

SIMULATION OF SINGLE PHASE MATRIX CONVERTER OPERATING AS A CONTROLLED RECTIFIER FOR POWER SUPPLY APPLICATION

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Abstract: - This paper proposed a boost rectifier using single phase matrix converter topology. A new boost rectifier is presented that could synthesize a greater DC output voltage from a given AC supply voltage. Basic operation on single-phase matrix converter which implement as boost operation is outlined. Safe commutation strategy was developed to avoid voltage spikes due to inductive load. The Pulse Width Modulation (PWM) technique is used to synthesize the output voltage.

Keywords: Single-Phase Matrix Converter (SPMC), Controlled Boost Rectifier, Boost Rectifier, PWM, safe commutation.

I. INTRODUCTION

Classical rectifier normally uses bridge-diode without affording any control function and is unidirectional in nature. Bidirectional operation is also possible with the inclusion of anti-parallel switch in H-bridge topology but is not fully controllable. Development of advanced power semiconductor devices, increased usage of power switching circuits and other power electronic applications are becoming a common place within modern commercial and industrial environment particularly in applications for AC-DC conversions.

The Single-phase matrix converter (SPMC) was first realized by Zuckerberger in 1997 [4] with other works on AC-AC [5], DC-DC [6] and some works on AC-DC [1, 2] conversion. This topology consists of a matrix of input and output lines with four bidirectional switches connecting the single-phase input to the single-phase output at the intersections. Each of the individual switch is capable of conducting current in both directions, whilst at the same time capable of blocking voltage [1,2,5 & 6].

Alternative topologies such as matrix converters (MC) present future potential and are an emerging research topic. It offers an "all silicon" solution for AC-AC conversion, removing the need for reactive energy storage components used in conventional rectifier-inverter based system. The key element in a matrix converter is the fully controlled four-quadrant bidirectional switch, which allows high frequency operation. Previous works are based on three-phase circuit topologies; with single-phase matrix converter (SPMC) emerging with works on AC-AC, DC-DC, DC-AC conversion and more recently the AC-DC rectifier [1, 2].

In this paper the basic SPMC topology is implemented as controlled rectifier operation. Insulated gate Bipolar transistor (IGBT) are used as the main power switching device. Simple resistive load will initially be used. Subsequently the input side will be provided with an inductance that is used for boost rectifier operation. Commutation problems that lead to switching spikes are also discussed with proposed safe-commutation algorithm implemented. A simple 'on-off' control with variations in duty cycle will be presented. Previous commutation strategies are evaluated to take into account, with modifications to suit. Pulse Width Modulation (PWM) technique is used to synthesize the output waveform. Simulation model of SPMC as rectifier developed using MATLAB/SIMULINK (MLS) software to study the behaviour of the proposed technique.

II. BOOST TOPOLOGY

Boost converters are widely used for electronic power supplies, in which the desired output voltage is high compared to a typical ac input voltage level; i.e $v_{out} \geq v_{in}$. Generally, a single-inductor, single-switch boost converter topology and its variations exhibits satisfactory performance in the majority of applications. In conventional topology, the power switching device and load are grounded as shown in Fig.1. where the operation are divided into two modes; mode one for the switch is turn 'on' and mode two for the switch is turn 'off' and can be summarized as;

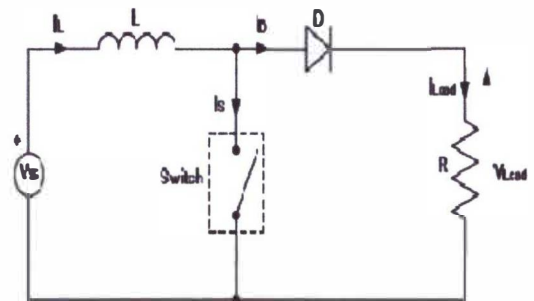


Fig 1: Main Circuit Diagram of Boost Converter

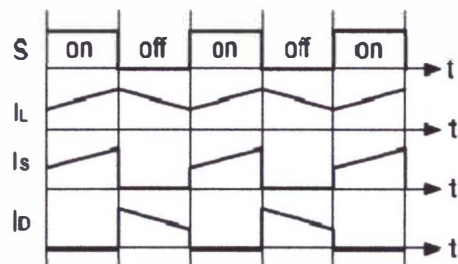


Fig. 2: Ideal Waveform of Boost Converter

Mode 1: During switch turn 'on', the inductor stores energy while the inductor current I_L increases as shown in Fig. 2.

Mode 2: During switch turn 'off', the inductor current decays as the stored energy is released to the output as shown in Fig. 2. In this stage, the energy retained by the inductor is transferred to the load.

This is the simplest topology which requires only a single switching device to be controlled. However, the uncontrolled bridge circuit may not be used in bidirectional and regenerative operations.

III. SPMC TOPOLOGY

The Single-phase matrix converter (SPMC) requires the use of bidirectional switches capable of blocking voltage and conducting current in both directions. Unfortunately there is no discrete semiconductor device currently that could fulfil the needs [15,16] and hence the use of common emitter anti-parallel IGBT, diode pair as shown in Fig. 3. The IGBT were used due to its popularity amongst researchers that could lead to high-power applications with reasonably fast switching frequency for fine control.

The SPMC is presented schematically in Fig. 4. Its instantaneous input voltage is V_s and its output voltage is V_o . It comprises four ideal switches $S1$, $S2$, $S3$ and $S4$ capable of conducting current in both directions, blocking forward and reverse voltages (symmetrical devices) and switching between states without any delays.

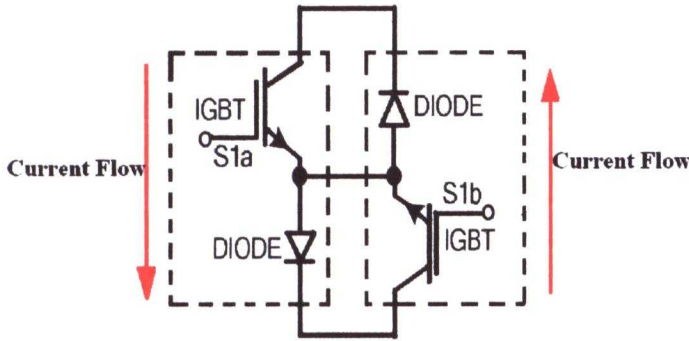


Fig. 3: Bi-directional switch

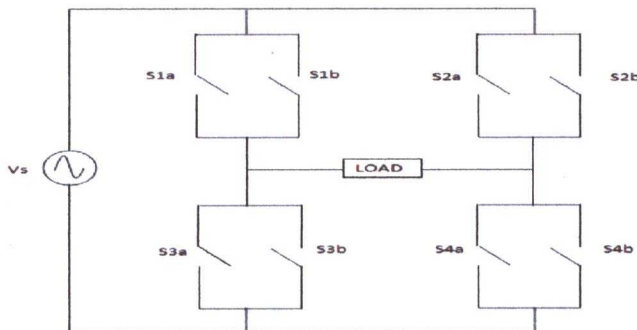


Fig. 4: Single Phase Matrix Converter SPMC topology.

IV. COMMUTATION PROBLEM

One of the problems associated with using of matrix converter topology is that spikes are generated during switch transitions when supplying R loads; limiting the use in industry applications [8]. Theoretically the switching in the SPMC must be instantaneous and simultaneous; unfortunately it is impossible for realization in practical systems due to the turn 'on/off' times within the IGBT characteristics, where the turn 'off' delay time is 420ns whilst the turn 'on' time is 75ns as illustrated in Fig. 5 that will create a short circuit during commutation. Without commutation problem also occur during switch turn 'off' transforming the stored energy in the inductor into switching spikes.

To solve these difficulties, safe commutation strategy was developed to prevent from current and voltage spikes induced by manipulation of the switch according to the switching state in Table 1 [1, 2]. By referring to Fig. 4 for state 1 (positive cycle), switch $S3a$ is controlled by PWM signal, whilst $S1a$ and $S4b$ is turn 'on' for positive state. With this proposed technique, the energy stored at the inductor will be released and flow back to the negative path during switch turn 'off'. This arrangement is similarly implemented for negative cycle, where switch $S4b$ is controlled by the PWM signal, whilst $S2b$ and $S3b$ is turned 'on' for negative state as illustrated in Fig. 6 & 7.

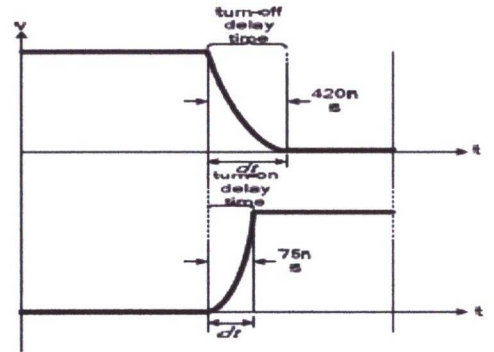


Fig. 5 : Time on/off proposed switch.

V. PROPOSED BOOST RECTIFIER OPERATION USING SPMC TOPOLOGY

All of the paper before is more to commutation process in three phase matrix converter. Thus, the commutation processed by previous researcher is studied first along with behaviour of inductance load. Based on the study, new commutation strategies for various a single phase matrix converters (SPMC) are propose. This paper proposes a few switching step in current commutation directly for various SPMC in boost rectifier for Resistive load. The simulation model was developed using MATLAB / Simulink software (MLS) based on propose switching strategies, to study the behaviour.

A safe commutation strategy using SPMC is shown in Fig. 6 & Fig. 7 which is derived from the PWM switching as shown in Fig. 12 according to the switching algorithm as shown in Fig. 13. Fig 10 & 11 illustrate the operation of boost rectifier following the switching scheme as tabulated in Table 2. The basic operation of controlled rectifier using SPMC has been described in [1 & 2] but not explicitly described in terms of boost rectifier operation. For boost rectifier operation; the pair of switches S1a & S4a are turn into 'on' state whilst switch S3a implements 'PWM' control for inductor charging/ discharging for positive cycle operation. For negative cycle operation, the pair of switches S3b & S2b is turn into 'on' state, whilst switch S4b provides control using PWM. The boost inductor L is connected in the ac side [3]. For this work, the different switching frequency of 5 kHz and 10 kHz were used to generate the PWM signal to control the switches S3a and S4b for boost operation.

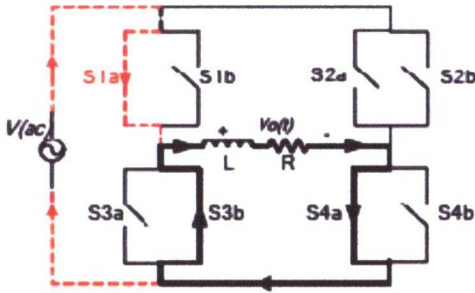


Fig. 6: Safe commutation strategy (positive state)

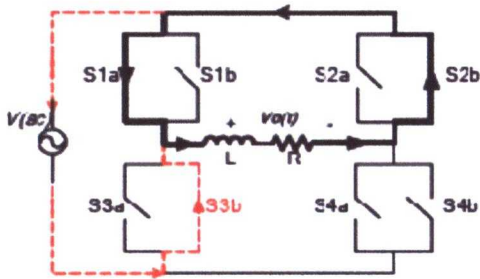


Fig. 7 : Safe commutation strategy (negative state)

Table 1: switching state for safe commutation strategy.

switch	s1a	s1b	s2a	s2b	s3a	s3b	s4a
positive cycle	pwm	off	off	off	off	on	on
negative cycle	on	off	off	on	off	pwm	off

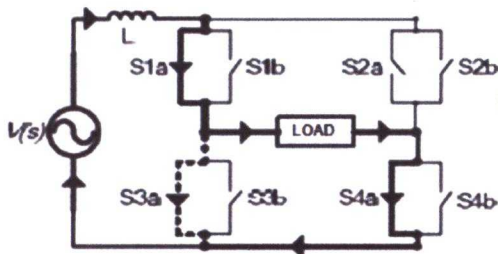


Fig. 8: Boost Rectifier topology (positive cycle)

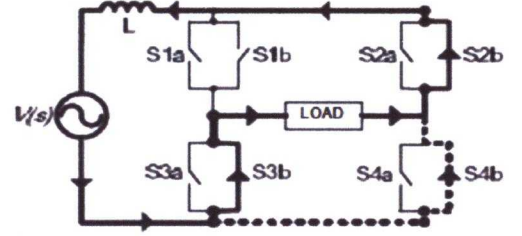


Fig. 9: Boost Rectifier topology (negative cycle)

Table 2: switching state for boost rectifier operation

Mode	ON'	PWM
positive cycle	S1a & S4a	S3a
negative cycle	S3b & S2b	S4b

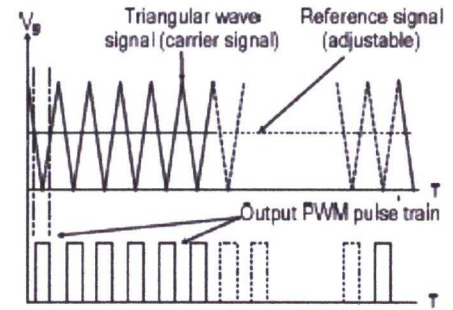


Fig. 10: PWM waveform

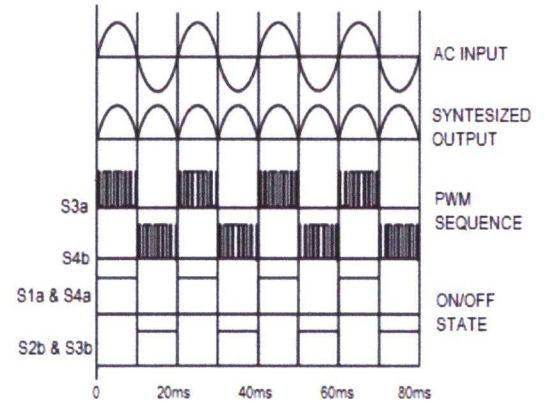


Fig. 11: Switching algorithm for boost rectifier

VI. MODELING AND SIMULATION

Simulation model (Matlab / Simulink)

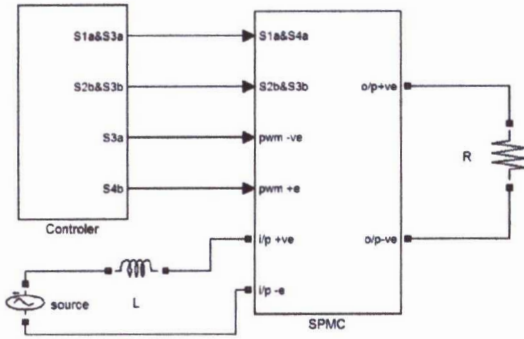


Fig. 12: Top level model of boost rectifier

The proposed control concept is verified through simulation using MATLAB/Simulink as shown in Fig. 12. For simulation implementation, Power System Block Set (PSB) in MATLAB/Simulink (MLS) is used to model and simulate the circuit. The supply voltage of $10.6 \text{ V}_{\text{rms}}$ and boost inductor value of 4 mH was used in the simulation. The controller circuit as shown in Fig. 14 to generate the pulse width modulation (PWM) switching signal for control of the switches. PWM generator was design by comparing reference signal and carrier signal. The output of PWM has positive cycle and negative cycle which then detect by phase detector. Phase detector was use to assign either positive cycle or negative cycle.

For this simulation, the parameters used are:

- Input AC Voltage, $V_{\text{ac}} = 10.6 \text{ V}_{\text{rms}}$
- Resistor, $R = 50 \Omega$
- Inductor, $L = 4 \text{ mH}$

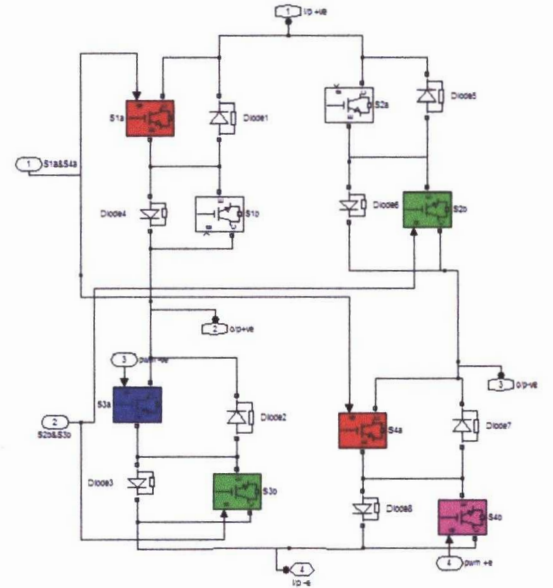


Fig. 13: Single Phase Matrix Converter

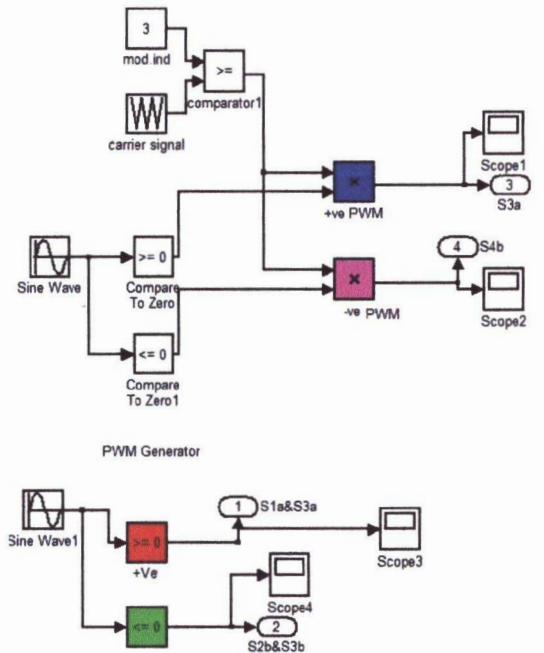


Fig. 14: Controller

VII. RESULTS

a) Using matlab

ma	THD	V peak	V average
0.1	15.53	14.0	6.272
0.2	15.78	16.73	6.278
0.3	15.89	19.8	6.28
0.4	15.84	23.46	6.292
0.5	15.68	28	6.304
0.6	15.43	34.37	6.322
0.7	15.16	44.18	6.351
0.8	14.63	62.74	6.396
0.9	12.75	116	6.45

Table 3: result at switching frequency 5khz

ma	THD	V peak	V average
0.1	15.42	13.338	6.343
0.2	15.42	15.427	6.397
0.3	15.41	18.04	6.431
0.4	15.38	21.027	6.462
0.5	15.35	25.5	6.537
0.6	15.24	31.17	6.626
0.7	15.05	41.866	6.696
0.8	14.56	60.226	6.699
0.9	12.54	121.8	7.127

Table 4: result at switching frequency 10khz

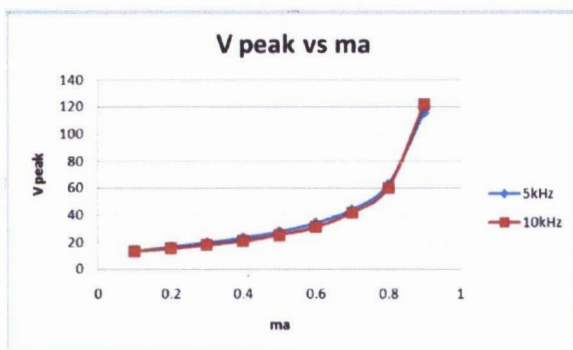


Fig. 15: Graph voltage peak plotted against Modulation index using 5 kHz and 10kHz switching frequency

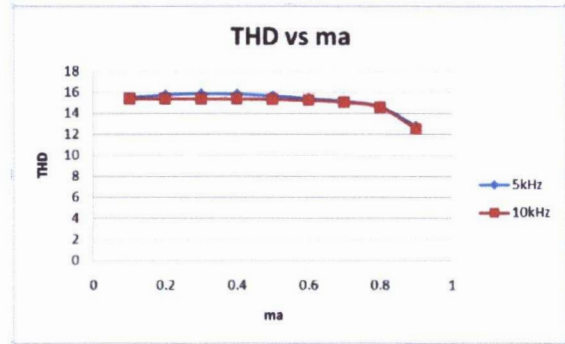


Fig. 16: Graph Total Harmonic Distortion plotted against modulation index using 5 kHz and 10kHz switching frequency

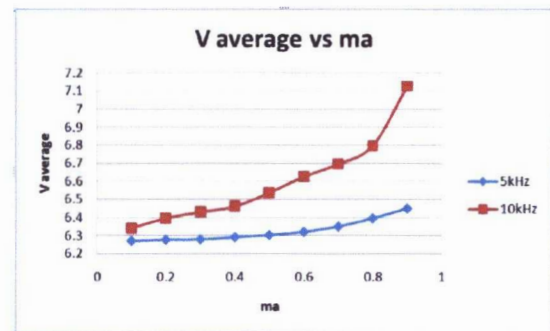


Fig. 17: Graph Voltage average plotted against modulation index using 5 kHz and 10kHz switching frequency

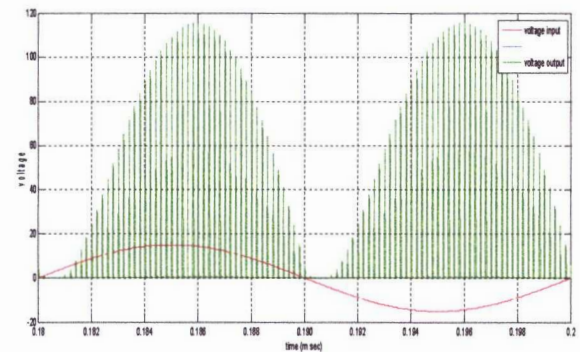


Fig. 18: result output for ma=0.9 at 5 kHz switching frequency

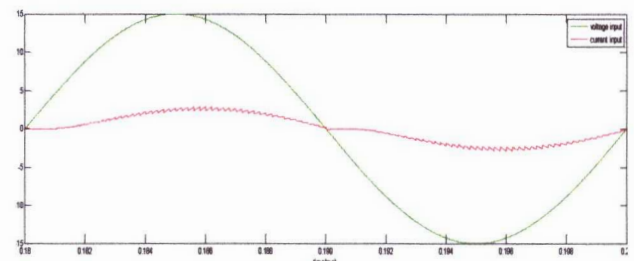


Fig. 19: result voltage input and current input for ma=0.9 at 5 kHz switching frequency

b) Using Psim

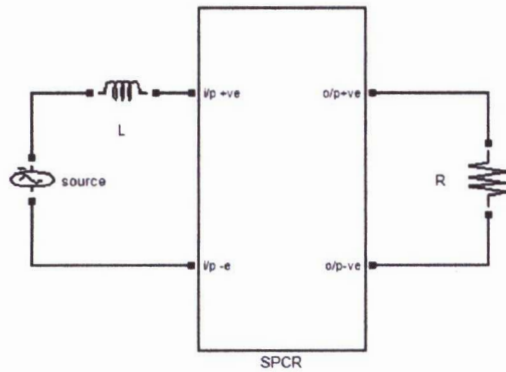


Fig. 20: Block diagram for single phase full-wave control rectifier with R load.

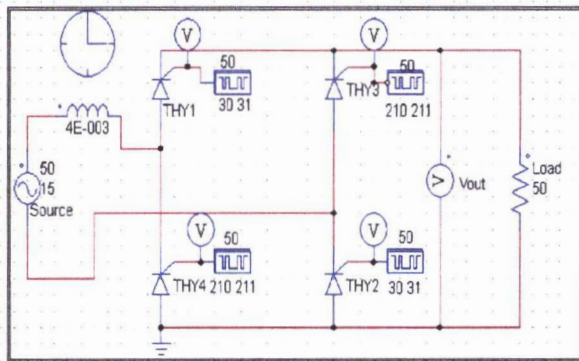


Fig. 21: circuit single phase full-wave control rectifier with R load.

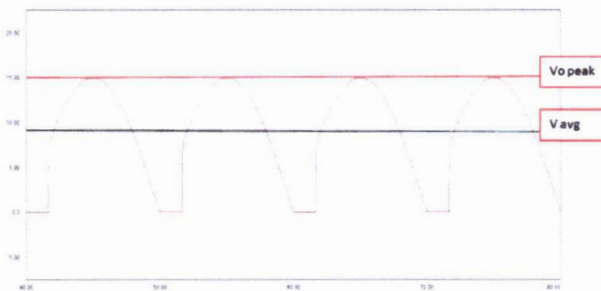


Fig. 22: result voltage output for single phase full-wave control rectifier with R load.

THD input current	45.88%
Vo peak	14.9953V
Vo average	8.9119V

Table 5: result for single phase full-wave control rectifier with R load.

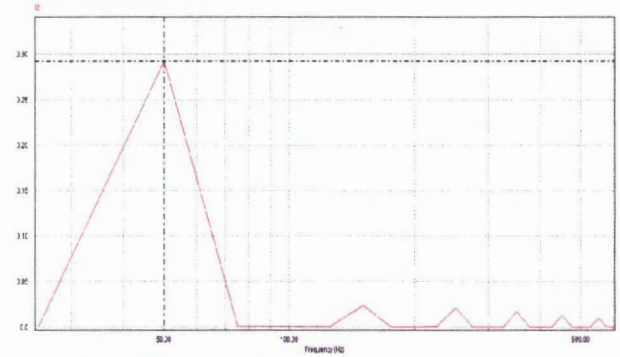


Figure 23: wave form of the input current

No of harmonic	Current	Current in rms
1	0.2923	0.2067
3	0.0237	0.0168
5	0.0209	0.0148
7	0.0171	0.0121
9	0.0130	0.0092
11	0.0093	0.0066

Table 6: harmonic current

Formula for finding RMS current

$$I_{Nrms} = \frac{I_N}{\sqrt{2}} \quad [1]$$

Formula for finding total RMS current

$$I_{Trms} = \sqrt{I_{1rms}^2 + I_{3rms}^2 + I_{5rms}^2 + I_{7rms}^2 + I_{9rms}^2 + I_{11rms}^2} \quad [2]$$

Formula for finding Total Harmonic current

$$THD = \sqrt{\left(\frac{I_{Trms}}{I_{1rms}}\right)^2 - 1} \times 100 \quad [3]$$

Based on the Fig. 23, the value of each harmonic current should be recorded in Table 6. This is because to find the THD need value of each current harmonic. After that, using the formula[2] for finding the value of I_{Trms} . Than, using the formula[3] for finding the value of THD.

VIII. Discussion

From this Fig. 15, there is a significant change occurred on the graph when there are changes to the voltage and m_a . This occurs because the voltage is directly proportional to m_a . Refer to Fig. 18, the voltage peak is 116V. While the voltage peak in Fig. 22, is 14.9953V. This shows that the SPMC is better than SPCR. SPMC is due to the higher voltage peak of the voltage peak in the SPCR.

From this Fig. 16, there is a significant change occurred on the graph when there are changes to the THD and m_a . This occurs because the THD is inversely proportional to m_a . See in Table 5, the THD is 45.88%. While the THD in Table 3, is 12.75%. This shows that the SPMC is better than SPCR. SPMC is due to the low of THD in the SPCR. It is because of the SPMC is much lower than the THD at SPCR

From Fig.17, shows that the difference between the two switching frequency. Referring to the graph, the red colored at 10 kHz switching frequency and the blue colored at 5 kHz switching frequency. At 10 kHz switching frequency, voltage greater than the switching frequency equal to 5 kHz. This is because when switching to change from 10 kHz to 5 kHz, cause THD is reduced and voltage is increase. These changes also occur when the m_a changed. This case because that m_a controls the voltage.

IX. Conclusion

Successful implementation of boost rectifier using SPMC topology has been presented. The proposed topology could be used for the power factor correction using boost rectifier technique for non-linear load operation. The SPMC could be effectively used for controlled boost rectifier application. It is shown that the SPMC topology has inherent versatility extending beyond the direct AC-AC converter, DC chopper and rectifier operation. Further advancement could be developed with redundant switches available but are subject to future research. This paper described one such advancement that has been explored.

X. ACKNOWLEDGMENT

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