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Single Phase Matrix Converter for Input Power Factor Improvement

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Abstract: *A new buck and boost rectifier using single-phase matrixconverter topology is presented that could synthesize a lower or a greater DC 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 current 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 APWMtechnique 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.*
Index Terms: *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 interfacewith 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[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.Buck andBoost 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 iscontinuous, sinusoidal and in phase with the supply voltage andhence input powerfactor improvement. The input side is provided with an inductance that is used for boost operation [4]. The performance results are compared with that of aconventional buck and boost rectifier circuits with RC load.

II. Single-Phase Matrix Converter

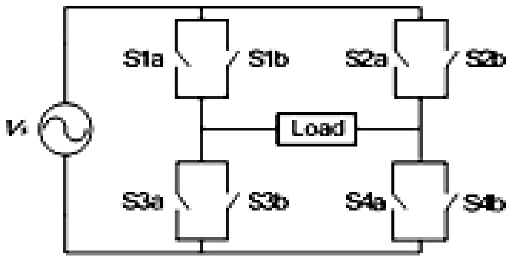


Figure 1. Single phase matrix converter

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.

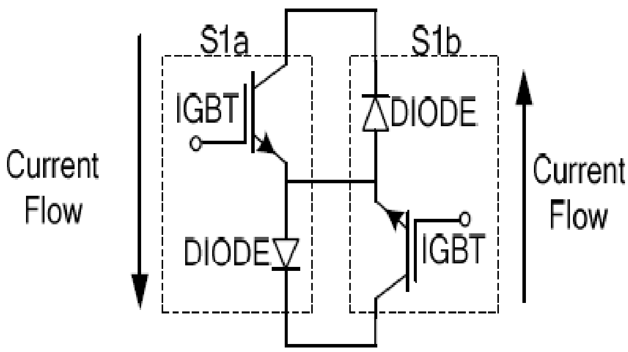


Figure 2. Bi-directional switch module

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 assafe-commutation when RL load is used and power factor correction operation when RCload is used.

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

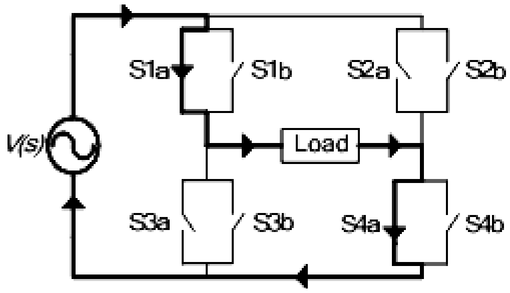


Figure 3. Controlled rectifier using SPMC (positive state)

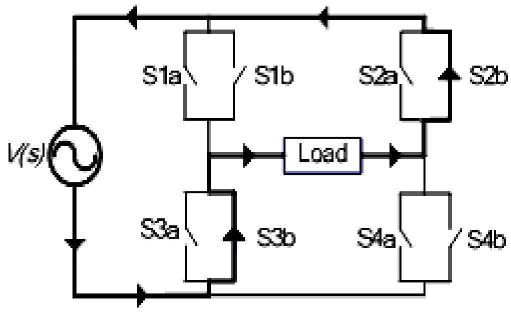


Figure 4. Controlled rectifier using SPMC (negative state)

Generating over current or overvoltage spikewhich 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 overvoltages 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. A high voltage is facilitated by the summation of the two sources.The switchingalgorithmis shown in Figure 5. A switching frequency of 5 kHz is used to generate the PWM control signal.

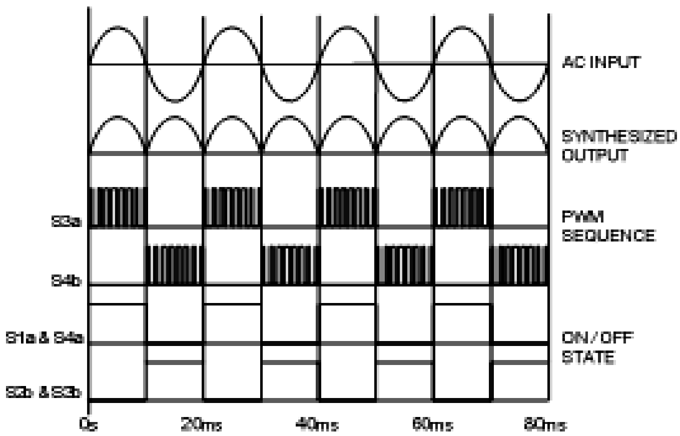


Figure 5. Switching algorithm for boost rectifier

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

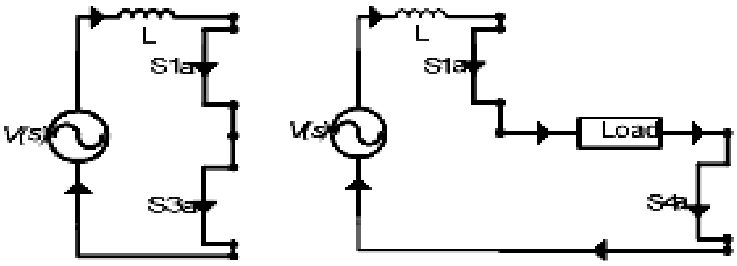


Figure 6. (a) Positive cycle

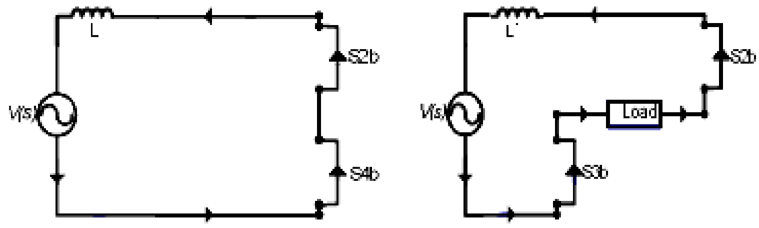


Figure 6. (b) Negative cycle

In this proposed method during the positive cycle operation, the current flows through switches S1a and S3a.The inductor stores enoughenergy in such a way that itincreases 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 (RC load used) 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. Buck Operation Using Spmc

Buck operation using SPMC can be implemented by changing the switching pattern.A buck converter requires an average output voltage lessthan the input voltage. Operation in SPMC for this purpose can be divided into four modes as shown in Table III.

Table III. Switching state for buckoperation

Switches		S1a	S2b	S3b	S4a
Positive cycle	Mode 1	ON	OFF	OFF	ON
	Mode 2	OFF	OFF	ON	ON
Negative cycle	Mode 3	OFF	ON	ON	OFF
	Mode 4	ON	ON	OFF	OFF

In mode 2 and mode 4, the input inductor is not connected in the circuit. So the output voltage will be less than the input voltage and hence buck operation. Achange in instantaneous current across the inductance will produce large voltage spikes that will destroy switches in use due to stress [7]. A systematic switching sequence is thus required that allows the energy flowing in the IGBT's to dissipate within the system. In conventional controlled rectifier, freewheeling diode is used for this purpose. In SPMC this does not exist, hence a switching sequence is required that could provide a path for current to dissipate during switch turn-off.The switching pattern for buck operation is shown in Figure 7.

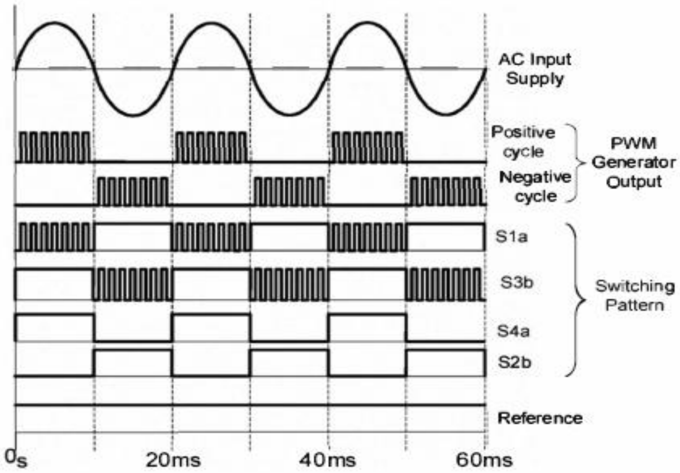


Figure 7.Switching pattern for buck operation

VI. Spmc Incorporating Apwm

Classical rectifier with DC capacitor filter has a disadvantage that it draws discontinuous supply current 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 proposedto 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 to a form that is continuous, sinusoidal and in phase with the supply voltage. Thus a unity power factor correctedinput irrespective of the load behavior can be obtained.

The proposed controlled rectifier with APWM technique using SPMC as shown in Figure 8, is divided into three major sections; a) SPMC circuit b)input inductor and c) controller. The load is represented by a resistor and a shunt capacitor. Control electronics is used to generate APWM.The purpose of active power filter is to force the supply current to follow the reference current (desired signal).The rectifier is controlled based on theAPWM control scheme to have asinusoidal line current with high pf.The current control loopis provided to monitor the supply current and for making corrections by current compensation techniques.

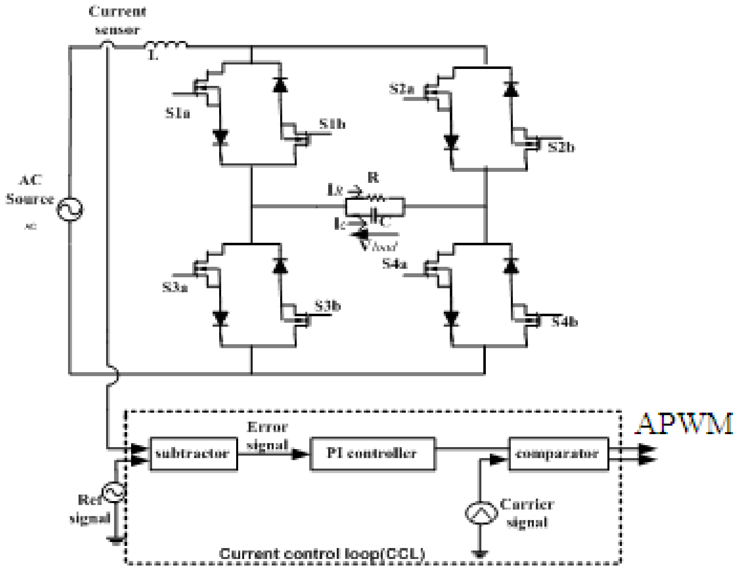


Figure 8. SPMC with APWM

The generation of APWM shown in Figure 9 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 thesinusoidalreference current closely, the currentcontrol 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.

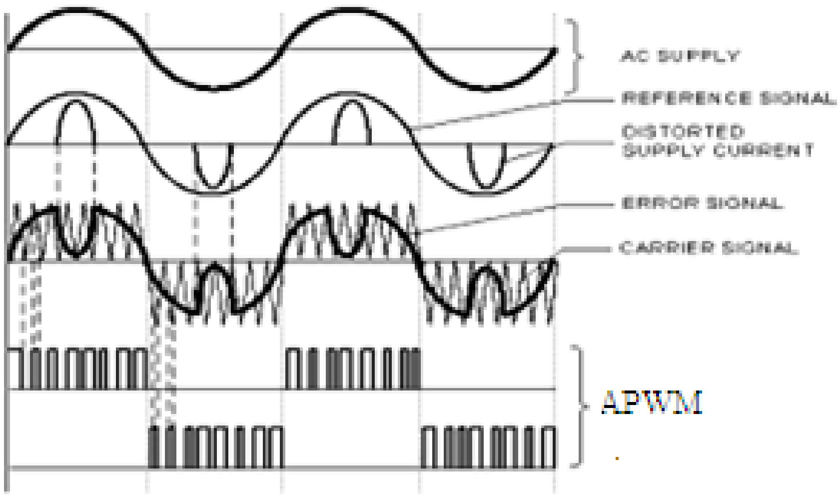


Figure 9 Switching Pattern

VII. Simulation Results

The proposed concept of SPMC as buck and boost rectifier forinput power factor improvement is verifiedthrough 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 IV. The supply voltage is 100V as shown in Figure 10(a). For conventional boost rectifier, the input current waveform is distorted and input power factor is very poor which is shown inFigure.10 (b).

Table IV. Parameter Specifications for boost operation

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

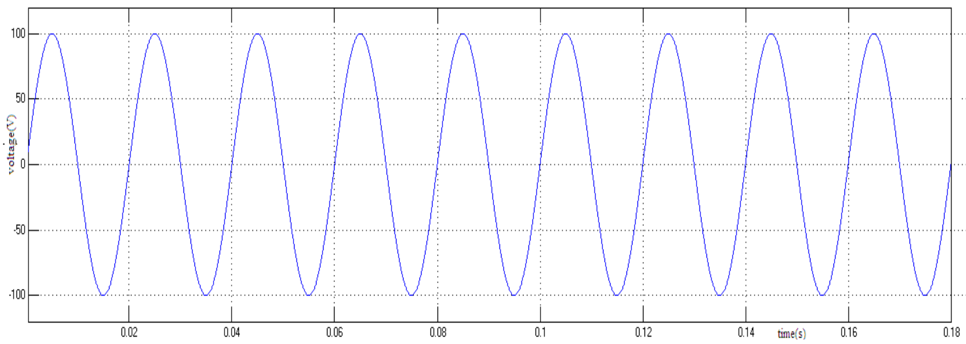


Figure.10(a) Supply voltage of conventional boost rectifier

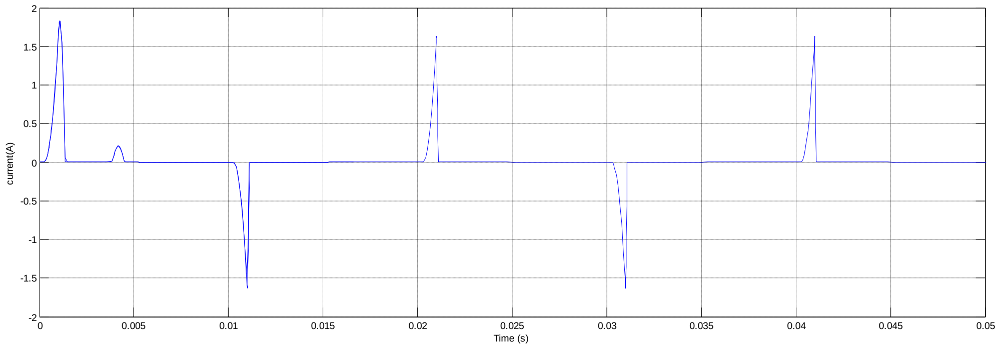


Figure.10(b) Supply current of conventional boost rectifier

So to make the current sinusoidal, continuous and in phase with supply voltage, SPMC with APWM technique is used.The sinusoidal input current waveform resulting in input pfimprovement is shown in Figure.11.

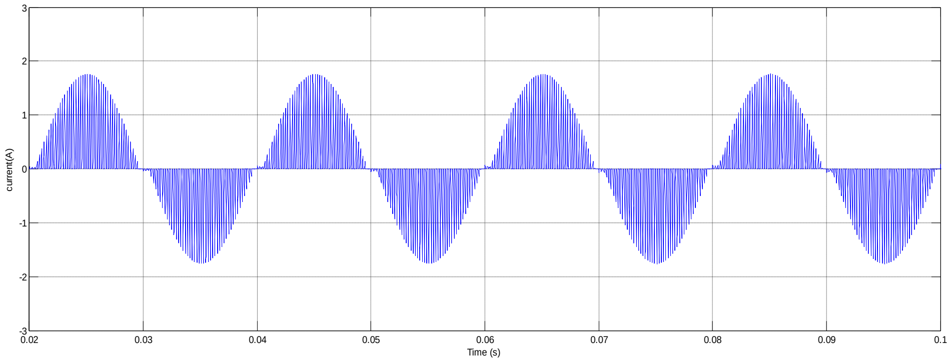


Figure.11. Supply current of SPMC with APWM for boost operation

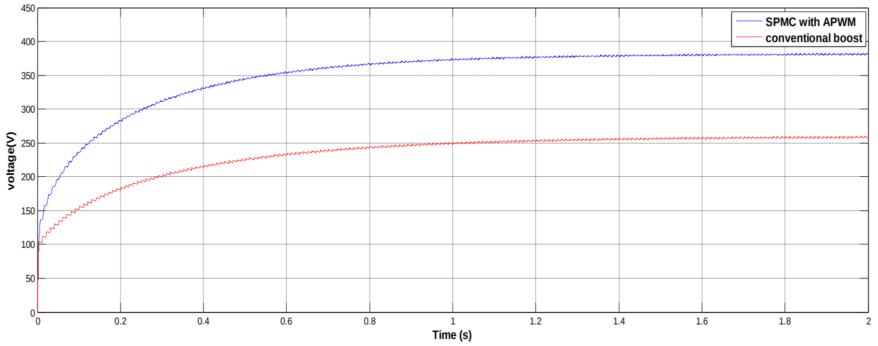


Figure.12 Boosted output voltage

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.

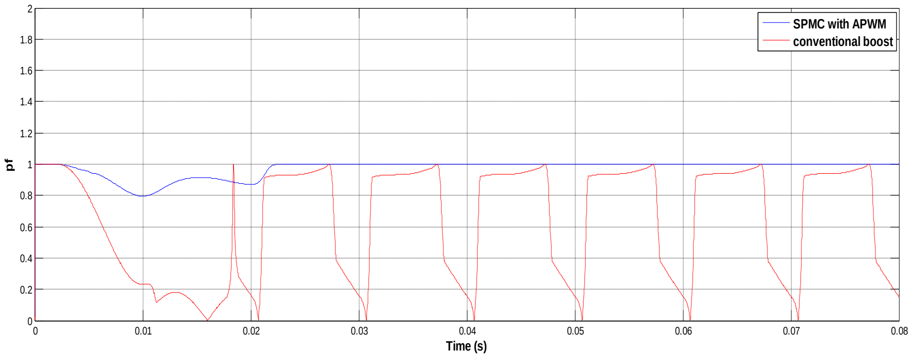


Figure.13pf comparison

Now the buck operation using SPMC with RC load is simulated with parameters as shown in Table V. The distorted supply current for conventional buck is shown in Figure.14.

Table V. Parameter Specifications for buck operation

Supply voltage	100V
carrier frequency	5KHz
Boost inductor	1.5mH
Resistance	300 Ω
Capacitance	1000 µF
MOSFET	IRFZ44

The input current waveform is shown in Figure.15. Output voltages and pf comparison of conventional buck and buck operation using SPMC is shown in Figure.16 and Figure.17.

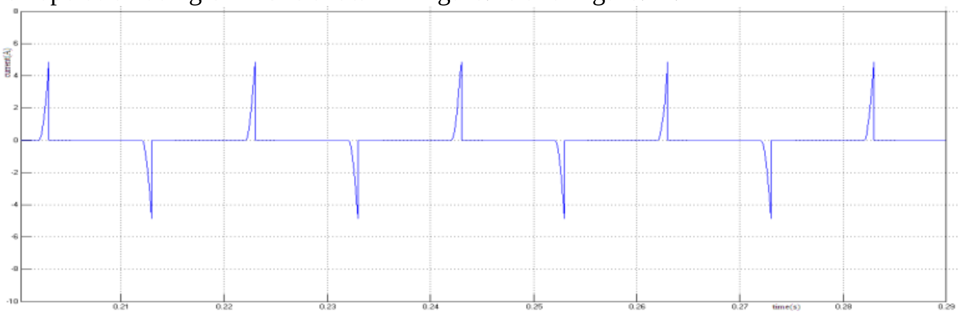


Figure 14. Supply current of conventional buck

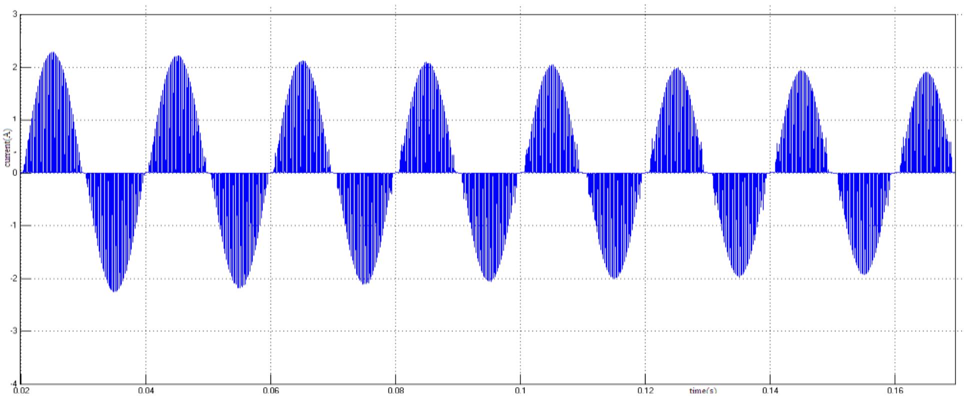


Figure.15. Supply current of SPMC with APWM for buck operation

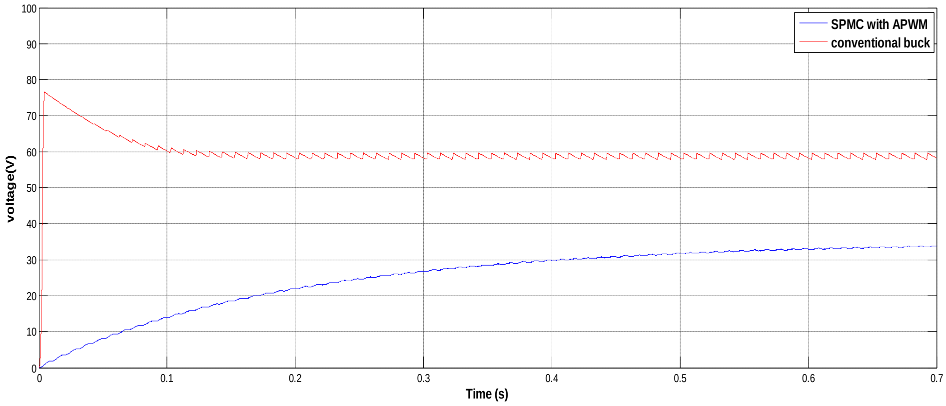


Figure.16 Output voltage

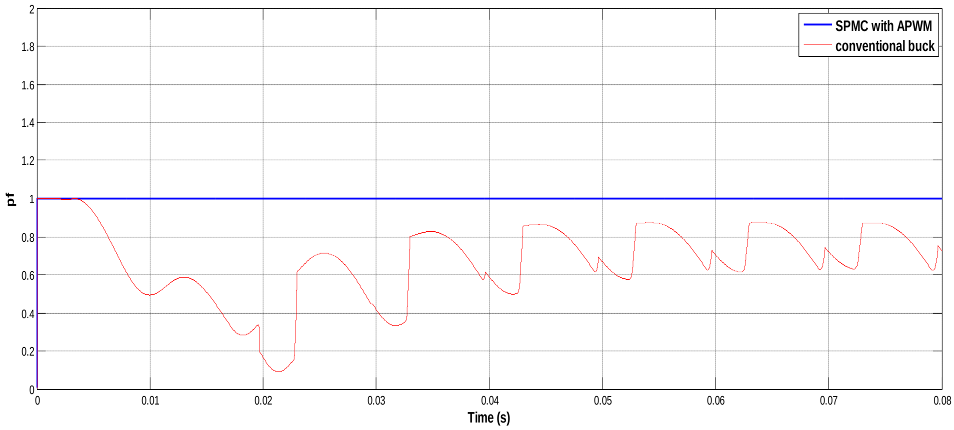


Figure.17pf comparison

Table VI. Comparison of conventional rectifier and SPMC with APWM

Mode	Parameter	Conventional rectifier	SPMC with APWM
Boost operation	Supply voltage	100V	100V
	Supply current	distorted	Sinusoidal,continuous and in phase with supply voltage
	Output voltage	260V	380V
Buck operation	Supply voltage	100V	100V
	Supply current	distorted	Sinusoidal,continuous and in phase with supply voltage
	Output voltage	60V	35V

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

VIII. Experimental Results

The proposed concept of SPMC with APWM for input pf improvementfor RC load is validated on a hardware prototype. The parameter specifications are shown in Table VII.

Table VII. 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. The supply voltage and input current waveform is shown in Figure 18. 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 19. THD analysis of supply current has beendone using power quality analyzer which is shown in Figure 20.

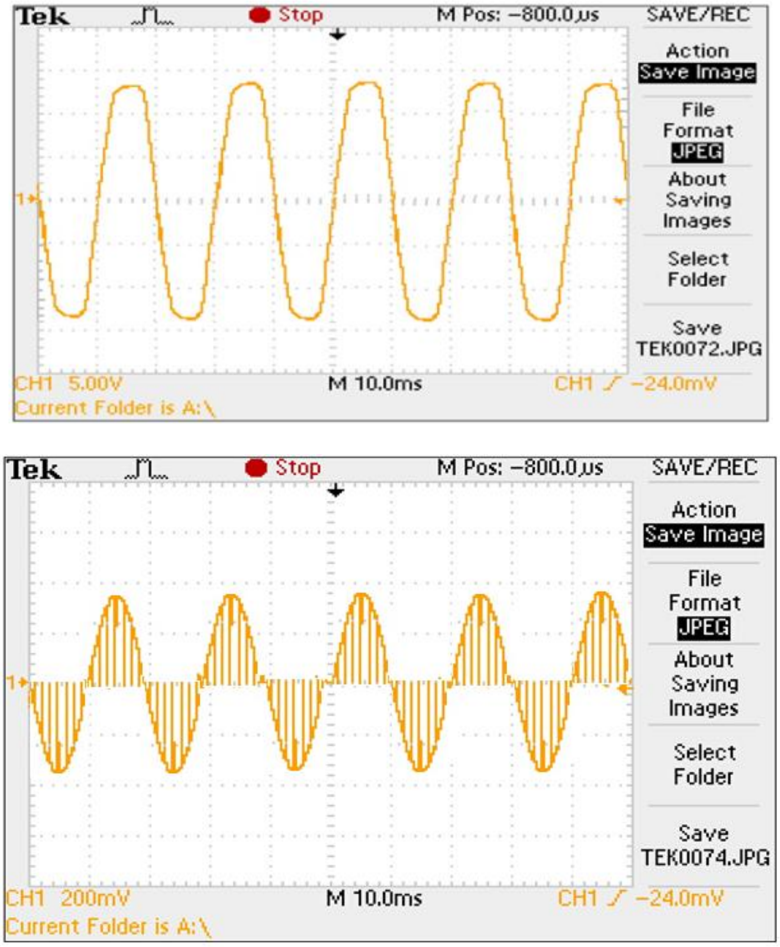


Figure 18. Supply voltage and current for SPMC with APWM

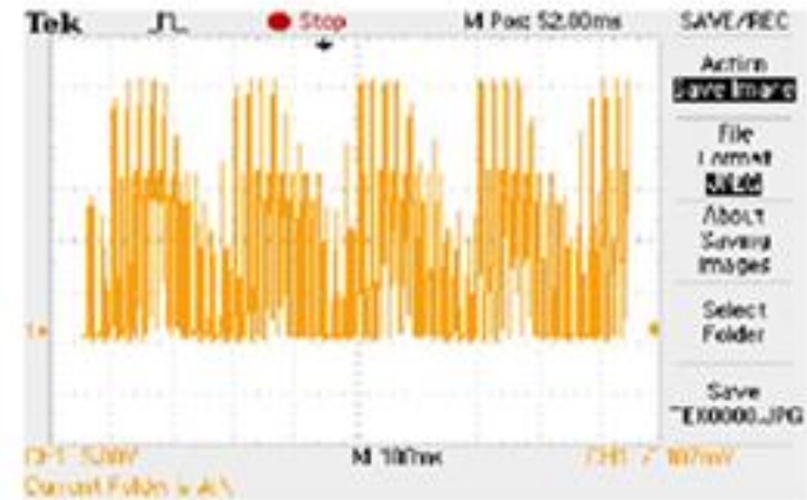
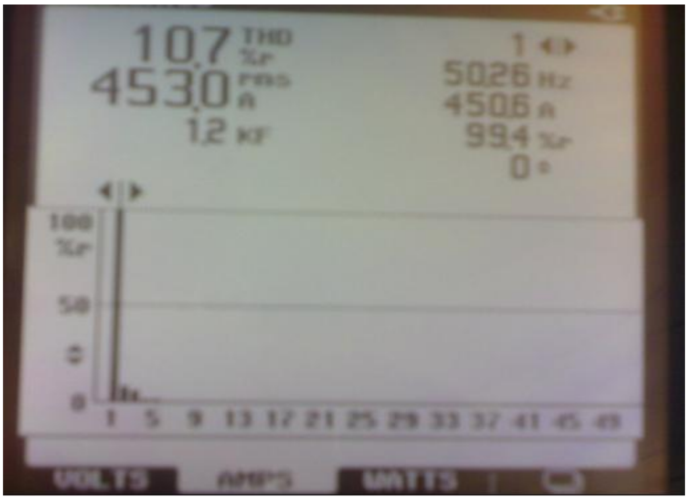


Figure 19. Boosted output voltage for R load



IX. 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 both buck and boost modes, thus avoiding many power quality problems and hence more advantageous than conventional rectifiers.Hardware has been implemented for SPMC with APWM technique and the converter works well with the proposed control technique. SPMC topology has inherent versatility extending beyondthe direct AC-AC converter, DC chopper and rectifieroperation. Further advancement could be developed withswitching control whichhas capabilities to eliminate spikes that is commonly induced with the use of inductive load.

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[7] R. Baharom and M.K. Hamzah, "Computer Simulation Of Single-Phase Matrix Converter Operating as Buck and Boost Rectifier", 2ndInternational Conference on Mechanical and Electronics Engineering. Figure 20.THD analysis ofsupply current using PQ analyzer