Control Techniques of Three Phase PWM Rectifier

V. Vaideeswaran, N. Sankar

Abstract--- This paper provides various control techniques of three phase PWM Rectifiers are presented. The working principle of three phase PWM Rectifiers is explained and three control techniques are presented. These control techniques are simulated in MATLAB/Simulink and the results from each control techniques are compared on the basis of Total Harmonic Distortion and Power factor. The FFT analysis of each control techniques are analyzed using MATLAB/Simulink. Also advantages and disadvantages of each control techniques are presented in this paper.

I. INTRODUCTION

Nowadays AC-DC conversion is used in various applications such as welding power source, electric ballast, house hold applications, charging units, DC and AC Drives. AC-DC converters can be classified based on switching frequency. In AC to DC Converters, diodes are used to rectify AC to DC. This type of converters is under the classification of Line commutated converters. In these converters, thyristor is also used to rectify AC to DC. In this type of converters, harmonics and reactive power generation is main advantage. In electrical system, harmonics have a major effect in the operation and it is necessary to control in generation units [1].

The Basic method for harmonic reduction is the multipulse pulse rectifier configurations with their phase shifting transformer. Another method is the use of passive filter to reduce the harmonics. But it has the disadvantages size and reliability. Nowadays active filters are introduced. With the help of power electronic components and converters, harmonics and reactive power generation is minimised. These types of converters are named as Power Factor Correction units [2]. From these converters the shape of the input current is actively controlled to reduce harmonics and to achieve power factor close to unity in the supply side. There are various PFC’s available such as boost converter, Vienna rectifier but these are not useful for regenerative application. But in various applications regeneration of power is used so the PWM rectifier is a bidirectional power flow converter. The principle of operation and control techniques are presented in this paper.

II. PWM RECTIFIER

PWM Rectifier is a regenerative converter and it is working on the principle of force commutation techniques. In this, output of the converter is DC voltage and it should be constant because DC Bus voltage is used for many applications. The constant DC bus voltage is achieved by using DC capacitor and a control loop. Fig.1 shows the PWM Rectifier [2],[3].

The principle of operation of rectifier comprises of maintaining the DC voltage across the capacitor as constant and it is done by means of feedback of output voltage as shown in Fig.2. The reference voltage given to the control loop should able to block the conduction of diodes so that the converter works in unity power factor mode otherwise it will become a three-phase bridge rectifier [4].

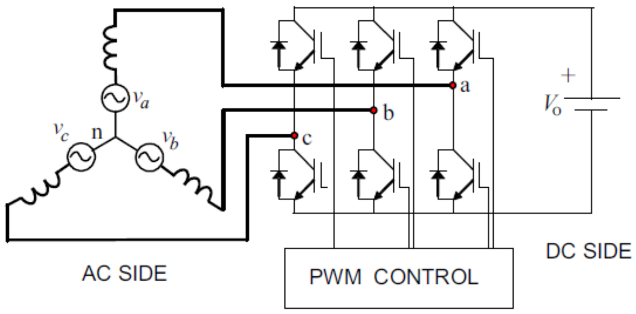

Figure 1. Three Phase PWM Rectifier

DC link voltage is compared with set reference voltage under which the condition is satisfied. The switching pattern of the converter is produce by different control methods [4]. These techniques will produce pulses on the basis of error signal generated from the comparator. So that current will return to source side with the help of DC link voltage.

The comparator compares the reference value of voltage with the actual value of voltage and if the error value of the comparator is positive then the capacitor connected in the DC link gets discharged and so that the converter is working under rectifier operation. Here the DC current *Io* will be positive. For this condition, the control block will generate six pulses to each of the power semiconductor devices. It will also provide appropriate phase shift and so that the power flows from the variable AC to DC sides and the capacitor voltage is regained. When the output current becomes negative the capacitor will be overcharged and compared with reference voltage and control system controls the discharging of capacitor so that AC will be controlled.

The PWM Rectifier operation is shown in the Fig. 2 and the working procedure is explained above. From this PWM Rectifier is used for four quadrant applications.

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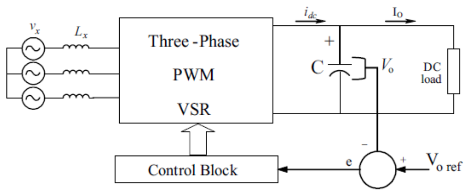

Figure 2. Operation of PWM Rectifier

The rectifier can be controlled with the help of supply voltage and its phase. Hence changing the magnitude of control voltage and its phase with respect to supply will be established. Thus, it can be operated in two quadrants each as rectifier and inverter i.e., leading power factor, lagging power factor thereby achieving four quadrant operations. The operation of PWM controls the active and reactive power and makes the rectifier to draw the current with improved power factor. That is the input current drawn for the source side will be sinusoidal and hence the harmonic distortion from the converter becomes very less. [5].

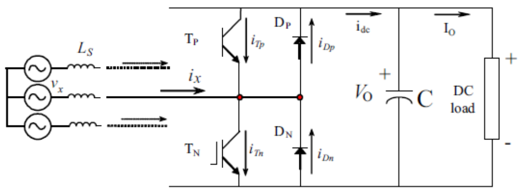

Figure 3. Single Leg Operation of PWM Rectifier

The current *ix* flow through the semiconductors shown in Fig. 3. During positive cycle the current *ix* starts to flow through TN (iTn) which is connected to the ground side of the capacitor in DC link and it is switched on in the positive half cycle. The current will come back to supply side and connected with another phase and also flows through a diode which is connected at the ground side of the capacitor in the DC link side The current can also flows through the constant voltage load (inversion) and again come back to the another transistor which is connected at the high potential side of the capacitor in the DC link. The current path is interrupted when transistor *TN* is switched OFF, and the current is ready to flow through diode *DP*, which is connected to the high potential side of the capacitor. This current *iDp* in Fig. 3, flows to the DC-link, for the production of current *idc*, which charges the capacitor *C* and will be able to generate DC power. For the conduction of Diode DP, inductance Ls is used to produce induces voltage. In the negative half cycle, same operation will be occurs but the thyristor and diode used for this operation which is Tp and Dn. The current paths are variant in nature under inverter operation because the currents flowing through the transistors come mainly from the capacitor C. [5],[6].

The control techniques include (a) Hysteresis-band PWM (b) Carrier-based sinusoidal PWM (c) Space vector PWM.

III. HYSTERESIS-BAND PWM

The control circuit is shown in Fig. 4 should perform three controls: 1. Source current 2. Source voltage 3. Output voltage. Output of PI controller decides the magnitude of current to be drawn from the source which depends on the required set voltage. From the source voltage, unit sine template is obtained and the reference current is obtained by multiplying the required magnitude of current and unit sine template. Hence the set value source current is obtained. The real time current through the inductor (actual source current) is controlled using hysteresis current controller method.

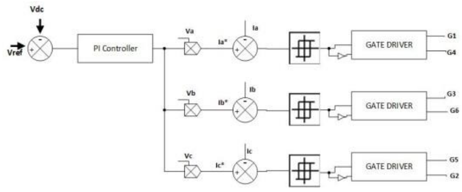

Figure 4. Hysteresis-band PWM control circuit

The Negative side of the DC link voltage is connected to the grid line when instantaneous current exceeds the reference current. If this is not happened phase of source grid will be connected to the positive side of DC link. The same process will be carried out for another two phases in similar manner.[7].

A MATLAB simulation model has been developed for the PWM rectifier with hysteresis-band control with the parameters in the table 1. Results are successfully obtained with THD= 9.33% and power factor of 1 at the input side. The simulink model, output voltage and current, input side current and voltage, total harmonic distortions are shown from Fig. 5 to 8.

Table 1. System parameters

Parameter	Value
AC line voltage	110V
Ref DC output voltage	180V
Line inductance	10mH
Load resistance	45ohm
DC link capacitor	1000uF
Hysteresis band	2%
Switching Frequency	10 kHz

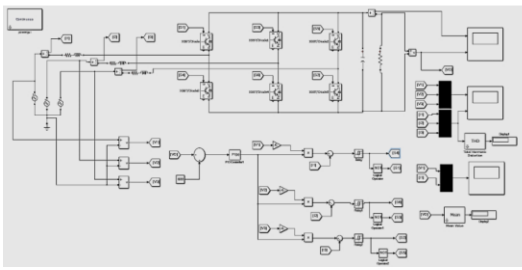

Figure 5. Hysteresis-band PWM Simulink Model

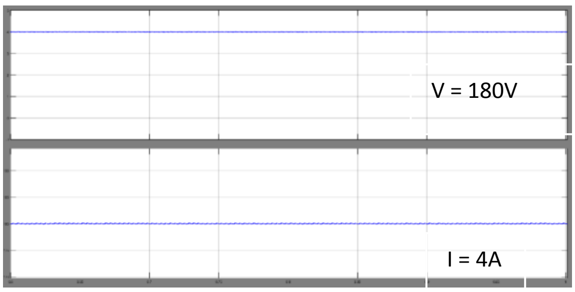

Figure 6. Hysteresis-band Output Voltage and Current

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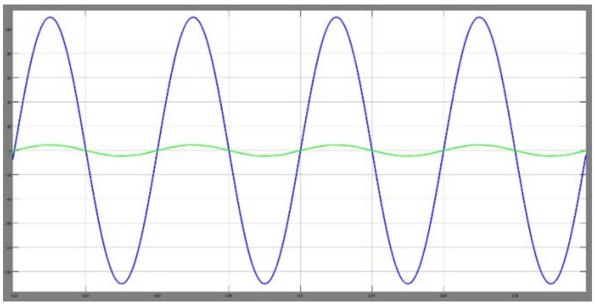

Figure 7. Input Voltage and Input Current

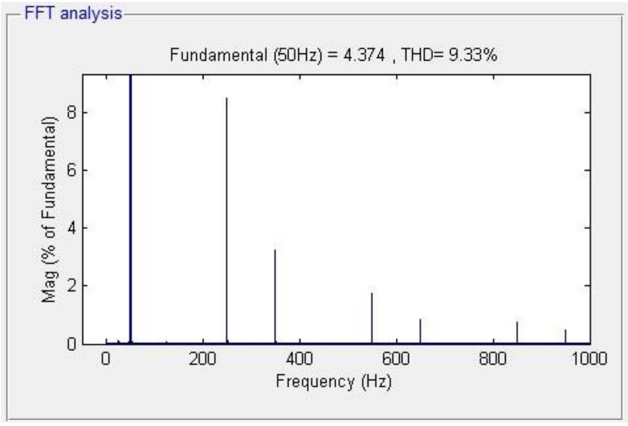

Figure 8. Hysteresis-band THD=9.33%

IV. CARRIER-BASED SINUSOIDAL PWM

In this technique voltage from the converter which is measure in real time and also the reference voltage which is set is compared and error signal generated is compared with high frequency carrier wave which is triangular in nature. This technique uses only the reference voltage but in hysteresis band PWM current reference will also be taken care for generating firing pulses. Output of PI controller decides the magnitude of current to be drawn from the source which depends on the required reference voltage. From the source voltage, unit sine template is obtained and the reference current is obtained by multiplying the required magnitude of current and unit sine template. Hence the reference source current is obtained. This reference source current is again compared with actual source current and error is send to PI controller. The output from PI controller gives reference source voltage which is compared with triangular carrier wave to obtain the switching sequence. Since reference source current is used to get reference source voltage, this method is known as Current controlled carrier based sinusoidal PWM [8]. The control circuit is shown in Fig.9.

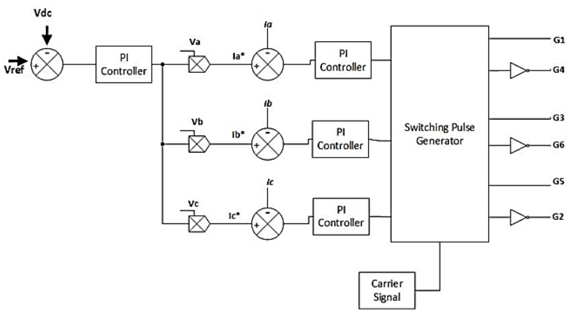

Figure 9. Carrier based sinusoidal PWM

A MATLAB simulation model has been developed for the PWM rectifier with CB-SPWM control with the parameters in the table 1. Results are successfully obtained with THD= 3.35 % and high power factor at the input side. The simulink model, output voltage and current, input voltage and current, total harmonic distortions are shown from Fig. 10 to 13.

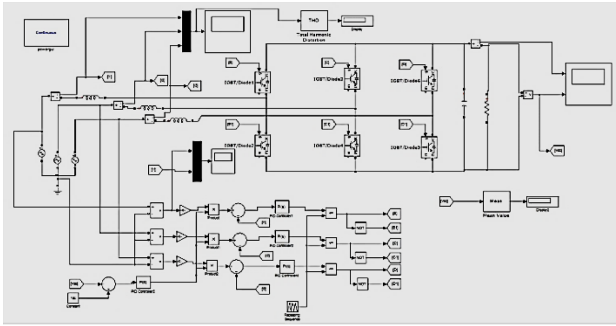

Figure 10. CB-SPWM Simulink Model

V. RESULTS

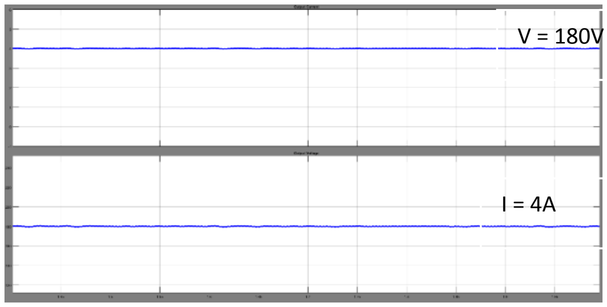

Figure 11. CB-SPWM Output Voltage and Current

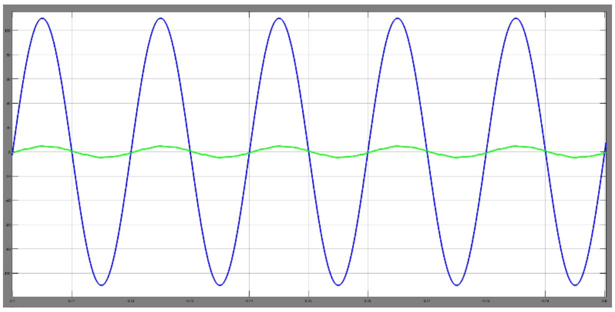

Figure 12. Input Voltage and Current

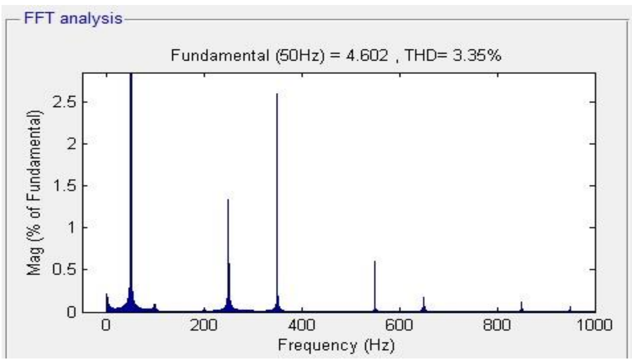

Figure 13. CB-SPWM THD=3.35%

VI. VOLTAGE ORIENTED CONTROL HYSTERESIS-BAND PWM

Voltage oriented control hysteresis-band PWM method is based on the comparison of actual current with the reference current obtained from the vector control method. The error from the PI controller is taken as d-axis reference current, q-axis current is assumed to be zero. This d-q reference is converted into alpha-beta reference which again converted back to abc reference signals. Here hysteresis band PWM is used for the switching control. Since voltage-oriented vector control is used for obtaining the reference signals, this method is known as Voltage oriented control hysteresis-band PWM. The control circuit is shown in Fig 14.

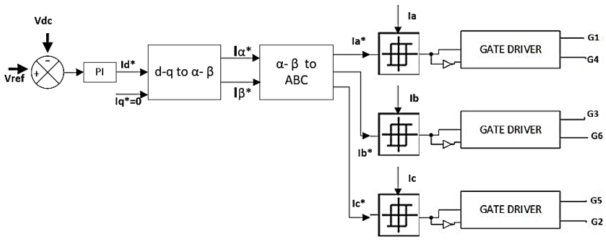

Figure 14. Voltage Oriented Control HB-PWM

A MATLAB simulation model has been developed for the PWM rectifier with CB-SPWM control with the parameters in the table 1. Results are successfully obtained with THD= 7.67 % and high power factor at the input side. The Simulink model, output voltage and current, input voltage and current, total harmonic distortions are shown from Fig. 15 to 18.

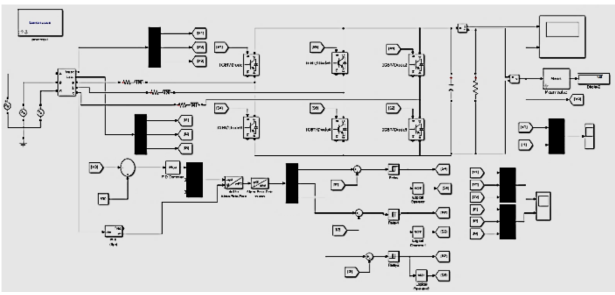

Figure 15. VOC – HB-PWMSimulink Model

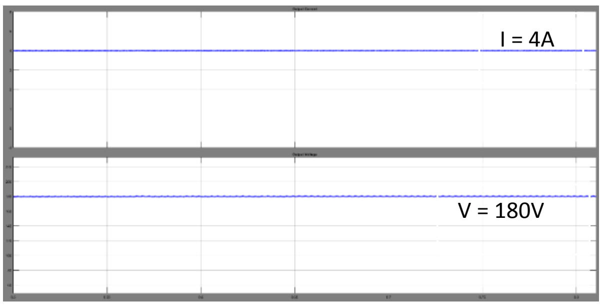

Figure 16. VOC – HB-PWM Output Voltage and Current

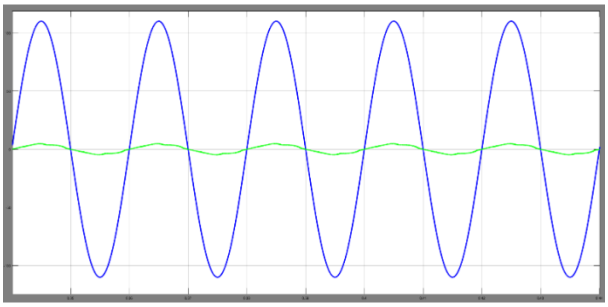

Figure 17. InputVoltage and Current

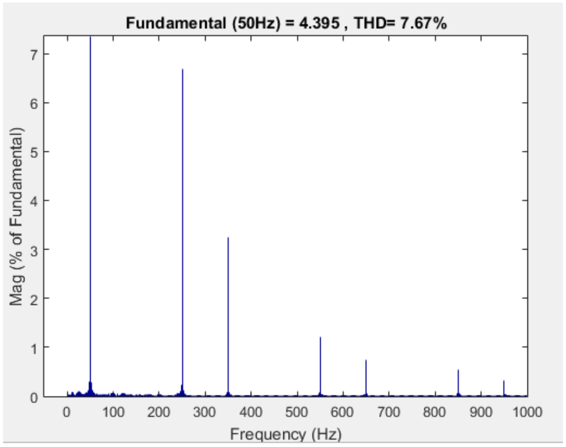

Figure 18. VOC HB-PWM THD=7.67%

VII. CONCLUSION

In this paper three different control techniques are discussed for the switching of PWM rectifier, MATLAB simulation are done and results are obtained. The first two methods are completely scalar control and do not need any complex transformations compared to the third one, a vector control technique. Anyhow third control technique VOC HB-PWM will give more accurate results compared to the other two methods. The comparison of these three methods tabulated in the Table 2, reveals that hysteresis control and voltage-oriented control has UPF and THD more than 5% but CB-SPWM control has less than 5% of THD, nearly unity power factor is achieved but need three more PI controllers compared to other techniques. Thus, by tuning the PI control more accurately, we can achieve an easy and efficient switching control using the first technique i.e., hysteresis control.

Table 2. Comparison

Control	Fundamental current	THD (%)	Power factor
HB-PWM	4.374	9.33	0.99
CB-SPWM	4.602	3.35	0.98
VOC HB-PWM	4.395	7.67	0.99

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