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Power Factor and Harmonic Analysis in Single Phase AC to DC Converter

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***Abstract* —This paper analyses the low power factor and harmonic issues in AC to DC converters i.e. conventional diode bridge rectifier and PWM rectifier. The peaky current drawn by the capacitor in diode bridge rectifier is the reason for high total harmonic distortion (THD) and low power factor. This problem can be overcomed by replacing the diode in bridge rectifier with IGBT and pulses given to these switches can be controlled to obtain a unity power factor and low THD. Such rectifier circuit is known as Pulse Width Modulated (PWM) rectifier. The circuits are simulated in MATLAB using simulink and the waveforms are analysed for harmonics, power factor and THD.**

I. INTRODUCTION

Most of the power conversion applications consist of an AC to DC conversion stage and this DC output is then used for further stages. An AC to DC converter is an integral part of most of the electronic equipments as most of these equipments are DC powered [1]. Generally to convert AC to DC a diode bridge rectifier is used. To reduce the ripple in the output voltage a suitable filter capacitor is used at the rectifier output. The filter capacitor draws a peaky current from the supply, as it charges only for a short duration in a half cycle. Hence the current drawn by a diode rectifier is non sinusoidal in nature. Due to the non sinusoidal nature of the input current, THD will be very high and input power factor also will be low. Two factors that provide a measure of the power quality in an electrical system are power factor (PF) and total harmonic distortion. The amount of useful power being consumed by an electrical system is decided by the PF of the system. The amount of harmonics injected by equipment is determined with respect to the THD of the current drawn by the system. The input current of diode rectifier contains odd harmonics making THD high and distortion power factor is less than resulting in poor power factor. Hence looking into the serious effects generated by conventional converters, the simple diode rectifiers should not be used. There is a need to achieve rectification at close to unity power factor and low input current distortion. In addition to achieve a regulated DC output, the main criteria in the design of such AC/DC power supply are in achieving high power factor and low THD. This is possible by replacing the diode with electronic switches like MOSFET, IGBT etc and controlling the gate pulses given to them in such a way to achieve a sinusoidal input current and low THD. Such rectifiers are known as PWM rectifiers. Hence this paper analyses power factor and total harmonic distortions of the single phase conventional diode bridge rectifier and PWM rectifier.

II. SINGLE PHASE AC TO DC CONVERTER

A. Single Phase Diode Bridge Rectifier

A single phase rectifier consists of four diodes connected in a closed loop bridge configuration so as to produce the rectified output voltage is shown in Fig.1..

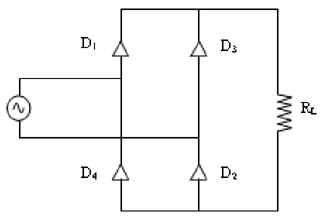

Fig.1 diode bridge rectifier

The four diodes are connected in series pairs with only one diode pair conduct during each half cycle. The rectifier with filter capacitor is called a conventional AC-DC utility interface which is given in Fig.2 (a). The filter capacitor reduces the ripples present in the output voltage. Although a filter capacitor significantly suppresses the ripple from the output voltage, it introduces distortions in the input current and draws current from the supply discontinuously, in short pulses as shown in Fig.2 (b).

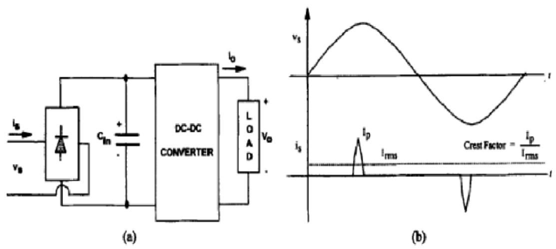

Fig.2.(a)Conventional Utility Interface. (b)Input voltage and current[2]

THD of such waveform will be very high and powerfactor also will be very low. This introduces several problems including reduction of available power and increased loss.

Total Harmonic Distortoin

Total harmonic distortion of a signal is a measurement of the harmonic distortion present and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency. THD is used to characterize the power quality of electric power systems. The THD in terms of current can be written as:

$$\%THD = \sqrt{\left(\frac{I_s}{I_{s1}}\right)^2 - 1} \qquad (1)$$

where, I_s is the rms value of input current I_{s1} is the fundamental frequency component.

Power Factor

Power factor is the ratio between the actual power (kW) and the apparent power (kVAr) drawn by an electrical load. It is a measure of how effectively the current is being converted into useful work output and also shows the effect of load current on the efficiency of the supply system. True power factor (PF) of the system can be written as:

$$PF = \cos\phi \times Distortion power factor \qquad (2)$$

where $\cos\phi$ is the displacement power factor. In an AC circuit, power is used most efficiently when the current is in phase with the voltage. Distortion power factor describes how the harmonic distortion of a load current decreases the average power transferred to the load. Distortion power factor (DPF) can be written as:

$$DPF = \frac{I_1}{I} \qquad (3)$$

where, I_1 is the fundamental component of the current and I is the total current. In diode rectifier with filter capacitor at output draws non-sinusoidal current hence distortion power factor is less than unity resulting in poor power factor. Due to the presence of high total harmonic distortion and poor input power factor generated by conventional converters, the simple diode rectifiers should not be used. There is a need to achieve rectification at close to unity consider pulse width modulated rectifier (PWM) is an improved version of the conventional AC to DC diode rectifier.

III. PWM CONVERTER

PWM rectifier is an AC to DC power converter, that is implemented using forced commutated power electronics devices like insulated gate bipolar transistors (IGBT) or gate turn-off thyristors (GTO) that are characterized by switch mode operation. The capability of forming sinusoidal currents is provided by the introduction of the sophisticated technique called pulse-width modulation (PWM). This technique provides the sequences of width-modulated pulses to control power switches. Many PWM techniques have been developed according to special requirements and optimization criteria. The choice of the particular PWM technique arises from the desired performance of the synchronous rectifiers.Generally pulse-width modulation techniques for frequency converters may be classified as carrier-based sinusoidal PWM, Hysteresis-Band PWM, space vector PWM, selected harmonic elimination PWM, minimum current ripple PWM, sinusoidal PWM with instantaneous current control and random PWM. The basic features of pwm rectifier as follows are bi-directional power flow, input current is nearly sinusoidal, regulation of input power factor to unity and stabilization of DC-link voltage (or current).Today, insulated gate bipolar transistors are typical switching devices. Different from diode bridge rectifiers, PWM rectifiers achieve bidirectional power flow.In frequency converters this property makes it possible to perform regenerative braking. PWM rectifiers are also used in distributed power generation applications, such as micro turbines, fuel cells and windmills. The major advantage of using pulse width modulation technique is the reduction of higher order harmonics and we can also control the magnitude of the output voltage. We can also improve the power factor by forcing the switches to follow the input voltage waveform using a phase locked loop.

IV. SIMULATION RESULTS

A. Diode Rectifier

MATLAB simulation is carried out for diode rectifier as per specifications given in TABLE.1.

TABLE.1.Parameters for diode rectifier

Parameters	Specification
Load	1 kW
Supply voltage	230V
Output voltage	315V
Load resistor	52.9Ω
Filter capacitor	67mF

The simulation model of diode rectifier is shown in Fig.3. When the instantaneous value of supply voltage is higher than

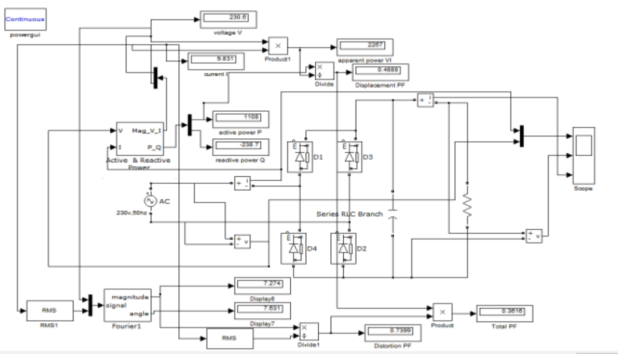

Fig.3. Simulation model of diode rectifier

capacitor voltage, the diodes (D_1& D_2 or D_3& D_4) will conduct and the capacitor is charged from supply. Ifthe instantaneous supply voltage falls below the instantaneous capacitor voltage, the diodes (D_1& D_2 or D_3& D_4) are reverse biased and the capacitor discharges through the load resistance. For a ripple factor of 0.1%, value of filter capacitor is designed using equation:

$$c = \left(\frac{1}{4fR}\right) \times \left(1 + \frac{1}{\sqrt{2RF}}\right) \qquad (4)$$

Where, *f* is the supply frequency, *R* is the load resistance and *RF* stands for the ripple factor.The waveforms obtained for the diode rectifier are shown in Fig.4.

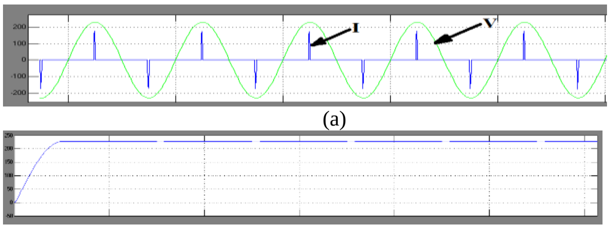

Fig.4. Waveforms of (a) Supply voltage and supply current (b)Output Voltage

It is observed that the nature of current of the single phase diode bridge rectifier with capacitive load turns out to be peaky in nature The input current is analysed for THD, which is shown in Fig.5.

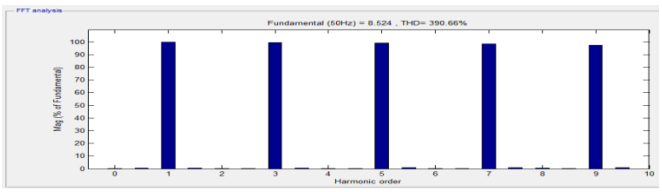

Fig.5. Harmonic spectrum of input current s

From the above figure it is clear that THD of the input current of single phase diode bridge rectifier is 108.94%.The input current mainly injects odd order harmonics into the supply system. If the diodes are replaced by IGBT and by controlling the pulses given to these switches, input current can be made sinusoidal and THD can be improved.

B. PWM Rectifier

The PWM rectifier is designed for following parameters

TABLE.2.Simulation parameters for PWM rectifier

Parameters	Values
Load	1kW
Supply voltage(V_s)	230V
Output voltage	410.3V
Delta (δ)	8°
Inductance	22.4mH
Modulation index(*M.I*)	0.8

Output voltage of PWM rectifier can be controlled by varying the modulation index using the formulae:

$$V_d = \frac{\sqrt{2}V_{conv1}}{M.I} \quad (5)$$

Fig.6. shows the simulation circuit model of a single phase PWM bridge rectifier along with the control circuit for generating the switching pulses.

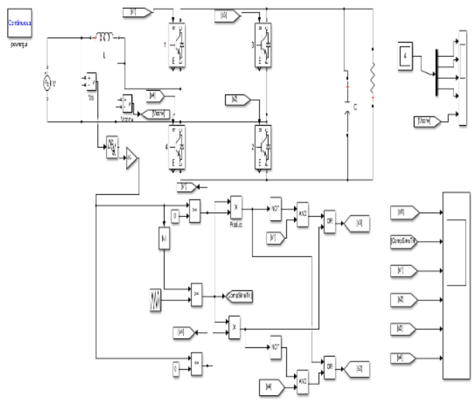

Fig.6. MATLAB model of PWM rectifier

Fig.7. shows the switching signals generated by the control circuit to obtain a unity power factor operation.

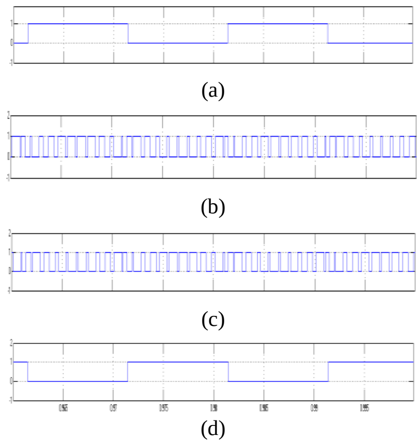

Fig.7. Control pulses for switches (a)T_1(b) T_2 (c)T_3 and T_4

PWM switching signals are generated with a phase delay of δ with respect to supply voltage. The input waveforms obtained after giving the pulses are shown in Fig.8.

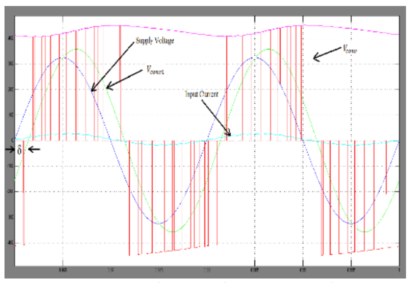

Fig.8. Waveforms of PWM rectifiier

It is observed that the input current waveform is almost sinusoidal in nature and in phase with the supply voltage which will improve the input PF compared to the case of conventional diode rectifier where the input current waveform was peaky in nature.The harmonic spectrum of input current is shown in Fig.8.

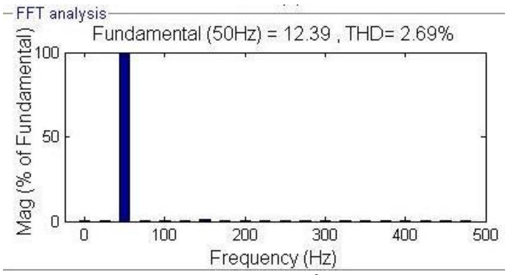

Fig.8.Harmonic spectrum of input current

The THD is very low since, the current drawn by PWM rectifier is sinusoidal in shapeFig.9. shows the block for calculation of input power factor of the single phase PWM bridge rectifier.

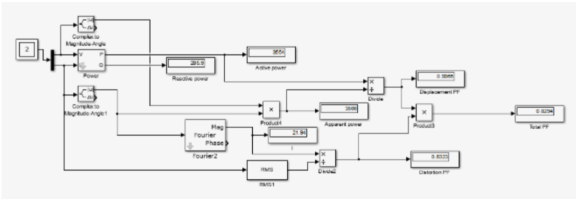
Fig.9. Simulation model for estimating power factor

The comparison table for various rectifer circuits are given in TABLE .3.From the table it is clear that, filter capacitor

TABLE.3. Comparison of THD and power factor of various rectifier circuits

Type of Rectifier	**THD (%)**	**Power factor**
Diode rectifier without filter capacitor at output	0.1	1
Diode rectifier with filter capacitor at output	300	0.36
PWM Rectifier	2.6	0.99

placed at output, is the component which makes the input current of diode rectifier non-sinusidalin nature. But in PWM rectifier, in addition to an output voltage with reduced ripple, it draws a sinusoidal input current as well.

V. Conclusion

Most of the electronic equipment is supplied by 50 Hz utility power, and in almost all of them power is processed through some kind of power converter. Usually, power converters use a diode rectifier followed by a bulk capacitor to convert AC voltage to DC voltage. Unless some correction circuit is used, the input rectifier with a capacitive filter circuit will draw peaky current from the utility grid resulting in poor power factor and high harmonic contents that adversely affect other users. In this paper, power factor and the total harmonic distortion of a single phase diode bridge rectifier and PWM rectifier is analyzed by simulation using MATLAB software. It is observed that in simple diode bridge rectifier the power factor is low and the THD is high due to the peaky nature of the current drawn by the converter. In PWM rectifier the power factor and THD has improved by replacing the diodes by switches and by controlling the pulses given to theses switches. Today, insulated gate bipolar transistors are typical switching devices. Different from diode bridge rectifiers, PWM rectifiers achieve bidirectional power flow.The major advantage of using pulse width modulation technique is the reduction of higher order harmonics and we can also control the magnitude of the output voltage.

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