RESEARCH ARTICLE

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Hardware Implementation of Single Phase PWM Rectifier

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ABSTRACT

This paper investigates the method of obtaining unity power factor operation in pwm rectifier. A brief description of the switching sequence adapted for obtaining upf operation is explained. In this work a MATLAB simulation was performed to analyse the working of rectifier for a resistive load. The waveforms so obtained are analysed for various harmonics injected by them. Later a hardware prototype was made to validate the results of simulation. A resistive load of 200W was taken for the experimental setup. The input current and voltage waveforms obtained in the hardware set up are also in phase and validates the simulation results.

Keywords : Unity power factor, PWM rectifier, modulation index.

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INTRODUCTION

There is a tremendous growth in the field of AC to DC converters. Development in the field of converter has enabled the transmission of high power and their control. However widespread use of converters has led to a negative effect on the supply network. International Electro technical Commission (IEC) 1000-3-2 has imposed limitation on harmonics injected by electronic converters into the supply system [1]. This is done to maintain the quality of power supplied by the supply system. Conventional diode bridge converters are used as the front end converters for most of the electronic circuits. But issue with diode converter is that, output voltage is not controllable and it injects odd harmonics into the power system. Output voltage of a converter can be controlled by replacing the diode with thyristor. But phase control of thyristor, introduces displacement power factor less than unity and draws reactive power from the power system. So both these converters draws non-sinusoidal current from the supply resulting in high THD and input power factor less than unity. Large number of such converter if operates together makes the supply voltage also non-sinusoidal in nature. A variety of circuit topologies for switched mode rectifiers has been proposed to provide nearly sinusoidal current [2]–[5]. But draw back with these circuits is that bidirectional power flow is not possible. In rectifier circuits, THD can be improved and unity power factor can be obtained if diodes are replaced by IGBT and width of the gate pulses to these switches is controlled accordingly. Such rectifiers are known as PWM rectifiers. In PWM rectifier output voltage is controllable and it ensures bidirectional power flow also. While operating the circuit at high frequency and with using PWM technique, they reduce filter dimensions [6]. A MATLAB simulation using Simulink were performed and observed that supply current and voltage are sinusoidal in nature. To validate the results of simulation, experiment on laboratory prototype were also performed.

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CIRCUIT DESCRIPTION

The PWM rectifier aims to consume sinusoidal current and maintain unity power factor at input side. The power circuit of single phase PWM rectifier includes four switches T_1, T_2, T_3 and T_4 with anti-parallel diodes D_1, D_2, D_3 and D_4 as shown in Figure 1. A filter capacitor C_d of high value is placed at the output for constant voltage and an inductor L_s is placed at the supply side which ensures a sinusoidal input current.

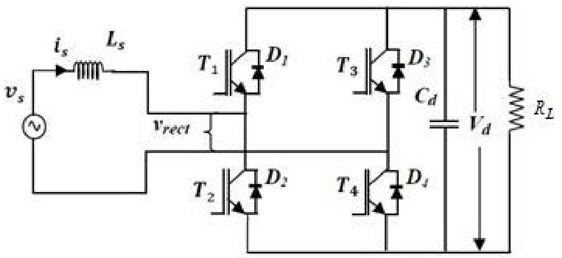


Figure 1: Single Phase Pulse Width Modulated Rectifier circuit [7]

V_{rect} is the input voltage to the PWM rectifier and the gate signals to the switches are given in proper switching sequence and pulse width of the control signal is controlled to obtain a sinusoidal input current. The input current is made sinusoidal in shape and in phase with the supply voltage by following the switching pattern shown in Table.1

Table-1: Switching pattern in PWM rectifier [7]

+ve cycle			
Steps	**On switches**	V_{rect}	i_s
1	D_1, T_3	0	increases
2	D_1, D_4	$+V_d$	decreases
-ve cycle			
3	D_2,T_4	0	increases
4	D_3, D_2	$-V_d$	decreases

By giving the switching pulse in the sequence given in Table.1 the voltage obtained at the rectifier input terminals given in Figure 2.

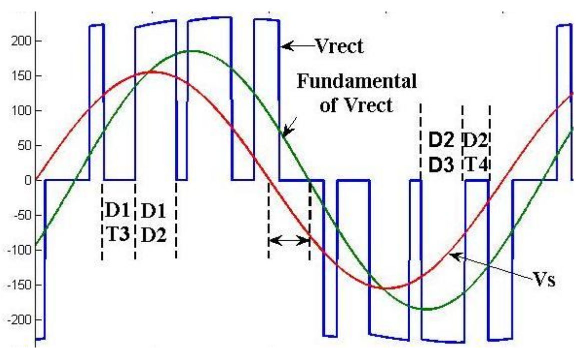


Figure 2: Voltage at input terminals of 1ø PWM rectifier [7]

The pulses for the switches are obtained by comparing sine and triangle ie using sine triangular pulse width modulation technique (SPWM). First reference sine wave is generated, which is phase delayed by an angle δ w.r.t supply voltage. The triangular wave is compared with this reference wave to generate the switching pulse. By applying the pulses to the switches, voltage V_{rect} is obtained across the input terminals. The fundamental of this voltage will have a phase difference of 'δ' w.r.t supply voltage V_s as shown in Fig.4. Output voltage V_d of the rectifier is controlled by controlling the fundamental of V_{rect} using the equation 1,

$$V_d = \frac{\sqrt{2}V_{rect1}}{M_a} \tag{1}$$

where M_a is the modulation index. The necessary condition for obtaining unity power factor operation in PWM rectifier is that, dc voltage V_d need to be greater than the peak of supply voltage V_s (V_d> "2V_s). This makes sure that input current is sinusoidal by tracking the reference current waveform.

Simulation Results

To understand the switching pattern and the harmonics injected by them a MATLAB simulation of PWM rectifier was performed. Simulation of PWM rectifier was done with the specifications presented in Table 2.

Table-2: Specification used in Simulation

Parameters	**Values**
Supply Voltage	230V
Output power	2kw
Output voltage	469V
Load Angle (δ)	30°
Switching Frequency (f_s)	10kHz
Input inductor	48mH
Filter capacitor(C_d)	800µF

Using the specifications given in Table.2 the MATLAB modelled in simulink is shown in Figure 3.

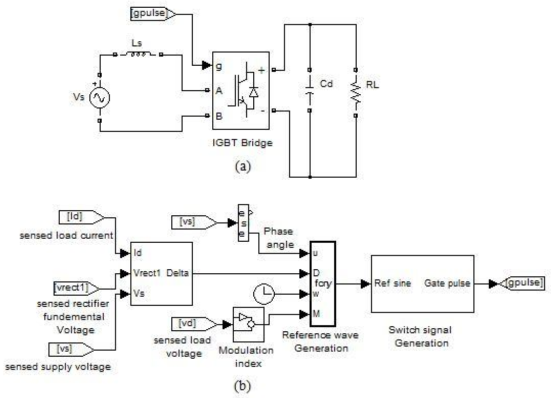


Figure 3: MATLAB model of PWM rectifier (a) Power circuit (b) control circuit

Output voltage V_d is obtained as per design as 469 V. The supply voltage and supply current are in phase. The simulated waveforms of input voltage and current of PWM rectifier are displayed in Figure 4.

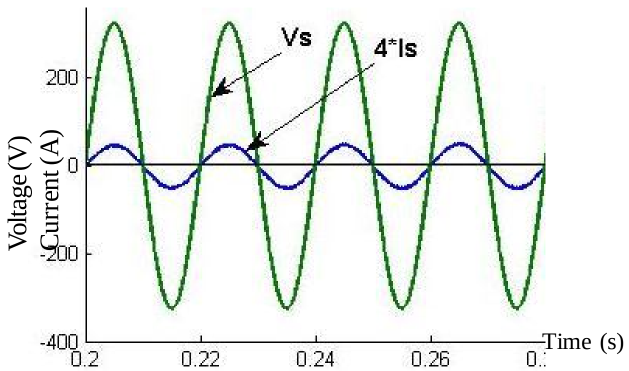


Figure 4: Waveforms of in phase input voltage and current

The input current is sinusoidal in nature and is in phase with the input voltage. In the following section the details of prototype developed for validating the simulation results are explained.

EXPERIMENTAL RESULTS

A prototype of single phase PWM rectifier was implemented with the specifications given in Table. 3.

Table-3: Specification of prototype of 1-Φ PWM rectifier

Parameters	Values
Supply voltage (V_s)	50 V
Output power	200W
Output Voltage (V_d)	100V

For the specification given in Table-3. The designed parameters obtained are given in Table-4.

Table-4: Designed parameters of 1-Φ PWM rectifier

Designed Parameters	Values
Load resistance (R_L)	50Ω
Inductor	22mH
Load angle (δ)	30°
Modulation Index	0.8
Switching frequency (f_s)	7kHz
Filter capacitor (C_d)	500μF

With the designed parameters as given in Table-4, the hardware of the PWM rectifier is implemented. The block diagram of the components required for the setup is shown in Figure 5.

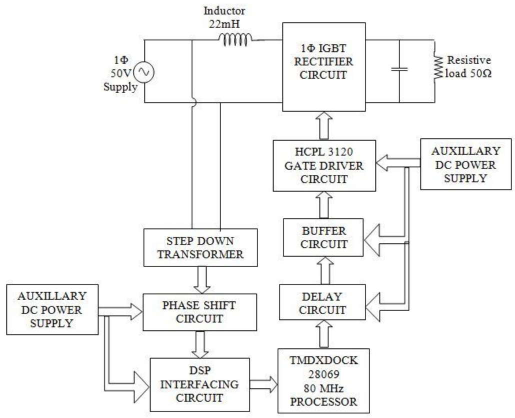


Figure 5: Schematic diagram of hardware implementation of 1-Φ PWM rectifier

First reference sine wave is obtained from the single phase supply. For this a step down transformer of 230/3 V is used. This reference wave is phase shifted by an angle 30o which is the load angle. The circuit for obtaining phase shift is given in Figure 6.(a) and the waveforms obtained are displayed in Figure 6(b).

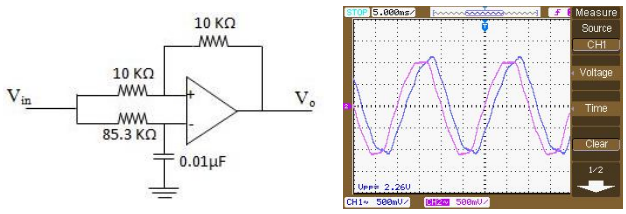
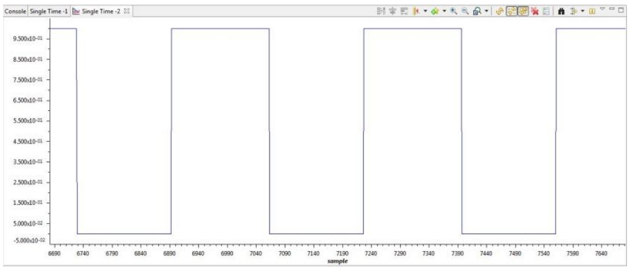
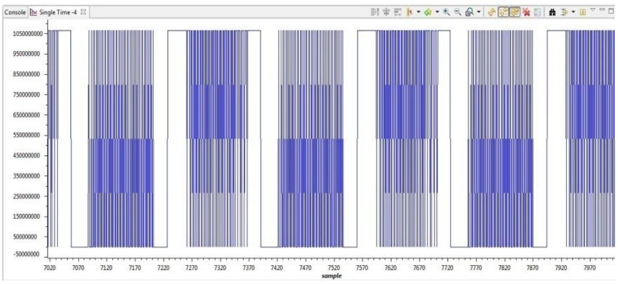


Figure 6: Phase shift (a) Circuit digram (b) Input output waveforms

Reference sine wave is then given to the DSP to generate the switching pulses using SPWM technique. Programming is done in DSP to generate PWM pulses T1, T2, T3 and T4 .Pulses T1 and T3 which is generated in DSP is shown in Figure 7.



(a)



(b)

Figure 7: Waveforms of (a) T_1 and (b) T_3

The other two pulses T_2 and T_4 are obtained by taking the compliments of T_1 and T_3. The programs for generating these pulses are written in code composer studio. Delay between pulses T_1 and T_2 as well as between T_3 and T_4 is generated using the circuit in Figure 8.(a)

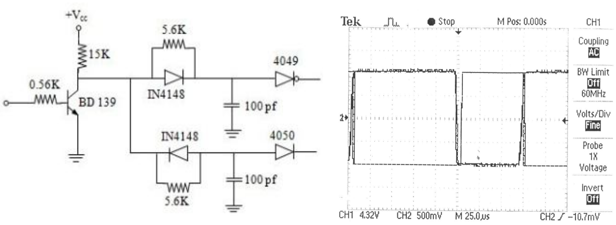


Figure 8: Delay circuit for generating dead band (a) Connection diagram (b) Waveform of pulses T_3 and T_4 with dead band between them

Delay of 5 μs was obtained between the pulses and the waveforms so obtained are shown in Figure 8(b). The switching pulses then is given to the IGBT switches as per the sequence given in Table-1. The input voltage of bridge rectifier obtained is shown in Figure 9. As in the simulation, the waveform of rectifier input voltage (V_{rect}), is in the form of pulses. Positive pulse is obtained during turn on of D_1 and D_4 and negative pulse as D_2 and D_3 is switched on. Remaining time is zero.

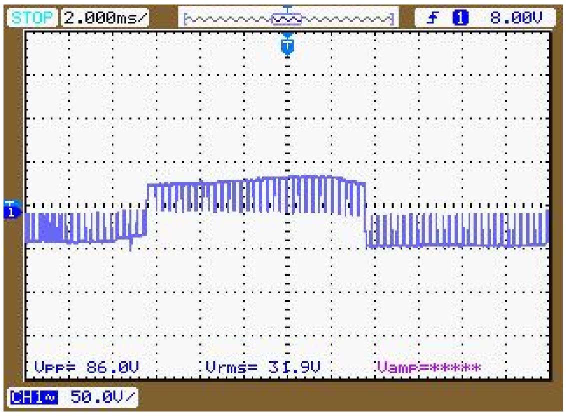


Figure 9: Input voltage waveform of PWM rectifier (v_{rect})

It was found from the experimental results, the supply voltage and current are in phase as shown in Figure 10.

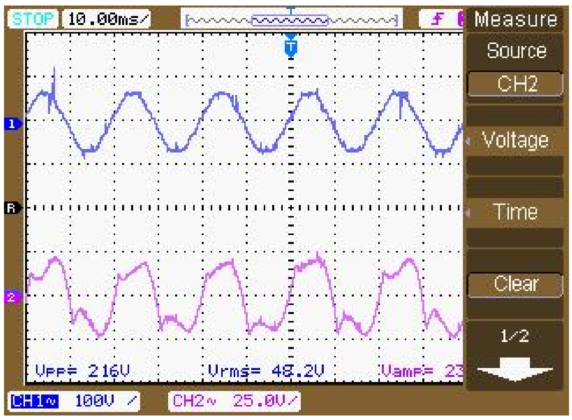


Figure 10: Waveforms of supply voltage and supply current

The input current is not a pure sine wave which can be further improved by the accurate setting of the DC phase shift of reference sine wave, which is given to the ADC pin of DSP. The Figure 11 shows the photograph of the entire setup of the prototype of single phase PWM rectifier.

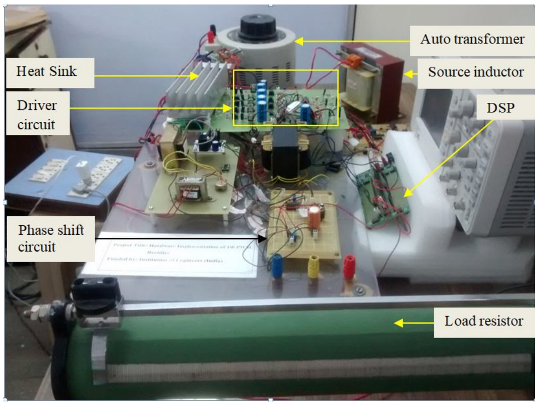


Figure 11: Complete hardware setup of 1-Φ PWM rectifier

CONCLUSION

This paper has analysed the operation of single phase PWM rectifier and the control scheme to regulate the output voltage. By following the switching pattern mentioned in the paper, only one switch is modulated in a half cycle of switching frequency. Other switch will be in conduction for the entire half cycle. Hence switching losses are reduced. Most of the electronic equipment employs a rectifier at front end. But rectifier always draws a peaky current which is highly non sinusoidal in nature. These current injects harmonics into the supply system and distort the quality of power. Such degraded power supply will have adverse effect on the other components connected in the power system. To improve the quality of power, the nonsinusoidal current drawn by the rectifier is made sinusoidal and in phase with supply voltage. This is possible by using PWM rectifier. Hence the power factor and THD improved by replacing conventional rectifier with PWM rectifier. Also in PWM rectifier it is possible to control both active and reactive power flow by adjusting the load angle. For generating switching pulses SPWM technique is used. Also switching losses in this method is less since in a half cycle only one switch is modulated at PWM frequency and other remains in conduction for entire half cycle. The future scope of PWM rectifier is that the study can be extended to bidirectional power flow. This is possible by making the reference sine wave leading with respect to supply voltage. The bidirectional power flow is required for applications like traction and HVDC.

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