

Assignment 2

by Liesel Williams

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Power and Machines

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Assignment 2

Investigation into AC Motor Drives

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1. Introduction

The aim of the report is to investigate AC motor drives and their control involving high frequency techniques.

Research into three-phase PWM inverters (DC to AC conversion) and three-phase cyclo-converters (AC to AC conversion) was carried out, further developed for configuration and control techniques used in commercial AC drives and design methods applied for improved stability when controlling a AC motor.

A commercial AC drive, the Allen Bradley Powerflex 40 its control functions and circuitry were included in the theoretical and practical tasks. Included in the report is waveform analysis of the input voltage, comparison with simulated and measured waveforms and critical analysis of the results with respect to theory providing conclusions on the performance of the system.

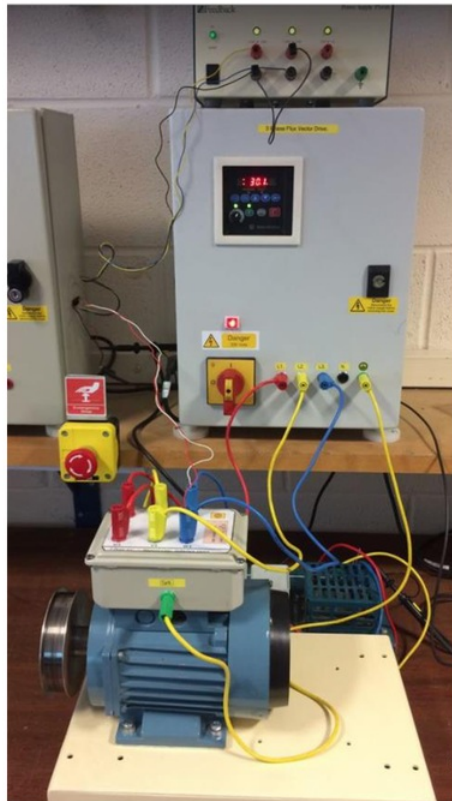


Figure 1 - Practical test apparatus

2. Research and Theory

Induction motor speed control can be achieved either from the stator side or from the rotor side; the later only applies to slip ring motors.

From the former, two methods exist, they are stator voltage control i.e. phase controller and stator frequency control i.e. inverter or cycloconverter.

Speed control by changing the applied voltage

The SCRs firing delay will adjust the RMS voltage to the stator (also called slip speed control)

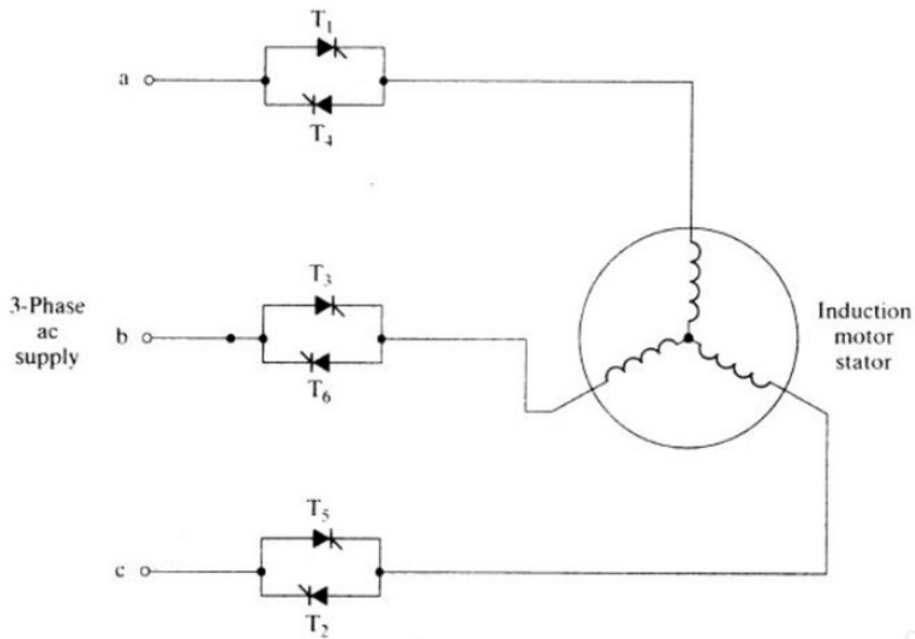


Figure 2 - Phase controlled induction motor drive (Krishnan p263)

Below is the torque equation of the induction motor including stator impedance:-

$$T_G = \frac{3 V_1^2 R_2'}{\omega_s s \left[\left(R_1 + \frac{R_2'}{s} \right)^2 + (X_1 + X_2')^2 \right]}$$

Rotor resistance is constant and in the linear region ($-0.1 < s < 0.1$) s is small, f is small X can be ignored $(sX_2')^2$ is small enough to be neglected.

$$T_G = \frac{3 V_1^2}{\omega_s R_2'} s$$

$$|I_2'| = \frac{V_1}{R_2'} s$$

Both are proportional to s

Thus $T \propto s V^2$ and so decreasing the supplied voltage will decrease the torque, which means for a constant load torque the slip increases with decreasing voltage therefore reducing the speed.

There are however disadvantages:

Efficiency is affected when high values of slip exist. According to (Krishnan 2001) "as the maximum efficiency is $(1-s)$, efficiency is poor at low speeds with slip controlled drive systems".

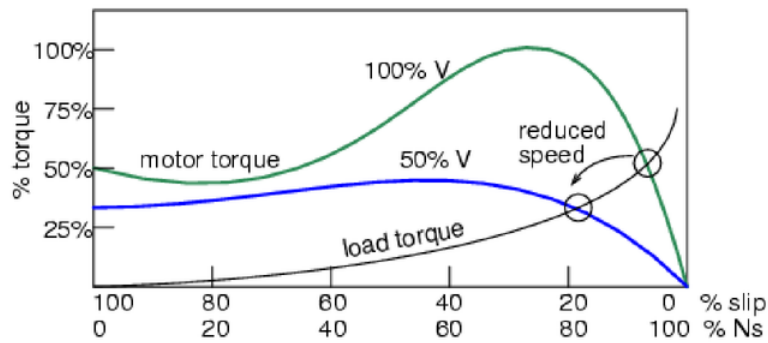


Figure 3 - Variable voltage controls induction motor speed

For a small speed change, large supply voltage change is needed.

The large change in supply voltage will cause disturbances in the magnetic conditions.

This method however, is used in soft starts, the voltage ramping starts with a long firing delay and reduces to zero. It is also relatively cheap.

Speed control by changing the applied frequency

Synchronous speed is given by the equation $N_s = 120f/p$

And the slip, $s = (n_s - n_r) / n_s$

Reducing the frequency makes the synchronous speed reduce and keeps s constant for maximum efficiency.

However, decreasing the current frequency to the motor means the reactance decreases and thus the stator current increases leading to magnetic saturation in the stator, conversely when frequency increases, increasing reactance must be overcome by more voltage which will maintain current and torque.

For an optimum air-gap flux, which prevents saturation, the voltage to frequency ratio, must be maintained because

$$\Phi = \frac{V_s}{f_s}$$

(Krishnan 2001 p324)

This makes control a more complex process than say for DC drives.

The two main methods in frequency control are:

Inverter - variable frequency achieved by chopping DC (see section 2.1)

Cycloconverter – a direct frequency changer, no DC stage needed (see section 2.2)

2.1 Three-phase PWM inverters

The rectifier stage can be controlled (thyristors) or uncontrolled (diodes). The DC link includes a shunt capacitor for constant voltage to the inverter (voltage source inverter VSI) or a series inductor for constant current to the inverter (current source inverter CSI) (Kumar 2018)

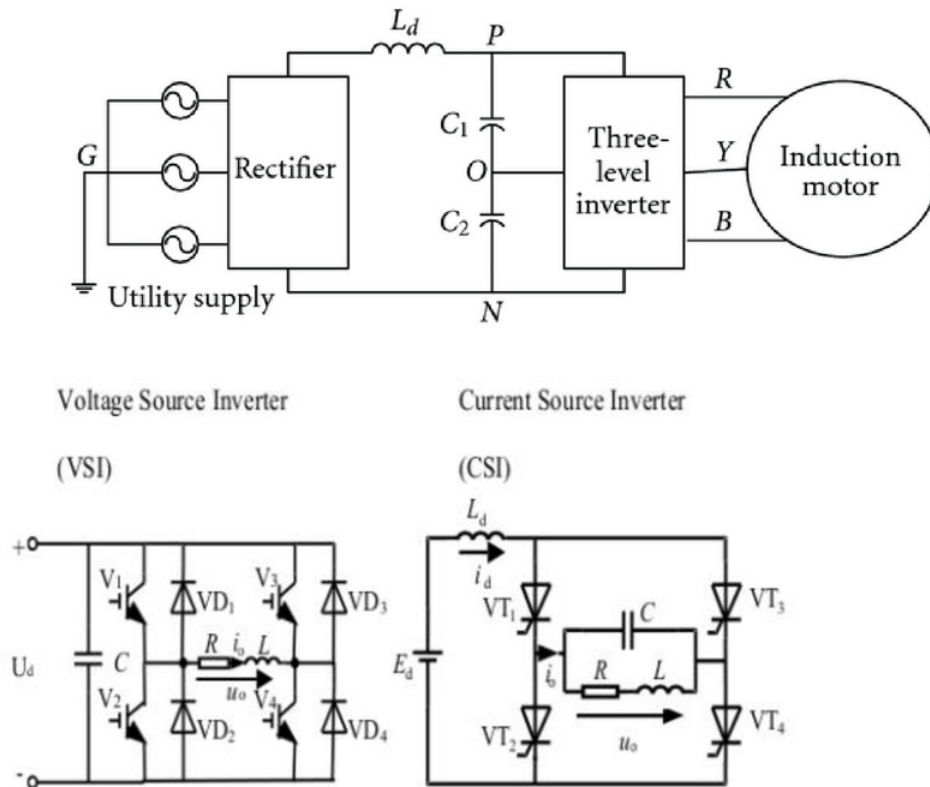


Figure 4 -Inverter types

Inversion uses two methods

Quasi-Square Wave – uses a variable voltage DC source for fixed V/f ratio

PWM – voltage varies naturally with frequency, constant voltage source with uncontrolled rectifier

As in the single phase VSI example above the load receives positive and negative voltage through switching V1, V4 or V3, V2 respectively, other devices other than bipolar transistors can be used. Below is a comparison table showing switching speeds and power ratings of typical devices that could be used.

Device	Max O/P Frequency (Hz)	Power Rating
SCR	100	High
GTO	2k	Medium
BJT	10k	Medium
IGBT	20k	Medium
MOSFET	50k	Low

By adding two more sets of switching devices and diodes three-phase output is achieved to a star connected load as shown below.

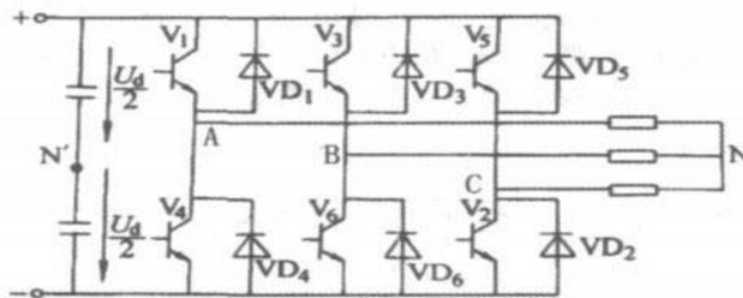


Figure 5 - Voltage type three-phase full-bridge inverter

Due to the high frequency switching there will be harmonic distortion which is reflected back to the supply causing potential damage. This method is best suited to transistors as there are high commutation losses that occur with thyristors.

Due to the inductive nature of induction motor loads the high frequency harmonics get attenuated and for PWM inverters the result is currents which are nearly sinusoidal when the voltages are not.

Using Fourier analysis the spectrum of the switching methods can be analysed to obtain information on harmonic currents affecting motor torque (this will be seen in the practical investigation).

For simplicity, an analysis on a quasi-square wave inverter where the transistors are ideal switches and the source is a variable voltage battery helps in developing the waveform analysis used later.

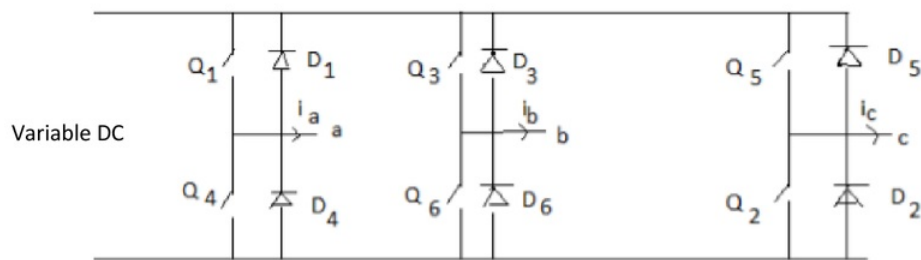


Figure 6 - Simplified inverter quasi square

When Q1 and Q6 are closed V_d appears at V_{ab} . Line voltages are the difference between phase voltages which are relative to star point.

e.g. $V_{ab} = V_a - V_b$

$V_{bc} = V_b - V_c$

$V_{ca} = V_c - V_a$

So $V_{ab} - V_{ca} = 2V_a - (V_b + V_c)$ and when balanced $V_a + V_b + V_c = 0$

$V_b + V_c = -V_a$ by substitution $V_{ab} - V_{ca} = 2V_a - (-V_a) = 3V_a$ so **$V_a = (V_{ab} - V_{ca})/3$**

This applies for all phase voltages with offsets of 120° and 240° .

The maximum voltage for each phase occurs when line voltages are equal and opposite.

i.e. $V_{ab} = V_d$ and $V_{ca} = -V_d$ so, by substitution **$V_{a(max)} = 2V_d/3$**

similarly when $V_{ab} = -V_d$ and $V_{ca} = V_d$ then **$V_{a(max)} = -2V_d/3$**

Triggering sequence for the switches is 1,2,3,4,5,6.

Output is quasi-square wave with peak of V_d

Line voltages are mutually phase shifted 120°

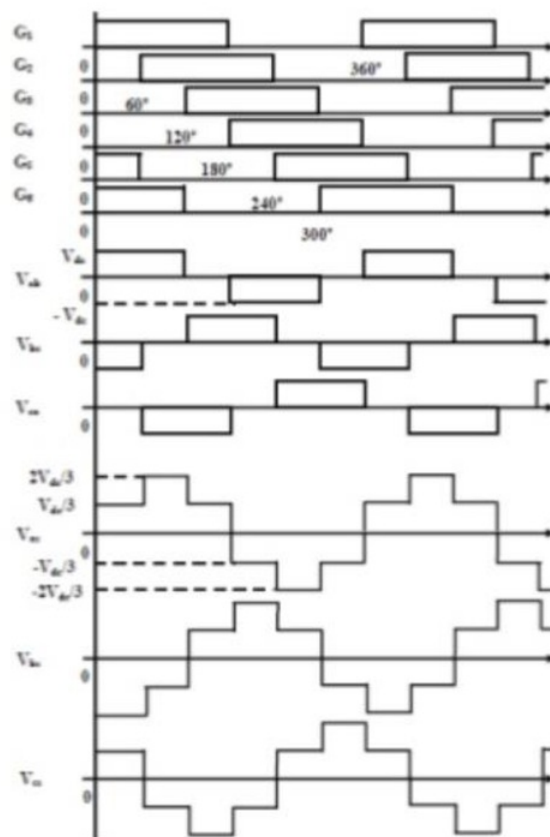


Figure 7 - Quasi square phase voltages

Phase voltages look like this six step wave above where the $1/3$ and $2/3$ values are evident.

With quasi-square wave inverter a controlled rectifier fed the dc link to vary the dc, an improvement is notching where the fundamental sinewave voltage can be varied. A further improvement is to vary the width of the output pulses i.e. PWM.

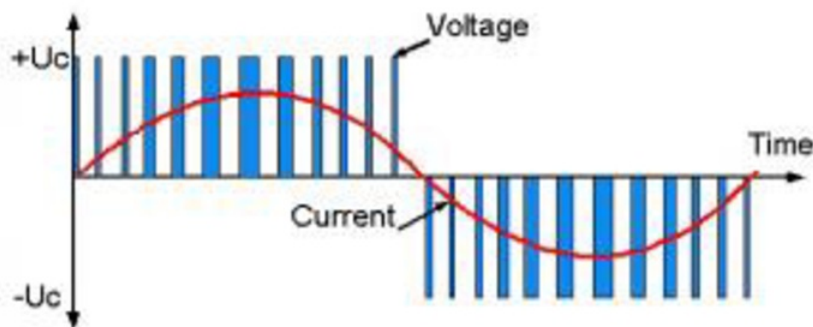


Figure 8 - PWM inverter output

The incoming VAC is rectified to DC and smoothed with capacitors at this stage and then inverted back to AC, when this pulsed output is fed to the motor due to the significant inductance the current is smoothed and resembles the fundamental sinewave with a small amount of ripple based on the switching frequency. A low frequency simplified wave is shown above. (Quantum-controls.co.uk, 2018)

Base controls signals can come from analogue techniques by the use of a comparator and a triangle wave so that when the reference is larger than the triangle wave the output goes high and vice versa, thus the width of the pulse varies with reference amplitude.

Opposite is shown the maximum output, then 50% and then minimum at half frequency. This way the V/f ratio is maintained as they are both varied, it is very flexible.

PWM-output voltage and frequency control

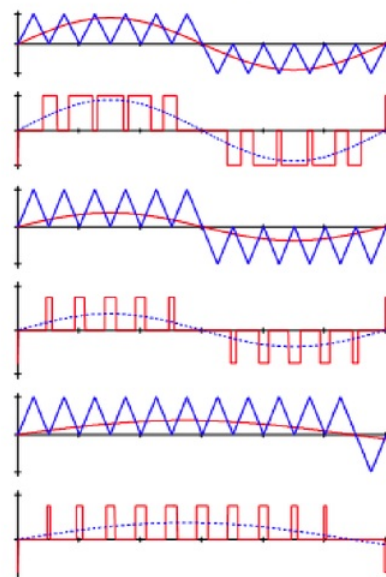


Figure 9 - PWM frequency control

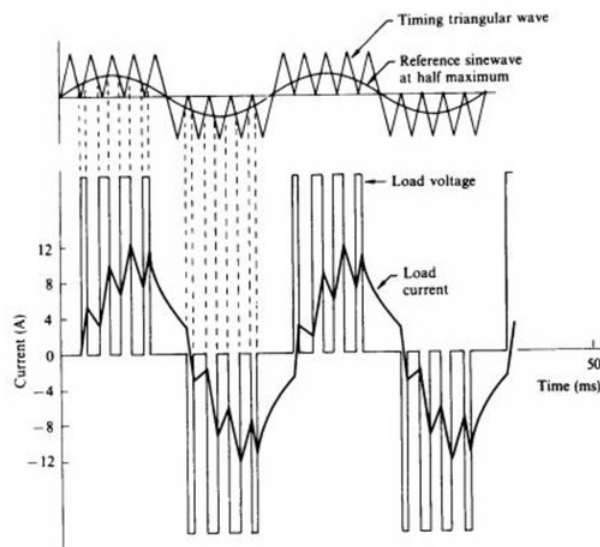


Figure 10 - PWM currents

Three-phase bridge inverter PWM waveforms.

From the reference sinewaves of each phase, the triangular wave modulation produces base or gate signals which provides the phase voltages.

The shape of the line voltage V_{ab} can be found from subtracting V_b from V_a .

Resultant waveform from PWM which contains the 2 distinct levels and a significant amount of THD.

When the voltage switches off the current decays thus forming a jagged edge wave, which rises exponentially and reverses for the negative half. Typical voltage and current waveforms for PWM inverter-fed induction motor are as shown. Peak current depends on pulse width.

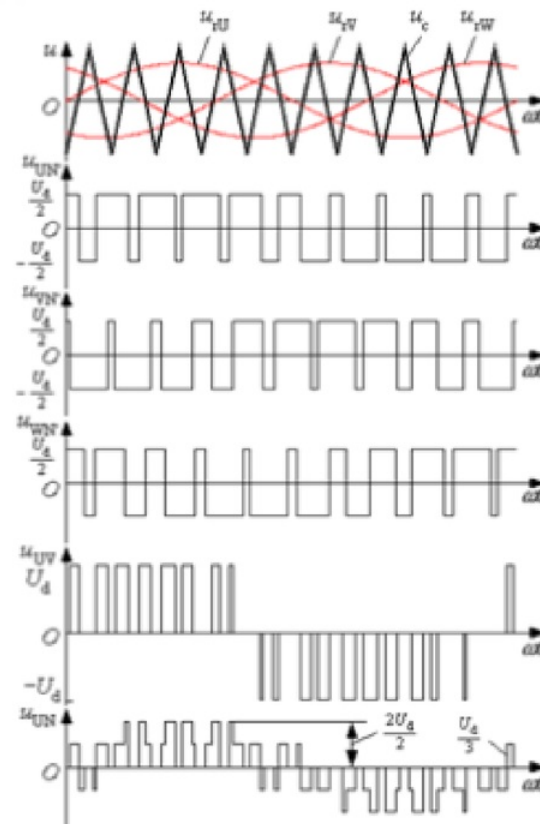


Figure 11 - PWM waveforms

There are two modulation indices for amplitude and frequency namely m_a and m_f respectively.

1. $m_a = V_{m,sin} / V_{m,tri}$ where peak of reference signal is $V_{m,sin}$ and frequency is f_{sin}
2. $m_f = f_{tri} / f_{sin}$ and peak of carrier is $V_{m,tri}$ and frequency is f_{tri}

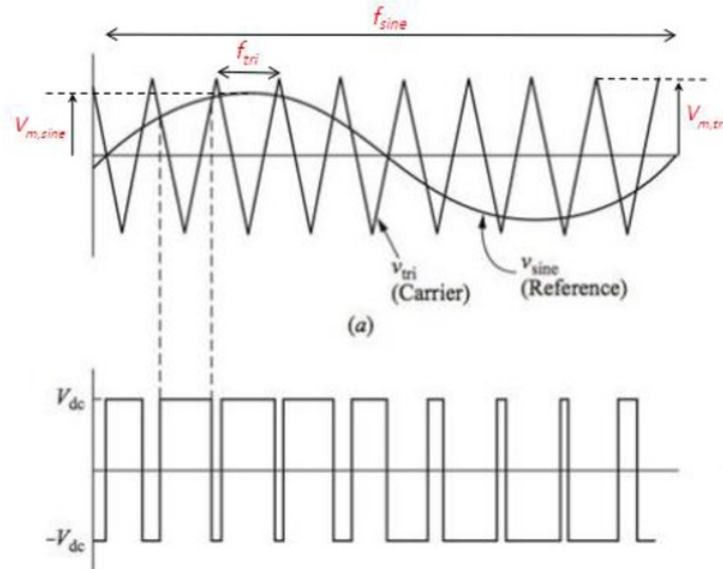


Figure 12 - modulation indices

Also fundamental amplitude output, V_1 is proportional to m_a so $V_1 = m_a V_{dc}$

Harmonics in PWM waveforms

Changing modulation index will alter fundamental amplitude and changing f_{sin} will alter output frequency. Altering m_f changes the harmonics and so if made high then the amount of low order harmonics is reduced. Thus improvement of THDV results and a higher cut off filter is used which is smaller and less complex. Caution is employed to avoid high switching losses and derating of supply. (Krishnan 2001 p.367)

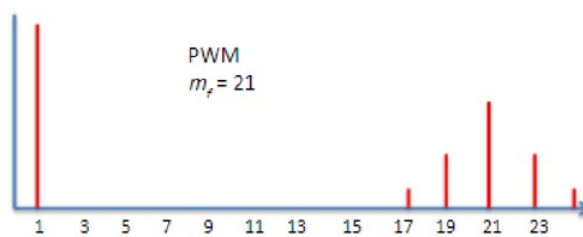


Figure 13 - PWM harmonics

2.2 Three-phase cyclo-converters

"Cycloconversion is concerned mostly with direct conversion of energy to a different frequency by synthesizing a low-frequency wave from appropriate sections of a higher-frequency source" (Lander 1993, p. 181). By taking two converters connected back to back and observing the load waveforms as shown below, there are two periods where power is flowing into the load i.e. rectification is taking place and two periods when power flows out of the load i.e. converters operate in inverting mode.

The operation is best described in principle with single phase and resistive loading. There is a positive group and negative group of bi-phase, half wave converters as shown in (a).

The graph is composed of several waveforms, for (b) output voltage for full conduction, (c) associated current flow, (d) output voltage with phase control, (e) associated current flow.

From these graphs the output voltage is at 1/5 the frequency with a poor approximation to a sine wave and significant low-harmonics. With the phase delay on the thyristors a closer sinusoidal approximation is achieved (d) thus reducing the harmonic content. (Lander 1993, p181-184)

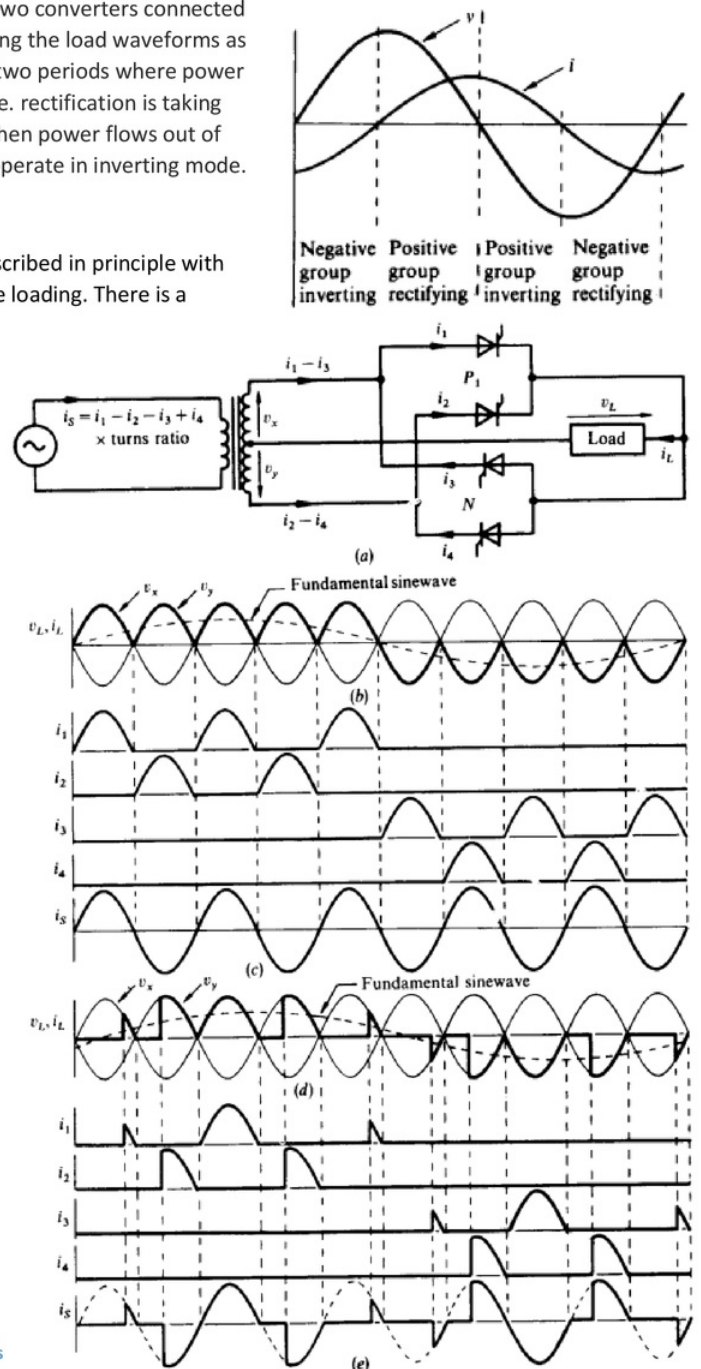


Figure 14 - Cycloconverter waveforms

Blocking mode cycloconverters use only one converter at a time i.e. positive converter for voltage at positive load current with negative converter blocked and vice versa. No intergroup reactors are needed as only one converter is working at any one time. Complexity, size and cost is reduced making them common for use in industry.

Circulating current cycloconverters have both converters working at the same time meaning the supply could be short circuited and to prevent this an intergroup reactor must be connected in between and a unidirectional circulating current exists.

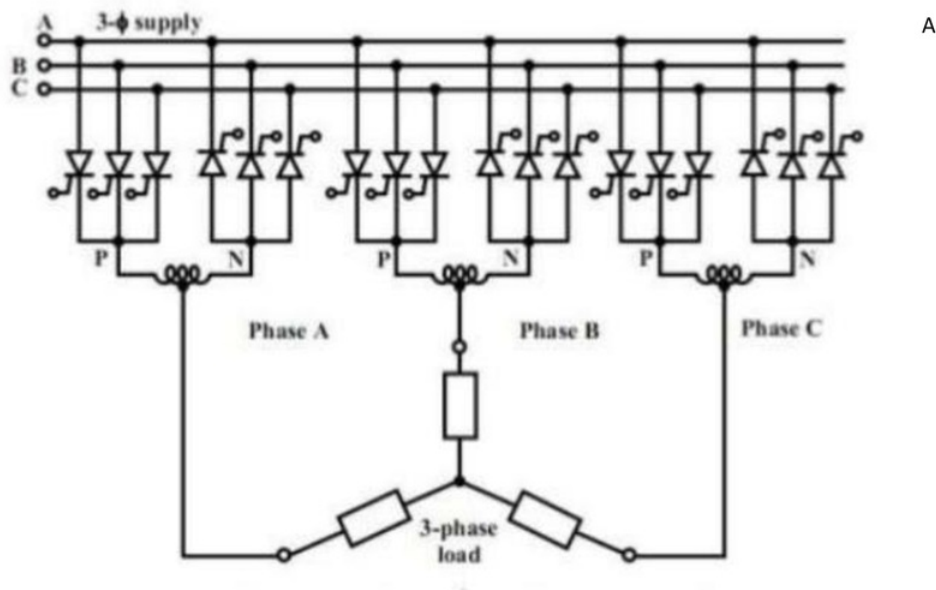


Figure 15 - Three-phase cycloconverter

three-phase to three-phase cycloconverter is formed from 3 three-phase to single cycloconverters linking to the load, this is used in AC machines, which can be connected as star or delta. The phase output is 120 degrees apart and the circuit diagram is shown above.

Hughes states "Cycloconverters are only capable of producing acceptable output waveforms at frequencies well below the main frequency, but this, coupled with the fact that large induction motors with high pole numbers are available means gearless drives become practicable" Cycloconverters are commonly used for cement drive mills, rolling mills, water pumps, mine winders etc.

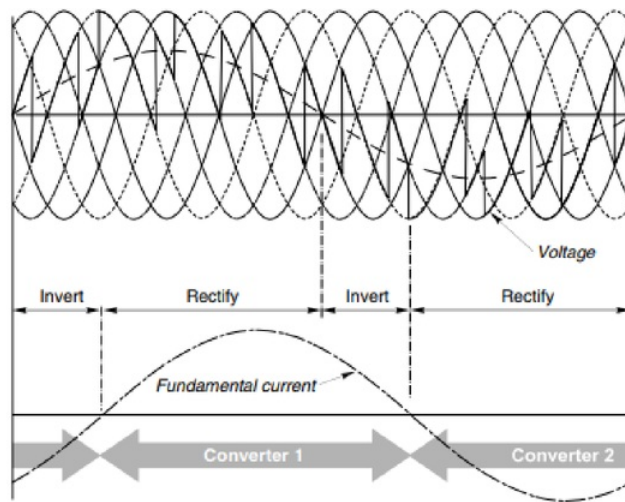


Figure 16 - Cycloconverter three-phase waveforms

In Fig 16 above the output voltage contains parts of the incoming and provides a suitable approximation of the fundamental sine wave (shown dotted). This is not any worse than that from a dc link inverter and the current will be smoothed by the inductive load. By controlling the amplitude and frequency of the reference then that of the voltage will also vary while keeping V/f ratio constant giving a constant torque characteristic. At higher frequencies too few samples are available to reproduce the sine wave and so are limited to about one third of mains frequency. (Hughes 2006)

2.3 Allen Bradley Powerflex 40

The Allen Bradley Powerflex 40 adjustable frequency AC drive is designed to control the speed of an AC induction motor.

This drive is designed for versatility and robust performance and is available in power ratings from 0.4 to 2.2kW (single phase) and 0.4 to 7.5kW (3 phase) in voltage classes of 230 and 400 volts.

The Product Manual is contained in the reference section.

The unit costs £475.00 from RS components.



Figure 17 - Powerflex 40

Figure 1.5 Control Wiring Block Diagram

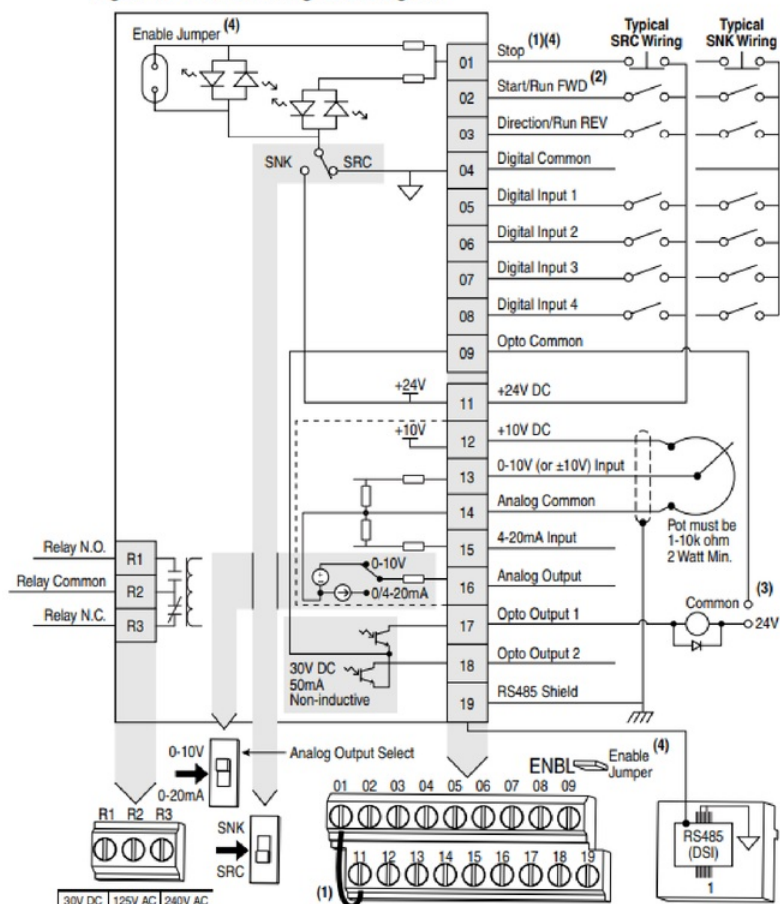
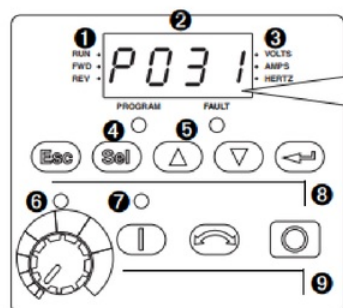


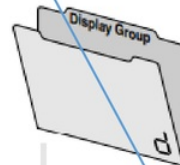
Figure 18 - Wiring Block diagram Powerflex 40

A section from the manual contains the information required to enable connection of the device.

By scrolling through the menu option d005 can be used to display the DC bus voltage (321V) which was used to determine the correct PWM waveform levels (see page 34)



Menu	Description
d	Display Group (View Only) Consists of commonly viewed drive operating conditions.
P	Basic Program Group Consists of most commonly used programmable functions.
A	Advanced Program Group Consists of remaining programmable functions.
F	Fault Designator Consists of list of codes for specific fault conditions. Displayed only when fault is present.



See page 3-3

Output Freq	d001
Commanded Freq	d002
Output Current	d003
Output Voltage	d004
DC Bus Voltage	d005
Drive Status	d006
Fault 1 Code	d007
Fault 2 Code	d008
Fault 3 Code	d009
Process Display	d010
Control Source	d012
Contrl In Status	d013
Dig In Status	d014
Comm Status	d015
Control SW Ver	d016
Drive Type	d017
Elapsed Run Time	d018
Testpoint Data	d019
Analog In 0-10V	d020
Analog In 4-20mA	d021
Output Power	d022
Output Power Fctr	d023
Drive Temp	d024
Counter Status	d025
Timer Status	d026
Stp Logic Status	d028
Torque Current	d029

Figure 19 - Program menu Powerflex 40

3. Simulation of inverter circuits

3.1. Single Phase PWM

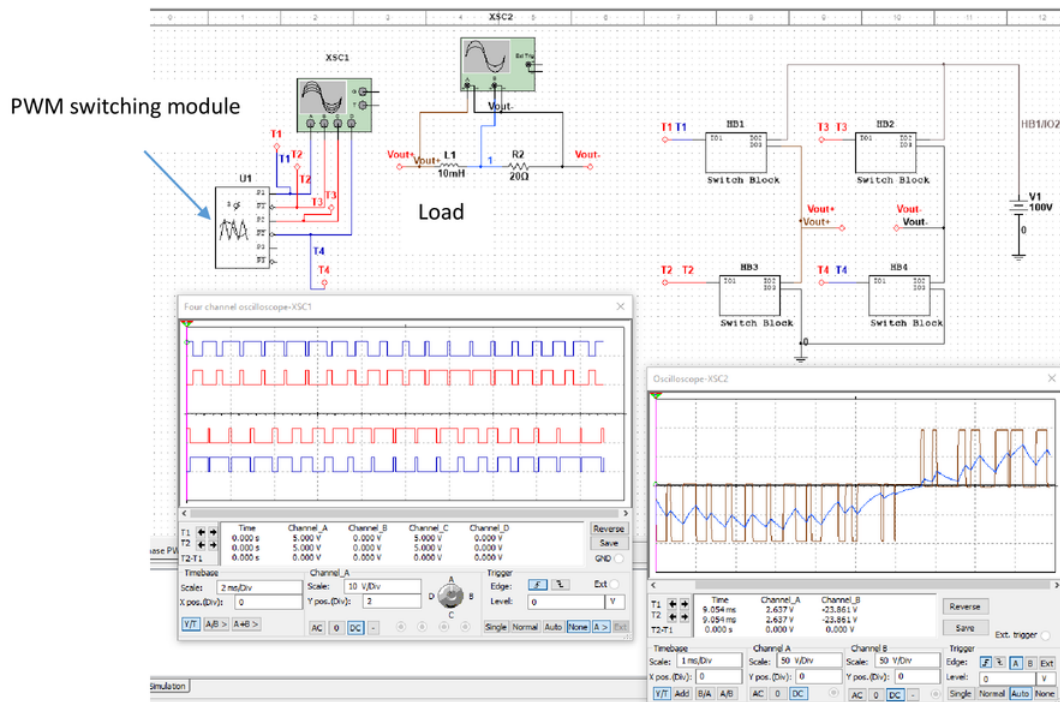


Figure 20 – Multisim Single phase PWM

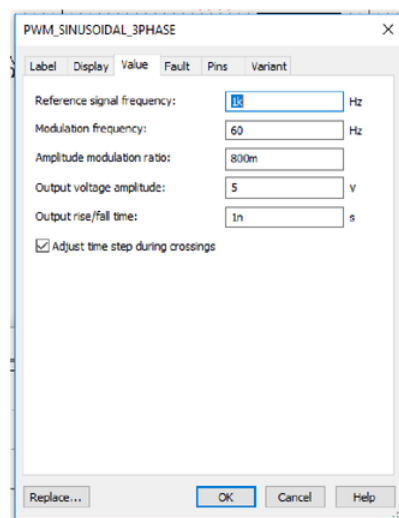


Figure 21 - PWM parameters

In this single-phase bridge inverter (VSI) the load is connected as shown. Positive and negative voltage is applied through switching T1, T4 for positive and T2, T3 for negative as in a chopper circuit. (XSC1)

XSC2 shows the load current which has the expected jagged edge shape dictated from theory.

On the PWM module four outputs are used and the signal frequency is 1kHz, modulation frequency is 60Hz, amplitude modulation ratio of 0.8 and output voltage of 5V.

Switch Block (HB1) – T1

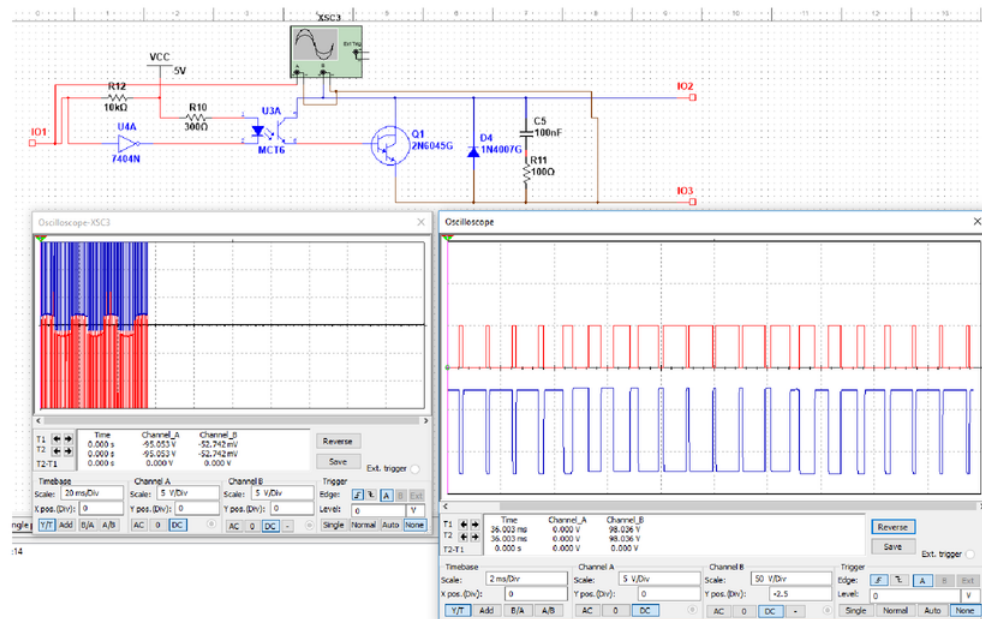


Figure 22 - Switch block

The on/off state of the switch block can be seen on the CRO waveforms.

3.2 Three-phase PWM inverter – star connected

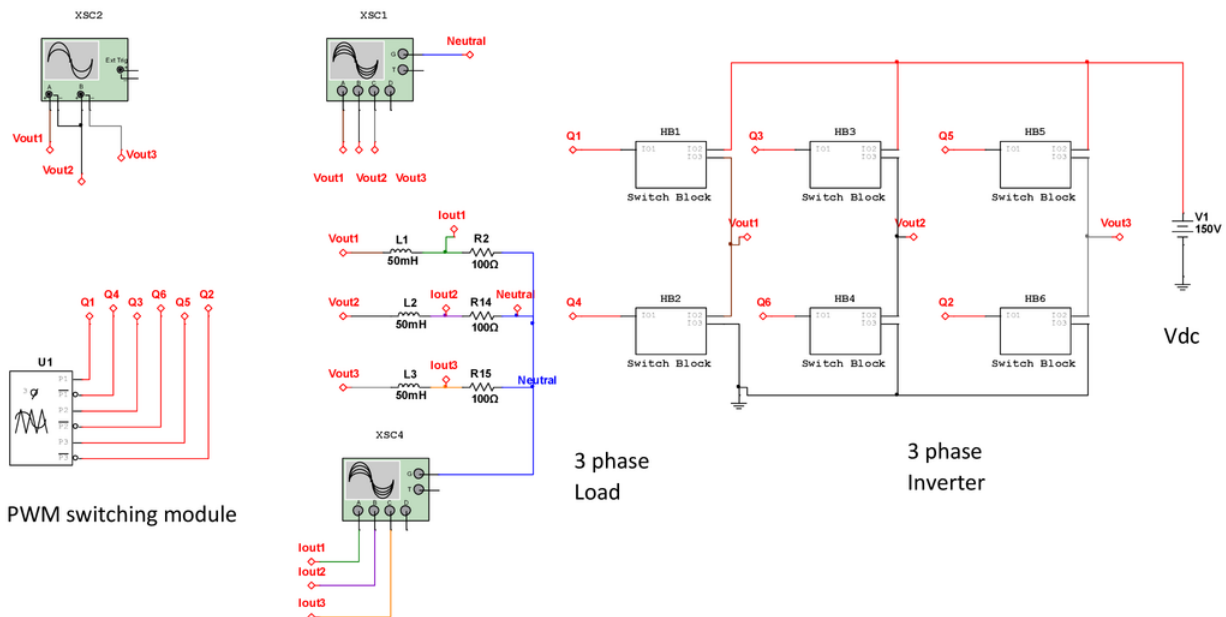


Figure 23 - Three-phase PWM inverter

This circuit is the three-phase PWM inverter connected to a star configured load of 100Ω and 50mH per phase.

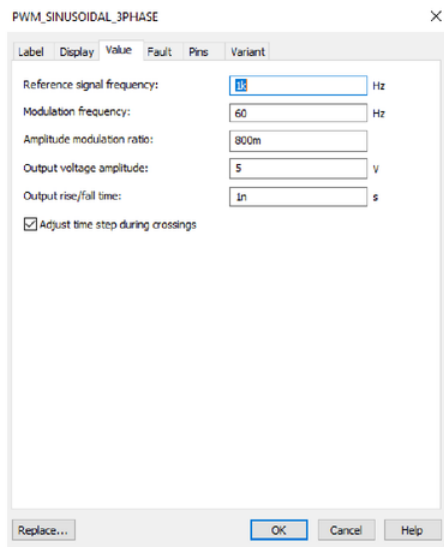


Figure 24 - PWM block parameters

The 3Phase PWM module has a reference signal of 1kHz , modulation frequency of 60Hz , amplitude modulation ratio of 0.8 and output voltage of 5V .

Six outputs are used as the triggers for Q1-6.

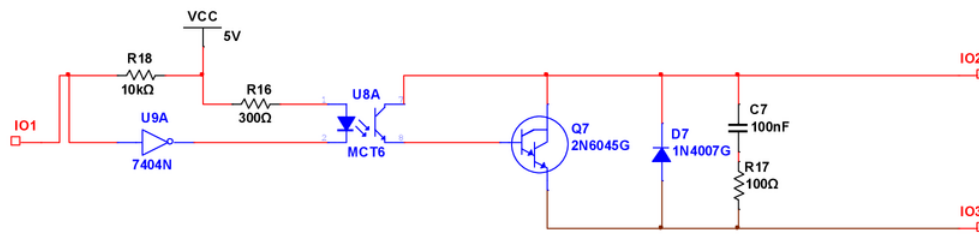


Figure 25 - Switching block

The switching block operates when current in IO1 puts 5V on the opto-isolator which puts current through the darlington pair thus connecting IO2 and IO3, CR branch is a snubber circuit, this makes the output either a closed or open switch.

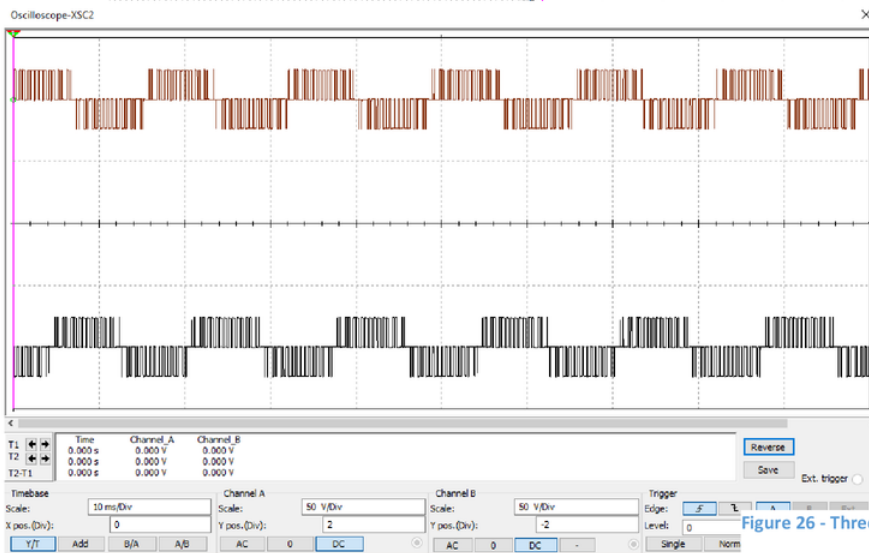
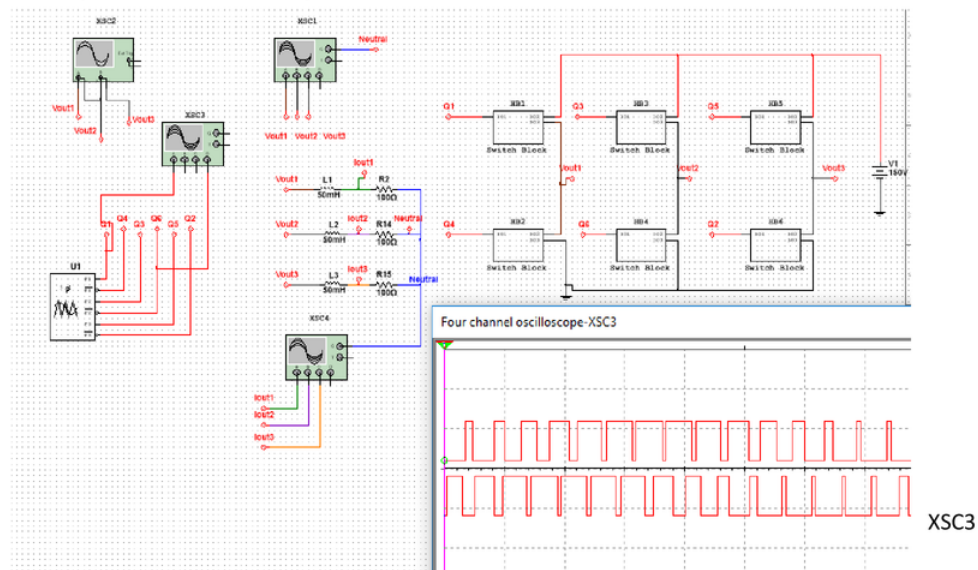


Figure 26 - Three-phase PWM Line voltages

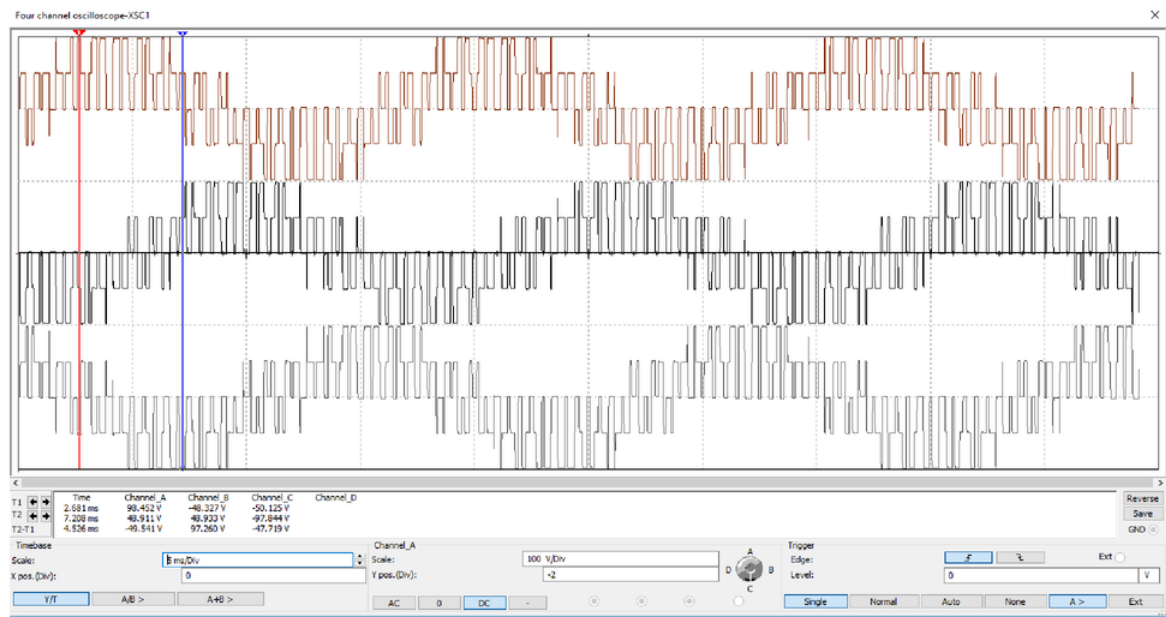


Figure 27 - Three-phase PWM phase voltages

XSC1 – shows the phase voltages above.

Enlarging the waveform overleaf shows the levels are as expected, minus transistor drops, being approximately 1/3 and 2/3 of 150V.

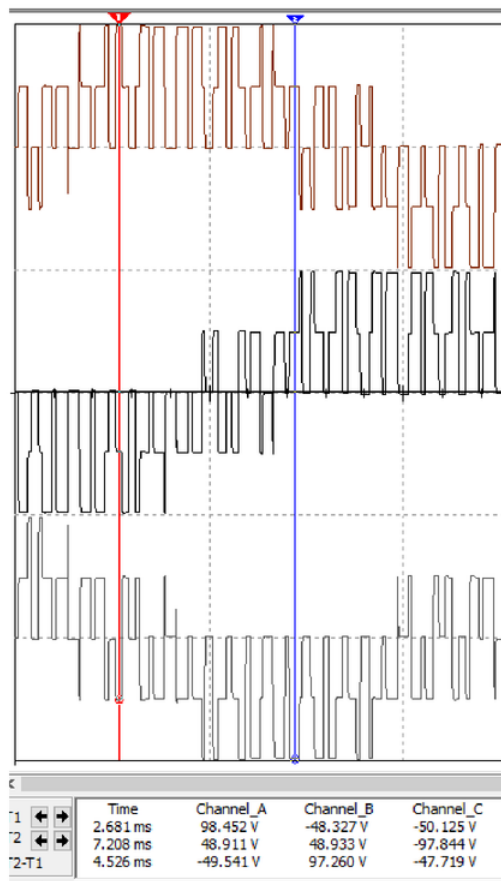


Figure 28 - Phase voltage enlarged view

Current waveforms

The shape of the current waveforms are as expected and a satisfactory approximation to a sine wave, due to the smoothing effect of the inductive load. The frequency is measured as $1/16.92\text{ms} = 58.8\text{Hz}$ (see Fig 24). This wave shape is also seen in the practical waveforms recorded.

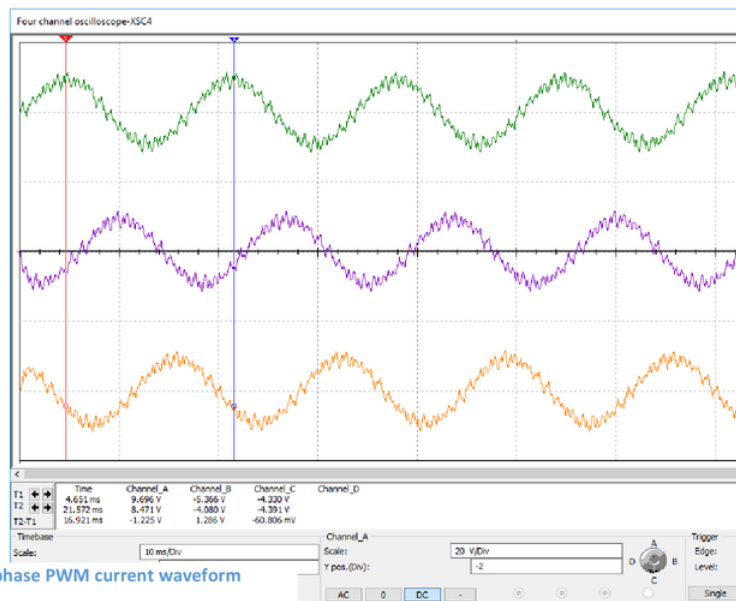


Figure 29 - Three-phase PWM current waveform

3.3.Three-phase Quasi-Square wave Inverter – star connected

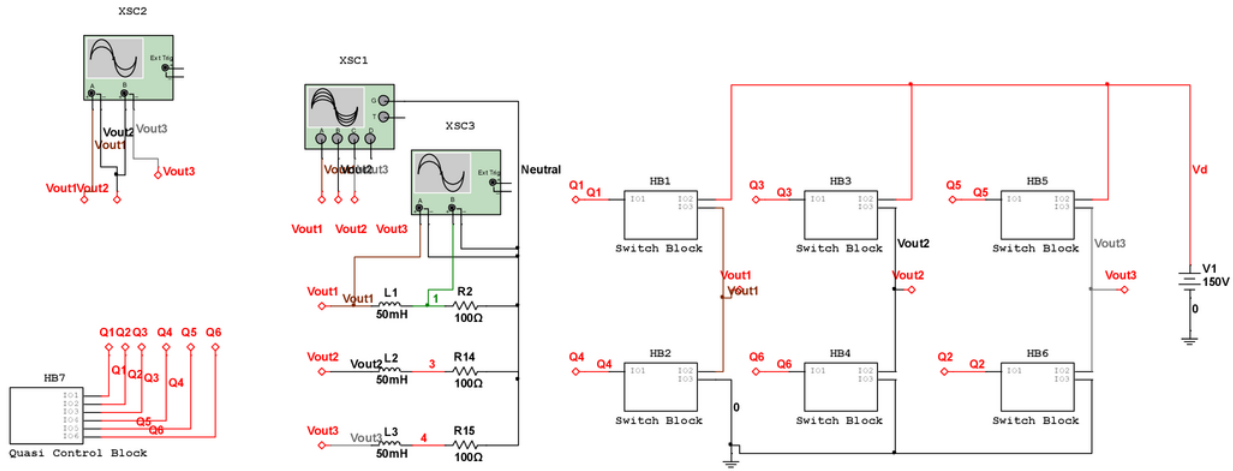


Figure 30 - Quasi-Square inverter circuit

HB7 – Quasi Control Block – shows the triggering sequence 1,2,3,4,5,6.

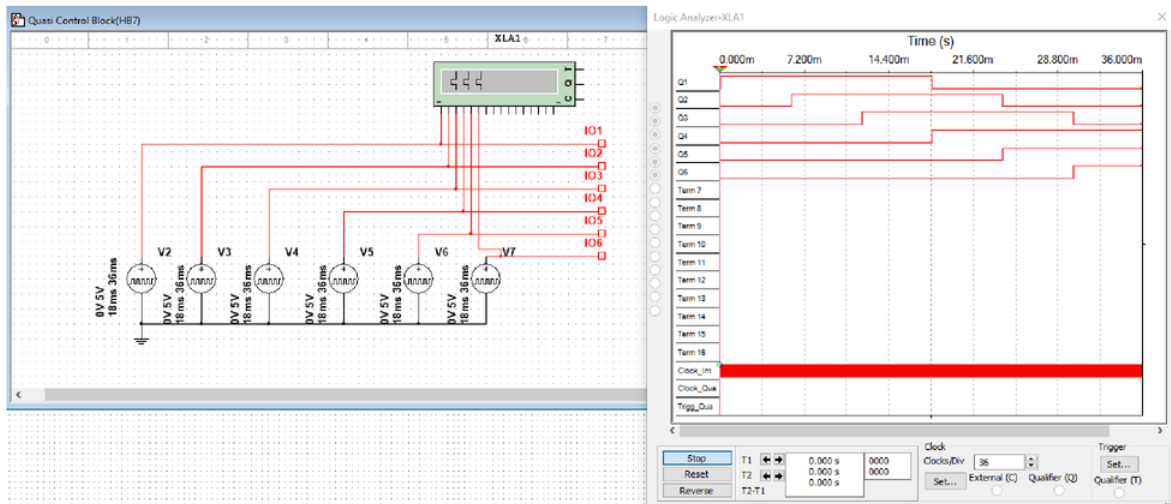


Figure 31 - Quasi control block

XSC1 – phase voltages

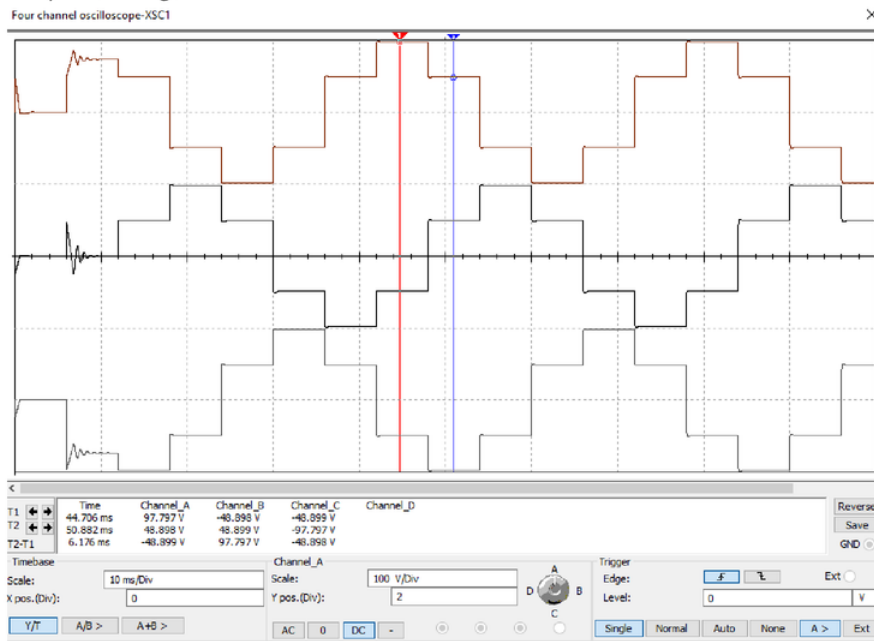


Figure 32 - Quasi phase voltages

Cursor T1 shows 97.797V and cursor T2 shows 48.898V, these are the 2/3 and 1/3 values from theory.

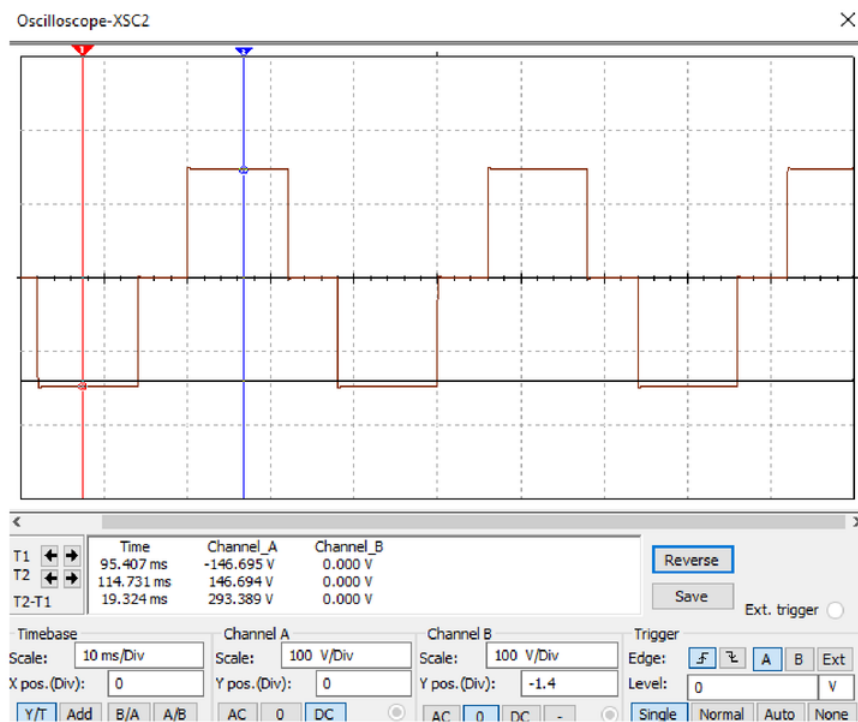


Figure 33 - Quasi line voltages

Line voltage on XSC2

XSC3 – shows the volt drop across the inductors

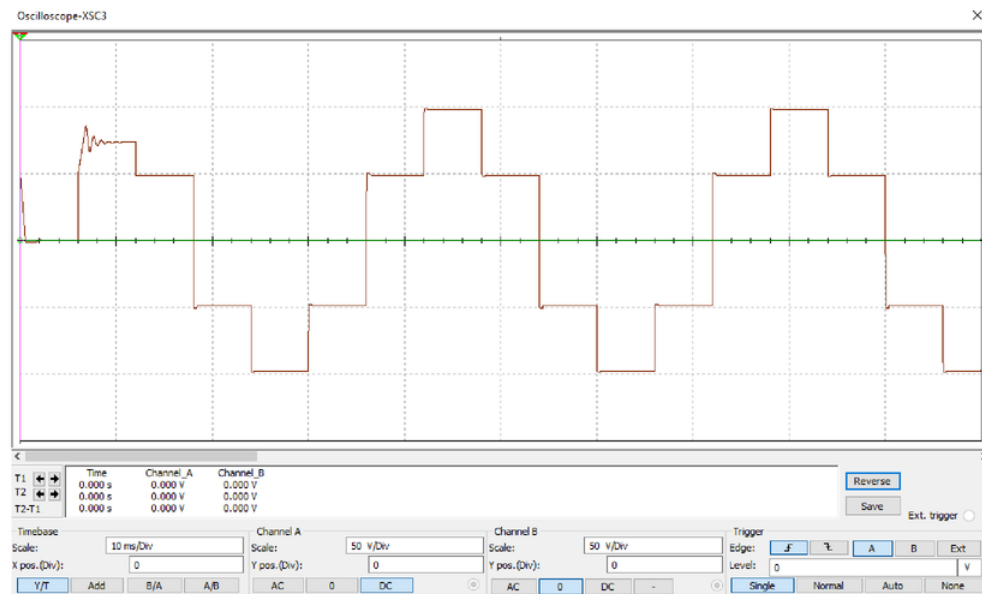


Figure 34 - Quasi inductor volt drop

By adding XSC4 shows the current waveform below demonstrating the smoothing effect.

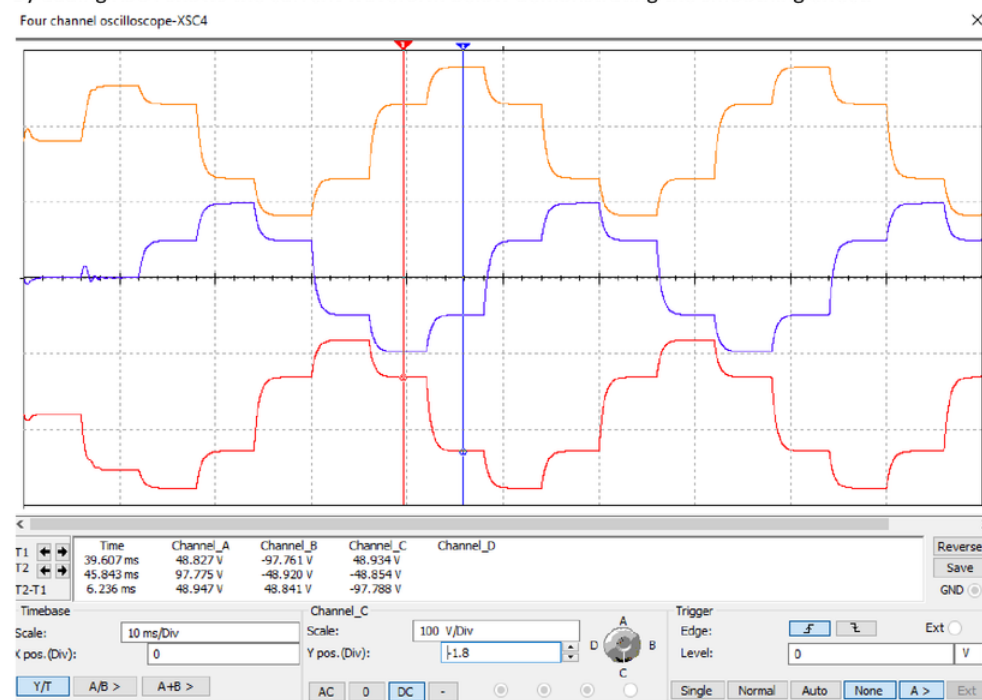


Figure 35 - Quasi current waveform

4. Practical AC Drive Investigation

In G22a, the equipment was set up as shown below.

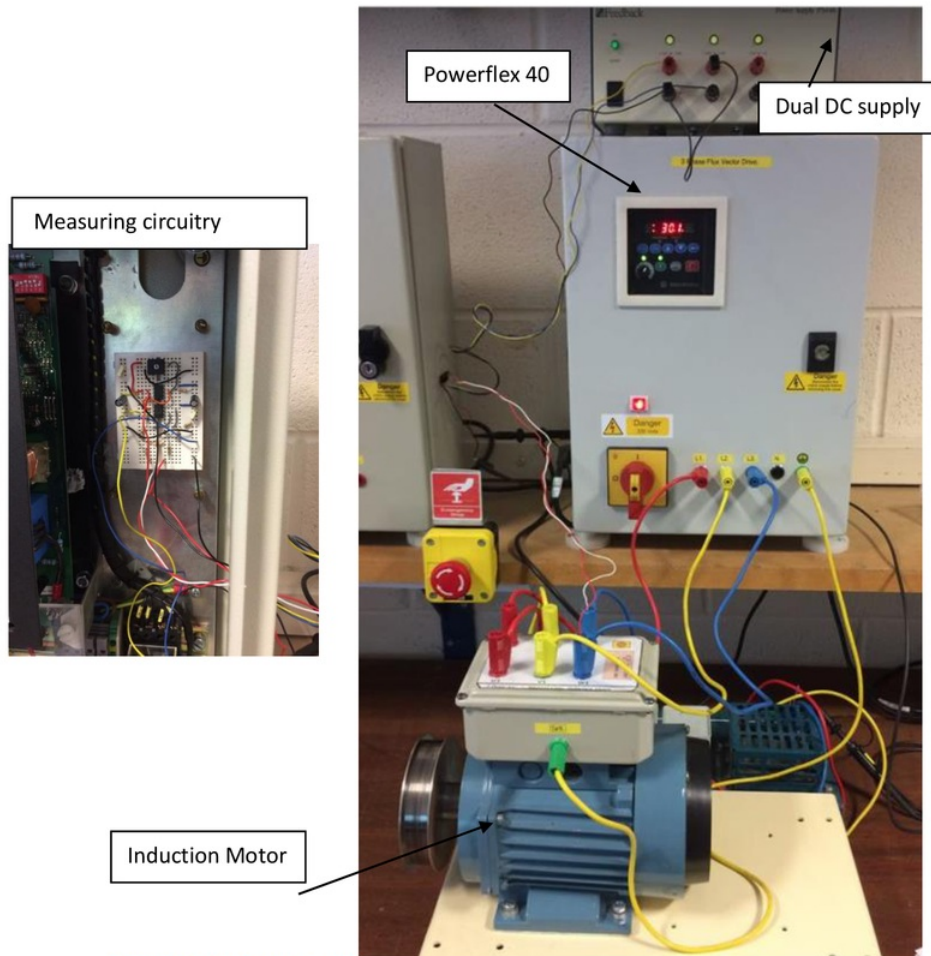
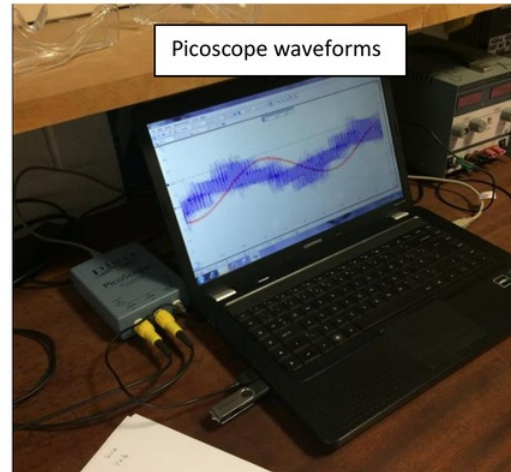
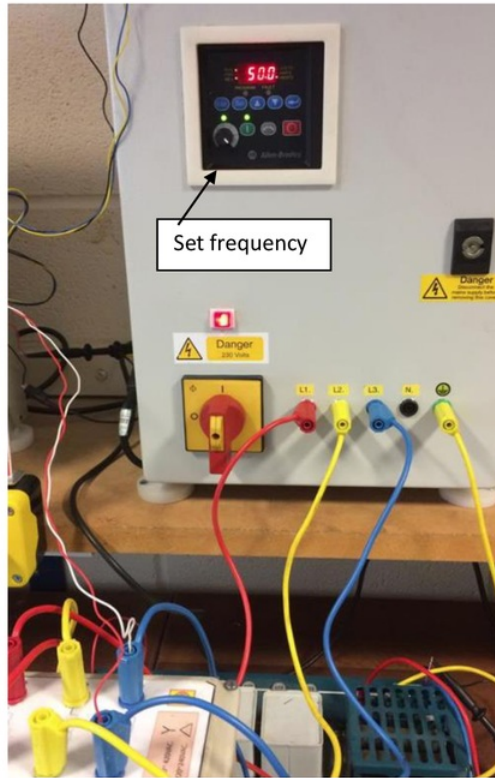


Figure 36 - Practical equipment

Inside the panel an amplifier circuit was connected to allow the picoscope readings of voltage which was divided by a factor 100 and current which was measured via 66ohm resistor giving a scaling factor of $\frac{10}{66}$.



These photographs show how the readings were taken for the analysis.

Figure 37 - Practical measurements

The first experiment undertaken was off load at three different speeds (50, 35 and 25 Hz)

No load test - speed set at 50Hz – 1498 rpm

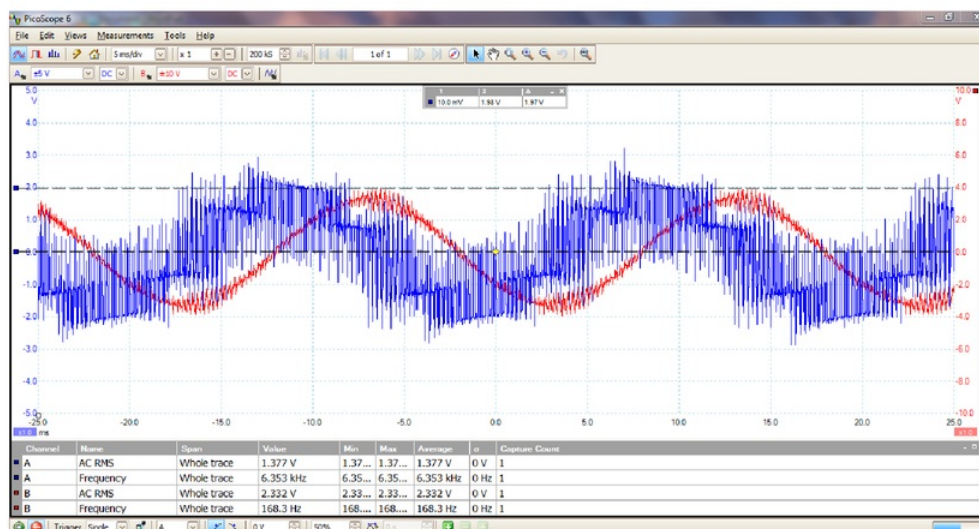


Figure 38 - No load 50Hz

No load test - speed set at 35Hz – 899 rpm (anomalous reading should be 1050rpm)

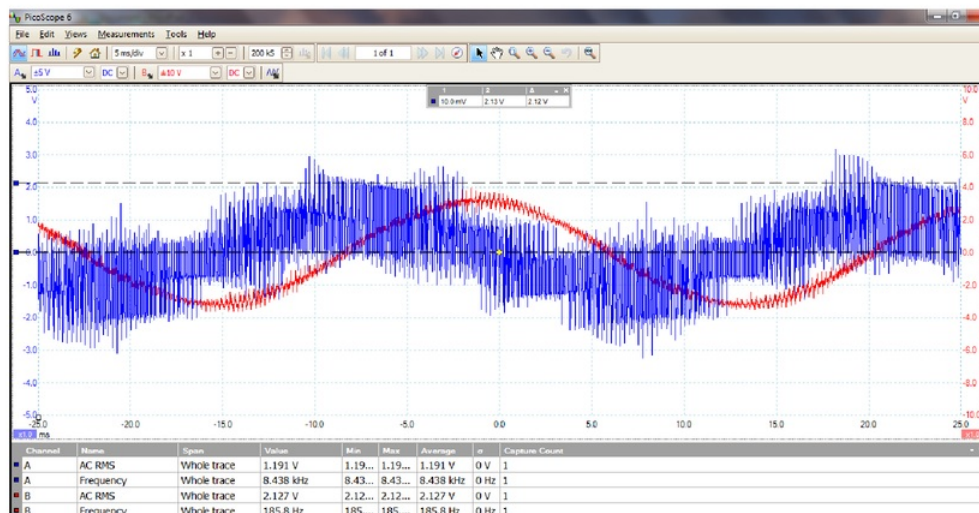


Figure 39 - No load 35Hz

No load test - speed set at 25Hz – 749 rpm

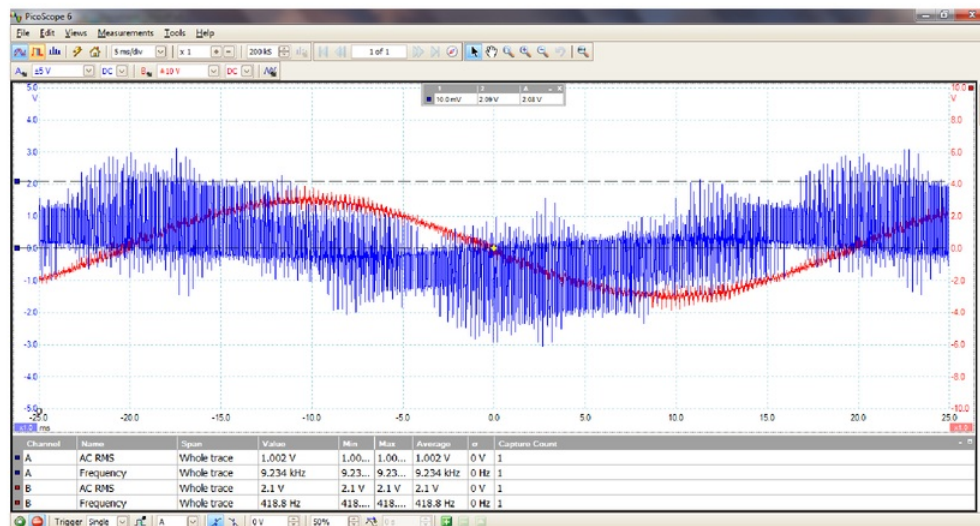


Figure 40 - No load 25Hz

No load test at 50 HZ - to measure pf.

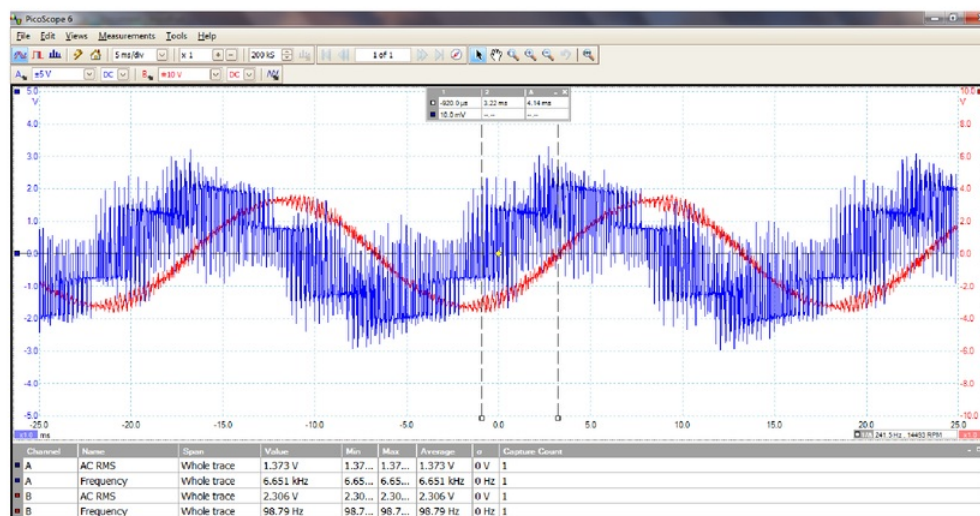


Figure 41 - No load p.f.

Loading

Speed set at 50Hz load at 0.4Nm - speed = 1450rpm

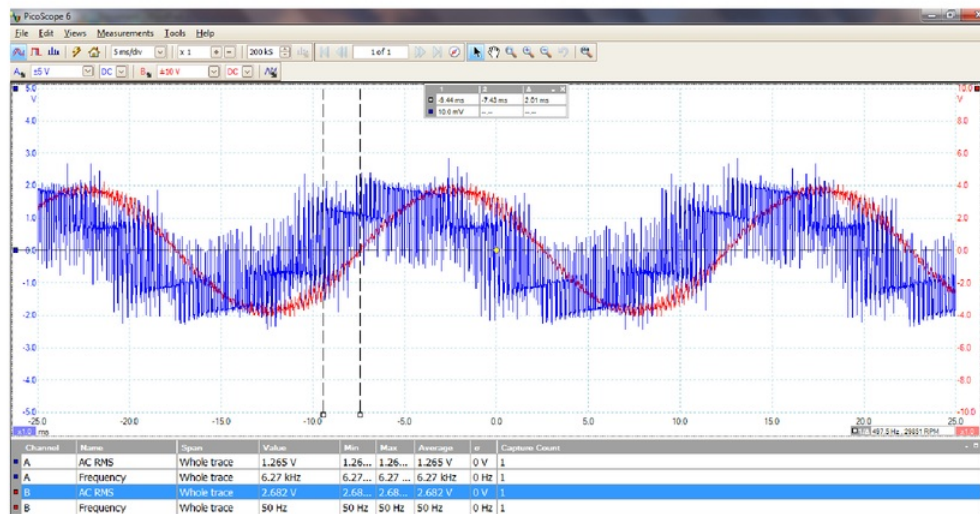


Figure 42 - Load 0.4Nm

Speed at 50Hz load at 0.7Nm – speed = 1362rpm

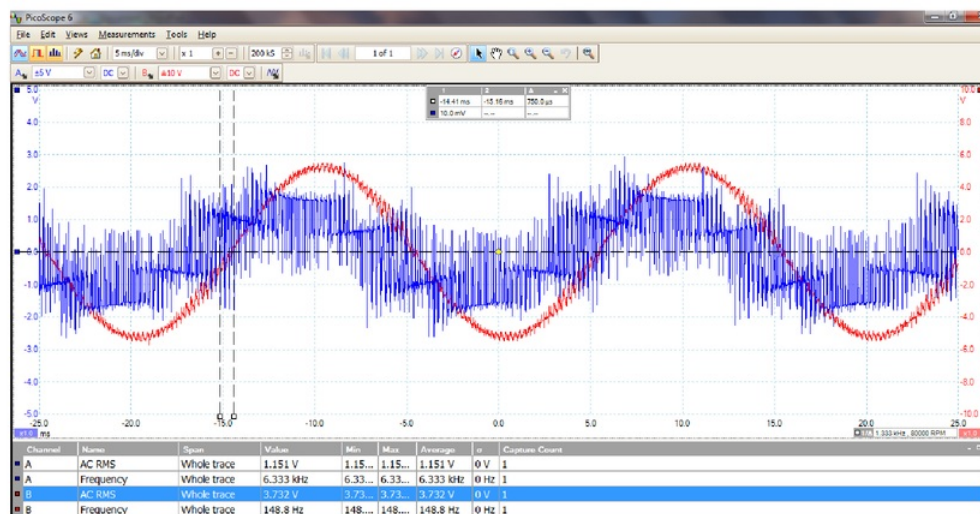


Figure 43 - Load 0.7Nm

Spectrum analysis of voltage at 50Hz shows the clumps of harmonics spread over a wide range.

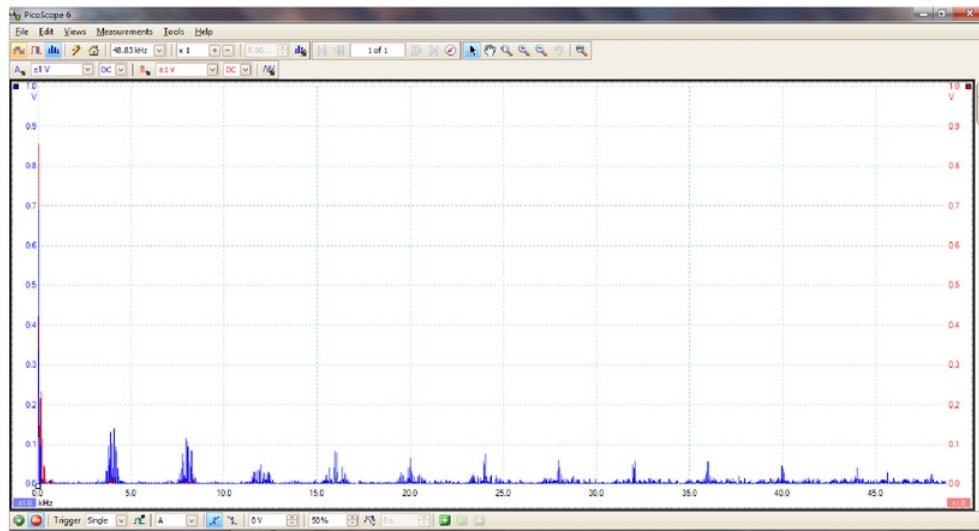


Figure 44 - Spectrum analysis voltage

The current spectrum below shows much less distortion with the fundamental at 50 Hz and 3rd and 5th harmonics present.

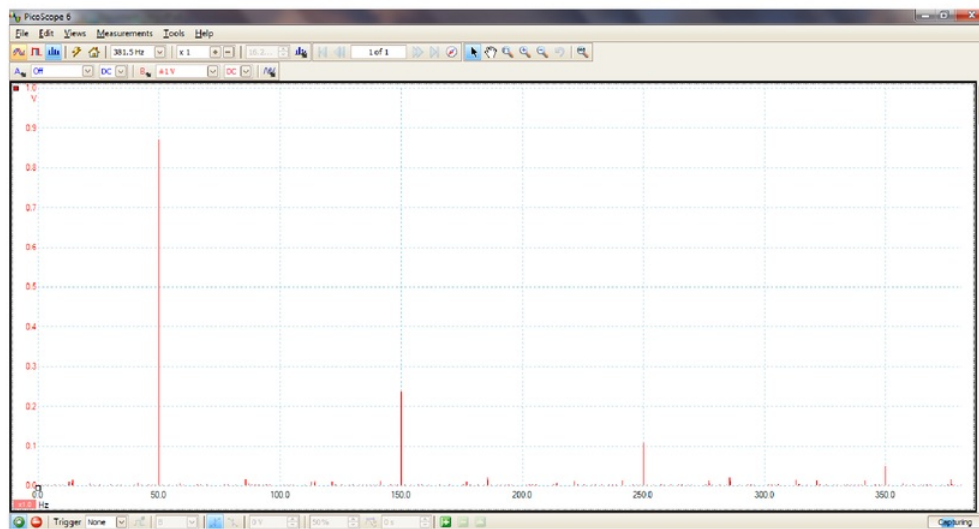


Figure 45 - Spectrum analysis current

5. Analysis of results

PRACTICAL RESULTS

Off-load results

Input Frequency	50Hz	35Hz	25Hz	Comment
Speed (rpm)	1498	899 (1050)	748	Reduced
Vrms (V)	137	119	100	Small change
2Vd/3 (V)	$1.98 \times 100 = 198$	$2.13 \times 188 = 213$	$2.09 \times 100 = 209$	Predicted
V freq (kHz)	6.35	8.44	9.23	Unreliable
Irms (A)	$2.33 \times 10 / 66 = 0.35$	$2.13 \times 10 / 66 = 0.32$	$2.1 \times 10 / 66 = 0.318$	Constant
I freq (Hz)	$1/20\text{ms} = 50$	$1/28\text{ms} = 35.7$	$1/40\text{ms} = 25$	Predicted
ϕ (mS)	$360 \times 4.14 / 20 = 74.5^\circ$	n/a	n/a	Poor
p.f.	$\cos 74.5 = 0.26$	n/a	n/a	Poor

The speed can be seen to reduce as would be expected ($N=60f/P$), the rms voltage has a small reduction. The waveform of the voltage shows two distinct levels at $1/3$ and $2/3$ of V_d the cursor was used to measure $2/3$ of V_d and this is consistent. From the incoming mains 240Vrms, the DC link voltage is given by $2V_{\text{max}}/\pi = 215\text{V}$, however the capacitor smoothing effect and also the effect of regulation has increased this to 321V which was measured on the controller using function d005 also with a DVM a reading of 319V was seen. Therefore this is consistent with the waveform where $2/3 = 214\text{V}$ and $1/3 = 107\text{V}$. The current readings show no increase in amplitude as there is no loading and the frequency of the waveforms can be seen by counting the number of squares for one time period and taking the inverse. Phase shift is measured with the cursors at 4.14ms. There is one anomalous result for speed at 35Hz, which would need a repeat reading.

On-load results (50Hz)

Torque	0.4Nm	0.7Nm	Comment
Speed (rpm)	1450	1362	Reduced
ϕ (mS)	$360 \times 2.01 / 20 = 36.2^\circ$	$360 \times 0.75 / 20 = 13.5^\circ$	Improved
p.f.	$\cos 36.2 = 0.81$	$\cos 13.5 = 0.97$	Improved
Irms (A)	$2.68 \times 10 / 66 = 0.41$	$3.73 \times 10 / 66 = 0.56$	Increased
I freq (Hz)	$1/20\text{ms} = 50$	$1/20\text{ms} = 50$	Constant

The theoretical effect of loading is to reduce the speed, increase the power factor and the current draw; this is borne out in the results.

By observing the spectrum analysis on page 32 it can be seen that there is a vast difference in THD for the voltage and current waveforms. As expected voltage has a high harmonic distortion content and the current which is more similar in shape to a sine wave has less distortion shown on the spectrum.

SIMULATED RESULTS

The results of the simulated tests compare well with theory and errors are due to cursor placement, rounding, etc. The $V_d/3$ and $2V_d/3$ levels are confirmed with a dc link voltage set to 150V so the cursor measurements are 48.911V and 98.452V these are the expected values minus the transistor drops.

(This relates directly to the theory in section 2.1 page 10 and waveform Fig 11)

The current waveforms are a good approximation to a sinusoid.

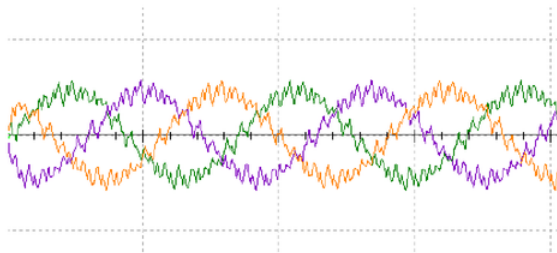


Figure 47 - PWM current waveforms

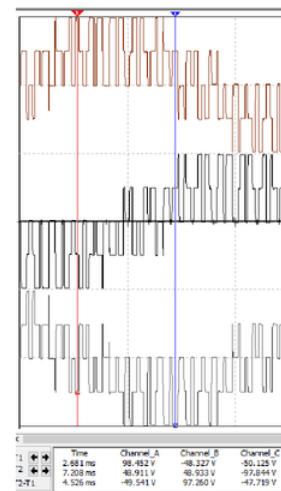


Figure 46 - PWM phase voltage values

Harmonic distortion would be as observed in the practical.

6. Conclusions and Recommendations

The aims of the assignment have been met by research informed theory and comparing results from both simulation and practical.

The Allen Bradley Powerflex 40 gave expected output waveforms and proved reliable. Simulated waveforms were also as expected from theory. Overall performance was robust and correlation with quantitative research was high.

Inverter drives are commonly used because of the advances in dc chopper electronics making conversion and inversion simpler and more efficient.

Cycloconverters are restricted in their use and their functionality is outlined below

Cycloconverters advantages	Cycloconverters disadvantages
Direct conversion no need for DC link	Requires a large number of thyristors
More compact power circuit, forced commutation loss eliminated	Uneconomical for small installations below 20kVA
Bi-directional power transfer, capable of regeneration over wide speed range	Output frequency limited to 1/3 of mains input frequency
At low frequencies a high quality sinusoidal waveform is delivered, good for low speed high power drives.	Low power factor especially at low outputs due to phase control with large firing angle delays
Loss of one phase does not cause shutdown	

Each phase has the same firing delays of the thyristors but with a lag of 120° and 240° with reference to phase A. Average output values are altered by changing the firing angles of the SCRs but frequency output is varied by altering the firing sequence of the SCRs. It can be seen from Fig 15 the positive and negative groupings of the thyristors, with each group having 3 SCRs, a total of 6 per phase and 18 for the entire circuit. Neutral connection is not needed for a balanced load. Output frequency is less than supply frequency

Cycloconverter applications include large reversing drives with rapid speed changes for example metal rolling mills.

The main differences in PWM and Quasi-Square are outlined below

Quasi-Square advantages	Quasi-Square disadvantages
Response time improved with fixed rectifier and dc chopper	Low power factor from variable DC link, large capacitor for smoothing gives sluggish response times
High efficiency >98%	Pulsating torques and instability at low speeds
Reliable	Low/medium power applications
Low harmonic content	Suited to SCR, low speed switching

The modified square wave contains spaces reducing distortion and thus the problems that this causes. They work well for resistive loads and inductive loads but can cause damage to electronic speed controllers. Also devices which contain transformers e.g. microwaves etc will run at a reduced

efficiency and higher heat than from a pure sine wave, thus it may not be an economical choice due to potential damage caused.

Quasi-square inverter applications include medium voltage drives requiring a good quality waveform

PWM control advantages	PWM control disadvantages
The need for filtering is reduced	Control circuitry is more complex
Frequency and amplitude control are independent	Switching losses are higher leading to heat damage
With an inductive load THD is greatly reduced in the load current	Can cause hunting around zero point.
Increased flexibility with control via microcomputer.	

Capable of producing varying AC voltages and frequencies by using a sinusoid of the demand frequency as the reference or control signal for the PWM circuit, a high power waveform with a sinusoidally varying average value can be achieved to drive ac motors. A microcontroller can be used to vary the control voltage I.e. the output pulse width in any manner required. For example the microcontroller could achieve acceleration and deceleration ramping, current limiting and varied V/f response curves by alterations to the software.

7. References

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Assignment 2

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

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GRADING FORM: CSG-RUBIC

LIESEL WILLIAMS

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RESEARCH-INFORMED LITERATURE



Section 2: Your research –There is very good

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evidence of reading from a wide range of sources covering most aspects of the task in some detail. However, the initial section (though helpful in filling in the background) was unnecessary and more emphasis could have been placed on the types of inverter and comparisons between them together with more detailed information about the commercial type of drive. Critical analysis should include an evaluation and summary of the devices. (16/20)
Section 6: Your use of Harvard for citing and listing – A wide range of source cited and listed correctly. However, many of the image sources have not been referenced. (3/5)

KNOWLEDGE AND UNDERSTANDING



Section 1: Introduction – Briefly stated. However, an introduction is not meant to be a summary of the report contents but rather a statement of the aims and objectives and the purpose of the assignment. (3/5)
Section 3: Explanation of simulation – Good with details of firing method given. However, only the three-phase PWM circuit was required. (3/5)
Section 4: Explanation practical experiment – Briefly stated with supporting photos. (4/5)

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ANALYSIS



Section 3: Analysis of results from simulation – Good results with some analysis and comparison with theory. (8/10)
Section 4: Analysis of results from practical experiment – Very good with a table provided for comparisons. However, there should be three load results. (7/10)
Section 5: Overall conclusions and recommendations – Good conclusions based on research, simulation and practical. However, quasi-square wave inverters

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were not part of the assignment. No recommendations provided. (11/15)

PRACTICAL APPLICATION AND DEP.



Section 3: Simulation – Good use of simulation software though more was done than required. (4/5)
Section 4: Practical experiment – Good use of equipment to obtain results. (4/5)

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SKILLS FOR PROFESSIONAL PRAC.



All sections – Well presented and structured. (8/10)
Section 5: Team role – Though observed, there is no evidence presented. (1/5)

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