DESIGN AND ANALYSIS OF AN INTERFACING CIRCUIT FOR
SOLAR CELL SYSTEM WITH AC LOAD

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ELECTRICAL & ELECTRONICS ENGINEERING
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By

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(15153)

FINAL PROJECT REPORT

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CERTIFICATION OF APPROVAL

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Approved:

_____

AP Dr. Nordin Saad

Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

September 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the reference and acknowledgement, and that the work contained herein have not been undertaken or done by unspecified sources or persons.

_____

Mohd Khairul Ariffin bin Seruji

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ABSTRACT

This report represents a design for an interfacing circuit for solar cell system with AC load. The aim is to produce 240 VAC with 50Hz frequency to power up small AC equipment such as the power drill. This work has involved the design of two circuits, namely the booster with two charge pump circuit and the half bridge parallel bridge inverter that satisfy the requirements. The booster circuit amplifies the very low input voltage from the solar panel to a larger output voltage, while the half bridge PRC converts the DC outputs from the booster to the corresponding AC voltage. The circuits' shows to be a viable to function as an interfacing circuit for the solar panel and the AC load as intended. The output voltage from solar panel, typically 24 V is multiplied using a booster circuit before being converted into alternating current by an inverter circuit.

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LIST OF ABBREVIATIONS

AC   Alternating current

DC   Direct Current

MOSFET   Metal Oxide Silicon Field effect Transistor

PRC   Parallel Resonant Converter

CHAPTER 1: INTRODUCTION

1.1 Background Study

The world energy consumption keeps on rising in parallel with the advancement of technology. The blooming of industrial production further contributes to cause the energy demand to soar. This is reflected in the rapid increment of fossil fuel prices. Apart from the rising cost, how long would the current source last to continue providing energy is also a major concern. Renewable energy sources offer the solution to that issue and could solve other problems caused by the conventional non-renewable energy sources such as pollution and global warming.

Non-renewable energy or often known as conventional energy is still the main source of energy. Despite of the rising cost, they are still cheaper compared to renewable energy, which require complicated and high tech harnessing facilities. Because of that, more study and effort is needed to further utilize renewable energy efficiently. Non-renewable energy sources such as oil are classified as so because they are consumable and will eventually run out. Contrary to that, renewable energy will never run out and supposedly to last forever coming from sources such as wind, wave, tidal, geothermal and solar.

Solar is one promising source of energy because they are available everywhere as it comes directly from the light and heat of the sun. The energy is so vast that the solar energy reaching the earth surface per year is twice than all the non-renewable sources combined [1]. Solar energy can be harnessed using a photovoltaic panels or commonly known as solar cells to produce electricity [2]. The photon inside sunlight will be absorbed , transferring its energy into an electron enabling it to move and becomes current [3].

Despite being a promising energy source, solar energy is still facing barriers as a replacement of conventional energy. One of the main barriers is the leakage inside interfacing circuit. Solar cell produces low DC voltage, which require

boosting, and conversion. The processes suffer some losses due to various issues. This project aims to solve these issues, by proposing to design a better interfacing circuit for solar cell system with AC load.

1.2   Problem Statement

Solar cell produces direct current (DC) voltage, which can be used directly by some small devices with no or minimal interfacing circuit. However some system require the usage of AC source such as in uninterupable power supply (UPS), aircraft power supply and large machine[4]. On the other hand , alternating current (AC) is actually more compelling in transmission and distribution part because it offers better maintenance over long range transmission and the ease in design of distribution networks. That is why there is a need to convert the solar cell DC output into AC . The voltage produced by solar cell is also small, unsufficient to power up an AC load which typically require 240V. Thus, a boost (DC-DC) converter is required to increase the output before being inverted (DC-AC).

Conventional inverter uses transformer to multiply the voltage, and not only the transformer is bulky but also suffered losses that reduced its efficientcy. Newer inverter uses the transformerless design that utilize rapid switching. The switching process will induce voltage spikes which reduce the conversion efficientcy and may cause damage. The inverter part itself also suffer losses due to inductance leakage. In order to maximize the power generated from solar cell, new design should be analysed to provide better features.

1.3   Objectives

Objective of this work are:

- To design high-voltage boost converter for a solar cell system
- To design and analyze a DC-AC Inverter for interfacing the boost converter to an AC load
- To simulate the design on MATLAB/Simulink tool box, OR any equivalent electronic CAD tool.
- To evaluate the performance and characteristic of the design

1.4   Scope of Study

1.4.1 Boosting Circuit

This work involves studying and designing boost converter to achieve high voltage conversion without the switching control strategy. Pre-defined voltage pulse is used in this work. For boosting circuit, the author needs to understand the basic fundamental and relevance theory of conventional boosting circuit and also the improved design that have been proposed by doing research on journal papers, books etc.

1.4.2 Inverter Circuit

Inverter part involves the study and analysis of using conventional method and Parallel Resonant Converter (PRC) strategy. Effect of frequency onto the inverter circuit is studied and analyzed.

1.4.3 Designing the Interfacing Circuit and Simulation Using PSpice

Based on review and research of previous work, the author has come out with suitable method for designing the convertor. PSpice then used to do develop the circuit for simulation and analysis.

1.5   Project Relevancy and Feasibility

This project is relevant to the current situation where researchers are on their way to find alternative energy source to replace the conventional fossil fuel as energy source. Solar energy is the most promising energy source because of its availability. However, the price of the technology is still expensive for domestic use as large area of solar panel is required to power up home equipment. With invention of proper interfacing circuit, the solar panel required would be reduced, reducing both the area and cost. The duration of two semesters is sufficient for the development of this project, which include research, design and analysis.

CHAPTER 2: LITERATURE REVIEW

2.1   Boost Converter

The increasing awareness on the need of renewable energy has driven the demand for solar cell. That will simultaneously increase the need to produce a better interfacing circuit and boost converter is one important part of the process. The traditional boost or fly-back convertor are often used as boosting converter because of their simplicity. Boost converter achieve high voltage gain by having high duty ratio, which also degrades the efficiency[5].Fly-back converter can achieve high voltage conversion without using as high duty ratio as traditional boost converter. However fly-back converter have high leakage despite having large conversion ratio [5]. In [6, 7], coupling inductors are used to get high conversion ratios. However, the voltage spikes caused by leakage inductance are still inevitable causing reduced efficiency [6]. [8] proposed another solution by to use two stage converter which has large conversion ratio and efficiency.

Boost converter also face another problem of voltage spike at the switch caused by sudden interruption of current when switching occurs[9]. The spike can be reduced by introducing snubber circuit which will provide secondary current path around the switch. A few researchers, for example [10 , 11], have proposed their design of boost converter with flyback snubber circuit which can achieve near zero-voltage and zero current switching while relieving stress onto the switch.

Another method of achieving high voltage conversion is by using extra capacitor configuration to further boost the output as proposed in [12]. The design as shown in Fig 1 uses 2-pump capacitor together with one output capacitor, which will be charged during the first mode. During mode 2, both pump capacitor will be discharged which will increase the voltage boosting.
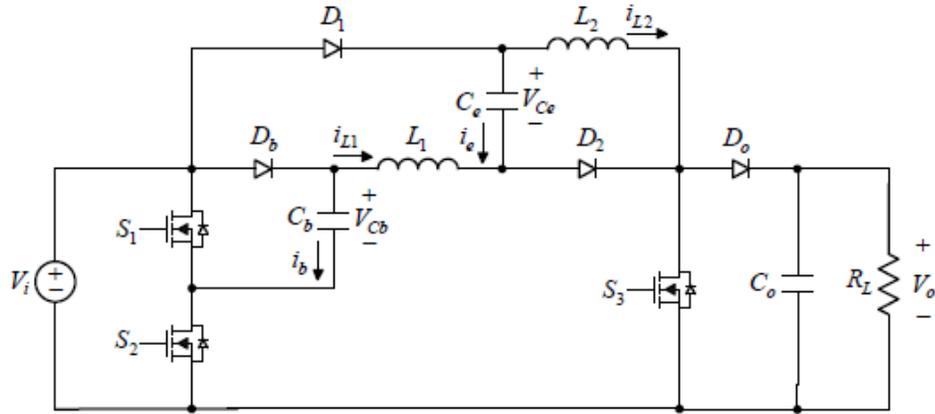
Figure 1: Boost Converter with Charge Pumps

2.2 DC-AC Inverter

DC-AC converter changes the fixed DC source to symmetrical AC output voltage typically at the frequencies of 50 Hz or 60 Hz. Conversion is performed by alternating current path from two sides generally by switching a pair of switch alternately. [13] proposed a design based on buck and boost converter. The design is similar to conventional buck boost converter with the addition of four switches that act as rectifier at the output. These switches will regulate the output to convert them into AC. One of the main issues in inverter circuit is the losses caused by leakage inductance. [14] address this issue especially in photovoltaic energy sources where the interconnection of several distributed solar cells would create parasitic capacitance that is the cause for leakage current. Transformer less inverter design offer lesser the losses, cost and size[15].

2.3 Parallel Resonance Converter (PRC)

Parallel resonance converter (PRC) is widely used dc-dc converters that consists of an inverter and one bridge rectifier and are often operated above resonant [16]. Operating the PRC above resonant has many advantages such as reduction in size of transformers and filter components, no turn on losses, and may not need to use snubber [17]. The operation of PRC below resonance has many disadvantages,

such as the need for RC snubber and di/dt limiting inductances, need for fast recovery diodes across the switches. In this project, the output voltage level is controlled by the switching frequency that is operating above resonance. The switching losses of the PRC are inherently low when operated above resonance [18].

Typical PRC in figure 2 consist of two switches for the inverter part. Only one switch will conduct at one time, allowing current to flow into the supply via the resonating component of inductor (L) and capacitor (C). The pulse duration need to be half of the resonant period time. Without the resonating components, the resulting output of the stage would be square wave that would result in high switching losses [19]. By controlling two identical parallel resonant converters, parallel resonant inverter could be obtained [20, 21]. The second part of the PRC circuit is the full bridge rectifier circuit that will convert the output back to DC waveform.
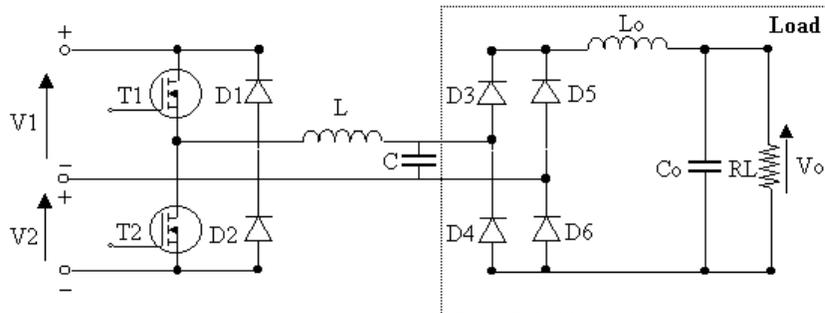
Figure 2: PRC Converter

CHAPTER 3: METHODOLOGY

3.1   Work phase:

1) Literature Review

Review-of previous work done .It is important to understand the concept and basic of interfacing circuit for solar cell. There are quite a number of proposed designs available to be analyze and studied.

2) Basic Design Block Diagram

Basic Block Diagram is as below (Fig 2). The input is to be determined later and the output would preferably be 240V AC, a common voltage used in household. Two circuits will be designed, i.e., a) Boost converter, and b) DC-AC inverter.
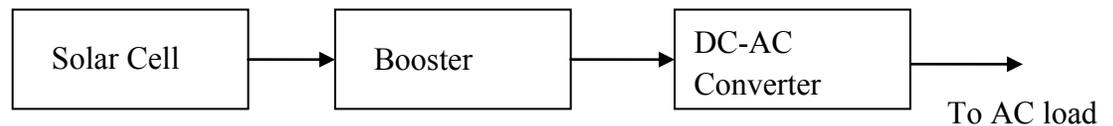
Figure 3 : Basic Block Diagram

3) Simulation of Previous Work

Before designing new circuit, it is important to analyze the existing design. Here, previous work   will be simulated using Multisim/Pspice in order to fully understand the concept.

4) Design and Simulation of Booster Circuit& DC-AC circuit

By referring to the previous work of others, the next step is to design an interfacing circuit with better features.   Based on previous step, it is hoped that enough information have been gathered to be utilized in designing the circuit.

5) Optimizing the design

Booster circuit and DC-AC circuit will be combined together to produce the desired output.

6) Analysis

The final work is to analyze the proposed design. Various performances should be observed to ensure that the circuit is able to reach the objective of project.

3.2 Expected Outcome

At this initial stage, the AC load of the interfacing circuit of the solar cell would be an AC motor with 0.25 kW, 0.5 Amp rating. The motor of this rating should find applications in portable electric drill and small electrical/electronic apparatus.

3.3 Tools/Equipment

1) Multisim
2) Pspice

CHAPTER 4: RESULT AND ANALYSIS

4.1 Conventional Boost Converter

4.1.1 Conventional Boost Converter Design

Analysis is done using PSpice Cadence software. The value for each component is calculated using formula in Appendix A to get the desired output voltage and current. The parameter of circuit and calculated value used are shown in Table 1 and Table 2 respectively. Note that for the purpose of simulation, output of twice the input is expected. However if higher gain desired, higher duty ratio will be required. The MOSFET switch is connected to a voltage pulse. A 12 V voltage source, an inductor and a capacitor are also used in this simulation work. The designed circuit is shown in Figure 4.

Table 1: Boost Converter Parameters

Parameters	Value
Voltage Input, V_i	12V
Voltage Output , V_o	24V
Switching Frequency , F_s	15kHz

Table 2 : Calculated Boost Converter Parameters

Parameters	Value
Duty Ratio	0.5
Output Current	1.2 A
Inductor , L	1.8mH
Capacitor, C	147uF

Analysis of Parametric Sweep performed to get load for different duty cycle and frequency with the range and increment as in table 3 below;

Table 3: Parametric Sweep Parameter for Boost Converter

Parameters	Value
Duty Cycle range	0.2-0.8
Duty Cycle Increment	0.2
Frequency range	10 - 110kHz
Frequency Increment	20kHz
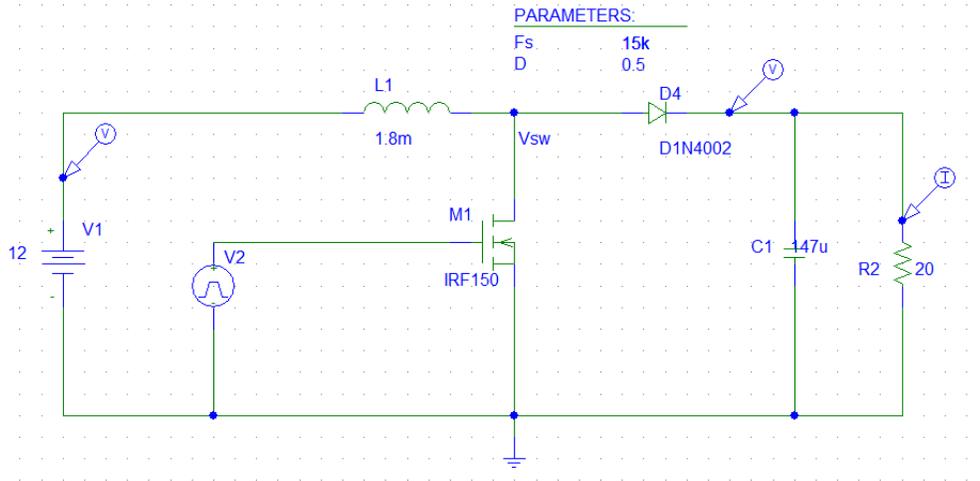
Figure 4 : Conventional Boost Circuit Diagram

Figure 5 shows the switching waveform for the conventional boost converter. V2 is the voltage from pulse source V2 with 15V amplitude during on time and 0 for the next cycle. VM1 is the voltage across the MOSFET switch IRF150. The voltage will be zero when it is conducting (on), and will shows the output voltage when it is off.
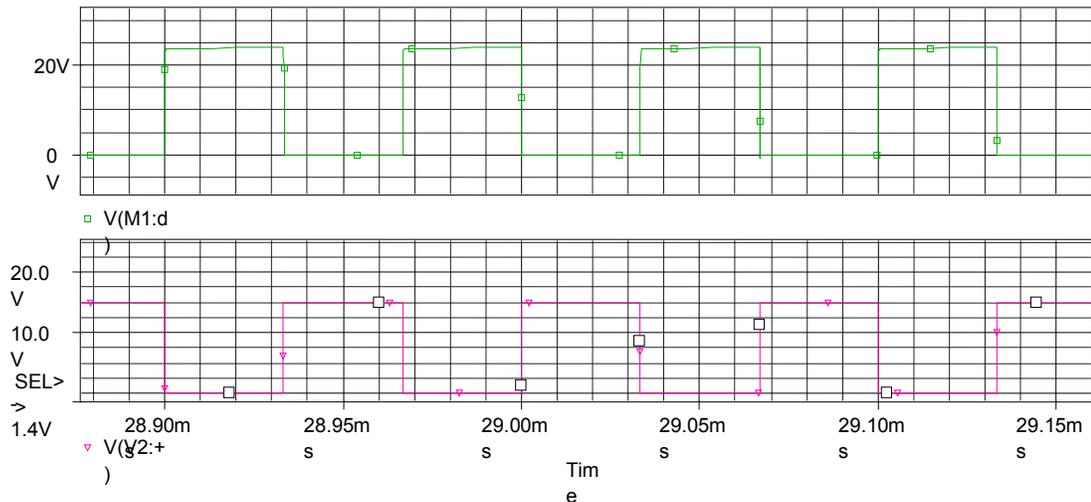
Figure 5 : Switching Waveform

4.1.2 Result of Conventional Boost Converter
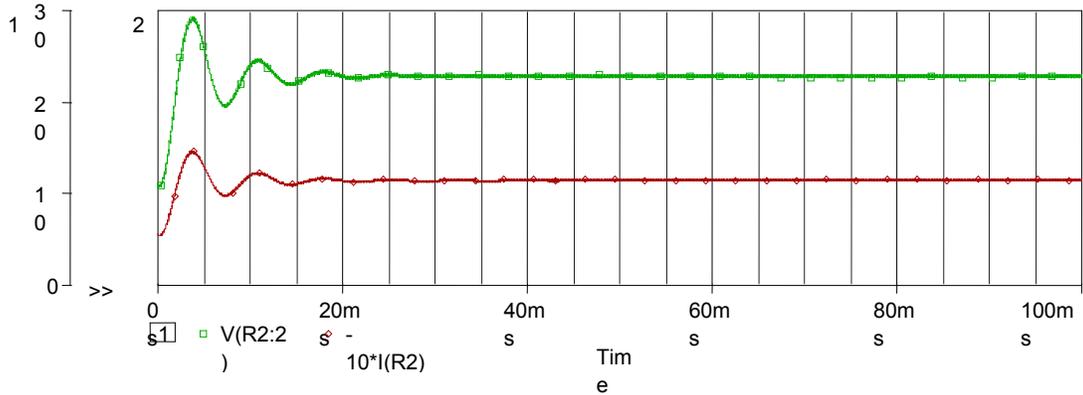
Figure 6 : Boost Converter Output Voltage & Current

Figure 6 shows the output of the conventional boost converter. The amplitude is slightly lower than the calculated value possibly caused by losses. The load current is somewhere around 1.14 Ampere also slightly lower than the theoretical value of 1.2A. Effect of varying the duty cycle and frequency are as shown in Figure 7 below;
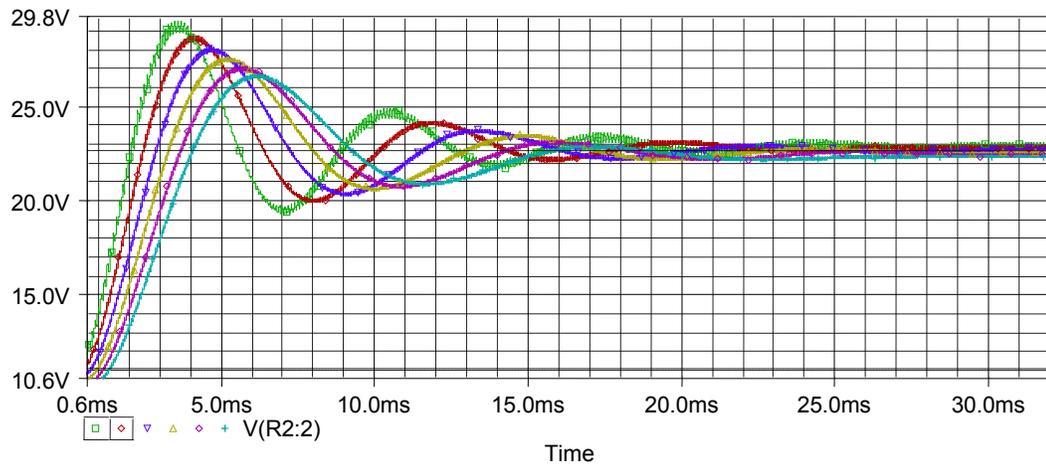
Figure 7 : Frequency Sweep

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The frequency sweep was applied with varying frequency from 10KHz to 110KHz with increment of 20KHz per step. Frequency increment only reduce the time to reach steady state. From the observation, it is safe to assume that the frequency have little impact to the output voltage. However, extreme frequency might have significant effect onto the output voltage .
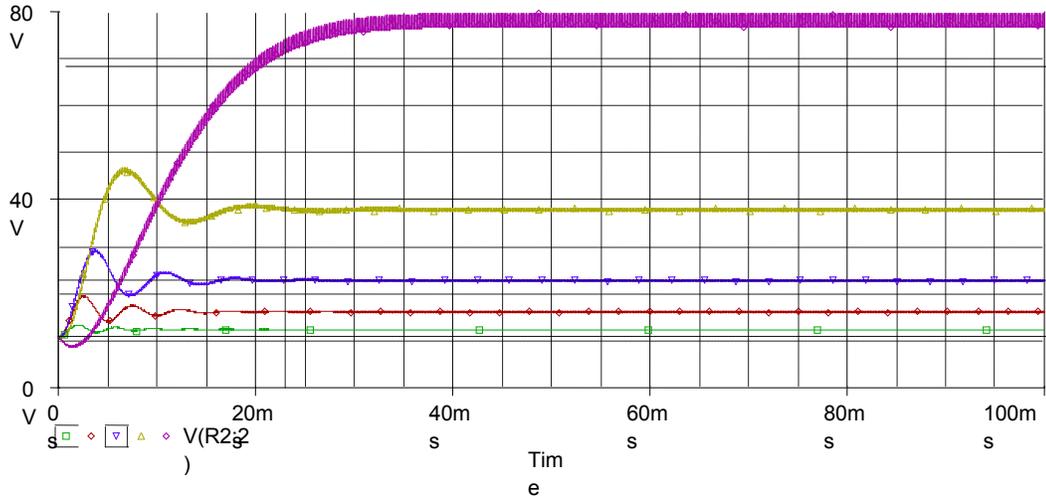
Figure 8 : Duty Cycle Sweep

The duty cycle which determines the duration of switch conduction is important to archieve high voltage gain. In figure 8, can be seen that the output voltage can reach up to 80 V from 12 V by using high duty cycle (D) of 90%. The duty cycle tested was 0.1,0.3, 0.5, 0.7 and finally 0.9. There is barely any voltage gain with 0.1 D, slightly increased voltage amplitude with 0.3 and 0.5 D. Significant changes is seen with D of 0.7 and 0.9 where the amplitude difference are huge compared to lower D. It seem wise to use very high duty cycle in order to get as high gain posible. However, that is not practical and may effect its efficiency. The switching circuit design would be too complicated which will also be reflected into higher cost.

4.2   High Boost Converter with Charge Pump

4.2.1   Boost Converter with Charge Pump Design

The circuit is based on design by [12] which uses 2 extra capacitors, C1 and C2. The value for each component is calculated using formula in Appendix B to get the desired output. The parameter of circuit and calculated value used are shown in Table 4. The designed circuit is shown in Figure 9.

Table 4: Boost Converter with Pump Capacitor Parameters

Parameters	Value
Voltage Input, V_i	24 V
Voltage Output , V_o	120V
Frequency	15 kHz
Duty Ratio	0.5
Output Current	-
Inductor , L1,L2	80uH
Output Capacitor, Co	680uF
Charge pump capacitor C2,C3	330uF

Voltage gain;

$$\frac{V_o}{V_i} = \frac{3 - D}{1 - D}$$

$$\frac{V_o}{V_i} = \frac{3 - 0.5}{1 - 0.5} = 5$$

$$V_o = V_i \times 5$$

$$120 = 24 \times 5$$

The circuit above work in two modes. In the first mode, M2 and M3 will conduct, causing capacitor C1 and C2 to be charged. During the next cycle, only M1 will turn on, while the other two switches are off. Current direction will change, causing C1 and C2 to be discharged into output.

Figure 10 : Switching Waveform

There are 3 MOSFET acting as switch, M1, M2 and M3 controlled by V2, V3 and V4 respectively. The switch M1 and M2 conduct complementarily, when one switch is on, the other switch will be off. A short dead time of 25us is introduced to avoid crossing that would cause switching loss.

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4.2.2 Result of Boost Converter with Charge Pump

This section will discuss the output simulation of High Voltage Boost Converter with pump capacitor.
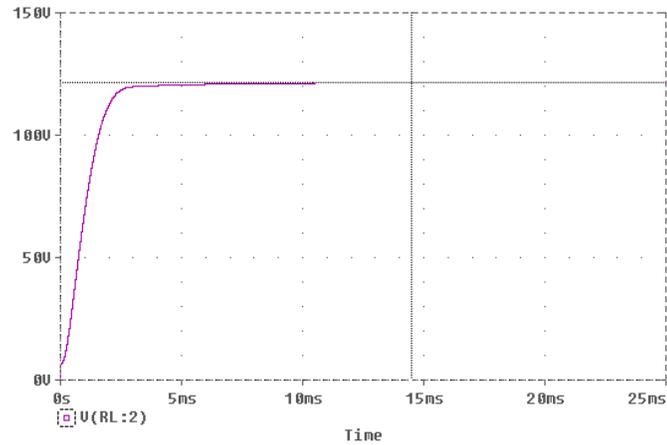
Figure 11 : Output Voltage

The boost converter managed to produce 120V output, which agrees to the theoretical calculation. Despite of using 0.5 duty cycle, the converter gain is 5 time, larger than using conventional boost converter which barely reach 80V with extreme duty cycle. Figure 12 below shows the load current for the circuit;
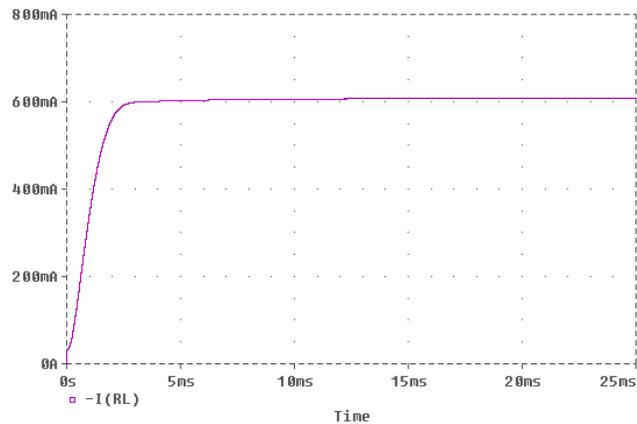
Figure 12: Load Current

The load current corresponds to its voltage value and is affected by the load of 200 ohm resulting in approximately 600mA of current.
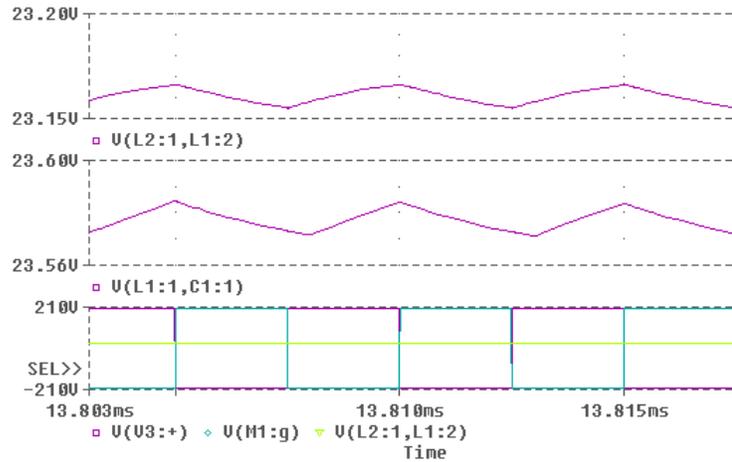
Figure 13 : (a) Capacitor C1 (b) C2 Voltage (c) Switch M1 & M2

The waveform in Figure 13 above shows the capacitor C1 and C2 voltage along with the signal supply to the switch to show the circuit conduction. During mode 2, switch M1 is on, capacitor C1 and C2 will be discharged as shown in the waveform above. During mode 1, switch M1 is off and M2 is on both capacitors will be charged.
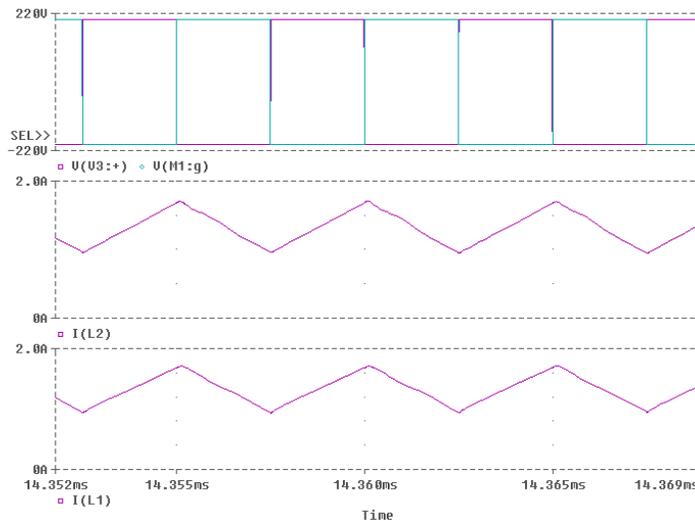
Figure 14: (a) Switch Sequence (b) L2 Current (c) L1 Current

Figure 14 shows the current waveform in inductor L1 and L2. The current flows start increasing during mode 2 (M1 conduct). Then the current flow will decrease during mode 1 (M2 conduct).

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Power loss is contributed by the switching topology, when both voltage and current exist at the same time. Proper switching would be able to reduce the power loss by implementing zero current or zero voltage switching. Figure 15 shows the current flow and voltage across M1;
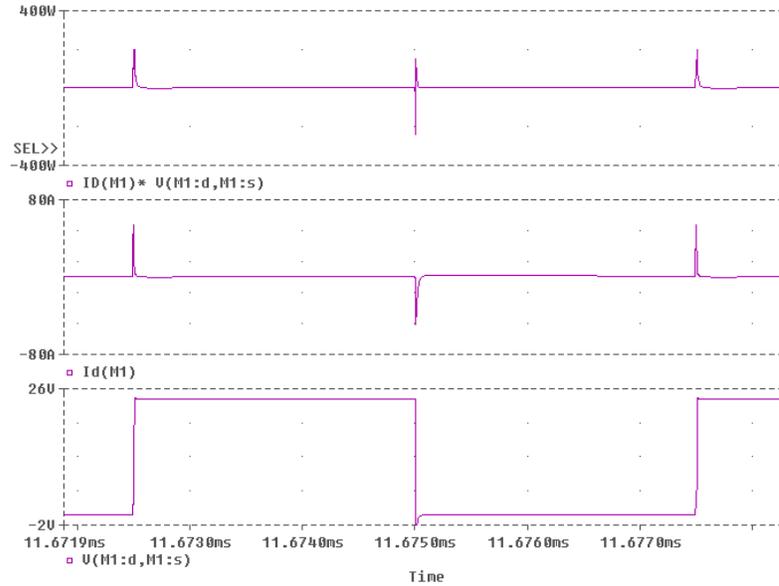
Figure 15 : (a) Power Loss (b) Current (c) Voltage across M1

Current spikes can be observed in figure 15 above. That result in switching loss as both current and voltage conduct at the same time causing power loss according to P = IV. However, the current spikes only happen for a short time (in microsecond), resulting in minimal losses. The concern here is the large current spike would damage the switch or other component or equipment.
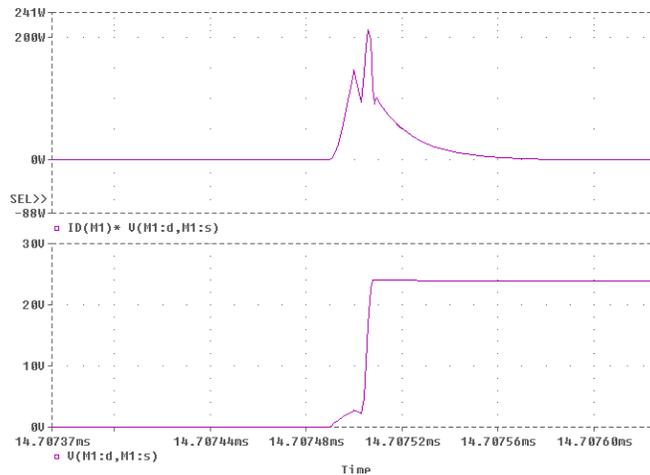
Figure 16: Loss during Switch M1 Turns On

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4.3   Inverter Circuit

There are three possible single phase inverter arrangement; Bi-phase, half-bridge and full bridge. All three inverter utilizes complementary switches to perform the conversion, where only one switch (S1) turns on at one time, while the other (S2) is off. In the next cycle, S2 start conducting and S1 will be off. Although full bridge inverters seem to have extra switches, the working principle is still the same; two switch conducting at a time to complete the circuit. The three configurations are shown below;

<p align="center">(a)   (b)</p>

<p align="center">(c)</p>
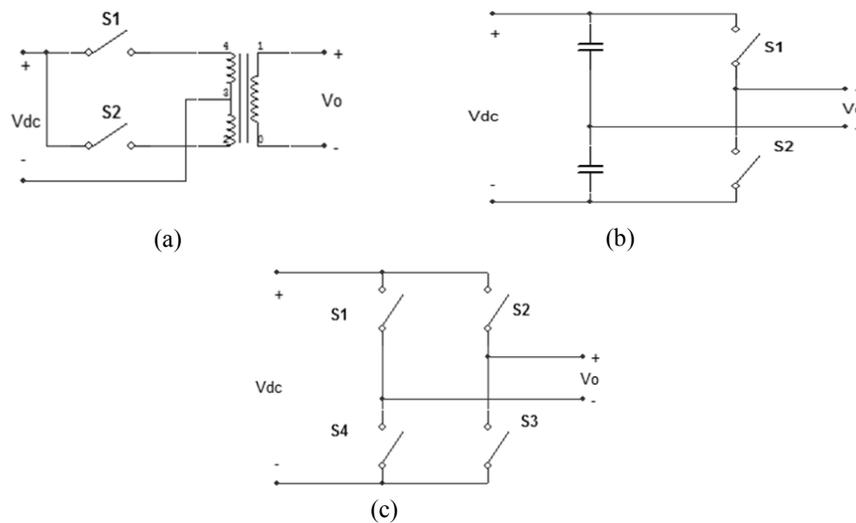
<p align="center">Figure 17: (a) Biphase (b) Half-Bridge (c) Full-bridge</p>

The switching waveform used for Biphase and Half Bridge is similar to previous waveform in figure 4 & 6. The AC output frequency (50Hz) is determined by the switching frequency, which is equal to 1/T. A number of ways can be used to archieve the required switching frequency such as; using RC circuit or implementation of timer 555 IC. However, producing the switching signal is not the main concern of this work, that using simple wave generator would suffice.

Biphase configuration is widely used due to its simple contruction and also the implementation of centre tap transformer. Aside of utilising its centre tap as common point for both cycle , usage of transformer also enable voltage step up. A typical transformer inverter is as shown in Figure 18.
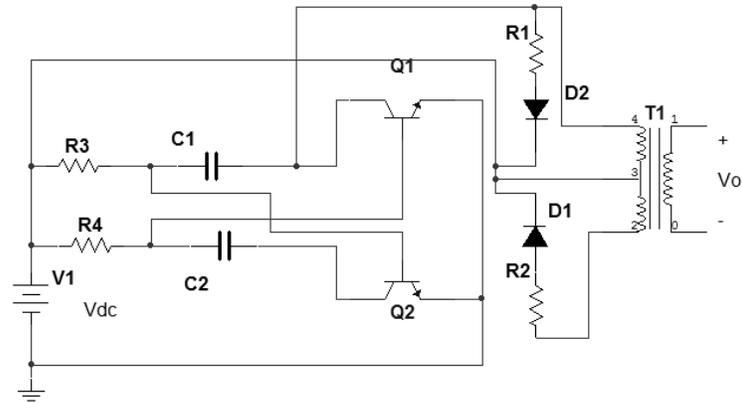
Figure 18 : Half Bridge Inverter

Transistor Q1 and Q2 act as the switch for this circuit, alternating the current flow between D1 and D2 path. The transformer centre tap is the common path to complete the circuit. The frequency used in this circuit is 50 Hz, determibed by the RC circuit. The transformer coil primary to secondary ratio is 0.1, which would be able to step up the voltage by 10 times while alternating the current as shown in Figure 19 below.
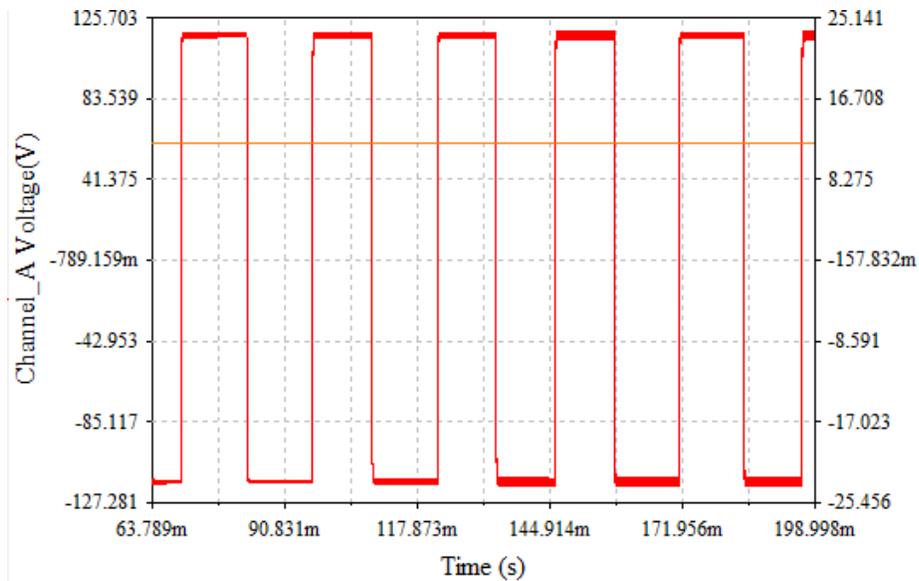
Figure 19: Input and Output Voltage of Half Bridge Inverter

From 12V DC input, AC output of approximately 120 V is obtained. It is important to study the characteristic of this configuration especially the losses suffered from using the transformer.

4.3.1 Half Bridge Inverter Design

Figure 20 shows the proposed inverter circuit for the second part of the project. The half bridge inverter circuit consists of two MOSFET switch, and filtering component LC. The capacitor C1 and C2 serve only to split the DC voltage V1. Power MOSFET is chosen as the switching device. Diode connected parallel with MOSFET is to block and bypass the current through the body diode with significantly higher conduction loses. For this circuit the switching frequency used is 50Hz, which is the desired output AC frequency.
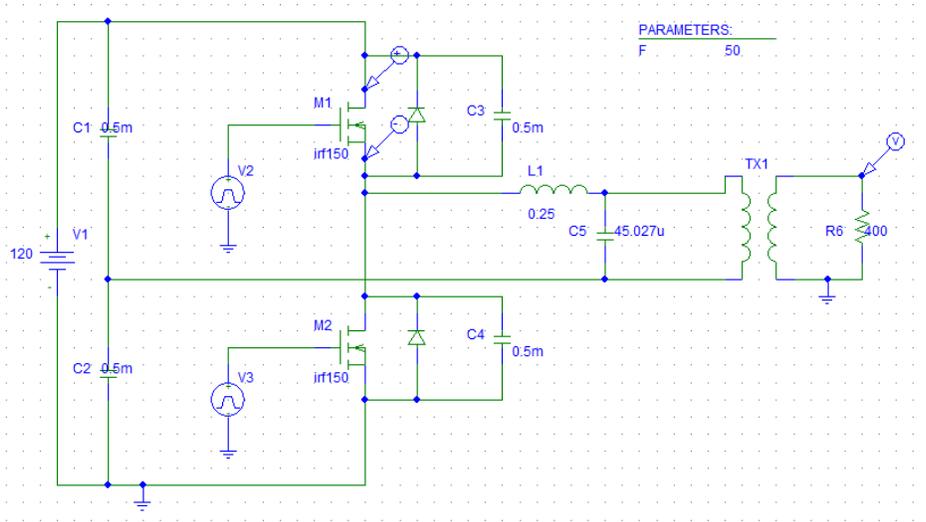
Figure 20: Half Bridge Inverter

To achieve 50Hz waveform, switch M1 and M2 conduct complementarily for half of the duty cycle. The switch setting is as in table below;

Table 5: Switch Parameters

Parameters	Formula	M1	M2
Delay Time	1/(2*F)	0	10ms
Rise Time	10n	10n	10n
Fall Time	10n	10n	10n
Pulse Width (PW)	0.975/(2*F)	9.75ms	9.75ms
Period (PER)	(1/F)	20ms	20ms

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Small dead time is introduced in the switching sequence to avoid overlapping that would contribute into losses. Figure 21 shows the switch M1 and M2 sequence with small dead time between the conduction.
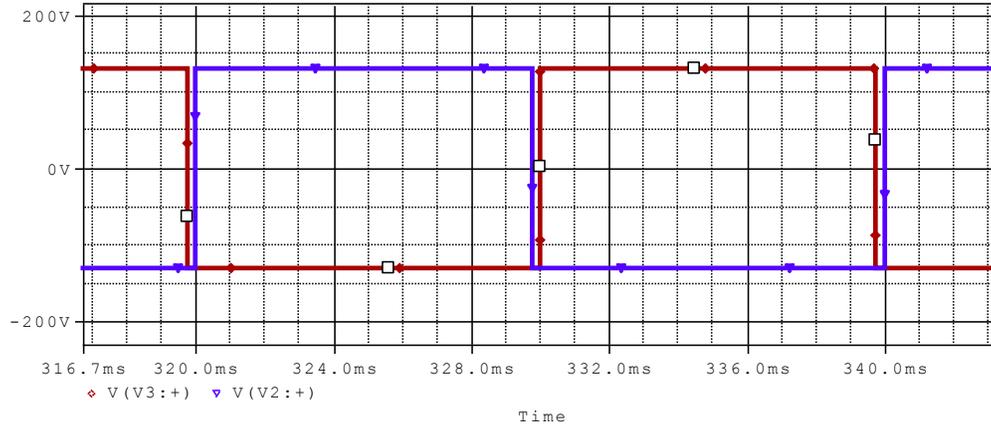
Figure 21: M1 & M2 Switching Sequence

The filtering element, LC is used to produce sinusoidal waveform from the square input. The value is chosen so that the gain, Q would be 5.37 (rms). Thus 240 AC rms (340V peak) voltages will be produced from 120V input.

$$Z_c = \sqrt{\frac{L}{C}}$$

$$Q = \frac{R_L}{Z_c}$$

$$F_r = \frac{1}{2\pi\sqrt{LC}}$$

In this design, the resistor value is set to be R = 400ohm. Using the formula above, Q and F_r formula is solved simultaneously to get L and C value. From the calculation capacitor C is found to be 45.027uF while inductor L is 0.25H.

4.3.2 Result of Half Bridge Inverter

This section will discuss the output simulation of half bridge inverter circuit. From the graph of figure 22, the inverter is able to produce sinusoidal waveform with peak of approximately 340 V from the 120 V DC input.
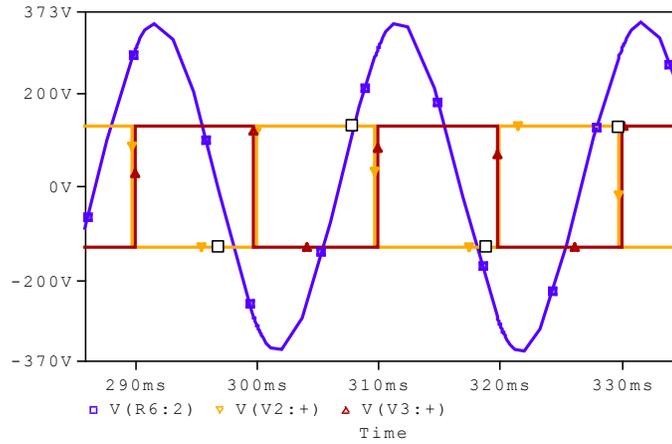
<div align="center">Figure 22: Half Bridge Inverter output</div>

The output waveform starts increasing from its negative peak when the switch M1 (V2) starts conducting. It will continue to increase up to 340V when switch M1 stop conducting. When switch M2 (V3) starts conducting, the output will decrease toward its negative peak of -340V, and the cycle would repeat. As observed in the graph, one cycle took approximately 20ms (340ms-320ms). That corresponds to the desired frequency of 50 Hz.

$$\frac{1}{20\text{ms}}=50\text{Hz}$$
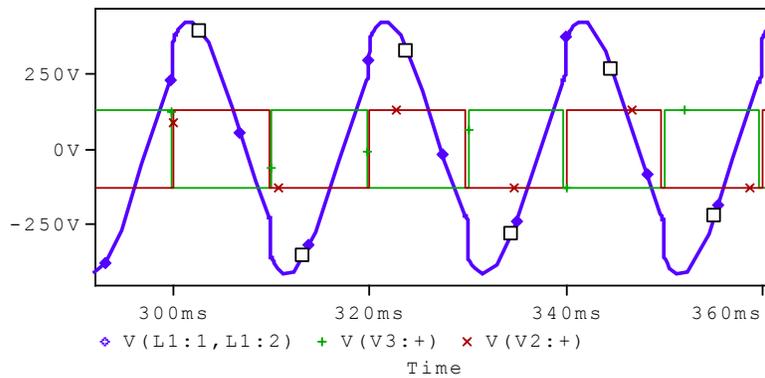
<div align="center">Figure 23: Voltage across Inductor L1</div>

<div align="center">22</div>

The current and voltage at switch M1 is analyzed to determine the losses and it is found that the losses only happen during the turn on as shown in Figure 24 and 25 below.
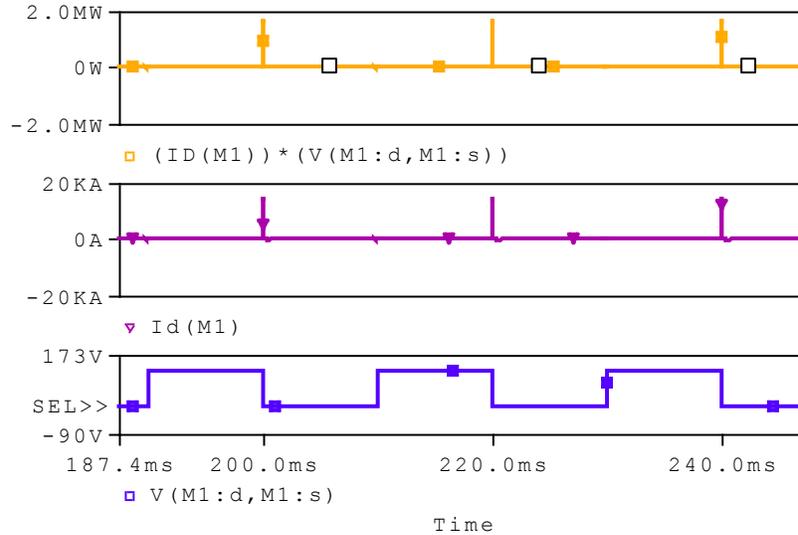
Figure 24: Switch M1 Losses
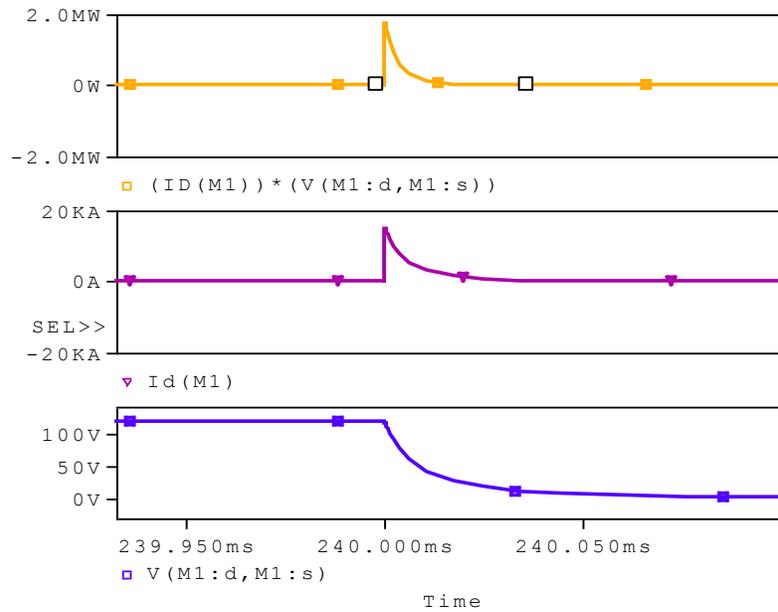
Figure 25: Switch M1 Turn on Losses

There is no current flow when the M1 is off. When switch M1 start conducting, the current increase rapidly resulting into high spike. As voltage across M1 starts falling, the current also reduces back to 0. Even though the duration is short the amplitude of power loss is very large as shown in figure below;
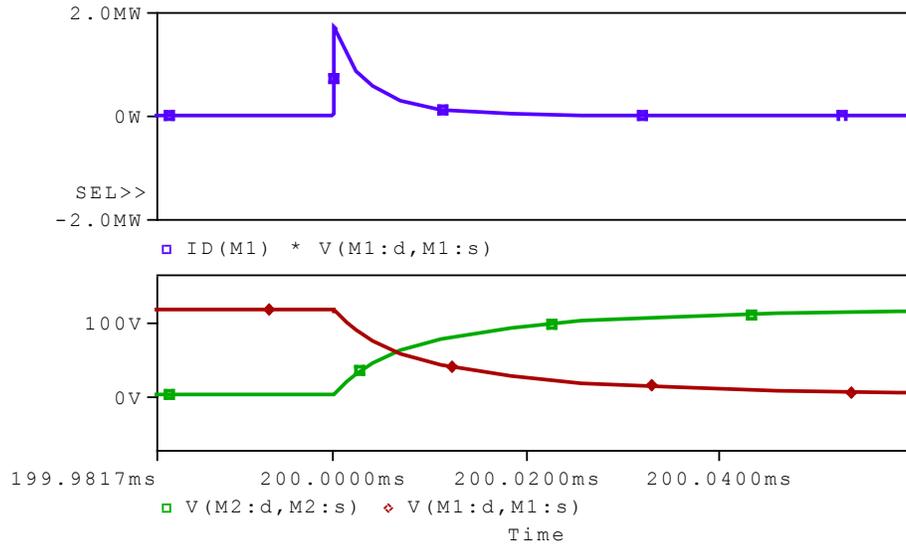
Figure 26: Switch Conduction and Power Losses

The voltage across M2 starts to increase the moment voltage across M1 start falling. The current is highest at that point and start decreasing as the voltage across M1 decreases rapidly.

Conventional inverter circuit is simple and easy in design, but suffers from very high losses as proved in this section. In the next section, an inverter which operates in high frequency is proposed to reduce the switching losses.

4.4   PRC Converter

4.4.1 PRC Converter Design

Parallel resonance converter uses the resonance circuit consisting of capacitor and inductor to control the output amplitude. The resonance frequency F_r and can be determined from the formula below;

$$F_r = \frac{1}{2\pi\sqrt{LC}}$$

The output level will be highest when the switching frequency F_s is equal to the F_r. As the F_s increase of decreases away from resonance; the output amplitude will also decrease. In theory, by applying varying frequency to the switch, a sinusoidal waveform could be obtained at load. For this project, the switch will be operated with frequency higher than resonance. The proposed PRC circuit is shown in Figure 26 below.
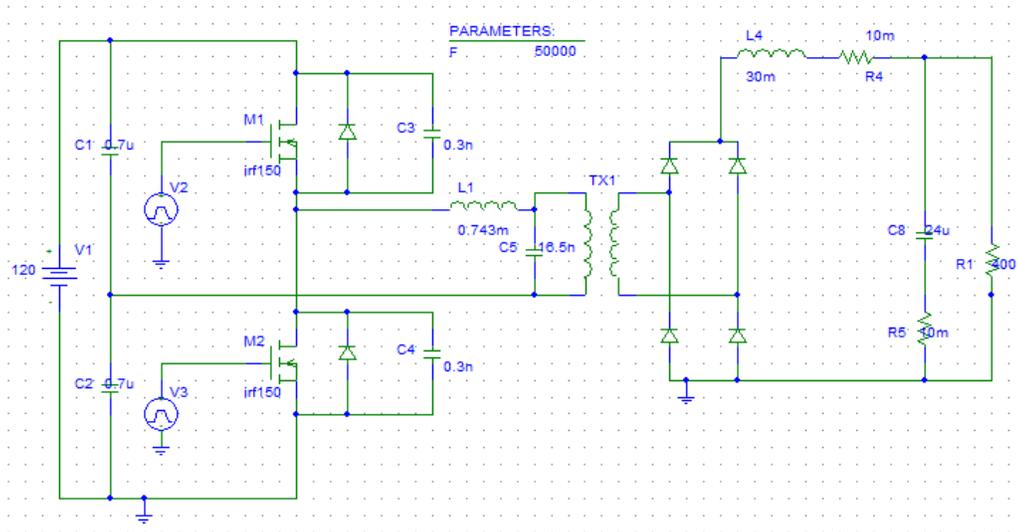
Figure 27: PRC Converter

The proposed PRC circuit consists of inverter part with parallel resonance tank which then connected to rectifier circuit through high frequency transformer. PRC converter is operated at much higher frequency compared to conventional inverter. The high switching frequency would offer better benefit particularly in reducing switching losses. In this design the resonant frequency is assumed to be F_r =45 kHz. The inductance set to be 0.742mH. By substituting the F_r and inductance value into the previous formula, the capacitance value found to be C=16.5n.

4.4.2 Switching Frequency Analysis

This section will show the effect of switching frequency to the converter output. The resonant frequency was set to be 45kHz.Using PSpice parameter sweep; the switching frequency increased with 10 kHz step beginning from the resonant frequency. Figure 28 below shows the voltage waveform across tank capacitor when operating the converter at 50 kHz, 60 kHz, 70 kHz, and 80 kHz switching frequency.
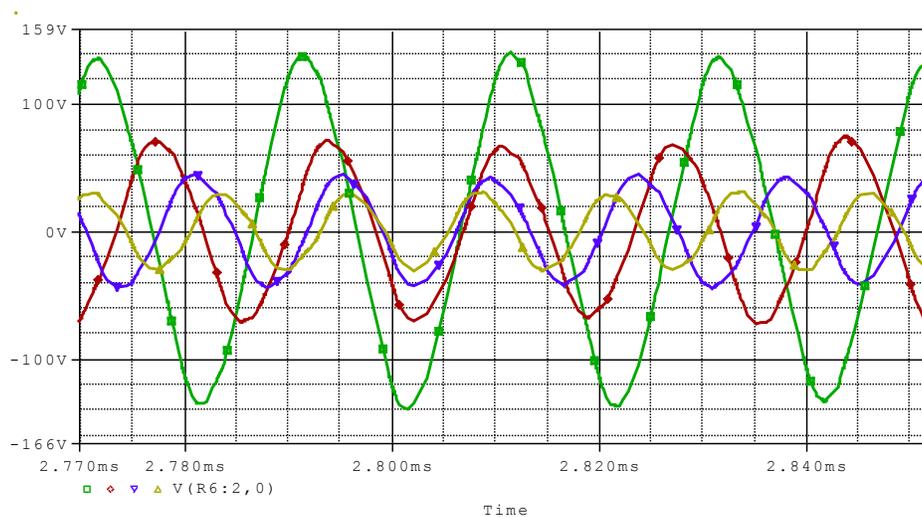
Figure 28: Result of Frequency Sweep on PRC

The lowest frequency 50 KHz produces the highest peak in this frequency sweep test. As the frequency increases, the amplitude starts to decrease significantly. Figure 29 shows the rectified output of the PRC converter.

26
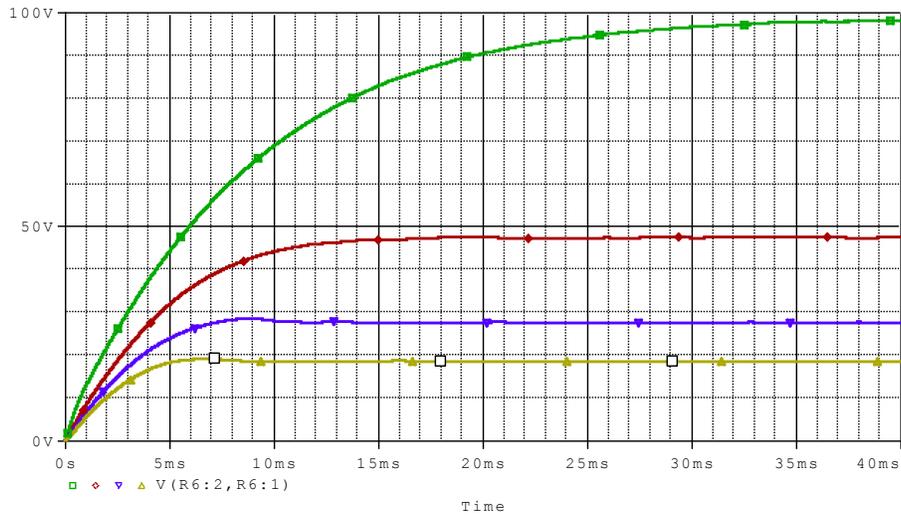
Figure 29: Rectified PRC Output

The rectified output shows the highest amplitude at lowest frequency. Further analysis shows that the amplitude is very near to zero when operated at 210 kHz as shown in figure below.
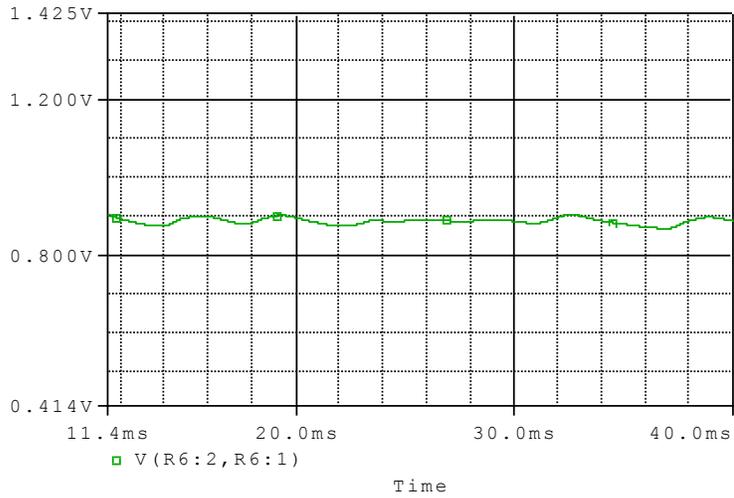
Figure 30: PRC at 210 KHz

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4.4.3 PRC Converter Result and Analysis

This section analyzes the circuit performance when operated above resonant frequency (45 KHz). Switching frequency of 60 KHz is used for the analysis. The voltage produced is 50V with current of approximately 100mA as seen in figure 31 below;
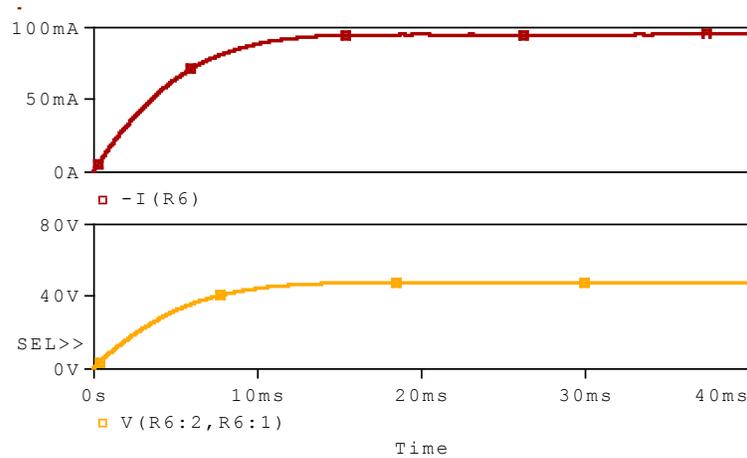
Figure 31: Output Voltage and Current

The switching sequence as well as the current and voltage across tank capacitor C5 are shown in figure 32 below. The current swing between negative and positive and reach the maximum value of 600mA when the switch stops conducting. The corresponding voltage also swing between -80 and 80 V, but the waveform is slightly lagging behind the current.
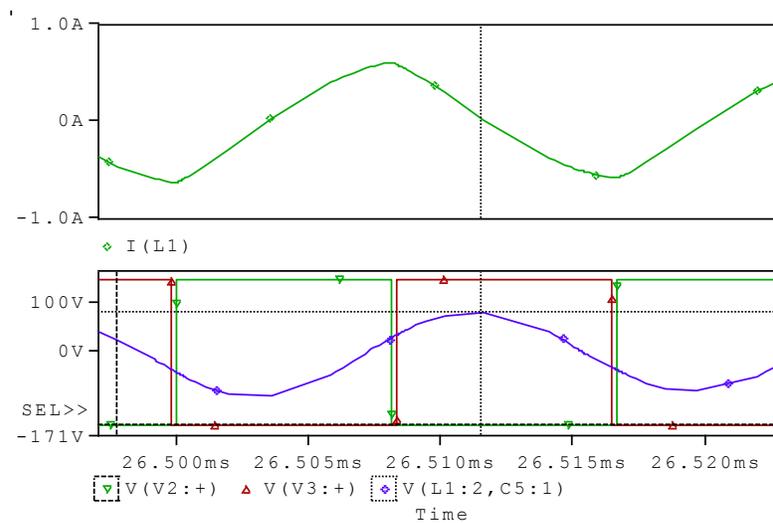
Figure 32: Tank Capacitor Voltage and Current

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Figure 33 shows the voltage and current across switch M1. It is assume that switch M2 is also having the same condition since both switch are identical and operated in the same manner. The bottom plot shows the switching sequence of M1 and M2, while the middle plot is the voltage across switch M1.When the switch is off, voltage across switch would be equal to the input. The voltage would become zero when the switch is on. On the top plot, current spike is clearly visible during both switch turn on and turns off.
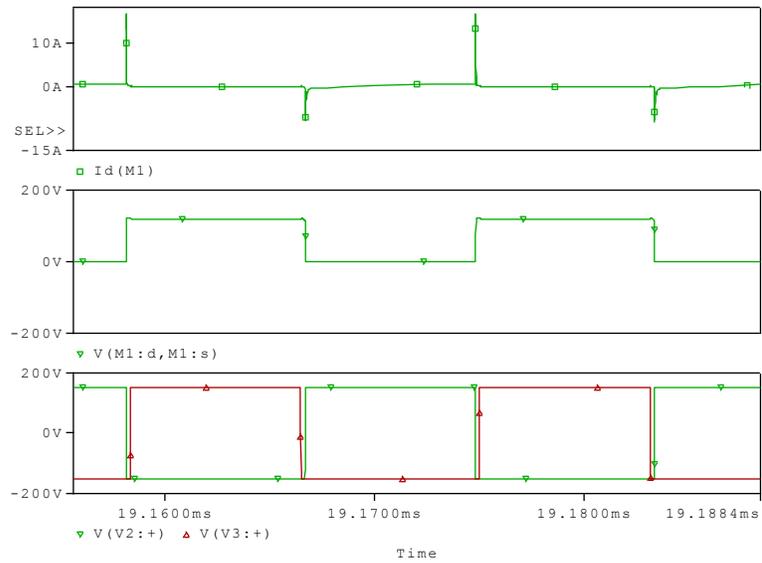
Figure 33: Voltage and Current across Switch M1
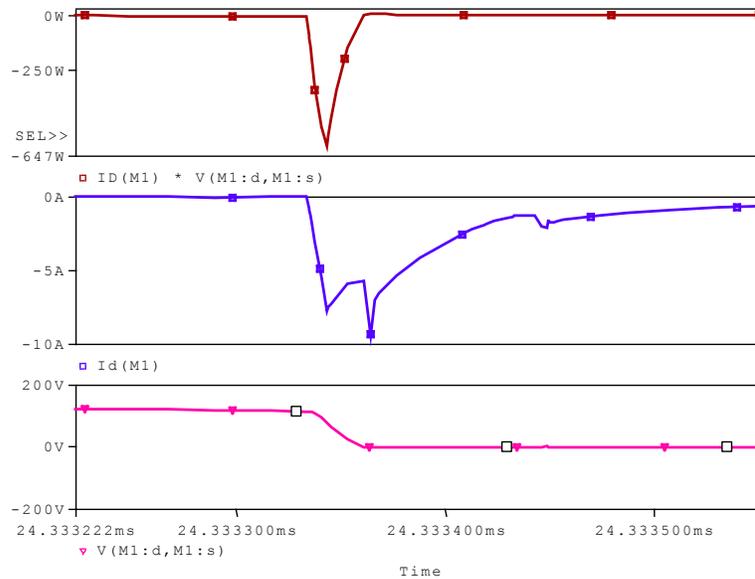
Figure 34: Switch M1 Turn on Losses

29
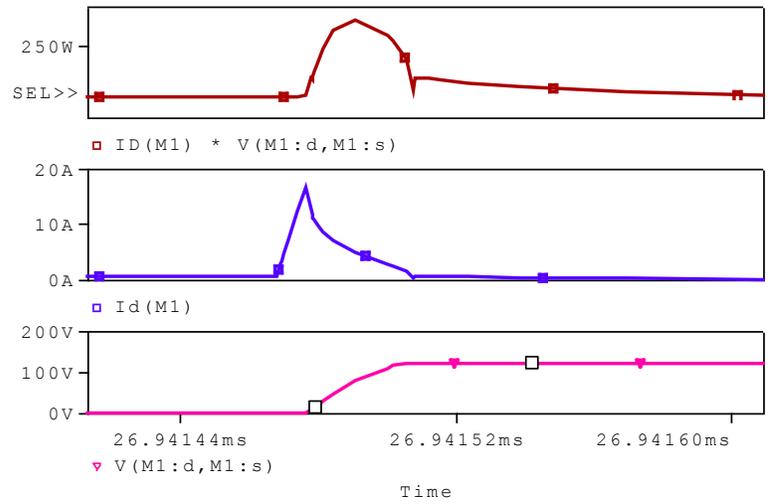
Figure 35: Switch M1 Turn off Losses

Previous figure 33 and figure 34 show the turn on and turn off losses respectively. The current flowing across switch M1 increases rapidly when the switch start to turn on. Once the switch completely turns off, the current starts to decrease back to zero. This results in power loss across the switch as both current and voltage exist at the same time. The current also spikes during switch turn off, but in inverse direction. Furthermore, there is slight difference because the current start flowing earlier than the moment voltage across the switch to start rising. When voltage starts to increase, the current flow rapidly decreases reaching 0 when the voltages reach its maximum. Further analyses are done to show the relationship between switching and power loss.
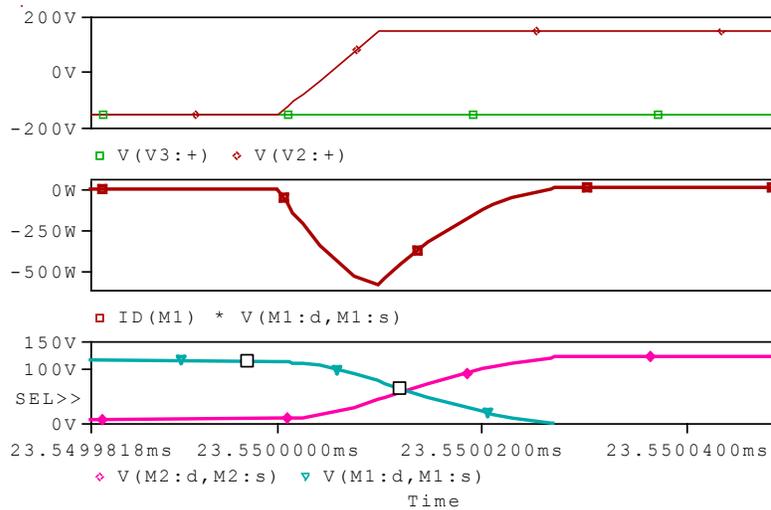
Figure 36: Voltage across Switches and Turn on Losses

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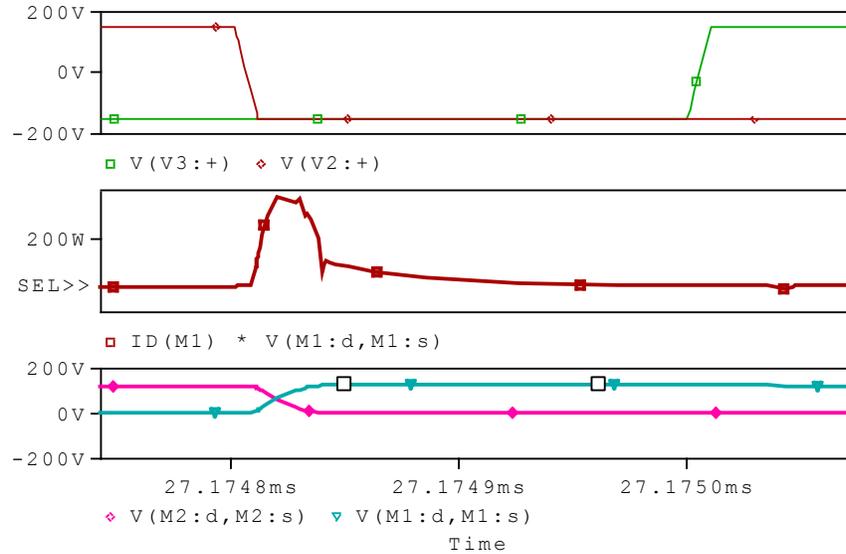
Figure 37: Voltage across Switches and Turn off Losses

Pulse controlling M1 and M2 has been properly set up and short dead time is included so that the switches will not conduct at the same time. However, as observed in Figure 36 and 37, the switch conduction crosses at one point, resulting in losses.

Even though the proposed PRC technique still suffer from switching losses, the amplitude and duration is much smaller compared to conventional half bridge inverter. The current spike only goes up to 20A, smaller compared to conventional inverter that suffers with current spike of 20kA. Apart from that, the duration is definitely shorter because of the high switching frequency used. Operating in high frequency also offer other benefits such as lower stress on the switch.

CHAPTER 5: CONCLUSION

The aim of this project is to design an interfacing circuit for solar cell to be used for AC load. The simulation is mainly performed using PSPICE software. Thorough understanding of the basic knowledge is required achievable by doing research especially onto previous work. It is hoped that the outcome of this project would lead into better development solar cell technology.

The first part of this project is to design boost converter circuit. Conventional boost requires extreme duty ratio to achieve high gain. The high voltage boost converter with 2 pumps capacitor design proposed proven to have very high gain and suitable to be used for the interfacing circuit. Compared to conventional boost converter, this design does not require high duty cycle to get high gain ratio. The gain from the circuit is 5, easily achieved using only 0.5 duty cycle.

Second part of the work is to analyze and design an inverter circuit. Conventional inverter circuit with resonant component can easily produces the desired sinusoidal AC voltage. However, operating in low frequency causes the circuit to suffer very high switching losses. PRC circuit is chosen and proved to be able to reduce the switching, losses. PRC can be utilized to produce AC voltage by manipulating the switching frequency above resonant and require proper control method that require further research.

The designed circuit is able to satisfy the requirement to be used as interfacing circuit for the solar panel and the AC load. A solar cell produces 0.3V and large arrays of solar panel are required to produce sufficient AC voltage, requiring large area and hefty cost. With the interfacing circuit, only a small solar panel is required, reducing both cost and area required. That will consequently result in growing usage of solar cell as cheaper alternative to produce electricity.

To get to the point of building the interfacing circuit would require more research especially in the control strategy. This work only focuses on the approach to the circuits design and analysis without the implementation of the control strategy. Thus, it is recommended that future improvement would include the design of switching control for better performance and efficiency.

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APPENDICES

Appendix A

Duty Cycle & Conversion Ratio;

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

Minimum and maximum inductor currents;

$$I_{Lmax} = V_i \left(\frac{1}{(1-D)^2 R} + \frac{DT}{2L} \right)$$

$$I_{Lmin} = V_i \left(\frac{1}{(1-D)^2 R} - \frac{DT}{2L} \right)$$

Average input and output currents;

$$I_{in} = \frac{I_{Lmax} + I_{Lmin}}{2}$$

$$I_o = I_{in}(1-D)$$

Capacitor peak currents;

$$I_{cmax} = I_{Lmax} - I_o$$

$$I_{cmin} = I_{Lmin} - I_o$$

Inductance minimum value for continuous conduction;

$$L_{crit} = \frac{RT}{2}(1-D)^2 D$$

Output ripple voltage;

$$\frac{\Delta V_o}{V_o} = \frac{D}{RCf}$$

Appendix B

Inductance Voltage;

$$V_{L1-On} = V_{in}$$

$$V_{L2-On} = V_{in}$$

$$V_{L1-Off} = \frac{-D}{1-D} V_{L1-On}$$

$$V_{L2-Off} = \frac{-D}{1-D} V_{L2-On}$$

Output Voltage;

$$V_o = -V_{L1-off} - V_{L2-off} + V_{in} + V_{c2} + V_{c3}$$

Conversion Ratio;

$$\frac{V_o}{V_i} = \frac{3-D}{1-D}$$

Appendix C: Gant Chart & Key Milestone

Activities	Weeks																													
	FYP1														FYP 2															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Extended Proposal - Documentation of literature review and findings							M1																							
Proposal Defense slide preparation								M2																						
Design and simulation of boost converter circuit													M3																	
Interim Report - Documentation on FYP1 progress														M4																
Design and simulation of DC-AC inverter circuit																				M5										
Progress Report																					M6									
Evaluation and performance analysis for optimization of combined boost and inverter circuit																										M7		M8		
Final Report - Full project documentation																														
Viva																										M9				

*M1-M9: Milestone 1-9

FYP 1		FYP 2	
Milestone 1- Completion and submission of Extended Proposal	28th June 2013	Milestone 5 - Completion of Inverter circuit design	19th October 2013
Milestone 2 - Proposal Defense	12th July 2013	Milestone 6 - Completion and submission of progress report	1st Nov2013
Milestone 3 - Completion of Boost Converter design	16th August 2013	Milestone 7 - Completion of combined circuit optimization	29th Nov 2013
Milestone 4 - Completion and submission of Interim Report	23rd August 2013	Milestone 8 - Completion of Final Report	13rd Dec 2013
		Milestone 9 - Project Completion and VIVA	27th Dec2013