Study of Boost Converter using MOSFET Single Phase Matrix Converter(SPMC)

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Abstract- **This paper presents a design and simulation of DC/DC boost converter operation of Single-Phase Matrix Converter (SPMC) using MOSFET as main power switching devices. The well-known Pulse Width Modulation (PWM) switching technique is used to control on and off of the SPMC circuit. Simulation model is developed using software Mentor Graphic to study the behavior of proposed technique. Selected simulation results are presented to verify the operation.**

Keywords- Single Phase Matrix Converter, Pulse Width Modulation (PWM), Mentor Graphic, Direct Current (DC), Power MOSFET, Matrix Converter, Boost DC to DC Converter.

I. Introduction

The Matrix Converter (MC) is an advanced circuit topology that offers many advantages with possible 'all silicon solutions', unrestricted switch control, or with minimal reactive device use, the ability to regenerate energy back to the utility, sinusoidal input and output current and controllable input current displacement factor. The topology was first introduced by Gyugyi in 1976 [1].

The DC to DC Converters are widely used in regulated switch mode DC power supplies. A Boost converter is a class of switching mode power supply containing at least two semiconductor switches which are diode and insulated gate bipolar transistor(IGBT) [2]. Graphically model of the boost converter using SPMC topology is shown in Fig. 1

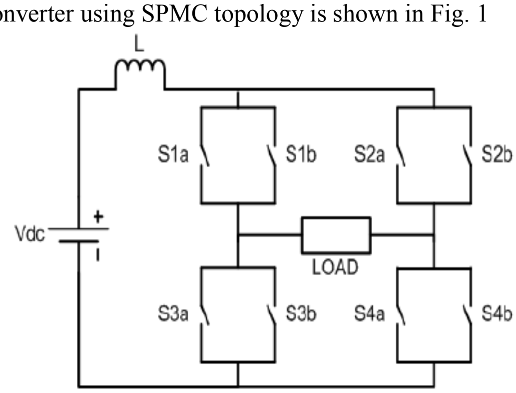

Figure 1: Boost DC to DC Converter using SPMC

A boost converter is simply is a particular type of power converter with output DC voltage greater than the input DC voltage. This type of circuit is used to 'step-up' a source voltage to a higher, regulated voltage, allowing one power supply to provide different driving voltages [3]. The Boost DC to DC converter also needs four external components: inductor, electronic switch, and diode and output capacitor.

Most of boost converters use IGBT as the main switching device because of its design to cater the high current and suitable high power applications but they are seen to be useful in low power applications. By studying the boost converter and exploring the use of MOSFET as the switching device, replacing the IGBTs, this boost converter could be used to raise DC voltage to certain value. This will enable a single DC source to supply different value of DC voltage to different circuits in system on chip (SOC) which each electronic device require a voltage level different than that supplied by the battery such as a digital camera or cell phone on a single integrated circuit, generally known as a microchip. Thereby it could save space instead of using multiple power supply or regulator to different parts of the device

This paper discusses SPMC topology in Section II, Boost topology in Section III, while the methodology, discussion and conclusions of the findings are presented in Section IV, V and VI.

II. Single Phase Matrix Converter Topology

The Single Phase Matrix Converter (SPMC) was first realized by Zuckerberger. The SPMC consists of a matrix of input and output lines with four bidirectional switches [4] connecting the single-phase input to the single phase output at the intersections as shown in Figure 3. The switching of these bi-directional switches is then modulated using suitable Pulse modulation to produce the desired output voltage and frequency. Each of the individual switches is capable of conducting current in both directions, blocking forward and reverse voltages [5]. The power MOSFETs were used because that would increase application in low power and high-frequency with fast switching speed for fine control. A power MOSFET are a voltage controlled device and requires only a small input current.

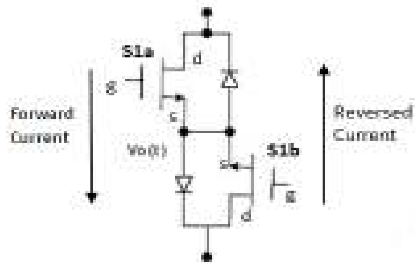

Figure 2: Bi-directional switch module

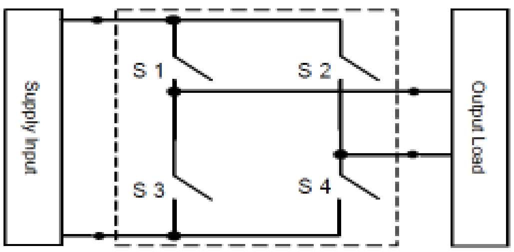

Figure 3: SPMC Topology

III. BOOST SPMC TOPOLOGY

Boost converters are widely used for electronic power supplies, in which the desired output voltage is high, compared to a typical dc input voltage level (*$Vo \geq Vin$*)[6]. In SPMC topology, the power switching device and load are grounded where the operations are divided into two modes. First mode for the switch is ‘on’ and second mode for the switch is ‘off’.

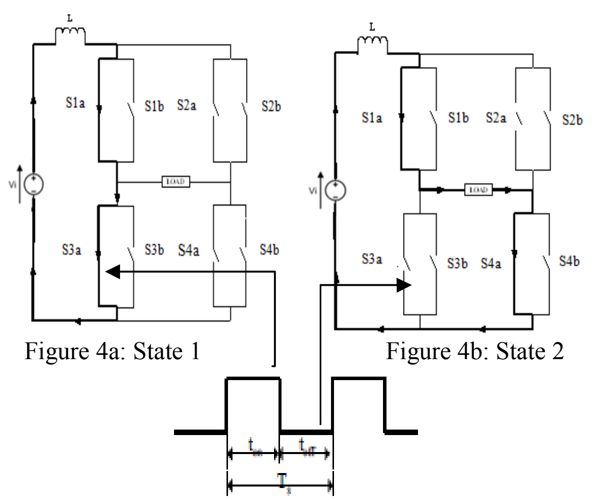

Figure 4a: State 1

Figure 4b: State 2

State 1: During switches turn ‘on’, the inductor stores energy whiles the inductor current I_L increases as shown in Figure 4a.

State 2: During switches turn ‘off’, the inductor current decays as the stored energy is released to the output as shown in Figure 4b. In this stage, the energy retained by the inductor is transferred to the load [7].

$$Vi_{ton} + (Vi - Vo)_{toff} = 0$$

Where;

V_i : The input voltage, V.

V_o : The output voltage, V.

t_{on} : The switching on of the MOSFET's, s

t_{off} : The switching off of the MOSFET's, s

Dividing both sides by T_s and rearranging items yield

$$\frac{Vo}{Vi} = \frac{Ts}{toff} = \frac{1}{1-D}$$

Where;

Ts : The switching period, s.

D : The duty cycle.

A. *Pulse-Width Modulation (PWM)*

The output of the Boost DC to DC Converter is controlled using the PWM, generated by comparing a triangle wave signal with an adjustable DC reference [8] and hence duty cycle of the switching pulse could be varied to synthesize the required Boost DC to DC Converter. This technique is used to produce stream of PWM train to turn on and off the switches as shown in Figure 5.

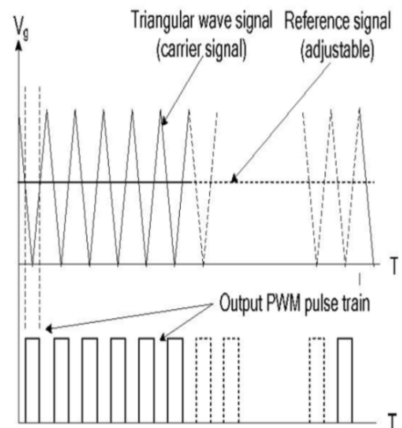

Figure 5. PWM waveform

B. *Commutation Problem In SPMC*

Theoretically the switching sequence in the SPMC must be instantaneous and simultaneous, unfortunately impossible for practical realization due to the turn on or off within Power MOSFET characteristic. During switch turn ‘off’, the commutation problem also occurs where transforming the stored energy in the inductor into switching spikes [9]. A charge in current due to PWM switching will result current and voltage spike being generated resulting in the occurring of a dual situation. First current spike will be generated in the short-circuit path and secondly voltage spikes will be introduced as a result of change in current direction across the inductance [10]. MOSFETs also have a maximum specified drain to source voltage, beyond which breakdown may occur. Exceeding the breakdown voltage causes the device to conduct, potentially damaging it and other circuit elements due to excessive power dissipation.

C. *Switching Strategy*

The implementation of the SPMC requires different bi-directional switching. The control strategy for SPMC is utilizing PWM, mean, a stream of pulse are sent to MOSFETs [11]. The time between PWM pulses are also need to be arranged so that the inductive load current is free-wheel. Hence, novel commutation proposed for SPMC must obey those rules:

a) Providing path for inductive load current between PWM pulses.
b) Providing delay between the transitions of ON State.
c) Providing path for inductive load current during delay.

The switching is designed as shown as in Table I. Figure 6 to shows the Boost DC to DC Converter using SPMC topology. S3a implemented as 'PWM' control for inductor charging/discharging for cycle operation which PWM generated by comparing a triangle wave signal with an adjustable DC reference using comparator. During S3a is turn on, the current flow from the supply to inductor and through S1a and S3a: the inductor voltage is Vin . During turn-off of S3a, switches S1a and S4a that using dc voltage are maintained as continuously ON during this cycle and the inductor that stored energy is released to the load through the diode: the voltage across the inductor in this period is Vin -Vo.

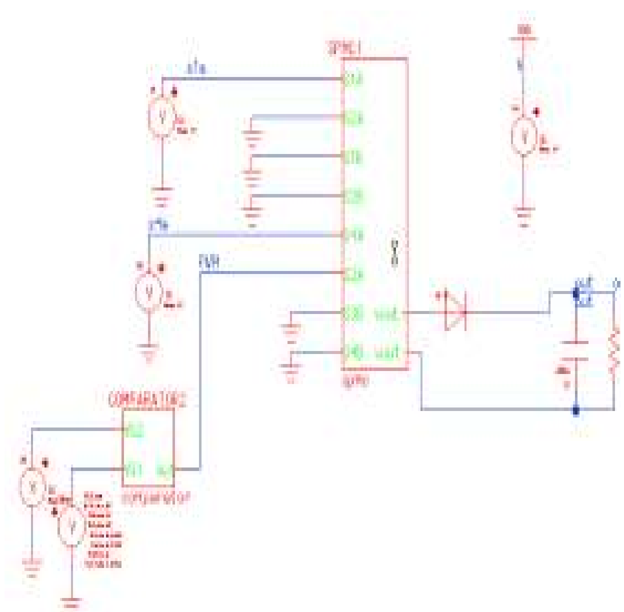

Figure 6: Operation in Boost DC to DC Converter

Switching State		
State 1	PWM Switch	Commutation switch "ON"
Positive cycle	S4a	S1a & S4a

TABLE 1: Switching Strategies

IV. METHODOLOGY

The implementation of boost converter on Single Phase Matrix Converter is developed and tested by using the procedure shown in Figure 7. Start with literature review of the project. After that, develop the comparator circuit is developed to generate Pulse Width Modulation. In simulation part, Mentor Graphic is used to study the behavior of SPMC as boost converter operation. Suitable value of the modulation index, switching frequency and RC filter are selected to find the expected output. The test is conducted for R_{load} with the commutation strategy.

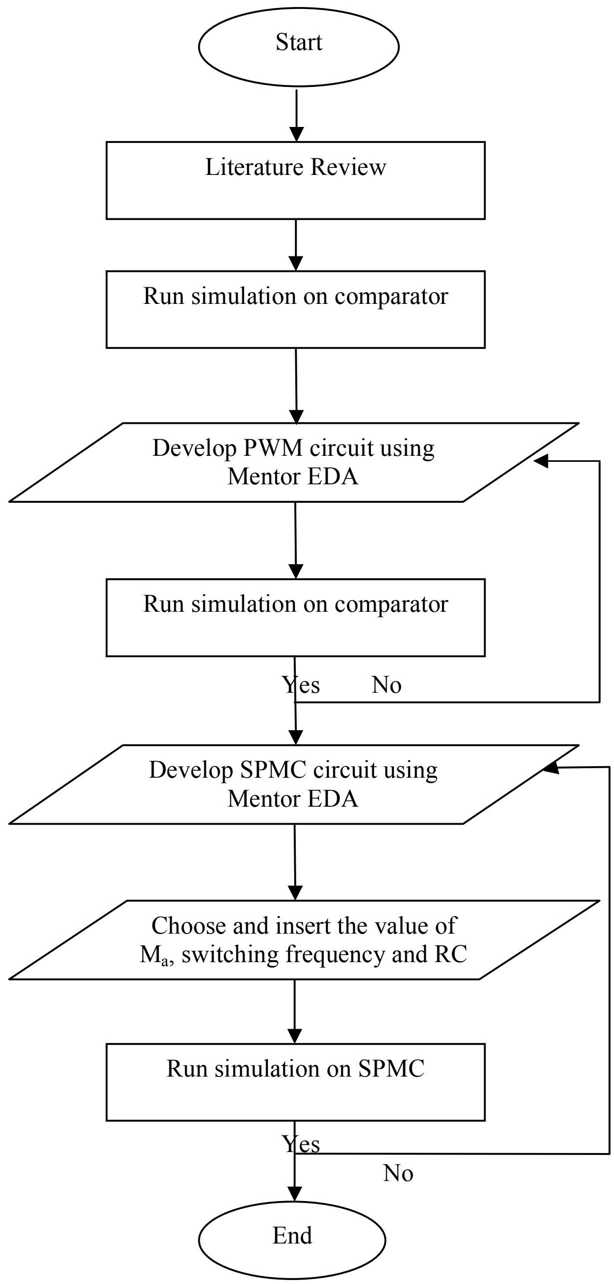

Figure7: The flowchart of the procedure Boost Converter

V. EXPERIMENTAL RESULT AND DISCUSSION

Fig 8 to 9 shows the SPMC circuit with its test bench and results of Boost DC to DC Converter with supply voltage of 3V and switching frequency of 200 kHz to 600 kHz with fixed modulation index, ma=0.5. Figure 10 show the circuit of comparator and Figure 11 is the PWM waveform which is a result from comparing a triangle wave signal with an adjustable DC. By increasing the switching frequency; it is expected to have a proportionate increase in the output voltage. At the highest switching frequency, ripples occur in the output waveform.

Component	Value
Input Voltage	3V
Resistor	15
Inductor	5uH
Capacitor	220uF
Modulation index, Ma	0.5
Switching frequency, *fs*	200kHz, 300 kHz, 400kHz,500kHz 600kHz

TABLEII: Simulation Parameter

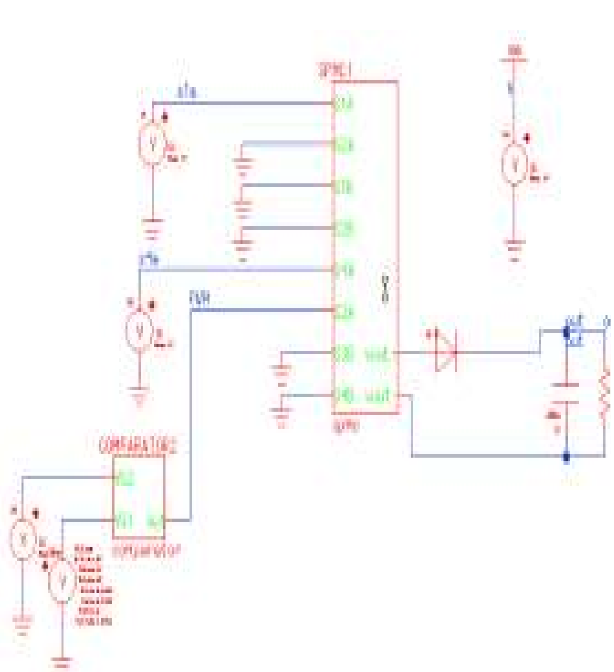

Figure 8: Simulation model in Mentor Graphic

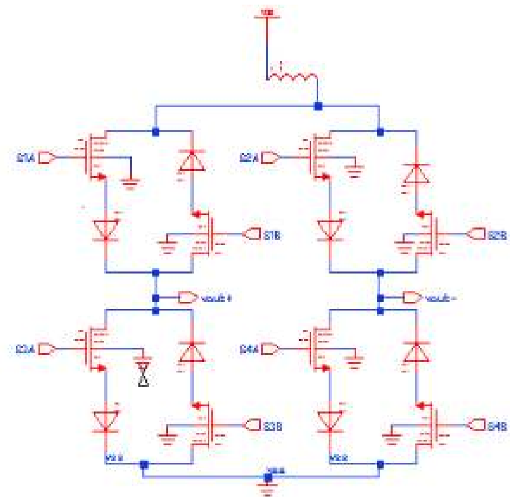

Figure 9: SPMC circuit in Mentor Graphic

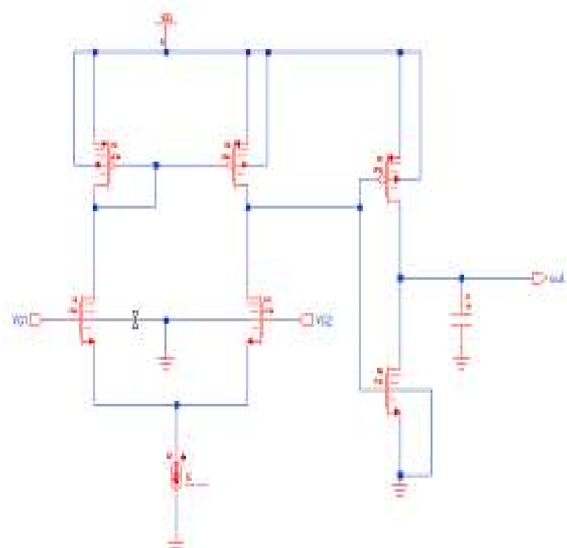

Figure 10: Comparator circuit in Mentor Graphic

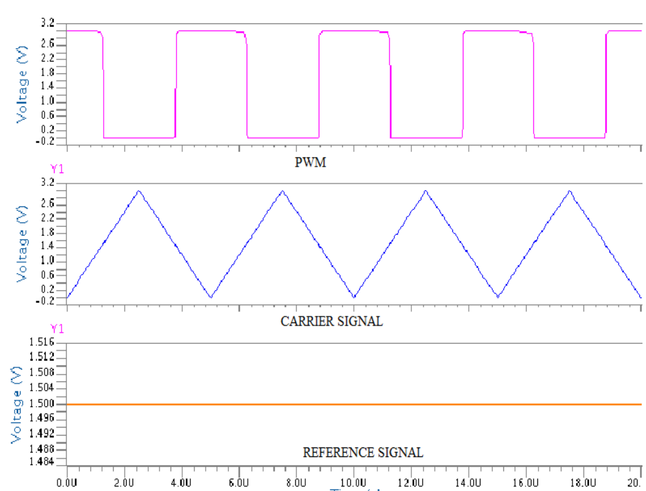

Figure 11: PWM waveform

The Figure 12 to Figure 16 shows the output voltage increases as the switching frequency increases where its outputs are 5.38V, 5.417V, 5.471V, 5.53V and 5.57V with switching frequency of 200 kHz, 300 kHz, 400 kHz, 500 kHz and 600 kHz and fixed modulation index of 0.5.

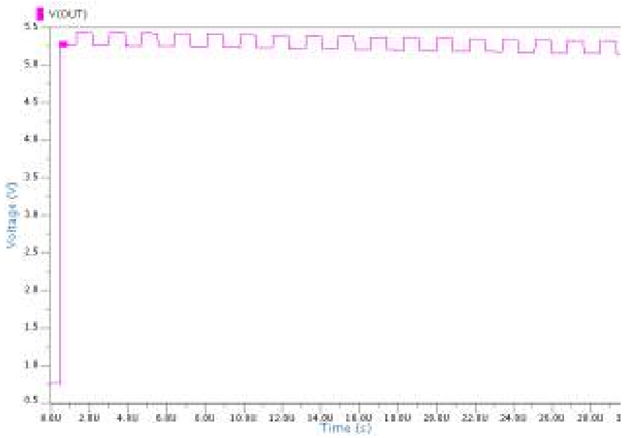

Figure 12: Vin=3V, Vo=5.38 for 200kHz

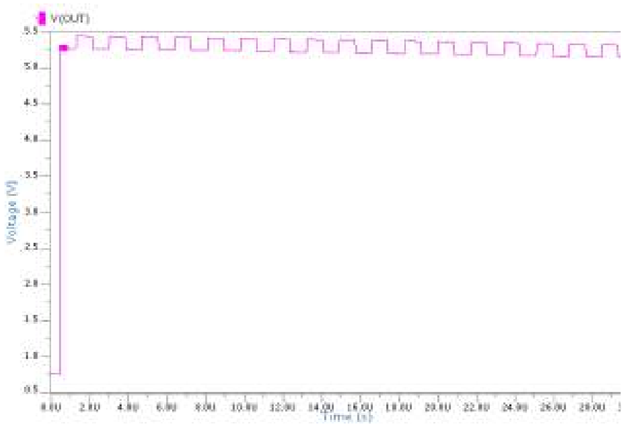

Figure 13: Vin=10, Vo=5.417 for 300kHz

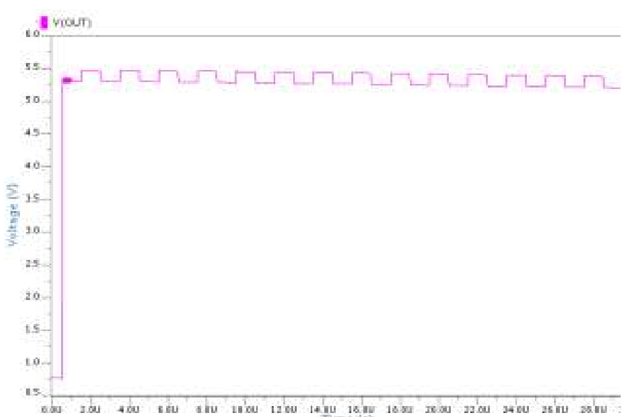

Figure 14: Vin=10, Vo=5.471 for 400kHz

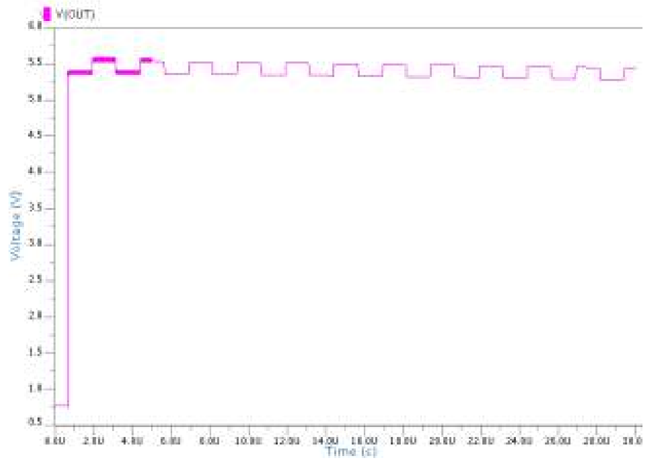

Figure 15: Vin=3V, Vo=5.53 for 500kHz

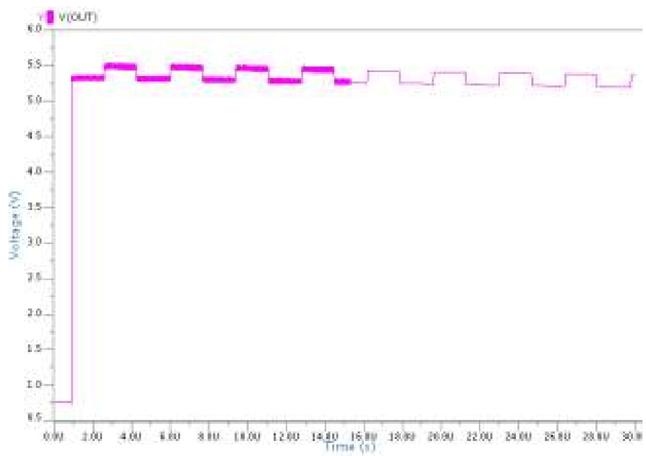

Figure 16: Vin=3V, Vo=5.57 for 600kHz

Table III: Output voltage

Switching Frequency fs	Ma=0.5	
	Vi	Vo
200kHz	3V	5.38V
300kHz	3V	5.417V
400kHz	3V	5.471V
500kHz	3V	5.53V
600kHz	3V	5.57V

The whole results are tabulated in Table III. However, ripple can be seen at the output voltage waveforms.

VI. CONCLUSION

An operation of the Single Phase Matrix Converter topology using MOSFET as switching devices has been presented and it is expected to operate as Boost DC

Converter. MOSFETs are used for the main power switching device. The comparator with two stages is used to synthesize the PWM waveform. Simulation model in Mentor Graphic is used to study the behavior of the proposed technique. Switching frequency used in this research are 200kHz, 300kHz, 400kHz, 500kHz and 600kHz with R=15, C=220uF and L=5uH. Generally, by increasing the switching frequency, it is expected to have a proportionate increase in the output voltage. However, in this simulation result the output voltage increases in small value when increasing the switching frequency. When increasing the switching frequency, ripples still occur in the output waveform. Even though, capacitor is need as the filter in this design.

VII. ACKNOWLEDGEMENT

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