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Voltage Oriented Control of Two Level and Three Level Neutral Point Clamped PWM Rectifiers

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***Abstract*—Pulse Width Modulated (PWM) Rectifiers are very popular for ac to dc conversion needs of the industry and utility grid. These converters support bidirectional power transfer, and act as boost rectifier with nearly unity power factor current drawn from the grid as well as provide controlled output dc voltage that is free of ripples at the dc side. To achieve this, a closed loop controlled converter is required. The objectives of any control technique is to regulate dc side voltage to achieve a near unity power factor (UPF), and to realize faster dynamic response to supply and load variations.Voltage Oriented Control (VOC) is one such technique that provides good dynamic response. In this paper, VOC of the conventional three phase two level PWM rectifier and three level Neutral Point Clamped(NPC) rectifier with Space Vector Pulse Width Modulation(SVPWM) technique is discussed.The paper aims at simulation and analysis of VOC based conventional three phase rectifier and three level NPC rectifier. The simulation is carried out using MATLAB/Simulink. The FFT analysis of each converter is compared with respect to the Total Harmonic Content in input current.**

***Index Terms*— Neutral Point Clamped (NPC)converter, Pulse Width Modulated(PWM) rectifier, Space vector modulation(SVM), Voltage oriented control(VOC).**

I. INTRODUCTION

Various configurations of three-phase Pulse Width Modulated (PWM) rectifiers are in use for industrial applications, which need substantial amount of power. These converters draw nonlinear current that is non-sinusoidal, and they also draw reactive power that lead to reduction in power factor and distortion of the line voltage [1].Three phase PWM rectifiers are the most hopeful solutions as they possess merits such as near sinusoidal current with reduced harmonics at the input and also supports bidirectional transfer of power [2].Many control strategies for PWM converters are reported in the literature which mainly aims to have lesser harmonic content in the current and that can provide accurate control of power [3-4].Depending on the working principle, they can be classified into two categories: strategies that use voltage and strategies that use virtual-flux for control of power [5] - [9].Each strategy can be further classified as Voltage Oriented Control(VOC) and Direct Power Control(DPC). The Direct Power Control (DPC) strategy uses a switching table that eliminates the need of PWM section as well as inner control loop. The input for this switching table is the error between reference and the measured values of DC link voltage[6-7],[10],[12].However, DPC technique is highly sensitive to inductance variation, hence wrong choice of inductance values will lead to increase of THD or uncontrolled operation. The other disadvantage is that, the computational intensity and processor load per sampling cycleis very high and hence faster DSP is required. In case of VOC technique, the inductance variation does not affect

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PWM operation. In addition, low sampling frequency that is less than 5kHz is used; hence cheaper ADC can be used for implementation. Many disadvantages of DPC method can be overcome by VOC technique.

The Voltage Oriented Control is an indirect power control method and is originated from the popular Field Oriented Control used for the control of Induction Machines. This technique offers good static and dynamic performance as it uses high quality inner current loop for the control. The current control is performed on dc currents that are sensed by rotating reference frame transformations of three phase quantities. In this method, the voltage reference at which the dc bus voltage has to be regulated is calculated from currents sensed from the grid in rotating synchronous d-q reference plane. The direct axis current component is controlled as per the real power demand and the quadrature axis current component is used for reactive power control. The pulse width modulation techniques used to generate the required references also decide the performance of the converter.

There are different PWM generation techniques such as Sinusoidal PWM (SPWM), third harmonic PWM (THIPWM), Bus clamping PWM (BCPWM), Space Vector PWM (SVPWM) techniques etc. that can be used for pulse generation. Among the available techniques, the SVPWM scheme is superior in performance as it possesses better dc link utilisation, reduced input current harmonics and reduced ripple in the output voltage. In the available literature, SVPWM based rectifiers that implement VOC technique are not discussed in detail for dynamic conditions. In this paper, simulation of VOC based conventional three phase PWM rectifiers and three level NPC PWM rectifiers is carried out and the dynamic performance is analysed for dynamic load conditions. For pulse generation, SVPWM technique is used for both types of controllers.

II. Simulation Model of Two and Three Level Converters

In this section, the simulation models and the corresponding mathematical equations for both types of converters are discussed.

A.Conventional two level PWM rectifier

This section discusses modelling and corresponding equation of the conventional Two level rectifier. Fig. 1 shows the basic three-phase PWM rectifier topology that is considered for the analysis. The per phase circuit equivalent of the converter is shown in Fig. 2 and the phasor diagram is shown in Fig. 3 [13]. The equations are derived using space vector transformations as shown below.

$$V^s = Ri^s + L\frac{d(i^s)}{dt} + V_R^s \qquad (1)$$

Where as $V^s = V_\alpha + V_\beta$ (2)

$$V_{dq} = V^s e^{j\theta} \qquad (3)$$

Substituting equation (3) in (1)

$$i_{dq} = i_d + ji_q \quad ; \quad V_{dq} = V_d + V_q \qquad (4)$$

It can be shown that,

$$V_d = Ri_d + L\frac{d(i_d)}{dt} - j\omega Li_q + V_{Rd} \qquad (5)$$

$$V_q = Ri_q + L\frac{d(i_q)}{dt} + j\omega Li_d + V_{Rq} \qquad (6)$$

Where, V^S, V^R are space vectors of source voltage and receiving end voltage respectively; V_α, V_β are the two phase transformation of source voltage space vector; V_d, V_q are the direct and quadrature axis components of source voltage space vector; R, L are the source resistance and inductance of source; i_d, i_q are the direct and quadrature axis components of line current.

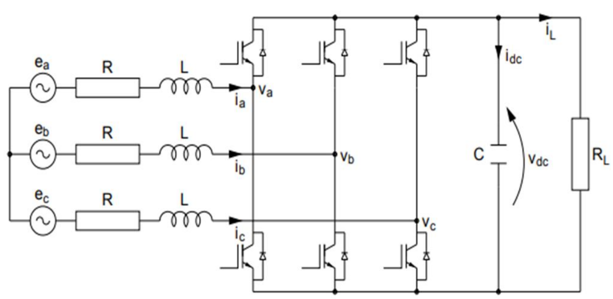

Figure 1. Conventional three-phase 2 level PWM rectifier configuration

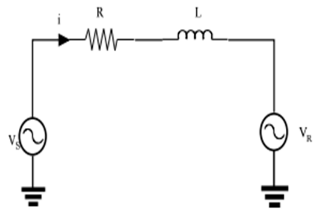

Figure 2. Equivalent circuit of per phase for the three-phase converter

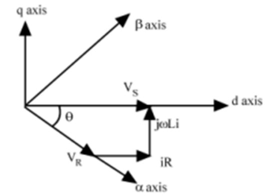

Figure 3. Vector diagram of converter operation

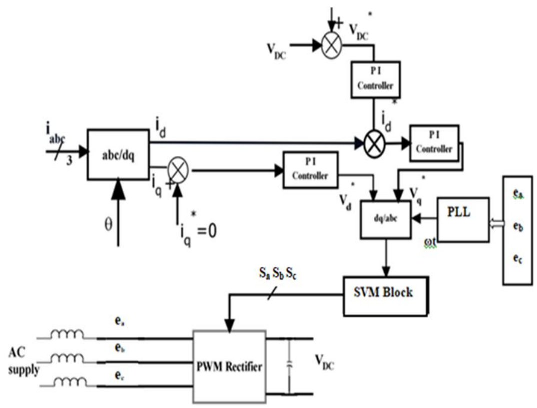

Figure 4. Block diagram of VOC for PWM rectifier

From equations (5) and (6), the voltage references in d-q reference plane can be obtained. The implementation of the same is shown in Fig.4. It is observed from the Figure that, the grid phase voltages, ea, eb and ec are measured to derive ωt using PLL block, which is necessary to carry out Park and inverse Park transformations. The three phase input current is measured and converted to the corresponding d and q components. id component is compared with the reference d component i_d^*, which is the output of the dc voltage controller. Fig. 5 shows the dc voltage controller block. The quadrature component of the current is compared with iq*, which is set to zero in this work to achieve unity power factor. The resulting errors are then sent to PI controllers as shown in Fig 4.that produce reference voltages vd * and vq * which are further used to generate the switching signals.. Then the switching signals Sa , Sb, and Sc for rectifier phases are produced by space vector modulation (SVM) block, as presented in the Fig.4.

As shown in Fig.5the error dc voltage is used to regulate the dc voltage fixed at a reference value. The current I from the output of the voltage controller ,is expressed as below

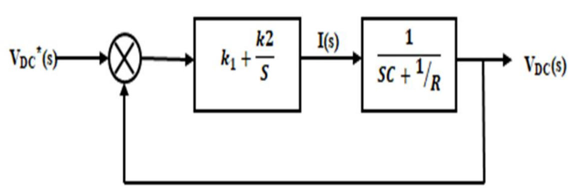

Figure 5. PI controller for DC link voltage

$$i = k_1 \Delta V_{dc} + \int k_2 \, \Delta V_{dc} dt \qquad (7)$$

Here, k_1 is a proportional gain and k_2 is an integral gain

The transfer function of the controller is given by equation (10).

$$\frac{V_{dc}(s)}{V_{dc}^*(s)} = \frac{k_1 R(s + \frac{k_2}{k_1})}{s^2 + 2\xi\omega_n s + \omega_n^2} \qquad (8)$$

Here, $k_1 = 2\xi\omega_n s - \frac{1}{R} and k_2 = \omega_n^2 C$

B. Neutral point Clamped PWM rectifier

Fig. 6 shows a three-level Neutral Point Clamped PWM converter. This topology has 12 switches and two dc link capacitors. These capacitors split the dc bus voltage. Each consists of 4switchesconnected in series and two diodes. The purpose of these diodes is to clamp the mid-point potential of the switches to the DC-link mid-point. Certain combinations of the switches in each leg give three different level of voltage [9]. The simulation model is as shown in Fig. 6.

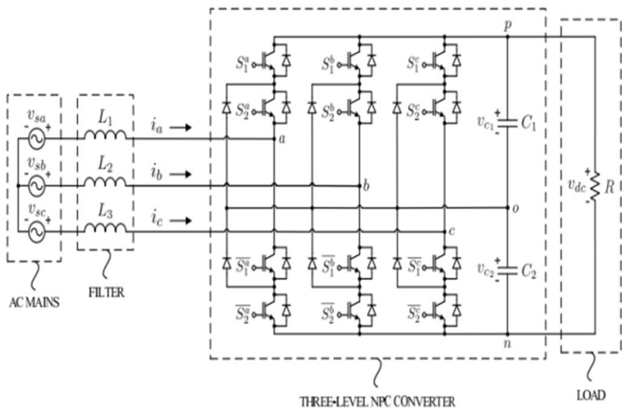

Figure 6. Three level NPC rectifier configuration

The aim of the control system for three level NPC rectifier is to provide a regulated output dc link voltage at a specified value to obtain a sinusoidal grid current and to maintain unity power factor. In case of NPC PWM rectifier, it should be taken care that the voltage across the two dc link capacitors should be equal which may otherwise damage the dc link capacitors and semiconductor devices.

C Space Vector Modulation Technique

Space vector modulation (SVM) is one of the preferred real-time modulation techniques.
This section presents the principle and implementation of the space vector modulation for three phase two level and three level NPC converters. Fig 7 and 8 show the space vector diagram of three phase 2- level converter and 3-level NPC converter respectively[14].Fig10 and 11 show the flowchart of SVPWM generation for the two converters respectively. V_d^* and V_q^* obtained from the VOC block are transformed into V_α and V_β as shown in Fig 8.The reference space vector V_{ref} is calculated using V_α and V_β. The dwell times[14] of the active vectors are calculated using the V_{dc} value, sampling time period T_s, sector 'n' and sector angle 'Phi'. These dwell times are used to generate the reference waves for pulse generation. The switching pulses are generated by comparing the reference waves with the triangular carrier wave of switching frequency f_s, which is chosen as1350Hz.In case of 3-level NPC converter each sector is subdivided into four regions as shown inFig 8.Hence in the flowchart of SVPWM generation shown in Fig 10 an additional block for region calculation is used.

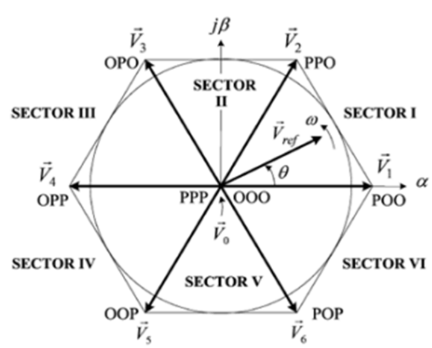

Figure 7. Space vector diagram of three phase two level converter

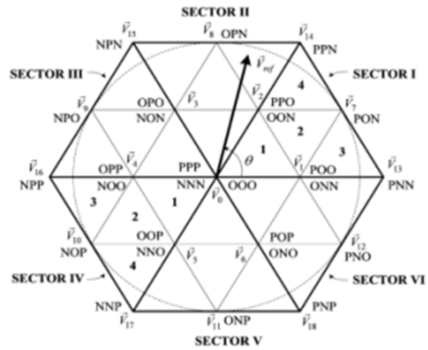

Figure 8. Space vector diagram of three phase three level converter

III. Simulation Results and Discussions

In this section, the performance of PWM rectifier with voltage oriented control using Space Vector Modulation scheme is presented. The parameters of the system considered are presented in Table I and II. The simulation is carried out using MATLAB/SIMULINK.

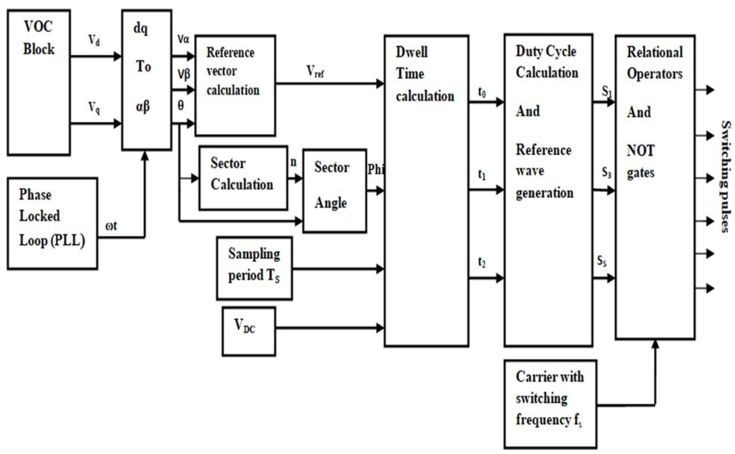

Figure 9. Flowchart for SVPWM generation (2-Level converter)

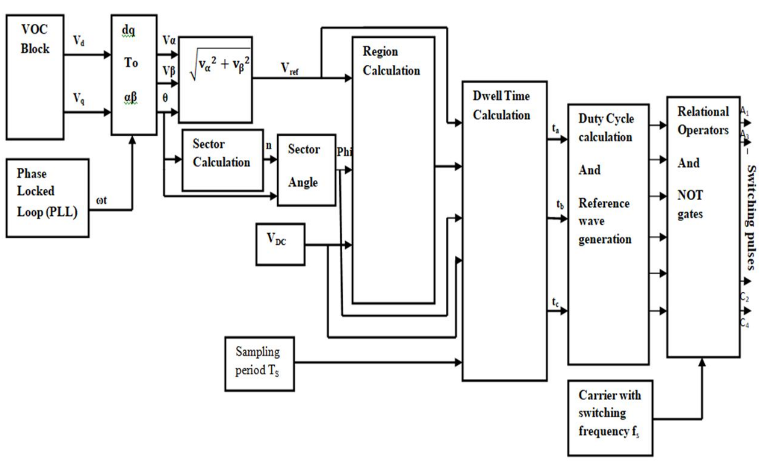

Figure 10. Flowchart for SVPWM generation (3-Level NPC converter)

TABLE I: PARAMETERS OF CONVENTIONAL TWO LEVEL RECTIFIER

Parameters	Values
Grid side volatge per phase	220V
Frequency	50Hz
Source resistance and inductance	0.05Ohm , 2mH
DC side capacitor	2200uF
Sampling frequency	5kHz
Switching frequency	1350 Hz
Load	100 Ohm

TABLE II: PARAMETERS OF CONVENTIONAL THREE LEVEL NPC RECTIFIER

Parameters	Values
Three phase grid voltage	400V, 50Hz
DC split bus capacitors	2200uF each
Source resistance and inductance	0.05Ohm , 2mH
Sampling frequency	5kHz
Switching frequency	1350 Hz
Load	100 Ohm

Fig 11 and 12 show the simulation results of two level converter and three level NPC converter. Fig 11(a) shows the waveforms of grid voltage and the current drawn from the converter. It is seen from the waveform that the input current is in phase with the grid voltage and hence, unity power factor is achieved and also the current is observed to be sinusoidal. After the load is changed, the current still follows the grid voltage and maintains unity power factor. Fig 11(b) shows the DC link voltage of the converter. To validate the dynamic response of the converter, the DC reference voltage of the controller is changed from 600V to 700V at 0.15 sec., and the load is increased at 0.3 sec. It is observed that, two level converter takes 0.01 sec to reach the steady state and three level converter takes 0.02 sec to reach the steady state. Fig 11c shows the zoomed version of DC link voltage. It's observed that the voltage follows the reference voltage and controller takes 0.05 sec to regulate the DC link voltage for two level converter. Fig. 11(d) shows the Fast Fourier Transformation(FFT) analysis of the input current of two level converter with VOC control and the Total Harmonic Distortion(THD) is 23.78%.Fig 11(e) shows the DC load current. The current raises to meet the increased load at 0.3 sec. Fig 12(a) shows the waveforms of grid voltage and the current drawn from the converter for thre level converter. Similar to two level converter, it is seen from the waveform that the input current is sinusoidal and is in phase with the grid voltage and hence, unity power factor is achieved. After the load is changed, the current still follows the grid voltage and maintains unity power factor. Fig 12(b) shows the DC link voltage of the converter. The dynamic response is similar to that discussed with two level converter but it settles at the reference voltage by 0.05 sec. Fig 12c shows the zoomed version of DC link voltage. Similar to two level converter, the voltage follows the reference voltage and controller takes 0.15 sec to regulate the DC link voltage for three level converter. Fig 12(d) shows the Fast Fourier Transformation(FFT) analysis of the input current of the converter with VOC control. It shows the Total Harmonic Distortion(THD) of the input current is 18.81%. Fig 12(e) shows the DC load current. The current raises to meet the increased load at 0.3 sec.Fig 12(f) shows the DC link capacitor voltages. It shows that the capacitor volatges are slightly unbalanced.

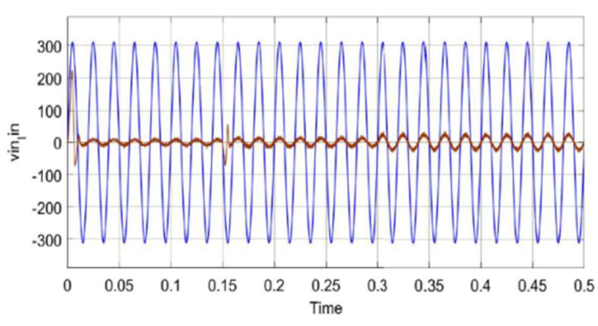

Figure 11(a). Grid voltage and curent

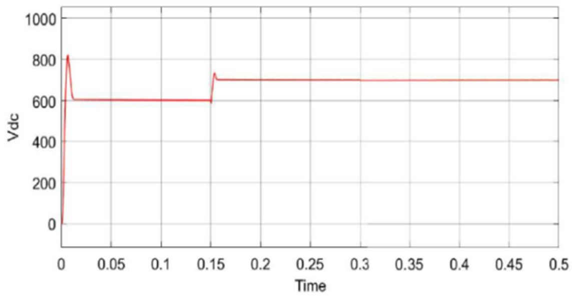

Figure 11(b) DC link voltage

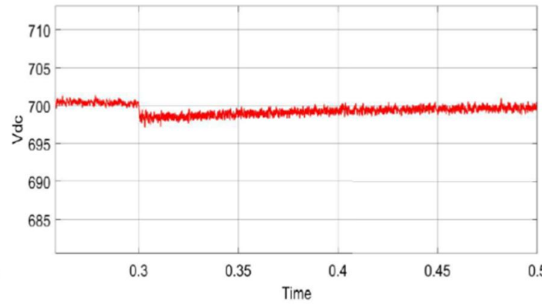

Figure 11(c). Zoomed version of DC link voltage

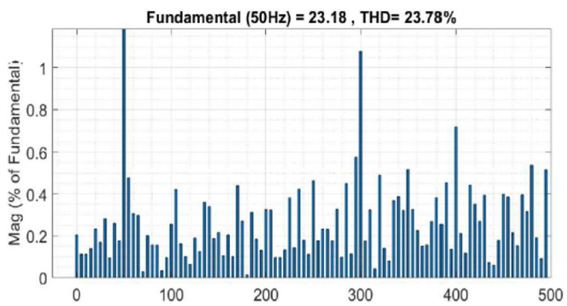

Figure 11(d). FFT analysis

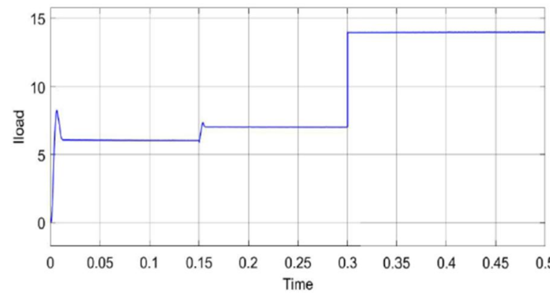

Figure 11(e). Load current(Load changes at 0.3sec)

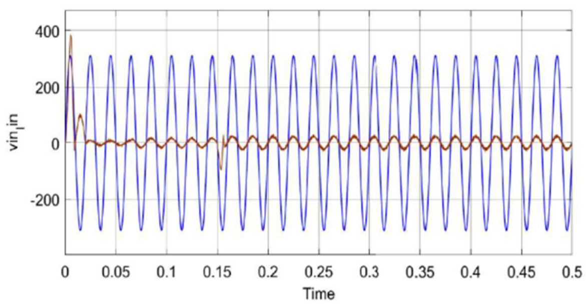

Figure 12(a). Grid voltage and current

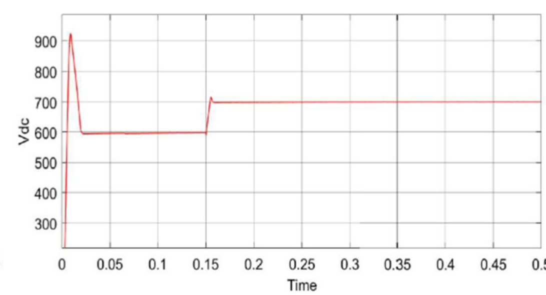

Figure 12(b). DC link voltage

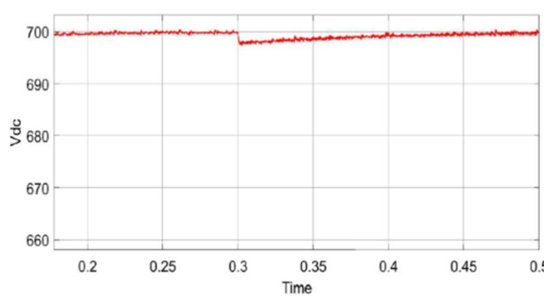

Figure 12(c). Zoomed version of DC link voltage

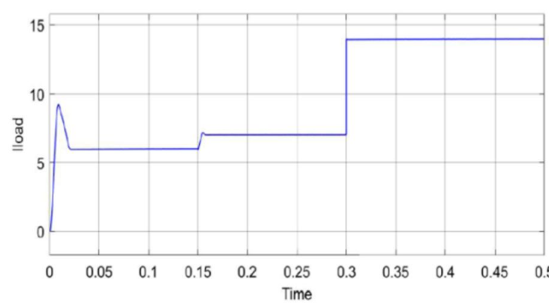

Figure 12(d) Load Current

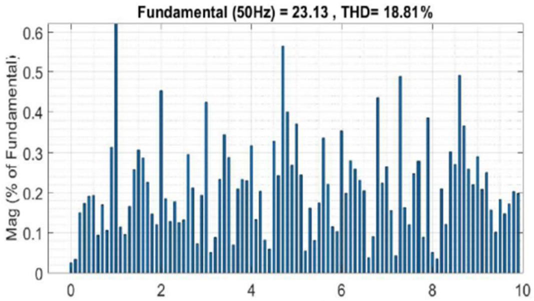

Figure 12(e). FFT analysis

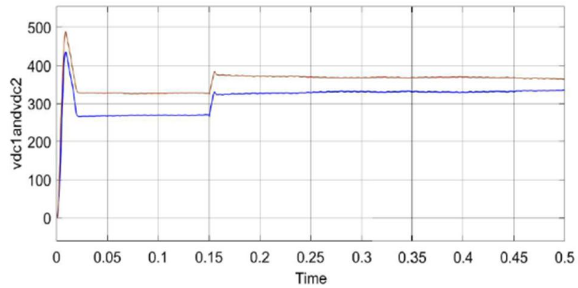

Figure 12(f). DC link capacitor voltage

IV. CONCLUSION

This work presents the Voltage Oriented Control technique with space vector modulation of conventional two level and three level NPC PWM rectifier. The simulation models and the control methodology for both types of converters are developed. The simulation results show that the Voltage-Oriented Control technique effectively maintains the dc-bus voltage and the current at the desired level. From the results obtained, it is found that, the proposed technique resulted in good static and dynamic performance. The total harmonic distortion for the input current is found to be lesser in case of three level NPC converter than two level conventional converter.

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