Boost Rectifier Using Single Phase Matrix Converter Topology

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***Abstract* – This paper presents work on the modeling, simulation and experimental test rig of single phase matrix converter topology as a single phase boost rectifier operation. The propose of this circuit is able to generate the output voltage greater than the input. This circuit employed eight Insulated Gate Bipolar Transistor switches connected in common emitter configuration in order to perform bidirectional operation. The pulse width modulation (PWM) technique was used to synthesize the output of the switching control algorithm by through calculating the switch duty ratio. The commutation strategy has been implemented with reduction in spikes, there was a common phenomenon that happens in matrix converter topologies. A simulation model is design using MATLAB/Simulink and the results of simulations and experimental test rig are presented to evaluate the behavior and feasibility of the proposed topology.**

Keywords–Single Phase Matrix Converter (SPMC); Boost Rectifier; Pulse Width Modulation (PWM); Controlled Rectifier; Commutation Strategy; AC-DC Converter; MATLAB/Simulink (MLS).

I. INTRODUCTION

Lots of theoretical studies have been investigated on Matrix Converter (MC) but it still has a limited practical application in power electronics. The advantage of matrix converter is the structure was very simple but has powerful controllability. In 1976 Gyugyi is the first who was proposed the topology. It shows the matrix converter offers possible an "all silicon" solution for AC-AC conversion and eliminates the need for reactive energy storage components that used in conventional converter system [1]. Then in 1980 it was followed by Alesina and Venturini that has representing the circuit as a matrix of bi-directional power switches that was the modern power conversion topology [2].

In industrial community and academic, there is considerable interest in matrix converter (MC) technology. Therefore the possibility of greater power density is due to the absence of a DC link in direct AC conversion. It was the major benefits that required for the matrix converter [3]. Besides that, MC is able to operate in four quadrants of the operation. The operation is straightforward, by controlling the switching devices appropriately, both output voltage and input current are sinusoidal with only harmonics around or above switching frequency. Furthermore, MC also has the advantage like no large energy storage components are required but it still can design for a large capacity and compact converter system. Besides that, the power factor is high input that comes from the clean input power characteristics. It also has possibility to increase the power density by operate the system at higher temperatures.

In this work the Single Phase Matrix Converter (SPMC) topology has been used to control the rectifier by suitable switching schemes. The first person who was realized the SPMC topology is Zuckerberger in 1997. The main power for switching device in this work is using IGBTs [4]. The objective of this paper is to present a switching algorithm for control boost rectifier using SPMC.

II. BOOST TOPOLOGY

In electronics power supplies, to get the output voltage is high compared to a typical ac input voltage level, so boost converters are widely used to the system. Using boost converter the equation output will get $v_{out} \geq v_{in}$ [8].

Figure 1 is the simplest basic topology of boost which requires only a single switching device to be controlled.

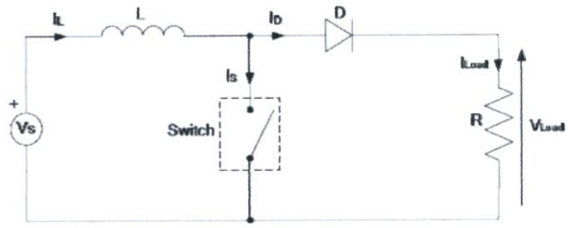


Figure 1: Main Circuit Diagram of Boost Converter

III. SINGLE PHASE MATRIX CONVERTER

The SPMC are required 4 bidirectional switches and each switch was capable to conduct current in both directions and also blocking forward and reverse voltage.

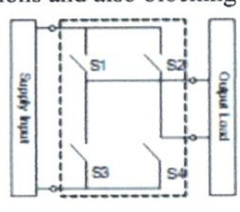


Figure 2a: Bidirectional Switch

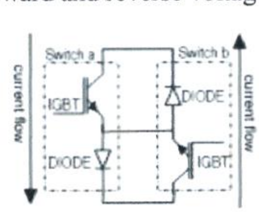


Figure 2b: Bidirectional Switch Module (common emitter configuration)

In this paper an algorithm is developed that enables a SPMC to perform the functions of boost operation of controlled rectifier. The input in the circuit simulation is supply with AC synthesizing in the form of DC output using technique of pulse width modulation (PWM) [5]. Then computer simulation was design using MATLAB/Simulink including the switching algorithm to illustrate its basic behavior and to operate as a controlled rectifier [6].

Therefore, the simulation results are presented to prove that the proposed technique is feasible. For modeling circuit a capacitive and resistive load is used to reducing the complexities of the circuit. Figure 2 consists of a matrix of input and output lines by designing four bidirectional switches to connect the single-phase input to the single-phase output at the intersections. Furthermore the design is including by common emitter anti parallel insulated gate bipolar transistor (IGBT). IGBT has been used because of its function that is high switching capabilities and high current carrying capacities desirable for high power applications.

IV. CONTROLLED BOOST RECTIFIER USING SPMC

A boost rectifier in this work was provided a higher output in dc than a given input in ac supply. Beside that an inductor is placed at the input and the function is to create a supplementary voltage source in series with the supply. Then from a summation of the two sources, it can make a high voltage that can happen because of the stored energy in the inductor was multiply the voltage through rapid discharging through switching control.

The operation of rectifier converter has been involved by the switching sequences of bidirectional switches. Figure 3 shown that it was controlled to allow only unidirectional current flow through the load, while the same time it has capable of blocking voltage. It is consist during positive and negative cycle as shown in Figure 4 [7].

The input frequency of power supply in this work is set at 50 Hz at the fundamental frequency. In this work by using the four switching state, it can manipulated to control AC-DC converter.

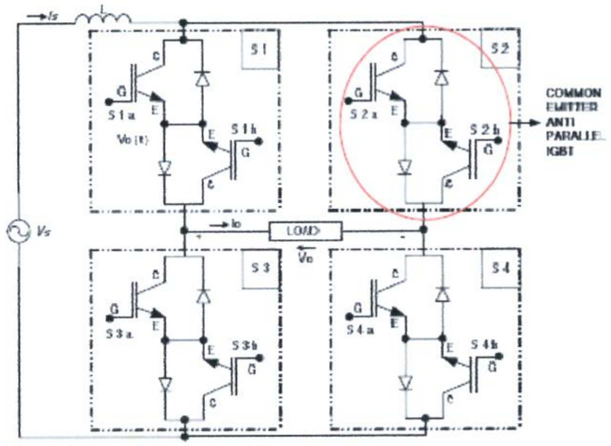


Figure 3: Boost Rectifier Using SPMC Topology

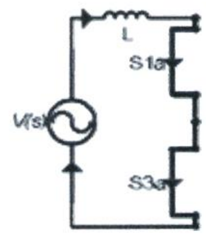


Figure 4a: Positive Cycle With Current Wave Shaping (State 1)

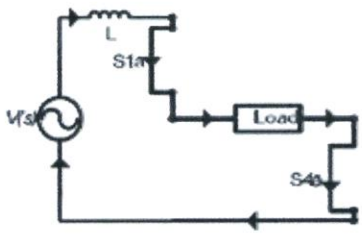


Figure 4b: Positive Cycle With Current Wave Shaping (State 2)

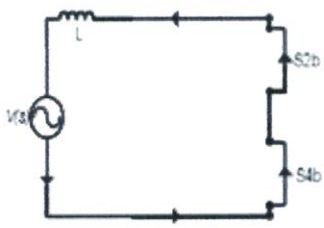


Figure 4c: Negative Cycle With Current Wave Shaping (State 3)

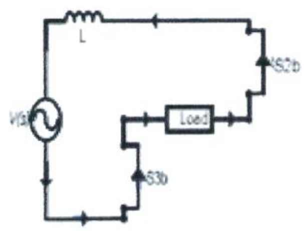


Figure 4d: Negative Cycle With Current Wave Shaping (State 4)

The operation of boost rectifier regulator using SPMC is divided into two switching condition, there are either in positive or negative cycle. The switching condition has been derived from the PWM switching as shown at Figure 6 and 7. The direction of current during positive cycle is followed by the 'on' and 'off' of the PWM switching. During state 1, PWM is state at switch S3a and the functions to control for inductor charging and discharging for positive cycle. The current that flow at the switch S3a would now flow through the load meanwhile the inductor current falls until the switch S3a is turn 'on' again for the next cycle. Otherwise the energy that has been stored in inductor, L is transferred to the load. Therefore for the positive cycle operation S1a and S4a were turn 'on'.

Otherwise during negative cycle, switch S4b was provided a control using PWM. During PWM in 'on' condition, so the current will flow through the S2b and when PWM in off condition, then the current will flow from S3b through the load and S2b. Table 1 and 2 are showing the 'on' and 'off' state of switching operation. To generate the PWM signal for controlling switches at S3a and S4b, switching frequency 5 kHz has been used.

Table 1: Switching States for Boost Rectifier Operation

Mode	ON	PWM
Positive cycle	S1a and S4a	S3a
Negative cycle	S3b and S2b	S4b

Table 2: Switching States for Boost Rectifier Using SPMC

Switches		**S1a**	**S1b**	**S2a**	**S2b**	**S3a**	**S3b**	**S4a**	**S4b**
STATE	**1**	ON	OFF	OFF	OFF	ON	OFF	OFF	OFF
	2	ON	OFF	OFF	OFF	OFF	OFF	ON	OFF
	3	OFF	OFF	OFF	ON	OFF	OFF	OFF	ON
	4	OFF	OFF	OFF	ON	OFF	ON	OFF	OFF

V. PULSE WIDTH MODULATION TECHNIQUE

The most common method to control the switching converters is PWM. The basic concept of PWM is by comparing the carrier signal (triangle wave) with the reference signal that is a straight line as shown. It will obtain the output waveform in a digital signal that represent by logic “1” for HIGH state (T_{on}) and “0” for LOW state (T_{off}), while a stream of PWM train is produced to control the switches as shown in Figure 5 [9].

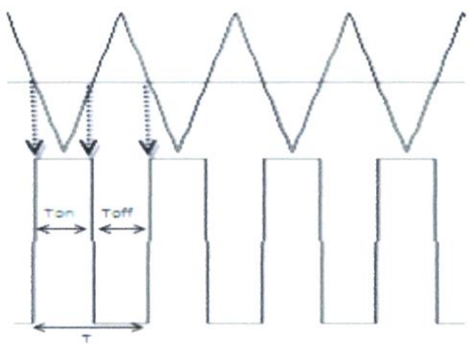


Figure 5: PWM Pattern

The switching frequency, *fs* of PWM was set at 5 kHz. The output of PWM is separated by two parts. The first part is during the operating from 0 to π degrees of sine wave that was called a positive cycle. Otherwise during the operating from π to 2π degrees was called a negative cycle. Figure 6 was shown the separation of PWM waveform generation for positive and negative cycles, while Figure 7 was shown the overall switching sequence of SPMC.

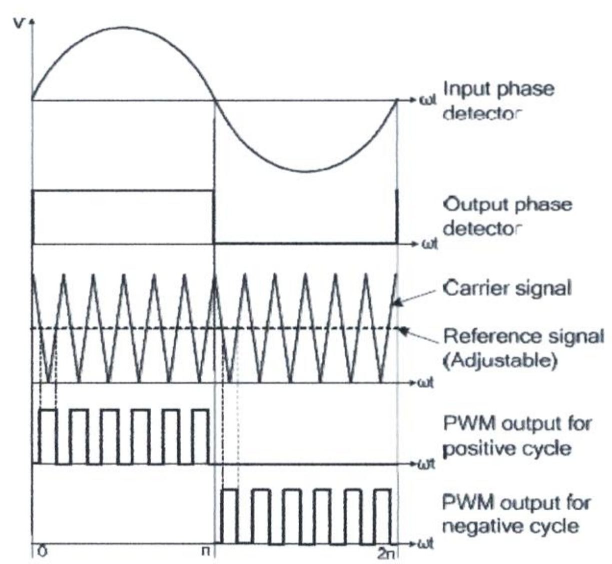


Figure 6: The Separation Of PWM Waveform Generation For Positive And Negative Cycles

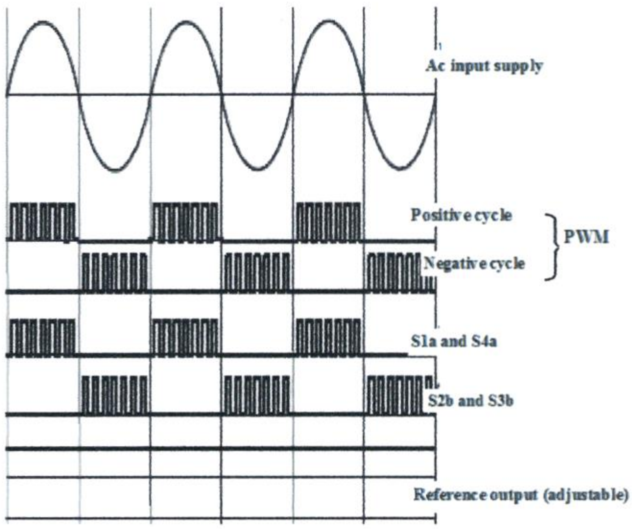


Figure 7: Waveform of Switching Pattern for Controlled Rectifier Using SPMC

VI. COMMUTATION PROBLEM

By using PWM switching in this converter, it will construct the voltage spikes as shown in Figure 8, that was a result of change in current if using the inductive loads [10]. This is because the first current spikes will be generated during short circuit path and secondly voltage spikes will be induced as a result of change in current direction across the inductance. Both of these situations will destroy the switches in use due to stress. So a systematic switching sequence is thus required that allows for the energy flowing in the IGBT’s to removed within the system.

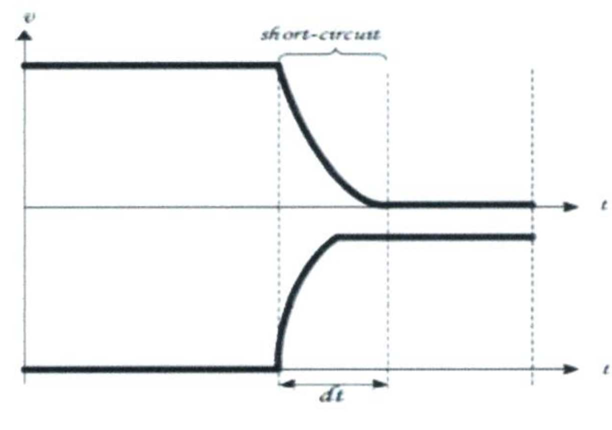


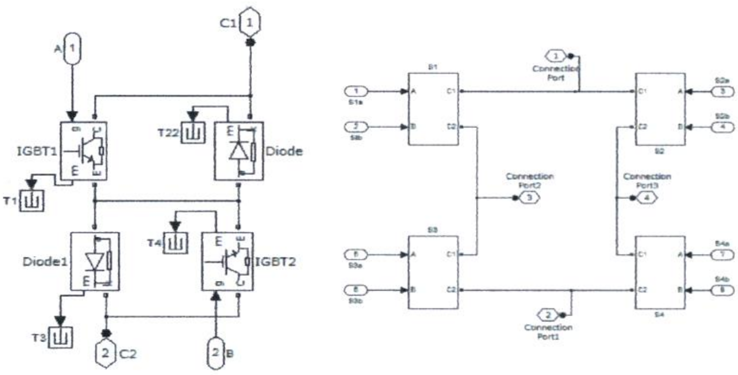
Figure 8: Switch Transition and Commutation

Besides that, for this purpose a free-wheeling diode was used in the conventional controlled rectifier. Otherwise in SPMC this is does not exist, hence switching sequence are required that could provide a path for current to removed during switch turn off.

VII. Simulation Model

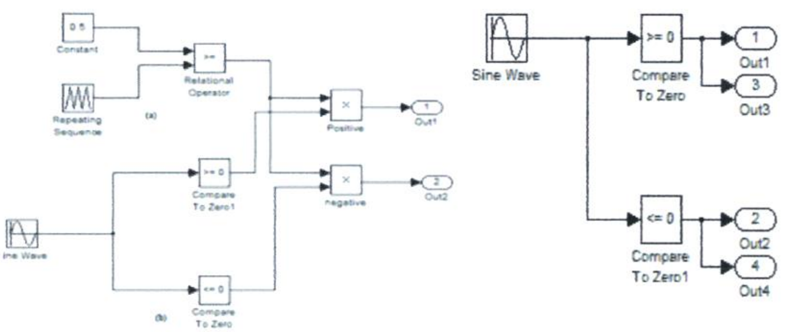
The model and simulation circuit is design by MLS. By using MLS, it can verify proposed of control concept. Figure 9 are shown the subsystem that was small structure that has been split from implementation of the large model as shown in Figure 12.

To varied modulation index for boost rectifier, the straight line which acts as a reference signal has been used to compare with the carrier signal to get the output signal of PWM shown in Figure 10. This can be done by using the "Relational Operator" block. By using the phase detector function a signal of positive and negative can be created. Therefore to obtain the desired output signal, the signal of phase detector should be synchronous with PWM by using 'OR' block from gate logic as shown in Figure 11.



(i) (ii)

Figure 9: (i) Bidirectional Switch and (ii) SPMC Model in MLS



(a) (b)

Figure 10: (a) PWM Generator Module Compared Phase Detector by Using 'OR' Gate Block (b) Phase Detector Module

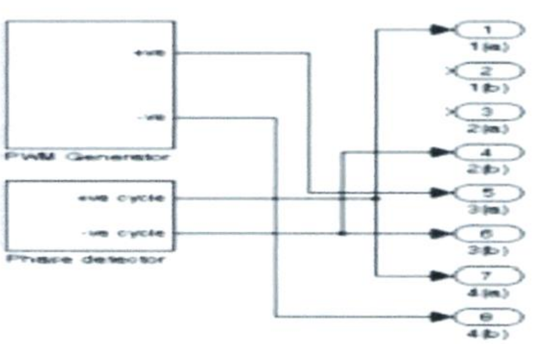


Figure 11: The Arrangement of Boost Rectifier

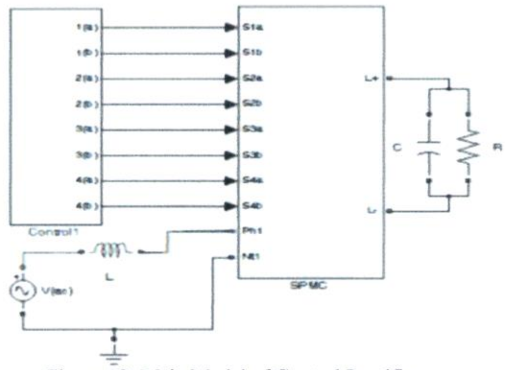


Figure 12: Main Model of Control Rectifier

VIII. Experimental Verification

The experimental test rig was design by follow from the circuit of simulation by MATLAB/Simulink. In this session phase detector circuit has been design to combine with the microcontroller PIC 16F84A. It is function to generate the pulse width modulation (PWM) switching signal and the phase detector signal to connect to the switching for positive and negative cycle. In this project, frequency 50 Hz is used for the phase detector switching signal meanwhile 5 kHz and 1 kHz is used for the switching frequency. The result simulation using MATLAB/Simulink and the experimental test rig was compared by using the same specification values of component are tabulated in Table 3.

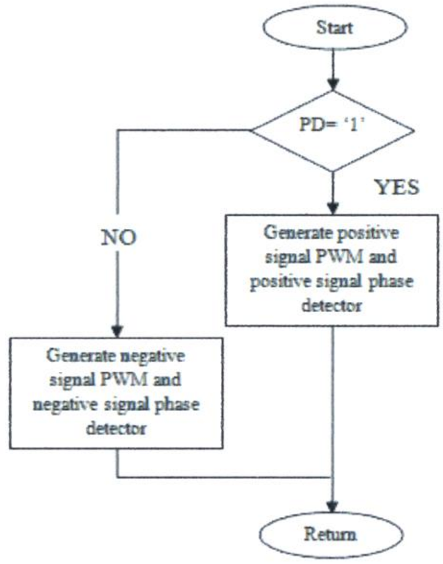


Figure 13: Flowchart For Switching Algorithm In SPMC

Table 3: Parameter of SPMC

Supply Voltage		12 Vac
Load	R	220 Ω
	C	8200 uF
Switching Frequency		1 kHz and 5 kHz
Inductor		1 mH

IX. Results And Discussion

The results simulation for this work has been shown in Figure 14 to 19. For figure 14 to 18, the results has divided by (a) and (b), which (a) was the result during switching frequency is 5kHz and (b) was the result during switching frequency is 1 kHz. The results output voltage during switching frequency, *fs* at 1 kHz is higher than using *fs* at 5 kHz. Besides that all the result of boost rectifier has shown that the output voltage is greater than the input voltage which is 12V (ac) at 50 Hz frequency.

Meanwhile the output voltage is represented in dc which is only creating a straight line; while the input voltage is create a sinusoidal waveform. Figure 20 and 21 shown the result from experimental test rig. Figure 19 has shown that the output voltage was increased proportionally with the increasing of the modulation index. Therefore the output voltage during *fs* at 5 kHz is smoother rising but the result during *fs* at 1 kHz has created a linear graph.

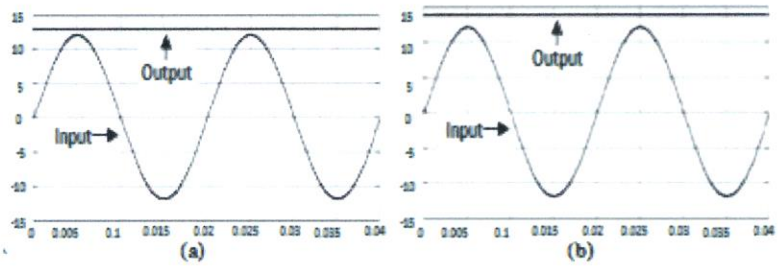


Figure 14:Input and Output Voltage During Ma = 0.1 at (a) 5 kHz and (b) 1 kHz

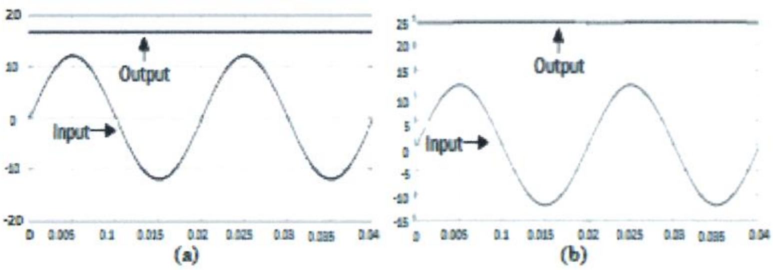


Figure 15:Input and Output Voltage During Ma = 0.3 at (a) 5 kHz and (b) 1 kHz

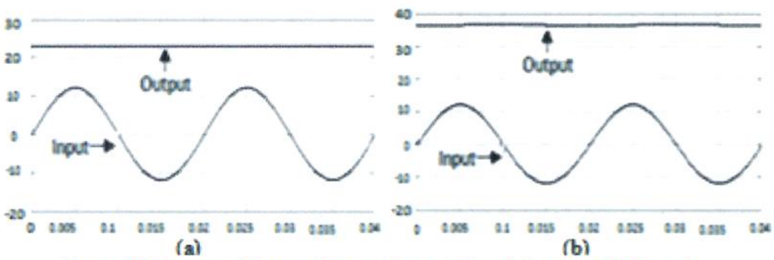


Figure 16: Input and Output Voltage During Ma = 0.5 at (a) 5 kHz and (b) 1 kHz

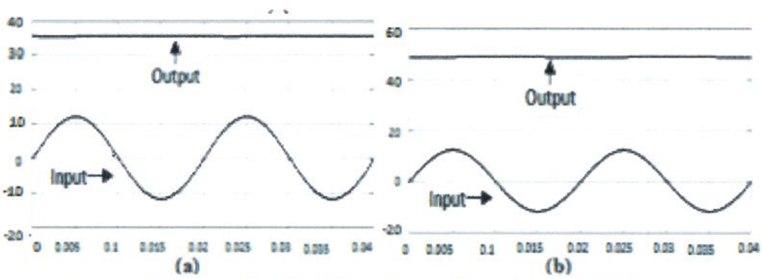


Figure 17: Input and Output Voltage During Ma = 0.7 at (a) 5 kHz and

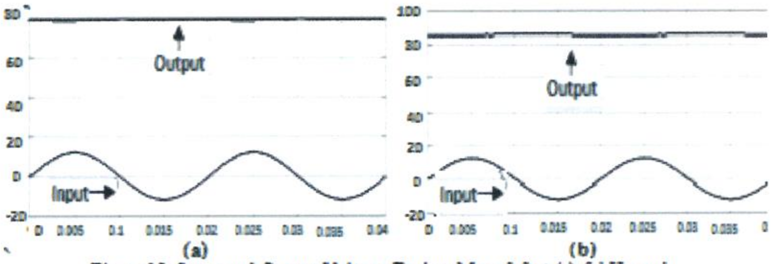


Figure 18: Input and Output Voltage During Ma = 0.9 at (a) 5 kHz and (b) 1 kHz

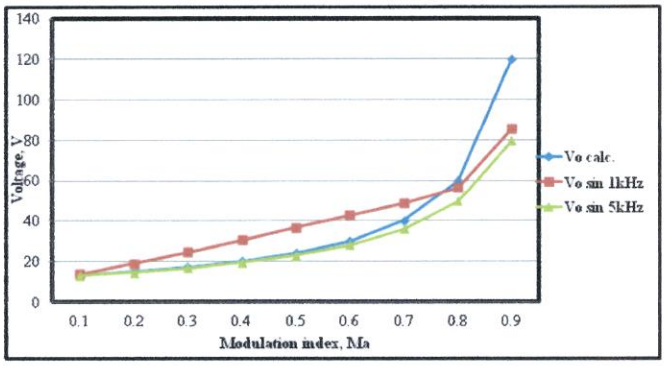


Figure 19: Graph outputvoltage (Vpk-pk) plotted against modulation index using 1 kHz and 5 kHz switching frequency

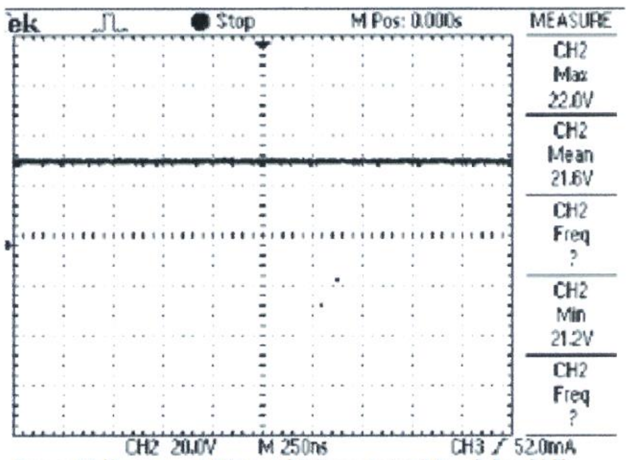


Figure 20: Experimental Output Voltage during Ma = 0.5 at 5 kHz

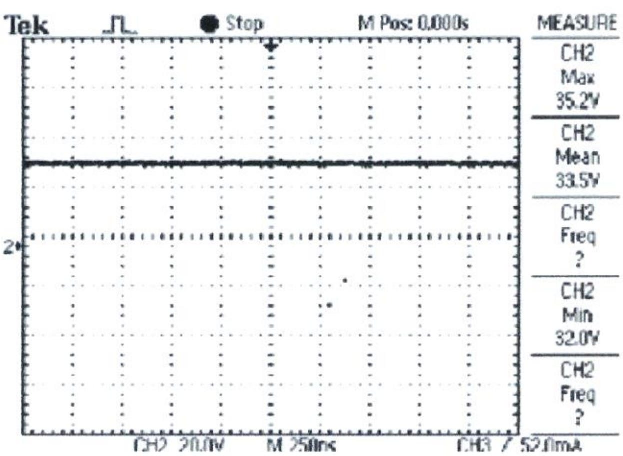


Figure 21: Experimental Output Voltage during Ma = 0.5 at 1 kHz

X. Conclusion

In this paper it has briefly illustrate that the rectifier using SPMC topology can operate successfully as a boost converter. Simulation results shows that an algorithm can be generate the output voltage higher than the input voltage. The value of the output voltage is created follow the value of modulation index. This is because the modulation index has been generated by switching frequency. Besides that, the experimental result also shows that the output is higher than the input. This project has been success because the objective was achieved. The results show that by increasing the modulation index, it can generate the increasing of output voltage. This paper shows that the SPMC was effectively used for the design of controlled boost rectifier application. In additional the SPMC also can be used for the controlled switching inverter application. In the other hand, for advancement the switching SPMC could be design less than eight main switches for future research. It might be able to reduce a cost of a switch.

Acknowledgment

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