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Simulation of Three Phase AC - DC Front End Converter with Vector Control

Mital Bhut[1], Kunjan Bhanderi[2]

[1]Department of electrical engineering, RK university, Rajkot, mital.bhut@gmail.com
[2]Department of electrical engineering, HJD Institute of Technical Education and Research, kunju.2013@yahoo.co.in

Abstract-- Active front end converter with vector control method in 3-phase AC/DC converter with bi-direction power flow capability. A control topology use for Boost converter with high power factor, sinusoidal input current and adjustable dc output voltage. PI controller is adopted to regulate the converter output voltage. Simulation and experiment results are also presented.

Keywords- AC-DC Conversion, PWM rectifier, Front end converter, Synchronous references frame control, Vector control.

I. INTRODUCTION

Three phase ac/dc converter is used in many power electronics system such as in Uninterruption power Supplies, battery charges and motor drive. Active rectifier is more used in industrial application because it has many advantages including unity power factor, low ripple of the dc voltage and low total harmonics distortion.

Generally diode rectifiers are used for ac-dc conversion. These rectifiers can only produce a constant dc voltage and Thyristor rectifier can be used to produce variable output voltage. Both rectifiers behave as nonlinear loads. Figure-1 represents Single-phase rectifier load. This is true for a three phase system.

This paper is includes the simulation model of 3-phase vector controlled voltage source PWM rectifier. FEC is used with stationary reference frame conversion of vector control theory. A simplified block diagram is proposed for vector control of Front end converter. PI controller is also used in this paper.

1.1 Basic block diagram of FEC with vector control

The Va, Vb, Vc are the supply voltage of 3-ϕ phases as shown in figure 1. Three phase wires are connected to grid side which is called as front end converter. [6]

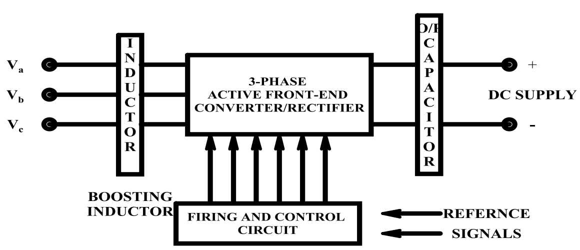


Figure 1. Basic block diagram

In figure, the line inductances are connected on the line side and capacitors on the connected to load side. The dc output is available at output side

1.2 Power topology

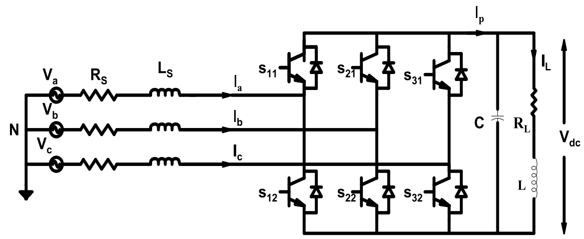


Figure 2. FEC with vector control system

Power circuit of three phase converter as show in figure 2 where, V_a, V_b, V_c are the input ac-side voltage, I_a, I_b, I_c are phase currents , r_a, r_b, r_c are per phase resistance, L_a, L_b, L_c are inductance per phase , S_{11},S_{21},S_{31},S_{12},S_{22},S_{32} are functional switches. In this figure power can flow in both directions.[2][3][11]

II. VECTOR CONTROL OF FEC IN STATIONARY REFERENCE FRAME

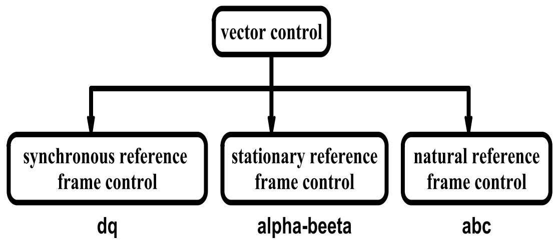


Figure 3 Classification of grid side converter control strategies

In this figure, d-q reference frame theory is used from which we can control the current. By using stationary reference frame, we can control the current as AC quantities and by using natural reference frame; we can control the current as AC quantities,

III. MATHEMATICAL MODEL

The circuit diagram of the 3-phase voltage source rectifier structure is shown in figure 4. It is assumed that the three phase AC voltage is a balanced and IGBT is ideal Power switch and loss less. The three phase grid voltage are Va, Vb, Vc are defined as, [14]

$$V_a = V_m \cos(\omega t) \quad \text{.................................(1)}$$

$$V_b = V_m \cos(\omega t - 120) \quad \text{.........................(2)}$$

$$V_c = V_m \cos(\omega t - 240) \quad \text{..........................(3)}$$

Where, Vm is the maximum value of the phase voltage. Transforming these 3-phase voltage into 2-phase stationary reference frame (α-β reference frame) [10]

$$V_\alpha = \frac{3}{2} V_a \quad \text{..(4)}$$

$$V_\alpha = \frac{3}{2}\sqrt{2}Vm\cos(\omega t) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

$$V_\beta = \frac{\sqrt{3}}{2}(V_b - V_c) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$V_\beta = \frac{3}{2}\sqrt{2}Vm\sin(\omega t) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

The voltage can be transformed into a synchronously revolving d-q reference frame, where d-axis and q-axis are aligned 90^0 shown in figure 4. Where θ is angle of the d-axis measured from α-axis. Three phase ia ,ib, ic are current of grid side. d-q reference frame equation is given as below,[1]

$$V_d = V_\alpha\cos\theta + V_\beta\sin\theta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

$$V_q = V_\beta\cos\theta - V_\alpha\sin\theta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

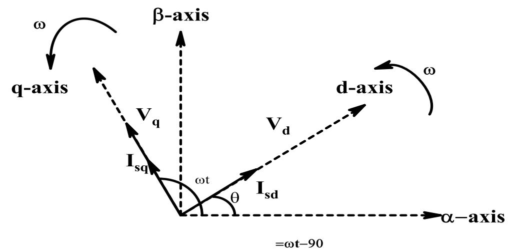


Figure 4 Vector Diagram

The voltage equations of front end converter for d-q rotating reference frame are given. Rs and Ls are resistance and inductance respectively. [7]

$$R_s i_{sd} + L_s\frac{di_{sd}}{dt} - \omega L_s i_{sd} + V_{id} = 0 \quad \ldots\ldots\ldots\ldots (10)$$

$$R_s i_{sq} + L_s\frac{di_{sq}}{dt} - \omega L_s i_{sq} + V_{iq} = 0 \quad \ldots\ldots\ldots\ldots (11)$$

IV. PRINCIPAL OF OPERATION

Phase diagram of an FEC under different operating as shown in figure 5.

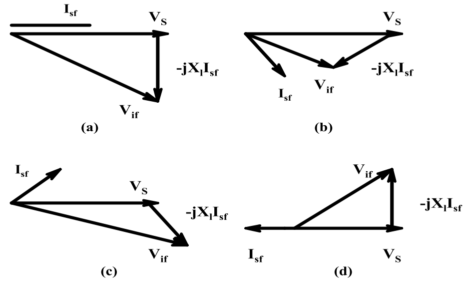


Figure 5. Phasor diagram of an FEC different operating modes (a) unity power factor (b) lagging power factor (c) leading power factor (d) regeneration at unity power factor

V. UNIT VECTOR GENERATION

Any vector can transform stationary reference frame into d-q reference frame, the quantities sinθ and cosθ, which are the component of revolving unit vector.

The voltage vector Vs is at an angle ωt with respect to the α-axis, V_c=0 unit vector generations shown in figure 6.Here V_c is voltage of phase c [08].

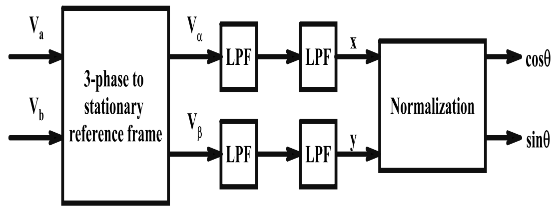


Figure 6 Unit vector generation

In figure shows the three phase supply to two phase conversion. Low pass filter, whose corner frequency equals the mains frequency and phase delay 45^0 two such filter in cascade delay by 90^0 as shown in figure. Such filter and normalization cos and sin. And θ is angle between α-axis and d-axis. [5][10]

$$\cos\theta=\frac{x}{\sqrt{x^2+y^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(12)}$$

$$\sin\theta=\frac{y}{\sqrt{x^2+y^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(13)}$$

Grid frequency remains unchanged at 50 Hz and grid voltage is balanced. The unit vector can be expressed as

$$V=V_\alpha+jV_\beta \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(14)}$$

$$V = \cos\theta + \sin\theta \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(15)}$$

$$V=\frac{x}{\sqrt{x^2+y^2}}+j\frac{y}{\sqrt{x^2+y^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(16)}$$

$$V=1,\ \angle V=\tan^{-1}\left(\frac{y}{x}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(17)}$$

Unit vector generated in magnitude is equal to one. The phase angle of the unit vector, which must be equal to ωt, does not change linearly with under steady state due to voltage imbalance. [13]

VI. VECTOR CONTROL APPROACH

Vector control overall block diagram as show in figure

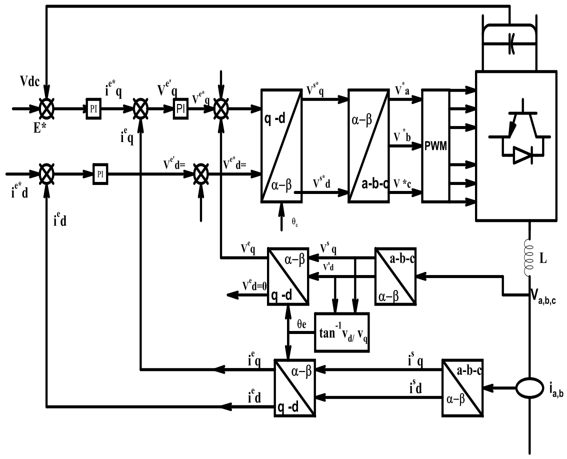


Figure 7 Block diagram vector control of front end convertor

In this paper mainly stationary reference frame theory is used. But comparison purpose d-q control is also used. [12]

In vector control is presents 3 loops:

1. DC-bus voltage
2. Active current control loop
3. Reactive current control loop

The vector control objective are given as

- Voltage regulation of dc link voltage.
- Independent active end reactive power control.
- Bidirectional power flow.
- Operation at any desired power factor.
- Low current harmonic.

VII. TRANSFORM FUNCTION OF 3-PHASE TO 2-PHASE

7.1 Clarke transform

In Clarke Transform, the first transformation is to move from a 3-axis 2-dimensional coordinate system referenced to the stator and a 2-axis system is also referenced to the stator.[1]

7.2 Park transform

At this point, the stator current phasor represented on a 2-axis orthogonal system with the axis called α-β. The next step is to transform into another 2-axis system, which is rotating with the rotor flux by using the Park Transform. From this perspective, the components of the current phasor in the d-q coordinate system are time invariant. Under steady state conditions, the outputs in the DC form. The stator current component along the d-axis is proportional to the rotor torque and the component along q-axis proportional to the rotor torque [1].

7.3 Inverse park transform

The outputs of the control loop have two voltage component vectors in the rotating d-q axis. Need to go through complementary inverse transforms to get again 3-phase voltage. First need to transform the 2-axis rotating d-q frame to the 2-axis stationary frame α-β. This is done by using Inverse Park Transformation.

VIII. SIMULATION AND RESULTS

The vector control of Front end converter simulation is done in MATLAB/SIMULINK. The triangle PWM method is employed with a carrier frequency of 5-KHz. Power circuit model and control circuit model simulation are given as below.[4][8]

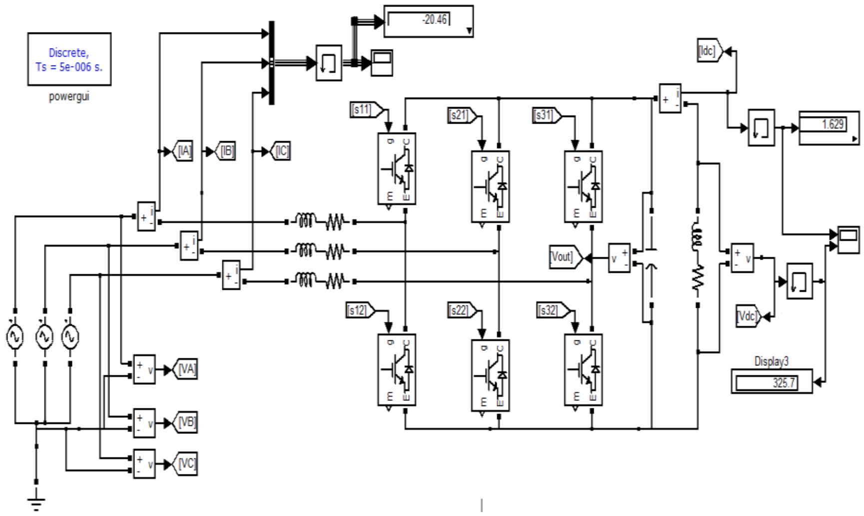


Figure 8 PWM rectifier

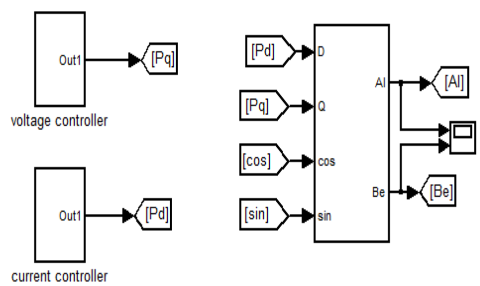


Figure 9 PI controller

PI controller in Ki and Kp value of voltage controller Kp=0.8,Ki=0.005and current controller [12] Kp=0.12,Ki=0.009.

8.1 Voltage controller

Three phase voltage Va, Vb, Vc are converted into two phase voltage Vd and Vq (as shown in Figure 10).

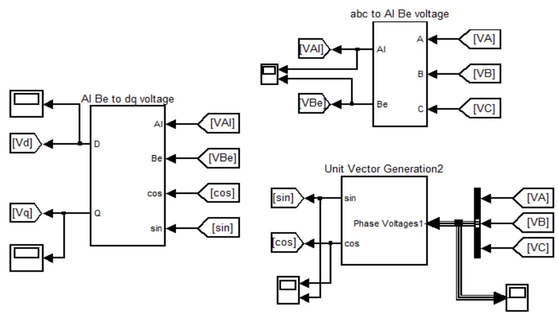


Figure 10 voltage control

8.2 Current controller

In this simulation model is used to three phase current to two (Id, Iq) phase current conversion.

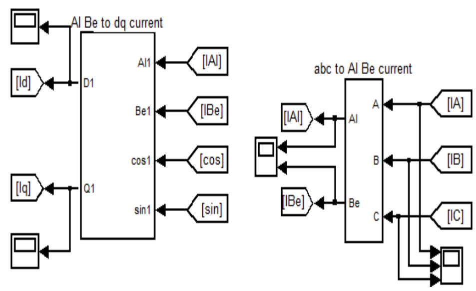


Figure 11 current control

IX. RESULTS

The waveform of three phase voltage as given below.

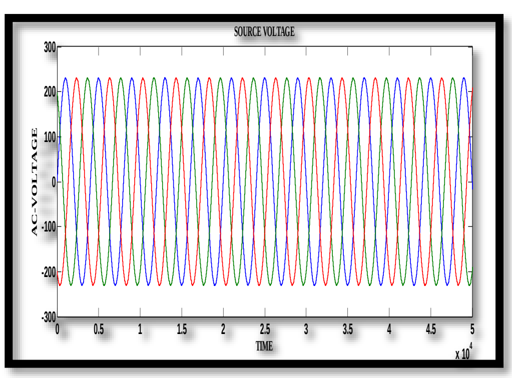


Figure 12 Input voltage

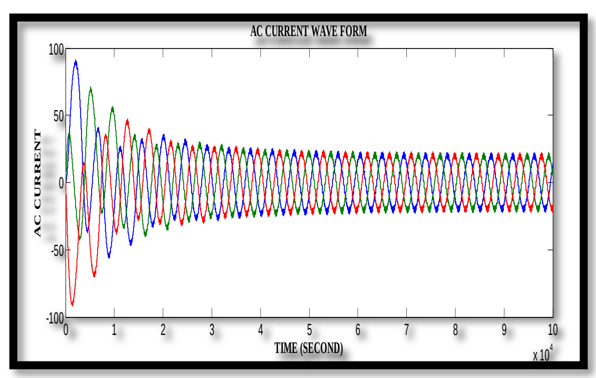


Figure 13 Sinusoidal source current

Figure 11.3 Shows the DC waveform of 325V Output voltage.

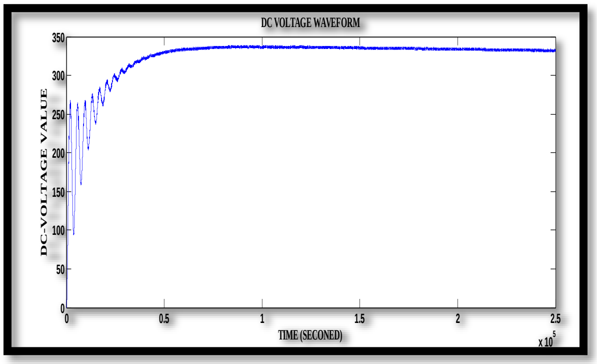


Figure 14 Output voltage

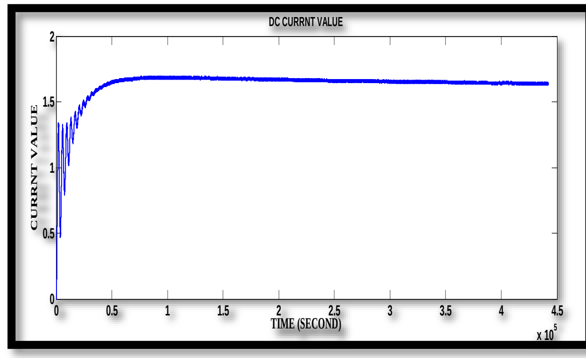


Figure 15 output dc current

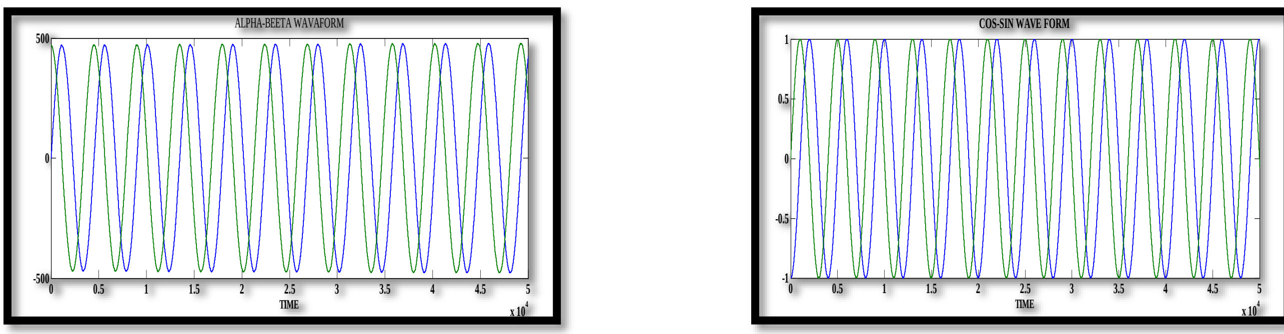
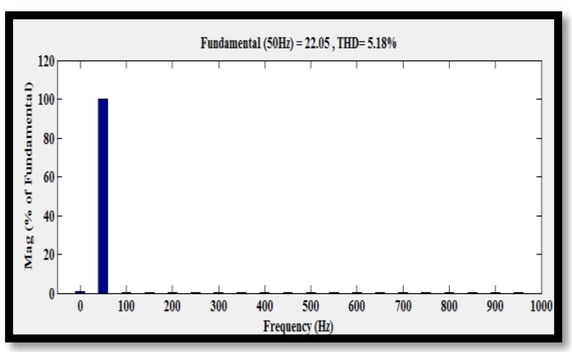


Figure 16 Voltage controller and current controller in abc to αβ and cos-sin waveform.

The waveforms of cos and sin generated by using Unit vector is given as below.

Below figure shows the source current of THD of a,b,c phase.



The THD value of b phase is 5.18%

Figure 17 Source current of THD of phase b

X. CONCLUSION

A converter system is operating for the single phase supply and three phase supply in ac-dc converter. In this paper 3-phase ac to dc converter is used and vector control strategy applies. The steady-state design considerations of front end converter have been discussed. The block diagram of vector control for rotating as well as stationary reference frame has been developed. Satisfactory results are obtained by implementing the block diagram of Vector control in MATLAB/SIMULATIONS. As shown in result, Ac link current is sinusoidal and proper dc link voltage at output side.

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