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Study of Harmonic Content Elimination with Three Phase PWM Rectifier and Phase Controlled Rectifier

J. Siva Alagesan, R. Thangasankaran, B. Karthikeyan
*EEE Department, Mepco Schlenk Engineering College, Sivakasi, Tamil nadu, India

ABSTRACT

This Pulse width modulated rectifier is a very popular topic nowadays. The modern industrial production demands continuous and lossless conversion of electrical energy parameters. This need leads to wide spread of power semiconductor converters. The rapid development in power electronics enables to apply sophisticated control methods that eliminate negative side effects of the power converters on the supply network. The phase controlled thyristor rectifiers overload the supply network with higher harmonics and reactive power consumption. That is why the PWM rectifier is being examined. Here FPGA based controller is used to generate necessary pulses to drive the devices of the rectifier. In comparison with the phase controlled rectifier it can be controlled to consume nearly sinusoidal current with power factor equal to unity. Another advantage is its capability of energy recuperation. This paper deals with the PWM rectifier functional model realization and examination. PWM rectifier and phase controlled rectifier is compared on the basis of the input current harmonic analysis.

Keywords : PWM Rectifier, Field-Programmable Gate-Array, Harmonic Distortion

I. INTRODUCTION

In recent years, ac to dc power conversion has become extremely essential in many power electronic applications such as battery charger, regulated dc voltage source, UPS systems, static frequency changer, ac line conditioner and motor drives [1]. Previously in most of the cases, the ac-dc power conversion was extensively carried out using passive techniques. These include diode bridge rectifiers and phase-controlled thyristor rectifiers with suitable passive filters at the output [2-5]. Though passive rectifiers are simple, these present themselves as nonlinear loads to the utility. The input currents of these rectifiers contain considerable lower order harmonics [6-8]. The harmonic currents drawn cause voltage distortion at the point of common coupling (PCC). These also cause considerable overheating in the distribution lines and the distribution transformer supplying the loads, and electromagnetic interference (EMI) with communication and control lines in the proximity. Further, a diode-bridge rectifier cannot regulate its output dc voltage against input voltage regulation. It also cannot regenerate, which is essential in certain motor drive applications. With the advent of fast semiconductor devices such as MOSFET and IGBT, and the development of various pulse width modulation (PWM) techniques [9-11], passive rectifiers are increasingly replaced with PWM rectifiers. The cost of development of such PWM rectifiers can be justified by the resulting line currents which contain lower harmonic content [12] and high power factor compared to those of line commutated rectifiers. For experimental setup the PWM gating signals are generated using FPGA based controller [13-14].

II. THREE PHASE pwm RECTIFIER

The PWM rectifier is realized by semiconductor devices (MOSFETs or IGBTs) that can be switched on and off. The rectifier is controlled by pulse width modulation. Rectifier controlled in this way consumes current with demanded waveform that is mostly sinusoidal. It works with given phase displacement between consumed current and supply voltage, enables control of power factor, and has minimal effects on the supply network [15-17]. There are two types of PWM rectifiers, with a voltage source output and a current source output. First of them called a boost rectifier (increases the voltage) which works with fixed DC voltage polarity, and the second, called a buck rectifier (reduces the voltage) that operates with fixed DC current flow.

Main features of PWM rectifiers are: bi-directional power flow, nearly sinusoidal input current, regulation of input power factor to unity, low harmonic distortion of line current (THD below 5%), adjustment and stabilization of DC link voltage (or current), reduced capacitor (or inductor) size due to the continuous current. Furthermore, it can be properly operated under line voltage distortion and line frequency variation [18-19].

III. THREE PHASE pwm RECTIFIER ARCHITECTURE

A three phase structure of PWM rectifier is shown in Figure 1. It consists of AC supply, switches and load. Six diodes are connected in series with these switches for the cancellation of freewheeling action of internal diodes present in the switches.

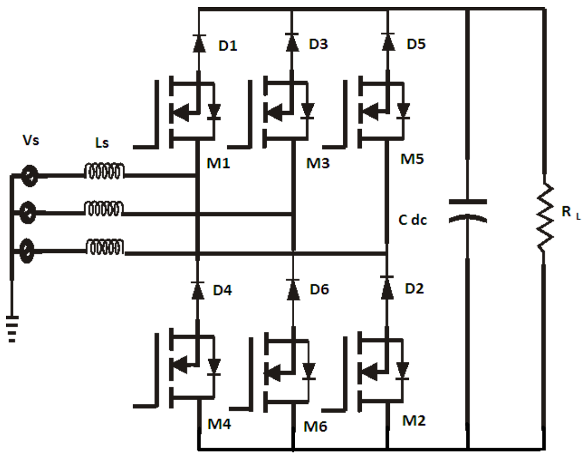

Figure 1. Three Phase PWM Rectifier

In PWM rectifier, first the input current can be changed to sinusoidal form which reduces the lower order line harmonics. Second, the input power factor can be controlled by adjusting the phase of input current with respect to the input voltage. Third, the dc-link voltage can be regulated quickly against the variation in load. Fourth, the excess power in the load side can be regenerated into the input side. In this paper sinusoidal Pulse Width Modulation technique is used. The input voltage and current waveform of PWM Rectifier is shown in Figure 2.

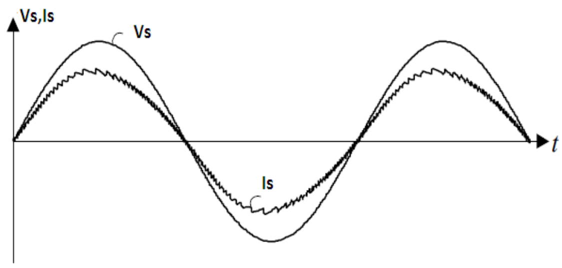

Figure 2. Typical Input Voltage and Current Waveform

IV. TOTAL HORMONIC DISTORTION

The THD is defined as the root mean square (RMS) value of the total harmonics of the signal divided by the RMS value of its fundamental signal. For currents, the THD is defined as

$$THD = \frac{I_H}{I_F}$$

Where

$$I_H = \sqrt{I_2^{\,2} + I_3^{\,2} + ... + I_n^{\,2}}$$

I_n : RMS value of the Harmonic n

I_F : RMS value of the fundamental Current

V. INTRODUCTION TO FPGA

A Field Programmable Gate Array is a reconfigurable digital integrated circuit that can be programmed to do any type of digital function. FPGAs are programmed using support software and a download cable connected to a host computer. Once they are programmed, they can be disconnected from the computer and will retain their functionality until the power is removed from the chip. The FPGAs can be programmed while they run, because they can be reprogrammable in order of microseconds. FPGA consists of three major configurable elements: Configurable Logic Blocks (CLBs), Input-Output Blocks (IOBs) and Programmable Interconnects. The design functionality is described either by using schematic editors or by using one of the various Hardware Description Languages (HDLs) like Verilog or VHDL. The main advantage of an FPGA over a microcontroller chip is the ability to operate faster and it supports hardware that is upwards of one million gates. The main differences between traditional programming languages and HDL are Traditional languages are a sequential process whereas HDL is a parallel process. HDL runs forever whereas traditional programming languages will only run if directed.

VI. SIMULATION RESULTS

The toolbox MATLAB/SIMULINK is used to simulate the system, by which various results are obtained. The experimental work is going on by using field-programmable gate-array (FPGA)-based digital controller to test on a prototype. The simulation model and gating pulse generation for Phase controlled rectifier and PWM rectifier are shown in the figures respectively. The gating pulses are generated by using Sinusoidal Pulse Width Modulation. A resistive load is connected across the dc link capacitor. The values of the components used are L = 200 mH, and C = 1000 μF with a load resistance of 75 ohms. The simulation model and results are shown in Figure 3, 4 & 5 respectively. Furthermore, the input frequency is observed to vary between 48.8–50 Hz, while the converter switching sequence is done assuming a constant supply frequency of 50 Hz. The harmonic analysis of both the Phase Controlled rectifier and PWM rectifier is presented here for the comparison of the performance of both the rectifier. The simulation model of pwm rectifier and analysis are shown in Figure 6, 7, 8 &9.

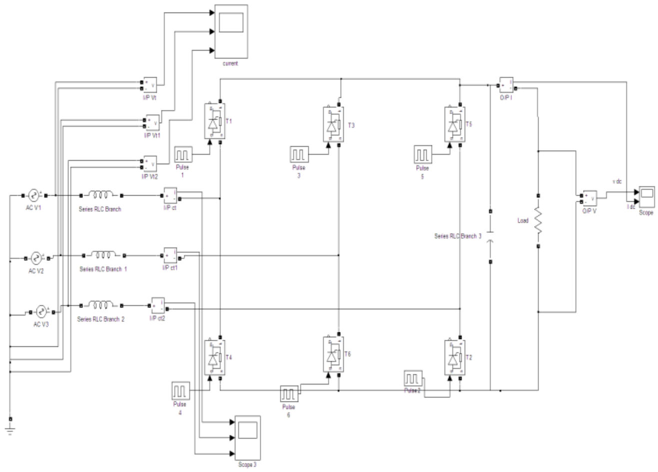

Figure 3. Simulation Model of Phase Controlled Rectifier

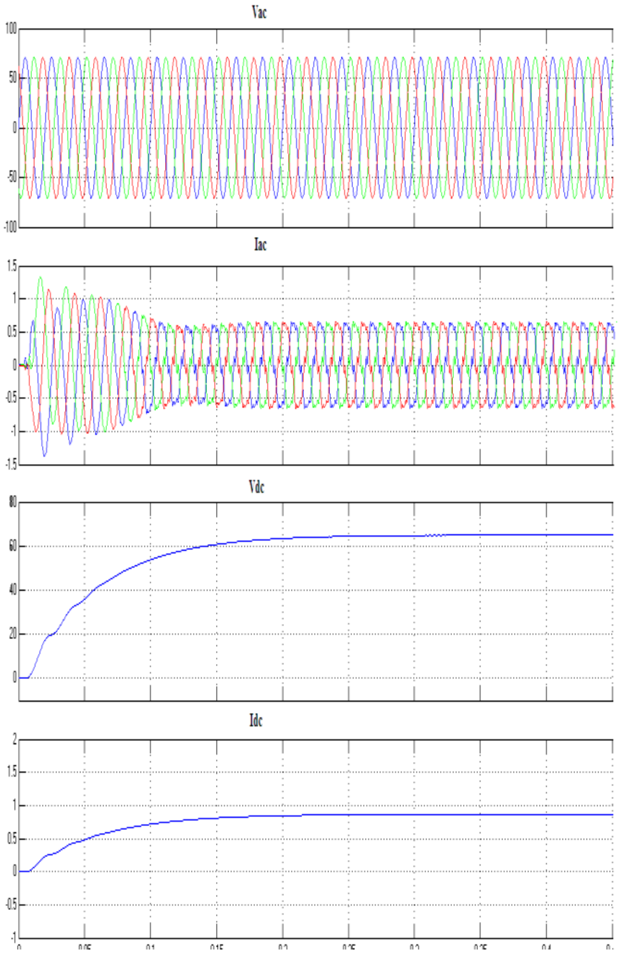

Figure 4. Simulation Result for phase Controlled Rectifier

Comparision of THD for PWM Rectifier and Controlled Rectifier has been analysed tabulated as shown in Table1. Graphical Repersentation of Phase controlled rectifier and PWM Rectifier shown in Figure 10 & 11.

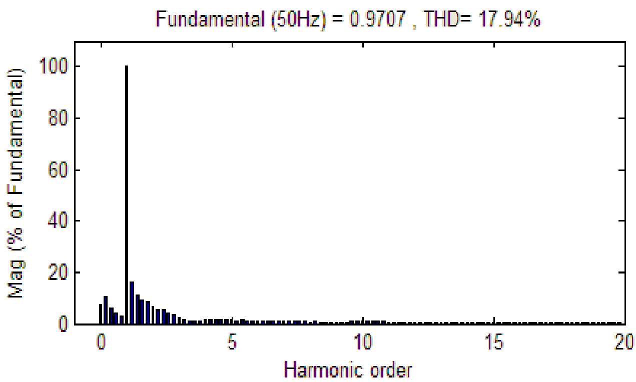

Figure 5. THD for Phase controlled rectifier

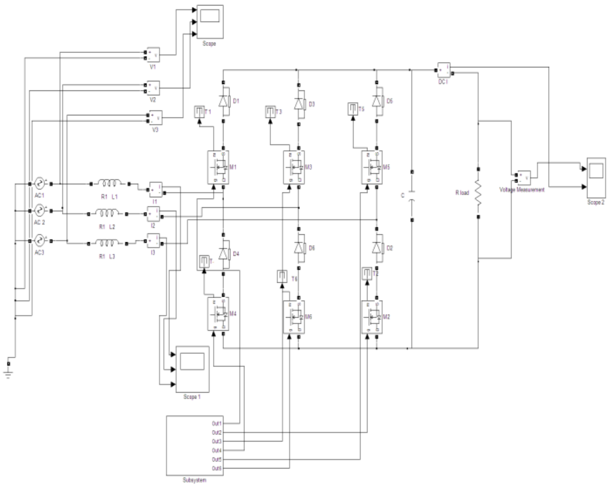

Figure 6. Simulation Model of PWM Rectifier

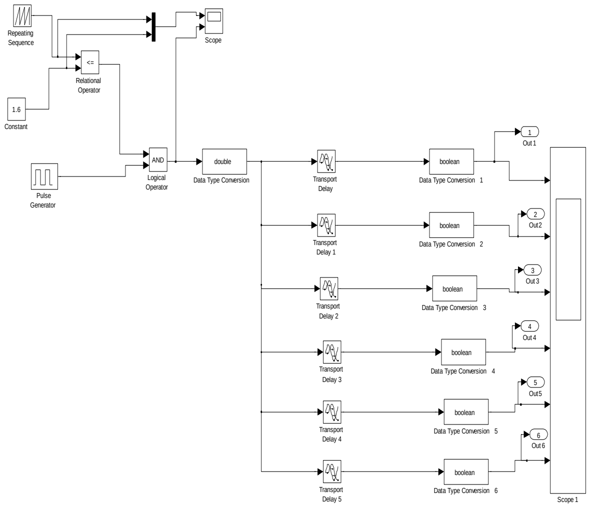

Figure 7. Control Circuit

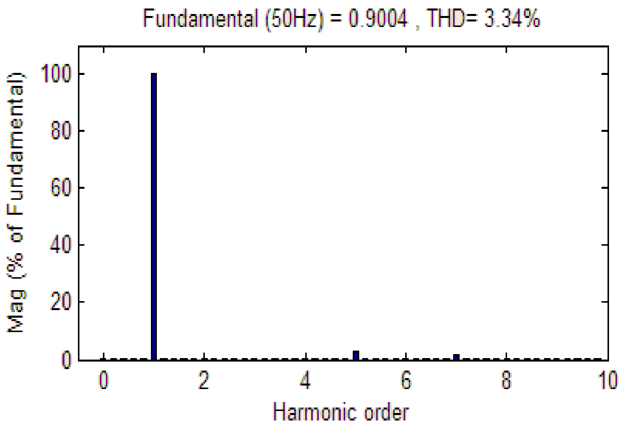

Figure 8. THD for PWM Rectifier

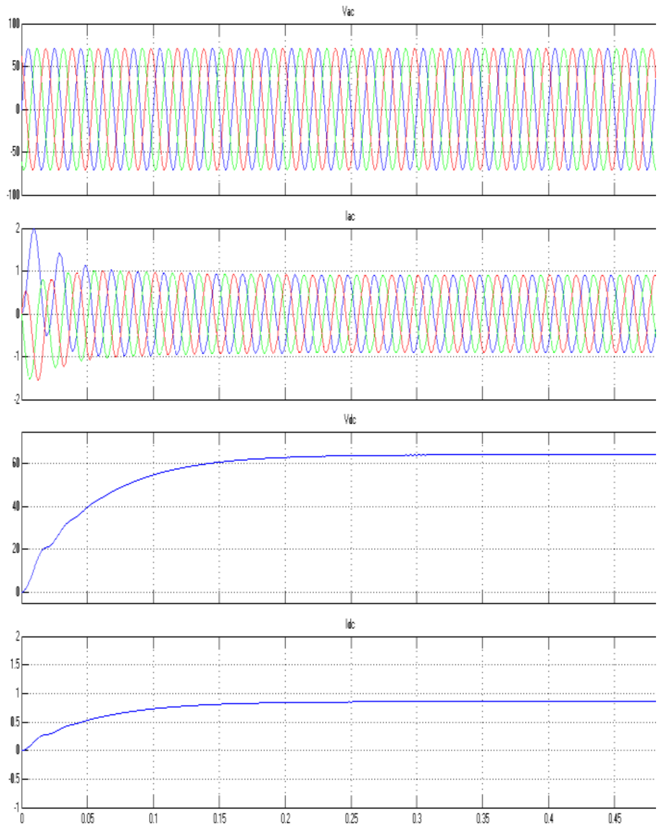

Figure 9. Simulation Result for PWM Rectifier

Table 1. Comparision of THD for PWM Rectifier and Controlled Rectifier

S.No	PWM Rectifier			Phase Controlled Rectifier		
	Pulses	Vo	THD	α	Vo	THD
1	3	64.23	3.41	26	64.93	17.94
2	5	64.26	3.34	45	45.93	28.34
3	7	64.24	3.27	60	28.39	41.62

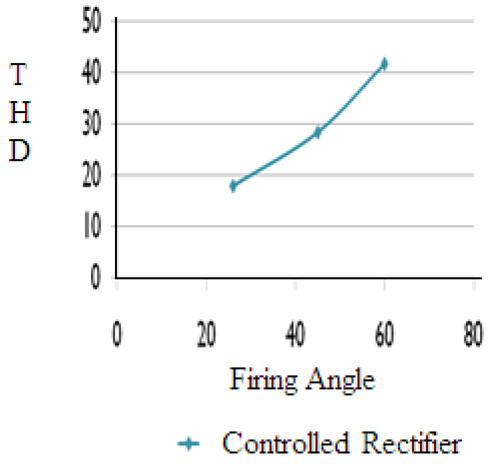

Figure 10. Graphical Repersentation of Controlled Rectifier

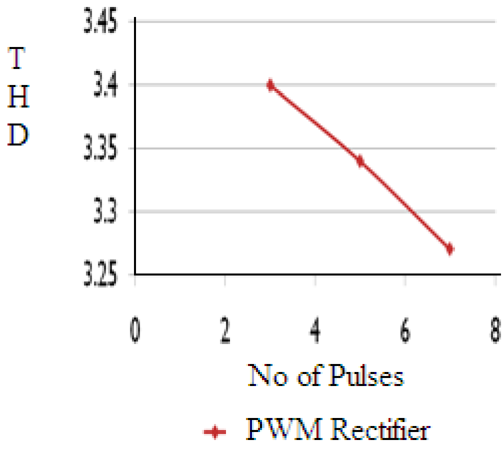

Figure 11. Graphical Repersentation of PWM Rectifier

VII. CONCLUSION

Utilization of PWM rectifiers eliminates the problems caused by using of phase controlled rectifiers. The PWM rectifier can assert itself for its good behaviour in many applications, for example as an active filter or as an input rectifier for indirect frequency converter. Measured properties of the realized phase thyristor rectifier and realized voltage type PWM rectifier are compared. The phase controlled rectifiers due to their phase control loads the supply grid with higher harmonics and consume reactive power. These side effects of phase control cannot be ignored and must be suppressed or compensated. The modern way is to apply the rectifier with pulse width modulation instead of the thyristor rectifier. Such PWM rectifier consumes current of demanded shape and with demanded phase shift between first harmonic of the input current and first harmonic of the supply voltage, so that the power factor can be regulated to the unity. Both rectifiers were tested under the same conditions and comparisons of the tests result are summarized.

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