SIMULATION OF THREE-PHASE ACTIVE FRONT END RECTIFIER BASED ON SPACE VECTOR PWM

Dhairya Purohit [1], Ruchita Koshti [2], prof. Nirav D. Mehta[3]

Department of Power Electronics (GTU)

Vishwakarma Government Engineering College

E-mail: [1] dhairyapurohit@gmail.com, [2]ruchitakoshti@gmail.com , [3]mehta_nirav1@gtu.edu.in

***Abstract* – This paper presents the simulation of three-phase Active Front-End Rectifier (AFE) using Space Vector Pulse Width Modulation (SVPWM). AFE Rectifier is also known as PWM rectifier. Conventional voltage source PWM rectifier use the Sinusoidal Pulse Width Modulation (SPWM), and the SPWM control waveform can be obtained by comparison of carrier wave and modulation wave. However, the utilization ratio of the DC voltage is low. This paper proposes the SVPWM control scheme for three-phase voltage source (VS) PWM rectifier, which is based on its model in synchronous reference frame. The DC bus voltage and power factor can be regulated with high performance. This paper presents the MATLAB/SIMULINK simulation model. Compared with the conventional SPWM method, the simulation results show that this method gives better dynamic performance of the system.**

***Key Words- AFE,* SPWM, PWM rectifier, SVPWM, power factor**

I. INTRODUCTION

According to the international standards such as IEEE519, the modern rectifiers are required to limit the current harmonics and to implement the power factor correction. The standard diode/thyristor bridge rectifier at the Front End side cause several problems such as: low input power factor, high values of harmonic distortion of ac line currents. The PWM/AFE rectifier is a preferred choice because it can provide a DC voltage source for DC loads, voltage source fed drives, as it is capable of input power factor regulation, line current harmonic mitigation, bi-directional power flow and dc voltage control [1].

Different types of control techniques are adopted for these rectification devices, which can improve input power factor and provide sinusoidal input current waveform.

There are many different PWM modulation techniques such as sinusoidal PWM, SVPWM, delta modulation, Third-harmonic PWM. Implementation of SPWM is easy compare to SVPWM scheme, SPWM might not capable of providing expected results. It has been analyzed theoretically and proved that the SVPWM technique is maybe the best modulation solution.

SVPWM method has become one of the most important PWM methods for three-phase converters. It is the best way to suppress harmonics, it can achieve 15%more fundamental component from output voltage. Implementation of SVPWM becomes easy because of development of DSP.

This paper presents the both design and simulation model of a three-phase VS-PWM rectifier with SVPWM scheme and having rating of 8kW. Simulation results are provided to validate the drawn conclusions.

II. MATHEMATICAL MODEL OF PWM RECTIFIER

The circuit diagram of the three-phase voltage source PWM/AFE rectifier is shown in figure 1. In this model it is assumed that the AC voltage is a balanced three-phase supply, the filter reactor is linear, IGBT is ideal switch and lossless [3].

Where V_a, V_b and V_c are three phase voltages of the three phase balanced source, and ia, i_b and i_c are phase currents, v_{dc} is the DC output voltage, R and L mean resistance and inductance of the filter reactor respectively, C is smoothing capacitor across the DC bus, R_L is DC side load, V_{ra}, V_{rb}, and V_{rc} are the input voltages of rectifier, and i_L load current.

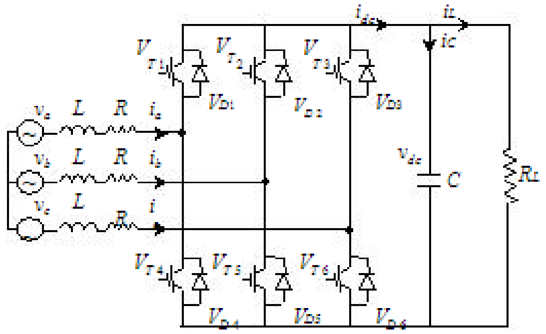

Figure 1. Circuit schematic of three-phase voltage source PWM rectifier.

The voltage equations are given by:

$$\begin{cases} V_a = L\frac{\mathrm{di_a}}{\mathrm{dt}} + Ri_a + V_{ra} \\ V_b = L\frac{\mathrm{di_b}}{\mathrm{dt}} + Ri_b + V_{rb} \\ V_c = L\frac{\mathrm{di_c}}{dt} + Ri_c + V_{rc} \end{cases} \quad (1)$$

And source phase voltage is expressed as

$$\begin{cases} V_a = V_M \sin\theta \\ V_b = V_M \sin(\theta\text{-} 2\pi/3) \\ V_c = V_M \sin(\theta\text{-} 4\pi/3) \end{cases} \quad (2)$$

Using he park coordinate transform [5],

$$\mathrm{P}= \frac{2}{3}\begin{bmatrix} \cos\theta & \cos(\theta-2\pi/3) & \cos(\theta+2\pi/3) \\ \sin\theta & \sin(\theta-2\pi/3) & \sin(\theta+2\pi/3) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \quad (3)$$

The dynamical behavior of the boost type rectifier can be expressed as:

$$\begin{aligned} L\frac{di_d}{dt} &= u_d - i_dR + \omega Liq - u_{rd} \\ L\frac{di_q}{dt} &= u_q - i_qR - \omega Lid - u_{rq} \\ C\frac{dV_{dc}}{dt} &= -\frac{V_{dc}}{\mathrm{Rl}} + \frac{3}{2}(S_di_d+S_qi_q) \end{aligned} \quad (4)$$

Where, $u_{rd}= S_dV_{dc}$, $u_{rq} = S_q V_{dc}$, u_{rd} ,u_{rq}, and S_d , S_q are input voltage of rectifier, switch function in synchronous rotating d-q coordinate, respectively. u_d, u_q and i_d, i_q are voltage source, current in synchronous rotating d-q coordinate, respectively. ω is angular frequency.

Equation (4) shows that the d-q current is related with both coupling voltages ωLiq and ωLid and main voltages u_d and u_q, Besides the influence of u_{rd} and u_{rq} . u_{rd} and u_{rq} in the equation (4) can be regulated to ensure the correctness of equation(5).

$$\begin{cases} u_{rd} = - u'_{rd} + \omega Liq + u_d \\ u_{rq} = - u'_{rq} + \omega Liq + u_q \end{cases} \quad (5)$$

Putting equation (5) into equation (4), equation (6) can be acquired.

$$\begin{cases} L\frac{di_d}{dt} = -i_dR + u'_d \\ L\frac{di_q}{dt} = - i_qR + u'_q \end{cases} \quad (6)$$

We can see from equation that the two axis current are totally decoupled. u'_{rd} and u'_{rq} are only related with i_d and i_q respectively. The simple proportional-integral (PI) controller are adopted in the current and voltage regulation. Figure.2 displays the double closed-loop control system, which fulfils the current decoupling of the PWM rectifier [1].

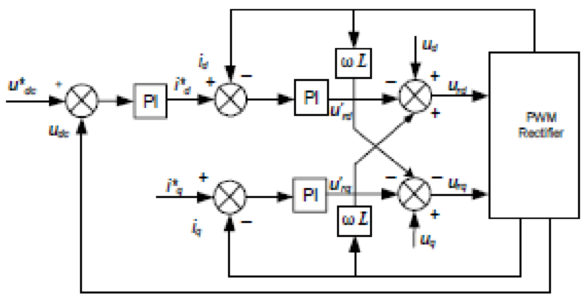

Figure2. Control block diagram of d-q dual-close-loop controller of the rectifier

Figure.2 shows that the process of decoupling is a course that each of PI regulated axis current result is injected with the other axis current components. When the u_{rd} and u_{rq} acquired, the SVPWM method is realized through d-q to α-β transformation to trace the AC current command exactly and regulate the DC bus voltage

III. SPACE-VECTOR PWM

The switch function is defined by

$$SW_i = \begin{cases} 1, \text{ the upper switch } SWi_{+} \text{ is on and the bottom switch } SW_{i-} \text{ is off} \\ 0, \text{ the upper switch } SWi_{+} \text{ is off and the bottom switch } SW_{i-} \text{ is on} \end{cases}$$

Where i= a, b, c;

There are 8 switch states $S_i = (SW_a, SW_b, SW_c)$, i=0, 1,…, 7. Defines 8voltage vector $\vec{V}_0$=[0,0,0]…$\vec{V}_7$ =[1,1,1].corresponding to switching state $\vec{S}_0$, … , $\vec{S}_7$respectively. The length of vectors$\vec{V}_1$, …, $\vec{V}_6$are unity and the length of $\vec{V}_0$and $\vec{V}_7$are zero and 8 vectors forms voltage-vector space as displayed in figure 3. The voltage vector space is divided up into 6 sectors [6].

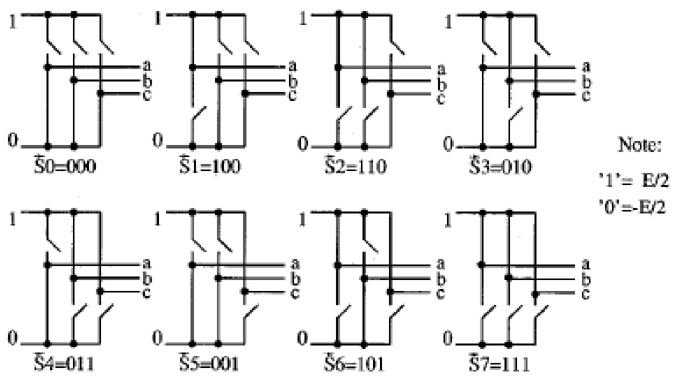

Figure 3(a). Switching states in each sector of space vector

From principle of equivalence

$$\vec{V}_1 = -\vec{V}_4$$
$$\vec{V}_2 = -\vec{V}_5$$
$$\vec{V}_3 = -\vec{V}_6$$
$$\vec{V}_0 = \vec{V}_7 = \vec{0}$$
$$\vec{V}_1+\vec{V}_3+\vec{V}_5 = \vec{0} \quad (7)$$

In one sampling interval, the output voltage vector $\vec{V}$ can be written as

$$\vec{V}(t)= \frac{t0}{Ts}\vec{V}_0 + \frac{t1}{Ts}\vec{V}_1 + \ldots + \frac{t7}{Ts}\vec{V}_7 \quad (8)$$

Where t_o, t_1,…, t7 are the turn-on time of the vectors $\overrightarrow{V1}$,…$\overrightarrow{V7}$; t_o, t_1,… ,$t_7 \geq 0$; $\sum_{i=0}^{7} ti = T_s$ is the sampling time.

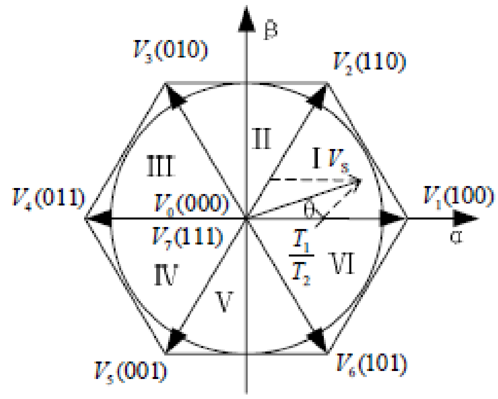

Figure 3 (b). Voltage vector space in SVPWM

IV. SPACE VECTOR SYNTHESIZATION

Depending on the switching state on the circuit.figure1, the bridge rectifier leg voltages can assume 8 possible distinct states, represented as voltage vectors (V_0 to V_7) in the $\alpha - \beta$ coordinate. All the vectors are shown in the figure 3.

There are many different methods of modulation to synthesize V_s according to different combinations of eight vectors. Among these methods, the two-phase modulation can make switching loss minimize, in which one switch should be always set ON or OFF in one working cycle. The desired reference vector is sampled in every sub-cycle T_s and realized by time averaging the three nearest space vectors in the space vector plane [4]. For example, the reference vector shown in figure 3 with magnitude V_s and angle θ in sector 1 is realized by applying the active vector 1, the active vector 2 and the zero vector. The durations T_1, T_2, and T_z of the three space vectors, respectively is calculated as:

$$\begin{cases} T_1 = \frac{T}{2Vdc}(3V_{s\alpha} - \sqrt{3}\, V_{s\beta}) \\ T_2 = \sqrt{3}\frac{T}{Vdc} V_{s\beta} \\ T_0 = T_s - T_1 - T_2 \end{cases} \quad (9)$$

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The vectors for other sectors can be synthesized similarly. The expressions which are developed on the universal variables X, Y, Z are shown following:

$$\begin{cases} X = \sqrt{3}\frac{T}{V_{dc}} V_{s\beta} \\ Y = \frac{\sqrt{3}}{2}\frac{T}{V_{dc}} V_{s\beta} + \frac{3}{2}\frac{T}{V_{dc}} V_{s\alpha} \\ Z = \frac{\sqrt{3}}{2}\frac{T}{V_{dc}} V_{s\beta} + \frac{3}{2}\frac{T}{V_{dc}} V_{s\alpha} \end{cases} \quad (10)$$

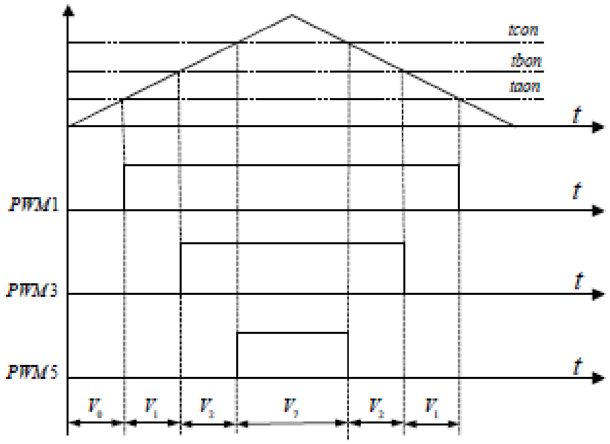

Figure 4 conventional and switching sequences in sector

In order to get situations of the synthetic V_s. Sector can be identified by simple logic;

If $\theta \geq 0$ or $\theta < 60$
Sector = 1
Else if $\theta \geq 0$ or $\theta < 120$
Sector = 2
Else if $\theta \geq 120$ or $\theta < 180$
Sector = 3
Else if $\theta \geq 180$ or $\theta < 240$
Sector = 4
Else if $\theta \geq 240$ or $\theta < 300$
Sector = 5
Else Sector=6

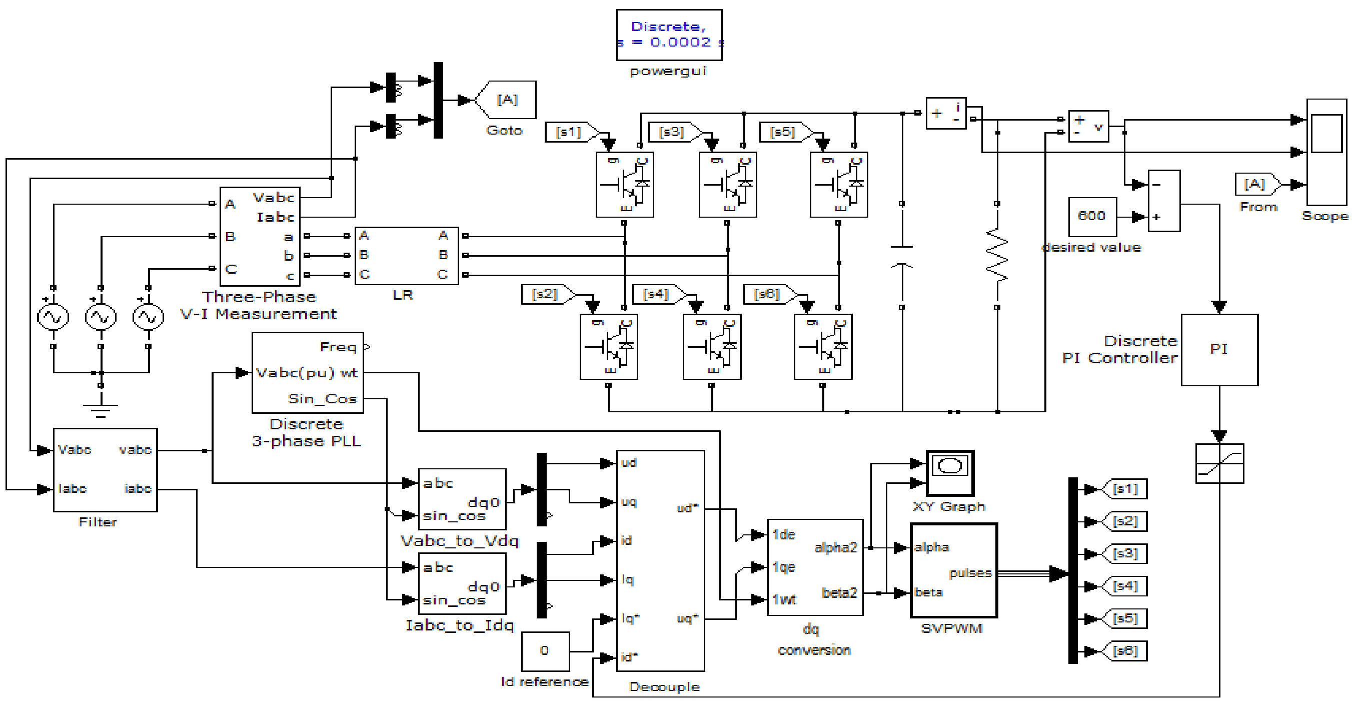

Figure 5 Three-phase Active Front End Rectifier simulation model

V. SIMULATION RESULTS

The simulation model is built using MATLAB/SIMULINK to test the performance of VSC described by the proposed model. The whole system behaviour is simulated as a discrete control system. The simulation model is shown in figure 5. The actual rectifier is shown at the top of the model in figure 5. In the circuits, the ac source is three-single phase voltage source with frequency of 50HZ. The phase to phase voltage is 380V. The line resister of each phase is 1Ω. The line inductance of each phase is 5mH. The output capacitor is 4700μF. In steady state, the DC voltage is set to be 600V. The switching frequency is 10 kHz.

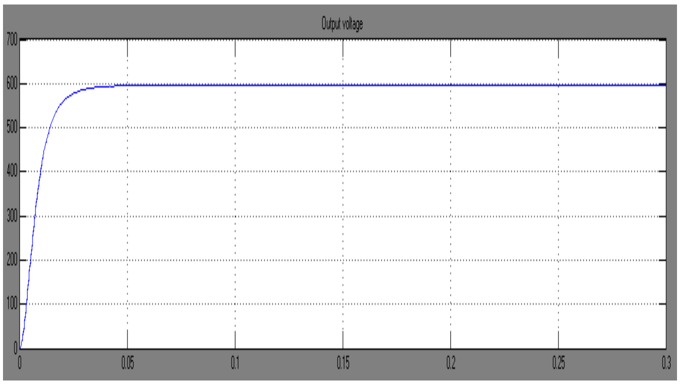

Figure 6 DC link voltage

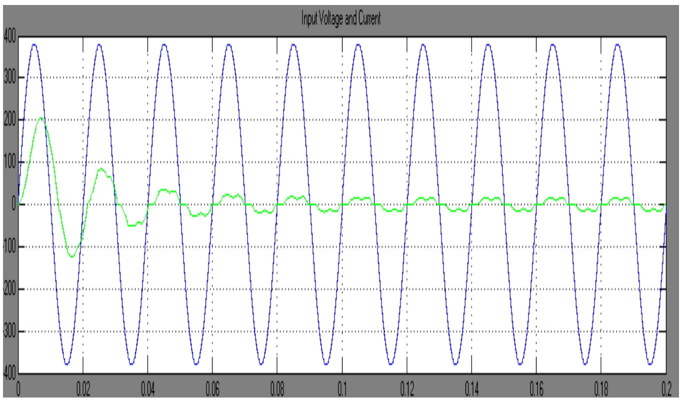

Figure 7 Input voltage and current

The above two figures summarize the results of the simulation. The DC output voltage is shown in figure 6 and the input voltage & input current are shown in figure 7.In this simulation, during starting the DC bus voltage rests at diode rectifier level and then control action is applied, by which the output voltage increases to the desired DC value. Figure 7 show the voltage and current on line side and current of wave is the same phase with the voltage.

VI. CONCLUSION

This model represents SVPWM based pwm rectifier. By using nonlinear input transformation, the conventional nonlinear models can be improved to linear models. Decoupled feed-forward controller for 3-phase voltage source pwm rectifier is designed in the paper. The control system based on SVPWM includes two PI controllers which are used to regulate the AC current and an outer DC voltage loop. The simulation results shows a good performance, providing a good regulation of dc voltage, unity power factor and the line current Waveshape is not purely sinusoidal .

VII. REFERENCES

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