# Modeling and Simulation of PWM Line Converter feeding to Vector Controlled Induction Motor Drive

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**ABSTRACT**
The objective of this project is to model and simulate a three-phase Voltage Source Pulse Width Modulation (PWM) Rectifier Based on Direct Current Control feeding an indirect vector controlled Induction Motor Drive (VCIM) . Based on the mathematical model of PWM rectifier, the dual close loop design with decoupled feed-forward control is applied to the three phase voltage source rectifier. The objective of this project is to model and simulate a three-phase Voltage Source Pulse Width Modulation (PWM) Rectifier The first objective is to realize unity power factor at the input ac mains and regulate output voltage. The second one is to realize that the above designed PWM rectifier will always give its objectives of stiff dc voltage and unity power factor irrespective of the load and its controlling methods. Considered resistive load on rectifier and check the performance of the PWM rectifier with direct current control. The induction motors is taken with indirect vector control and consider a load on inverter, so as to reflect the most practical aspect of the load for checking the viability of the rectifier design. The operation of Induction machine is not disturbed the PWM rectifier objectives. The designed PWM rectifier is considered as capable of feeding the Common DC coupling point(dc bus).

***Keywords:***
*Pwm rectifier, VCIM, Direct Current Control (DCC), Indirect Vector control.*

## 1. Introduction

The control and estimation of induction motor drives constitute a vast subject and the technology has further advanced in recent years. The applications include pumps and fans, paper and textile mills, and sub-way and locomotive propulsions, electric and hybrid vehicles, machine tools and robotics, home applications, heat pumps and air conditioners, rolling mills and wind generation systems. The control and estimation of ac drives in general are considerably more complex than those of dc drives, and this complexity increases substantially if high performances are demanded. The main reason for this complexity are the need of variable frequency, harmonically optimum converter power supplies, the complex dynamics of ac machines, machine parameter variations, another difficulties of processing feedback signals in the presence of harmonics.

Power electronics equipment used nowadays very more. The standard diode/Thyristor bridge rectifiers at the input side several problems come as: Low input power factor, high values of harmonic distortion of ac line currents, and harmonic pollution on the grid. In nowadays, the PWM rectifier offers several advantages such as: control of DC bus voltage, bi-directional power flow, unity power factor, and sinusoidal line current. Many pulse-width modulation (PWM) techniques have been adopted for these rectification devices to improve the input power factor and shape the input current of the rectifier into sinusoidal waveform. The current regulating fashion in synchronous frame has the advantages of fast dynamic current response, good accuracy, fixed switching frequency and less sensitive to parameter variations. In actual implementations, the direct current control scheme is used. Various control strategies have been proposed to regulate the dc bus voltage while improving the quality of the input ac current in direct current control scheme. The expanding use of electric loads controlled by power electronics such as PC's, TV's, stereos, and adjustable speed drives (ASD's) has made power converters an important. Nevertheless, the increasing use of power converters has also led to an increase of current harmonics drawn from the utility grid. In the last decade, main research focus has been on harmonic reduction techniques and, as a result of this, several useful harmonic reduction techniques exist for the single-phase rectifier. However, finding the right solution for the three-phase rectifiers is still very difficult. Even though there exist many proposals for the three-phase rectifier, many of the existing solutions may not be qualified for a grade-purpose ASD. Various methods based on the principle of increasing the number of pulses in ac–dc converters have been reported in the literature to mitigate current harmonics. These methods use two or more converters, where the harmonics generated by one converter are cancelled by another converter, by proper phase shift. To ensure equal power sharing between the diode bridges and to achieve good harmonic cancellation, this topology needs Inter phase transformers and impedance matching inductors, resulting in increased complexity and cost. Moreover the dc-link voltage is higher, making the scheme non applicable for retrofit applications. The solution is either only practical for low-

Manuscript received August 5, 2013
Manuscript revised August 20, 2013

power applications or the price and complexities are too high. Some summaries on three-phase harmonic reduction techniques can be found . So far, most customers of ASD's use the low-cost diode rectifier and accept the harmonic currents. Harmonic reduction Equipment such as an active filter or active rectifier is only used when there are severe problems with harmonic distortion. Due to the new standards, such as IEEE 519-1992 and EN 61000-3-2/EN 61000-3-12. Figure 1 shows a three phase diode-rectifier working as a line side Converter, with this common DC Link, many of the Drives Vector Controlled IM Drive, systems are inter connected. Due to the rectification process, the input current is highly discontinuous and contains excessive low frequency harmonics resulting in high total harmonic distortion (THD). The IEEE-519 recommended practices specify limits on the harmonics generated. Also, with this configuration, power can flow only in one direction making the PWM drive system incapable of regenerating. In order to meet clean input power requirements and allow regeneration, the diode rectifier shown in Figure2. Such system is currently available up to 500kW rating from many ASD drive manufactures

## 2. Three-Level Inverter

Figure1 shows the simplified circuit diagram of a popular three-level neutral point clamped (NPC) inverter. The
Inverter leg 'a' is composed of four IGBT switchesS1 to S4 with four ant parallel diodes D1 to D4. On the DC side of the inverter, the DC bus capacitor is split into two, providing a neutral point 'n'. When switches S2 and S3are turned on, the inverter output terminal a is connected to the neutral point through one of the clamping diodesDn1 and Dn2. Ideally, the voltage across each of the DC capacitors is Vdc/2, which is half of the total DC-link voltage Vdc. With a finite value for C1 and C2, the capacitors can be charged or discharged by neutral Current in, causing neutral-point voltage deviation.

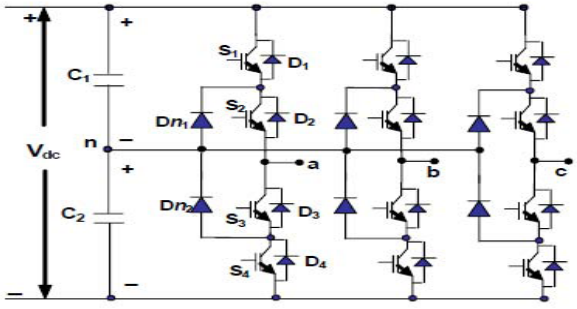



Figure1. 3-Level NPC PWM Inverter

The operating status of the switches in the NPC inverter can be represented by the switching states shown Switching state 'P' denotes that the upper two switches in leg 'a' are on and the inverter pole voltage Va, which is ideally +Vdc/2, whereas 'N' indicates that the lower two switches conduct, leading to Va = -Vdc/2. Switching state 'O' signifies that the inner two switches S2 and S3 are on and Va is clamped to zero through the clamping diodes. Depending on the direction of the load current ia, one of the two clamping diodes is turned on. For instance, a positive load current (ia > 0) forces Dn1 to turn on, and the terminal 'a' is connected to the neutral point 'n' through the conduction of Dn1 and S2. The switches S1 and S3 operate in a complementary manner similar to switches S2 and S4.

## 3. Three-phase voltage source PWM Rectifier model

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 source, and $i_a$ , $i_b$ and $i_c$are phase currents,$V_{dc}$ is the DC output voltage, $R_1$ and L mean resistance and inductance of filter reactor, respectively, C is smoothing capacitor across the dc bus, $R_l$ is the DC side load, $u_{ra}$ , $u_{rb}$ , and $u_{rc}$ , are the input voltages of rectifier, and $i_L$ is Load current

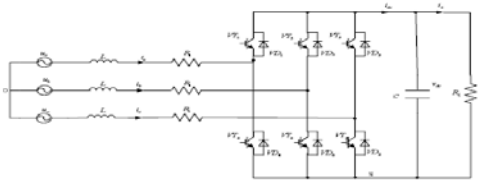


Figure2. Circuit schematic of three-phase two-level boost type Rectifier

The following equations describe the dynamical behavior of the boost type rectifier in Park coordinated or in d-q:

$$L\frac{di_d}{dt} = u_d - i_d R_1 + \omega L i_q - u_{rd}$$

$$L\frac{di_q}{dt} = u_q - i_q R_1 - \omega L i_d - u_{rq}$$

$$C\frac{dV_{dc}}{dt} = -\frac{V_{dc}}{R_L} + \frac{3}{2}(S_d i_d + S_q i_q) \quad (1)$$

Where, $u_{rd} = s_d v_{dc}$ ,$u_{rq} = s_q v_{dc}$, $u_{rd}$ , $u_{rq}$ 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. □angular frequency respectively.

## 4. Design of current loop

It is seen from (1) that mutual interference exists in the d-q current control loops. The voltage decouples are therefore designed to decouple the current control loops and suitable feed forward control components of source voltages are also added to speed up current responses. The d–q current control loop of the rectifier
in the proposed system is shown in Figure 2.Where the d – q voltage commands can be expressed as

$$u_{rd} = -u'_{rd} + \omega L i_q + u_d$$
$$u_{rq} = -u'_{rq} + \omega L i_d + u_q \quad (2)$$

Let us take into account this assumption in (1) and get the following equations

$$L\frac{di_d}{dt} = -i_d R_1 + u'_{rd}$$
$$L\frac{di_q}{dt} = -i_q R_1 + u'_{rq} \quad (3)$$

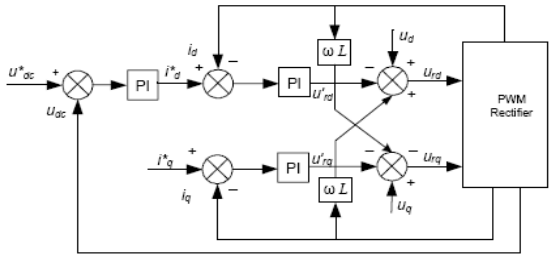



Figure3.Control block diagram of d-q dual closed-loop controller of rectifier

The simple proportional-integral (PI) controllers are Adopted in the current regulation, $u_{rd}$ and $u_{rq}$ are controlled by the following expression:

$$u_{rd} = -(K_{ip} + \frac{K_{iI}}{S})(i^*_d - i_d) + \omega L i_q + u_d$$
$$u_{rq} = -(K_{ip} + \frac{K_{iI}}{S})(i^*_q - i_q) + \omega L i_d + u_q \quad (4)$$

Assume that the d–q voltage commands are not saturated and the d–q current control loops have been fully decoupled. For d-axis current control loop, the structure can be simplified to Figure 3.

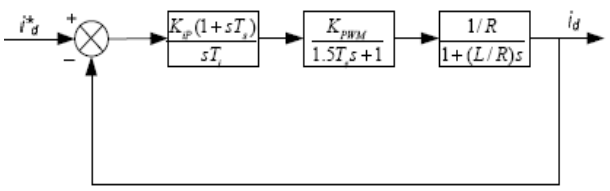



Figure4. Equivalent control block diagram of d-q current -loop

When the current responses speed is concerned, the current regulator can be designed as the typical I model system. For pole-zero cancellation, take T =L/R. The open-loop current transfer function can be expressed as

$$W_i(s) = \frac{K_{iP}K_{PWM}}{RT_i s(1.5T_s+1)} \quad (5)$$

According to Parameter adjusting method for typical model I system, when damping ratio ξ=0.707, we have the following equation

$$\frac{1.5T_s K_{iP} K_{PWM}}{RT_i} = \frac{1}{2} \quad (6)$$

The parameters of the PI controller should be chosen as

$$K_{iP} = \frac{RT_i}{3T_S K_{PWM}}$$
$$K_{iI} = \frac{K_{iP}}{T_i} = \frac{R}{3T_s K_{PWM}} \quad (7)$$

## 5. Design of voltage loop

The transfer function of voltage regulator is
$G(s)= K_{vp}(1 + T_s)/T_v s$ (8)
Where $K_{vl} = K_{vp}/T_v$ (9)

By Figure 4, the open transfer function of system can be expressed as

$$W_{ov}(s) = \frac{0.75K_{vP}(1+sT_v)}{CT_v s^2(4T_s s+1)} \quad (10)$$

Due to the main function of voltage control loop is to keep stability of output voltage, so the noise immunity must be taken into account in the course of design voltage loop. The proper choice to this end is to adopted typical model II system. So

$$\frac{0.75K_{vP}}{CT_v} = \frac{h_v + 1}{32h^2{}_vT^2{}_s} \quad (11)$$

Where $h_v = T_v/4T_s$ is the frequency width in the voltage loop, take $h_v = 5$ then $T_v = 20T_s$ (12)

Finally the result obtained is:

$$K_{vP} = \frac{C}{5T_s}$$

$$K_{vI} = \frac{K_{vP}}{20T_s} \quad (13)$$

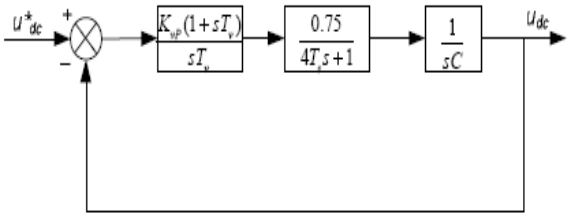



Figure5.Equivalent control block diagram of the voltage control loop

## 6. Induction Motor Modeling and control

The dynamic equations of the induction motor in any reference frame can be represented by using flux linkages as variables. This involves the reduction of a number of variables in the dynamic equations. Even when the voltages and currents are discontinuous the flux linkages are continuous. The stator and rotor flux linkages in the stator reference frame are defined as

$$V_{qs} = R_s i_{qs} + \rho\psi_{qs}$$
$$V_{ds} = R_s i_{ds} + \rho\psi_{ds}$$
$$V_{dr} = R_{dr} i_{dr} + \omega_r\psi_{qr} + \rho\psi_{dr}$$
$$V_{qr} = R_{qr} i_{qr} - \omega_r\psi_{qr} + \rho\psi_{qr} \quad (14)$$

$$\psi_{qs} = L_s i_{qs} + L_m i_{qr}$$
$$\psi_{ds} = L_s i_{ds} + L_m i_{dr}$$
$$\psi_{qr} = L_r i_{qr} + L_m i_{qr}$$
$$\psi_{dr} = L_r i_{dr} + L_m i_{ds}$$
$$\psi_{qm} = L_m (i_{qs} + i_{qr})$$
$$\psi_{dm} = L_m (i_{ds} + i_{dr}) \quad (15)$$

$$T_e = 3/2\ \rho/2 L_m/L_r(i_{qs}\psi_{dr} - i_{ds}\psi_{qr})$$
$$T_e - T_l = 2/p^*\ jd\omega_r/dt \quad (16)$$

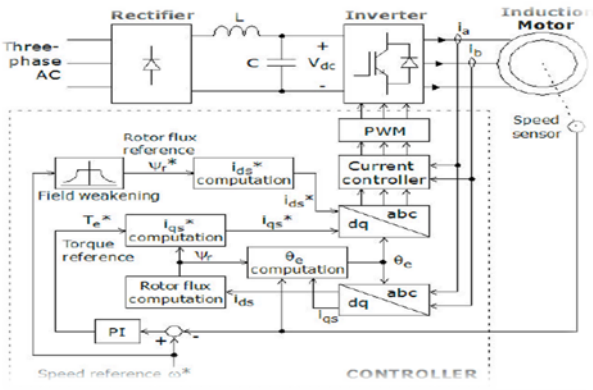



Figure6.Induction Motor controlled by indirect vector control

## 7. Simulation Results and Discussion

The circuit designing in MATLAB. MATLAB has been chosen in this work due to its versatility. To verify the above design, the proposed Converter-Drive system is simulated in MATLAB/SIMULINK. The simulation is carried out on

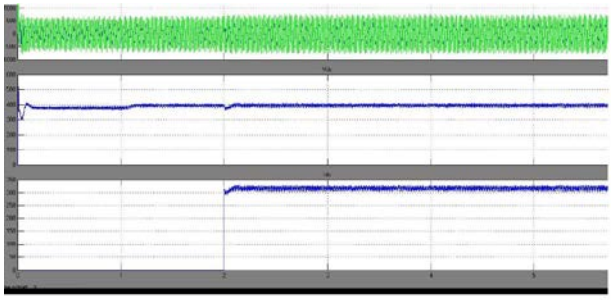
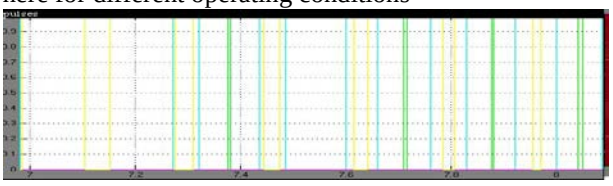


Figure7.source voltage, source current, Dynamics of DC link voltage and Current waveforms of PWM Rectifier with DCC

Direct current controlled PWM rectifier with the following load conditions. Each time it is verified that the input power factor is unity and the DC voltage is stiff under all the conditions. Simulation results are presented here for different operating conditions



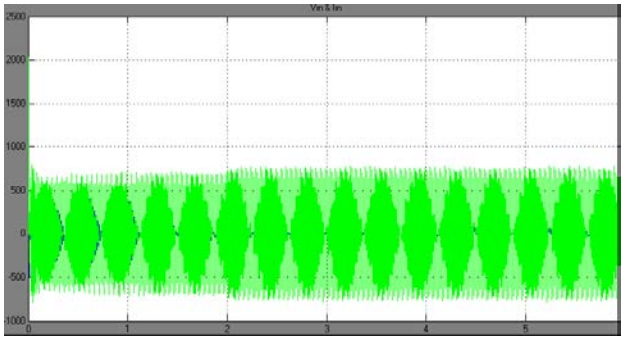


Figure8.Input voltage waveforms (at Boost Inductor) of PWM Rectifier with DCC

The dynamics of source current, generated torque and rotor speed of the Indirect vector controlled Induction motor drive with pwm rectifier against step speed changes and load torque changes are shown in theFigure9. The reference speed of the drive is changed from 2500 rpm to1500 rpm, at this instant the generated torque of the VCIM undergoes a bit dynamics and immediately after 1ms the generated torque is tracking its reference value 0 N-m.The Load torque (TL) is changed from 0 N-m→2 N-m & 2 N-m →8 N-m, the moment when the load torque changes, there is no dynamics in the rotor speed of VCIM i.e the generated torque and speed are decoupled

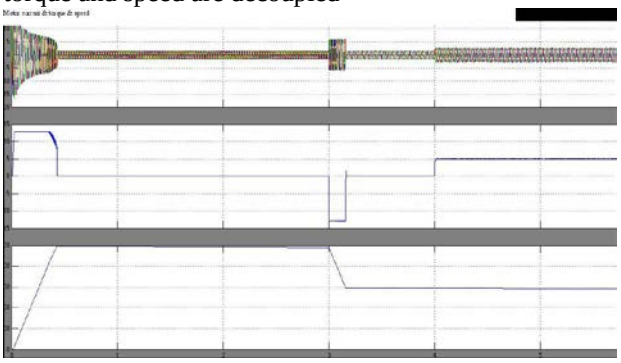


Figure9.Input current, Generated Torque and Rotor Speed waveforms of VCIM with PWM Rectifier

## 8. Conclusion

The DC bus voltage remains unchanged except with a very little dynamics for any load variation in the output rectifier side. The operation of the Drives will never makes the DC bus voltage to pulsate or fall. This is the most important requirement of the power System, particularly at common coupling. One more important aspect of the rectifier is that it is maintaining the unity power factor even under dynamic Loads and disturbances in speed, torque and current of the induction motor.

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