AC-DC Single Phase Matrix Converter with Reduced Switch Count and Unity Power Factor Wave Shaping Current Control Loop

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***Abstract*-This paper presents the implementation of AC-DC single phase matrix converter with reduced switch count and unity power factor wave shaping current control loop. Basic operation of rectifier by using PWM was used to calculate the switch duty ratio to synthesis the output. Safe commutation strategy was implemented to avoid voltage spikes due to inductive load. Reduced switch count were proposed after analyze all the switching scheme and operation. A current control (CCL) using standard proportional integral control was used to develop power factor correction to correct the pulsating nature of the input current to almost unity power factor form with low total harmonic distortion (THD) level well below the acceptable limit that was defined in the IEEE 519 Standard. Active current wave shaping control was used to ensure the supply current waveform could perform corrections making it continuous, sinusoidal and in phase with the voltage supply. Prior to its practical realization a computer simulation model is developed to investigate the behavior of the SPMC using MATLAB/Simulink. Selected simulations results are presented to verify proposed operation.**

Keywords- single phase matrix converter, unity power factor, reduced switch count, ac-dc rectifier

I.INTRODUCTION

Among of all types of energy conversion, the AC-DC rectifier has the widest application in the industries. Conventionally, the rectifier technologies are developing using diodes and thyristor to provide uncontrolled and controlled rectifier with bidirectional or unidirectional power flow. However this implementation has poor power quality due to injected current harmonic, causing low power factor and also current distortion. Because of this severity problem, some options are carried out to solve the problem. SPMC can be used conventionally to solve the conversion by removing the needs for reactive energy store component used in conventional rectifier based system. It has distinct advantages of affording bi-directional power flow with any desired number of input and output phase. By proper modulation, it's possible to generate any required output.

In this work, the use of SPMC for controlled rectifier operation incorporated with PFC and reduced switches are investigated for better quality improvement.

II.SPMC

The Single Phase Matrix Converter (SPMC) was first realized by Zuckerberger *et al.* [1] in 1997 with other works on DC-AC (Inverter) by Hosseini *et al.* [2] in 2001.The Single Phase Matrix Converter (SPMC) is consists of 4 bi-directional connecting to the single phase input to the single phase output at the intersection. Each switches capable blocking voltage and conducting current in both directions. The SPMC topology is illustrated in Figure 1.

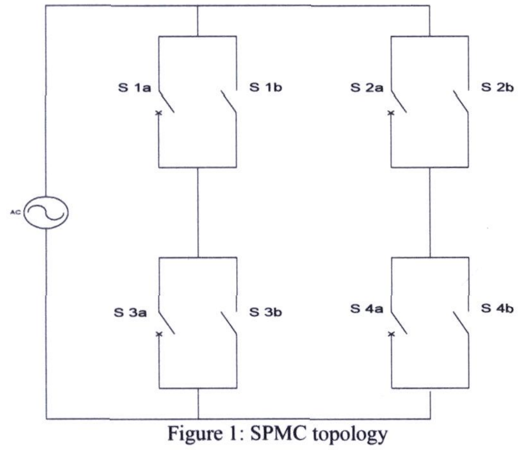


Figure 1: SPMC topology

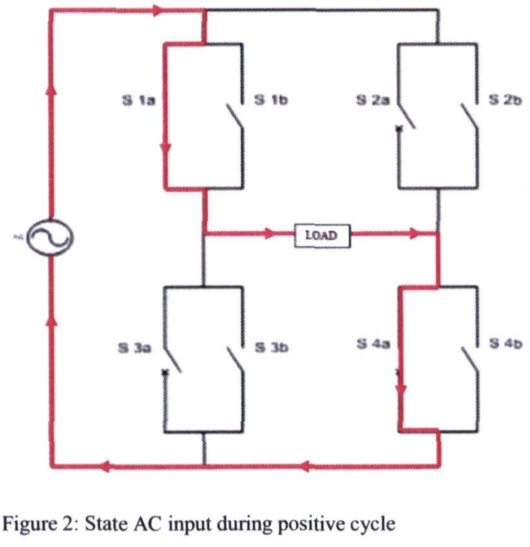


Figure 2: State AC input during positive cycle

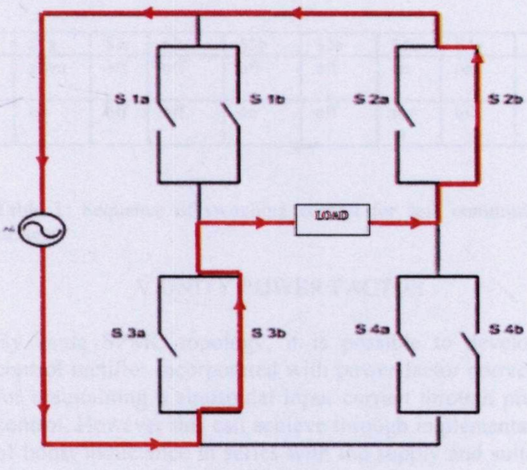


Figure 3: State AC input during positive cycle

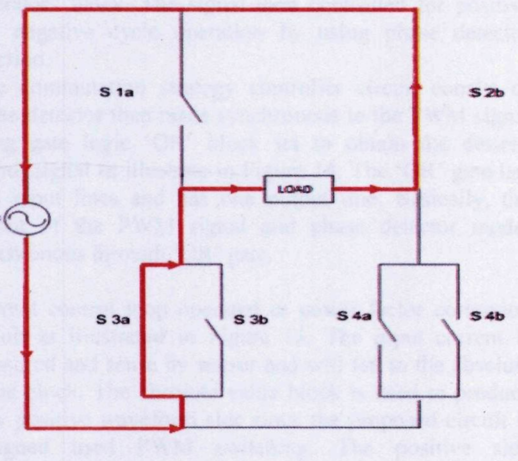


Figure 6: State AC input (negative cycle)

III. THE REDUCED SWITCH COUNT

The proposed of reduced switch count is to analyze the operation of flow current in 8 IGBTs for all propose of switching scheme; AC state, safe commutation strategy and power factor correction. By studied the switching scheme and circuit operation, it found that only 6 IGBTs are used for all purpose. Another 2 IGBT, S 1b and S 2a tend to remove. By removing the 2 IGBTs, it doesn't affect any operation; AC state, safe commutation strategy and power factor correction technique that being proposed.

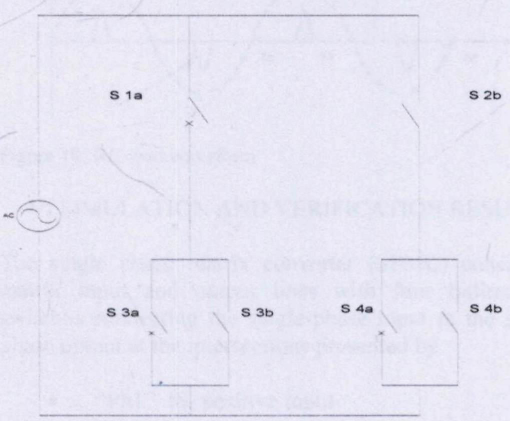


Figure 4: SPMC topology with reduced switch count

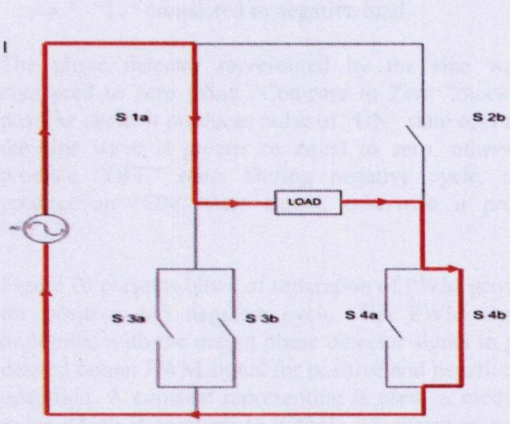


Figure 5: State AC input (positive cycle)

III.SAFE COMMUTATION STRATEGY

Theoretically the switching sequence in the SPMC must be instantaneous and simultaneous but it impossible to develop for practical realization due to turn-of IGBT characteristic. A systematic switching sequence is required that allows for energy flowing in the IGBTs to decay. The freewheeling diodes are used for this purpose. This purpose not exists at SPMC, but the needs to allow energy dissipation as illustrated in Figure 7 and Figure 8. The sequence of switching control for safe commutation strategy outlines at Table 1.

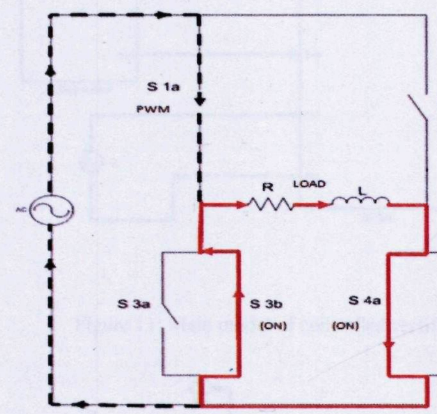


Figure 7: Safe commutation strategy (positive state)

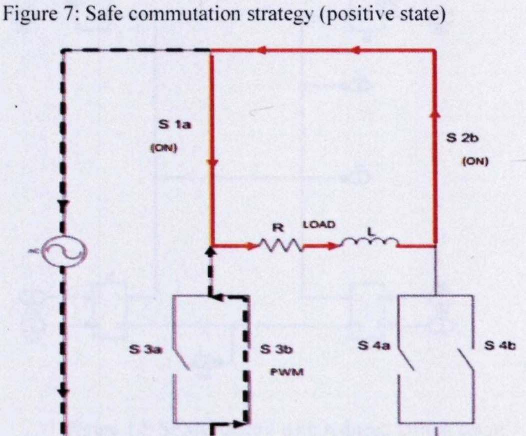


Figure 8: Safe commutation strategy (negative state)

Switches	Sla	Slb	S2a	S2b	S3a	S3b	S4a	S4b
Positive cycle	pwm	off	off	off	off	on	on	off
Negative cycle	on	off	off	on	off	pw m	off	off

Table 1: Sequence of switching control for safe commutation strategy

V.UNITY POWER FACTOR

By using SPMC topology, it is possible to develop a control rectifier incorporated with power factor correction for maintaining a sinusoidal input current through proper control. However this can achieve through implementation of boost inductance in series with the supply and suitable control the switches of SPMC.

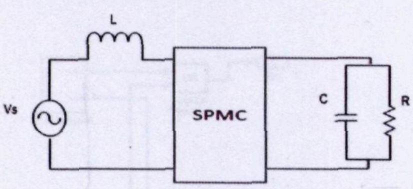


Figure 9: SPMC with RC load

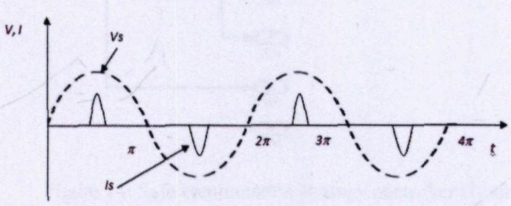


Figure 10: RC load waveform

VI.SIMULATION AND VERIFICATION RESULT

The single phase matrix converter (SPMC) consists of matrix input and output lines with four bidirectional switches connecting the single-phase input to the single-phase output at the intersections presented by

- "Ph1" for positive input
- "Nt1" for negative input
- "L+" connected to positive load
- "L-" connected to negative load

The phase detector represented by the sine wave is compared to zero using "Compare to Zero "block. For positive cycle, it produces pulse of "ON" state operation if the sine wave if greater or equal to zero, otherwise it produce "OFF" state. During negative cycle, it will produce an "ON" state signal; otherwise it produces "OFF".

Figure 16 presents block of separation of PWM generation for positive and negative cycle. The PWM signal is multiplied with the output phase detector signal to get the desired output PWM signal for positive and negative cycle operation. A constant representing is used as modulation index which is compare to triangle waveform as a carrier signal to produce the required respective PWM output signal. This is implemented by using the "Relational Operator" block. The signal then controlled for positive and negative cycle operation by using phase detector function.

Safe commutation strategy controller circuit consist of phase detector then made synchronous to the PWM signal using gate logic 'OR' block set to obtain the desired output signal as illustrate in Figure 14. The 'OR' gate has two input lines and has one output line. Basically, the output of the PWM signal and phase detector model synchronous through 'OR' gate.

Current control loop operated in power factor correction circuit as illustrated in Figure 15. The input current is measured and sense by sensor and will fed to the absolute value block. The absolute value block is used to produce only positive waveform side since the proposed circuit is designed used PWM switching. The positive side waveform will compare with the input voltage by using a subtractor. The input voltage is sense by voltage sensor. The error produced from the subtraction will feed to the PI controller.

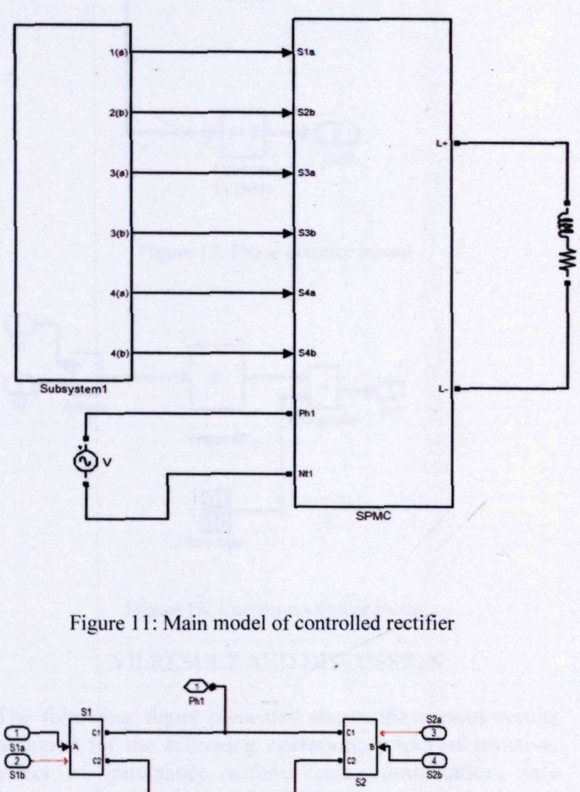


Figure 11: Main model of controlled rectifier

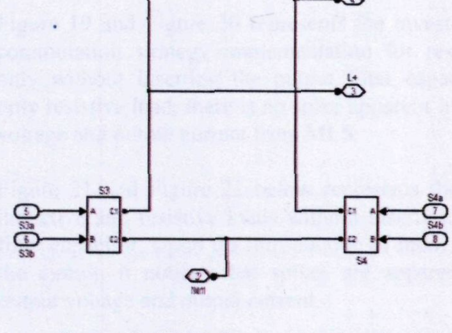


Figure 12: SPMC circuit with reduced switch count

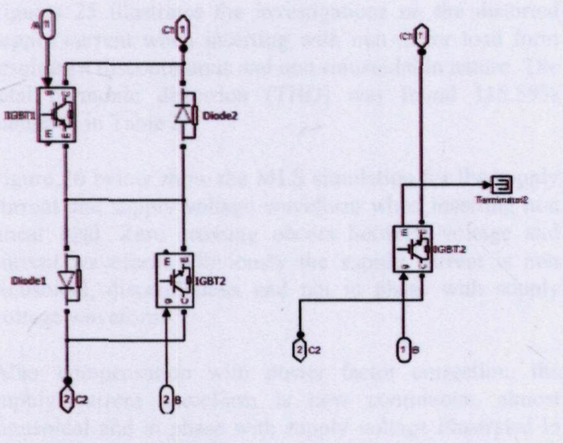


Figure 13: Bidirectional switch (common emitter anti parallel with diode pair) and single diode

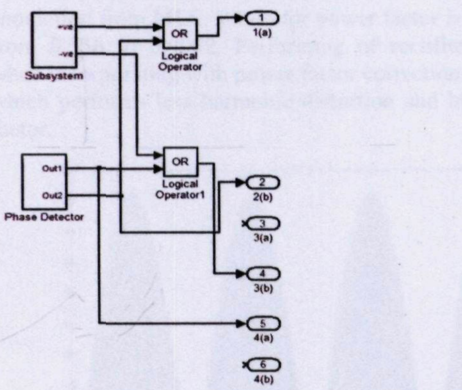


Figure 14: Safe commutation strategy controller circuit

PARAMETERS OF CONTROLLED RECTIFIER WITH PFC

Boost inductor	4mH
Switching frequency	5KHz
Proportional gain, Kp	15
Integral gain, Ki	50

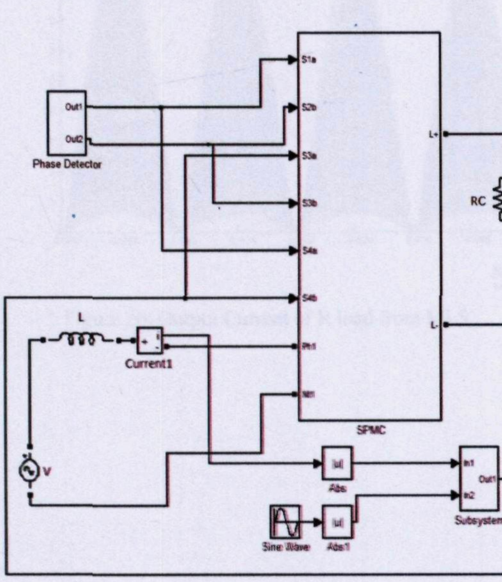


Figure 15: modeling rectifier with APF function

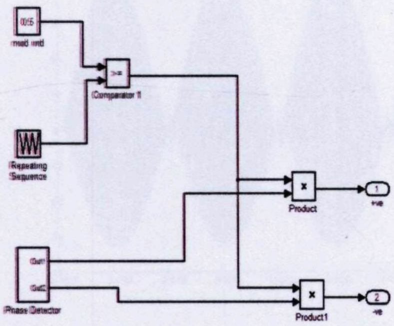


Figure 16: PWM generator model

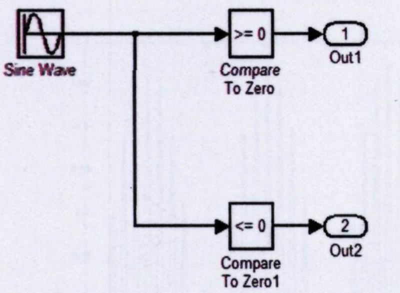


Figure 17: Phase detector model

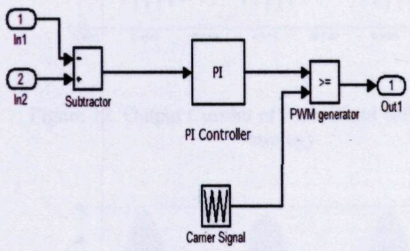


Figure 18: Current controller model

VII.RESULT AND DISCUSSION

The following figure presented shows the various results obtained for the following operation; output of resistive, effect of inductance without safe commutation, safe commutation strategy and PFC implementations.

Figure 19 and Figure 20 represents the investigations on commutation strategy implementation for resistive load only without inserting the output filter capacitor. With only resistive load, there is no spike apparent in the output voltage and output current from MLS.

Figure 21 and Figure 22 below represents the output of inductive and resistive loads without inserting the output filter capacitor. Upon the introduction of inductive load to the circuit, it notices that spikes are apparent for both output voltage and output current.

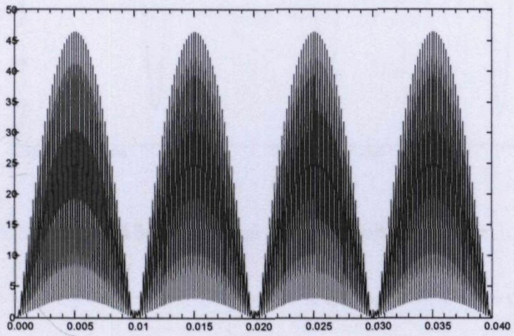
Figure 23 and Figure 24 below shows the result of spikes for both current and voltage has being eliminated by implemented the safe commutation strategy.

Figures 25 illustrates the investigations on the distorted supply current when inserting with non linear load form resulting a discontinuous and non sinusoidal in nature. The total harmonic distortion (THD) was found 115.59% tabulated in Table 2.

Figure 26 below show the MLS simulation for the supply current and supply voltage waveform when inserting non linear load. Zero crossing occurs between voltage and current waveform. Obviously the supply current is non sinusoidal, discontinuous and not in phase with supply voltage waveform.

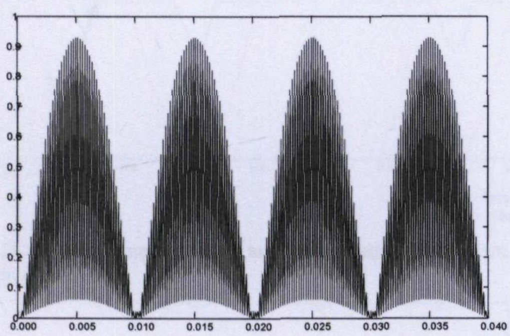
After compensation with power factor correction, the supply current waveform is now continuous, almost sinusoidal and in phase with supply voltage illustrated in Figure 27. The THD level reduces to below 5% with almost unity power factor correction achieved.

THD is become less from 115.59% to 3.93% for simulation from MLS. While for power factor is increased from 0.516 to 0.9992. Performing of rectifier improve when incorporating with power factor correction technique which performs less harmonic distortion and high power factor.



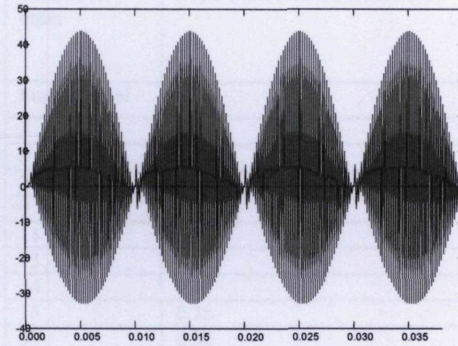
Scale: X: 4ms/div
Y: 50V/div

Figure 19:Output Voltage of R load from MLS



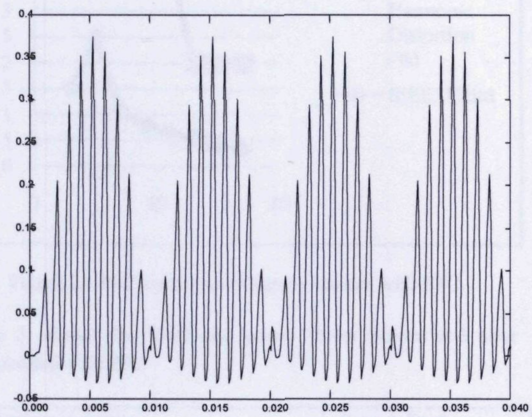
Scale: X: 4ms/div
Y: 50V/div

Figure 20: Output Current of R load from MLS



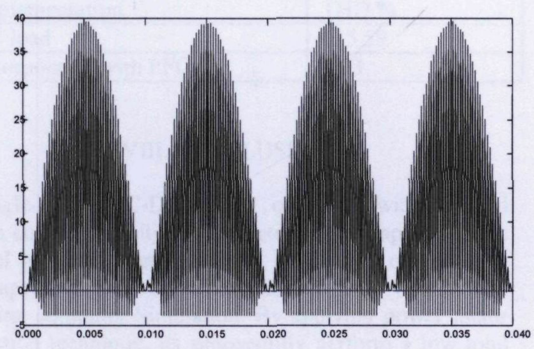
Scale: X: 4ms/div
Y: 50V/div

Figure 21: Output voltage of RL without safe commutation strategy



Scale: X: 4ms/div
Y: 50V/div

Figure 22: Output Current of RL without safe commutation strategy



Scale: X: 4ms/div
Y: 50V/div

Figure 23: Output voltage with safe commutation strategy

Scale: X: 4ms/div
Y: 50V/div

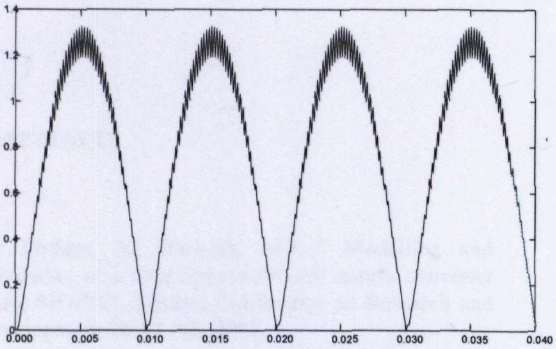


Figure 24: Output Current with safe commutation strategy

Scale: X: 4ms/div
Y: 50V/div Gain: 10

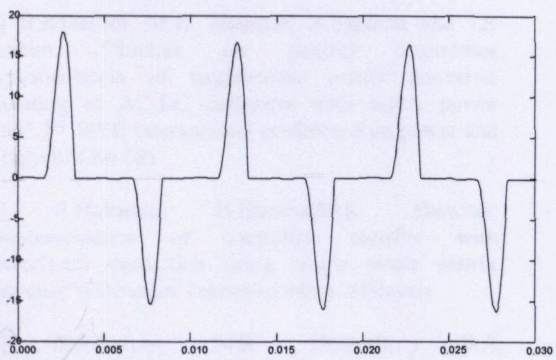
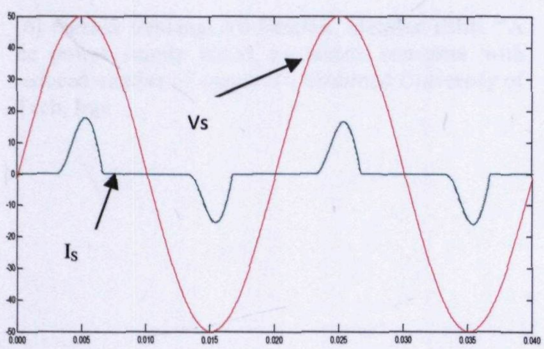


Figure 25: Distorted Supply current waveform with non linear



Scale: X: 4ms/div
Y: 50V/div Gain: 10

Figure 26: Distorted supply current and supply voltage waveform with non linear load

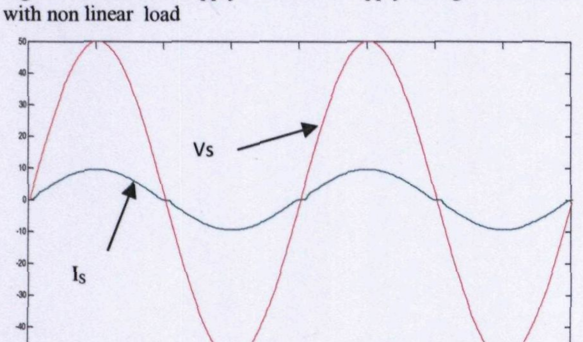


Figure 27: Supply current waveform with RC load

Scale: X: 4ms/div
Y: 50V/div Gain: 10

Harmonics order	Total Harmonic Distortion (%)
Fundamental	100
3	1.49
5	2.48
7	1.05
9	0.81
11	0.65
13	0.54
14	0.45
15	0.38
17	0.32

Table 2: Harmonics order

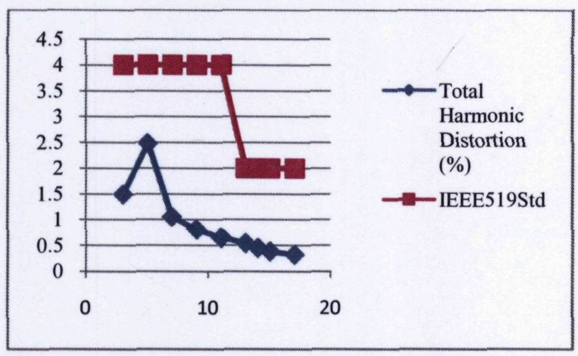


Figure 28:THD spectrum of supply current with PFC

Table 3: Result for THD and power factor before and after incorporated with PFC

Implementation	Power Factor
RC load	0.516 (leading)
Incorporated with PFC	0.9992 (lagging)

Implementation	THD %
RC load	115.59
Incorporated with PFC	3.93

VIII. CONCLUSION

A single-phase AC-DC matrix converter with reduced switch count and unity power factor wave shaping current control loop has been presented detail with operation in this paper. All proposed circuit methodology was studied by using computer Simulation. By applying power factor correction technique, its successfully perform a low total harmonic distortion and high power factor. By construct active current wave shaping technique, supply current performs the waveform in phase, continuous, and sinusoidal with the supply voltage. It shows that SPMC is a very versatile topology by extending the various type operations such as commutation strategy, power factor correction and reduced switch count.

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