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Analysis and Control of Three Phase PWM Rectifier for Power Factor Improvement of IM Drive

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Abstract- Conventional way of obtaining DC power from AC is by using diode bridge rectifier. In case of diode rectifier, they inject unwanted current harmonics of relatively high amplitude into the grid and also reduces input power factor. Reduction in current harmonic injection into the grid and also power factor can be controlled by using effective control strategies like vector control techniques on pulse width modulated rectifiers. It improves the power factor in a great extent. While using PWM rectifier output voltage can be control. In this paper VOC based three phase PWM rectifier is implemented for Voltage Source Inverter(VSI) based induction motor drive. At no load induction motor has very low power factor. It improves at increasing load from no load to full load. In the VSI based induction motor drives, power factor and thereby efficiency can be increases by controlled in the rectifier. In vector control method voltage error is a direct input control variable to realize the fast response of the rectifier. The output voltage of rectifier varies under large disturbance of load, but the good control resulted a more accurate voltage stability and have better dynamics response. Simulation of vector controlled PWM rectifier is done in MATLAB/Simulink. It uses a three phase supply with 100 V and obtained a constant output voltage of 337 V in DC link.
Keywords – VOC, Three Phase PWM Rectifier, IMC, IM Drive, Power Factor Improvement, Harmonic Elimination.

I. INTRODUCTION

Conversion of DC power from AC power using an AC to DC converter finds its application in a wide range of area like electric drives, UPS. etc. Conventionally for obtaining DC power from AC grid, diode bridge or thyristor bridge rectifiers are used. The use of these topologies is mainly motivated due to their advantages in size, control, reliability, structural simplicity and mainly economics.

The usage of such bridge circuits is quite disadvantageous as they inject unwanted current harmonics of relatively high amplitude into the grid. A reduction in current harmonic injection into the grid can be achieved by using effective control strategies like vector control or direct power control techniques on Pulse Width Modulated rectifiers. In this paper vector controlled PWM rectifier is done, with Vector control or Voltage Oriented control(VOC) method. In which, voltage error is a direct input control variable to realize the fast response of the rectifier. The output voltage of rectifier varies under large disturbance of load, but the good control effect resulted a more accurate voltage stability. have better dynamics response compared to conventional control strategies. In vector control method active component and reactive component of current can be control independently. By using this input power factor can be controlled in a predefined range. Nearly unity power factor can be attained by making reactive component equals zero. Low power factor affect the efficiency of whole system. While using inductive load power factor became very low. In case of induction motor drives, power factor reduces because induction motor is highly inductive.

Induction motors are the most widely used electrical motors. At no load induction motor has very low power factor. It improves at increasing load from no load to full load. In this paper VSI based induction motor drive is used as rectifier load. The air-gap between the stator and rotor of an induction motor increase the reluctance of the magnetic circuit developed in motor. So it draws a large magnetizing current to produce the required flux in the air-gap. At no-load condition motor draws a large magnetizing component and low active component to meet the losses. So the power factor became very low. When load on motor increases active component of current increases and power factor improves. In the Voltage Source Inverter(VSI) based induction motor drives, power factor can be controlled in the rectifier. This rectifier controller is turned using Internal Model Control (IMC) method. This is a PID controller turning method.

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II. THREE PHASE PWM RECTIFIER

The power circuit of the three-phase PWM rectifier is shown in Figure.1. In PWM rectifiers, by controlling the width of switching pulse the output voltage can be controlled in a desired value. In vector controlled PWM rectifiers [2] all quantities are transformed into synchronous(dq) reference frame [3]. In abc reference frame control, all control values are varying with time. so control became more complicated. In case of dq these values are time independent and these values are dc in nature, so a step change can be applied as a perturbation.

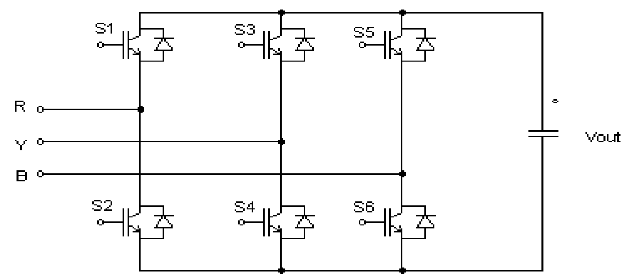

Figure 1. Three Phase PWM Rectifier

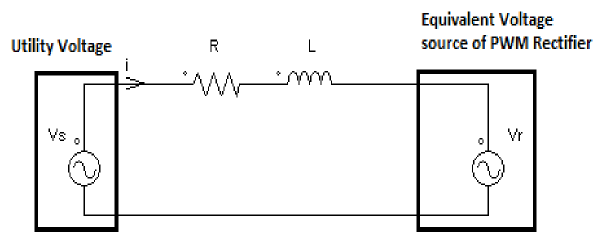

Figure 2. Single Phase Equivalent of Rectifier

The dq model of three phase rectifier is shown below,

$$L\frac{di_d}{dt} + Ri_d = \omega L i_q + V_{sd} - V_{rd}$$

$$L\frac{di_q}{dt} + Ri_q = -\omega L i_d + V_{sq} - V_{rq} \quad (1)$$

Where, V_{sd} = d component of source side voltage.
V_{rd} = d component of rectifier side voltage.
i_d = d component of current.

and others are corresponding q components. By making $i_q = 0$, reactive power become zero and power factor can be made unity.

2.1 Control strategy –

The Figure. 3 shows the controller for PWM rectifier, consists of an inner current controller and an outer dc voltage regulator. The inner current controller controls the input line currents to track the reference current; the unity power factor operation can be achieved if the reference current vector is in phase with the mains voltage. The voltage controller regulates the output voltage of the rectifier. The current controller outputs the reference voltage, which is used to generate PWM pulses for the rectifier switches [4].

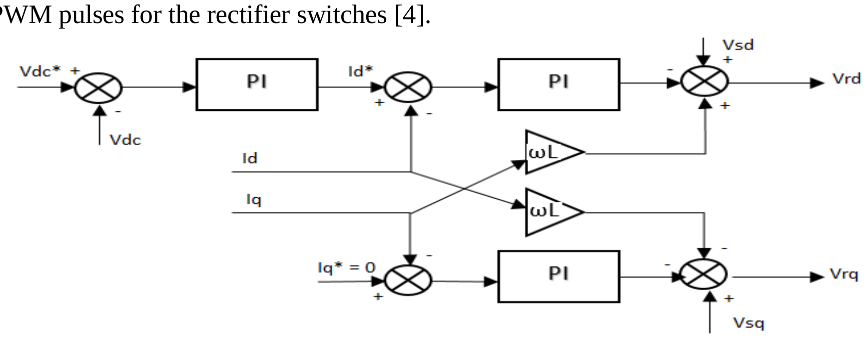

Figure 3. Vector control of PWM rectifier

The outer dc voltage regulator PI controller regulates the current indirectly to maintain a constant dc voltage. The speed of outer DC voltage regulator will be low and that of inner current controller will be high. The current controllers are cross coupled by a term ωL.

2.2 Internal Model Control Based PI controller –

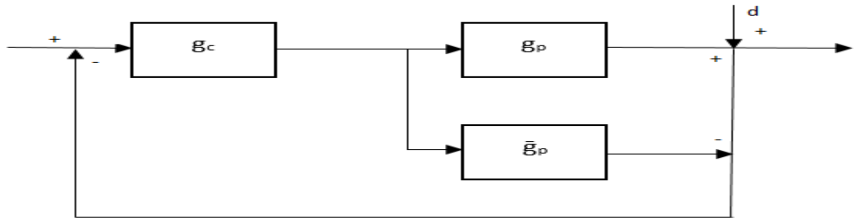

Figure 4. Internal Model Control

In control applications, model based control are always using to track set point and reject disturbances. The distinguishing characteristic of IMC [6] structure is the incorporation of the process model which is in parallel with the actual the plant. To improve the robustness of the system the effect of model mismatch should be minimized. Since mismatch between the actual process and the model usually occur at high frequency end of the systems frequency response, a low pass filter f(s) is usually added to attenuate the effects of process model mismatch.

This contains a plant with Transfer function(TF) g_p and a controller with TF g_c, model of the plant $\bar{g}_p$ and a disturbance *d*. This plant model and actual plant outputs are cancels and *d* feed to the input. The controller used in the IMC control is an inverse of plant transfer function series with a low pass filter. Low pass filter is used for make the system improper, or at high frequency actual plant and plant model output may mismatch, to avoid it a low pass filter is used.

$g_c(s) = g_p^{-1}(s)*f(s)$ (2)

where $f(s)=\frac{1}{\lambda s+1}$ Transfer function of low pass filter.

The IMC closed loop TF is,

$$\frac{g_c(s)}{1-g_p^{-1}(s)*g_c(s)} \quad (3)$$

2.3 Current Controller Design –

The transfer function can be formed as follows,

$$V_s - \left[Ri + j\omega Li + L\frac{di}{dt}\right] - V_r = 0 \quad (4)$$

Laplace transform and TF are,

$$[R + j\omega L + sL]i = V_s - V_r$$

$$g(s) = \frac{i}{V_s} = -\frac{1}{R + sL + j\omega L} \quad (5)$$

Transfer function contains the term $j\omega L$ this is the cross coupling component to cancel out the cross coupling component,

$$V_r = V_s - V^1 - j\omega Li$$

$$g_p(s) = \frac{i}{V^1} = \frac{1}{R + sL} \quad (6)$$

Rearranging this TF of $g_p^{-1}(s)$ became,

$$g_p^{-1}(s) = k_p[1 + T_p s] \quad (7)$$

Where $T_p = \frac{L}{R}$, Time constant

Then IMC closed loop TF ,

$$\frac{K_p[T_p(s)+1]}{\lambda s} \quad (8)$$

Rearranging and comparing with transfer function of PI controller. The proportional gain and integral gain can be obtained as,

$$K_{pi} = \frac{L}{\lambda_i}$$

$$K_{ii} = \frac{R}{\lambda_i} \quad (9)$$

Where, $\frac{1}{\lambda i} \leq \frac{2\pi f_s}{10}$ controller speed term.

2.4 Voltage Controller Design –

For voltage controller,

$$g(s) = \frac{3E_g}{sC} \quad (10)$$

Closed loop TF of IMC based voltage controller,

$$\frac{C}{3E_g s} \quad (11)$$

Rearranging and comparing with transfer function of PI controller. The proportional gain and integral gain can be obtained as,

$$K_{pv} = \frac{C}{3E_g \lambda}$$

$$K_{iv} = \frac{C}{3E_g \lambda^2} \quad (12)$$

Here $\frac{1}{\lambda} = \frac{1}{10 * \lambda i}$

2.5 Soft Startup –

In case of PWM rectifiers, there will be a voltage error controller which controls the output voltage in a defined value. When we start this circuit the output voltage is zero. So the error of voltage controller will be very high, due to this high error there will be a large spike in output voltage and also in current.

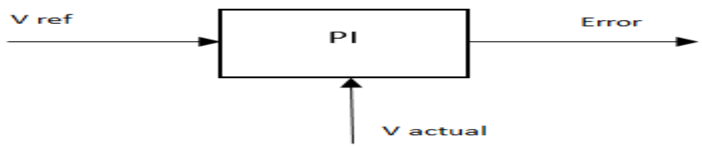

Figure 5. Soft start

To limit this starting voltage and current spike. Reference voltage needs to control, to control error in limit. For this we control the reference voltage to vary in such a way that a ramp. So reference start from an initial value and then increases gradually and reaches its final value after a number of power cycle. Typical value of time delay will be 10 power cycle.

2.6 Design of Component –

Value of supply side inductance is calculated as,

$$L \leq \frac{T_s\left(\sqrt{2}V_{sa} + \frac{2}{3}V_{dc}\right)}{\Delta i_{a\max}} \quad (13)$$

Value of DC link capacitance is calculated using,

$$C \geq \frac{\Delta W}{V_{dc}\Delta V_{\max}} \quad (14)$$

III. SIMULATION STUDIES

Simulation Parameters are shown in Table I.

Table -1 Simulation parameters

Parameters	**Values**
Source side inductance	9mH
Source side resistance	5Ω
DC link capacitor	470μF
Output Voltage	337V
K_{pi}	113.0973
K_{ii}	628.3185
K_{pv}	6.3286e-4
K_{iv}	0.794685
Switching frequency	2kHz

The simulation model of Three phase rectifier is shown in Fig. 6.

In which supply voltage and currents are transformed into its corresponding *α*-*β* and then its *dq* values, and this feed to the controllers. Current and voltage transformations are done using respective subsystem. The VSI feed induction motor drive is driven by an inverter at a frequency of 30*Hz*. While running induction motor rated at 415*V*,50*Hz* in 30*Hz* voltage required is only 240*V*, according to *V/F* control. This voltage reduction is done because of hardware limitations. The vector control subsystem is used in MATLAB is shown in Figure. 7.

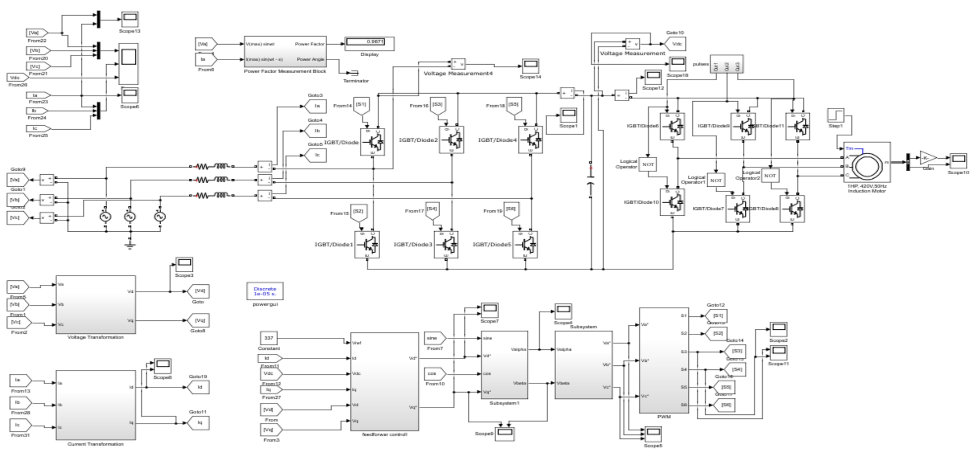

Figure 6. Simulation Model of three phase PWM rectifier

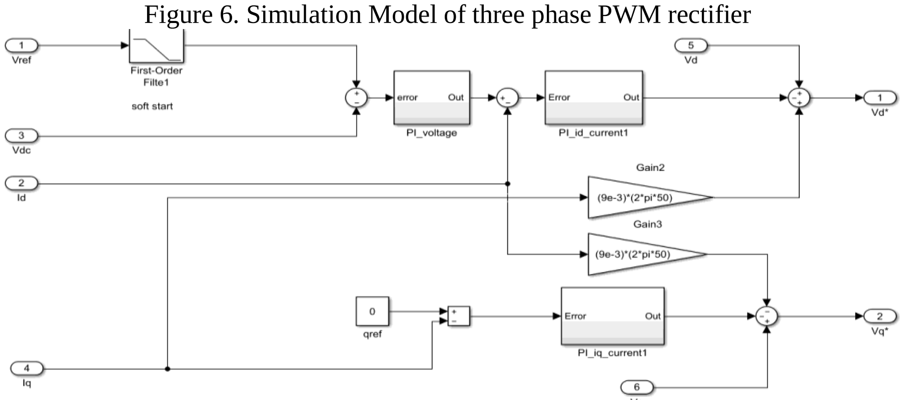

Figure 7. Simulation of vector control subsystem

The vector controlled PWM three phase rectifier output voltage wave form is shown in Figure. 8. There is a change in torque in motor is applied in 3 Sec, it draws a high current and make a reduction in DC link voltage. This voltage change is compensated by the controller in 0.4sec.

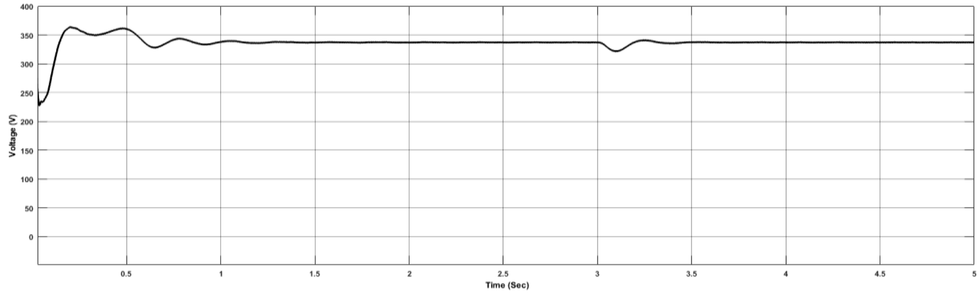

Figure 8. Output Voltage wave form without soft start

This shows the voltage regulation wave form. For an induction machine load of 1 HP as load. By implementing soft start-up voltage spike in start can be eliminate. Figure. 9 shows the output voltage for soft start-up. Due to the application of soft startup current spike in the start is also reduced.

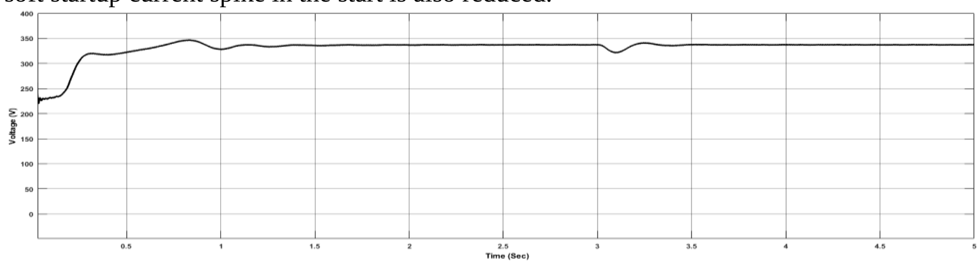

Figure 9. Output Voltage wave form with soft start

Per phase voltage and current that ensure unity power factor is shown in Figure. 10. In this figure voltage and current are in phase that ensure unity power factor operation.

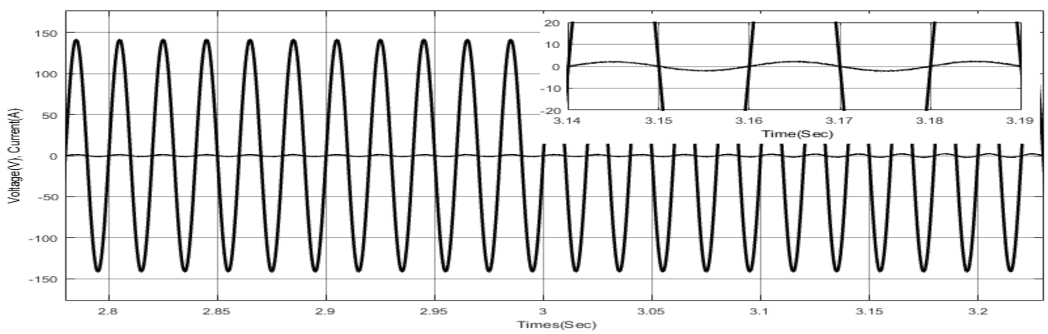

Figure 10. Per phase Voltage and current

Fig. 11 shows the FFT analysis of phase current. This shows that THD of supply side current is only 3.79 percentage. This shows that current harmonics that injected by this three phase PWM rectifier is low. This current harmonic can be further reduces by using large inductor.

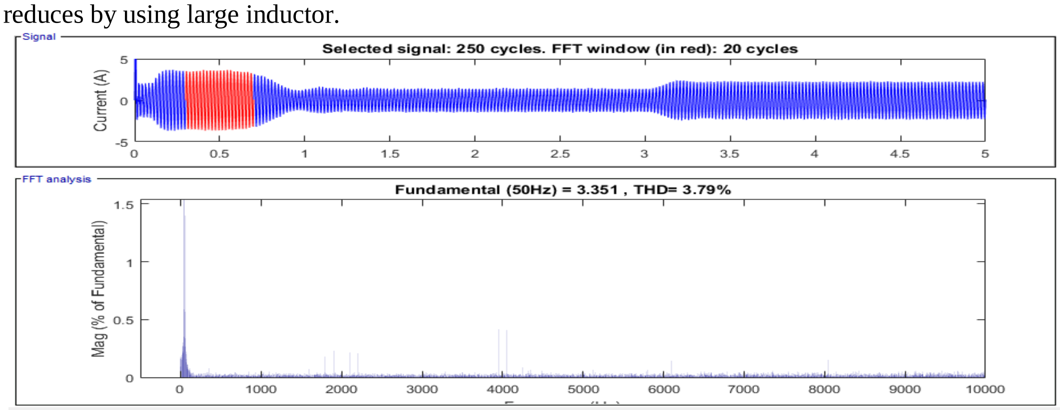

Figure 11. FFT analysis of input current

IV.CONCLUSION

A vector controlled three phase rectifier is implemented for a voltage source inverter (VSI) based induction motor drives. Induction motor at its variable load conditions changes it power factor in wide range. Ranging from 0.1 to 0.9 but this makes large power loss. By using PWM rectifier, the power factor can be make nearly unity. By using vector control, power factor, output voltage and current harmonics developed in the supply currents reduces to a very low value. It helps to improve power quality.

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