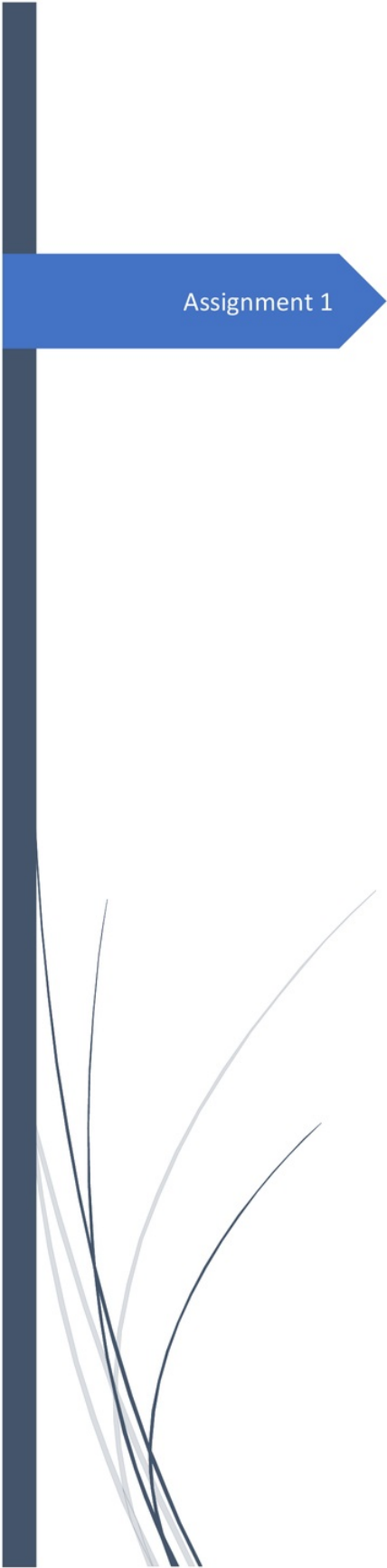


# Ass 1 final

*by* Michael Lewis

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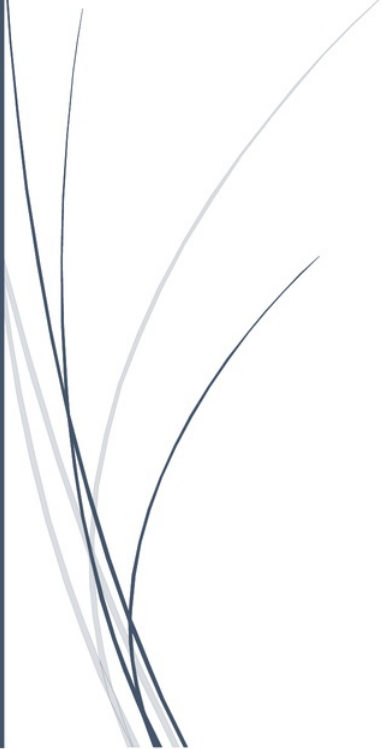
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## Assignment 1

# Investigation into converters – Power electronics and drives

Mike Lewis

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## 1. Research

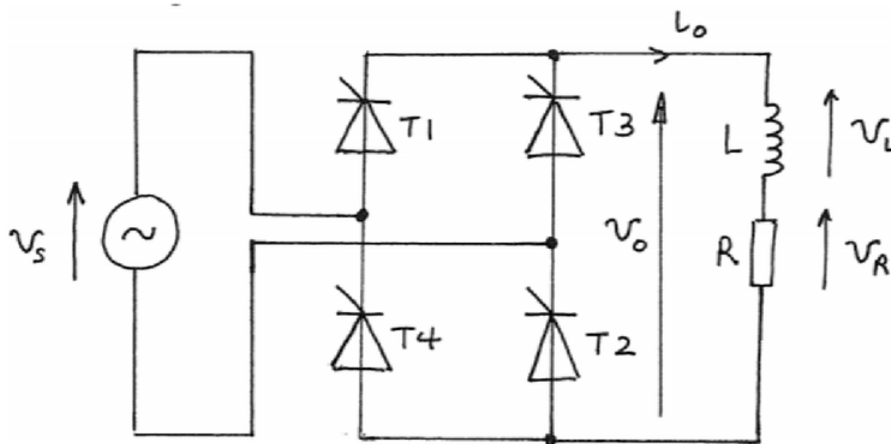
In the analysis of the waveforms produced by the rectifying circuit, a few assumptions are made:

The rectifying devices will have a zero-forward volt drop and rectifying devices will have zero reverse recovery time. These assumptions can be made when the supply voltage is large, and the frequency of the supply is low (50/60Hz).

Citation Needed

### Single phase, full wave, controlled rectifier

The first circuit to be researched is the single phase full-wave controlled rectifier; with a low resistance, high inductance and back EMF. The diagram in Figure 1 shows this circuit.



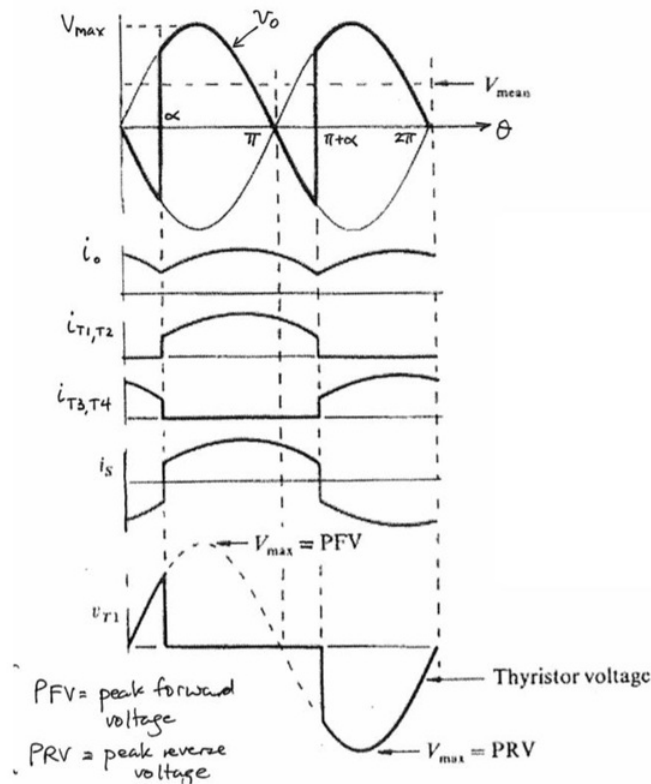
(Coleg Sir Gar) *This is not a published source but a hand drawing, no citation needed.*

Figure 1 - single phase, full-wave, controlled rectifier

Basic operation of the circuit:

For the thyristors to conduct and allow current to flow, the thyristors must be fired in pairs;  $T_1$  &  $T_2$ ,  $T_3$  &  $T_4$ . The easiest way to achieve this is to connect the pairs to the same firing circuits,  $T_1$  &  $T_2$  controlled by one firing circuit,  $T_3$  &  $T_4$  fired by a separate firing circuit. (Lander, 1993, pp. 50-52)  $T_1$  and  $T_2$  are fired at the angle  $\alpha$ ,  $T_3$  and  $T_4$  are fired at  $\pi + \alpha$ .

The firing angle  $\alpha$ , is the value that effects when the thyristors are fired. When the load current is **continuous**, the load  $V_{mean} = \frac{2V_{max}}{\pi} \cos \alpha$  (Lander, 1993, p. 53). Using the  $V_{mean}$  equation it can be seen that: The maximum value of  $V_{mean}$  is achieved when  $\alpha$  is  $0^\circ$ . The minimum value of  $V_{mean}$  is achieved when  $\alpha$  is  $90^\circ$ . This is the very basic principle behind the control of a dc machine connected to the output of the rectifying circuit, by varying only angle  $\alpha$ .



(Coleg Sir Gar)

Figure 2 - Single phase rectifier waveform

Figure 2 shows the waveform produced from the circuit in Figure 1, with a small value of alpha that produces a continuous load current. The output voltage waveform can clearly be seen as a sine wave, with the strange shape being caused by the firing delay. If the firing delay was set to 0, the complete sine wave would appear across the load. It can be seen from the waveforms that the output current is the sum of the two sets of thyristor currents, or the supply current if the negative half cycle was flipped positive. The back EMF does not appear in this example as the current is continuous.

The peak forward and peak reverse voltage values are also shown in Figure 2. The thyristors must be correctly rated based on the respective max voltage levels.

The firing angle can be pushed passed  $90^\circ$  which causes  $V_{mean}$  to become negative. This is called Inversion. This happens because if  $\alpha > 90^\circ$ ,  $\cos \alpha$  in the  $V_{mean}$  equation becomes negative.

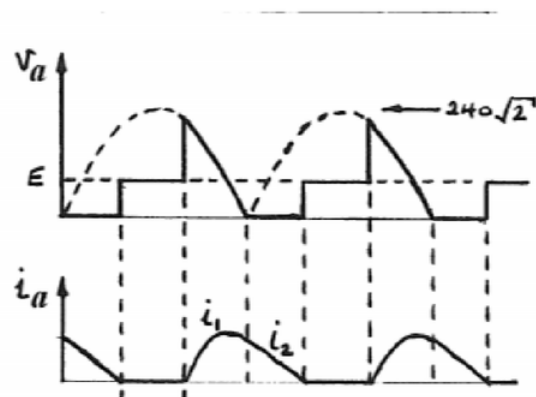
When the output current is discontinuous, the equation is slightly more involved, as one can't simply integrate the area under the voltage output curve. This is because when the current becomes discontinuous, the sine wave is no longer intact: The back EMF appears across the load and must be taken into consideration as it effects the average output voltage. The following equation can be used:

$$\frac{1}{\pi} (E(\alpha - \beta)) + \frac{V_m}{\pi} [\cos(\alpha) - \cos(\pi + \beta)]$$

Where:  $V_m = V \text{ max}$ .  $E = \text{Back EMF}$ .  $\alpha = \text{firing angle}$ .  $\beta = \text{current conduction angle}$ .

(Krishnan, 2001)

Figure 3 shows an example of what discontinuous current looks like, in terms of the load voltage and load current. The moment the output current drops to 0 the back EMF is clearly seen across the load.

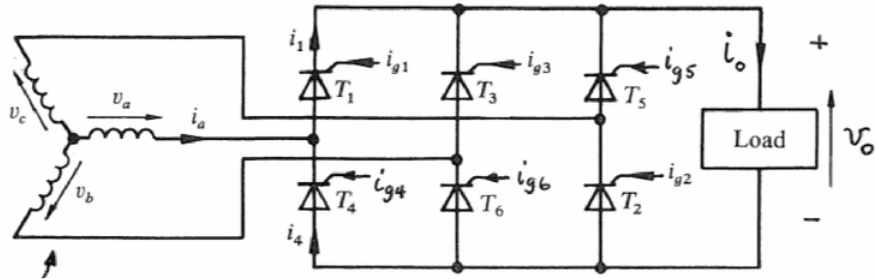


(Coleg Sir Gar)

Figure 3- Discontinuous current example

### Three-Phase full-wave rectifying circuit

The diagram in Figure 4 shows a three-phase, full-wave, fully controlled rectifier. The three coils on the left-hand side of the diagram represents the transformer secondary. The load is assumed to be inductive.



(Coleg Sir Gar)

Figure 4 - 3 phase, full-wave, fully controlled

An industrial supplier of electronics states that the type of rectifying circuits shown in Figure 4 are "extensively used in industrial power applications up to about 120kW output power level, where two quadrant operations is required". (Pantech Solutions, 2017)

The resulting waveforms for the circuit in Figure 4 are shown in Figure 5. On the waveform diagram, numbers 1 to 6 have been written along vertical lines that represent each key stage of the circuits operation. From both diagrams it can be seen that:

At stage 1 T1 and T6 are fired together.  $V_o = V_a - V_b$

At stage 2 T2 and T1 are fired together.  $V_o = V_a - V_c$

At stage 3 T3 and T2 are fired together.  $V_o = V_b - V_c$

At stage 4 T4 and T3 are fired together.  $V_o = V_b - V_a$

At stage 5 T5 and T4 are fired together.  $V_o = V_c - V_a$

At stage 6 T6 and T5 are fired together.  $V_o = V_c - Vb$

The average load voltage can be found by integrating between  $\pi/3 + \alpha$  and  $2\pi/3 + \alpha$ , averaged over  $\pi/3$  rads. This equation simplifies down to:

$$V_{mean} = \frac{3V_{\max(line)}}{\pi} * \cos(\alpha)$$

(Krishnan, 2001, p. 52)

From both diagrams at:

Stage 1: T1 and T6 are fired together. Load current flows from phase 'a' through T1, into the load, through T6, then returns through phase 'b'.

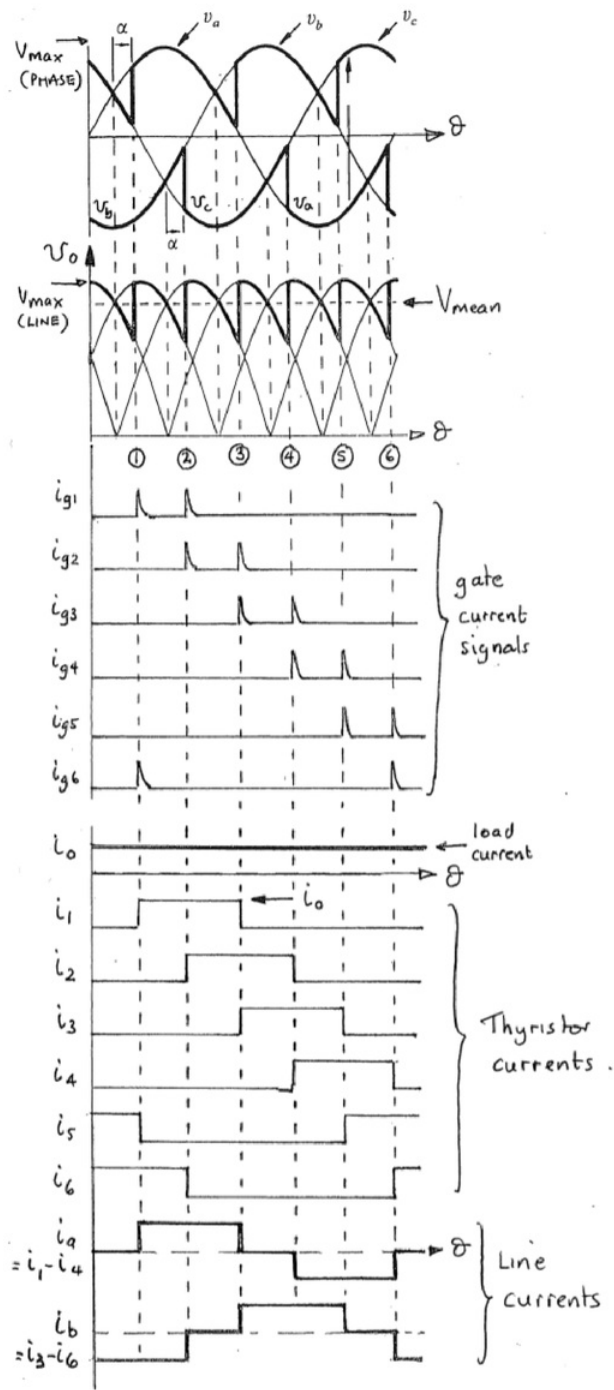
Stage 2: T1 and T2 are fired together. Load current flows from phase 'a' through T1, into the load, through T2, then returns through phase 'c'.

Stage 3: T3 and T2 are fired together. Load current flows from phase 'b' through T3, into the load, through T2, then returns through phase 'c'.

Stage 4: T3 and T4 are fired together. Load current flows from phase 'b' through T3, into the load, through T4, then returns through phase 'a'.

Stage 5: T4 and T5 are fired together. Load current flows from phase 'c' through T5, into the load, through T4, then returns through phase 'a'.

Stage 6: T5 and T6 are fired together. Load current flows from phase 'c' through T5, into the load, through T6, then returns through phase 'b'.



(Coleg Sir Gar)

Figure 5 - Three-phase, full-wave, fully controlled waveforms

#### 4-Quadrant operation of DC drives

The diagram in Figure 6 best describes what each quadrant means in terms of controlling a DC machine.

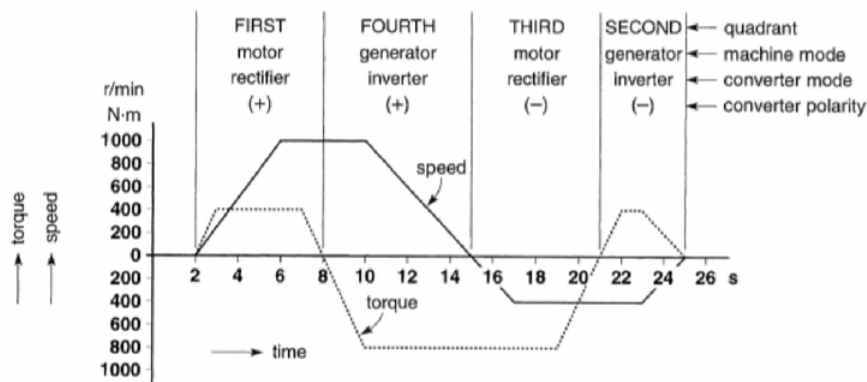
The first quadrant is the motor turning forwards (i.e. Clockwise), producing mechanical power at the shaft with a positive speed and positive torque.

The third quadrant is the opposite; the motor is effectively turning backwards (i.e. Anti-Clockwise). Mechanical power is still being produced at the shaft as the speed and torque are both negative.

The fourth quadrant is the DC machine operating as a generator. As the speed is positive it can be said that the shaft is still turning clockwise, but because the torque is negative, this produces a braking effect. Eventually the shaft will stop, change direction and then it is motoring in the third quadrant (anticlockwise) again.

The second quadrant is generating in the opposite direction. The speed is negative, so it can be said that the shaft is turning anti-clockwise. The torque is positive which opposes the negative speed creating a braking effect. The speed will eventually reach 0 and then swap directions, which will return to the first motoring quadrant.

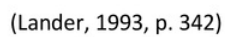
Torque-speed characteristic of an industrial drive.



(Wildi, p. 564)

Figure 6 - 4 quadrant operation

The rectifying circuits that have been investigated up until this point are only capable of one or two quadrant operations. To allow the rectifying circuit to make use of all 4 quadrants of operation, another converter consisting of 6 thyristors are added to the load, but allow the current to flow the other direction into the load. (Krishnan, 2001, p. 60) This is shown on the diagram in Figure 7. The diagram assumes that the method for controlling this DC motor is keeping the field the same polarity and using the reversing of the applied voltage to the armature to control speed and direction.



11

### Control techniques used in commercial drives

There are 3 main ways that the speed of a DC motor can be controlled: Field control, armature control and a combination of both (field and armature control). Why this is possible can be explained by the mathematical relationship between rotor speed, field current and

Del. 

#### Field control

If the armature voltage remains constant and the field voltage is varied, this is known as field control. The reason this is possible is the speed of the rotor is inversely proportional to the field current.

$$\omega_m \propto \frac{1}{i_f}$$

(Krishnan, 2001, p. 37)

The equation shows that; If the field current is changed, the rotor speed is changed. If the current is reversed (negative value), the rotor speed becomes negative, which effectively reverses the direction. One limitation of field control is that the field cannot be strengthened passed its rated value, due to the magnetic saturation of the steel laminations. (Krishnan, 2001, p. 37)

#### Armature control

If the field voltage remains the same and the armature voltage is varied, this is known as armature control. This is due to the relationship between the rotor speed and armature current, shown in the following equation:

$$\omega_m \propto (v - I_a R_a)$$

(Krishnan, 2001, p. 38)

The advantage to armature control over field control is the much quicker response time to an applied voltage. This is due to the time constant of the armature being 10 to 100 times smaller than that of the field. (Krishnan, 2001, p. 38)

*good reason given*

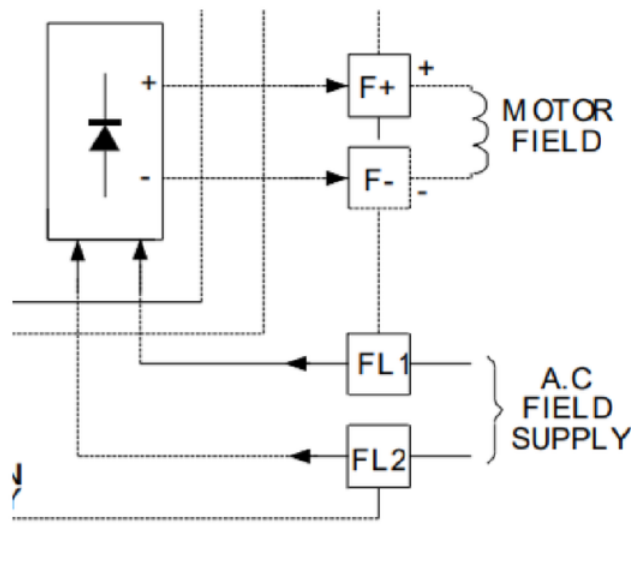
#### Field and armature control

Both control methods can be combined to allow both currents to be varied, enabling the motor to work above and below its rated value. *This enables* Which enable a much broader speed operating range than either control method on its own. (Krishnan, 2001, p. 38)

The main commercial DC drive that will be investigated is the Parker 514C, which will be used in the practical experiment. A product manual for this drive states that “The regenerative 514C DC drive offers full four quadrant control of DC motors from single phase supplies” (Parker, 2012); [page number needed here for a direct quote](#)

Improper Citation

Studying the technical documentation, the function block diagram, it appears that this device does not control the field voltage of the motor. The AC voltage fed into terminals FL1 and FL2 simply go through rectifying diode, then into the field in the correct polarity. See Figure 8. For the field voltage to be controlled, firing circuits and thyristors would have to be connected to F+ and F-, which is not present in this model. [good observation](#)

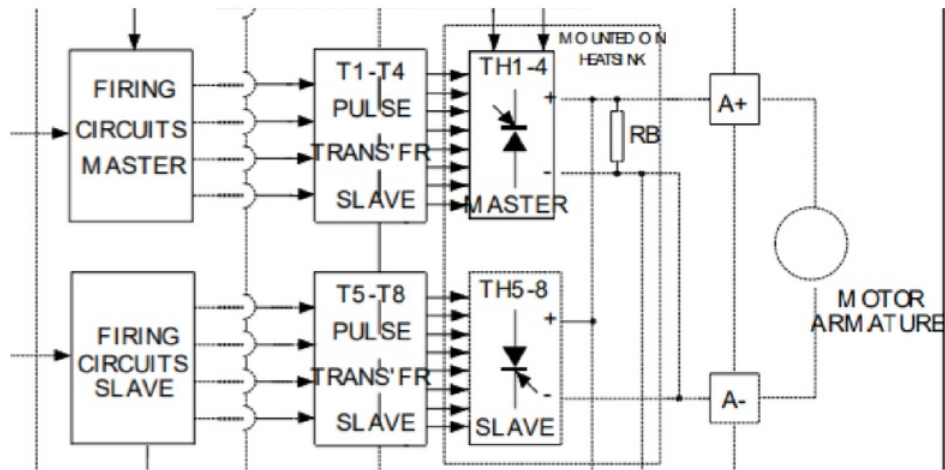


(Parker, 2007)

Figure 8 - 514C - Field supply

It can be deduced from the documentation that the 514C controller uses only armature control. This is confirmed by the function block diagram showing the armature terminals of the controller, shown in Figure 9. This is a single phase, full wave, 4 quadrant rectifying circuit. The dual-bridge configuration is apparent from the separate thyristor blocks, which allow current to flow in either direction. As it's a single-phase setup, 2 sets of 4 thyristors allow the device to run the DC machine in all 4 quadrants.

Although the 514C has many additional features, at a fundamental level the controller uses the same techniques as simple rectifying circuits to allow the speed of the motor to be controlled. The difference with the modern DC controllers are the precision in which they can control the speed of a DC motor, using tacho feedback or armature current feedback. (Parker, 2007)



(Parker, 2007)

Figure 9 - 514C - Armature control

*you could have looked into the control loops for current, voltage and speed from the datasheet*

## 2. Simulation of rectifying circuits

Multisim was used to setup simulations of full-wave, fully-controlled single phase and three phase rectifying circuits, like the circuits investigated during research. The circuits contain an inductance, resistance and back EMF.

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

The following parameters were provided by the specification:  $L = 100\text{mH}$ ,  $R = 10\text{ Ohms}$  and  $E = 100\text{V}$ . Two firing angles were used to test the simulation. The values of  $\alpha$  that were chosen were:  $77^\circ$  and  $44^\circ$ , which corresponds to the angle  $\alpha$  in degrees. The two angles chosen were selected to produce discontinuous current and continuous current respectively. Figure 10 shows the first simulation setup for a firing angle of  $77^\circ$ . Isolation transformers are used between the thyristor controller and the thyristors themselves.

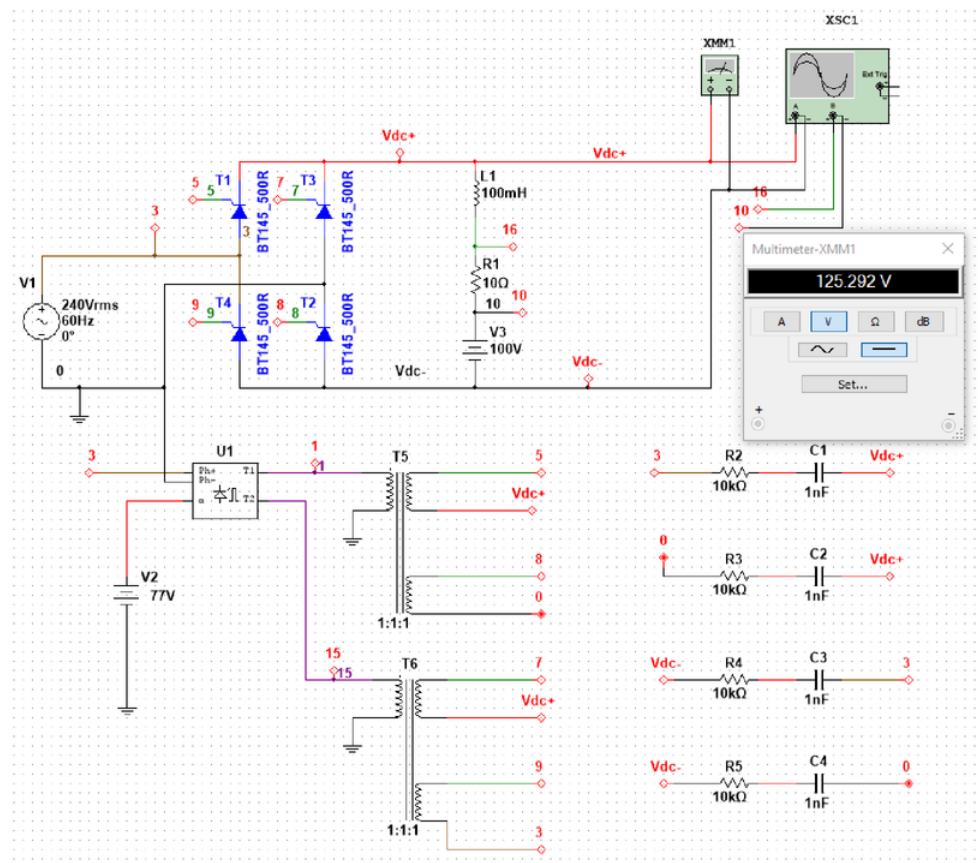


Figure 10 - Simulation, single phase,  $\alpha = 77^\circ$

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To confirm that the firing angle is  $77^\circ$ , and to calculate  $\beta$ , various time readings were taken from the oscilloscope output. Figure 11 shows half a cycle, which equates to  $180^\circ$  or  $\pi$  radians, which occurs in 8.32ms. Alpha and Beta were then measured using the same starting point. Figure 12 and Figure 13 shows the time values where alpha and beta occur respectively, as well as where the points where the measurements were taken. The LHS marker is T1 and the RHS marker is T2.

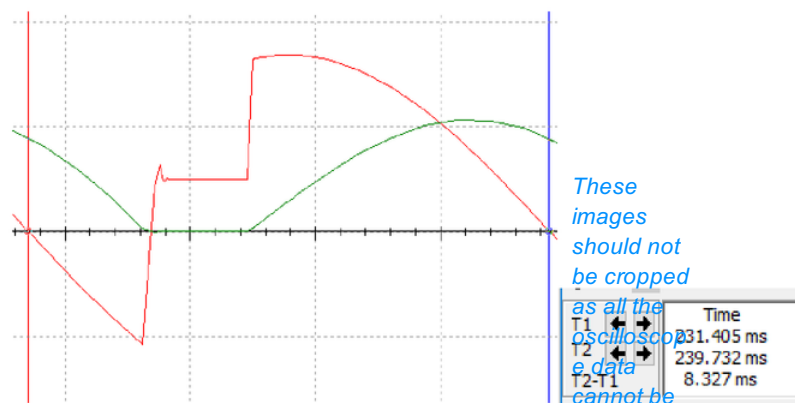


Figure 11- Single phase,  $\alpha = 77^\circ$  - Calculating alpha

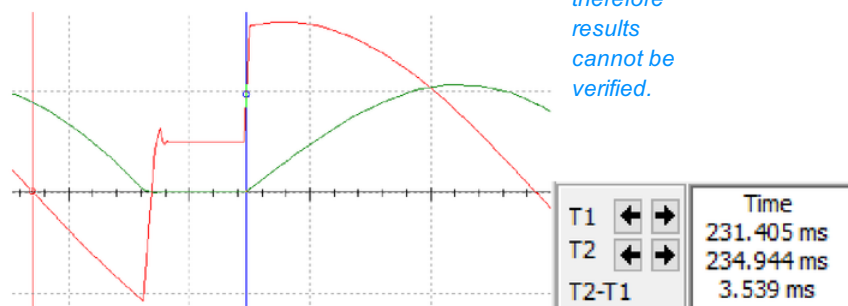


Figure 12 - single phase,  $\alpha = 77^\circ$  - Alpha

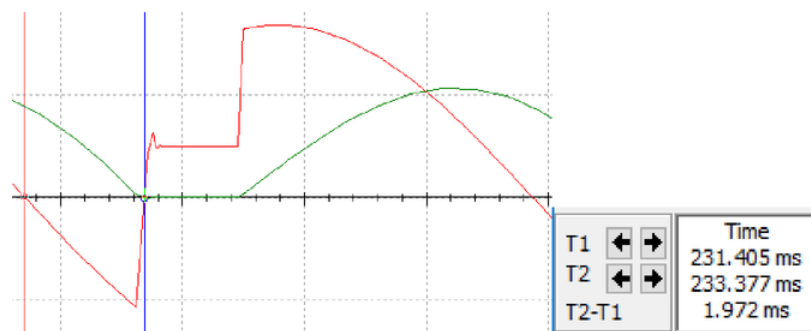


Figure 13 - single phase,  $\alpha = 77^\circ$  - beta

The following equation will be used throughout in the same manner to confirm  $\alpha$  and calculate  $\beta$ .

$$\alpha = \frac{3.54ms}{8.33ms} * 180^\circ = 76.5^\circ$$

$$\beta = \frac{1.97ms}{8.33ms} * 180^\circ = 42.6^\circ$$

The firing angles and current conduction angles are converted from degrees into radians for use in the equation.

$$\alpha = 77^\circ * \frac{\pi}{180} = 1.34 \text{ rads},$$

$$\beta = 42.6^\circ * \frac{\pi}{180} = 0.74 \text{ rads}$$

As this first simulation is discontinuous current, the following equation that was researched earlier is used:

$$\frac{1}{\pi} (E(\alpha - \beta)) + \frac{V_m}{\pi} [\cos(\alpha) - \cos(\pi + \beta)]$$

$$\frac{1}{\pi} (100(1.34 - 0.74)) + \frac{339}{\pi} [\cos(1.34) - \cos(\pi + 0.74)] = 123.5V$$

The multimeter in Figure 10 shows that the mean output voltage is 125.3V, which is reasonably close to the calculated value of 123.5V.

The simulation was run a second time with a different firing angle, shown in Figure 14. The value of  $\alpha$  used in the second simulation was 45V. As the current is continuous,  $\beta$  is not apparent, and a different equation that was researched earlier is used to calculate the mean voltage.

$$\alpha = \frac{2.077ms}{8.33ms} * 180^\circ = 44.9^\circ$$

$$\alpha = 44.9^\circ * \frac{\pi}{180} = 0.78 \text{ rads}$$

$$V_{\text{mean}} = \frac{2V_{\text{max}}}{\pi} \cos \alpha = \frac{2 * 339}{\pi} \cos 0.78 = 153.4V$$

The multimeter in Figure 14 shows the average voltage to be 152.3V, which is very close to the calculated value of 153.4V. As the cursors used to get the time values of  $\alpha$  and  $\beta$ , the calculated answer was not expected to be exact. The fact that the values are so close, proves the formulae researched earlier apply to simulated single phase circuits.

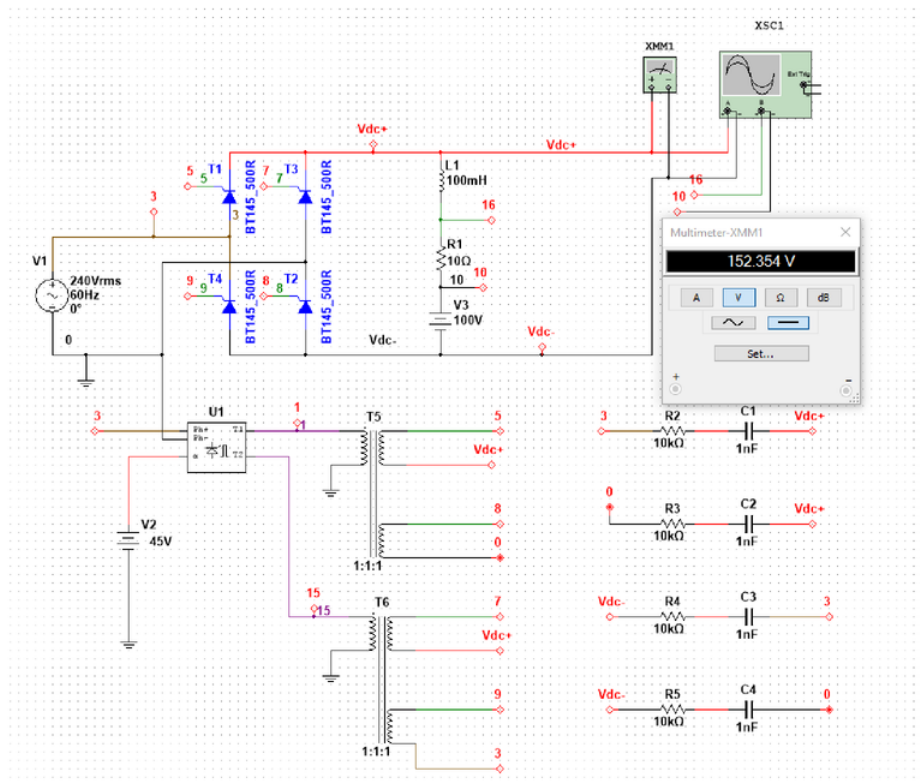


Figure 14 -Simulation, single phase,  $\alpha = 45$

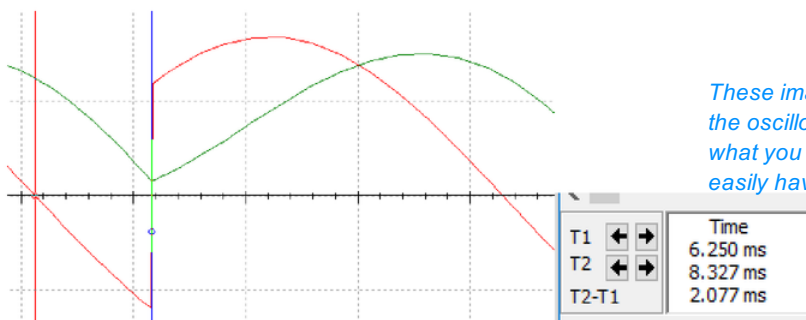


Figure 15-Single phase,  $\alpha = 45$ , alpha

*These images should not be cropped as the oscilloscope data cannot be seen, what you have shown to the right could easily have been taken from elsewhere.*

One relationship that is apparent from the simulation is: The smaller the firing angle, the larger the average output current. The reason for this is as the firing angle gets reduced, more of the sine wave appears across the load, until the point where  $\alpha = 0$  and the whole sine wave is allowed through. When  $\alpha$  raises above a certain threshold (exact threshold not apparent from these tests) the current becomes discontinuous, back EMF appears across the load which affects the average output voltage.

### Three-phase, full-wave, fully controlled

A three-phase rectifying circuit was modelled on Multisim to test the effect two different firing angles have on the output. Only continuous current will be investigated in this task. As Multisim measures alpha from the zero-crossover point, 60° must be added to the firing angle to offset it, shown in the circuit as a battery in series.

An equation researched earlier was used to calculate the mean output voltage:

$$\alpha = 20^\circ * \frac{\pi}{180} = 0.35 \text{ rads}$$

$$V_{mean} = \frac{3V_{\max(line)}}{\pi} * \cos(\alpha)$$

$$V_{rms(line)} = 415V, V_{\max(line)} = \sqrt{2} * 415 = 586.9V$$

$$V_{mean} = \frac{3*586.9}{\pi} * \cos(0.35) = 526V$$

The DC voltmeter shown in Figure 18 shows the mean voltage to be 516V, which is reasonably close to the calculated value of 526V.

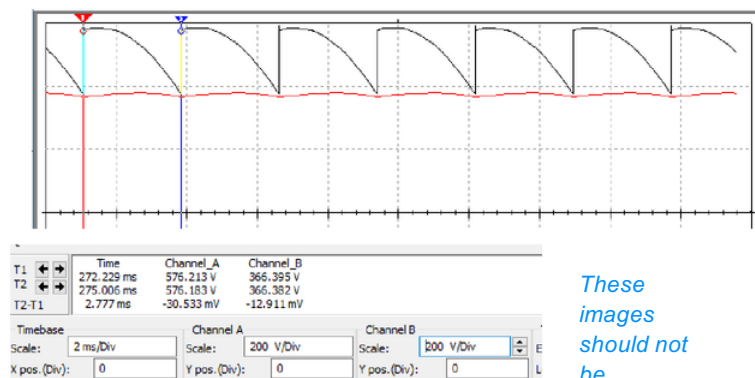


Figure 16 - three phase,  $\alpha = 20$ , oscilloscope output

*These images should not be cropped as all the oscilloscope data cannot be seen.*

The circuit was simulated again with a firing angle of 55.

$$\alpha = 55^\circ * \frac{\pi}{180} = 0.96 \text{ rads}$$

$$V_{mean} = \frac{3V_{\max(line)}}{\pi} * \cos(\alpha)$$

$$V_{rms(line)} = 415V, V_{\max(line)} = \sqrt{2} * 415 = 586.9V$$

$$V_{mean} = \frac{3 * 586.9}{\pi} * \cos(0.96) = 321.4V$$

The voltmeter shown in Figure 17 shows the mean voltage to be 315V, which is reasonably close to the calculated 321.4V. The small differences between the calculated values and the measured values most likely because of rounding errors. The equation was found from a trustworthy and reliable source, so the differences between actual and measured doesn't necessarily mean that the research doesn't tie in with actual results. The fact that both answers are so close points towards human error in the calculations.

The sawtooth shaped waveforms in Figure 16 and Figure 17 is the armature voltage, with the other waveform showing the armature current. It's clear to see when comparing both output graphs that the armature current gets considerably lower as the firing angle gets larger. Which is a similar relationship to the single-phase rectifiers. Three-phase discontinuous current cannot be compared or commented on as this was not investigated during the assignment. Once the firing angle gets too large, the Multisim simulation goes into error.

The single-phase and three-phase simulations show exactly how the armature voltage of a DC machine can be controlled using thyristors and a firing circuit, due to the relationship between rotor speed and armature voltage that was researched earlier.

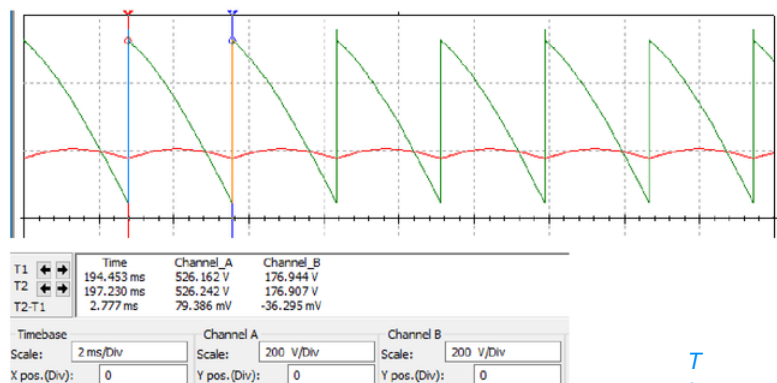


Figure 17 - Three phase,  $\alpha = 55$ , oscilloscope output

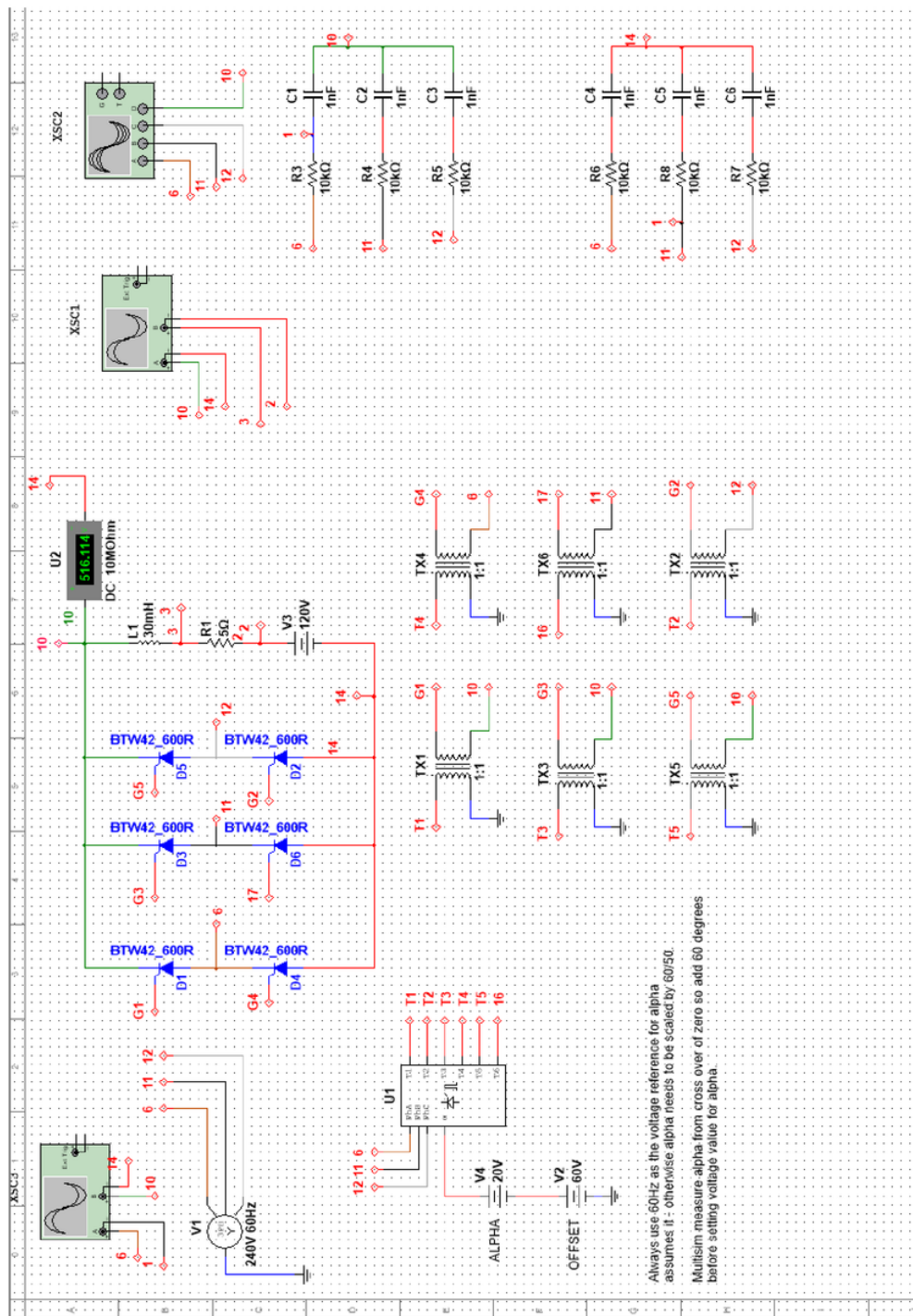


Figure 18 - three phase,  $a = 20$

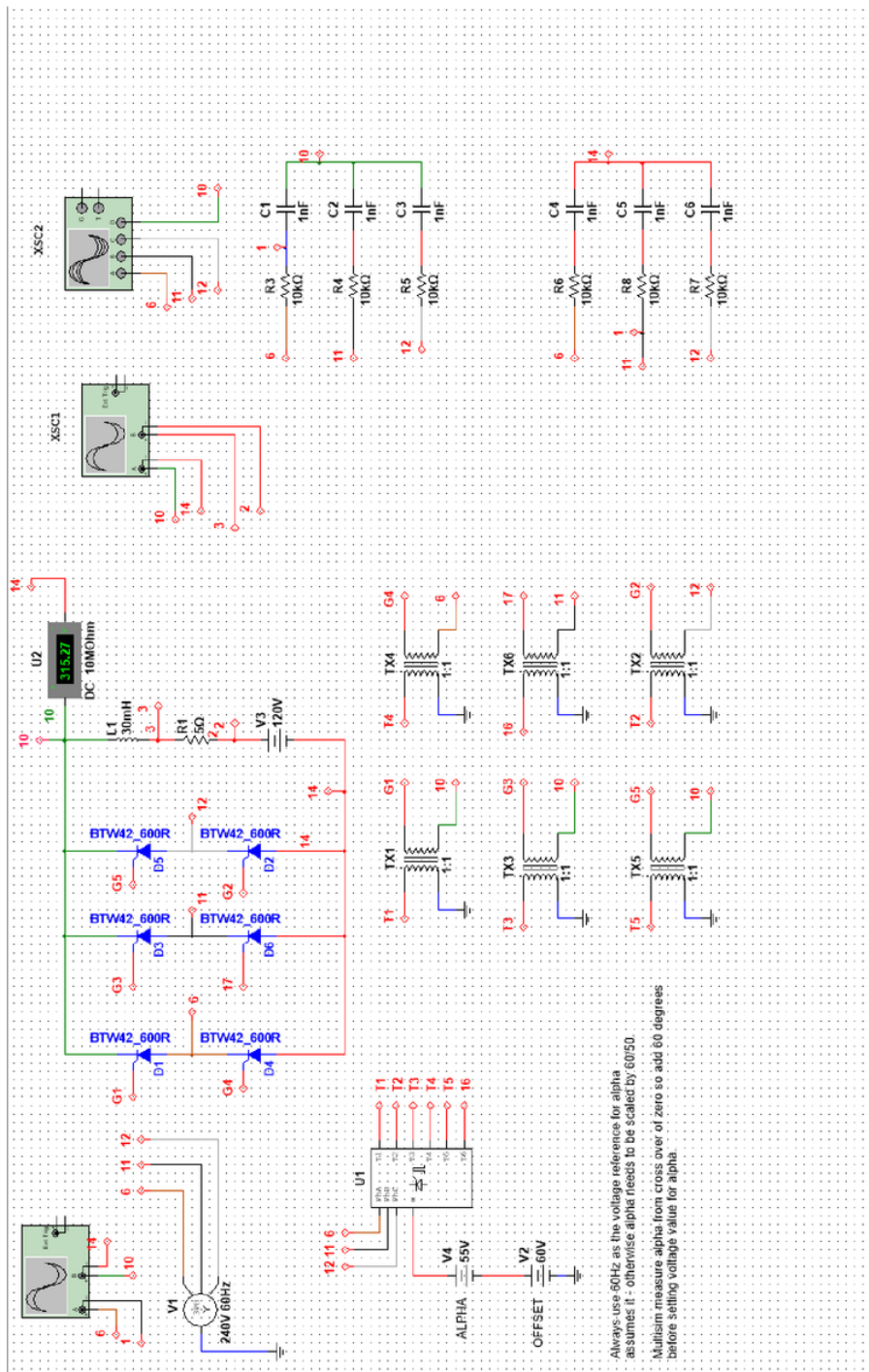


Figure 19 - Three phase,  $a = 55$

### 3. Practical DC drive investigation

514

A practical investigation of the Parker 415 DC drive was carried out to compare real world results with simulations and calculations. The drive was connected to a suitable DC motor, Feedback brand VSD drive, pony brake and suitable measuring instruments. Health and safety was top priority during the entire experiment. Shown in

The DC motor was run at one speed setpoint, with the load changing each test. The effect the load has on the performance of the DC motor will be investigated, by recording average voltage and current and comparing with calculated values.

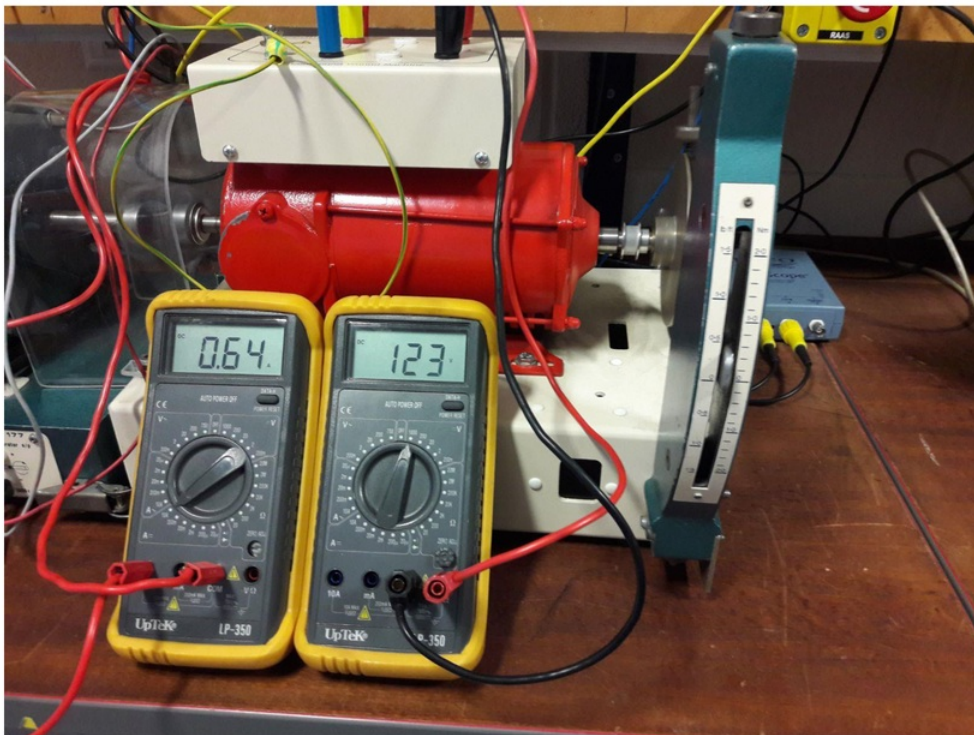


Figure 20 - practical experiment

The first test carried out was the no load test, the output waveform measuring alpha and beta is shown in Figure 21 and Figure 22 respectively.

$$\alpha = \frac{7.34ms}{10ms} * 180^\circ = 132^\circ * \frac{\pi}{180} = 2.3 \text{ rads},$$

$$\beta = \frac{1.11ms}{10ms} * 180^\circ = 20^\circ * \frac{\pi}{180} = 0.35 \text{ rads}$$

The waveforms show that the current is discontinuous, which means that the back EMF appears across the load, from the graph EMF is roughly: 69V. The values for voltage that are on the screenshots must be multiplied by 100 to get actual voltage. Vmax for the supply is roughly 339V.

$$\frac{1}{\pi} (E(\alpha - \beta)) + \frac{V_m}{\pi} [\cos(\alpha) - \cos(\pi + \beta)]$$

$$\frac{1}{\pi} (69(2.3 - 0.35)) + \frac{339}{\pi} [\cos(2.3) - \cos(\pi + 0.35)] = 72.3V$$

The measured average values for this experiment were: V = 74V, I = 0.22A. Which is very close to the calculated value of 72.3V.

photographic  
evidence  
needed  
for  
multimeter  
results

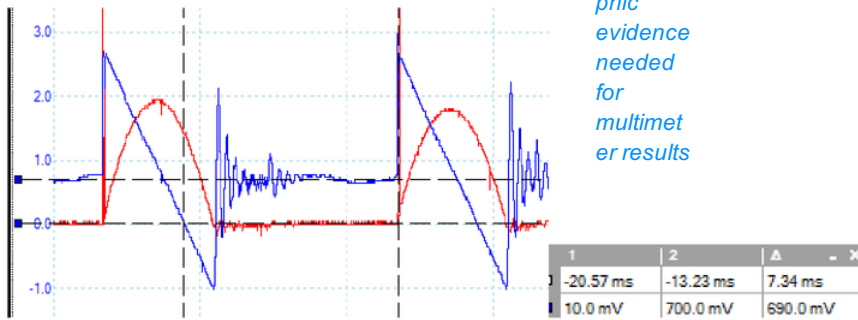


Figure 21 - No load test alpha

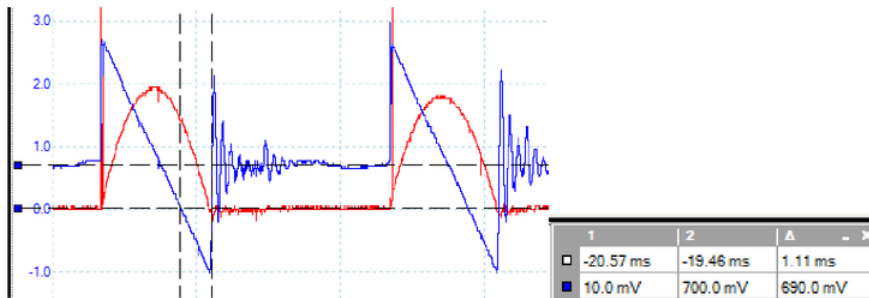


Figure 22 - No load test beta

The next test was the same speed setpoint, with a load of 0.2Nm. The screenshots for measuring alpha and beta are shown in Figure 23 and Figure 24 respectively. EMF is roughly 114V.

$$\alpha = \frac{6.31ms}{10ms} * 180^\circ = 113.58^\circ * \frac{\pi}{180} = 1.98 \text{ rads},$$

$$\beta = \frac{0.87ms}{10ms} * 180^\circ = 15.66^\circ * \frac{\pi}{180} = 0.27 \text{ rads}$$

$$\frac{1}{\pi} (114(1.98 - 0.27)) + \frac{339}{\pi} [\cos(1.98) - \cos(\pi + 0.27)] = 123.1V$$

These are the values that were measured: v = 123v I = 0.66. The calculated average voltage is exact.

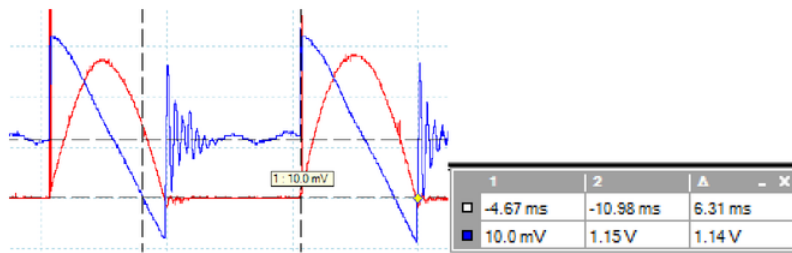


Figure 23- 0.2Nm alpha

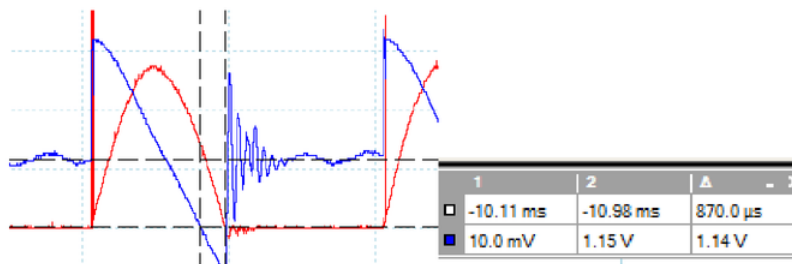


Figure 24- 0.2Nm beta

The load was then increased to 0.4Nm producing the graphs in Figure 25 and Figure 26. The back EMF is roughly 115V.

$$\alpha = \frac{6.12ms}{10ms} * 180^\circ = 110.16^\circ * \frac{\pi}{180} = 1.92 \text{ rads},$$

$$\beta = \frac{1.23ms}{10ms} * 180^\circ = 22.14^\circ * \frac{\pi}{180} = 0.39 \text{ rads}$$

$$\frac{1}{\pi} (114(1.92 - 0.39)) + \frac{339}{\pi} [\cos(1.92) - \cos(\pi + 0.39)] = 118.9V$$

These are the values that were measured:  $v = 125V$   $I = 1a$ . There is a slight difference between the measured value of 125V and the calculated value of 118.9V. As the difference is relatively small, this does not indicate a problem between the practical and experiment. As the measurements were taken by eye (using markers on the software) this could be a potential cause of the values not being exact in this case.

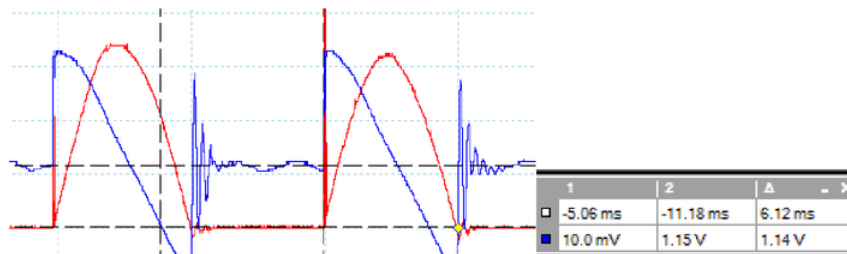


Figure 25- 0.4Nm alpha

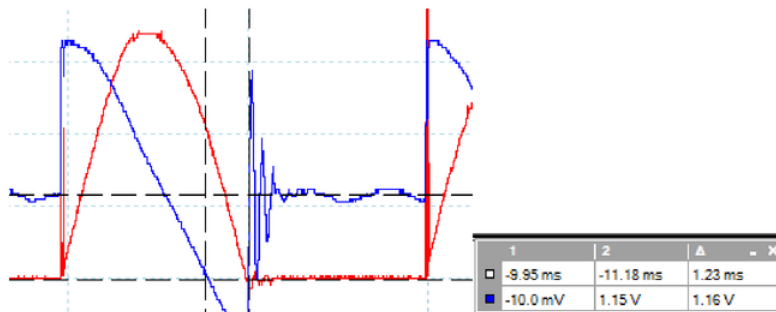


Figure 26- 0.4Nm beta

A load of 0.6Nm was then applied to the DC motor. Producing the graphs in Figure 27 and Figure 28.  
The back EMF is roughly 112V.

$$\alpha = \frac{5.73ms}{10ms} * \pi = 1.8 \text{ rads},$$

$$\beta = \frac{1.31ms}{10ms} * \pi = 0.41 \text{ rads}$$

$$\frac{1}{\pi} (112(1.8 - 0.41)) + \frac{339}{\pi} [\cos(1.8) - \cos(\pi + 0.41)] = 124V$$

The measured values were:  $v = 127$  I = 1.37a, which is very close to the calculated 124V.

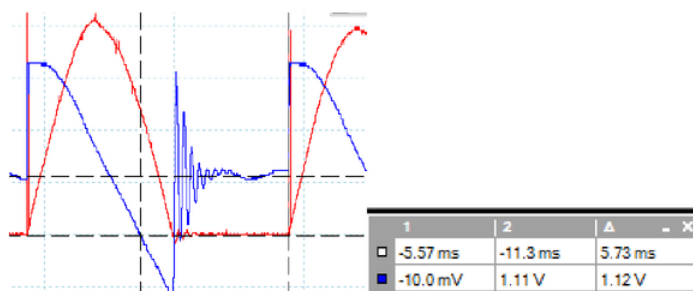


Figure 27- 0.6Nm alpha

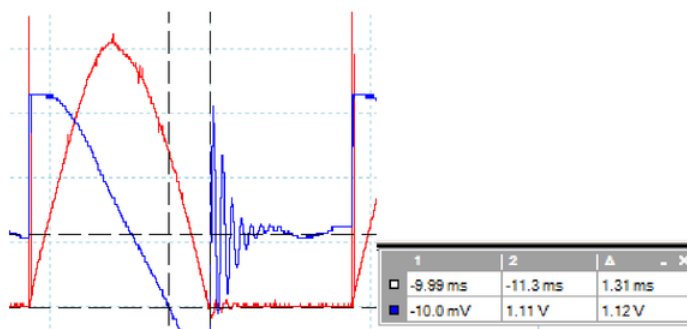


Figure 28- 0.6Nm beta

The next sets of tests to be carried out are: No load reversed, regenerative braking and example of the DC machine operating in all 4 quadrants on one graph. No load reversed waveform is shown in Figure 29, as no calculations were asked to be done on this test, its relationship to theory will be discussed instead. As discussed in research, it's clear to see that the machine is motoring: Due to the current and voltage being negative. This is the third quadrant which is motoring in the opposite direction to the first quadrant.

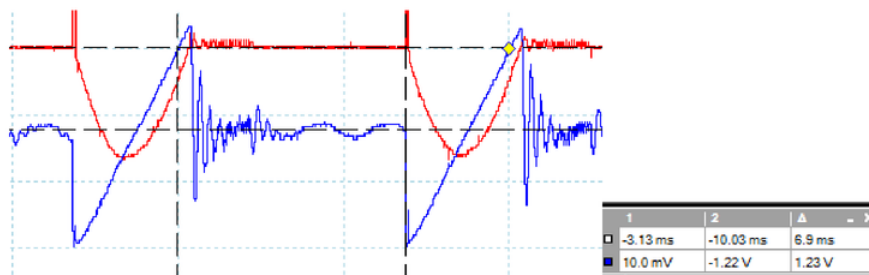


Figure 29- no load reversed

The next effect to be discussed is regenerative braking: The current being the opposite polarity to the voltage means that the current is flowing in the other direction. This means the load is being driven faster than the magnetic field, causing a braking effect, and generating current. The DC drive recovers this current, hence the term regenerative braking.



The speed and average current is plotted whilst the motor is taken through each of the 4 quadrants. Although the graph that was researched was torque against speed, torque is a product of armature current so similar relationships can be drawn.

The motor operating in quadrant 1 is shown in Figure 30. The speed is positive, and the current is positive. The spike in current at the start is the starting torque of the motor, which is higher because the inertia of the motor at standstill.

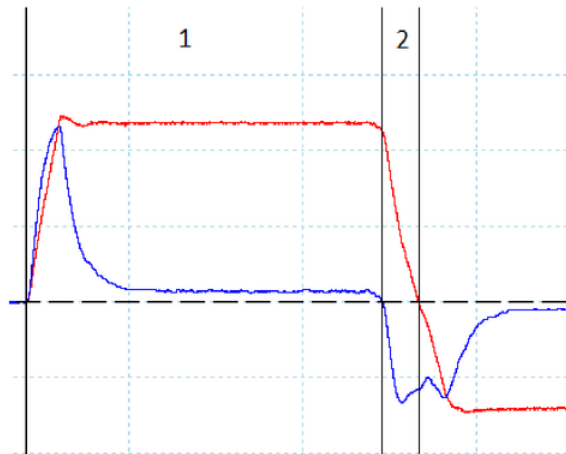


Figure 30- Quadrant 1 and 2

The second quadrant of operation is shown in Figure 30. The speed is still positive, but declining very quickly. This is because the direction of the motor has been swapped, indicated by the negative spike in current. This has a braking effect until the speed becomes negative, the motor then enters the third quadrant of operation. The third quadrant of operation is effectively the motor turning in the opposite direction to the first quadrant, shown in Figure 31. The motor enters the fourth quadrant when the direction of the motor is swapped again. The braking effect occurs again until the current and speed are positive, at which time the motor returns to the first quadrant.

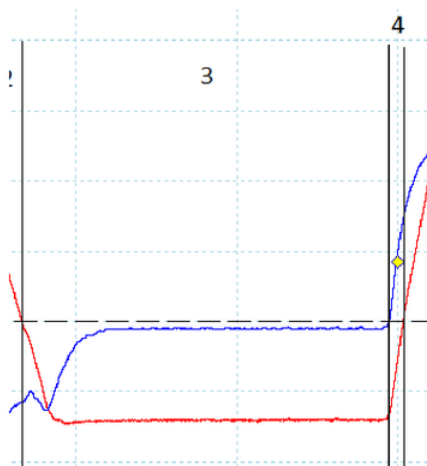


Figure 31 - Quadrants 3 and 4

The DC drive current control loop was now investigated. The current is controlled with a PI controller,  $K_i$  and  $K_p$  were set to minimum as a starting point. See Figure 32 for the current waveform. With minimum  $K_i$  and  $K_p$  settings, there is a small amount of overshoot, negligible oscillations and takes 1.25s to reach a steady state.

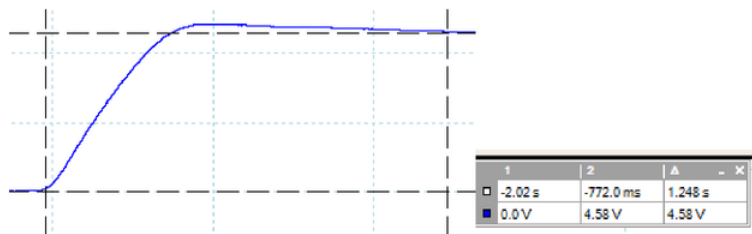


Figure 32- min  $k_i$  and  $k_p$

$K_p$  was set to a maximum value and  $K_i$  was left at its minimum, results show in Figure 33. Changing  $K_p$  to its maximum value introduced some oscillations but achieved steady state much faster, in 633ms.

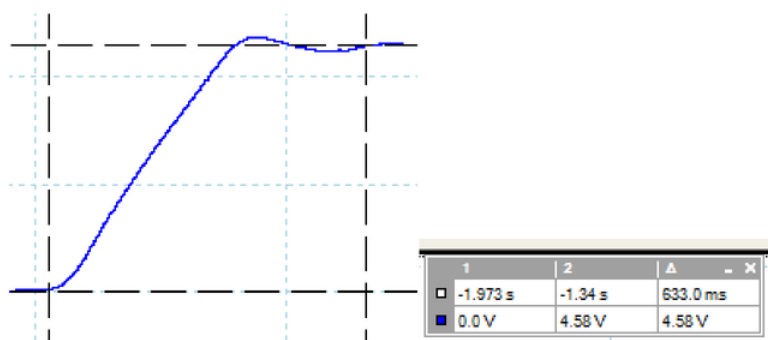


Figure 33-  $K_p$  max  $K_i$  min

Kp was set to its minimum value and Ki was set to its max, shown in Figure 34. Lots of overshoot and oscillations were introduced, as well as raising the steady state time to 3.69s.

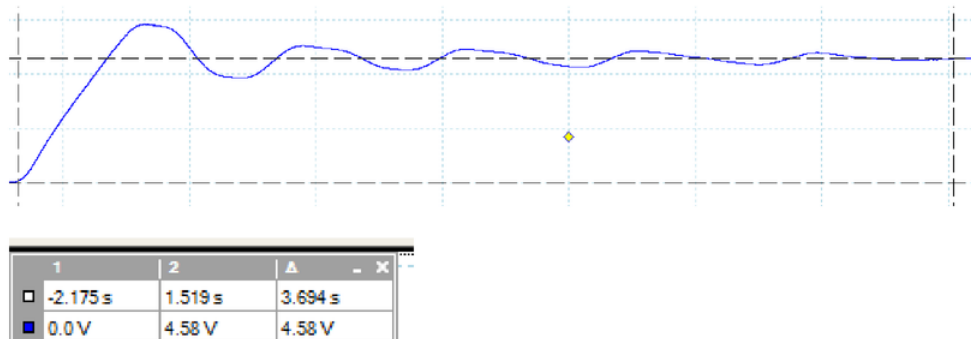


Figure 34- Ki max Kp min

Both Ki and Kp were set to their maximum values, shown in Figure 35. Reasonable amount of oscillation occurred and reached steady state in 1.08s.

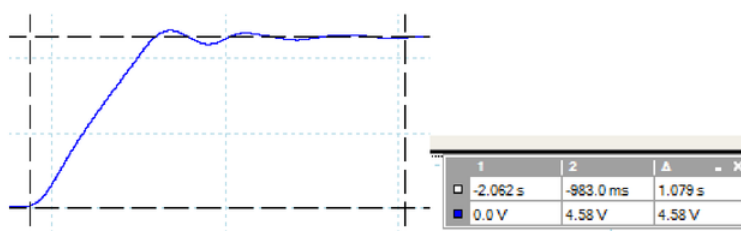


Figure 35- Ki max Kp max

Ki and Kp were then set to mid values, shown in Figure 36. Overshoot and oscillations are negligible and achieved steady state in 732ms. The results are similar to the Ki min Kp max tests, but the difference is only 100ms.

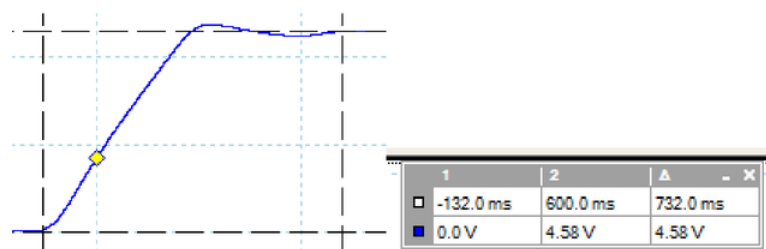


Figure 36- Ki mid Kp mid

#### 4. Conclusion and recommendation

Although summaries have been provided throughout each section, the general conclusion for this assignment is the mathematical equations match up with real world results as well as the simulation. Specifically, the researched performed on single phase rectifying circuits related to the operation of the real world industrial controller. The values matched up, exactly in some cases, with small differences caused by taking manual readings or rounding errors. All researched that was carried out allowed the functional operation of the DC controller to be deduced; The use of dual bridge firing circuits, only allowed armature control on the 514 controllers and the understanding of how the controller operates in all 4 quadrants.

The simulation results for single phase matched up with the practical and the calculation that were researched. The three-phase simulation confirmed that the research was correct. As a practical experiment on three-phase drives wasn't carried out, this cannot be commented on.

The practical experiment shown how the 4-quadrant torque/speed graph applies to a real-world motor and controller. The research into various methods of controlling a DC motor shows how DC motors can be controlled in different ways, depending on the application. Even allowing the motor to be operated below or past its rated values in some cases.

Tuning the current control loop inside the 514 controller shows how the performance of the system can be optimised even further by tweaking the current parameters. Some settings would have introduced unwanted behaviours, such as oscillations and taking almost 4 seconds in some cases for the current to settle to its setpoint value.

The authors role within the team during the practical was taking Pico Scope screenshots during the experiment, annotating them in a word document, and recording the load that was being applied at each stage.

## 5. Citation List

Coleg Sir Gar, n.d. *Course notes*. s.l.:s.n.

Krishnan, R., 2001. *Electric Motor drives*. 1st ed. Blackburg: Prentice Hall.

Lander, C. W., 1993. *Power Electronics*. 3rd ed. Leicester: McGraw-Hill.

Mohan, U. R., 2003. *Power electronics*. 3rd ed. s.l.:Wiley.

Pantech Solutions, 2017. *Introduction of Three Phase Half/Full Wave Converter*. [Online]  
Available at: <https://www.pantechsolutions.net/powerelectronics-tutorials/introduction-of-three-phase-half-full-wave-converter>  
[Accessed 10 1 2018].

Parker, 2007. *514C DC controller technical manual*. [Online]  
Available at: <http://www.parker.com/literature/SSD%20Drives/DC%20Drives/HA463296.pdf>  
[Accessed 8 1 2018].

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Available at:  
[https://www.epnormand.co.za/images/parker\\_dc\\_drives/parker\\_514c\\_dc\\_drive/parker\\_514c\\_dc\\_drive.pdf](https://www.epnormand.co.za/images/parker_dc_drives/parker_514c_dc_drive/parker_514c_dc_drive.pdf)  
[Accessed 5 1 2018].

Wildi, T., n.d. Electronic control of direct-current motors. In: 6th, ed. *Electrical machines, drives and power systems*. s.l.:Pearson, p. 564.

## 6. Appendices

There are no appendices for this assignment.

# Ass 1 final

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## GRADEMARK REPORT

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FINAL GRADE

GENERAL COMMENTS

**Instructor**

75/100

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PAGE 2

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PAGE 3

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**Text Comment.** This is not a published source but a hand drawing, no citation needed.

PAGE 6

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PAGE 7

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Spelling error

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#### ***Additional Comment***

any more to say or should this word be deleted?

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### **Improper Citation**

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**Text Comment.** good observation

**Text Comment.** you could have looked into the control loops for current, voltage and speed from the datasheet

**Text Comment.** very good, shows the result on the voltmeter

**Text Comment.** These images should not be cropped as all the oscilloscope data cannot be seen and therefore results cannot be verified.

**Text Comment.** These images should not be cropped as the oscilloscope data cannot be seen, what you have shown to the right could easily have been taken from elsewhere.

**Text Comment.** These images should not be cropped as all the oscilloscope data cannot be seen.

PAGE 21

**Text Comment.** These images should not be cropped as all the oscilloscope data cannot be seen.

PAGE 22

PAGE 23

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PAGE 25

**Text Comment.** photographic evidence needed for multimeter results

PAGE 26

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PAGE 34

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PAGE 36

GRADING FORM: CSG-RUBIC

MICHAEL LEWIS

75

## RESEARCH-INFORMED LITERATURE

 Section 1: Your research - Very good evidence of background reading covering most aspects of the required research. (23/30) Section 5: Your use of Harvard for citing and listing – Good range of source listed correctly but not always cited correctly (use of page numbers is needed for a direct quote.) (3/5)

**26**

## KNOWLEDGE AND UNDERSTANDING

 Section 2: Explanation of simulation - very good explanations given. (5/5) Section 3: Explanation of practical experiment – Very good explanation given. (4/5)

**9**

## ANALYSIS

 Section 2: Analysis of results from simulation - Excellent analysis but you could have considered more reasons for the differences in the results when compared with theory. (8/10) Section 3: Analysis of results from practical experiment – Good waveforms with analysis done but voltmeter images are missing. You could also have summarised results in a table. (7/10) Section 4: Overall conclusions and recommendations – Overall conclusions have been made but no recommendations. You could have said more about what exactly you have learnt about the circuits and the drive. (6/10)

**21**

## PRACTICAL APPLICATION AND DEP.



Section 2: Simulation - Excellent work but I would advise you not to crop images as important evidence is lost. (4/5) Section 3: Practical experiment - Very good practical application but voltmeter readings should have been photographed. (4/5)

**8**

#### **SKILLS FOR PROFESSIONAL PRAC.**



All sections - Well structured, presented and written. (8/10) Section 4: Team role - Briefly and succinctly explained. (3/5)

**11**