

power electronic converters

by Carl Jones

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Contents

Table of figures	3
Executive summary	4
Task 1 - Research	5
1.1 Methods of Speed control for a 3 Phase Squirrel cage Induction Motors.	5
1.2 Commercial AC induction motor drives	9
1.3 - filtering.....	9
2.0 – Simulation of Inverter Drives	11
2.1 Analyse of The Quasi-Square wave inverter	11
2.2 Analyse the PWM (Pulse Wave modulation) inverter	17
3.0 Design and simulation of switch Mode power supplies.	20
3.1 Buck converter	20
3.2 Boost converter	25
Conclusions and recommendations	29
Citation list	30

Table of figures

Figure 1-AC drive components.....	5
Figure 2-PWM input voltage waveform.....	6
Figure 3 - PWM drive Speed to torque ratio.....	7
Figure 4-stator voltage control drawing.....	8
Figure 5- Rotor resistance speed control.....	8
Figure 6- images of drives	9
Figure 7- input reactor (https://www.vfds.com/ , n.d.)	10
Figure 8- output reactor or choke (http://www.industrial-electronics.com , n.d.).....	10
Figure 9- Multisim circuit for Quasi - square wave	11
Figure 10- Multisim switching block	11
Figure 11- Multisim switching sequence control block	12
Figure 12- Multisim sequence signals	12
Figure 13- Analysed waveform of Va	13
Figure 14-Analysed waveform Vb	14
Figure 15= Analysed waveform Vc.....	14
Figure 16- output squarewave 3 phase	14
Figure 17- output wave, blue Vca and Red Vab.....	15
Figure 18-resultant output wave 1 phase.....	15
Figure 19- output waveform with motor inductance	16
Figure 20- Multisim circuit for PWM.....	17
Figure 21- PWM- DC output wave	17
Figure 22- PWM 3phase output line wave	18
Figure 23- 3phase current wave with falling jagged edges	18
Figure 24 - Multisim setting box	19
Figure 25- resultant signal wave to output wave	19
Figure 26- Buck converter circuit.....	20
Figure 27- Multisim Test circuit of Buck converter.....	23
Figure 28- Input voltage waveform.....	23
Figure 29- pulse off times	24
Figure 30 - pulse on time	24
Figure 31-Boost convert circuit diagram.....	25
Figure 32- Multisim circuit for the boost converter	27
Figure 33- input voltage waveforms boost converter	27
Figure 34- charging capacitor generating higher voltage than E	28

Section should be numbered

Executive summary

This assignment covers research in to how easy it is to control the speed of an AC induction motor, how many manufactures are industry with so many types, sizes and applications. The problem that come with inverter such as harmonics. *What are the problems?*

Build and simulate two methods of inverter and how they chance DC to AC current output waves. *luck?*

The two simple inverters are Pulse wave modulation and Quasi- Square wave.

The last task is switch mode DC power supplies, they are designed and simulated to prove the theory behind the circuit's components.

A summary should contain details of each task including findings and conclusions. Were you successful.

Task 1 - Research

1.1 Methods of Speed control for a 3 Phase Squirrel cage Induction Motors.

Motors.

Three phase induction motors are used widely in all types of industry, this is due to they're rugged and maintenance free design. Induction motors are generally used for applications that require constant speed for varying loads. As industrial needs advance the increasing need for speed control of induction motors has increased.

The rotor speed of an induction motor is expressed as

$$N_r = N_s(1-s), \text{ where } N_s = \text{synchronous Speed} = 120f/P$$

$$\text{So, } N_r = 120f/P(1-s)$$

From the expression it can be seen that to control the speed of an induction motor either frequency (f), No. of poles (P) or the Slip(s)

There are five control methods available to achieve speed variation.

- 1) VVVF Speed Control.
- 2) Pole Changing Method
- 3) Rotor circuit resistance control
- 4) Stator Voltage control
- 5) EMF injection in rotor circuit.

VVVF (Variable voltage, variable frequency) speed control is the most common method used today for accurate control of speed for the AC induction Motor. An inverter is used to change the supply frequency and voltage to the Motor. Figure 1 below show the basic internal setup of the inverter.

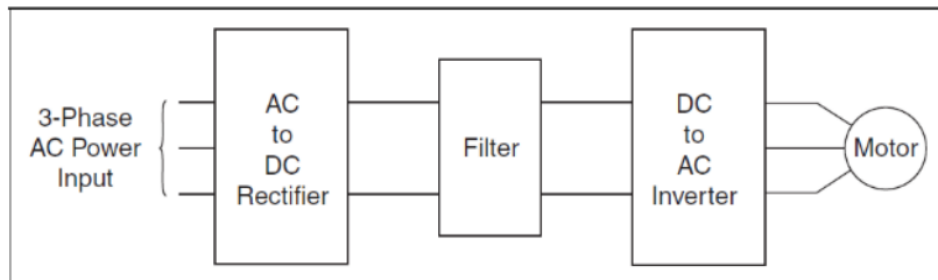


Figure 1-AC drive components

The 3 phase supply is converted from AC to DC at the rectifier, then smoothed out through the filter and then inverted back from DC to AC. The output AC wave is created from the inverter using pulse wave modulation, shown in figure 2 below.

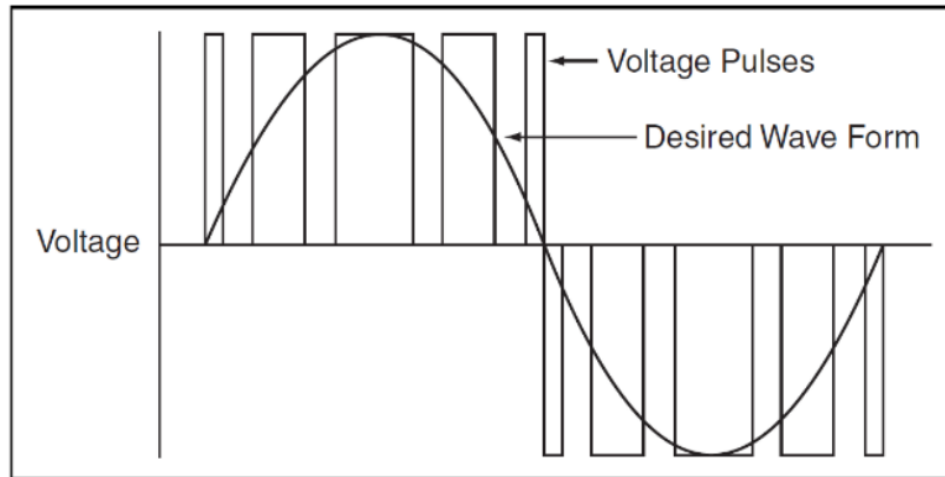


Figure 2-PWM input voltage waveform

Output voltage to the motor is varied by increase or decreasing the width and number of voltage pulses created by the switching on/off and frequency is changed by altering the length of the cycle. *Only true for PWM drives*

In VVVF control the ratio between voltage and frequency is (V/F), with relation to torque changing the frequency has no effect but as the frequency increase so does the speed. As speed increase so does the rate that maximum torque for the induction motor is reached.

Figure 3 below shows a graph of speed against torque and at the point maximum torque is reached.

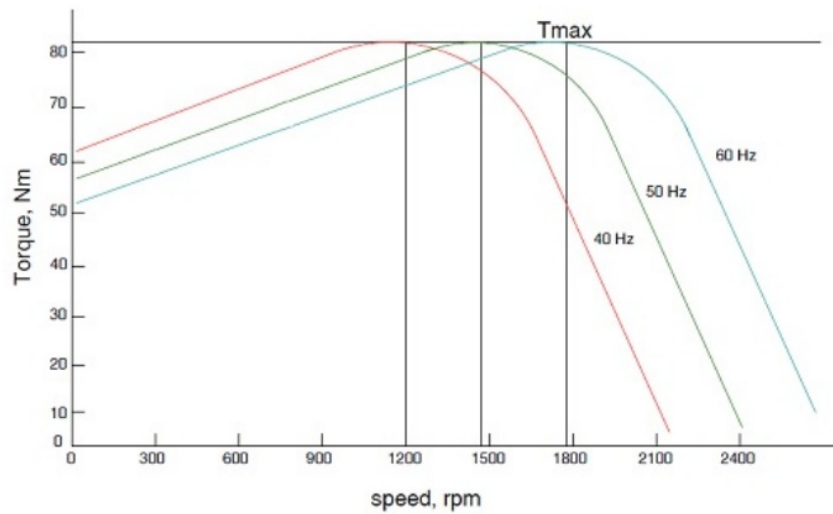


Figure 3 - PWM drive Speed to torque ratio

VVVF motor control is used widely in HVAC units, pumps and Elevator systems.

It offers low starting currents and higher power factor, which makes it more efficient.

Stator Voltage control is used to control the speed of an induction motor by two anti-parallel SCRs placed on each phase of the supply cables. Now by changing the firing angles of the SCRs the voltage to the stator can be adjusted which can increase or decrease the speed of the motor. The frequency of the supply is not varied in this method, Figure 4 shows the SCRs in line with the motor.

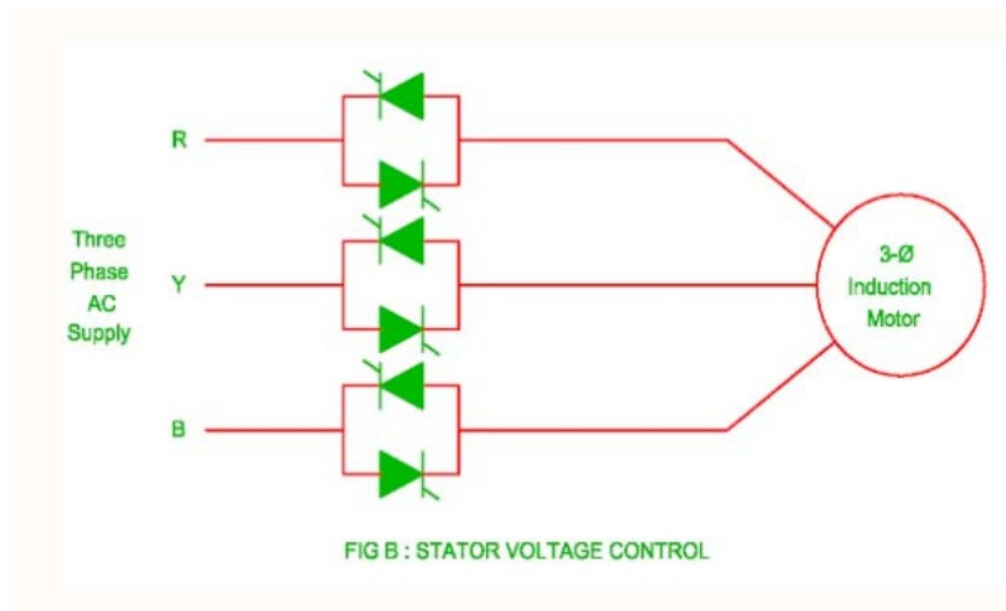


Figure 4-stator voltage control drawing

Stator voltage control is not an efficient method of controlling speed as it draws high currents from the supply.

*main problem is large
fractional slip affecting
efficiency*

Rotor resistance control, this is done by introducing an external resistance in to the slip rings of the induction motor. When the resistance is increase, the value of slip (s) becomes greater which decreases the motor speed and vice versa.

*out dated method, question asks for cage
rotor speed methods*

A chopper circuit is used for rotor resistance control as shown in figure 5 below.

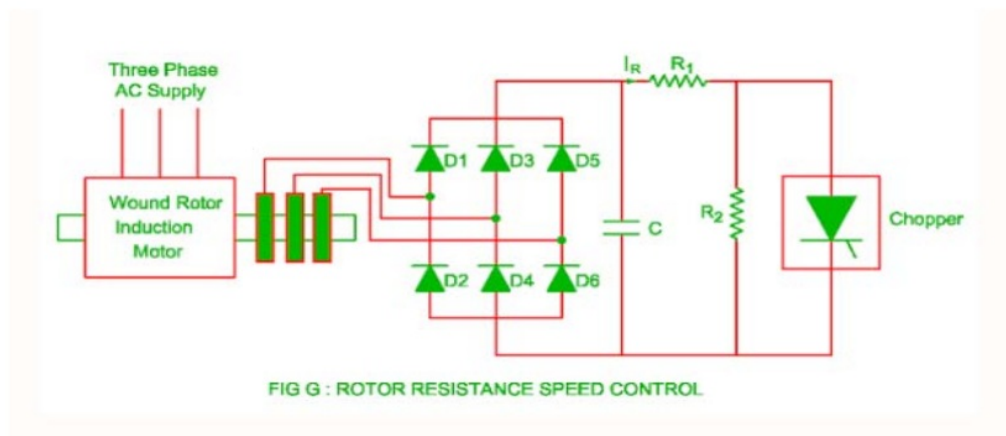


Figure 5- Rotor resistance speed control

The chopper switches on and off controlling which resistance is produced at the slip rings

The circuit in figure 5 shows when the chopper is off the resistance is $R_1 + R_2$, when the chopper is on then the resistance is R_1 .

The rotor resistance $R = R_1(T_{on}) + R_2(T_{off}) / (T_{on} + T_{off})$

This method of speed control is simple and can create large starting torques at low current due to small values of Slip(s) at low speeds.

In industry this form of speed control is used for cranes and other intermittent load applications due to low cost and the capability of high torque at low speeds.

1.2 Commercial AC induction motor drives

The drive manufacturing sector is large with a lot of companies out there producing AC drives, below is a small list.

- 1) ABB – ACS series from
- 2) Siemens – Sinamics series Spelling
- 3) Hitachi – NEMA series
- 4) Mitsubishi – FREQROL series
- 5) Danfoss – VLT and VACON series

AC drives come in all different sizes from small and compact too large multiple panels as in figure 6.



Figure 6- images of drives

Drives vary in power rating from 0.37KW – 1800KW and each manufacture

1.3 - filtering

As AC drives become part of every industry provisions need to be made to protect the supplier's voltage lines and effects on the local motor which could be effected by how the AC drive produces an AC current output from the use of DC.

This is not Harvard method of citing

(<https://www.wolfautomation.com/blog/when-should-you-use-a-line-reactorload-reactor/>, n.d.) Input and output reactors serve two different purposes, one to protect the drive the other the motor.

Input reactors protect VFDs from line disturbances and reduces harmonics the drive create from effecting the main line supply.

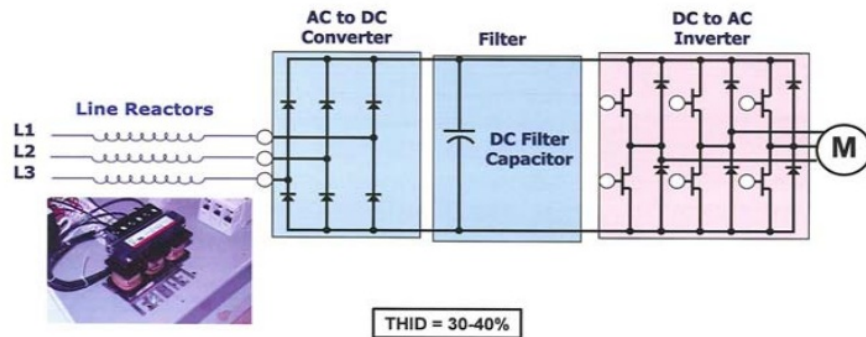


Figure 7- input reactor (<https://www.vfds.com/>, n.d.) *not Harvard*

Line reactor sizes are based on KW and voltage rating of drive.

Output reactors are used to protect the motor if it is position large distance away from the drive. Drives create high frequency PWM outputs. Noise generated can be amplified and cause higher capacitance in cables, this can cause insulation to break down.

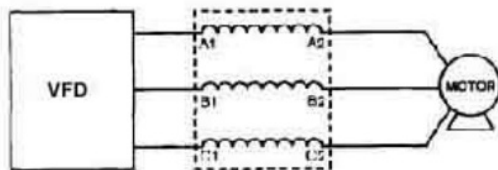


Figure 8- output reactor or choke (<http://www.industrial-electronics.com>, n.d.)

2.0 – Simulation of Inverter Drives

2.1 Analyse of The Quasi-Square wave inverter.

Using Multisim the below circuit is created to simulate how the Quasi-square wave inverter controls an AC induction motors speed

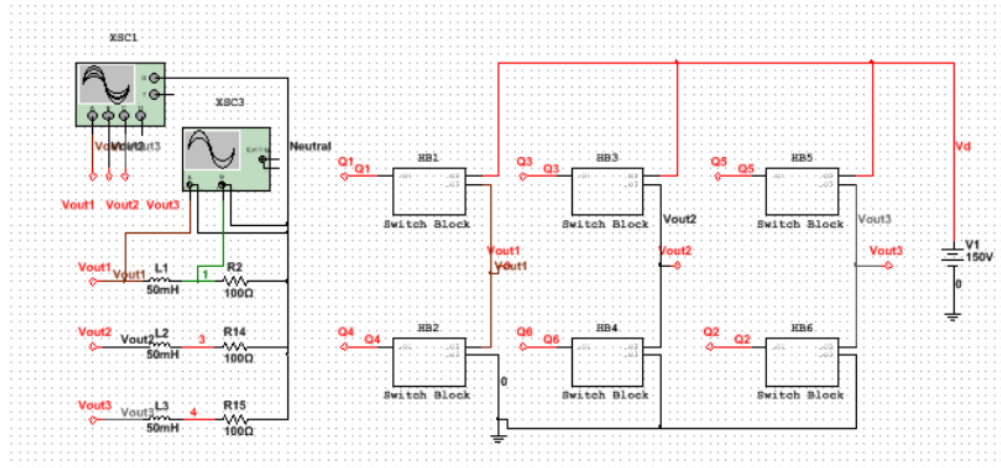


Figure 9- Multisim circuit for Quasi - square wave

Figure 9 above is the three phase Quasi-square wave inverter with a star connected load.

Switch Blocks HB1 – HB6 represent the three phase Bridge inverter, figure 8 below shows the components involved in the blocks

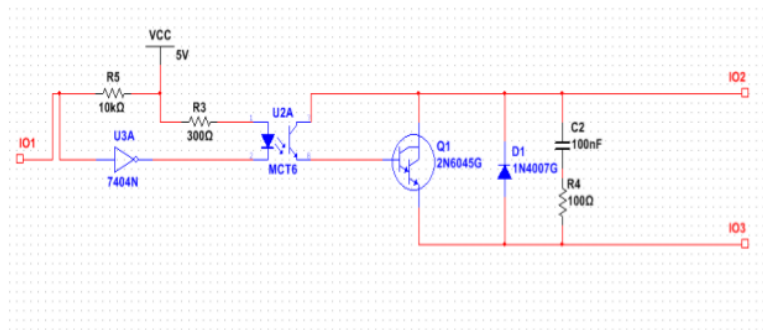


Figure 10- Multisim switching block

In the block is the transistor and diode with a capacitor and resistor from smoothing the output signal, a 5v reference voltage is used to switch the base of the transistor.

To generate the full cycle of an AC wave a control block was created figure 11, this allowed the switching sequence of the transistors for all three phase from 60° - 360°. Figure 10 shows the resultant switching output.

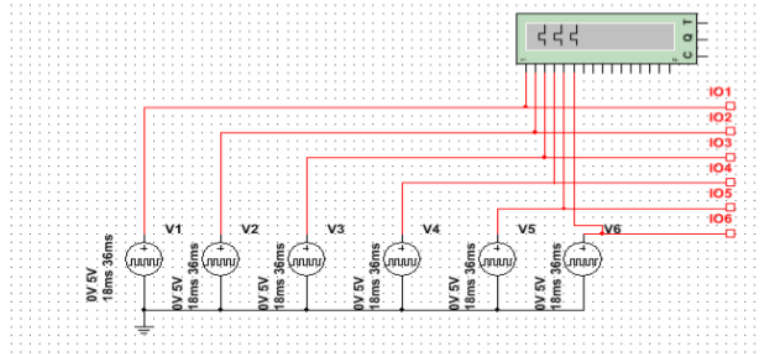


Figure 11- Multisim switching sequence control block

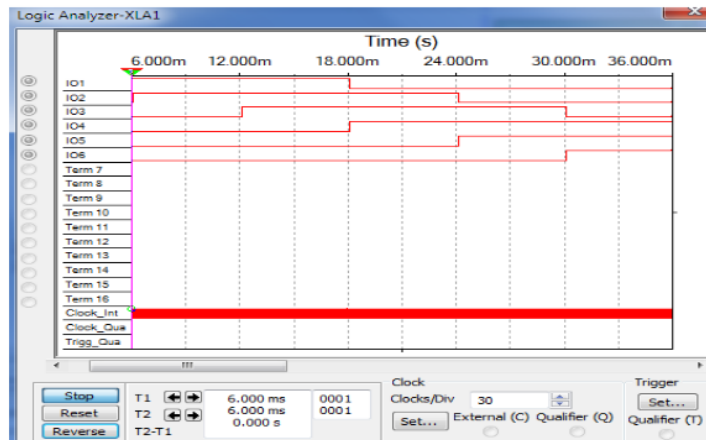


Figure 12- Multisim sequence signals

A variable dc voltage link V_d is connected to the circuit, this would normally be from a controlled rectifier. This variable dc source must be used with the Quasi-square wave so that the V/f ratio is maintained.

From the Multisim circuit $V_{out 1} = a$, $V_{out 2} = b$ and $V_{out 3} = c$, this means that the phase voltages are V_a , V_b , and V_c relative to the star point.

The line voltages are V_{ab} , V_{bc} and V_{ca} , Where

$$V_{ab} = V_a - V_b \quad (1)$$

$$V_{bc} = V_b - V_c \text{ - (2)}$$

$$V_{ca} = V_c - V_a \text{ - (3)}$$

(1)– (3) gives

$$V_{ab} - V_{ca} = 2V_a - (V_b + V_c)$$

In a balanced system phase voltages $V_a + V_b + V_c = 0$

There for $V_b + V_c = -V_a$

And

$$V_{ab} - V_{ca} = 2V_a - (-V_a)$$

$$V_{ab} - V_{ca} = 3V_a$$

$$V_a = \frac{V_{ab} - V_{ca}}{3}$$

There for

$$V_b = \frac{V_{bc} - V_{ab}}{3}$$

$$V_c = \frac{V_{ca} - V_{bc}}{3}$$

By running the analyser on the outputs in figure 13-15, the following waveforms for V_a , V_b , and V_c are recorded.

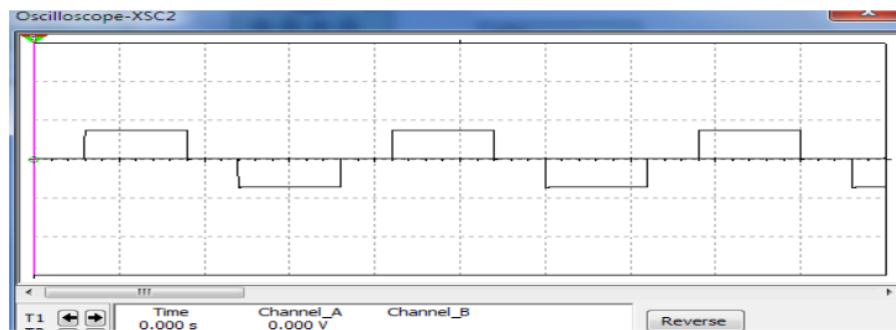


Figure 13- Analysed waveform of V_a

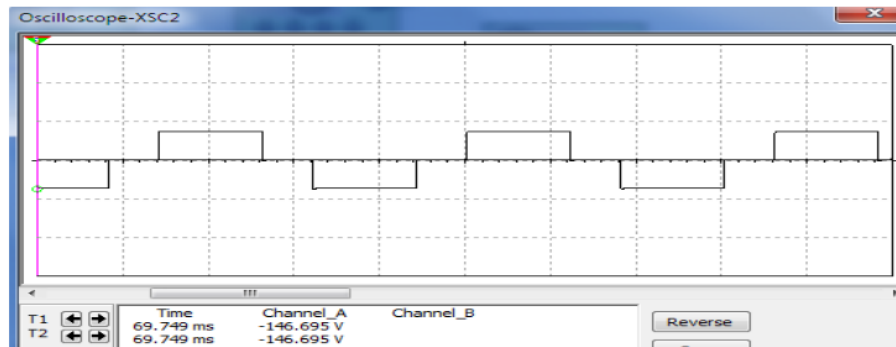


Figure 14-Analysed waveform Vb

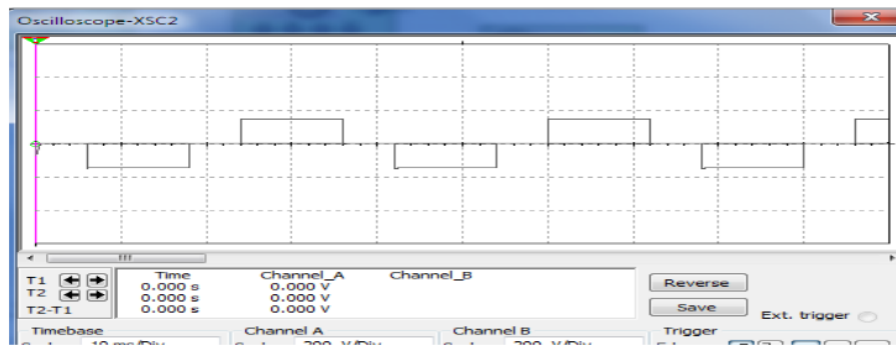


Figure 15= Analysed waveform Vc

Phase output voltage is derived from the control signal which is the transistors switching and the line voltage produced.

Using the circuit in figure 13-15 an analysis of the output phase voltages Va, Vb and Vc is carried out.

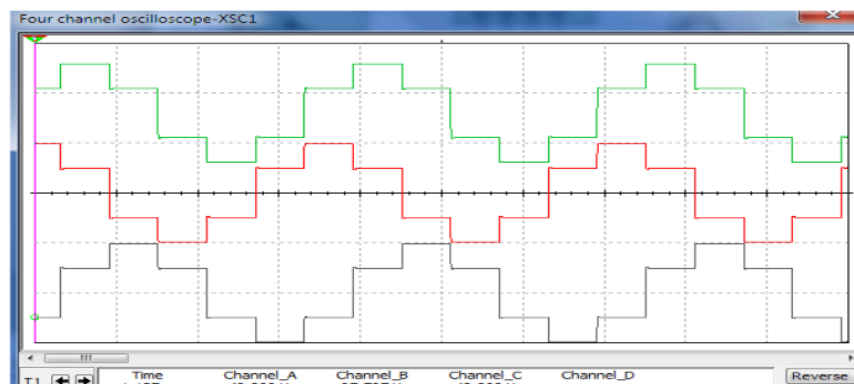


Figure 16- output squarewave 3 phase

The maximum output voltage of each phase occurs when the line voltages are equal in magnitude.

Results of the waveforms from the analyser were verified for V_a

when $V_{ab} = -V_d$ and $V_{ca} = +V_d$

$$V_a(\max) = \frac{V_d - (-V_d)}{3} = \frac{2V_d}{3}$$

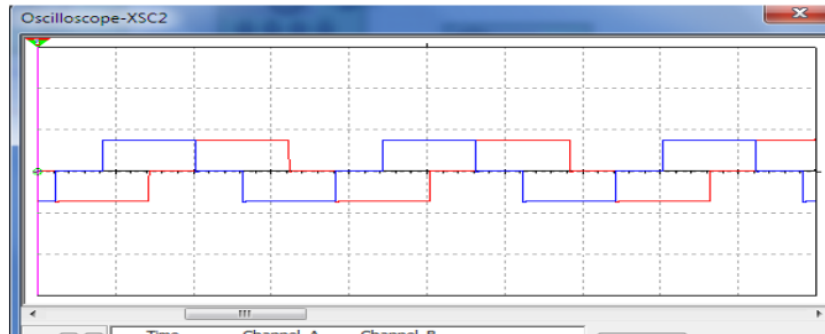


Figure 17- output wave, blue V_{ca} and Red V_{ab}

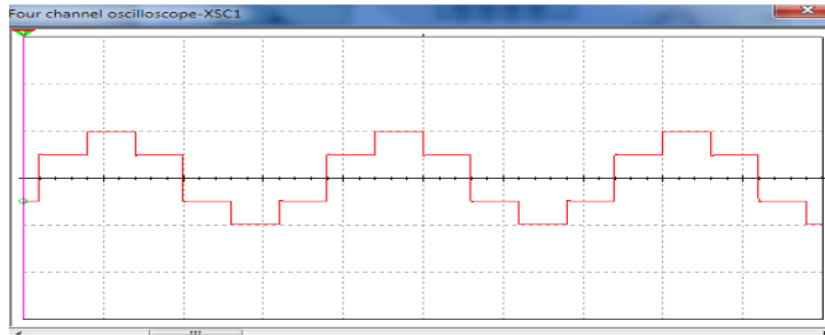


Figure 18- resultant output wave 1 phase

From the results of the analyser it seems that V_a and V_b are reversed, this can be seen in figure 16 as the red line (V_b) is lagging green line V_a . Each of the phases have the same shaped phase voltage but shifted by 120° .

Quasi-square wave inverters are known as low cost reliable inverters, they are ideal with purely resistive loads like motors. The harmonics generated from the square wave are filtered out due to the inductance in the stator windings of the induction motor. Using the

circuit in figure 7 an analyser is placed on the phase line before the inductance and after to see how the square output wave is affected. Figure19 Shows the results.



Figure 19- output waveform with motor inductance

From the results it can be seen that the inductance in the line acts as a filter and smooths out the edges of the square wave making them rounder like a sine wave, thus reducing the effects of harmonic distortion.

2.2 Analyse the PWM (Pulse Wave modulation) inverter

Using Multisim the below circuit is created to simulate how the PWM inverter generates a three phase output to control the speed of an AC induction motor.

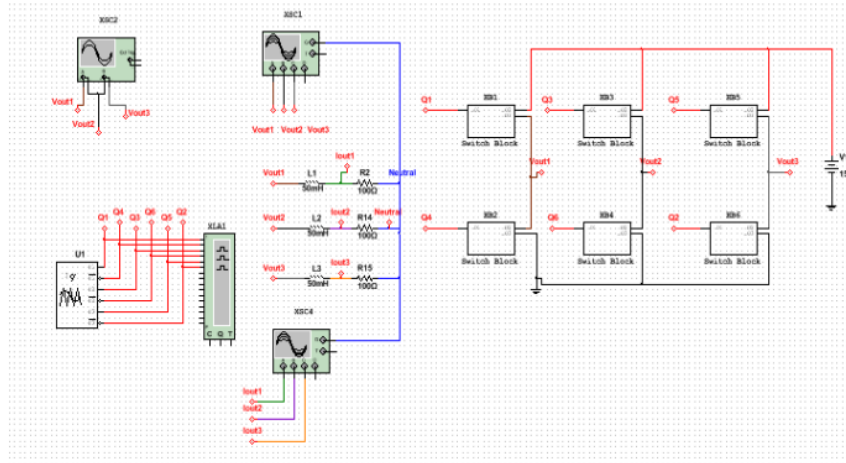


Figure 20- Multisim circuit for PWM

The same transistor block as the in Quasi – square wave experiment is used to create on/off switching of the transistors to generate an RMS voltage output. A PWM inverter uses two signals through a comparator to produce an output wave, one signal is a sinewave and the other a triangle wave. To create these signals a PWM 3phase block in Multisim is used. Using an analyser on the bridge circuit output before the load, figure 21 below shows the resultant wave form generated.

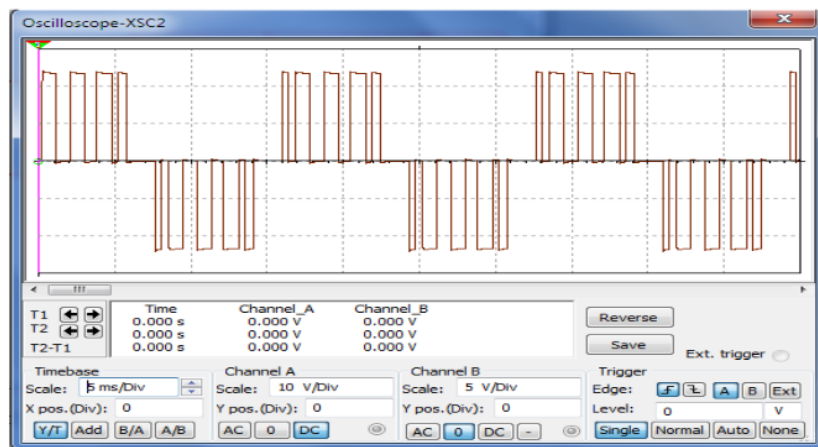


Figure 21- PWM- DC output wave

The pulse wave form has been generated from the reference sinewave and the carrier triangular wave. As each combination of transistors switch the resultant pulse wave switches

between positive and negative. The width of each pulse determines the output RMS voltage at that point which simulates the sinewave. The wave shown Line to Line voltage output.

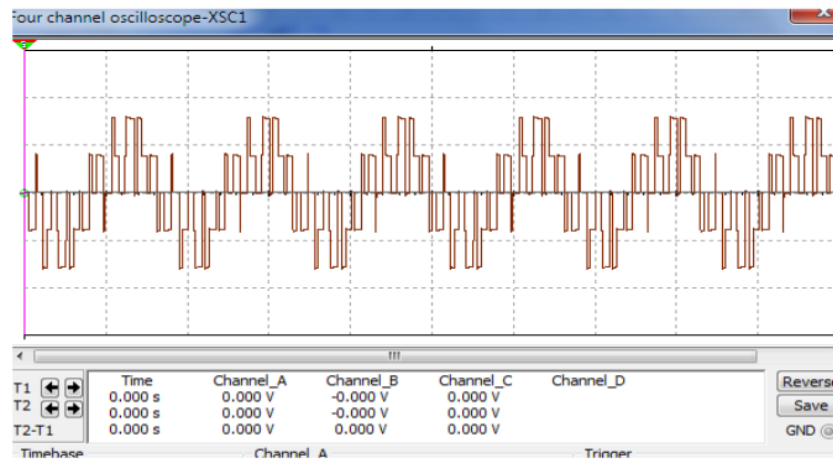


Figure 22- PWM 3phase output line wave

Figure above from another analyser shows all three phases as line to neutral voltages. To simulate the effect that a load has on the output inductor are used. As these drives are used on motors a combination of three inductors and resistors are used connected in star formation. Adding an inductive load is used to create a load current. Figure is from the analyser monitoring the output current of each phase to neutral.

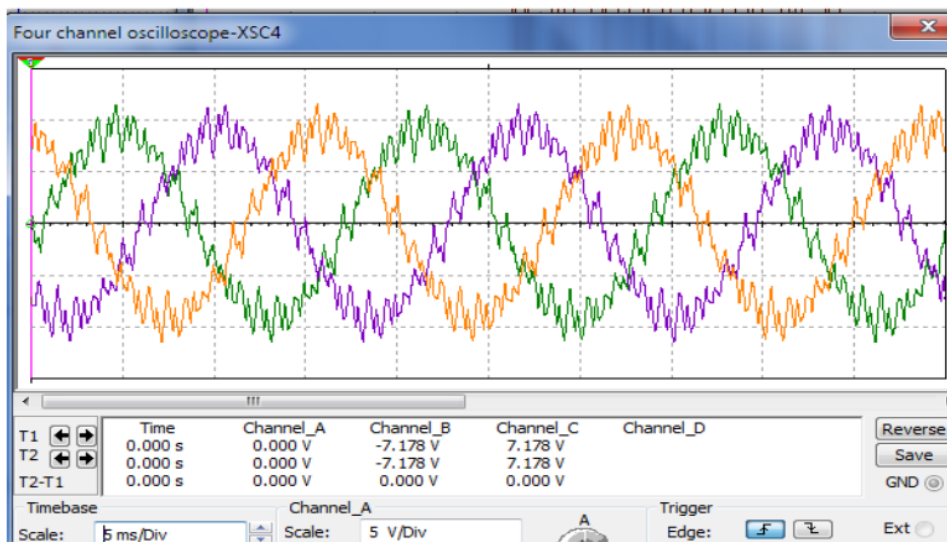


Figure 23- 3phase current wave with falling jagged edges

As seen from the resultant waveform, current builds up in the inductive load on positive pulses. When the voltage pulses switch to zero, current falls causing jagged edges in the current wave, this can be seen in figure23 on all three phases.

We know that if the reference signals is increased the pulse width increase creating higher RMS output voltages. To show the effects on output current in Multisim the PWM block allows the reference frequency to be modified. Figure24 shows the device settings.

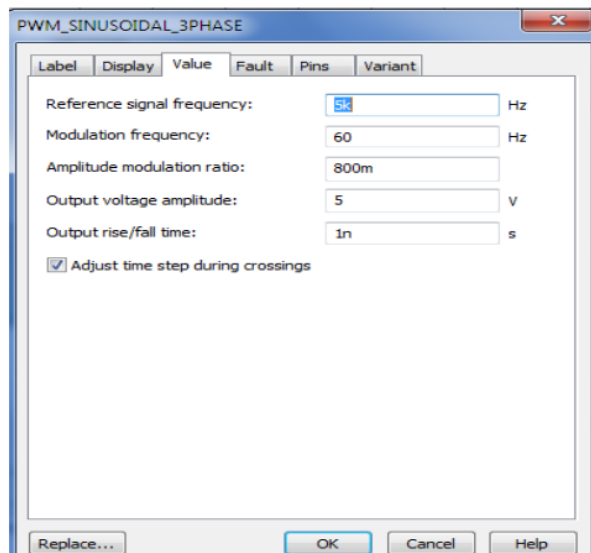


Figure 24 - Multisim setting box

The reference signal is changed to 5KHZ and the resultant current output is shown in figure25.

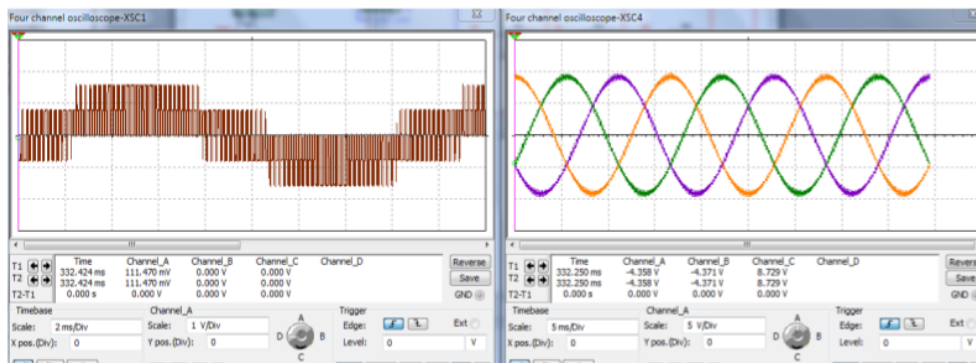


Figure 25- resultant signal wave to output wave

From analysing the results it shown that the higher the RMS voltage generated by the larger pulse with the smoother output current becomes making it more continuous.

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3.0 Design and simulation of switch Mode power supplies.

Switch mode power supplies are electronic powers supplies that can convert input voltages to higher or lower output voltages. The two converters which will be simulated are the Buck and Boost converters, these are both DC to DC converters. To enable the circuits to be designed calculation need to be carried out.

3.1 Buck converter

This converter is a DC-DC converter which is used to step down input voltage while increasing output current.

Design for the buck converter is shown below in figure.

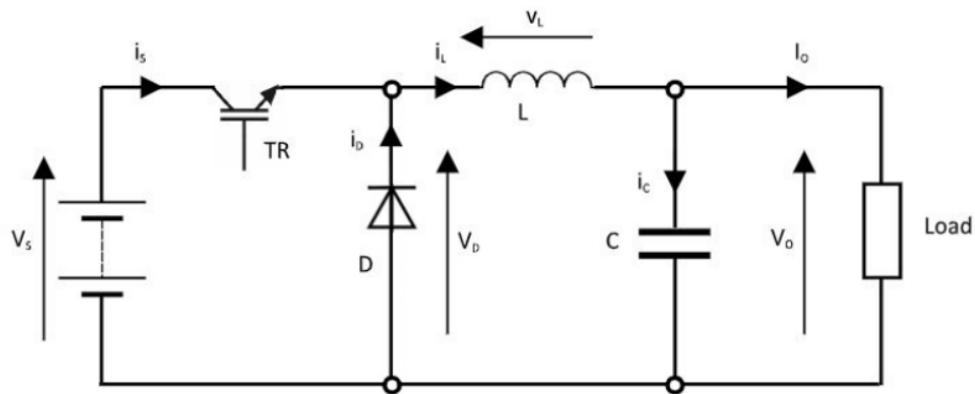


Figure 26- Buck converter circuit

Before the circuit is built in Multisim rating of component need to be calculated. Components are assumed to be ideal, all other specification are listed below.

Source Voltage $V_s = 40V$

Load = 2 ohms

Load voltage $V_o = 16V$ stepped down

Switching Frequency of 200KHZ

Required calculations follow.

$$\text{Output load current } I_o = I_o = \frac{V_o}{R_{Load}}$$

$$I_o = \frac{16}{2} = 8A$$

The duty cycle required and on off switching times for the transistor.

For a given frequency f , the values of $t_1 + t_2$ can be calculated if V_o and E are known

$$V_o = 16, E = 40, f = 200 \text{ KHz}$$

$$t_1 + t_2 = \frac{1}{f}$$

$$t_1 + t_2 = \frac{1}{200 \times 10^3} = 5 \mu\text{s}$$

$$D = \frac{16}{40} = 0.4$$

$$\frac{t_1}{t_1 + t_2} \times E = V_o$$

$$t_1 = D \times (t_1 + t_2)$$

$$t_1 = 0.4 \times (5 \times 10^{-6})$$

$$t_1 = 0.4 \times (5 \times 10^{-6}) = 2 \mu\text{s}$$

$$t_2 = (t_1 + t_2) - t_1$$

$$t_2 = 5 \mu\text{s} - 2 \mu\text{s}$$

$$t_2 = 3 \mu\text{s}$$

The peak current of the inductor i_L when switch closes, the "ON" time t_1 builds up to

$$I_{max} \text{ Voltage drop across the inductor } L \text{ is } E - V_o \text{ this must be } L \frac{di_L}{dt}$$

It is assumed that the coil L is a pure inductor with no resistance $R=0$

Therefore

$$\frac{di_L}{dt} = \frac{E - V_o}{L} = \frac{di_L}{dt} = \frac{40 - 16}{L} = \frac{24}{L}$$

i_L Rises linearly as E and V_o are assumed to be constant

When the switch opens, the "OFF" time t_2 , i_L starts to reduce. The reducing current of i_L starts to flow through the capacitor C , back up through the diode creating a free wheel loop which charges C .

Part of i_L is still flowing through the load at during this time

During the off time t_2 , voltage drop across L and is

$$0 - V_o = L \frac{di_L}{dt}$$

$$\frac{di_L}{dt} = \frac{-16}{L}$$

For current to be continuous i_L must rise to $2 \times I_o = 16\text{A}$ and fall to zero again before rising

$$I_o = i_L + i_C = 10A$$

So while i_L rises, i_C must fall, this means the current waveform will be 8A to -8A.

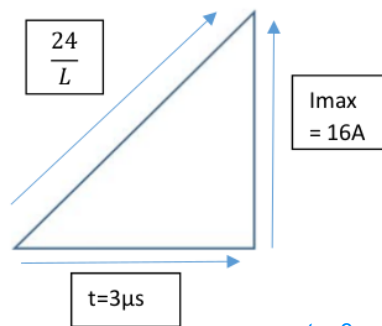
Inductor current $i_L = i_S + i_D$ at all times, therefore

$$\text{Time } t_1 \text{ "ON"} = i_L = i_S$$

$$\text{Time } t_2 \text{ "OFF"} = i_L = i_D$$

The value of inductor requires

$$\frac{di_L}{dt} = \frac{E - V_o}{L} = \frac{di_L}{dt} = \frac{40 - 16}{L} = \frac{24}{L}$$



t = 2us, the ON time, you have used the OFF time

Using Gradient of a triangle =

$$\frac{16}{3 \times 10^{-6}}$$

$$\frac{24}{L} = \frac{16}{3 \times 10^{-6}}$$

$$L = 3 \times 10^{-6} \times \frac{24}{16}$$

$$= 4.5\mu H$$

Circuit capacitor requires for a ripple voltage 0.1V

$$\Delta q = \Delta i_C \times t$$

$$\Delta q = \frac{1}{2} \times 2.5 \times 10^{-6} \times 8 = 10\mu C$$

$$\Delta VC = \frac{\Delta q}{C}$$

$$C = \frac{\Delta q}{\Delta VC}$$

$$= \frac{10 \times 10^{-6}}{0.1} = 100\mu f$$

Using Multisim the circuit in figure is generated, all calculated values for components, cycle time's voltages and output load are entered and analysers setup at different points to verify theory.

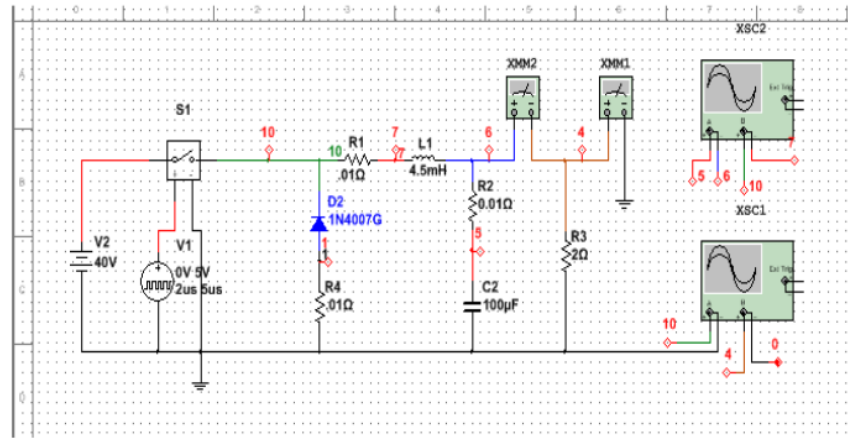


Figure 27- Multisim Test circuit of Buck converter

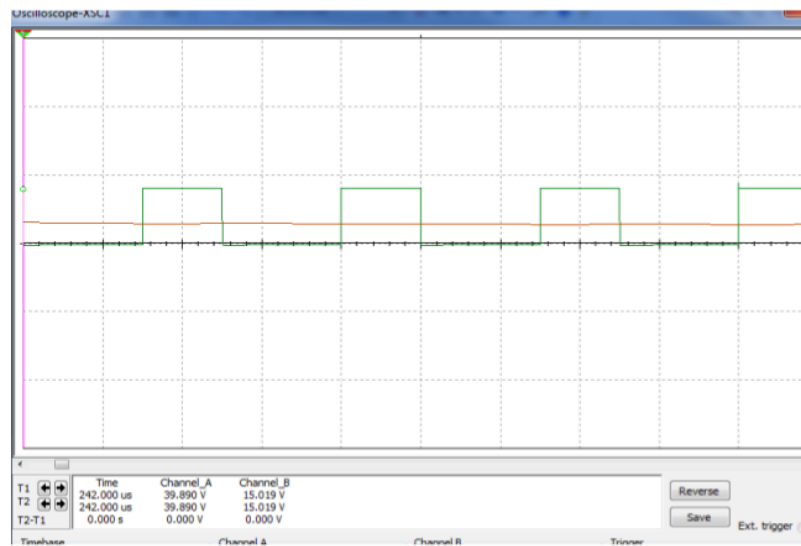


Figure 28- Input voltage waveform

Figure 28 shows the results of analyser 1, the green pulse is DC input voltage “E” switching between 0V and peak voltage of 40v. The red line is Vo which is 15.1 V which is continuous voltage to the load. The output voltage required is 16v output, there is a slight difference of less than 1 volt. Reason for this may be down to the extra resistances applied in the circuit so that the Multisim software can run the simulation.

The second analyser is connected to the output load, results below prove the theory.

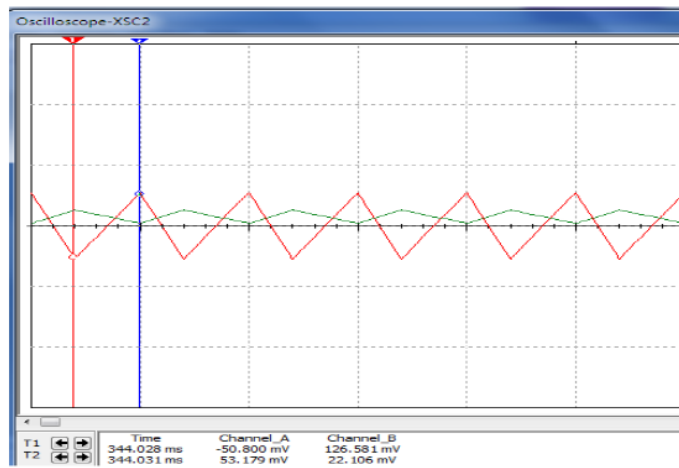


Figure 29- pulse off times

The two indicators on figure29 show t2 “OFF” time, the red waveform show the capacitor charging as I_c increase as the green wave shows i_L falling, i_L is assumed to be continuous due to as it hits zero it rises again.

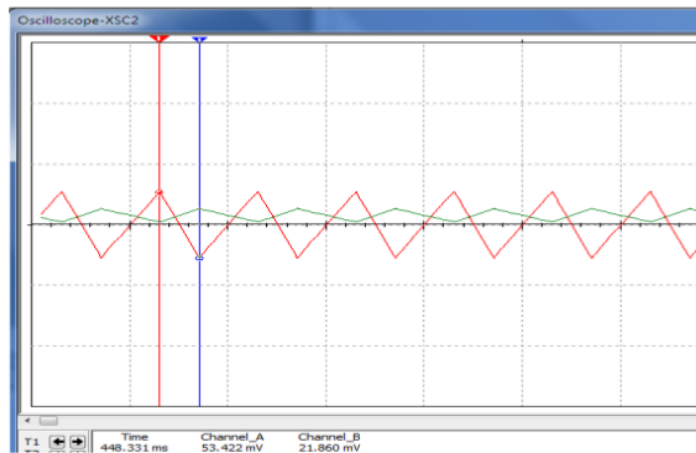


Figure 30 - pulse on time

Figure30 above shows t1 “ON” time, the red waveform shows the capacitor discharging as i_c falls and the green wave shows the inductor i_L rising.

These results prove the theory of $I_o = i_L + i_C$

you could have also measured the average current and voltage to compare with the design requirements.

3.2 Boost converter

This converter is a DC-DC converter which is used to step up input voltage. By using the same components as the Buck converter but rearranging them.

Design for the boost converter is shown below in figure 31

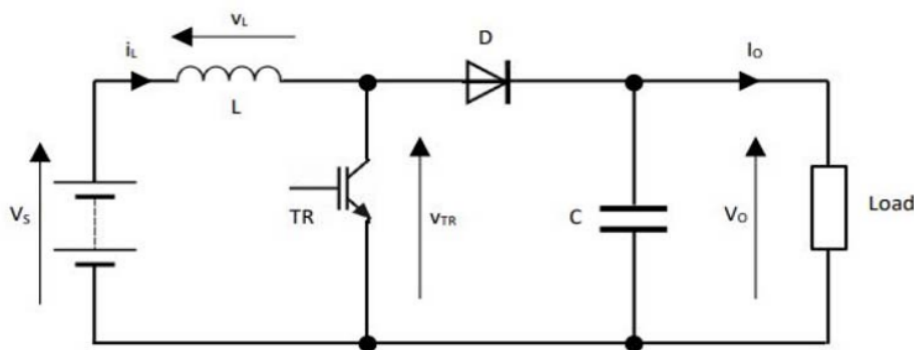


Figure 31-Boost convert circuit diagram

Before the circuit is built in Multisim rating of component need to be calculated. Components are assumed to be ideal, all other specification are listed below.

Source Voltage $V_s = 12V$

Capacitor = 270uf

Load voltage $V_o = 20V$ stepped up

Switching Frequency of 20KHZ

Load current $I_o = 1.5A$

Inductor = 150uH

Required calculations follow.

The output voltage across the output resistor can be calculated knowing that voltage across the inductor $L = 0$ for 1 cycle.

$$V_s \text{ ton} - (V_o - V_s) \text{ toff} = 0$$

Therefore

$$V_s DT = (V_o - V_s)(1 - D)T$$

And

$$\frac{V_o}{V_s} = \frac{1}{1 - D}$$

D = duty cycle, T = switching period

$$D = 1 - \frac{V_s}{V_o} = 1 - \frac{12}{20} = 0.4$$

$$D = 1 - \frac{12}{20} = 0.4$$

The current rise in the inductor for the “ON” time

$$\Delta i_L = \frac{V_s \text{ ton}}{L} = \frac{V_s D t}{L}$$

$$\frac{12 \times 0.4 \times 50 \times 10^{-6}}{150 \times 10^{-6}} = 1.6A$$

If losses are neglected,

$$V_s I_L(av) = V_o I_o$$

$$I_L(av) = \frac{V_o}{V_s} I_o I_L(av) = \frac{20}{12} \times 1.5 = 2.5A$$

Continuous and dis-continuous current boundaries for inductor current

$$I_L(av) = \frac{\Delta i_L}{2}$$

$$I_L = 2.5A + \frac{1.6}{2} = 3.3A$$

$$\frac{V_o}{R} = \frac{\Delta i_L}{2} (1 - D) = \frac{V_s}{2L} DT (1 - D)$$

$$L = \frac{1}{2} RTD(1 - D)^2$$

$$L = \frac{1}{2} \times \frac{20}{1.5} \times 50 \times 10^{-6} \times 0.4 \times (1 - 0.4)^2 = 48\mu H$$

$$D = 20\mu s$$

$$R_o = \frac{20}{1.5} = 13.33$$

Using Multisim the circuit in figure is generated, all calculated values for components, cycle time's voltages and output load are entered and analysers setup at different points to verify theory.

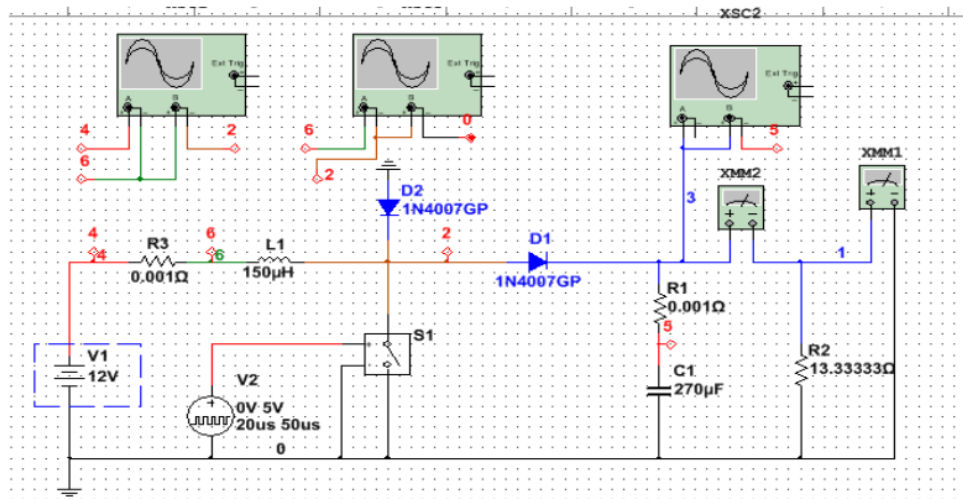


Figure 32- Multisim circuit for the boost converter

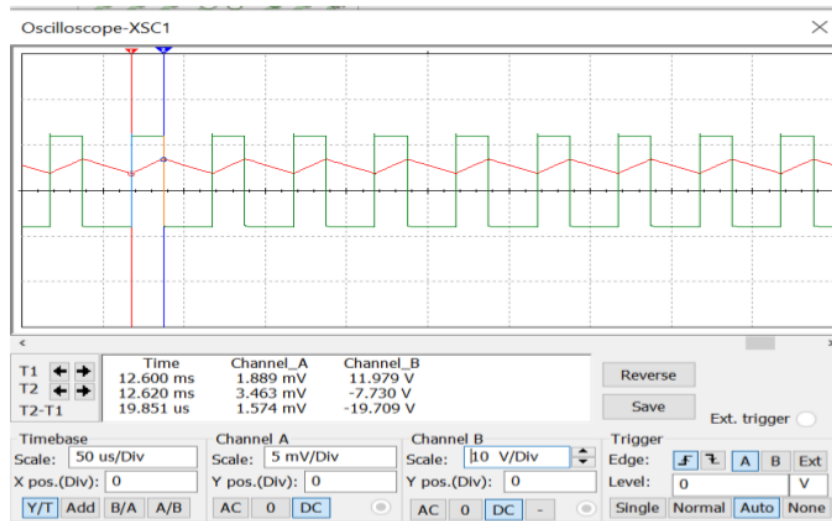


Figure 33- input voltage waveforms boost converter

Figure 33 is the results from the first analyser on the input circuit. The indicators represent the input voltage pulse peak to peak and continuous output voltages

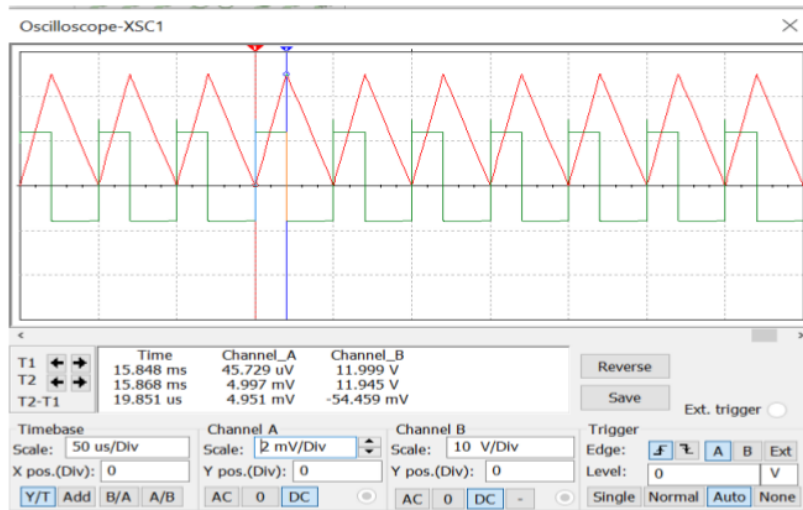


Figure 34- charging capacitor generating higher voltage than E

Figure 34 above shows the results of the switching to generate a higher voltage.

The indicators show t_2 "open" switch, the current in the inductor now needs to discharge to do that the diode allow current to flow to the capacitor so that it can charge above the value of E . As this is repeated the value of V_o becomes greater.

Result prove the theory

Conclusions and recommendations

To conclude this assignment, all objectives set out in the assignment brief were achieved.

The research in to speed control of AC induction motors proves how versatile the motor is and that it probably sculpted the development of speed control today. The main and easiest ways to control speed is changing voltage or frequency ^{and}. The research showed the theory behind how AC three phase supplies are being converted into DC and back to AC output current wave with DC components.

There seem to be so many AC induction motor speed control inverters within the industry all with different application, the competitiveness in the commercial market is just going to aid the way for more advanced technologies to become a reality. The research also showed that with AC speed control comes problems which effect supply characterises, generating AC from DC causes harmonics and these harmonics need to be suppressed so that they don't cause unwanted damage to supply line or effect the efficiency of a the motor running.

Simulating how the two main types of inverted use different types of conversion methods to produce the same output requirements proved interesting. Using simple DC switching techniques to produce output waves and how easy with DC it is to change rates of frequency or voltages. The simulation also proved that there is a defined ratio between voltage and frequency to produce more accurate smoother speed control with good motor torque.

Designing and simulating switch mode power supplies is a great take, it proved how a basic circuit with transistors, inductor, diodes and a capacitor can be used to step up or down DC input voltages and also given high or lower currents. The calculation were worked out for values of inductors and capacitors for a given loads and voltage outputs. The calculation proved that a simple gradient equation can be used in cooperating the key components of duty time to create current max output. The theory was backed up with the aid of Multisim allow practical wave forms of voltages and current to be compared. This task experiment definitely proved the theory.

Recommendations would be to actually fully physically test a switch mode power supply and prove all components working together.

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power electronic converters

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

40/100

PAGE 1

PAGE 2

Text Comment. Well structured

PAGE 3

PAGE 4

Text Comment. Section should be numbered

Text Comment. What are the problems?

Text Comment. luck?

Text Comment. no comment

Text Comment. A summary should contain details of each task including findings and conclusions. Were you successful.

PAGE 5

PAGE 6

Text Comment. Only true for PWM drives

PAGE 7

PAGE 8

Text Comment. main problem is large fractional slip affecting efficiency

Text Comment. out dated method, question asks for cage rotor speed methods

PAGE 9



Spelling

Spelling error

PAGE 10

Text Comment. This is not Harvard method of citing

Text Comment. not Harvard

PAGE 11

PAGE 12

PAGE 13

PAGE 14

PAGE 15

PAGE 16

PAGE 17

PAGE 18

PAGE 19

Text Comment. continuous - refers to dc currents only

PAGE 20

PAGE 21

PAGE 22

Text Comment. $t = 2\mu s$, the ON time, you have used the OFF time

PAGE 23

PAGE 24

Text Comment. you could have also measured the average current and voltage to compare

with the design requirements.

PAGE 25

PAGE 26

PAGE 27

PAGE 28

PAGE 29

Text Comment. and

PAGE 30

GRADING FORM: NEW CSG-RUBRIC

CARL
JONES

57

1. ENGAGEMENT WITH LITERATURE



There is some evidence of research from a wide range of sources. However, the Harvard method has not been used. Some research covers aspects not required by the brief. 9/20

9

2. KNOWLEDGE AND UNDERSTANDING



Knowledge and understanding is generally good. 12/20

12

3. COGNITIVE AND INTELLECTUAL



Good evidence of analysis through calculations and results with some useful conclusions. 12/20

12

4. PRACTICAL APPLICATION



Good use of simulation software for inverters and switch mode power supplies. 14/20

14

5. TRANSFERABLE SKILLS



Well structured and presented but there are spelling and grammatical errors. Written within word count limit. Sections should be numbered according to the brief. 10/20 Mark has been capped to 40 due to late submission.

10