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by Sean Jones

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Executive summary

The power and control for induction motors is researched to find what types of inverter suit applications. It was found that sensor less vector drives work best for speed control and a servo drive would be best for position control. It was found that filters are best to be placed before these drives to prevent damage to the motor. Inverter circuits were tested on multisim to compare against theory and found they do. Switch mode power supplies were designed and tested on multisim. These were compared against theory and found the wave forms matched.

A good brief summary but there is much more you could have said about your research

Research

According to Rashid M. H. (2014) the most common ways to control a squirrel cage induction motor's speed is through stator voltage or frequency being varied.

Varying voltage *As an electrical engineer, you have to remember*

how to spell the word voltage
The method of voltage varying will be using phase controllers. Thyristors are placed in parallel but back to back on each phase as stated by Lander "Voltage controllers use two thyristors in antiparallel." (1993, p. 706). One of these is for the positive half of the wave form and the other for the negative half. According to Lander (1993) SCRs are a suitable type of thyristor for this as they have a high power rating, the switching speed doesn't have to be fast so its 100Hz switching speed will be ok and it not being to be turned off is fine because its on the back end of the wave form that ends at 0v so that will turn it off. Figure 1 shows a typical circuit diagram for this.

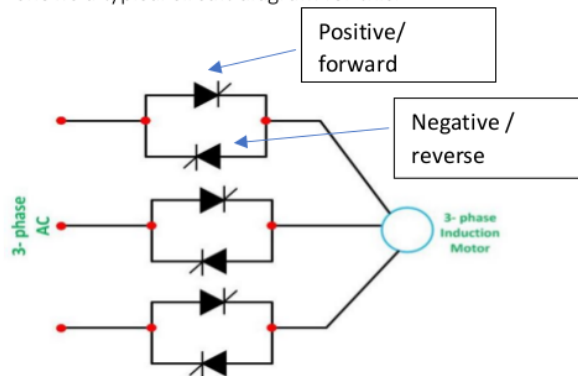


Figure 1 Phase control

After an adjustable delay from the start of the waveform going positive the thyristor is fired allowing current to pass until the voltage goes negative where the same delay takes place for the opposing thyristor. This reduces the RMS due to there's less area under the curve. The thyristor fire only has to be long enough for the SCR to start conducting as it will hold open after that. According to Krishnan (2001) this reduced voltage affects the relationship between voltage and torque on the induction motor resulting in a reduced load and thus a reduced motor speed. Figure 2 shows how the wave form of this speed controller looks. Alpha is the delay angle of the trigger of the thyristors. There is voltage present through back emf within this part.

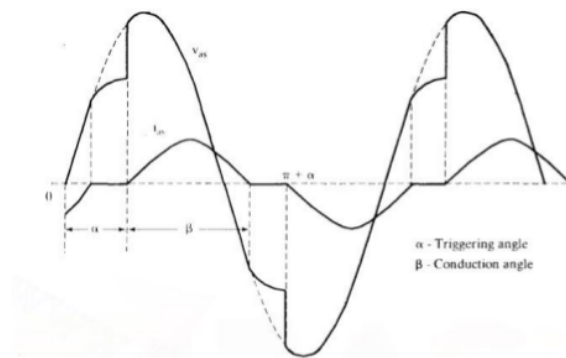


Figure 2 voltage and current characteristics of a phase controller (Krishnan, 2001)

Varying frequency

When using frequency control, the AC is converted to DC then chops up the wave form to make AC at the desired frequency. According to Shirke (2013) a 3 phase system will usually have the principle of Figure 3 where an AC single or three phase input is rectified to DC then inverted back to 3 phase AC. There are multiple methods of converting the DC back to AC in the bridge inverter.

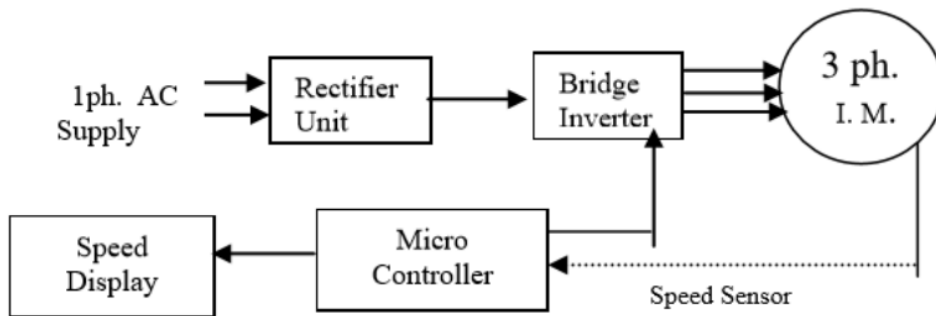


Figure 3 Block diagram of 3 phase speed controller (Mrs.DeepaliS.Shirke, 2013)

PWM is an ideal method for the bridge inverter. It offers low harmonics on the lower voltages which is the bad trait of a quasi-square inverter. A PWM inverter works like a traditional PWM system where the ratio between on and off times within 1 period determines the output voltage. There are extra components in the circuit to allow the negative half of the AC waveform. Figure 4 shows the PWM circuit.

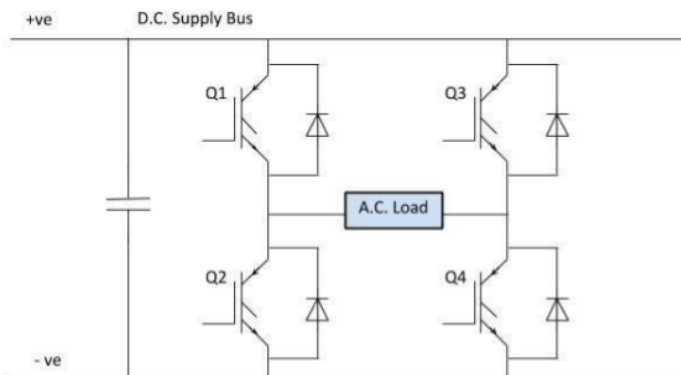


Figure 4 Bridge inverter for PWM circuit

The controller is set up so that the thyristors are fired for longer until the peak of the average voltage is reached then gradually reduced until its back at 0v it then does this in reverse for the negative half. This is shown in Figure 5.

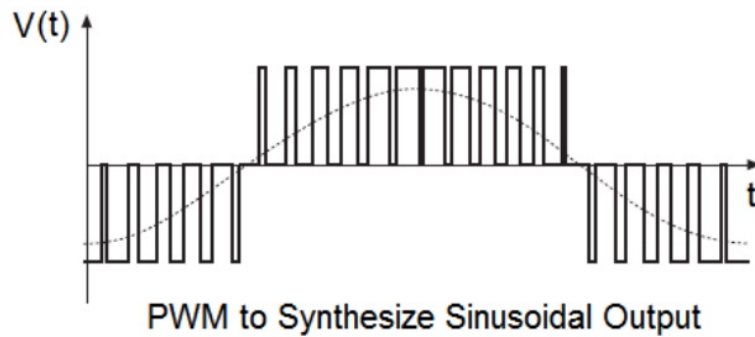


Figure 5 PWM Sin wave

punctuation

The motors maximum torque is achieved when at an optimum ratio between voltage and frequency. This allows another concept of speed control which is to combine voltage and frequency control to maintain a constant ratio between voltage and frequency. IJERT states "V/F ratio is kept constant which in turn maintain the magnetizing ux constant so that maximum torque remain unchanged" (2015, p. 166)

Commercial AC induction motor drives

According to Hughes (2013) sensor less flux vector drives are common in industrial applications. The reason for this is due to it not needing a tacho feedback to the drive. The drive monitors the output voltage and current and predicts the motor speed and makes relevant adjustments. The advantage is that it can turn any simple motor into high control motor without changing the motor. Low start of torque is achieved with these drives as the flux is variable. According to siemens (2020) there is a large range of sensor less vector drives available catering for any AC motors that may be in industries. Figure 6 shows the size range that these drives come in.



Figure 6 Siemens sensor less vector drives (siemens, new.siemens.com, 2020)

Siemens states “It is advantageous to use variable-speed drives wherever bulk, liquid or gaseous materials have to be moved, transported, pumped or compressed” (2020). These drives must be selected correctly for the motor application which must be calculated in advance. These drives tend to be very reliable and require no maintenance other than filters in the enclosure they are placed in when used in dusty environments as airflow is key with these for cooling. The cost of these systems is dependent on size and power of the system. The main increase in price is for the IGBTs and cooling systems.

For more precision position control a servo drive may be more suitable. These systems have encoder feedback which allows a fully closed loop system. According to Advanced Motion Controls “control systems used in everything from CNC machines, robotics, factory automation and more.” (2020). With the availability of advanced modern servo drives any AC motor can be turned into a servo motor with an encoder. This may be ideal for some industrial problems where there is a big motor being used and there isn’t enough budget for a new motor as well as a drive. Siemens offer a large range of these drives, in a range of prices and power. **Figure 7** shows some of the drives available.

Not relevant to the research task, as these use synchronous motors not induction motors.

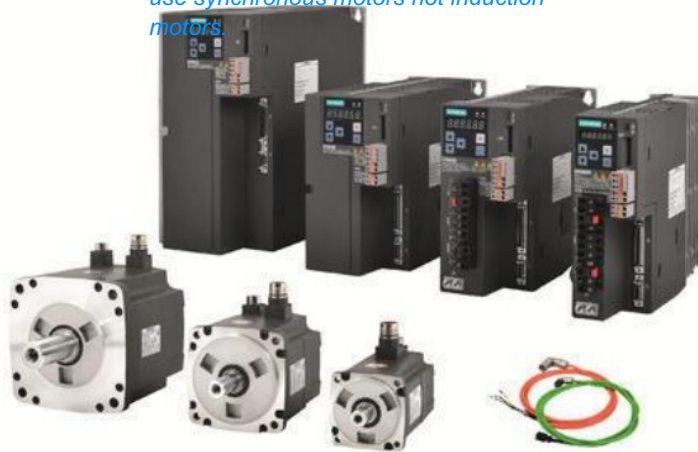


Figure 7 siemens servo drives

Filtering requirements of modern power converters

In any system that involves switching, there is a large opportunity for harmful harmonics. Krishan states “The harmonic voltages produce harmonic currents. which reflect onto the ac-source side.” (2001, p. 98) there aren’t any harmonics in the AC source as it’s a sinusoidal wave form. Without a filter for harmonics a drive may turn into a harmonic generator. Large amounts of heat can be induced into the motor and torque errors whilst running. Filters can be put inline on the AC source side of the drive. An EMC filter will be suitable for a flux vector drive. **Figure 8** shows where the filter will go in the circuit.

You have not answered all parts of the research.

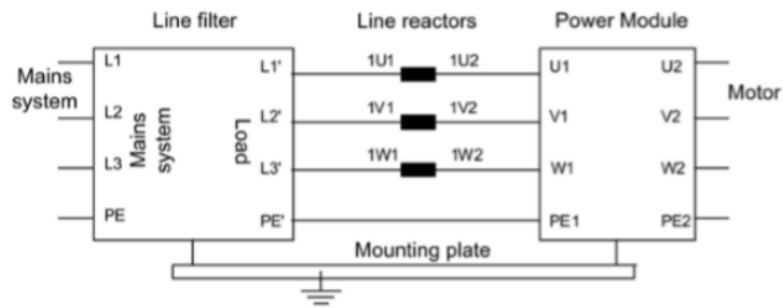


Figure 8 line filter installation (siemens, 2014)

Figure 9 shows the typical circuit design that is used inside a line filter

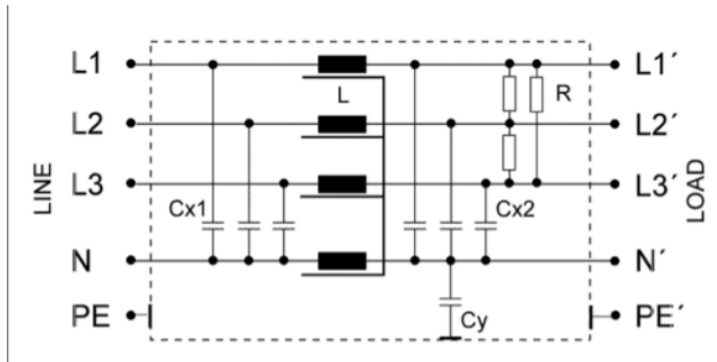


Figure 9 filter circuit

Filters don't have to be specific for on manufacture of drive. As long as the filter is the correct power ratings for the drive and suitable it can be used on the system. Figure 10 shows a list by siemens which associates part numbers for filters related to the power of the motor.

Power Module	Unit rating of the Power Module	Suitable line filter
Line voltage 3-phase 380 – 480 VAC		
6SL3310-1GE32-1AAx	110 kW	6SL3000-0BE32-5AA0
6SL3310-1GE32-6AAx	132 kW	6SL3000-0BE34-4AA0
6SL3310-1GE33-1AAx	160 kW	6SL3000-0BE34-4AA0
6SL3310-1GE33-8AAx	200 kW	6SL3000-0BE34-4AA0
6SL3310-1GE35-0AAx	250 kW	6SL3000-0BE36-0AA0
6SL3310-1GE36-1AAx	315 kW	6SL3000-0BE41-2AA0
6SL3310-1GE37-5AAx	400 kW	6SL3000-0BE41-2AA0
6SL3310-1GE38-4AAx	450 kW	6SL3000-0BE41-2AA0
6SL3310-1GE41-0AAx	560 kW	6SL3000-0BE41-2AA0
Line voltage 3-phase 500 – 600 VAC		
6SL3310-1GF31-8AAx	110 kW	6SL3000-0BG32-5AA0
6SL3310-1GF32-2AAx	132 kW	6SL3000-0BG32-5AA0
6SL3310-1GF32-6AAx	160 kW	6SL3000-0BG34-4AA0
6SL3310-1GF33-3AAx	200 kW	6SL3000-0BG34-4AA0
6SL3310-1GF34-1AAx	250 kW	6SL3000-0BG34-4AA0
6SL3310-1GF34-7AAx	315 kW	6SL3000-0BG36-0AA0
6SL3310-1GF35-8AAx	400 kW	6SL3000-0BG41-2AA0
6SL3310-1GF37-4AAx	500 kW	6SL3000-0BG41-2AA0
6SL3310-1GF38-1AAx	560 kW	6SL3000-0BG41-2AA0
Line voltage 3-phase 660 – 690 VAC		
6SL3310-1GH28-5AAx	75 kW	6SL3000-0BG32-5AA0
6SL3310-1GH31-0AAx	90 kW	6SL3000-0BG32-5AA0
6SL3310-1GH31-2AAx	110 kW	6SL3000-0BG32-5AA0
6SL3310-1GH31-5AAx	132 kW	6SL3000-0BG32-5AA0
6SL3310-1GH31-8AAx	160 kW	6SL3000-0BG32-5AA0
6SL3310-1GH32-2AAx	200 kW	6SL3000-0BG32-5AA0
6SL3310-1GH32-6AAx	250 kW	6SL3000-0BG34-4AA0
6SL3310-1GH33-3AAx	315 kW	6SL3000-0BG34-4AA0
6SL3310-1GH34-1AAx	400 kW	6SL3000-0BG34-4AA0
6SL3310-1GH34-7AAx	450 kW	6SL3000-0BG36-0AA0
6SL3310-1GH35-8AAx	560 kW	6SL3000-0BG41-2AA0
6SL3310-1GH37-4AAx	710 kW	6SL3000-0BG41-2AA0
6SL3310-1GH38-1AAx	800 kW	6SL3000-0BG41-2AA0

you could have summarised the table and cited it for reference

Figure 10 filters for power use (siemens, new.siemens.com, 2020)

Simulation of Inverter Drives

Multisim is used to simulate a quasi-square wave inverter drive. The circuit for this simulates the switch blocks, quasi control block and the motor. Figure 11 shows the circuit. The motor is simulated theoretically with the inductor and resistor in series. The switch blocks are sub circuits shown in Figure 12. This circuit turns the low current pulse into high current handling switch. Figure 13 shows the quasi control block sub circuit. This circuit has a group of signal generators which control the pulsing of the switch blocks.

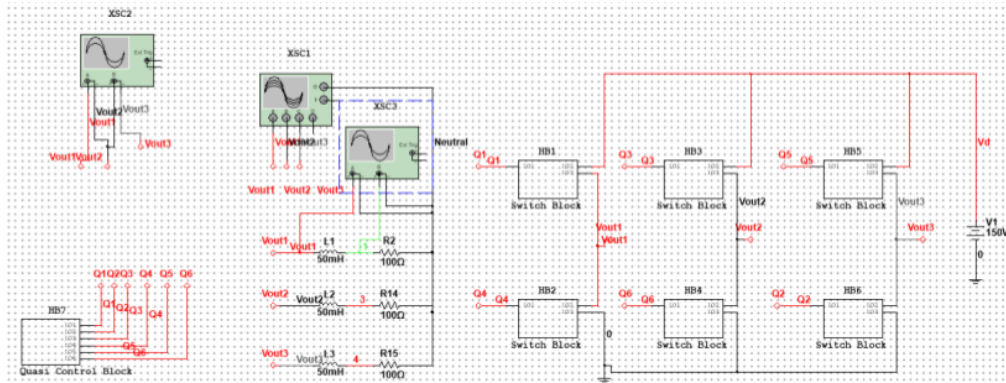


Figure 11 Quasi-square wave inverter circuit

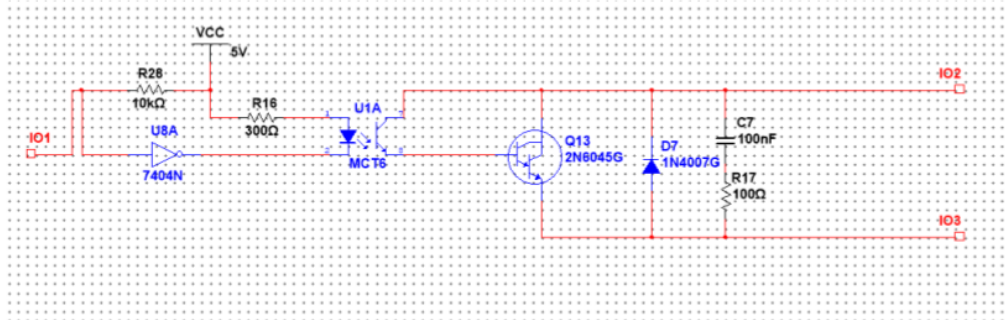


Figure 12 switch block sub circuit

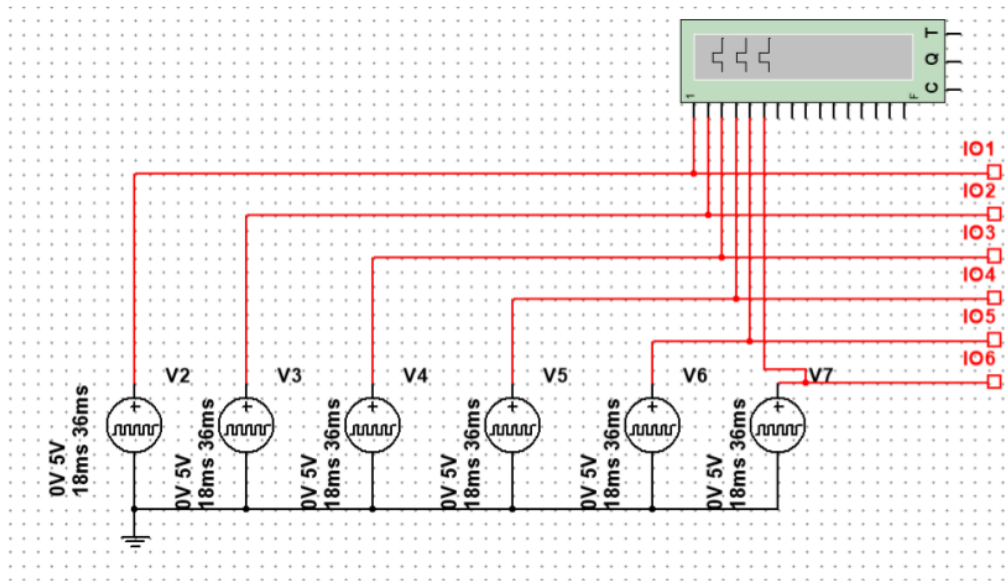


Figure 13 quasi control block

The three-phase waveform produced by this circuit is shown in Figure 14 it shows the phase shift of the 3 phases. They have been shifted up and down to see this. All the wave forms centres are on 0v.

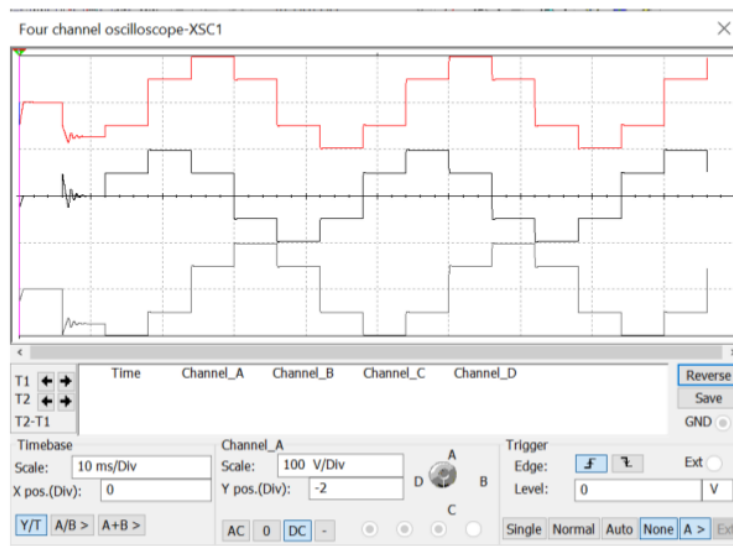


Figure 14 3 phase quasi wave form

The waveform shown in Figure 15 shows the output of the circuit. On the instant of voltage change the current gradient is steep and flattens out this is due to the inductor in the circuit growing and shrinking its field.

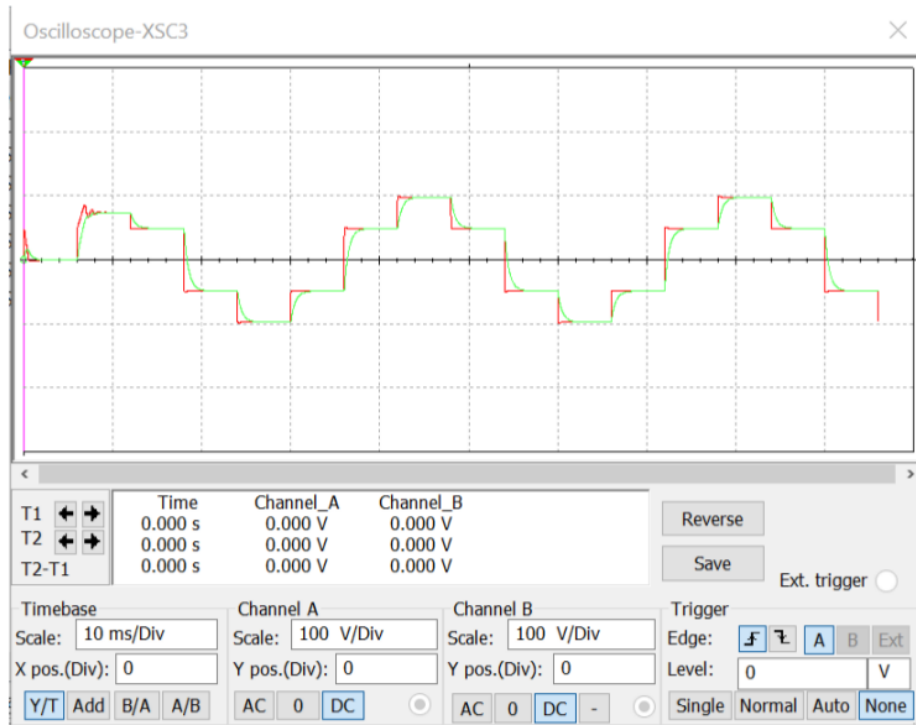


Figure 15 quasi square RMS voltage and current waveform

PWM

Multisim is used to simulate a PWM inverter and motor in Figure 16. The same switch blocks from the Quasi-square circuit are used here and everything is relatively the same apart from instead of the quasi control block a PWM controller is used instead which is standard component for multisim.

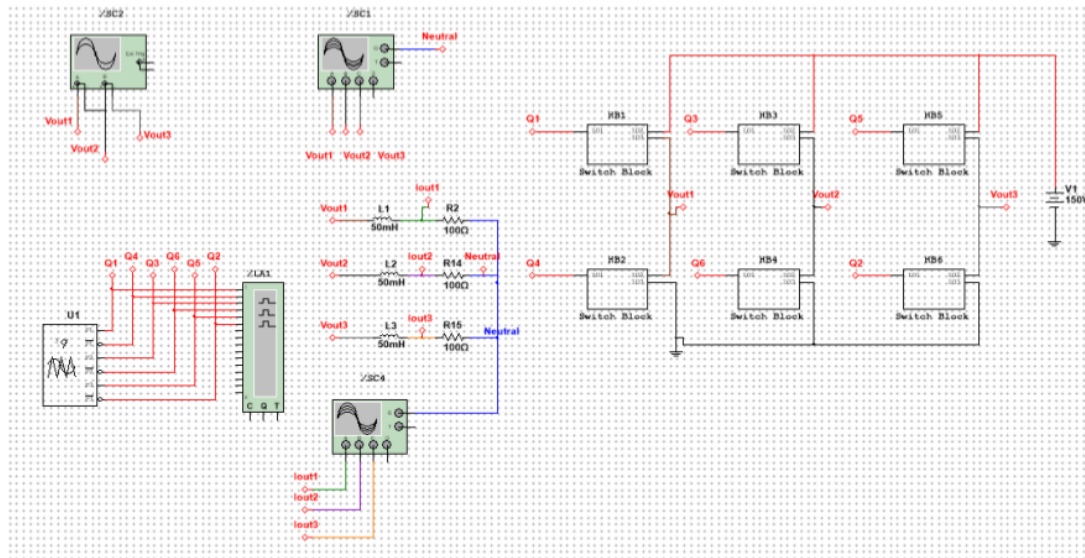


Figure 16 PWM multisim circuit

the output of this circuit replicates what was seen in the research. When the AC waveform begins to rise the pulse are very narrow starting the voltage off small shown in Figure 17. As the waveform reaches its peak in Figure 18 the pulses are much longer giving a higher average voltage. Figure 19 shows the descend of the AC where the pulse gets smaller and smaller until they go negative replicating theory exactly.

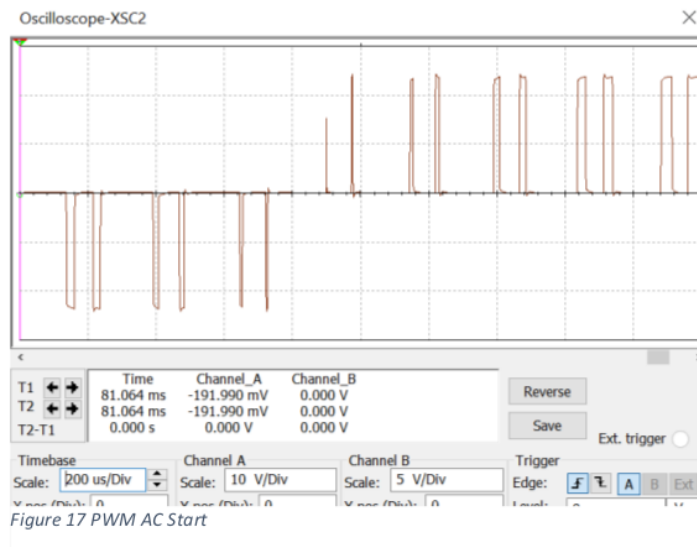


Figure 17 PWM AC Start



Figure 18 PWM AC peak

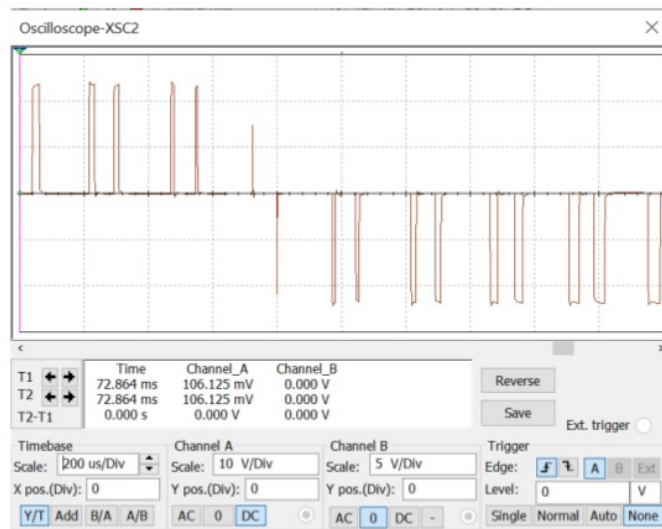


Figure 19 PWM AC descend

Figure 21 shows the average voltage between phases and how it works as a 3 phase system.

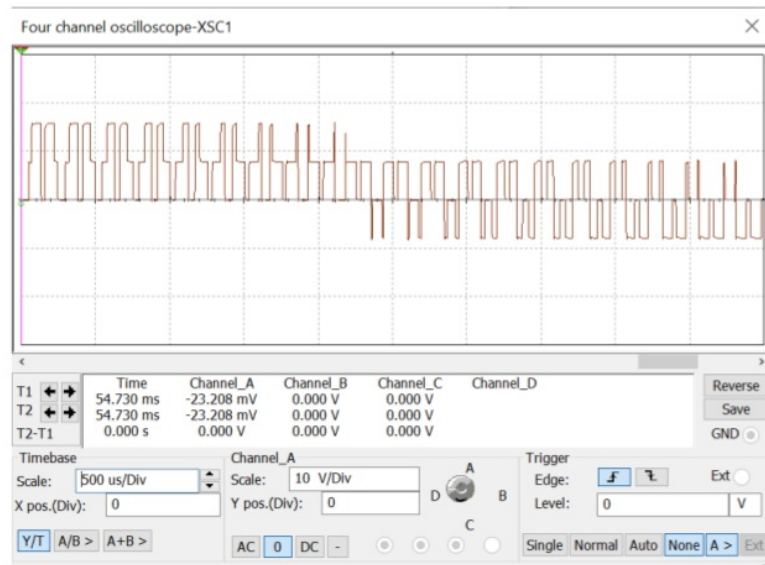


Figure 21 phase voltage

The 3-phase output voltage at a higher frequency is shown in Figure 20 shows the near perfect phase shifted sin waves. There is noise on the wave form due to the pulsing of the circuit but shouldn't produce too much harmful harmonics. This output matches the predicted notes.

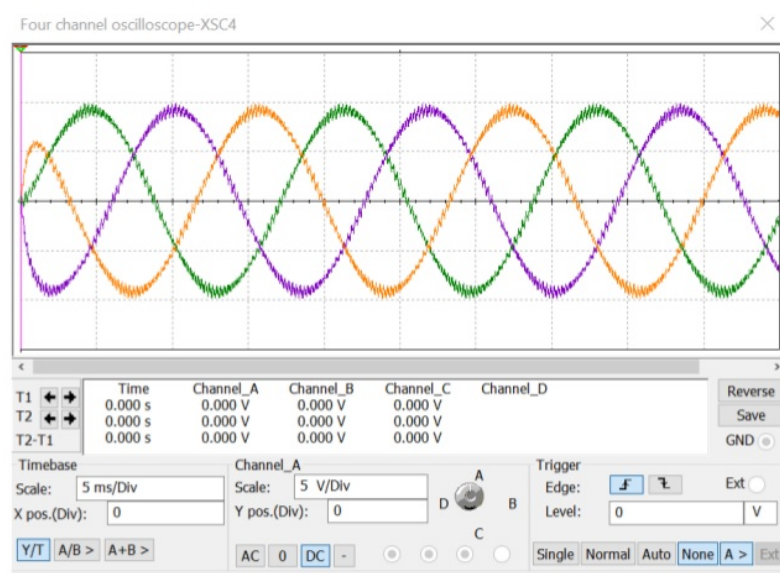


Figure 20 PWM 3 phase wave form

The resolution of the waveform can be increased or reduced to help eliminate some harmonics. This increases the frequency of the pulses without effecting the output frequency or voltage. This is done on the PWM controller by changing the reference signal frequency. Figure 23 shows the frequency reduced by a factor of 10 which will make the resolution worse as shown in Figure 22

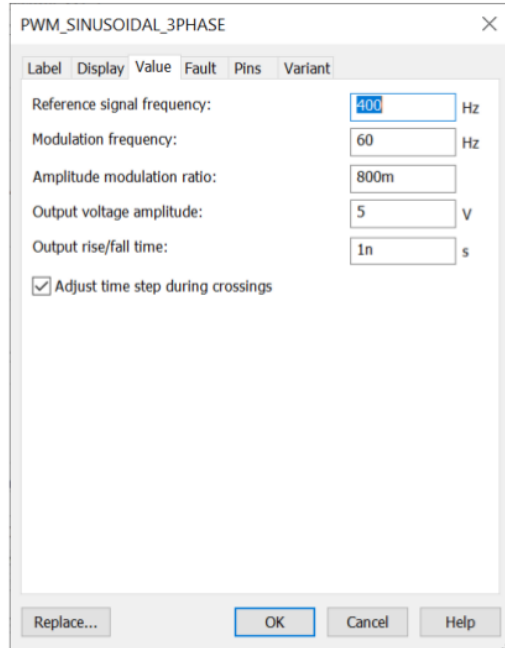


Figure 23 PWM controller reference signal frequency

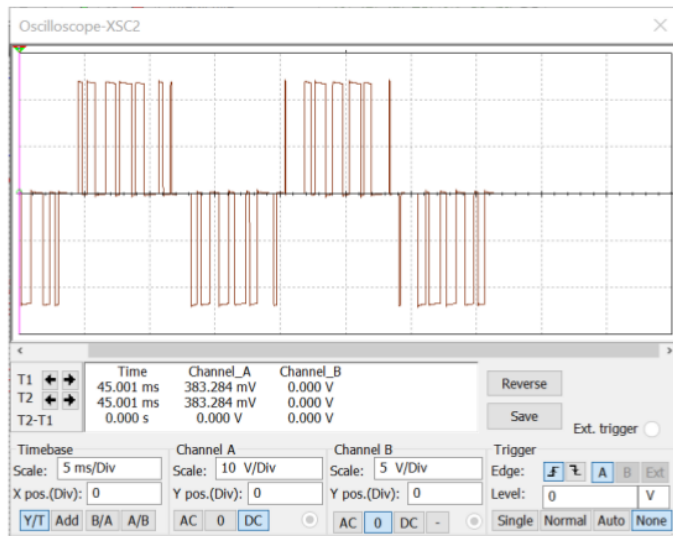


Figure 22 PWM low resolution

Design and Simulation of Switch Mode Power Supplies

Buck Converter

A buck converter is a DC to DC voltage step down converter. It also works as a regulator giving a smooth DC output. Figure 24 shows the circuit.

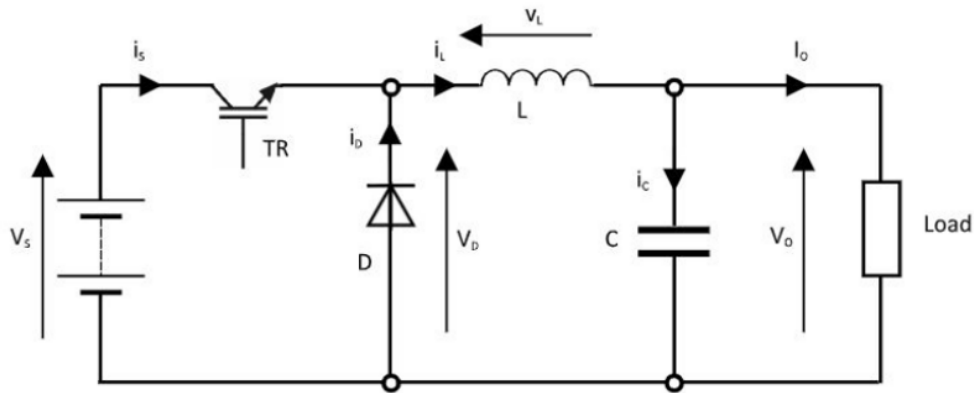


Figure 24 Buck convertor circuit

The values for the inductor, capacitor and the on off times of the transistor are calculated first.

$$V_s = 40V$$

$$\text{Load} = 2\Omega$$

$$V_o = 16V$$

$$\text{Switching frequency} = 200\text{KHz}$$

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

The duty cycle and on off times are now calculated

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

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

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

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

Therefore

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

$$t_1 = \frac{16}{40} \times (5 \times 10^{-6})$$

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

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

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

The rate of rise of i_L is $E - V_o = L \frac{di_L}{dt}$ when the switch is closed

Therefore

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

When the switch is opened. The equation $0 - V_o = L \frac{di_L}{dt}$ meets the rate that i_L will fall.

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

i_L will rise to double $i_o = 16A$

since

$$I_o = i_L + i_C = 8A$$

i_C falls from $8A$ to $-8A$ as i_L rises

inductor current is

$$i_L = i_S + i_D$$

When switch is on

$$i_L = i_S$$

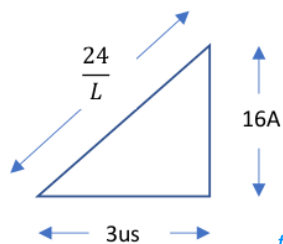
When switch is off

$$i_L = i_D$$

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

Therefore

$$\frac{di_L}{dt} = \frac{24}{L}$$



the
correct
on
time is
 $2\mu s$

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

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

Therefore

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

$$= 4.5 \mu H$$

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

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

Therefore

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

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

The circuit is simulated onto multisim and the values Figure 25 shows this circuit. The values shown on the Multimeters shows the 8.11A and 15.968V output across the load. this shows the circuit meets the requirements of the design.

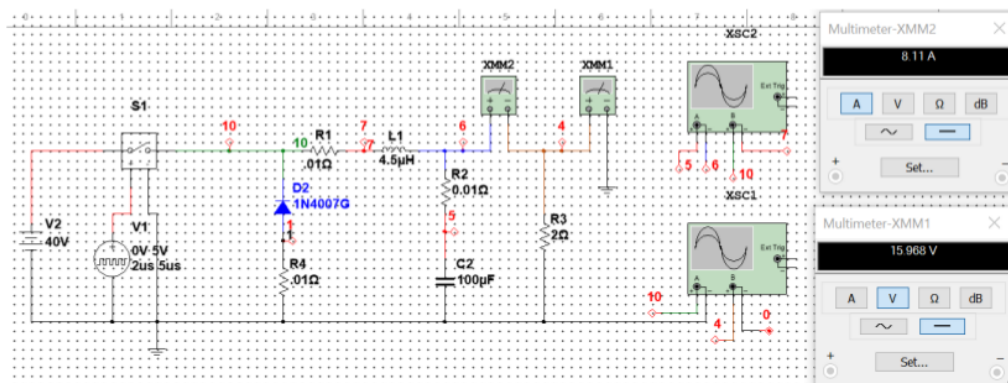
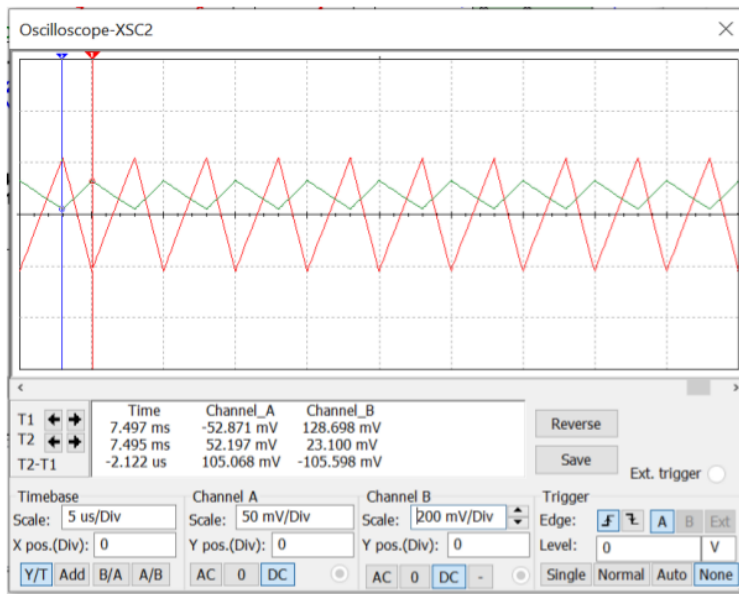


Figure 25 Buck convertor circuit



current is not 'just continuous'

Figure 26 Buck convertor peak to peak ripple

Figure 26 shows the peak to peak ripple being 0.105A which is within the specification. This waveform replicates the theory and was expected. The current is continuous here as the green line stays above 0. The red line is the capacitors current which starts to fall as the current on the load goes up and vice versa

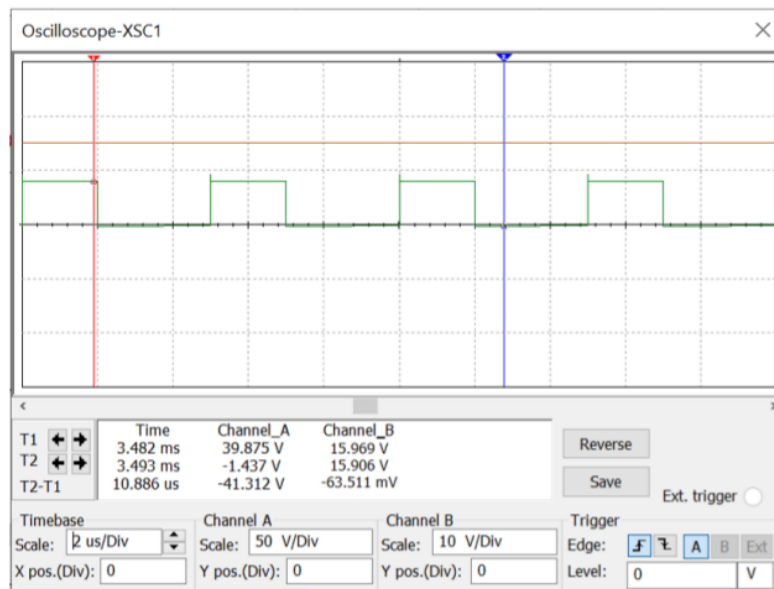


Figure 27 Pulse input Vs output

Figure 27 compares the pulsing input against the solid output. It shows the input as 41 volts but this is due to it going slightly negative on the waveform. The output shows 15.969 which is ideal.

Boost convertor

A boost converter uses the same components as a buck converter but for different purposes. The boost converter is used as a step-up DC to DC voltage converter. Figure 28 shows the circuit. This circuit works by having the thyristor open and charging up the capacitor. The thyristor is then closed allowing the inductor to build up a charge. The switch then opens which creates large voltages on the inductor as its field shrinks. This voltage passes through the diode and further charges up the capacitor until the capacitor voltage is greater than the inductor voltage then the diode blocks any return current. The thyristor then closes and repeats the process. The limiting factor of this system are the components ratings.

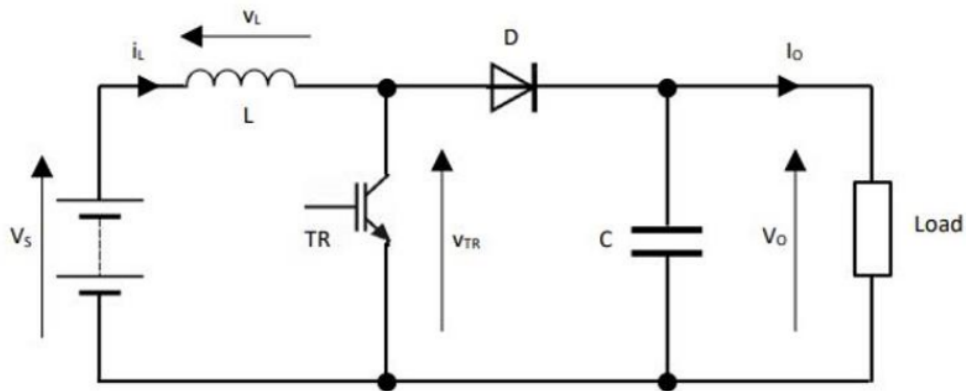


Figure 28 boost convertor circuit

The component values are calculated in order to simulate this design.

V average across the inductor in a complete cycle = 0

Therefore

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

Therefore

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

And

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

The switching period is T & the duty cycle is D

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

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

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

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

$$T = \frac{1}{20KHz}$$

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

$$I_l(av) = \frac{V_o}{V_s} I_o$$

$$I_l(av) = \frac{20}{12} \times 1.5 = 2.5A$$

$$I_l(peak) = I_l(av) + \frac{\Delta iL}{2}$$

$$I_l(peak) = 2.5A + \frac{1.6}{2} = 3.3A$$

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

So,

$$I_o = \frac{V_o}{R} = I_l(av) \frac{V_s}{V_o} = I_l(av)(1 - D)$$

$$I_l(av) = \frac{\Delta iL}{2}$$

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

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

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

$$D = 20us$$

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

Multisim is used to simulate this circuit in Figure 29. A controllable switch and a square wave function generator are used in control of the switch. The output of the circuit is what was required from the design when tested.

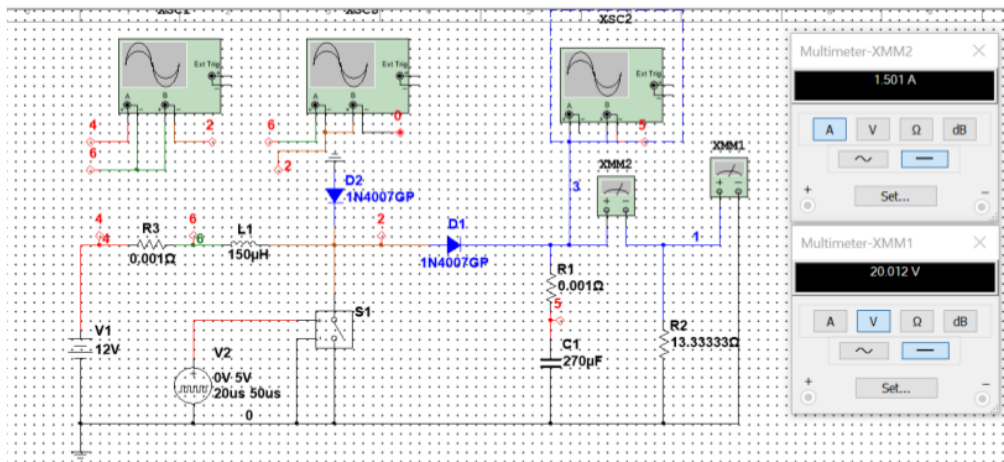


Figure 29 boost converter multisim circuit

Figure 30 shows the capacitor voltage compared to the inductor voltage. the inductor is the green line. When it falls the capacitor voltage (red) rises and vice versa.

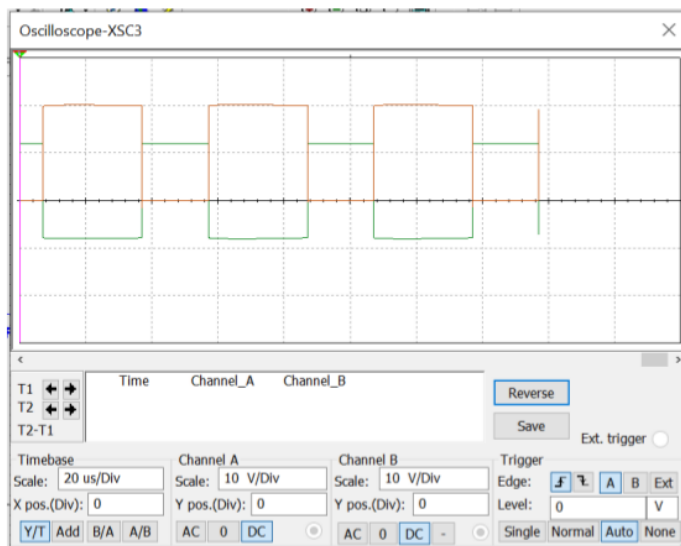


Figure 30 boost convertor inductor vs capacitor voltage

The output voltage and current is shown in Figure 31. The current has a 0.001 A peak to peak ripple and is continuous

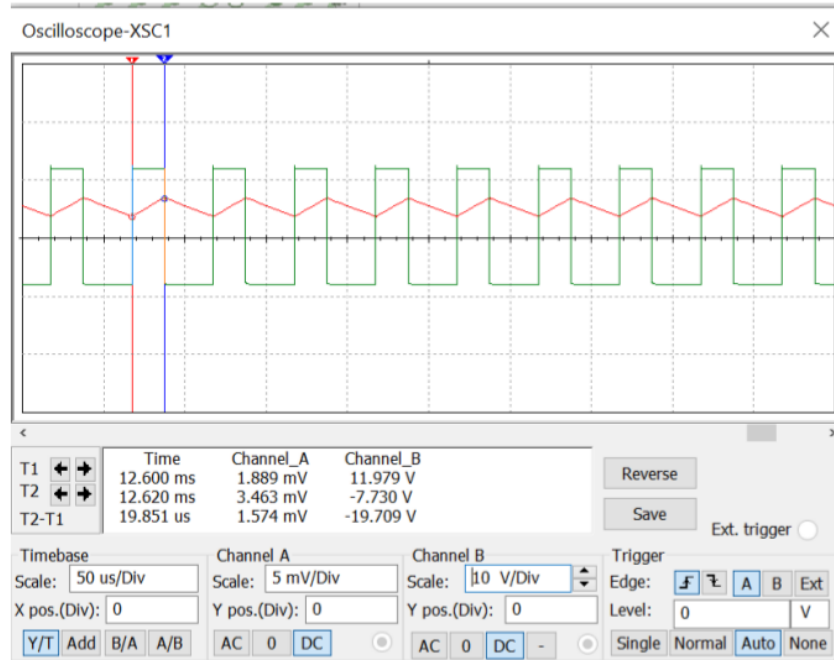


Figure 31 boost convertor output

The lowest value for the inductor that was calculated is tested in Figure 32.

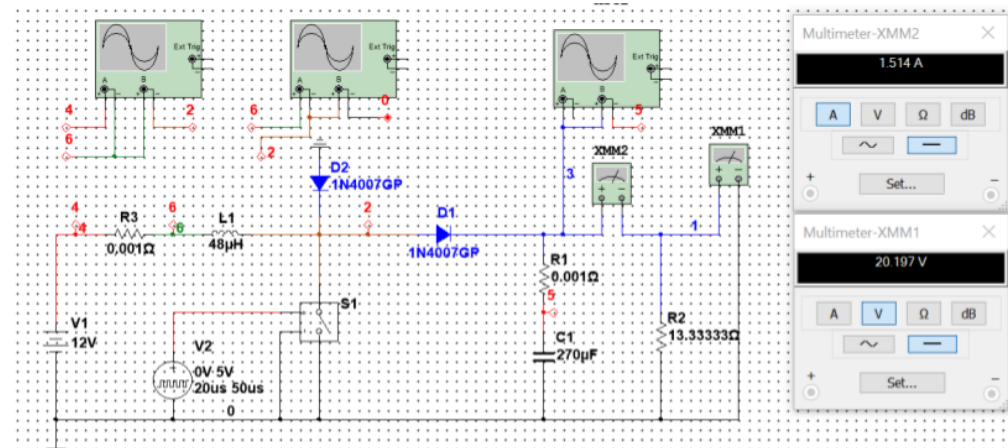


Figure 32 boost convertor lowest inductor value

The output shown in Figure 33 shows the current on the output having a lot more ripple and is only just continuous proving that the calculated minimum value is correct.

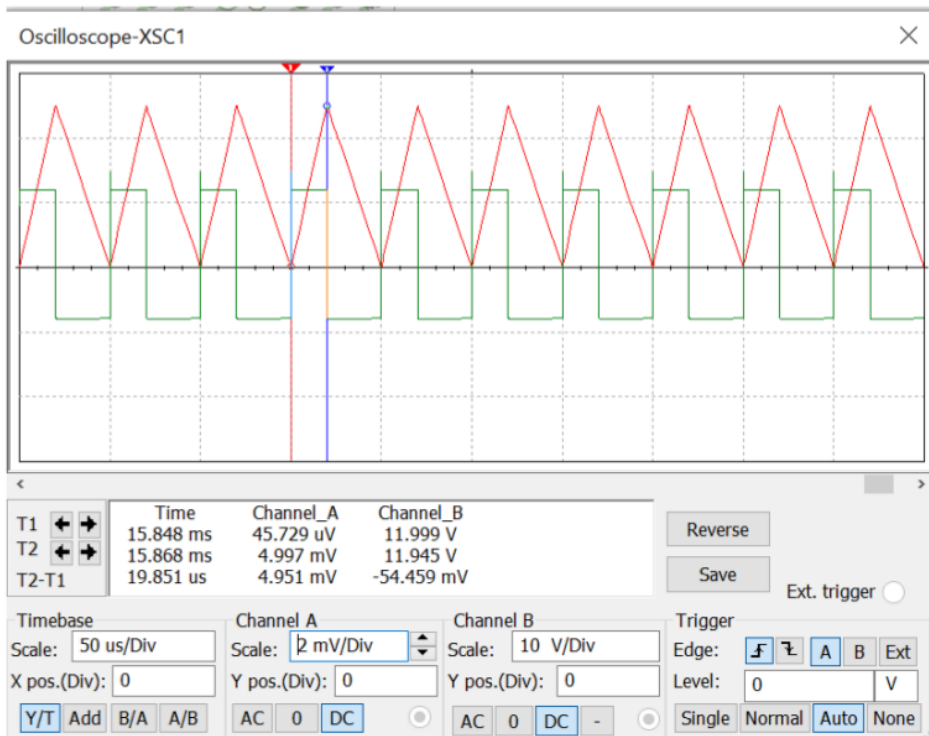


Figure 33 low inductor value results

Conclusions and recommendations

The research found the methods to control the speed of an AC motor. It was found the 2 main ways are through voltage control and frequency control. The voltage control systems were basic systems that although are relatively effective it doesn't give the smoothest of output wave form. Every motor has an ideal V/F ratio and with the voltage control with phase control method only voltage can be altered. A frequency control system such as a PWM drive allows the voltage to be reduced with the on off times of the pulses and the frequency can be varied with the pulses. This allows the correct V/F ratio for maximum motor torque. Types of motor drives and control systems for this was looked at and found that a sensor less vector drive is one of the main methods of motor speed control. The advantage of this system is no speed detection device is needed on the motor it is all done by monitoring the output voltage and current. It was found that filters need to be used on these motor drives to prevent damage to the motor, unwanted noise and effect on other systems in the power network.

Multisim was used to simulate the circuits to understand the behaviour of the circuits. The multisim proved the circuits to work just as the theory and showed the slightly distorted AC output but was found that this could be improved by increasing the resolution of the pulses to give a better average waveform. Switch mode power supplies were designed and values calculated to give ideal components for the workings. These were then tested on multisim to prove their workings and calculations.

It would be recommended to look deeper into the servo control of AC motors to see how the systems control the power and speed of the more under fast acceleration and deacceleration to get to precise positions without overshooting. Further tests could be done to see which types of drives are most efficient for money savings for industries.

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FINAL GRADE

GENERAL COMMENTS

Instructor**63**/100

PAGE 1

PAGE 2

Text Comment. Sections should be numbered as stated in the brief**Text Comment.** Title is "List of Figures"PAGE 3

Text Comment. A good brief summary but there is much more you could have said about your researchPAGE 4

Text Comment. As an electrical engineer, you have to remember how to spell the word voltage

QM

Spelling

Spelling error

QM

Spelling

Spelling error

QM

Spelling

Spelling error

PAGE 5

QM

Correctly cited

Citation method conforms to Harvard standard, well done

Citation method conforms to Harvard standard, well done.

Text Comment. Always start a sentence with a capital letter

PAGE 6

Text Comment. punctuation

PAGE 7

Text Comment. Not relevant to the research task, as these use synchronous motors not induction motors.

Text Comment. You have not answered all parts of the research.

PAGE 8

PAGE 9

Text Comment. you could have summarised the table and cited it for reference

PAGE 10

PAGE 11

PAGE 12

PAGE 13

PAGE 14

PAGE 15

PAGE 16

PAGE 17

PAGE 18

Text Comment. unfinished

Text Comment. the correct on time is 2us

PAGE 19

Text Comment. This is incorrect because you have used the off time instead of the on time

Text Comment. current is not 'just continuous'

GRADING FORM: NEW CSG-RUBRIC

**SEAN
JONES**

63

1. ENGAGEMENT WITH LITERATURE



Evidence of reading from a small range of sources cited correctly but listing should contain dates accessed. Further areas could have been researched and not all aspects have been covered. Section on servo drives was not appropriate to this assignment. 11/20

11

2. KNOWLEDGE AND UNDERSTANDING



Knowledge and understanding are good as seen in the research and the explanations of the simulation tasks. 14/20

14

3. COGNITIVE AND INTELLECTUAL



There is good evidence of critical analysis in calculations and comparison with simulation results and reasonable conclusions. 13/20

13

4. PRACTICAL APPLICATION



Excellent use of the Multisim software with good present of results. 15/20

15

5. TRANSFERABLE SKILLS



Report is well structured but sections should be numbered as stated in the brief. Writing style is awkward, contains many spelling, punctuation and grammatical errors. You must proof read your work before submission.

10