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Vector Controled Voltage Source PWM Rectifier

Shweta. Patil(1)
PG Student
Department of EEE
National Institute of Engineering
Mysore, India

S. Nagendraprasad(2)
Associated professor
Department of EEE
National Institute of Engineering
Mysore, India

***Abstract*-The objective of this paper is to model and simulate a three-phase voltage source boost rectifier based on vector control method. The control system based on SVPWM (Space Vector PWM) includes three PI controllers which are used to regulate the AC currents and DC link voltage. The active and reactive current can be controlled independently for this system. The DC bus voltage and power factor are regulated with high quality factor in place. The paper presents MATLAB/SIMULINK model. The results validities of the model and its control method.**

Keywords: Ac to Dc converter, power factor, vector control, SVPWM.

I. INTRODUCTION

Diodes and thyristor are widely used in the conventional rectifier circuits, but the problems arising during operating should not be ignored, such as, harmonic problems and low power factor. These problems may do harm to the grid, which in turn may cause serious repercussion, thus limiting the application of such systems. With the continuous development of PWM technology nowadays, people pay attention to the PWM rectifier systems gradually replacing the previously referred systems. For convertor, PWM rectifier has many advantages which non-controlled rectifier does not have. For example, the power factor can be controlled, harmonics mitigated and the power can flow in both directions. So the PWM rectifier is also called "green energy converter" [1, 2].

In this paper, the mathematical model of three-phase voltage rectifier in the three-phase stationary coordinates is analyzed in order to regulate DC voltage and to get unity power factor with less harmonic distortion using vector control based rectifier designed with SVPWM switching techniques.

II. THE MATHEMATICAL MODEL OF PWM RECTIFIER

In the set up math model, it is assumed that the AC voltage is a balanced three phase supply, the filter reactor is linear, and IGBT is ideal switch and lossless. Where U_a, U_b and U_c are the phase voltages of three phase balanced voltage sources.

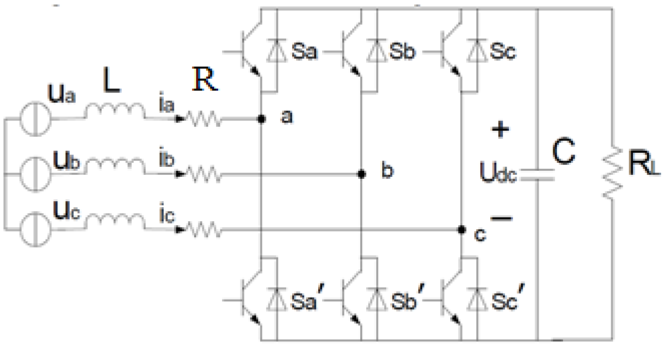


Fig 1. Three phase boost rectifier

and ia , ib and ic are phase currents, Vdc is the DC output voltage, Rand Lmean resistance and inductance of filter reactor, respectively, C is smoothing capacitor across the dc bus, R_L is the DC side load, Ura , Urb , and Urc , are the input voltages of rectifier, and I_L is Load current.

Definition of the three-phase bridge switching function are Sa, Sb and Sc : Sx=l (x=a, b, c) on behalf of turn on the higher switch while turn off the lower one in the same bridge; s = 0 is just the other way round, on behalf of turn off the higher switch while turn on the lower one.

To establish the formula of voltage Kirchhoff's voltage law is applied. Therefore, the mathematical model of three-phase PWM rectifier in the three-phase stationary coordinates is

$$\begin{cases} L\frac{dia}{dt} + Ria = Ua - Ura \\ L\frac{dib}{dt} + Rib = Ub - Urb \\ L\frac{dic}{dt} + Ric = Uc - Urc \end{cases} \quad (1)$$

The following equations describe the dynamical behavior of the boost type rectifier in Park's coordinates or in d-q form of representation:

$$\begin{cases} \frac{Ldid}{dt} = Ud - Rid + wLiq - Urd \\ \frac{Ldiq}{dt} = Uq - Riq + wLid - Urq \\ \frac{CdVdc}{dt} = -\frac{Vdc}{RL} + \frac{3}{2}(Sdid + Sqiq) \end{cases} \quad (2)$$

The transformation matrix from three-phase stationary coordinate system to two-phase stationary coordinate system is shown as:

$$C_{3s/2s}=\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \quad (3)$$

From equation (2)

$$\begin{cases} \mathrm{U}d = L\frac{\mathrm{d}id}{\mathrm{d}t} + \mathrm{R}id - w\mathrm{L}iq + \mathrm{U}rd \\ \mathrm{U}q = \frac{\mathrm{Ld}iq}{\mathrm{d}t} + \mathrm{R}iq + w\mathrm{L}id + \mathrm{U}rq \end{cases} \quad (4)$$

III. VECTOR CONTROL APPROACH

Vector control is a popular method for control of three-phase induction motors. The basic idea of this scheme is to control the flux producing and the torque-producing components of motor current in a decoupled manner to achieve fast dynamic response. The outer control loop controls the speed of the motor, while the inner loop controls the components of current vector, which correspond to torque and flux.

Similar control approach can be used for FEC (Front End Converter) also. Here, the three-phase voltages and line currents are converted into an equivalent two-phase system, called stationary reference frame. These quantities are further transformed into a reference frame called stationary reference frame, which revolves at the grid frequency. In stationary reference frame, the components of current corresponding to active and reactive power are controlled in an independent manner similar to the torque and flux producing components in a motor drive. The outer loop controls the dc bus voltage and the inner loop controls the line current

The vector controller has an outer voltage loop to control V_{dc}. The voltage controller sets the reference to the inner *q*-axis current controller as shown in figure 3.

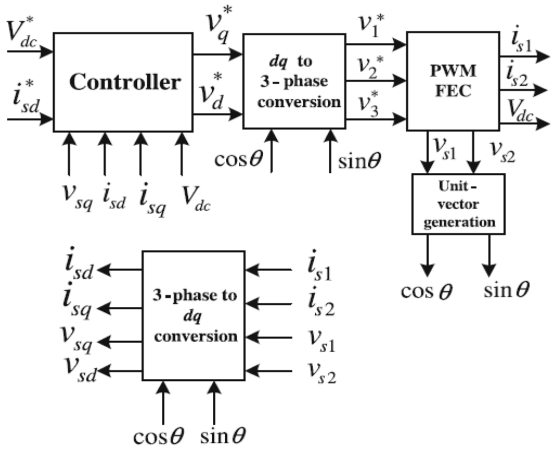


Fig 2. Block diagram of a vector controlled front-endConverter

IV. FEED-FORWARD DECOUPLING CONTROL

Just as shown, i_d and i_q are of mutual coupling from (4), which means that if we control one of them, then the other one will be changed correspondingly, thus we cannot control them independently. So we need to carry on the decoupling control in order to control them independently.

We use the strategy of feed-forward decoupling control, make

$$\begin{cases} \frac{Ldid}{\mathrm{d}t} + Rid = \left(Kp + \frac{Ki}{s}\right) * (Id - id) \\ \frac{Ldiq}{\mathrm{d}t} + Riq = \left(Kp + \frac{Ki}{s}\right) * (Iq - iq) \end{cases} \quad (5)$$

Substitute (5) in (4)

$$\begin{cases} \mathrm{U}d = \left(Kp + \frac{Ki}{s}\right) * (Id - id) - w\mathrm{L}iq + \mathrm{U}rd \\ \mathrm{U}q = \left(Kp + \frac{Ki}{s}\right) * (Iq - iq) + w\mathrm{L}id + \mathrm{U}rq \end{cases} \quad (6)$$

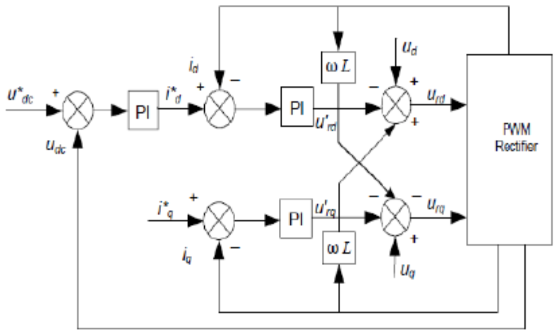


Fig 3. Control block diagram of dual closed loop controller of the PWM rectifier.

Here the direct axis current loop regulates the DC bus voltage and quadrature axis current control loop regulates the unity power factor.

$$\begin{cases} \frac{\mathrm{d}id}{\mathrm{d}t} = \frac{1}{L}\left(Kp + \frac{Ki}{s}\right) * Id - \frac{1}{L}\left[R + \left(Kp + \frac{Ki}{s}\right)\right] * id \\ \frac{\mathrm{d}iq}{\mathrm{d}t} = \frac{1}{L}\left(Kp + \frac{Ki}{s}\right) * Iq - \frac{1}{L}\left[R + \left(Kp + \frac{Ki}{s}\right)\right] * iq \end{cases} \quad (7)$$

Thus currents i_d and $i_q$can be controlled independently after decoupling, therefore respectively controlling the active power and reactive power independently resulting in the design of current loop. Current loop design block diagram is shown in Figure 3.

For the voltage loop design, the reactive component should be 0 to ensure the PWM rectifier power factor is unity [3, 4, and 5].The given value of active component i_d is produced by PI controller, which is shown in Eq.(11), the K_{uP} is the proportionality factor, and theK_{uI} is the integral coefficient.

After the double decoupled controlling and coordinate transforming stationary reference voltages are converted into three phase voltage signals and are fed to PWM module in order to generate pulses to turn on and off the switches to get regulated output.

V. SIMULATION

MATLAB/ SIMULINK platform is used for the design and simulation of the proposed control strategy. System behavior is approximated as a discrete control system. The complete simulation model is shown in Fig. 4. The rectifier is shown in the top part of the Fig. 5. As already explained, the AC source used is a balanced three phase voltage source with a frequency of 50 Hz and 415 volts per phase. The value of the line resistance and line inductance are 0.0001 ohms and 0.002 mH respectively. A value of 1015 V is assumed for the DC voltage in the steady state. Switching frequency of 10 KHz is employed.

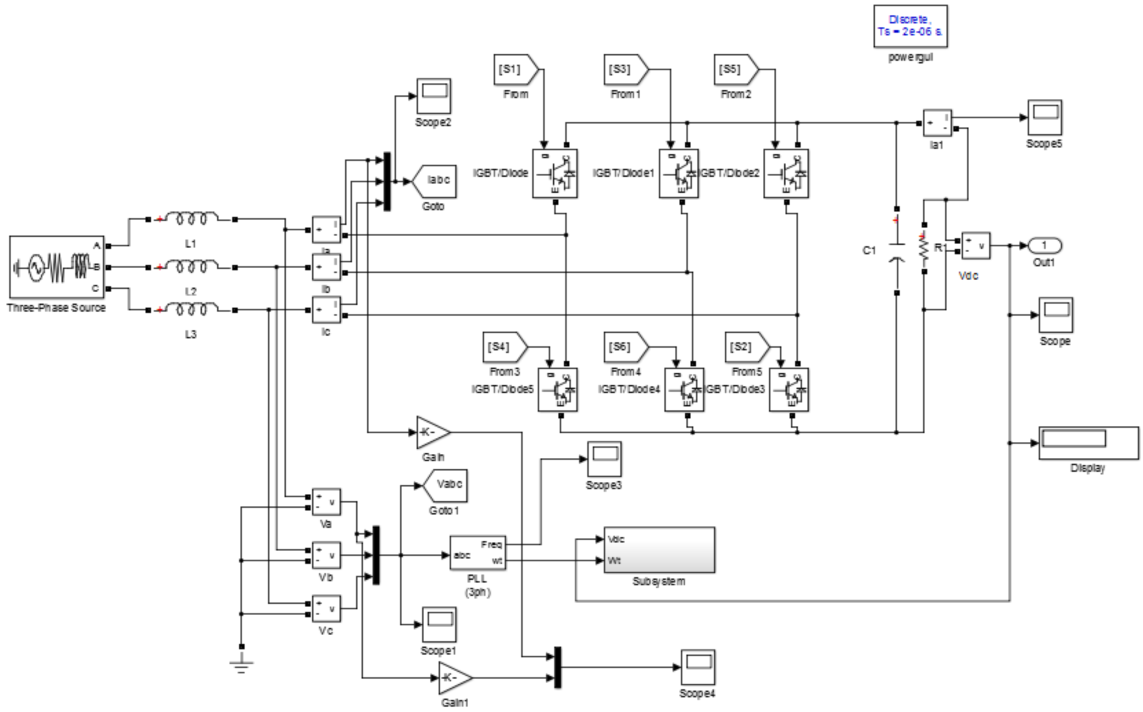
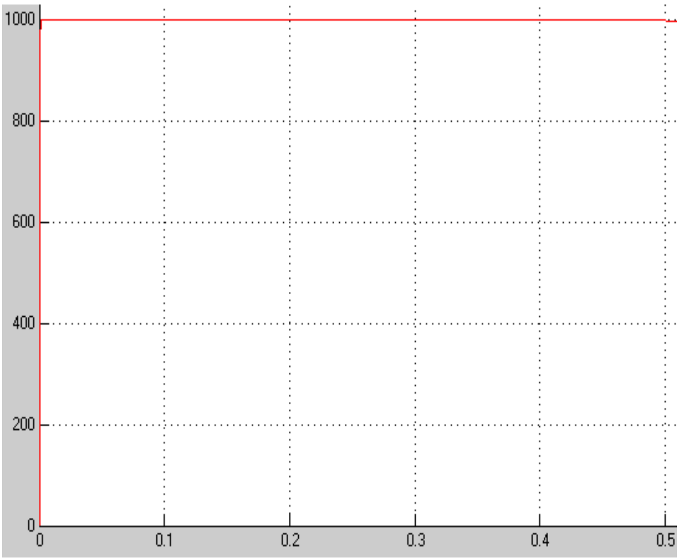
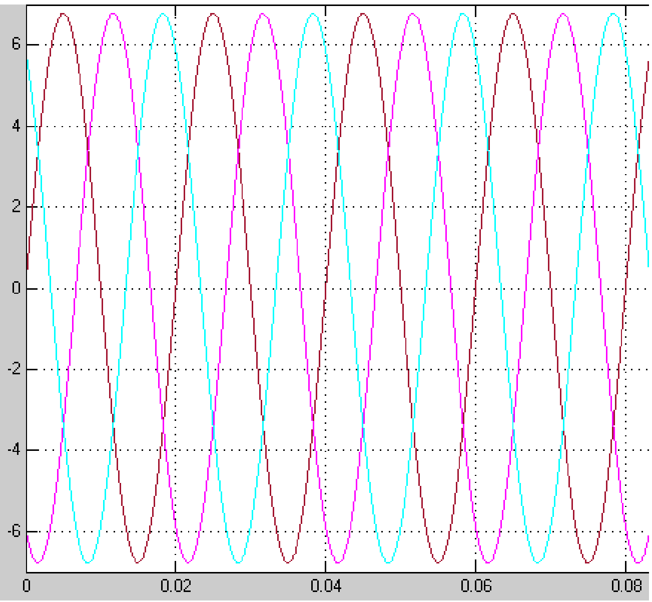


Fig 5. The simulation model

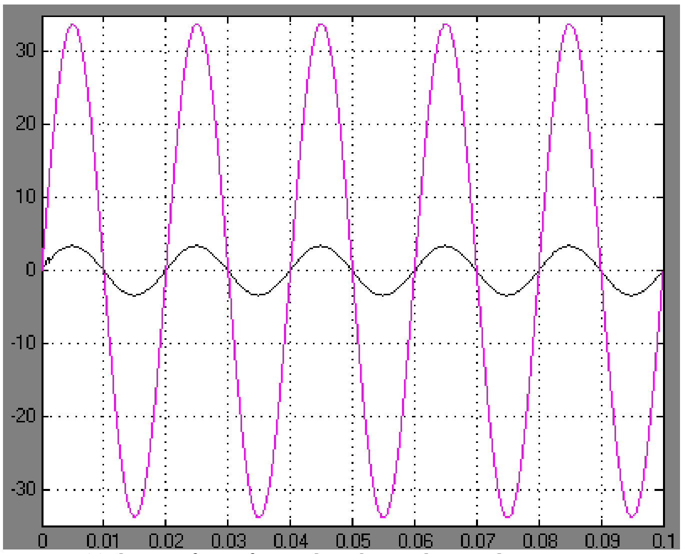
Simulation was conducted to demonstrate the performance of the proposed control strategy. Fig 6 consistsof the simulation results. Fig 6(a) shows the DC output voltage and fig 6 (b) demonstrate the line current and fig 6 (c) shows the power actor of the system.



(a) The waveform of DC side voltage



(b)) The waveform of AC side line current



(c)The waveform of AC side a phase voltage and current (Power Factor)

Figure 6. (a) The waveform of DC side voltage. (b) The waveform of AC side line current (c).The waveform of AC side a phase voltage current (power factor)

VI.CONCLUSION

In this paper, the mathematical model of three-phase voltage-source PWM rectifier is analyzed. Then based on the idea of the feed-forward decoupling control, the method of the voltage current double closed loop control is adapted. The system with PWM rectifier is simulated in the MATLAB /SIMULINK environment. The simulation and test results have shown that the system based on feed forward decoupling control has high dynamic and steady-state performance.

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