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Boost Rectifier Using Single Phase Matrix Converter

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ABSTRACT:
A new boost rectifier using single-phase matrix converter topology is presented that could synthesize a greaterDC output voltage from a given AC supply voltage. This paper describes the generation of an Active Pulse Width Modulation (APWM) technique in order to maintain input current waveform continuous, sinusoidal and in phase with the supply voltage and hence input power factor improvement. Conventional rectifiers with DC capacitor filter have a drawback that it draws discontinuous supply current waveform with high harmonics content. As a result it contributes to high Total Harmonic Distortion (THD) level and low total effective supply power factor affecting the quality of the power supply system. To solve this problem, Matrix converter acting as a single phase rectifier with APWM technique is proposed to suppress the harmonic current drawn by rectifier with a capacitor-filtered load. Selected simulation results are presented to verify the proposed concept. A prototype is implemented and the performance is found to be satisfactory.

KEYWORD: Single-Phase Matrix Converter (SPMC), Controlled Boost Rectifier, Active PWM

I. INTRODUCTION:

Development of semiconductor devices and microprocessor technology during the last thirty years has changed rapidly power electronics technology and the number of applications has been on the increase. A typical power electronic system is normally used as an interface between the load and the supply comprising a power converter, a load/source and a control unit. Development of advanced power semiconductor devices Increased the usage of power switching circuits and power electronic applications are becoming commonin modern commercial and industrial environment particularly in applications for AC-DC conversions. The AC-DC converters (rectifier) are by far the largest group of power switching circuits applied in industrial applications. These type of converters are widely used in adjustable-speed drives (ASD), switch-mode power supplies (SMPS), uninterrupted power supplies (UPS) and utility interface
with non-conventional energy sources such as solar PV and battery energy storage systems etc.

Conventionally, the rectifier topologies are developed using diodes and thyristors to provide uncontrolled and controlled dc power with unidirectional and bidirectional power flow. However, they have demerits of poor power quality due to
injected current harmonics, causing current distortions, poor power factor at input ac mains, slow varying rippled dc output at load end and low efficiency requiring large size ac and dc filters.

Matrix converter has been described to offer “all silicon” solutions for AC-AC conversion, removing the need for reactive energy storage component used in conventional rectifier-inverter based system and hence an attractive alternative converter. The matrix converter is a forced commutated converter which uses an array of controlled bidirectional switches as the main power elements to create a variable output voltage system with unrestricted frequency. It has a distinct advantage of affording bi-directional power flow with any desired number of input and output phases. The key element in a matrix converter is the fully controlled four-quadrant bidirectional switch, which allows high-frequency operation [1].

The matrix converter has many advantages over traditional topologies. It is inherently bi-directional and soit can regenerate energy back to the supply [2]. It draws sinusoidal input currents and, depending on the modulation technique, it can be arranged that unity displacement factor is seen at the supply side irrespective of the type of load. It does not have any dc-link circuit and does not need any large energy storage elements. So the size of the power circuit has been reduced in comparison with conventional technologies since there are no large capacitors or inductors to store energy [3].Table I shows comparison of different power converters.

Table I: Comparison of different power converters

	Rectifier- Inverter System	**Multilevel converter**	**Matrix converter**
Capacitors	Large sized capacitors, reduced lifetime	Small capacitors but in large numbers	No large capacitors
Temperature	Very sensitive	High influence in behaviour	Less influence in behaviour
Switching loss	High	High	Low
Control	Simple	Very complex	Complex
Power quality	Poor	Acceptable	Good

This paper presents the application of SPMC as an AC-DC controlled rectifier. Boost rectifier using SPMC is implemented with RC load. IGBTs are used as the main power switching devices. Active current wave-shaping technique is proposed to ensure that the supply current waveform is continuous, sinusoidal and in phase with the supply voltage and hence input power factor improvement. The input side is provided with an inductance that is used for boost operation [4]. The performance results are compared with that of a conventional buck and boost rectifier circuits with RC load.

II. SINGLE-PHASE MATRIX CONVERTER:

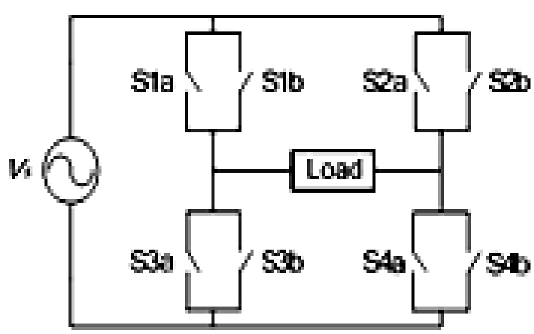

Figure1. Single phase matrix converter

SPMC as shown in Figure 1 consists of a matrix of input and output lines with four bidirectional switches connecting the single-phase input to single-phase output at the intersections. However, in the case of AC-DC conversion, only two units of IGBTs are used at a time. The other switches are redundant.Each of the individual switches is capable of conducting current in both directions, whilst at the same time capable of blocking voltage [5]. The bidirectional switch module can be made by connecting two IGBTs in antiparallel which is shown in Figure 2.

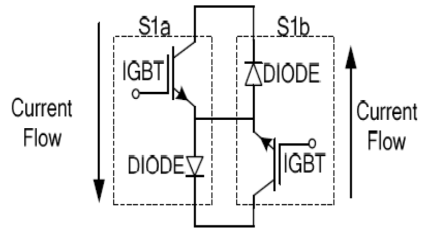

Figure2. Bi-directional switch module

III. CONTROLLED RECTIFIER USING SPMC:

Classical rectifier normally uses bridge-diode without affording any control function, thus are major contributors to power factor and current distortion problems resulting in poor overall power factor, heating effects, device malfunction and destruction of other equipments. Therefore the demand for high quality power supply has shown an increase in the provision of unity power factor supply.

SPMC can be used as a controlled rectifier by operating only two switches at a time as illustrated in Figure 3 and 4, making other switches redundant. During positive half cycle, the switches S1a and S4a are turned on and during negative half cycle, S2b and S3b are on. Thus the voltage across the load will be unidirectional all the time. However, the redundant switches could be used to provide additional features to the controlled rectifier such as safe-commutation when RL load is used and power factor correction operation when RCload is used.

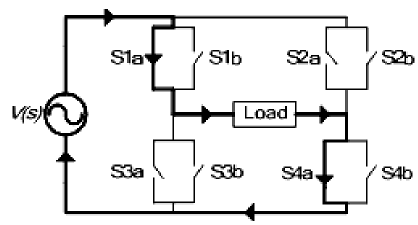

Figure3. Controlled rectifier using SPMC (positive state)

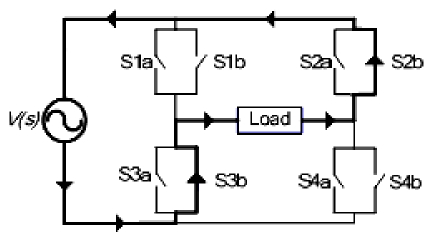

Figure4. Controlled rectifier using SPMC (negative state)

The commutation problem is an important practical issue to be considered in the employment of matrix converter in case of inductive load. It is difficult to achieve simultaneous commutation of controlled bidirectional switches in matrix converters without generating over current or overvoltage spikes which in turn can destroy power semiconductors [6]. So the switches should not both be 'OFF' at the same time since there is then no path for the inductive load current to dissipate resulting in large over voltages which will destroy the switches. So to ensure successful commutation, dead time is provided to avoid current spikes of switches and at the same time establishes a current path for the inductive load to avoid voltage spikes.

IV. BOOSTRECTIFIERUSING SPMC:

For boost rectifier operation; an inductor is used at the input to create a supplementary voltage source in series with the supply[7]. A high voltage is facilitated by the summation of the two sources. The
Switch in algorithmis shown in Figure 5. For this work, the switching frequency of 5 kHz is used to generate the PWM control signal.

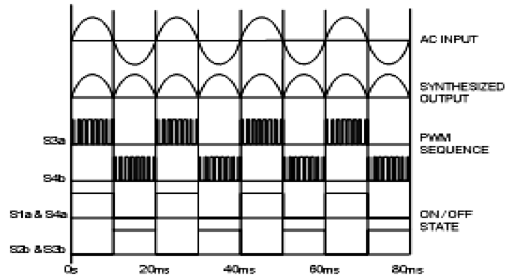

Figure5. Switching algorithm for boost rectifier

The switching state for boost operation is shown in Table II.Figure.6 illustrates the different modes of operation of boost rectifier using SPMC.

Table II. Switching state for boost rectifier operation

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

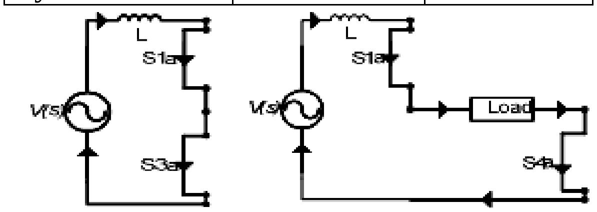

Figure6. (a) Positive cycle

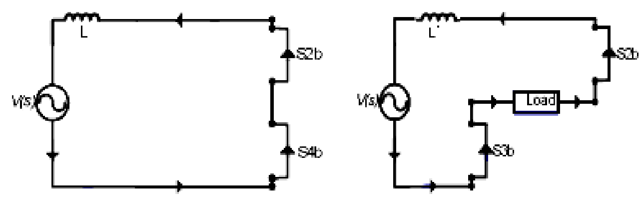

Figure6. (b) Negative cycle

In this proposed method during the positive cycle operation, the current flows through switches S1a and S3a.The inductor stores enough energy in such a way that it increases the value of supply current above the value of the reference current; while during current flow through switches S1a and S4a pair, the capacitor C is connected to the line circuit in such a way that its voltage brings about a drop in the supply current below reference value; a capacitor charging operation. During the negative cycle, the pair of switches S4b and S2b is used for charging the inductor while the pair of switches S3b and S2b for discharging operation. The equivalent circuits for the modes of operation are shown in Figure6. (a) &6. (b).

V. SPMC INCORPORATING APWM:

Classical rectifier with DC capacitor filter has a disadvantage that it draws discontinuous supply current waveform with high harmonics content. As a result it contributes to high THD level and low total effective supply power factor affecting the quality of the power supply system. Aseries active power filter (SAPF) arrangement is proposed to suppress the harmonic current drawn by rectifier with a capacitor-filtered load. Using SPMC it is possible to develop a control rectifier incorporated with active power filter function for

Maintaining a sinusoidal input current through proper control. This is done by injecting compensation current to the system, in order to improve the supply current waveform to a form that is continuous, sinusoidal and in phase with the supply voltage and hence to near unity power factor corrected input irrespective of the load behavior.

The proposed controlled rectifier with APWM technique using SPMC as shown in Figure 7, is divided into three major sections; a) SPMC circuit b)input inductor and c) controller. In this work, the load is represented by the use of a resistor and a shunt capacitor. Control electronics is used to generate APWM. The purpose of active power filter in this work is to force the supply current to follow the reference current (desired signal).The proposed rectifier is controlled based on the APWM control scheme to have a sinusoidal line current with high pf.

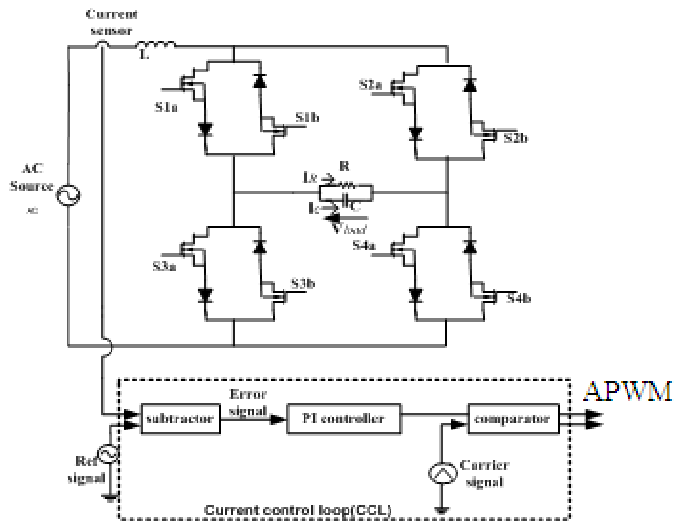

Figure 7. SPMC with APWM

The current control loop is to provide control to the system by monitoring the supply current waveform and for making corrections by current compensation techniques. It consists of three elements; a) Subtractor, b) Proportional Integral (PI) controller and c) PWM generator. The sensed supply current is subtracted from the reference sinusoidal signal and the error signal is amplified by means of a PI controller. A comparator is used to compare the carrier signal with the output of PI controller (modulating signal) to generate APWM signals.

The generation of APWM shown in Figure.8 involves fast switching action of the switching devices that is carried out in the current control loop. Since instantaneous switching action is required from the SPMC to make the supply current follow the inusoidal reference current closely, the current

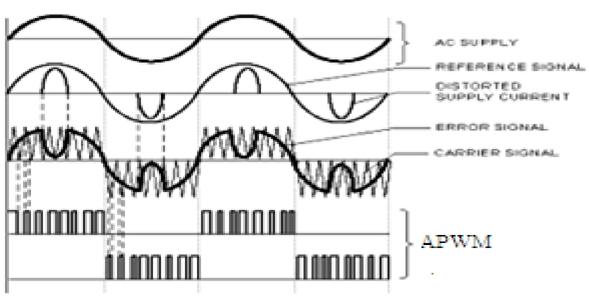

Figure8. Switching Pattern

control loop response time must be fast. For boost operation APWM signals are given to the switches S3a and S4b and for buck operation, the switches S1a and S3b.

VI. SIMULATION RESULTS:

The proposed concept of SPMC as boost rectifier for input power factor improvement is verified through simulation using MATLAB/Simulink.For simulation, Power System Block Set (PSB) in MATLAB/Simulink (MLS) is used to model and simulate the circuit. The results are compared with conventional rectifier circuits.

The proposed boost rectifier using SPMC with RC load is simulated. The parameter specifications are shown in Table III. The supply voltage is 100V as shown in Figure 9(a). For conventional boost rectifier, the input current waveform is distorted and input power factor is very poor which is shown in Figure.9 (b).

Table III. Parameter Specifications for boost operation

Supply voltage	100V
carrier frequency	5KHz
Boost inductor	1.5mH
Resistance	100KΩ
Capacitance	100µF
MOSFET	IRFZ44

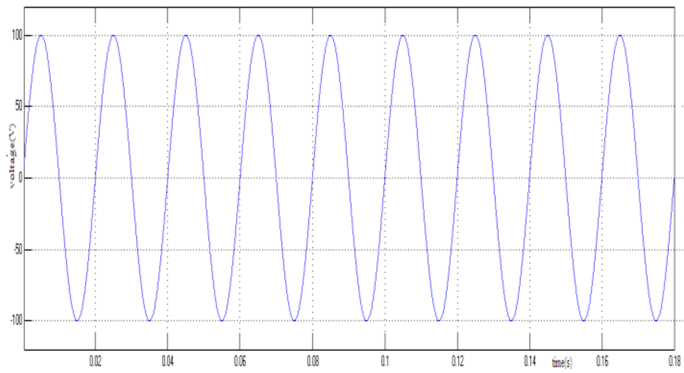

Figure.9(a) Supply voltage of conventional boost rectifier

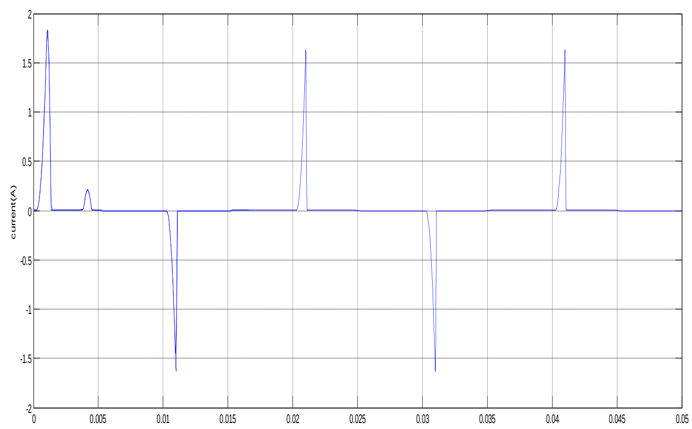

Figure.9(b) Supply current of conventional boost rectifier

So to make the current waveform sinusoidal, continuous and in phase with supply voltage, SPMC with APWM technique is used. The switching pattern is shown in Figure.10.

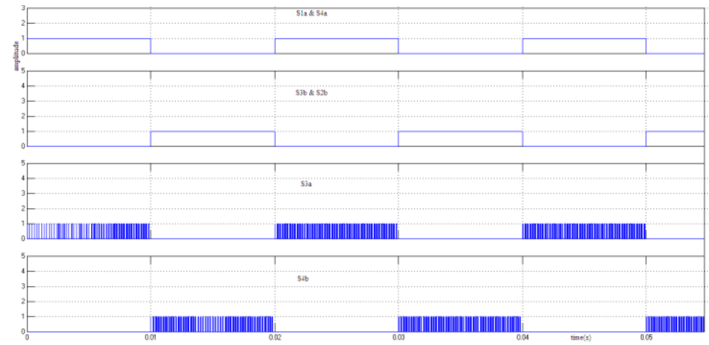

Figure.10. Switching pulses of SPMC with APWM for boost operation

The sinusoidal input current waveform resulting in input pf improvement is shown in Figure.11.The output voltages of conventional boost and boost rectifier using SPMC is shown in Figure 12. Also the pf comparison is shown in Figure.13.THD analysis of supply current for conventional boost and for SPMC with APWM is shown in Figure 14(a) and 14(b).

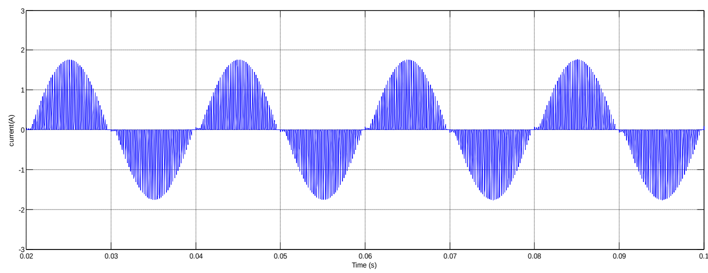

Figure 11. Supply current of SPMC with APWM for boost operation

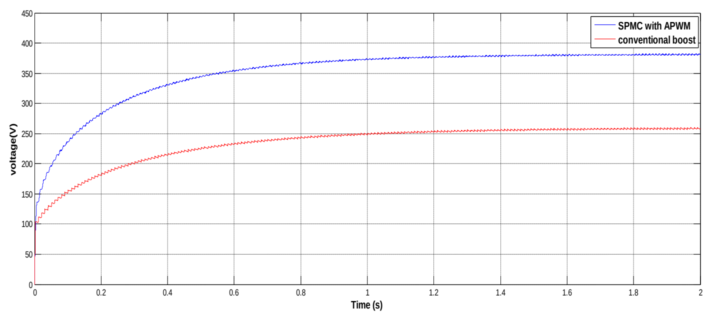

Figure.12 Boosted output voltage

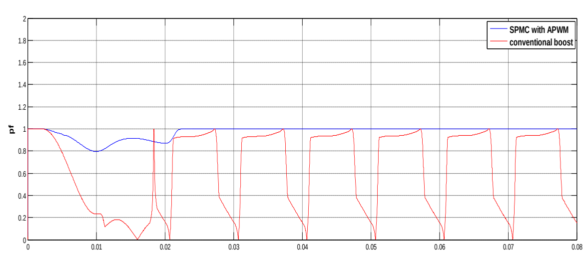

Figure.13 pf comparison

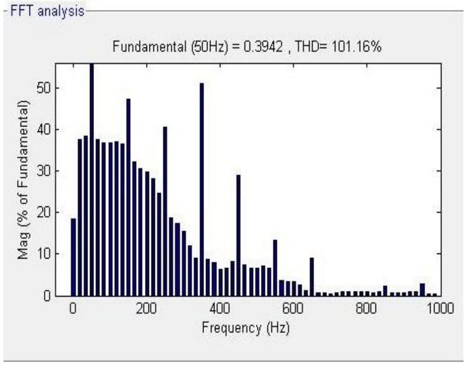

Figure.14(a)THD in supply current of conventional boost

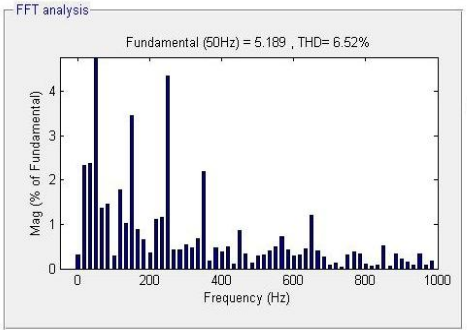

Figure 14(b)THD in supply current of SPMC with APWM

TableIV. Comparison of conventional rectifier and SPMC with APWM

Parameter	Conventional boost rectifier	SPMC with APWM
Supply voltage	100V	100V
Supply current	distorted	Sinusoidal, continuous and in phase with supply voltage
Output voltage	260 V	380 V
THD	101.6%	6.52%

From the Table IV it is clear that SPMC with APWM in boost operation has higher output voltage than conventional boost. Conventional boost rectifiers have distorted input current waveform. SPMC with APWM results in sinusoidal and continuous input current waveform which is also in phase with supply voltage resulting in input pf improvement and hence more advantageous compared to conventional boost rectifier. Also the supply current THD has been improved for SPMC with APWM compared to conventional circuits and hence more advantageous than conventional boost rectifier.

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VII. EXPERIMENTAL RESULTS:

The proposed concept of boost rectifier using SPMC for R load and SPMC with APWM for input pf improvementfor RC load is validated on a hardware prototype. The parameter specifications are shown in Table V.

Table V. Parameter specifications for hardware implementation

PARAMETERS	SPECIFICATIONS
Supply voltage	12V(ac)
Inductance	2.2mH
Resistance	100k
Capacitance	20μF
Switches	MOSFET(IRFZ44)
Diode	IN5408
Carrier frequency	2KHz

The supply voltage given is 12V.For input pf improvement APWM technique is incorporated. APWM pulses are shown in Figure 15. The supply voltage and input current waveform is shown in Figure 16(a) and 16(b). The input current is sinusoidal, continuous and in phase with supply voltage. Also for a supply voltage of 12V, the output has been boosted to 27V which is shown in Figure 17.THD analysis done using power quality analyzer is shown in Figure 18. The experimental setup is shown in Figure 19.

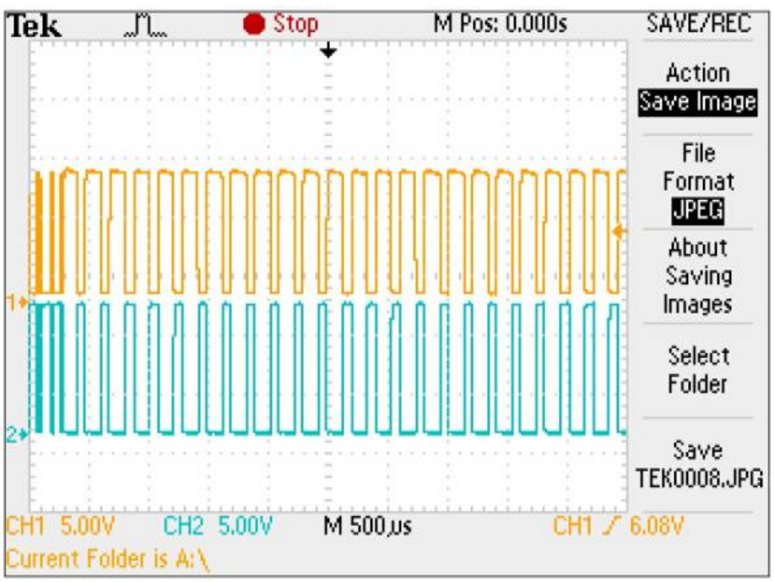

Figure15. APWM pulses for S3a and S4b

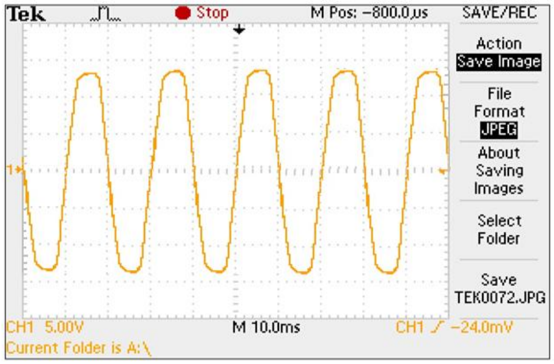

Figure 16(a). Supply voltage

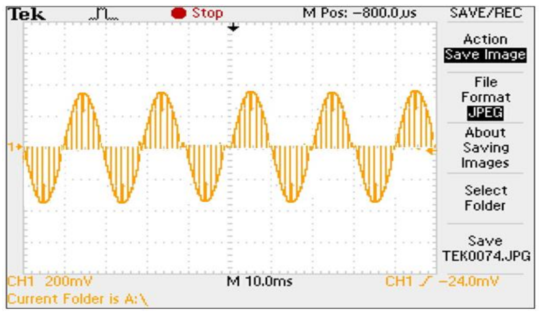

Figure 16(b). Supply current for SPMC with APWM

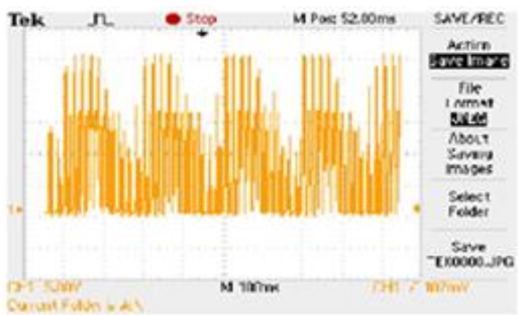

Figure17. Boosted output voltage for R load

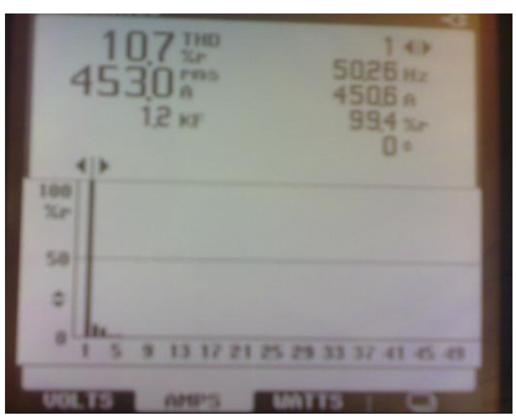

Figure 18.THD analysis using power quality analyzer

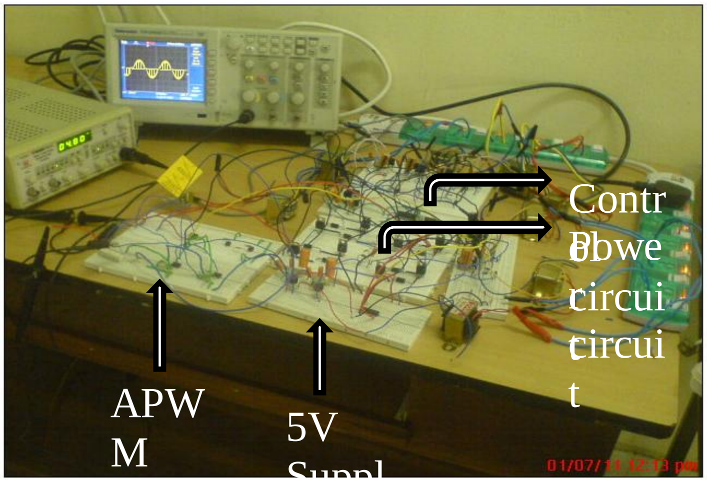

Figure 19. Experimental setup for the proposed method of SPMC

VIII. CONCLUSION:

The input current is made sinusoidal, continuous and in phase with the supply voltage for input pf improvement and also with reduced THD by using SPMC with APWM technique in boost mode, thus avoiding many power quality problems and hence more advantageous than conventional rectifier. Hardware has been implemented for boost rectifier operation and the converter works well with the proposed control technique. SPMC topology has inherent versatility extending beyond the direct AC-AC converter, DC chopper and rectifier operation. Further advancement could be developed with switching control which has capabilities to eliminate a spike that is commonly induced with the use of inductive load.

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