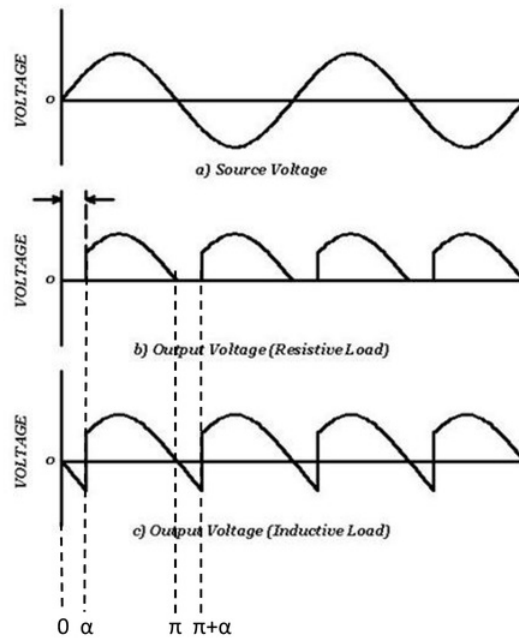
2.2 Rectification

2.2.1 SINGLE_PHASE, FULL_WAVE, CONTROLLED, INDUCTIVE LOAD

The circuit main elements in the diagram below are four thyristors in a bridge arrangement connected to the load such that T1 and T2 are fired together at angle α and T3 and T4 are fired together at angle $(\pi + \alpha)$. Thus, the gates of the thyristors are triggered from the same firing circuit using pulse transformers for isolation. It is important that thyristors are correctly rated i.e. Peak Forward Voltage and Peak Reverse Voltage can withstand the mains input peak value. ($240 \times \sqrt{2}$)



Our area of interest is the shape of the output waveform on the DC side and how its value can be controlled by varying the firing delay angle α . This of course depends on the nature of the load. With either a resistive or inductive load the waveform is such as Fig 9 below (Protorit.blogspot.co.uk, 2018)



Citation Needed

Figure 9 - Output waveforms, resistive, inductive

There are two pulses per mains cycle and the load voltage contains sections of the mains, the size of which depends on the firing angle. The larger the delay angle, the lower the output voltage. The average voltage can be found by :-

$$V_{av} = \frac{1}{\pi} \int_{\alpha}^{\pi} V_{max} \sin(\theta) d\theta$$

$$V_{av} = \frac{V_{max}(1+\cos(\alpha))}{\pi} \quad (\text{eqn 1.1})$$

And so with a resistive load V_{av} can be varied from max to zero by varying α from 0 to 180° .

Due to motor loads being inductive in nature current cannot change instantaneously and this means we cannot give a simple formula for V_{av} in terms of α until the load inductance is sufficient to make the current continuous i.e. it does not fall to zero. This is indeed the case for many motor loads and the waveform is as shown above and depends only on α .

$$V_{av} = \frac{1}{\pi} \int_{\alpha}^{\pi+\alpha} V_{max} \sin(\theta) d\theta$$

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

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

$$\text{Since:- } \cos(\pi+\alpha) = -\cos(\alpha)$$

$$V_{av} = \frac{2V_{max}(\cos(\alpha))}{\pi} \quad (\text{eqn 1.2})$$

Citation Needed

We see that the larger the delay angle the lower the output voltage, but it is negative for short periods due to the smoothing effect on the current and as a result one or other pair of thyristors continues to conduct until all the stored energy is released, thus the average output voltage is reduced. Introducing a free-wheel diode would stop the output going negative and would hold it at about zero while the stored energy is released, thus increasing the average output.

From (eqn 1.2) when $\alpha < 90^\circ$ the converter is rectifying but at $\alpha = 90^\circ$ then the voltage is as much negative as positive and $V_{av} = 0$ and at $90^\circ < \alpha < 180^\circ$ then V_{av} is negative thus the average power flow is negative, this is called inversion and the converter returns stored mechanical energy from load to supply i.e. regenerating mode.

When the current is discontinuous as seen on the bottom waveform, the back emf, E appears in the top waveform:

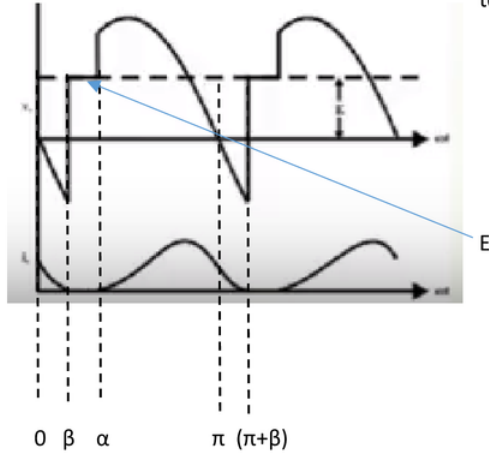


Figure 10 - Output waveform discontinuous current

In order to find V_{av} divide the waveform up into sections as shown and integrate between α and $\pi + \beta$:

$$V_{AV} = \frac{1}{\pi} [E(\alpha - \beta) + \int_{\alpha}^{\pi+\beta} V_{max} \sin \theta d\theta]$$

$$V_{AV} = \frac{1}{\pi} [E(\alpha - \beta) + \frac{V_{max}}{\pi} [-\cos \theta]_{\alpha}^{\pi+\beta}]$$

$$V_{AV} = \frac{1}{\pi} [E(\alpha - \beta) + \frac{V_{max}}{\pi} [-\cos(\pi + \beta) - (-\cos(\alpha))]]$$

Solving gives:

$$V_{AV} = \frac{1}{\pi} (E(\alpha - \beta)) + \frac{V_{max}}{\pi} [\cos(\alpha) - \cos(\pi + \beta)] \quad (\text{eqn 1.3})$$

Citation Needed

2.2.2 THREE_PHASE, FULL_WAVE, CONTROLLED, INDUCTIVE LOAD

The circuit consists of six thyristors in a bridge arrangement and again the load is inductive. When switching AC inductive loads or DC relay contacts or motors transients occur due to the reactive load being switched off and suddenly releasing energy causing a voltage spike to be superimposed on the supply which can reach high values. The high dv/dt transient can be suppressed using low-pass filters so that the high frequency spike is attenuated.

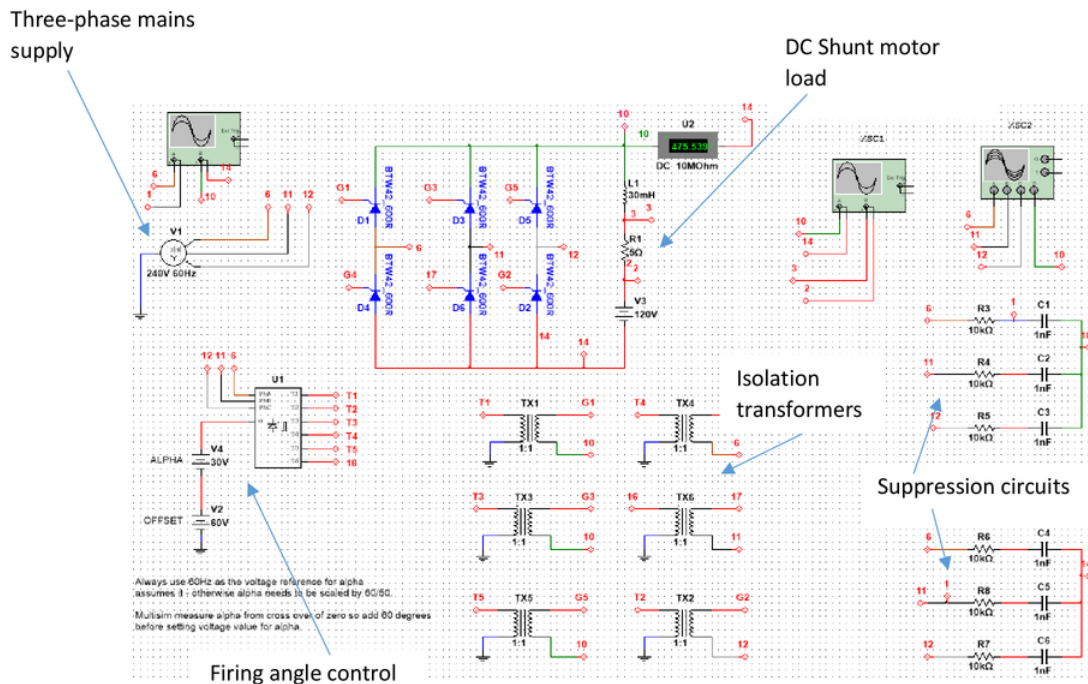


Figure 11 - Three-phase Full-wave control circuit

Alpha is now measured from the 'cross-over' of phases not the zero cross over.

Always use 60Hz as the voltage reference for alpha
 assumes 0 : otherwise alpha needs to be scaled by 60/50
 Multisim measure alpha from cross over of zero so add 60 degrees
 before setting voltage value for alpha.

The above note can be understood by examining the waveform for V_{av}

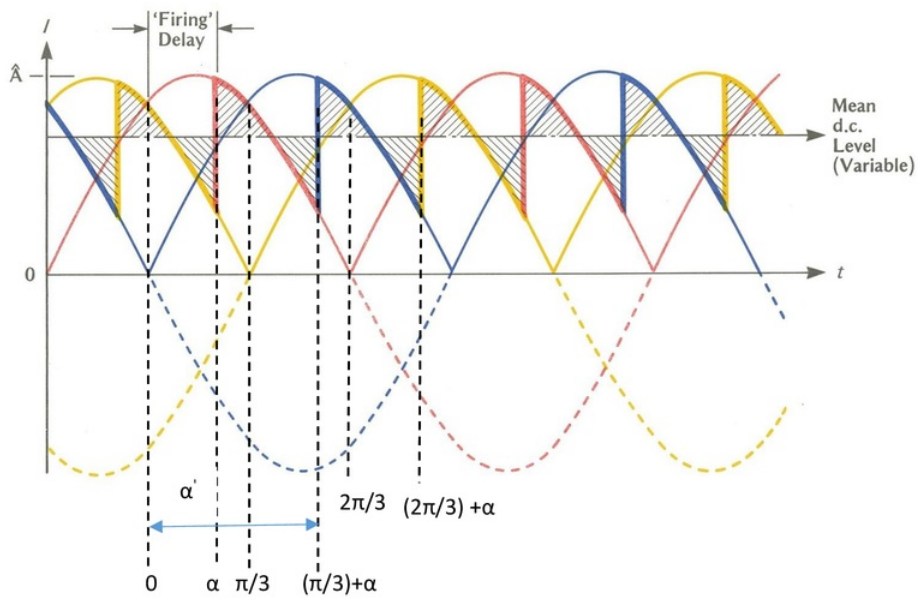


Figure 12 - Output waveform three phase

Multisim uses this angle α' for firing so actual value of alpha must be taken as this angle minus $\pi/3$

Now V_{av} is found by integrating between $(\pi/3)+\alpha$ and $(2\pi/3) + \alpha$ averaged over $\pi/3$ radians.

$$V_{av} = \frac{1}{\pi/3} \int_{\pi/3 + \alpha}^{2\pi/3 + \alpha} V_{max}(LINE) \sin \theta d\theta$$

Integrating and using the trig identity $\cos(A+B) = \cos(A)\cos(B) - \sin(A)\sin(B)$ leads to the solution:

$$V_{av} = \frac{3V_{max}(LINE)}{\pi} \cos \alpha \quad (\text{eqn 1.4})$$

From this it is seen that when $\alpha = 90^\circ$ $V_{av} = 0$ and that inversion takes place when $\alpha > 90^\circ$

2.2.3 Parker 514C

"The Parker 514C controller is designed to control the speed of a DC Shunt wound or permanent magnet motor. It will provide control of the motor speed in all 4 Quadrants of operation".

(Parker, 2006)

This Analog DC drive has closed loop with Proportional Integral control action and adjustable stability. Chassis mount IP00 rated and with a max rating of 32A/12HP typical. It is designed for speed control in all 4 quadrants of operation of DC shunt wound or permanent magnet motors.

There is a linear closed loop system for speed control, feedback is switch selectable from either a tachogenerator or from armature voltage. There is a current loop within the speed loop which ensures current levels applied to the motor are controlled a set of programmable switches allow the levels to be scaled appropriately. A stall detection circuit protects the motor removing current after 60 seconds and the drive is protected by an Instantaneous Overcurrent trip circuit for short circuit protection.

The Product Manual HA463296 is contained in Appendix A.

The unit costs £595.95 and the block diagram is given overleaf in Fig 15. Highlighted in red are the armature and field configuration and firing arrangement.

The speed control loop is highlighted in green; the speed set point is entered at terminal 13. The speed feedback from the tachogenerator enters terminal 1 and is filtered before entering selection switch 1/2 (which can also be set for armature voltage feedback). Scaling occurs and then onto the comparison element; its value is subtracted and fed to the speed loop PI controller the maximum allowable current has limits for safety and lifespan; it is then fed to the firing circuit.

The current control loop is highlighted in blue; a reading of armature current is fed back via the comparison element to the current PI controller, ensuring controlled levels are applied.

Highlighted in yellow is the IR compensation (P8); used for regulating speed under load when using armature voltage feedback. Adjustment changes compensation and reduces regulation care must be taken when adjusting to avoid instability.

Note that this cannot be used to run a shunt connected motor, it must be separately excited to allow for the four quadrant operation. Reversing polarity of both armature and field will not reverse the direction if the motor is connected in shunt. However, what the manual is saying is that the field has a high impedance and although it could be used in shunt, it must not be connected that way as the 514 has a separate field supply.



Figure 14 - Parker 514C Drive

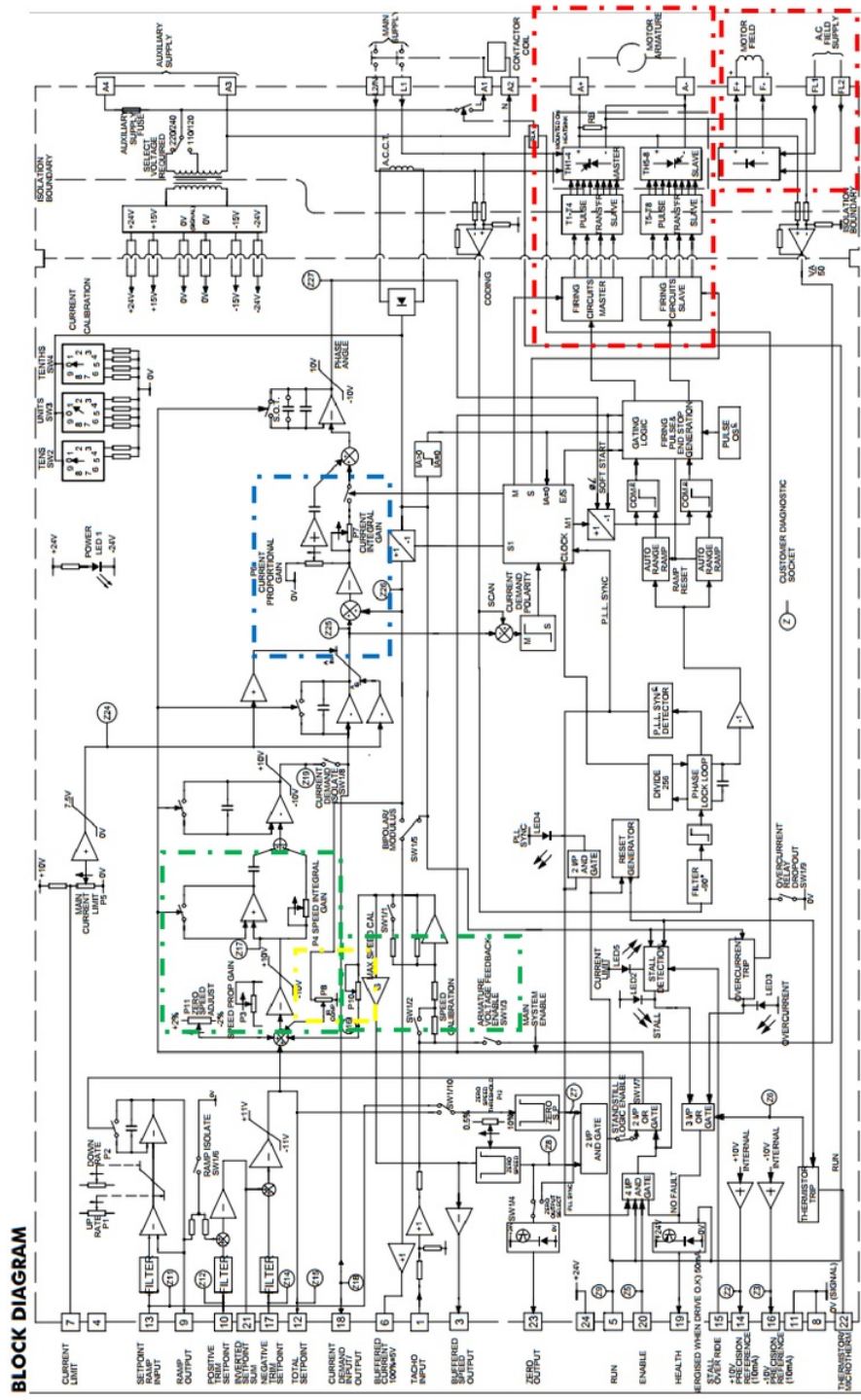


Figure 15 - Parker 514C Block diagram

3. Simulation of rectifying circuits

3.1 Single-phase, full-wave, fully controlled rectifier

A simulation circuit was built with a load, which contained an inductance L , a resistance R , and a back EMF E to model the DC motor, fed from a single-phase supply voltage 240V, 60Hz.

With $L=100\text{mH}$, $R=10\Omega$, $E=100\text{V}$ the first firing angle was chosen to be 70° in order to show discontinuous current.

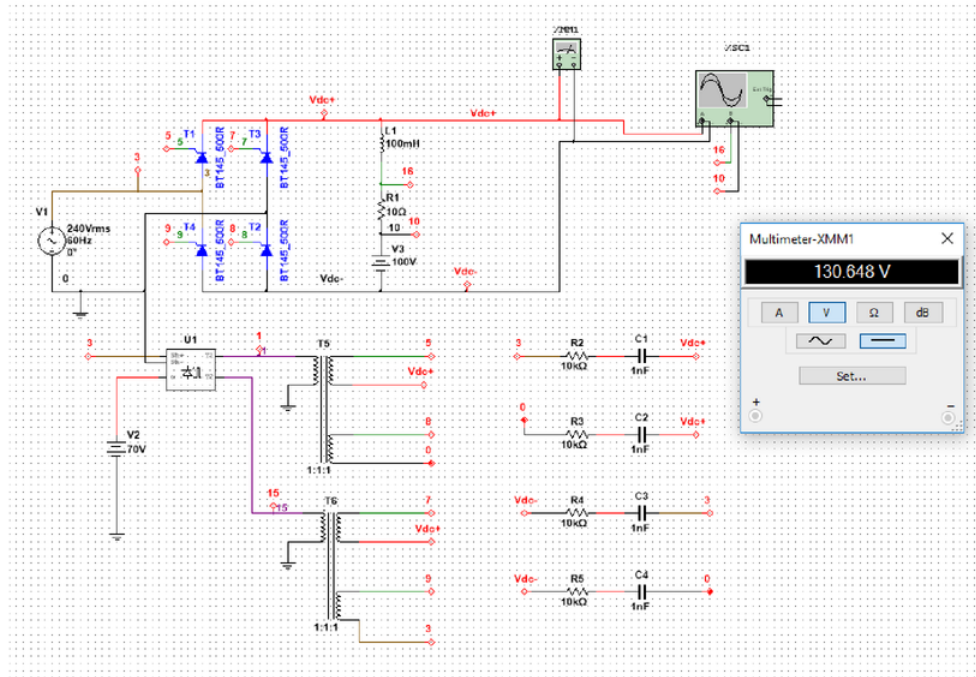


Figure 16 - Single phase discontinuous current simulation

As can be seen a measurement of average armature voltage (130.648V) was taken using a multimeter, this can be compared with theoretical results.

Pulse transformers are for isolation purposes, when firing the thyristors need voltage between gate and anode, which is supplied via the phase angle controller through the isolation transformers.

Voltage and current waveforms are seen below and include the timings necessary to allow calculation of average voltage.

The values of L , R and E are typical of the DC motor which was run during previous practical tests. In section 4 a calculation of R from measured values gave 4Ω for the actual motor used. E depends on speed and L is typical for this kind of shunt motor.

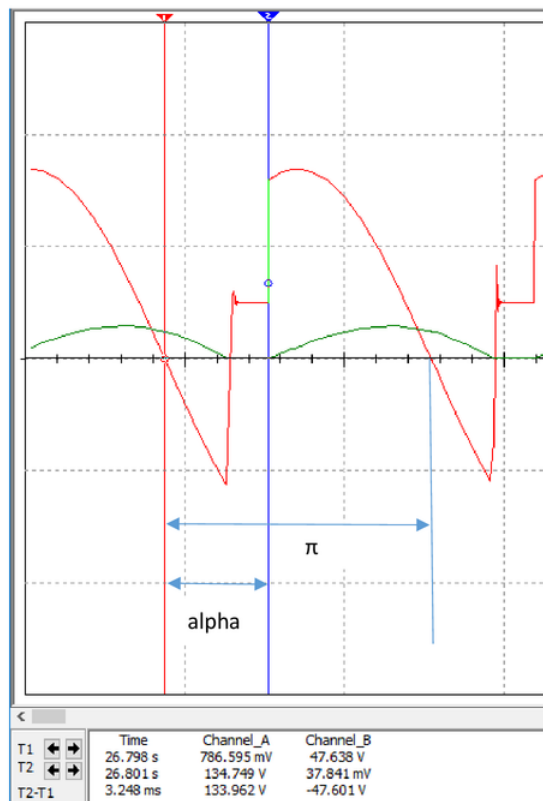


Figure 17 - Measure alpha 70 deg

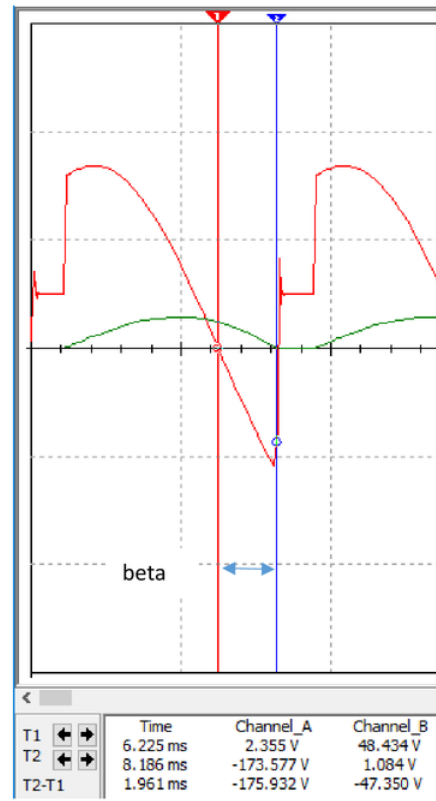


Figure 18 - Measure beta 42 deg

These screenshots show the output of voltage and current at 70°, at 60Hz half a cycle is 8.3333ms.

Calculate $\alpha = (3.248/8.3333) \cdot \pi = 1.22\text{rad} = 69.9^\circ$

Calculate $\beta = (1.961/8.3333) \cdot \pi = 0.739\text{rad} = 42.36^\circ$

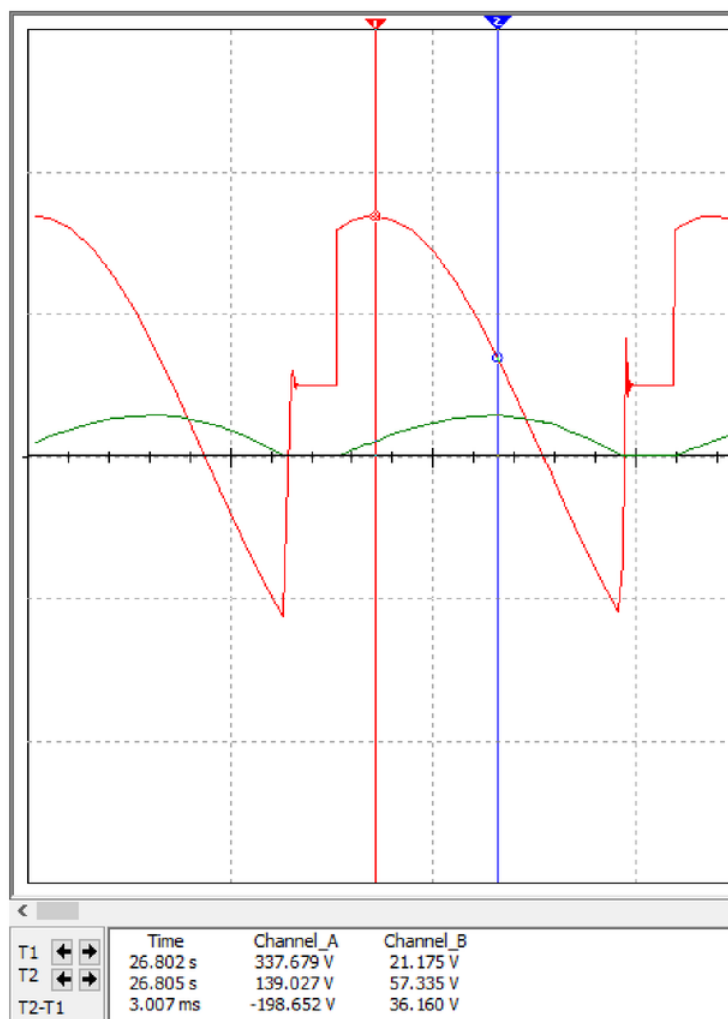


Figure 19 - Measure Vmax and I max (70deg)

The same waveform is analysed for Vmax and I max

$$V_{\max} = 337.679\text{V}$$

$$I_{\max} = 57.335/10 = 5.73\text{A (using ohms law } R=10\Omega)$$

$V_{\max}$ at the input = $1.414 \times 240 = 339.41\text{V}$ and this is confirmed with the CRO

The difference $339.41 - 337.68 = 1.73\text{V}$ is a drop across the rectifying bridge.

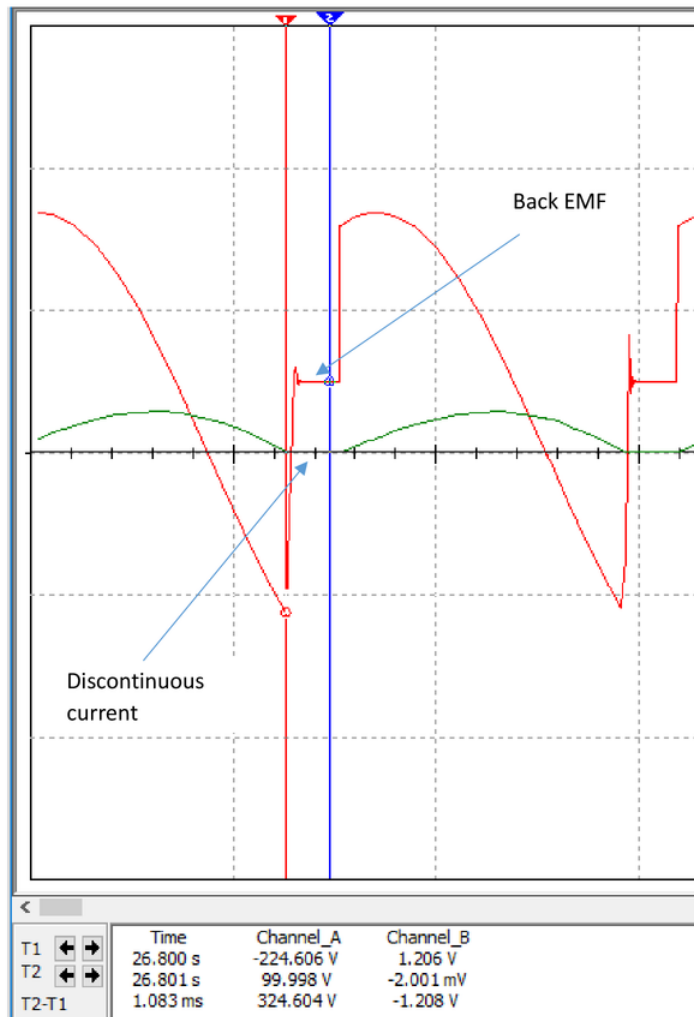


Figure 21 - Measure Eb and Vmin



Figure 20 - Input voltage

Due to the firing angle delay the back EMF becomes visible and the current is discontinuous.

Eback = 99.998V

Vout has gone negative lowest value -224.606V

The formulae deduced from research (eqn 1.3) can be applied:

$$V_{AV} = \frac{1}{\pi} (E(\alpha - \beta)) + \frac{V_{max}}{\pi} [\cos(\alpha) - \cos(\pi + \beta)]$$

$$V_{AV} = \frac{1}{\pi} (100(0.48)) + \frac{337.7}{\pi} [\cos(1.22) - \cos(\pi + 0.74)] = 131.16V$$

This compares well with the DVM reading of 130.72V

When alpha is increased beyond 77 deg there is a simulation error

The same circuit was analysed with a firing angle delay of 40° the waveforms now show that the current is continuous and therefore the back EMF is not visible.

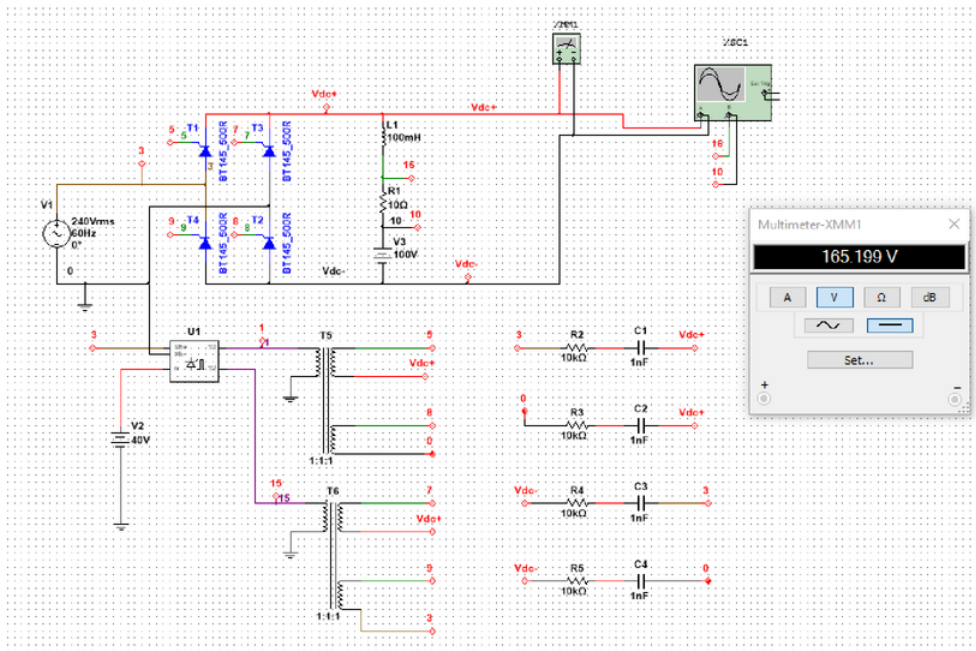


Figure 22 - Single phase continuous current simulation

Here we see the average armature voltage has increased to 165.199V as would be expected with a shorter delay angle.

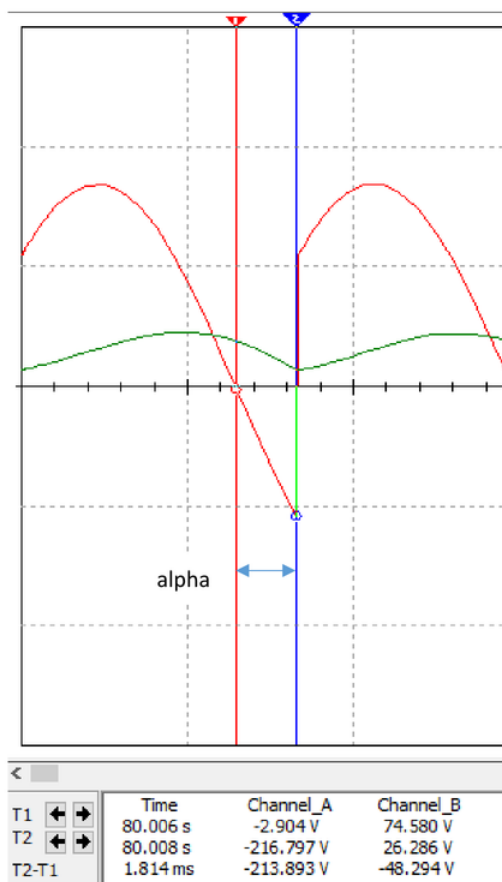


Figure 24 - Measure alpha 40 deg

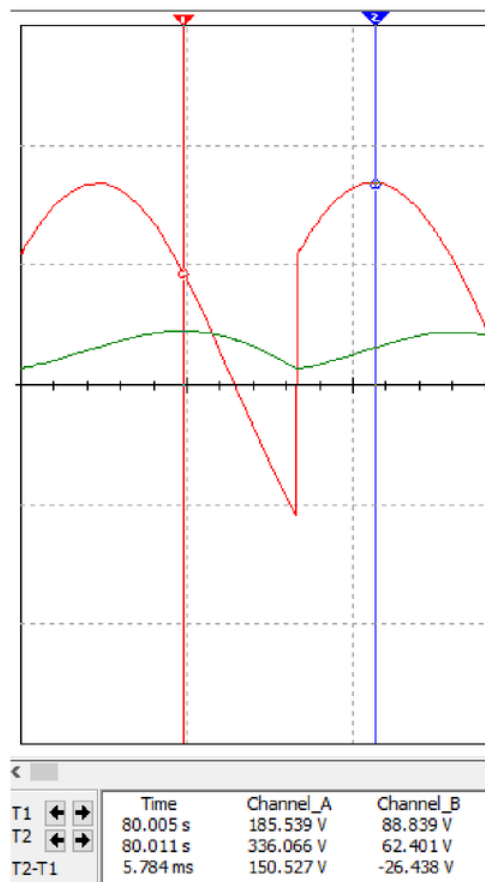


Figure 23 - Measure Vmax and I max (40 deg)

The voltage and current waveforms appear different; alpha can be measured thus:

$$\text{Calculate } \alpha = (1.814/8.3333) * \pi = 0.68 \text{ rad} = 39.2^\circ$$

$$V_{\text{max}} = 336.066 \text{ V}$$

$$I_{\text{max}} = 88.839/10 = 8.88 \text{ A}$$

The formulae deduced from research (eqn 1.2) can be applied:

$$V_{\text{AV}} = 2 \frac{V_{\text{max}}}{\pi} \cos(\alpha) = 2 \frac{336.066}{\pi} \cos(0.68) = 166.32 \text{ V}$$

This compares well with the DVM reading of 165.2V

Simulation results are tabulated for convenience on page 28.

3.2 Three-phase, full-wave, fully-controlled rectifier

A new simulation circuit was built with a load, which contained an inductance L , a resistance R , and a back EMF E to model the DC motor, fed from a three-phase supply voltage 240V, 60Hz. Again isolation transformers form a buffer between firing angle controller and thyristor gates and RC suppression protection is utilised.

With $L=200\text{mH}$, $R=30\Omega$, $E=150\text{V}$ the first firing angle was chosen to be 20° and the waveforms analysed as before.

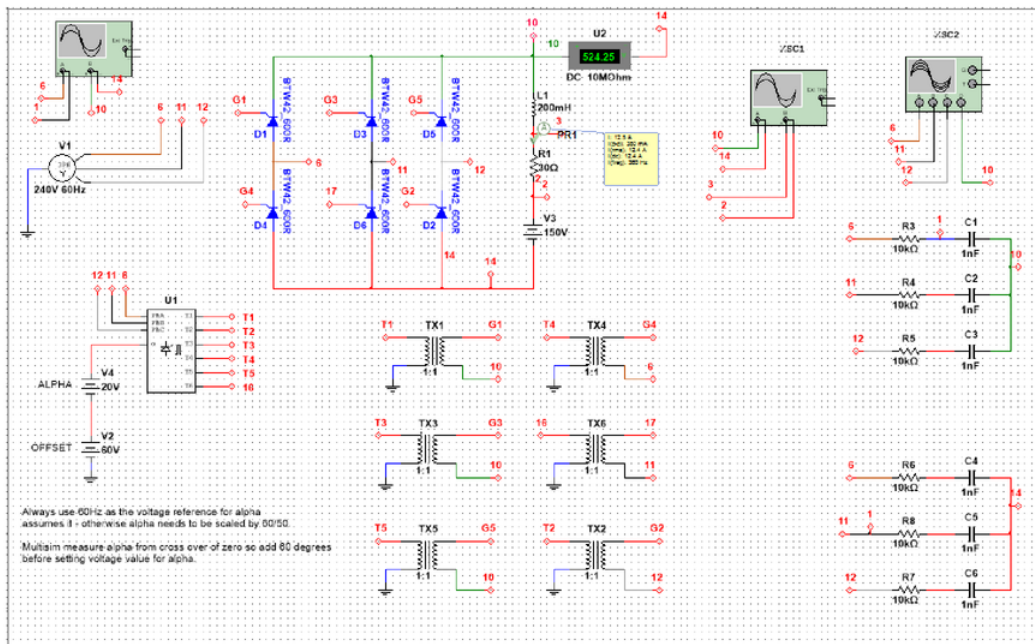


Figure 25 - Three phase simulation 20 deg

The average armature voltage measured was 524.25V

Alpha set to 20 deg

From CRO 2 a measurement for alpha can be taken $T2-T1 = 927\mu s$

Calculate $\alpha = (0.927/8.3333)*\pi = 0.35 \text{ rad} = 20.05^\circ$

For 240V, 60Hz the time period is $1/60 = 16.666\text{ms}$ and for full wave rectification half the period is $16.666/2 = 8.3333\text{ms}$

Theoretical values:

$V_{\text{max}} = 240 * \sqrt{3} = 415\text{V}$ and $V_p = 415 * \sqrt{2} = 586.89\text{V}$

For these values $V_{\text{mean}} = (3 * V_{\text{max(LINE)}} / \pi) \cos(\alpha)$
 $= (3 * 586.89 / \pi) \cos(20) = 526.56\text{V}$

From CRO 1 the output voltage and current can be measured

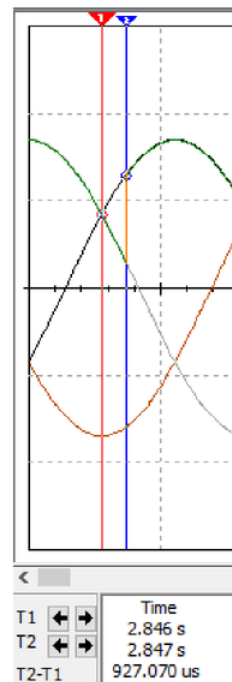


Figure 26 - Measure alpha 20deg

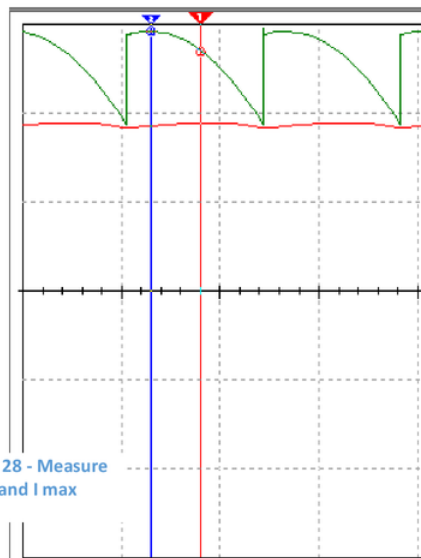


Figure 28 - Measure Vmax and I max

	Time	Channel_A	Channel_B
T1	4.815 s	539.284 V	377.484 V
T2	4.814 s	584.661 V	371.053 V
T2-T1	-1.004 ms	45.377 V	-6.431 V

$V_{\text{max}} = 584.661\text{V}$ (CHN A T2)

$I_{\text{max}} = 377.484/30 = 12.58\text{A}$ (CHN B T1)

The current probe shows 12.5A

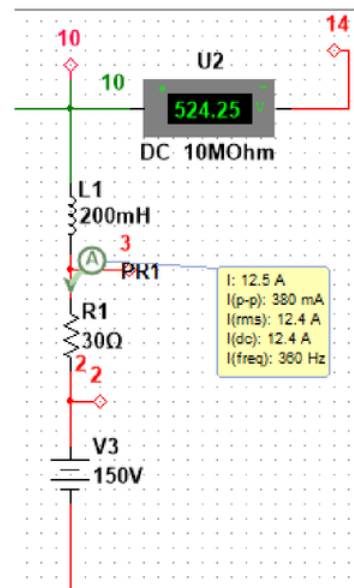
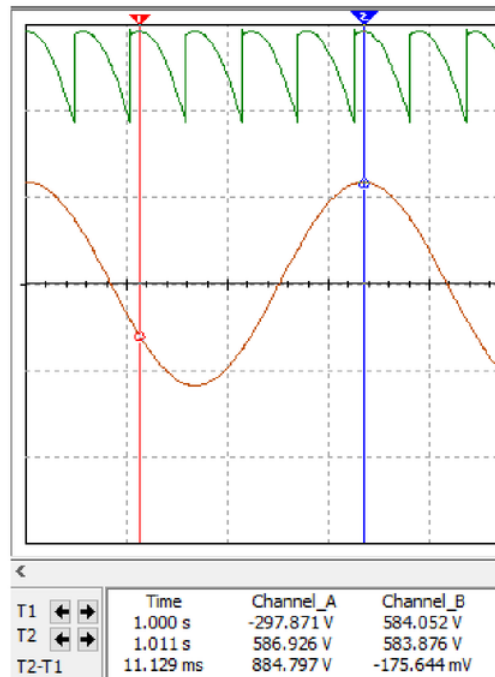


Figure 27 - DVM readings (20 deg)

$$V_{\text{mean}} = (3 * V_{\text{max(LINE)}} / \pi) \cos(\alpha)$$

$$V_{\text{mean}} = (3 * 584.661 / \pi) / \cos(20.05) = 524.6V$$

These values are very similar with only a 0.35V difference, this can be accounted for in the inaccuracies when taking measurements using the cursors etc.



From CRO3 the input waveform is shown on CHN A and the armature voltage on CHN B

$V_{\text{IN(MAX)}} = 586.926V$ (CHN A T2)

$V_{\text{MAX}} = 584.052V$ (CHN B T1)

The reason for the difference $586.92 - 584.052 = 2.87V$ is the drop that would occur across the rectifying bridge.

Figure 29 - V_{in} and V_a waveforms

The same circuit was now simulated with a firing angle of 50° and as expected the average voltage has dropped due to the larger delay angle and is now 358.046V

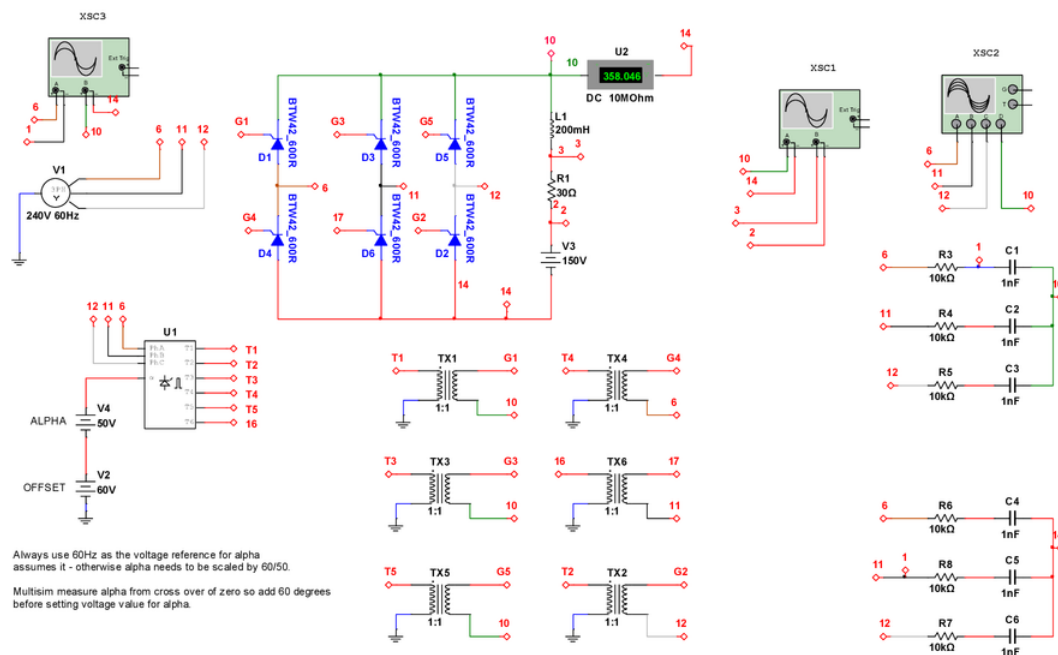


Figure 30 - Three-phase simulation 50 deg

From CRO 2 a measurement for alpha can be taken $T2 - T1 = 2.287\text{ms}$

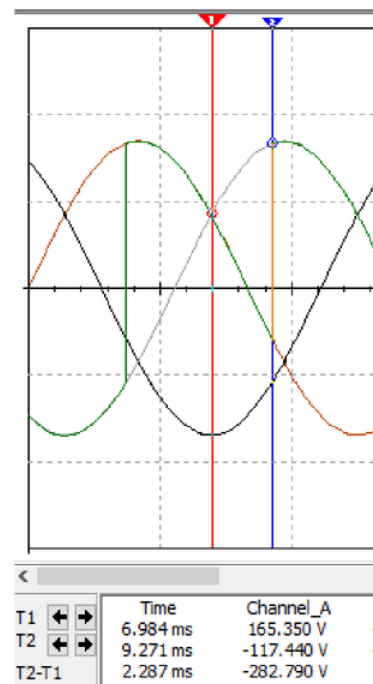
Calculate $\alpha = (2.287/8.3333) * \pi = 0.86 \text{ rad} = 49.39 \text{ deg}$

Theoretical values:

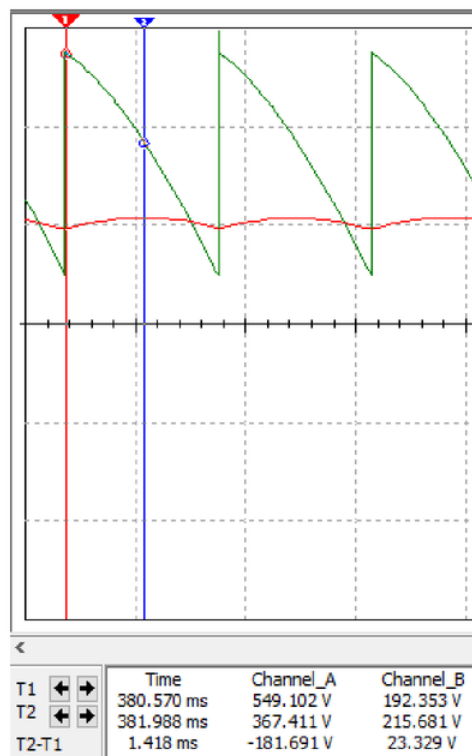
$V_{\text{max}} = 240 * \sqrt{3} = 415\text{V}$ and $V_p = 415 * \sqrt{2} = 586.89\text{V}$

For these values $V_{\text{mean}} = (3 * V_{\text{max(LINE)}} / \pi) \cos(\alpha)$
 $= (3 * 586.89 / \pi) \cos(50) = 360.24\text{V}$

Figure 31 - Measure alpha 50 deg



From CRO 1 the output voltage and current can be measured



Vmax = 549.102V (CHN A T1)

I_{max} = 215.281/30 = 7.17A (CHN B T2)

The current probe shows 6.92A

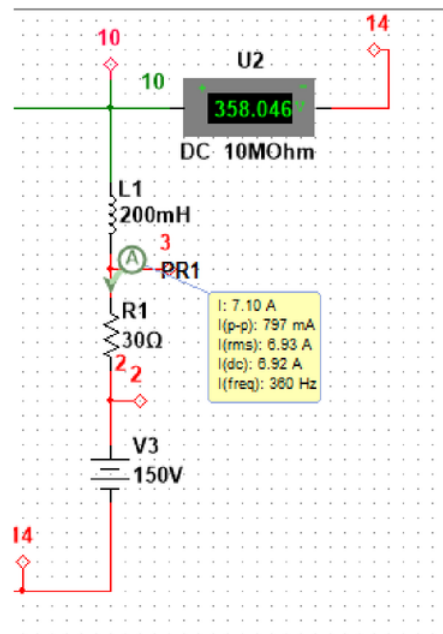


Figure 33 - DVM readings

V_{mean} measured is 358.046V

$$V_{\text{mean}} = (3 \cdot V_{\text{max(LINE)}} / \pi) \cos(\alpha)$$

$$V_{\text{mean}} = (3 \cdot 585.405 / \pi) \cos(49.39) = 363.87V$$

As alpha is increased the section of waveform is reduced and at this angle the cut off is beyond the peak of the waveform, therefore V_{max} on this waveform is reduced to 549.102V. Also see CRO3 overleaf.

However, taking V_{max} as that measured from CRO3 then V_{mean} becomes 363.87V as shown above.

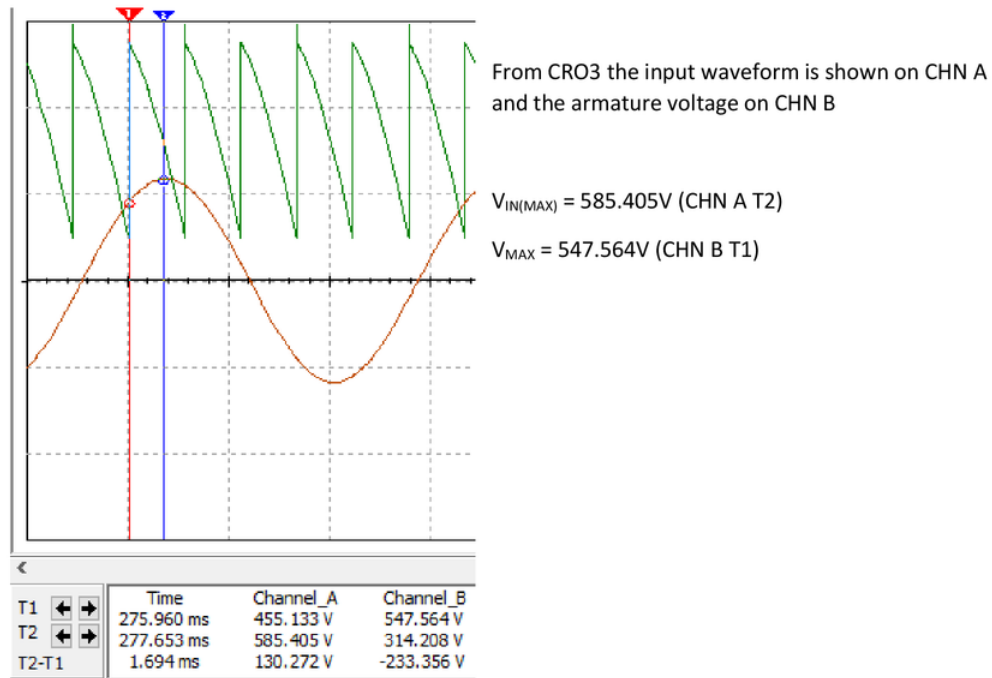


Figure 34 - Measure V_{in} and V_a

Single-phase	Theory		Simulation			Max error (V)
	Vmax (V)	Vmean (V)	Vmax (V)	Vmean (V)		
				CRO	DVM	
70°	339.41	131.16	337.68	131.64	130.65	-1
40°	339.41	165.54	336.07	166.32	165.2	+0.78
Three-phase	Theory		Simulation			
	Vmax	Vmean	Vmax	Vmean		
				CRO	DVM	
20°	586.89	526.56	584.66	524.6	524.25	-1.96
50°	586.89	360.24	585.41	363.87	358.05	+3.63

Figure 35 - Simulation results table

the difference is only 0.35 not -1.96

The three-phase simulation has larger errors for analysis of results see section 5.

4. Practical DC Drive Investigation

The motor, drive, measuring equipment and ancillary circuits were set up in G22A, as shown below. Initially a measure of $V = 92\text{V}$, $E = 91\text{V}$, $I_a = 0.25\text{A}$ under no load enabled a rough calculation of R_a

$$R_a = (92 - 91) / 0.25 = 4\Omega$$

Using two different speeds and measuring V_{av} giving 0.71mV/rpm enables motor constant k to be determined. Also the commutator effect on the back emf shows the ripple which needs filtering before processing.

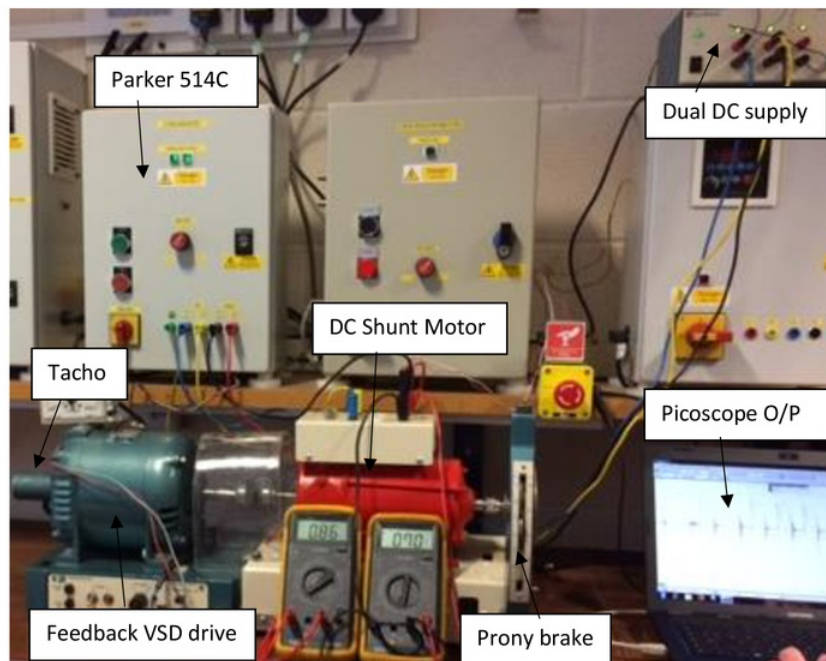


Figure 36 - Practical equipment

Behind the motor and contained within the drive panel are some extra electronics. A circuit containing a 0.1Ω resistor (value chosen so as not to affect R_a) and an amplifier is used to provide a direct, scaled current measurement, the buffered values obtainable from the drive would be no good for waveform analysis. 1:100 scaling for the picoscope is taken care of by another opamp which means $0.01\text{V} = 1\text{V}$

The current waveforms (red trace) are seen to have an initial temporary high value when the drive first overcomes motor inertia.

Investigations are detailed on the following pages, when *actually, this is due to switching back emf of the coil* motoring a reduction in V makes I temporarily negative to brake, same thing happens in reverse. When overdriven regenerative braking can be seen, when driven in the opposite direction, plug braking occurs heat and wasted energy occurs, this is called dynamic braking. The drive does not allow for generative braking when driven in reverse.

Experiment 1

With the Feedback VSD drive switched off and motor running forward meter readings taken were 74V and 0.20A. The picoscope was used to record the waveform of armature voltage and current so

that back emf, alpha and beta can be measured.

$$V_{max} = 240 \times \sqrt{2} = 339V$$

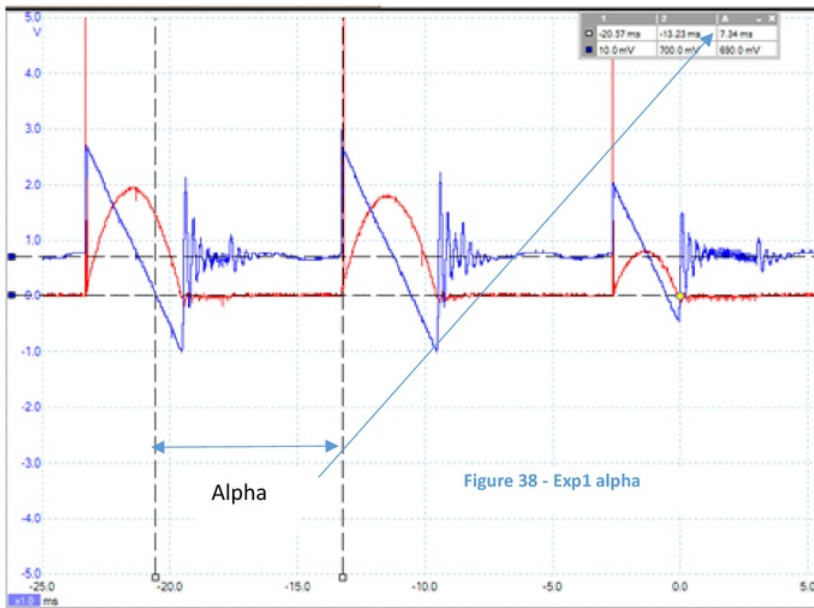


Figure 38 - Exp1 alpha

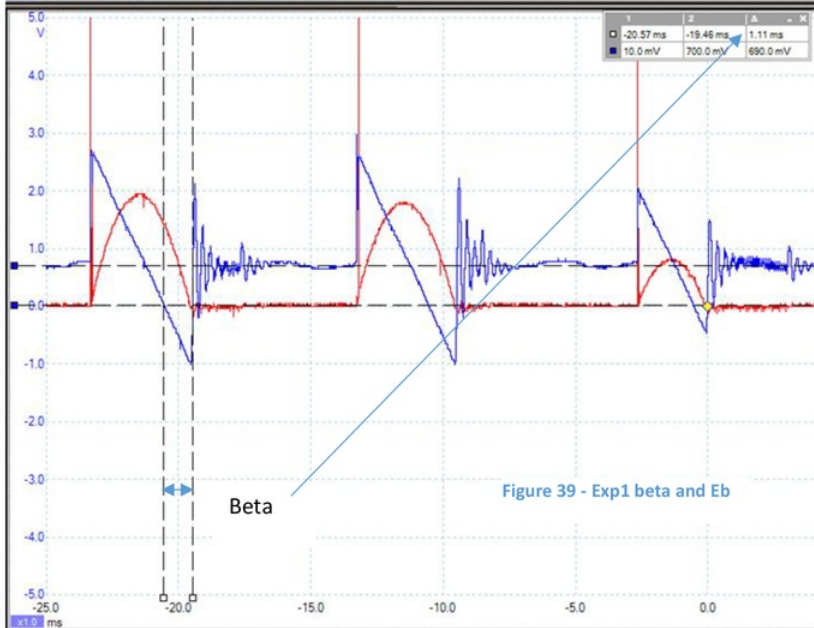


Figure 39 - Exp1 beta and Eb

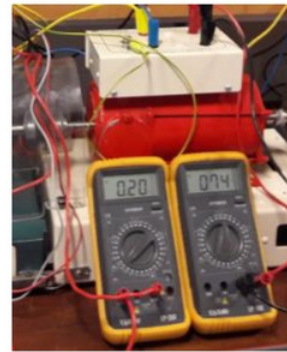


Figure 37 - Exp1 DVM

$$E_b = 700mV \times 100 = 70V$$

$$\text{Alpha} = 7.34ms = (7.34/10)\pi = 2.3rad$$

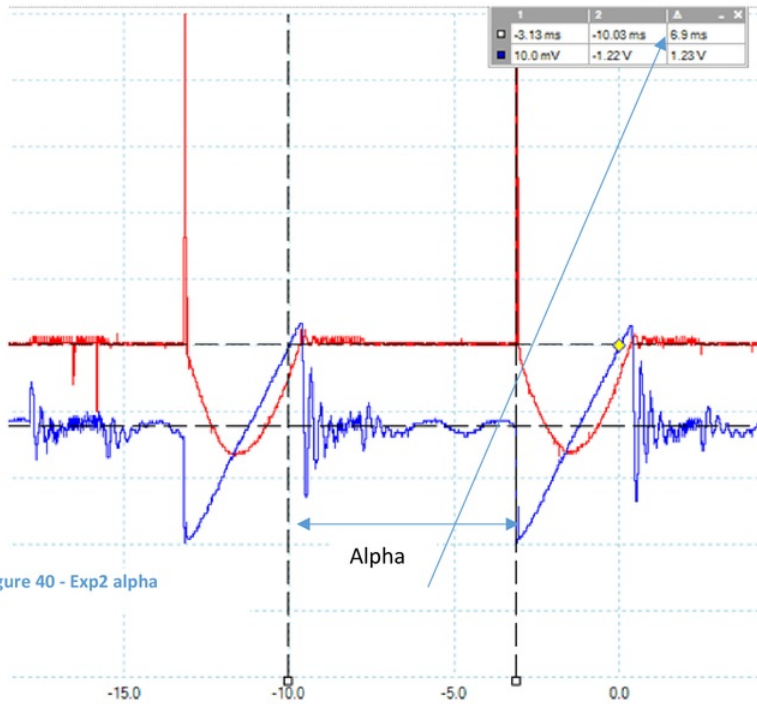
$$\text{Beta} = 1.11ms = (1.11/10)\pi = 0.35rad$$

Using eqn 1.3

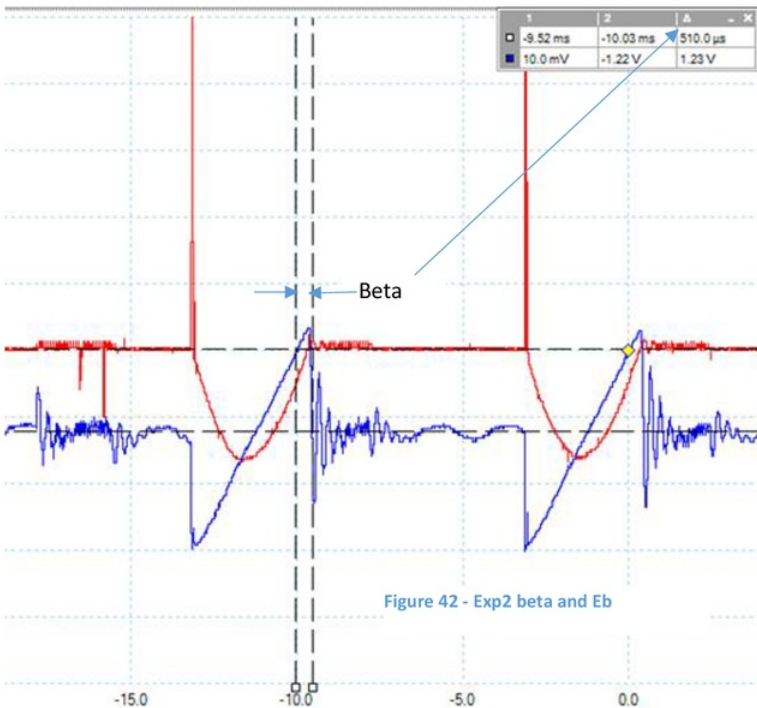
$$V_{AV} = \frac{1}{\pi} (E(\alpha - \beta)) + \frac{V_{max}}{\pi} [\cos(\alpha) - \cos(\pi + \beta)] = 72.9V$$

Experiment 2

Again with the Feedback VSD drive off but the drive motoring in reverse, meter readings were taken



-125V and -0.23A. With both being negative it confirms reverse motoring and thus operation of the other bridge rectifier. Waveforms are flipped over.



$$E_b = -1.22 \times 100 = -122V$$

$$\alpha = 6.9ms = (6.9/10)\pi = 2.17rad$$

$$\beta = 510\mu s = (0.51/10)\pi = 0.16rad$$

Using eqn 1.3

$V_{av} = 123.7V$, waveform is below 0V and therefore negative, this agrees with the negative sign on the DVM which shows the polarity and confirms direction.

Experiment 3

Using the Feedback VSD and the prony brake a load of **0.2Nm** was applied and meter readings taken 123V and 0.64A, the speed was recorded with a digital tachometer of 1723rpm

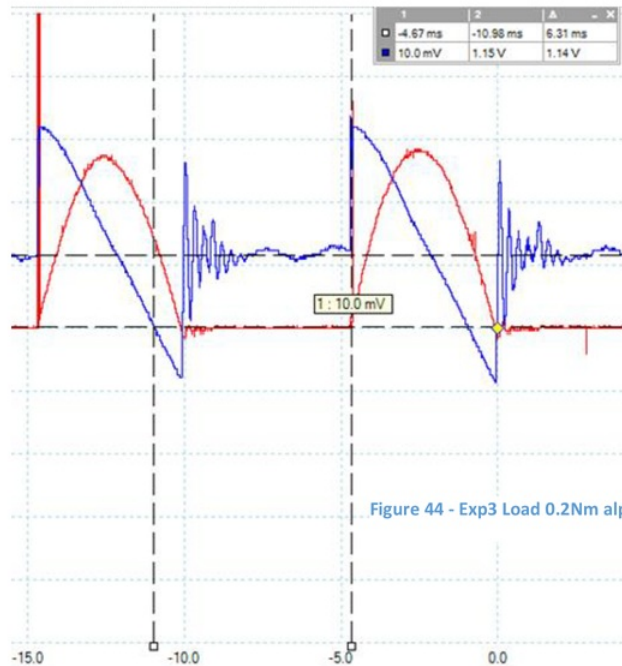


Figure 44 - Exp3 Load 0.2Nm alpha

$E_b = 115V$

$\alpha = 6.31ms * \pi / 10 = 1.98 \text{ rad}$

$\beta = 870\mu s * \pi / 10 = 0.27 \text{ rad}$

From eqn 1.3

$V_{av} = 123.64V$



Figure 43 - Exp3 0.2Nm DVM

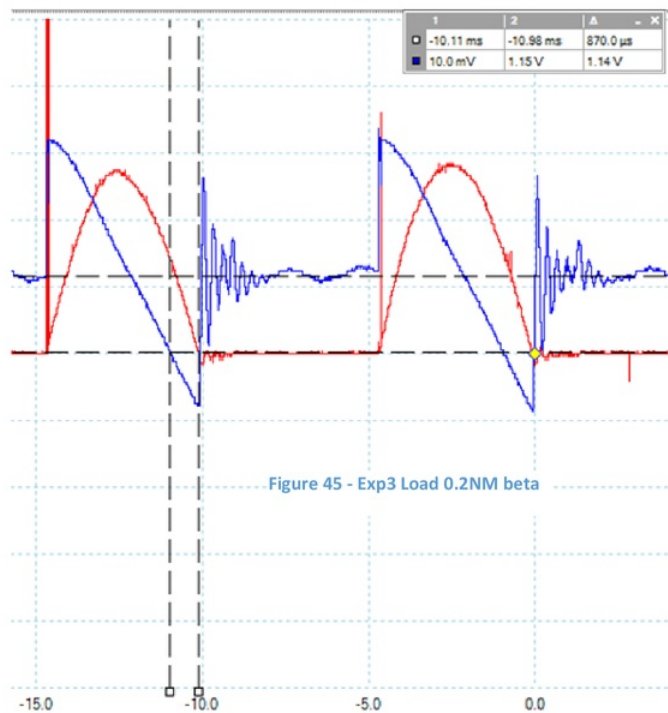


Figure 45 - Exp3 Load 0.2NM beta

Load increased to **0.4Nm**, meter readings 125V and 1.01A, speed 1727rpm

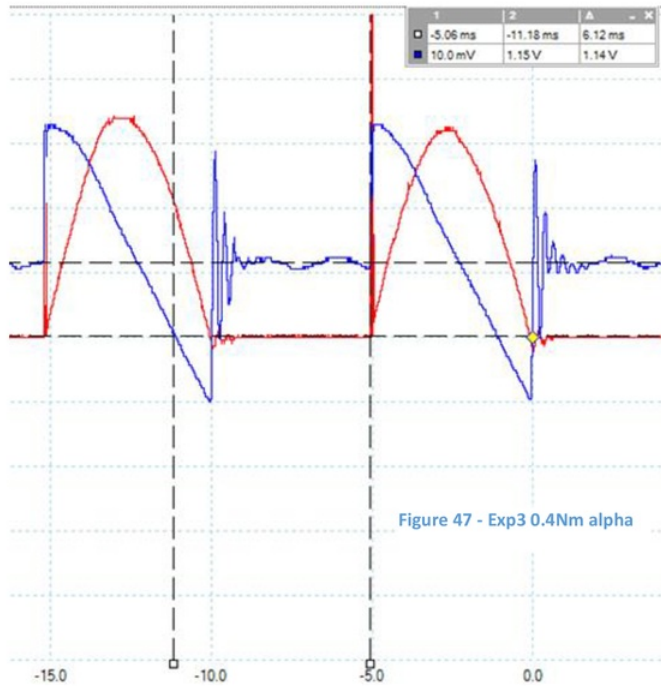


Figure 47 - Exp3 0.4Nm alpha

$E_b = 115V$

$\alpha = 6.12ms * \pi / 10 = 1.923$
rad

$\beta = 1.23ms * \pi / 10 = 0.386$
rad

From eqn 1.3

$V_{av} = 118.99V$

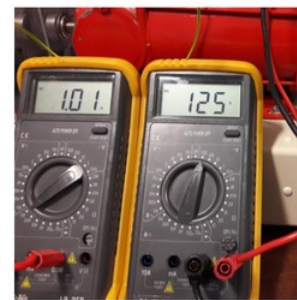


Figure 46 - Exp3 0.4Nm DVM

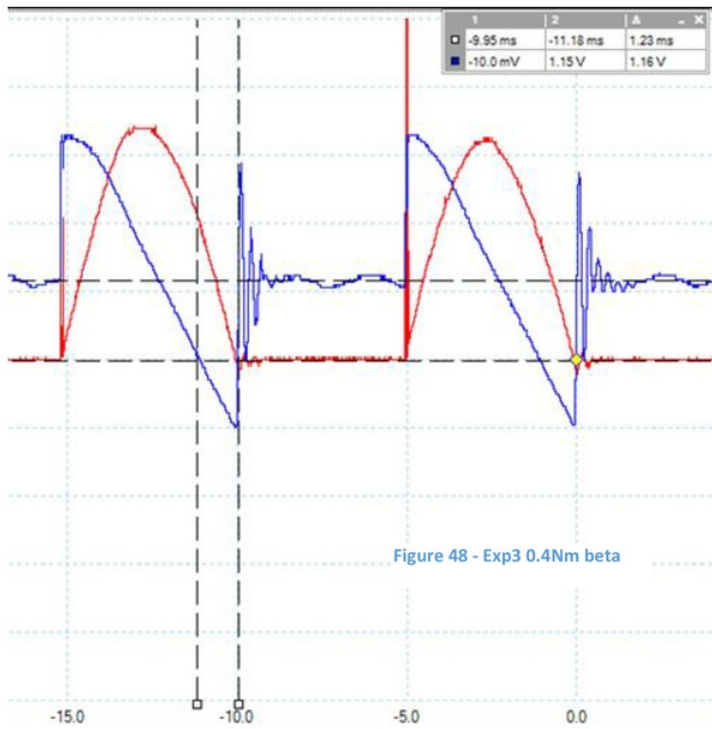
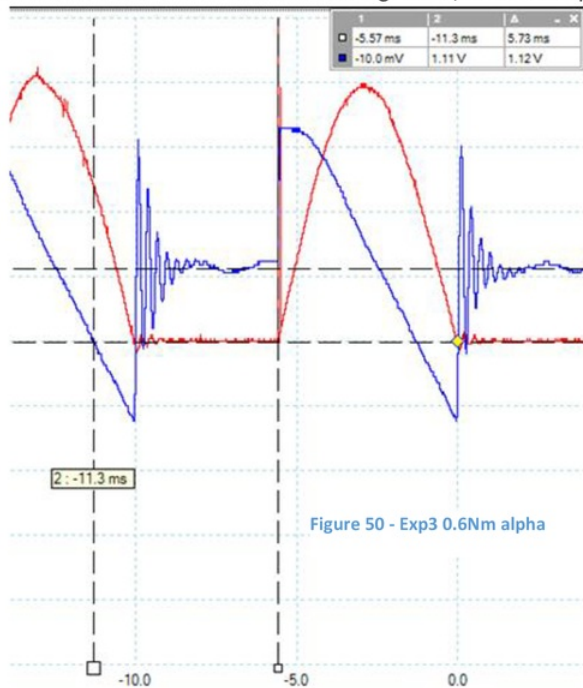


Figure 48 - Exp3 0.4Nm beta

Load increased to **0.6Nm** and meter readings 126V, 1.42A and speed 1731rpm



$E_b = 111V$

$\alpha = 5.73ms * \pi / 10 = 1.8 \text{ rad}$

$\beta = 1.31ms * \pi / 10 = 0.41 \text{ rad}$

From eqn 1.3

$V_{av} = 123.39V$

Figure 50 - Exp3 0.6Nm alpha



Figure 49 - Exp3 0.6Nm DVM

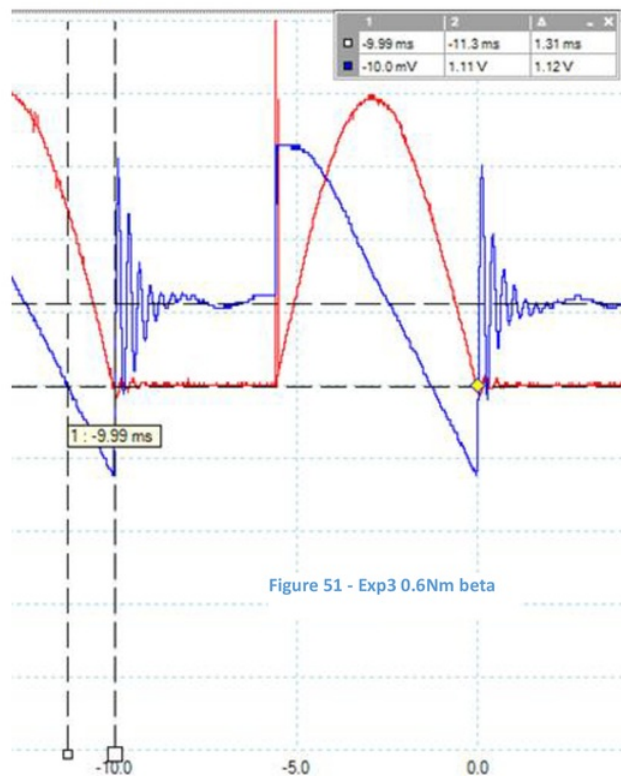


Figure 51 - Exp3 0.6Nm beta

Experiment 4

The Feedback VSD drive was run slightly faster than the DC motor, when the motor is overdriven like this the current changes polarity and the machine is now in regenerative braking mode (quadrant 2)

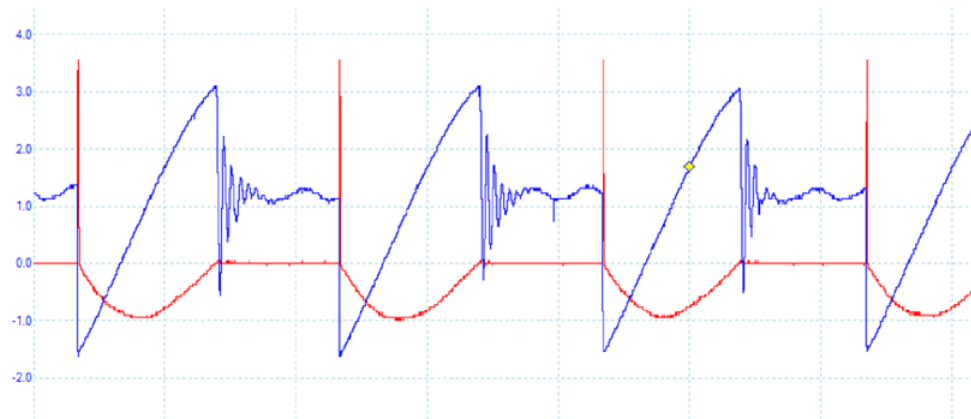
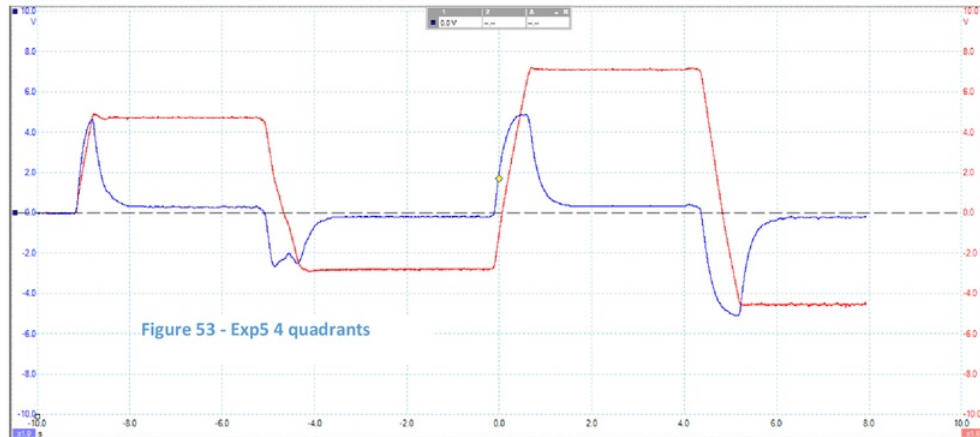


Figure 52 - Exp4 waveform regenerative braking

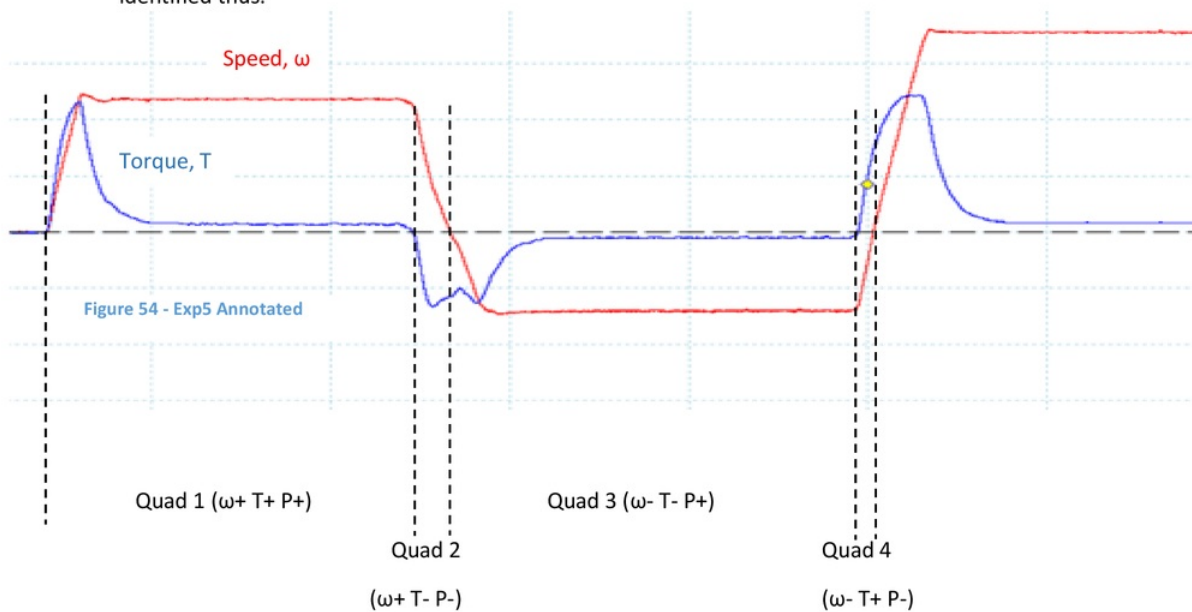
The current waveform has gone negative meaning energy is being fed back to the supply.

Experiment 5

The speed and average current were recorded over a longer period during which the speed set point was changed from forward motoring to reverse motoring quickly and back again. The oscilloscope was used as a data logger to trace speed (red) and torque (blue) and each quadrant can be seen below.



Expanding the trace and investigating the signs of the speed and torque then the four quadrants are identified thus.



It can clearly be seen that these quadrants concur with theory as shown in figs 3 and 4 in terms of the polarity of the variables being exactly as expected.

Experiment 6

The tuning parameters of the drive control loops were adjusted to show effects on stability at start-up. The results show that altering K_p and K_i on the speed feedback loop will allow the user to get a better response from the motor with lower overshoot, less oscillation and faster settling time.

Tuning parameters	Response	Result
K_p min K_i min		$T_s = 1.24s$
K_p max K_i min		$T_s = 633ms$
K_p min K_i max		$T_s = 3.694s$

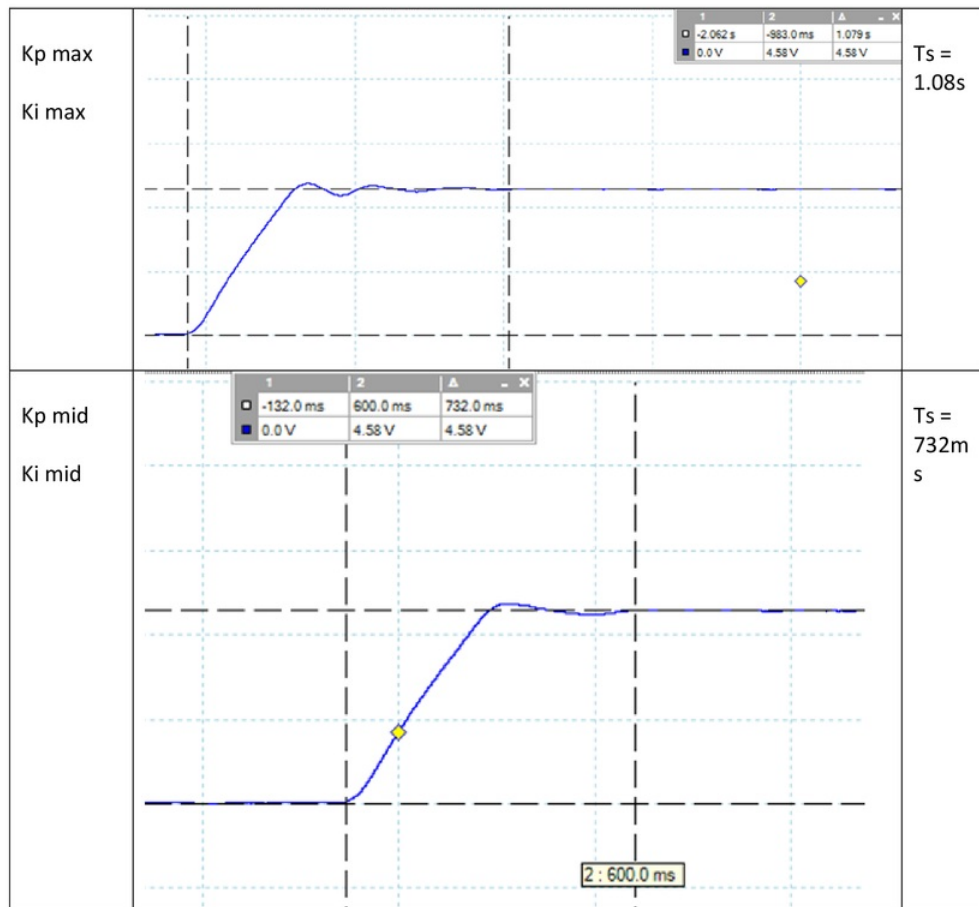


Figure 55 - Exp6 Results

The best result is seen with a settling time of 633ms, this is with Kp at max and Ki at min, the number of oscillations is 2

5. Analysis of results

PRACTICAL RESULTS

The first set of tests carried out in the practical task were under no-load conditions for both forward and reverse motoring

Table 1 - Practical results varying speed set-point

	FORWARD	REVERSE
Firing angle α (rad)	2.3	2.17
Firing advance angle β (rad)	0.35	0.16
Calculated V_{av} (V)	72.9	-123.7
Measured V_{av} (V)	74.0	-125
Error in V_{av} (V)	1.1	1.3
Back emf (V)	70	-122
Measured Current (A)	0.20	-0.23

These results clearly show correlation between practical and theory, waveforms are as expected with discontinuous current, there is agreement between calculated and measured average voltage. The back EMF is close to the value for V_{av} as the motor is unloaded.

The theoretical dynamic behaviour of a dc motor without mechanical load means when current flows in the armature speed increases until the back EMF equals the applied voltage and thus reduces current to zero. However, the effects of friction and windage cause some loading, also inductance has an effect. (Hughes A. , 2006)

Errors between results calculated from the waveform integration and measured values are small and caused by cursor placement, rounding errors and the assumption that the waveform is ideal in nature.

The second set of test results show an increasing mechanical load being applied and are shown below. See summary of waveforms on pages 30-32.

Table 2 - Practical results - load effect

	TEST 1 – 0.2Nm	TEST 2 – 0.4Nm	TEST 3 – 0.6Nm
Firing angle α	1.98 rad	1.92 rad	1.8 rad
Firing advance angle β	0.27 rad	0.39 rad	0.412 rad
Calculated V_{av}	123.64	118.99	129.39
Measured V_{av}	123	125	126
Error in V_{av}	0.64	6.01	3.39
Back emf (V)	115	115	111
Current (A)	0.64	1.01	1.42

With increased loading as expected firing angle decreases, which increases V_{av} and the current, is seen to increase. E_b remains steady with speed. Due to the controlling action of the drive in maintaining the speed setpoint a few other subtle effects on average voltage and back EMF occur. Test 2 gave one spurious result for which I would recommend taking a repeat measurement had time allowed.

SIMULATED RESULTS

The results of the simulated tests can be seen to correlate well with theory and errors are due to cursor placement, rounding, etc.

Single-phase	Theory		Simulation			Max error (V)
	Vmax (V)	Vmean (V)	Vmax (V)	Vmean (V)		
				CRO	DVM	
70°	339.41	131.16	337.68	131.64	130.65	-1
40°	339.41	165.54	336.07	166.32	165.2	+0.78
Three-phase	Theory		Simulation			
	Vmax	Vmean	Vmax	Vmean		
				CRO	DVM	
20°	586.89	526.56	584.66	524.6	524.25	-1.96
50°	586.89	360.24	585.41	363.87	358.05	+3.63

Unlike a real motor drive with natural negative feedback multisim is open loop with no speed compensation included

The firing angle has a direct effect on V_{av} as expected with lower angles giving higher voltages and thus causing speed to increase under steady load conditions, E_b remains unchanged however.

Continuous and discontinuous current waveforms are analysed to show the effects of both.

6. Conclusions and Recommendations

Through research, practical and simulation the aims of the assignment have been met fully. Research on four quadrant operation and rectifying circuits was essential for informing the analysis of simulated and practical results. The Parker 514C was reliable and gave expected output waveforms. Waveforms from simulation were also as expected, closely matching theory. Overall performance was robust and correlation with quantitative research was high.

Recommendations for SCR protection:

During the practical current spikes are seen upon firing.

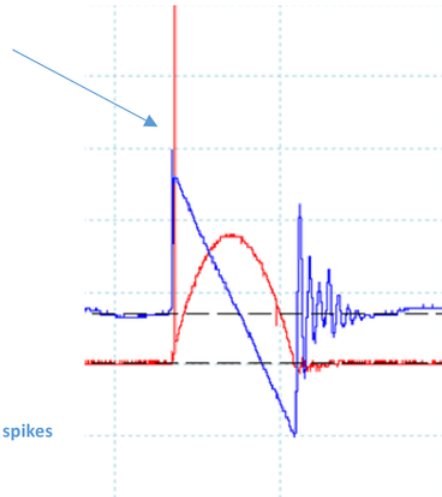


Figure 56 - Current spikes

The spike could damage the thyristors so protective measures like a clamping device (capacitor snubber) could be used. Circuit breakers must be used to protect against over current problems.

Problems commonly encountered with rectifier DC drives include supply distortion. The harmonics cause heat and torque pulsations along with resonance from interaction of rectifier RL and pf correction capacitors. This could be overcome by removing dominant harmonics with tuned LC filters at input or installing self-commutating devices in the converter like GTOs, IGBTs. Another problem is low supply power factor in relation with the firing angle when operating at low speed. In response to this PWM rectifiers with high power factors and low supply distortion are desirable. However, switching losses then effect efficiency.

The overall effect on the motor includes current ripple, torque ripple and heat but adding L_a will smooth current. Effect of discontinuous current means rectifier voltage output increases and thus poor speed regulation under open loop occurs.

The practical was carried out in a small team, my contribution was essential in recording the various parameters, and ensuring results for all experiments required were within an acceptable range or necessitated a repeat experiment. I also analysed promptly the results making sure anomalies could be accounted for.

7. References

- Hughes, A. and Drury, B. (2013). *Electric motors and drives*. Oxford: Newnes.
- Lander, C. (1993). *Power Electronics*. Berkshire: McGraw-Hill.
- Parker. (2006). *Parker 514C Technical Manual*. Retrieved from Parker:
<http://www.parker.com/Literature/SSD%20Drives/DC%20Drives/HA389196.pdf> [Accessed 16/12/2017]
- Electronics, P., Converter, I. and Converter, I. (2018). *Introduction of Single Phase Dual Converter*. [online] Pantechsolutions.net. Available at:
<https://www.pantechsolutions.net/powerelectronics-tutorials/introduction-of-single-phase-dual-converter> [Accessed 4 Jan. 2018].
- YouTube. (2018). *#EEE - Four Quadrant Operation Of DC Motor (Version 1.0)* (<https://electronics2electrical.com/>). [online] Available at:
<https://www.youtube.com/watch?v=g8l3Ckx4AIQ> [Accessed 4 Jan. 2018].
- Wildi, T. (2002). *Electrical machines, drives, and power systems*. Upper Saddle River, NJ: Prentice Hall, p.p.550. [Accessed 4 Jan 2018]
- Uk.mathworks.com. (2018). *Electric Drives Library - MATLAB & Simulink - MathWorks United Kingdom*. [online] Available at:
<https://uk.mathworks.com/help/physmod/sps/powersys/ug/about-the-electric-drives-library.html?requestedDomain=www.mathworks.com&requestedDomain=uk.mathworks.com> [Accessed 9 Jan. 2018].
- Protorit.blogspot.co.uk. (2018). *Thyristor Single-Phase Bridge Rectifier/Inverter*. [online] Available at: <http://protorit.blogspot.co.uk/2013/01/power-electronics-thyristor-single-phase-bridge-rectifier.html> [Accessed 9 Jan. 2018].

8. Bibliography

Lander, C. (1993). *Power Electronics*. Berkshire: McGraw-Hill.

Parker. (2006). *Parker 512C Technical Manual*. Retrieved from Parker:
<http://www.parker.com/Literature/SSD%20Drives/DC%20Drives/HA389196.pdf>

Hughes, A. and Drury, B. (2013). *Electric motors and drives*. Oxford: Newnes.

Wildi, T. (2002). *Electrical machines, drives, and power systems*. Upper Saddle River, NJ: Prentice Hall, p.p.550.

Tankonyvtar.hu. (2018). Four-Quadrant Thyristor DC Drive/Digital Textbook Library. [online]
Available at: http://www.tankonyvtar.hu/en/tartalom/tampo425/0048_VIVEM19EN/ch01s04.html
[Accessed Jan.2018].

Basic Electronics Tutorials. (2018). Transient Suppression Devices and Voltage Clamping. [online]
Available at <http://www.electronics-tutorials.ws/power/transient-suppression.html> [Accessed 10 Jan 2018]

assignment 1

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

81 /100

Instructor

PAGE 1

PAGE 2

PAGE 3

PAGE 4

Text Comment. punctuation

Text Comment. Good evidence of research but this task also asked for the following: Review of single and three phase full-wave rectifying circuits for controlled rectification when connected to a load containing low resistance, high inductance and a back EMF. Explain the shape of the expected output waveforms of voltage and current. Consider continuous and discontinuous current. Review of suitable formulae and performance parameters for analysing the behaviour of controlled rectifiers with suitable comparisons made between types of rectifier

PAGE 5

Text Comment. a good way of explaining it

PAGE 6

Text Comment. note that this author is using 4th quadrant for 2nd and 2nd quadrant for 4th.

PAGE 7

Text Comment. This needs clarifying; do you mean that the control signals to the thyristors are in milliwatts?

Text Comment. This is not always true since PI controller could be used. It would be true for a P controller only

PAGE 8

Text Comment. poor quality image

QM

Citation Needed

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http://www.plagiarism.org/plag_article_citation_styles.html

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Text Comment. Note that this cannot be used to run a shunt connected motor, it must be separately excited to allow for the four quadrant operation. Reversing polarity of both armature and field will not reverse the direction if the motor is connected in shunt. However, what the manual is saying is that the field has a high impedance and although it could be used in shunt, it must not be connected that way as the 514 has a separate field supply.

PAGE 20

PAGE 21

PAGE 22

PAGE 23

PAGE 24

PAGE 25

PAGE 26

PAGE 27

Text Comment. the difference is only 0.35 not -1.96

PAGE 28

Text Comment. actually, this is due to switching back emf of the coil

PAGE 29

PAGE 30

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PAGE 35

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PAGE 40

PAGE 41

PAGE 42

RESEARCH-INFORMED LITERATURE

-  Section 1: Research - Excellent evidence of research on all aspect required. However, equations should have been cited from a source. (25/30)
Section 5: Your use of Harvard for citing and listing – A good range of sources listed and cited correctly. However, the bibliography also contained many of the sources already found in the citation list. A bibliography would normally contain a list of sources read but not cited. (2/5)

27

KNOWLEDGE AND UNDERSTANDING

-  Section 2: Explanation of simulation - Excellent explanations given for both circuits.(5/5) Section 3: Explanation of practical experiment – Excellent. (5/5)

10

ANALYSIS

-  Section 2: Analysis of results from simulation - Excellent analysis carried out with very good summary table. One error noted in final column. (9/10) Section 3: Analysis of results from practical experiment – Excellent analysis of results given. (9/10) Section 4: Overall conclusions and recommendations – Very good with some recommendations. You have clearly benefited from this assignment .(7/10)

25

PRACTICAL APPLICATION AND DEP.



Section 2: Simulation - Excellent use of MultiSIM. However, avoid cropping images when presenting results from oscilloscopes. (4/5) Section 3: Practical experiment - carried out to a high standard with results well presented (5/5)

9

SKILLS FOR PROFESSIONAL PRAC.



All sections - A well structured, presented and written report covering all aspects of the assignment. However, one image is of poor quality and should have been drawn using a computer or imported from a source.(8/10) Section 4: Team role -Brief explained (2/5)

10