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Improved Power Quality Rectifier Using Control Technique

Xavier Macwan, P. S. Modi

Electrical Engineering Department, Electrical Engineering Department
The Maharaja Sayajirao University of Baroda
E-mail:xmacwan53@gmail.com, ps_modi@yahoo.com

ABSTRACT

This paper presents improved power quality rectifier which provides improved power quality to load as compared to conventional diode bridge rectifiers and thyristor bridge rectifiers. In this paper problems like input current harmonics, output dc voltage with large ripple content, difficulty in regulating dc output voltage and low power factor are rectified by PWM rectifiers using LCL Filter and d-q control method. In this method power factor is improved by triggering the switches in such a way that input voltage and input current are in phase by implementing a phase locked loop (PLL). This paper also explores an important task of PWM rectifiers that is reactive power compensation function and hence it connects advantages of PWM rectifiers and reactive power compensation. The control system used in this paper is able to stabilize dc output voltage and also eliminates steady state error. Generation of gate pulses using sinusoidal pulse width modulation (SPWM) technique is shown and performance of PWM rectifiers and Total harmonic distortion(THD) on different types of loads are analyzed.

Keywords: *PWM Rectifiers, Phase locked loop (PLL), DQ control, LCL Filter, Sinusoidal pulse width modulation (SPWM), Unity power factor***.**

I. INTRODUCTION

In high performance industrial applications three phase voltage source PWM rectifiers are gaining wide popularity as compared to conventional diode bridge rectifiers and thyristors based control rectifiers because of their number of advantages like low input current distortions, improved power factor, regulated dc link voltage, etc [2] – [5]. Diode bridge rectifiers and thyristors bridge rectifiers have unidirectional power flow topology that is current flows from input side to output side whereas PWM rectifiers provide bidirectional power flow [1]. Thyristors controlled rectifier contains lower order harmonics which increases cost and size of filter. Hence, saturation of transformer takes place due to the presence of DC component in the source current. LCL Filter provides better filtering performance and reduces size of filter [6]. Unity power factor is not achieved in case of diode bridge rectifiers and thyristors bridge rectifiers because large amount of harmonics are present on ac side and due to uncompensated reactive power which is not the case with improved power PWM rectifiers [7] – [9]. The main advantage of using PWM techniques is in the reduction of harmonics by using proper number of pulses per cycle and hence the output voltage can also be controlled by adjusting the modulation index.

There are various types of modulation techniques available, but among all of them Sinusoidal pulse width modulation (SPWM) and space vector pulse width modulation (SVPWM) are widely used [1]. PWM Rectifiers are used in many applications like motor drives, battery management systems, distributed power generation systems, etc.

II. CIRCUIT DIAGRAM OF PWM RECTIFIER AND ITS WORKING

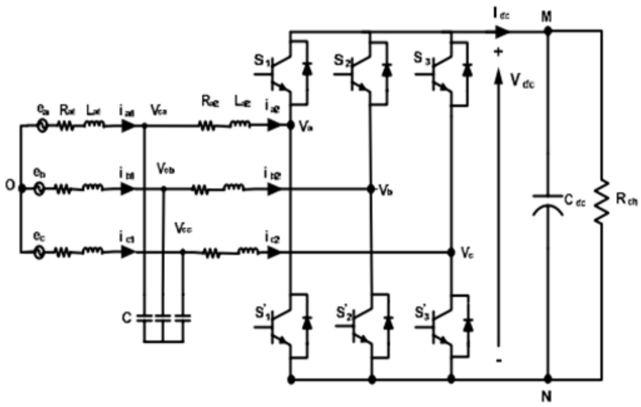

Fig. 1 Circuit diagram of IGBTs based PWM rectifier

The circuit diagram of three phase voltage source PWM Rectifier is as shown in Fig 1. The magnitude and phase angle of the currents flowing through the ac side are regulated by using a current control loop. The current control loop has three controlling parameters. They are i) The currents flowing through ac side, ii) The line voltages on ac side and iii) voltage at dc side of the front end Rectifier. Using these three controlling parameter values the controller decides the switching pulses to be applied to the three phase PWM Rectifier. PWM rectifiers has total 8 possible switching states out of which first 6 states are active and are used for providing dc output voltage to the load and for triggering the pulses to turn on/off the respective switches as shown in table 1) and the rest 2 states are inactive.

STATES	ON SWITCHES	OFF SWITCHES
1	S1, S3, S2’	S1’, S3’, S2
2	S2’, S3, S1’	S1, S2, S3’
3	S2, S3, S1’	S2’, S3’, S1
4	S2, S3’, S1’	S2’, S3, S1
5	S2, S3’, S1	S2’, S3, S1’
6	S1, S2’, S3’	S1’, S2, S3

7	S2, S3, S1	S1’, S2’, S3’
8	S2’, S1’, S3’	S1, S2, S3

Table.1 Switching states of 3 phase PWM Rectifier.

In this paper for triggering IGBTs, sinusoidal pulse width modulation technique is used and its performance analysis is shown. By using a closed loop, the output dc voltage of PWM Rectifier can be set to desired value as per its application.

III. ANALYSIS OF PWM RECTIFIERS USING SPWM MODULATION TECHNIQUE

Sinusoidal pulse width modulation is one of the simplest and efficient pulse width modulation method used for generating the gate pulses of the switches used in converters. In this method a high frequency triangular carrier wave (Vc) is compared with modulating reference wave (Vm) of desired frequency and the intersection of both these waves determines the switching instants and commutation of the modulated pulse. In this paper frequency of triangular carrier wave is taken as 10 kHz and frequency of modulating wave is taken as 50 Hz. The triangular wave and modulating wave are mixed in the comparator and when modulating wave has higher magnitude than the triangular wave, the comparator output is high, otherwise it is low. The ratio Vm/Vc is called modulation index and it controls the harmonic content of the output voltage waveform. Thus the output voltage is controlled by modulation index. The ratio of high frequency triangular carrier wave to frequency of modulating wave gives number of pulses per cycle. Carrier based SPWM modulation technique have advantages like easy generation of gate pulses, less complexity, good dynamic response, high power handling capability, compatible with today’s digital microprocessors. The simulation diagram for PWM gate pulse generation by SPWM method is shown in Fig 2.

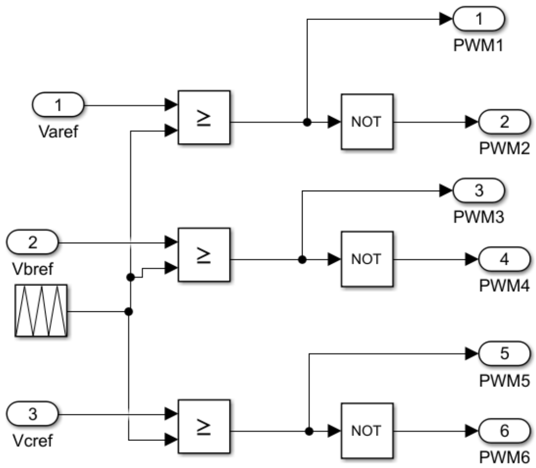

Fig.2 PWM pulse generation using SPWM Technique

In fig 2 as shown the triangular carrier wave of frequency 10 kHz is compared with modulating reference signals of frequency 50 Hz and then both are mixed in comparator and hence produces PWM pulses which are given to the gates of IGBTs used in PWM Rectifier.

The simulation diagram of SPWM based PWM Rectifier is as shown in Fig 3

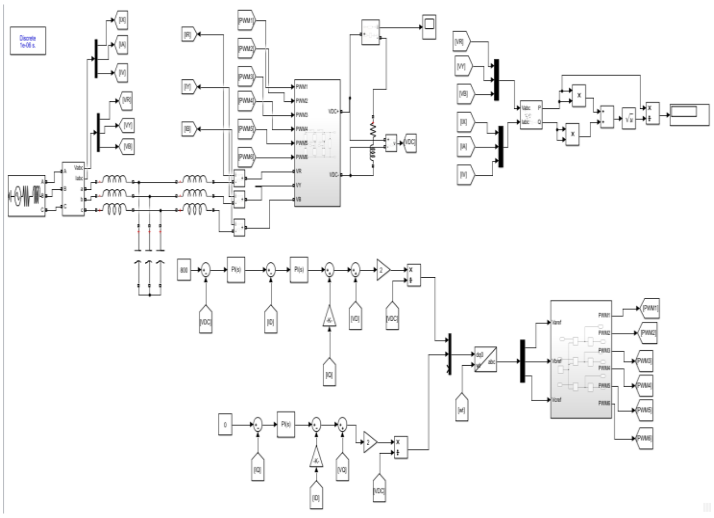

Fig 3 Simulation diagram of SPWM based PWM Rectifier

A. PHASE LOCKED LOOP

In order to send active power to the load, the currents flowing through the grid side has to be in phase with the grid side voltages. To send this current, PLL will generate a reference signal and that signal should be in phase with actual voltage. Similarly to send reactive power to the load, PLL will generate a signal which is 90 degree out of phase with the actual voltage. Hence PLL is used to generate reference signals and that signals are used as a reference for the implementation of current controller in grid connected system. There are 2 methods for the implementation of PLL. They are as follows :

1) OPEN LOOP PLL

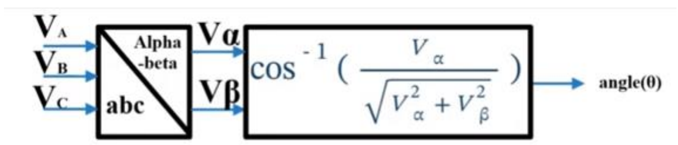

Fig.4 Block diagram of PLL with Open loop control

From this angle information as shown in Fig 4 PLL will generate the current reference for active and reactive power. There are few problems in this method and hence this method is not used in many applications. Some major problems are 1) As it is an open loop system, the system can go to unstable situation under critical grid conditions. 2) It cannot withstand conditions like harmonics, surges, noise, spikes. Due to such problems, the output of PLL gives wrong angle information as drifting of angle takes place.

(2) CLOSED LOOP PLL

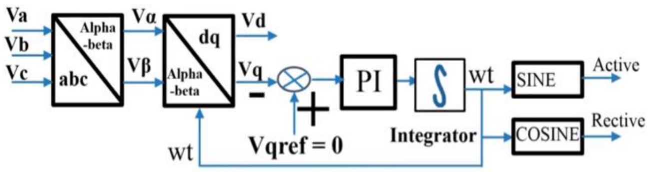

Fig.5 Block diagram of PLL with closed loop control

By using this method of PLL all the issues are sorted which are occurring in open loop system. From the phasor diagram in fig 6 it is shown that d-axis is not aligned with grid voltage, so there are non zero values of d- axis and q-axis voltages. By control mechanism, Vd gets aligned with grid voltage axis as shown in fig. 7.

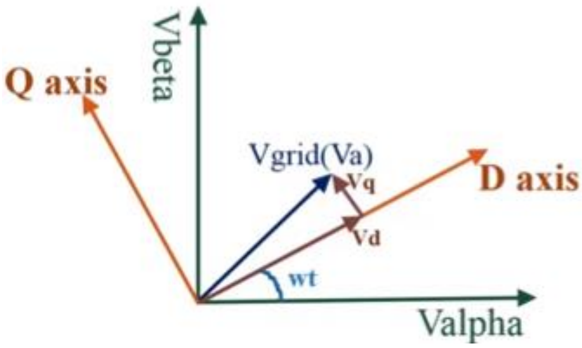

Fig.6 d- axis not aligned with grid voltage.

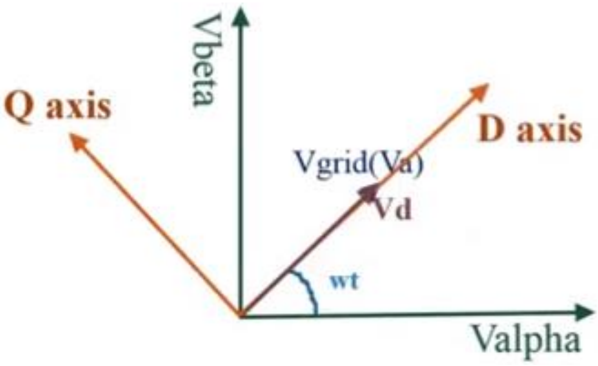

Fig.7 d- axis aligned with grid voltage

As shown in fig 7 the angle now has been shifted to a new value. So this angle, as shown in fig 7 can be used for generating active and reactive component. Active component is aligned in phase with Vα and reactive component is aligned in phase with Vβ.

The simulation diagram of PLL for the closed loop system is as shown in Fig 8.

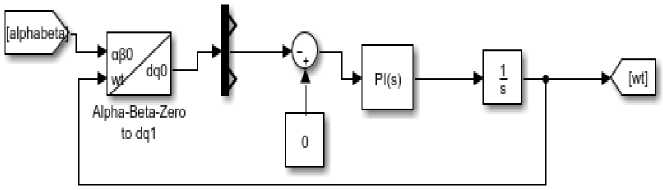

Fig.8 Simulation of closed loop PLL

PI controller is used to make q value 0, so Vqref = 0. Output of PI controller is given to integrator to generate angle ωt.

IV. CONTROL LOGIC

The simulation diagram for control logic is as shown in Fig.9

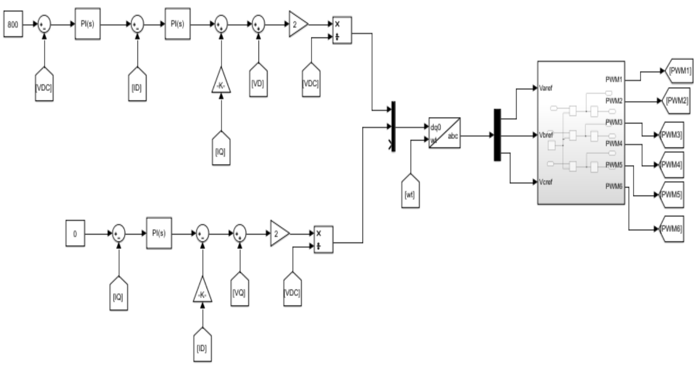

Fig.9 Simulation diagram of control logic used in PWM Rectifier.

In this closed loop operation, the abc coordinates are transformed to dq coordinates by using Park's transformation to achieve two components of current Id and Iq and angle ωt is obtained from Phase Locked Loop (PLL).

$$I_d = I_\alpha * \cos(\omega t) + I_\beta * \sin(\omega t)$$

$$I_q = I_\beta * \cos(\omega t) - I_\alpha * \sin(\omega t)$$

In order to control dc output voltage, the error obtained by comparing the actual dc output voltage Vdc with Vdc reference of 800V is fed to PI controller. The output of PI controller is taken as Id current reference and compared with the d- component of input current (Id). The q component of input current (Iq) is set to 0 for maintaining unity power factor. The errors obtained from both the components of current are fed to their respective PI current controllers and output of both the controllers are scaled and fed to PWM scheme. After applying inverse Park's transformation we get Va*, Vb* and Vc*.

$$V_\alpha = V_d * \cos(\omega t) - V_q * \sin(\omega t) \quad - (1)$$

$$V_\beta = V_q * \cos(\omega t) + V_q * \sin(\omega t) \quad - (2)$$

From the above equations (1) and (2) Va*, Vb* and Vc* are calculated.

Va*=Vα -(3) Vb*=(-Vα+√3*Vβ)/2 -(4) Vc*=(-Vα-√3*Vβ)/2 - (5)

SPWM technique is operated with 10 kHz switching frequency. The simulation results of input current, input voltage and output dc voltage of rectifier is as shown in fig 10 and 11 respectively.

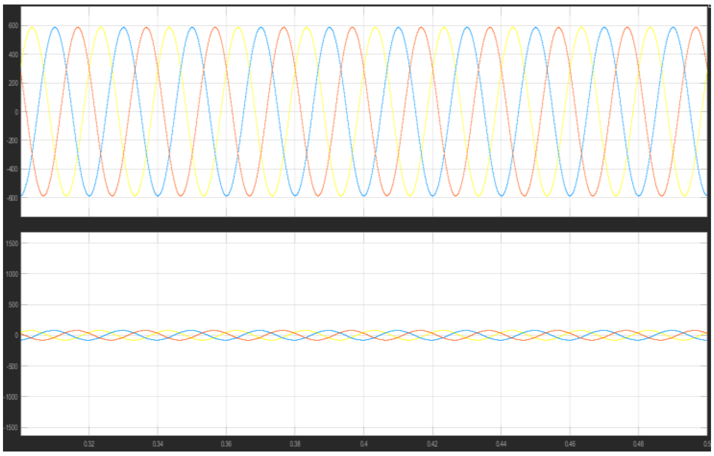

Fig.10 3 Phase input voltage and input current of SPWM Based PWM Rectifier

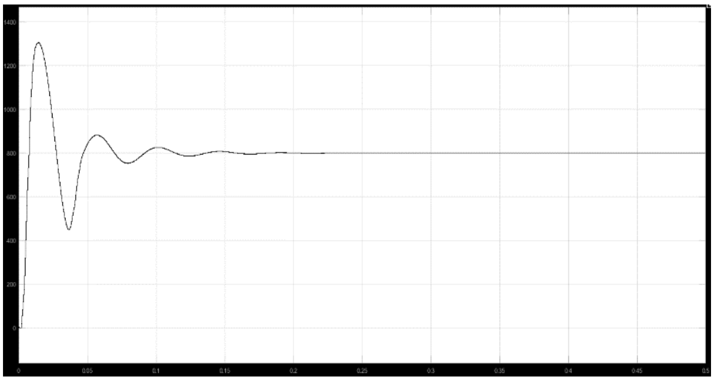

Fig.11 Output dc voltage of 3 Phase PWM Rectifier

V. SIMULATION RESULTS

SR. NO	LOAD (KW)	LOAD PARA-METERS	OUTPUT VOLTAGE	THD (%)	POWER FACTOR
1	R	R = 10Ω	800 V	0.86	0.998
2	RL	R = 20Ω, L = 100mH	800 V	1.56	0.994
3	RL	R = 30Ω, L = 500mH	800 V	2.24	0.988
4	RL	R = 20Ω, L = 300mH	700 V	2.26	0.991

5	RL	R = 30Ω, L = 700mH	900 V	1.74	0.992
6	RL	R = 40Ω, L = 1000mH	1000V	3.19	0.988

TABLE.2 Performance analysis of PWM Rectifier by changing load parameters and dc output voltage.

FFT analysis graph for different types of loads and output voltages mentioned in table 2) are shown below:

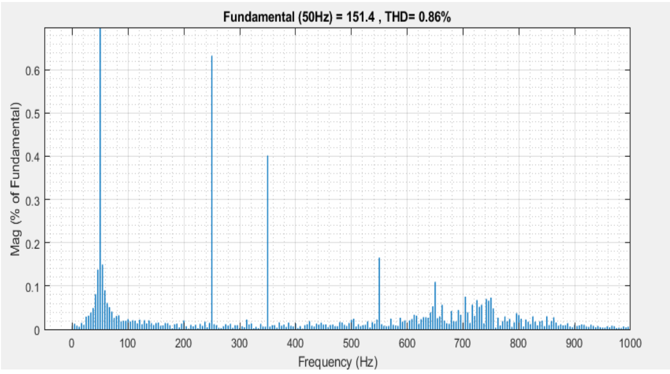

Fig.12 Harmonic spectrum for R=10Ω and output dc voltage = 800V.

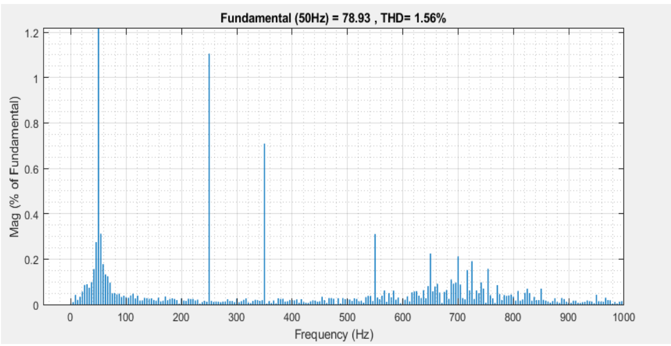

Fig.13 Harmonic spectrum for R= 20Ω, L=100e-3H and output dc voltage = 800V.

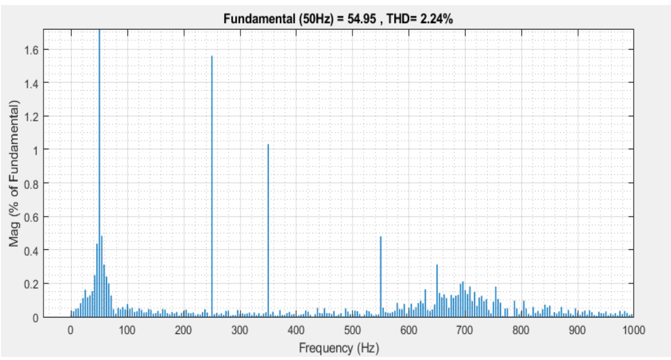

Fig.14 Harmonic spectrum for R=30Ω, L=500e-3H and output dc voltage = 800V.

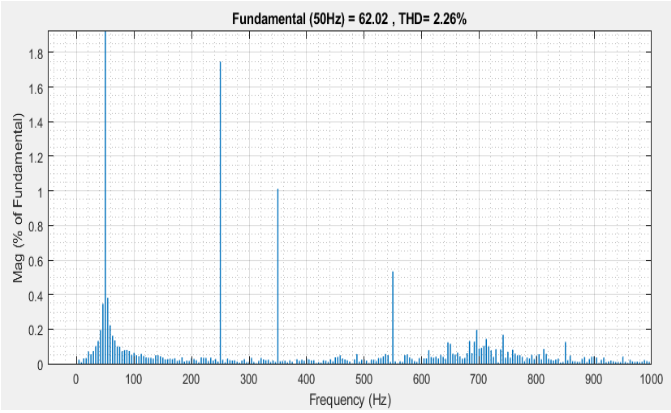

Fig.15 Harmonic spectrum for R=20Ω, L=300e-3H and output dc voltage = 700V.

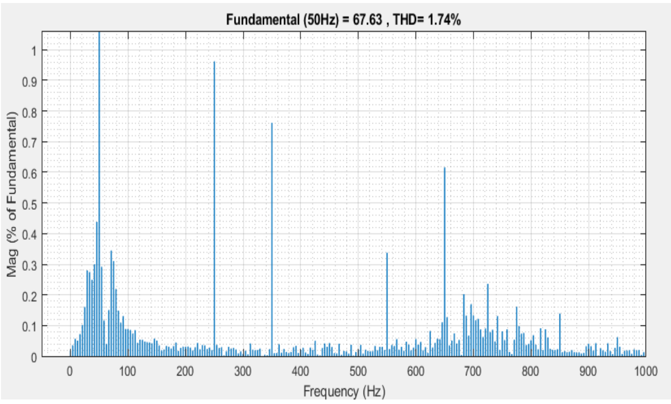

Fig.16 Harmonic spectrum for R=30Ω,L=700e-3H and output dc voltage = 900V.

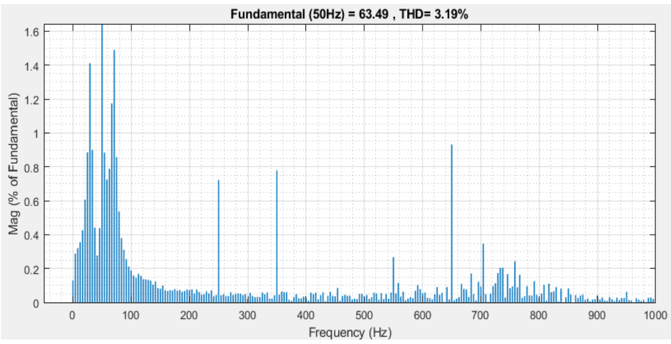

Fig.17 Harmonic spectrum for R=40Ω,L=1000e-3H and output dc voltage = 1000V.

VI.CONCLUSION

In this paper, working of Improved power PWM Rectifier is shown and reactive power compensation is achieved using dq control method on SPWM based PWM Rectifier. Output of PWM Rectifier gives stabilized output dc voltage. From harmonic spectrum analysis and simulation results it has also been demonstrated that the proposed system provides power factor (very close to unity) to load with very low content of total harmonic distortion(THD).

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