ANALYSIS, MODELLING AND SIMULATION OF DIFFERENT CONTROL STRATEGIES FOR PWM RECTIFIERS

S.Md.Mazhar-ul-haq[1], Dr.S.S.Tulasi Ram[2], Dr.JBV.Subramanyam[3]
[1]Research Scholar, Dept. of EEE, JNTU College of Engineering, Hyderabad, India
[2]Professor, Dept of EEE, JNTU College of Engineering, Hyderabad, India
[3]Professor, Dept of EEE, TKR Engineering College, Hyderabad, India

Abstract

In this paper the different control techniques of PWM (Pulse width modulation) Rectifiers are compared and presented. Simulation and modelling of different Control Strategies for three Phase Boost Rectifier like Voltage oriented control and Direct Power Control schemes are described and compared with their counterparts. These are the voltage oriented control (VOC) and voltage based Direct power control (V-DPC) techniques and Virtual flux based Direct power control. Total Harmonic Distortion (THD), Dynamic performance and parameter sensitivity is studied Theoretical concept is provided and results of computer simulations are given by using matlab, documenting the limitations and advantages of the individual control strategies. Based on the comparisons it is found that Virtual flux based Direct power control gives good results and also reduces the current control loops in the circuit and also improves the line voltage sensorless operation

Keywords: Direct Power Control, PWM Rectifiers, Virtual flux

I. INTRODUCTION

THE expeditious growth of ac adjustable speed drives (ASDs) in industry exacerbates the problem of harmonic pollution of the power system caused by the commonly used line-side dioderectifiers. Apart from demand of active and passive filters, use of PWM rectifiers constitutes the best solution. The recti-fiers have an additional advantage of the bi-directional power flow. Therefore, issues of control of PWM rectifiers have recently been accepting significant attention of researchers. Control techniques for PWM rectifiers can generally be classified as voltage based and virtual-flux based. Four types of these techniques can be distinguished: a)voltage oriented control (VOC); b)voltage-based direct power control (V-DPC); c)virtual-flux oriented control (VFOC); d)virtual-flux-based direct power control (VF-DPC).

In this paper, logical background for each control technique is provided, correlative analysis, based on computer simulations and laboratory experiments, is carried out. Operating characteristics, advantages, and drawbacks of individual techniques are described to serve as a guide for ASD design engineers.

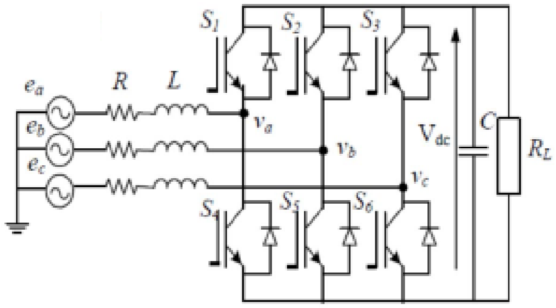


Fig.1 2-LEVEL PWM RECTIFIER

II. CONTROL TECHNIQUES FOR PWM RECTIFIERS

Most ASDs retain voltage-source inverters. Then, the PWM rectifier is of the current-source type, with the topology identical to that one of the inverter. The goal of the control system is to maintain the output voltage (dc-link voltage), v_{DC}, at the required level, while currents drawn from the power system should, elegantly, be sinusoidal and in phase with respective phase voltages to satisfy the unity-power-factor (UPF) condition. The classic solution, the voltage oriented control (VOC) scheme, is shown in Fig. 2. The UPF condition is met when the line current vector, $i=i_d+ji$, is aligned with the phase voltage vector, $v=v_d+jv$, of the power line supplying the rectifier. There-fore, a revolving reference frame aligned with v is used, and the reference value, i_* , of the quadrature component of i is set to zero. Switching signals, a, b, and c, for individual phases of the rectifier are generated by a typical space vector modulator [1], [2]

Another solution is based on the idea of direct power control (DPC) [3]. This control scheme, depicted in Fig. 3, will be referred to as voltage-based direct power control (V-DPC). The real and reactive powers, p and q, determined from the power line are calculated using information about the dc-link voltage, rectifier state, and line currents, i_a, i_b, and i_c. Specifically

$$p=L\left(\frac{di_a}{dt}i_a+\frac{di_b}{dt}i_b+\frac{di_c}{dt}i_c\right)+v_{DC}(ai_a+bi_b+ci_c) \quad (1)$$

$$q=\frac{1}{\sqrt{3}}\left\{3L\left(\frac{di_a}{dt}i_c-\frac{di_c}{dt}i_a\right)-v_{DC}[a(i_b-i_c)+b(i_c-i_a)+c(i_a-i_b)]\right\} \quad (2)$$

Where L denotes inductance of the input reactor. The UPF condition requires the reactive power to be zero. Two bang-bang controllers, and an identifier of the vector-plane sector currently housing the line voltage vector, allow direct selection of the next state of the rectifier.

Distinct similarities enclosed the outlined control schemes and those for ac motor control can be detected. The VOC principle resembles the field orientation, and the use of bang-bang controllers for direct selection of the converter state in the V-DPC is specific for the direct torque control method [4], [5]. An even closer analogy between the rectifier and induction motor controls is obtained using the so-called virtual flux vector, $\Psi_L=\Psi_L\angle\gamma_L$, defined as a time integral of the phase voltage vector, v [6], [7]. It has been recommended to improve the rectifier control below non ideal supply voltage conditions, taking advantage of the integrator's low-pass filter properties [8], [9]. A block diagram of the virtual-flux oriented control (VFOC) scheme with only voltage sensors is shown in Fig. 4. The vector of virtual flux lags the voltage vector by $90_\circ$. Therefore, for the UPF condition, in contrast with the VOC,

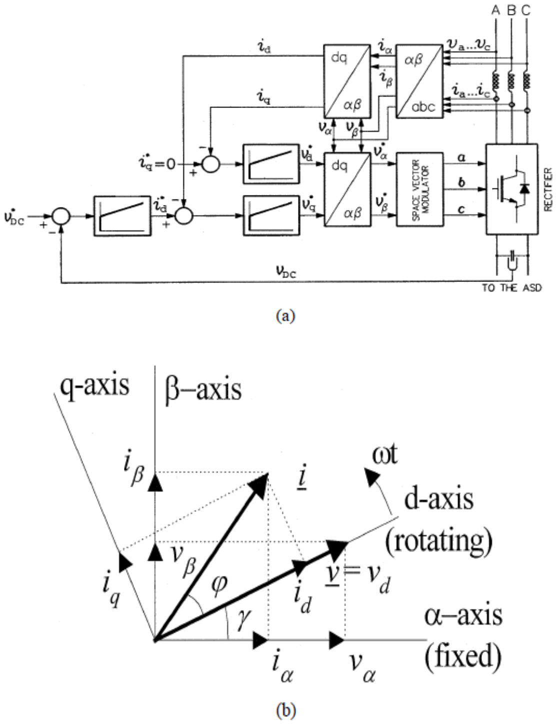


Fig. 2. Voltage oriented control (VOC): (a) block diagram and (b) vector diagram (stationary $\alpha-\beta$ coordinates, rotating $d-q$ coordinates).

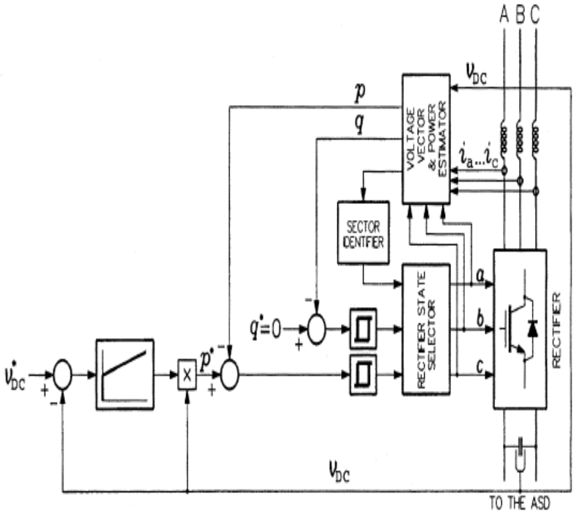
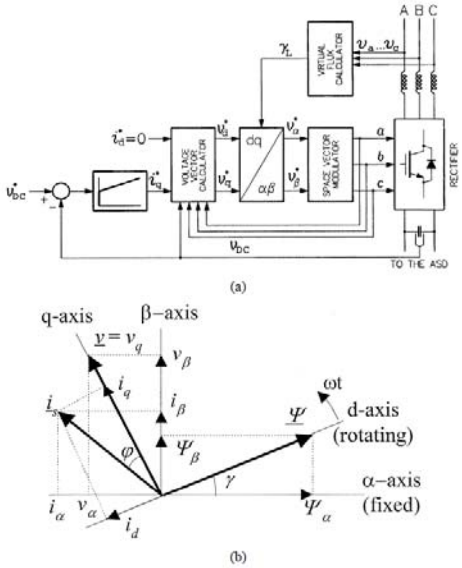


Fig. 3. Voltage based direct power control (V-DPC) scheme.



(a)

(b)

Fig. 4. Virtual-flux oriented control (VFOC): (a) block diagram (current sensorless version), (b) vector diagram (fixed $\alpha-\beta$ coordinates, rotating $d-q$ coordinates).

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It is the reference value, i_{d*} , of the direct component of the current vector that is set to zero.

The reference voltage vector, $v_{*}=v_{d*}+jv_{*}$, in the revolving coordinates is calculated from the reference current signals, i_{d*} and i_{*} , and the vector, $v_{r}=v_{dr}+jv_{r}$.

$$v_d^* = v_{dr} + Ri_d^* + L\frac{di_d^*}{dt} - \omega L i_q^* \qquad (3)$$

$$v_q^* = v_{qr} + Ri_q^* + L\frac{di_q^*}{dt} + \omega L i_d^* \qquad (4)$$

where R denotes resistance of the line reactor and ω is the supply frequency. The phase input voltages, v_{ar}, v_{br}, and v_{cr}, to the rectifier engaged for calculation of v_r, are computed from the output dc voltage, v_{DC}, and switching signals, a, b, and c, as

$$\begin{bmatrix} v_{ar} \\ v_{br} \\ v_{cr} \end{bmatrix} = \frac{v_{DC}}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix}. \qquad (5)$$

Parameters R and L and the phase voltages, v_a, v_b, and v_c, can be considered as the stator resistance, leakage inductance, and EMF parameters of a virtual motor, respectively. As an alternative, if current sensors are used, a closed-loop current control scheme analogous to that shown in Fig. 2 can be employed.

The solution of virtual flux can also be used to enhance the direct power control [10]. The virtual flux based DPC (VF-DPC)

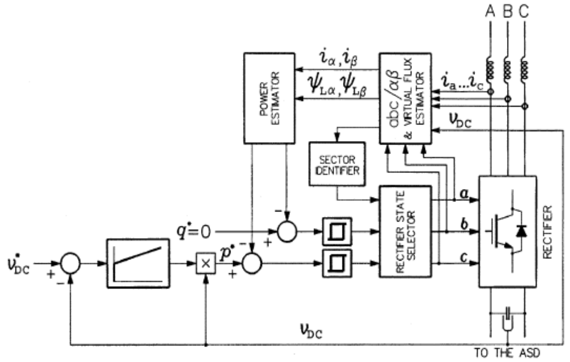

Fig. 5. Virtual-flux based direct power control (VF-DPC) scheme (voltage sensorless version).

Scheme is shown in Fig. 5. The line voltage is estimated as a sum of the rectifier input voltage and voltage drop across the line reactors. The real and reactive powers are calculated as

$$p = \left[\frac{d\Psi_L}{dt}\right]_\alpha i_\alpha + \left[\frac{d\Psi_L}{dt}\right]_\alpha i_\beta + \omega(\Psi_{L\alpha} i_\beta - \Psi_{L\beta} i_\alpha) \qquad (6)$$

$$q = -\left[\frac{d\Psi_L}{dt}\right]_\alpha i_\beta + \left[\frac{d\Psi_L}{dt}\right]_\beta i_\beta + \omega(\Psi_{L\alpha} i_\alpha - \Psi_{L\beta} i_\beta) \qquad (7)$$

Where subscripts α and β stand for the direct and quadrature axes of a stationary reference frame in where in vectors of the virtual flux and line current are expressed.

III. MODELLING AND SIMULATION OF CONTROL STRATEGIES

A. *Voltage Oriented Control*

In Voltage Oriented Control (VOC) control system uses closed-loop current control in rotating reference frame. A quality feature for this current controller is processing of signals in two coordinate systems. The initial is stationary α-β and the second one is synchronously rotating d-q coordinate system. Three phase measured values are converted to equivalent two phase system α-β and then are changed to rotating coordinate system in a block α-β/d-q.

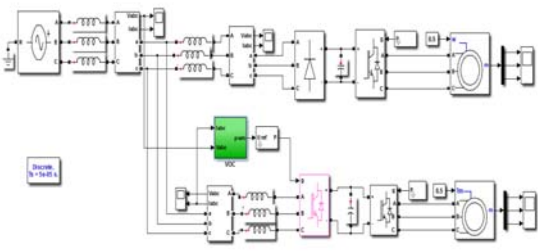

Fig.6 Simulink block of VOC

B. Direct Power Control

Direct Power Control (DPC) is based on the instantaneous active and reactive power control loops. In DPC there are actually no internal current control loops and no PWM modulator block, because the converter switching states are selected by a switching table based on the instantaneous errors between the commanded and estimated values of active and reactive power. Therefore, the most important point of the DPC implementation is a correct and fast estimation of the active and reactive line power.

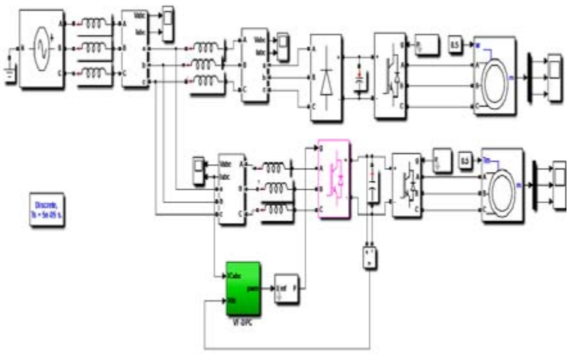

Fig.7 Simulink block of VF-DPC

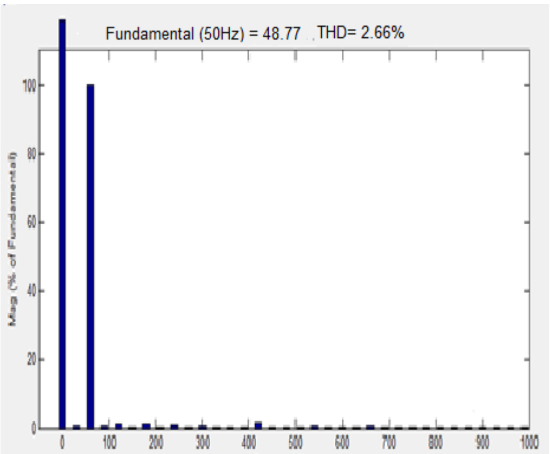

Fig.8 Total harmonic distortion (THD) for VF-DPC

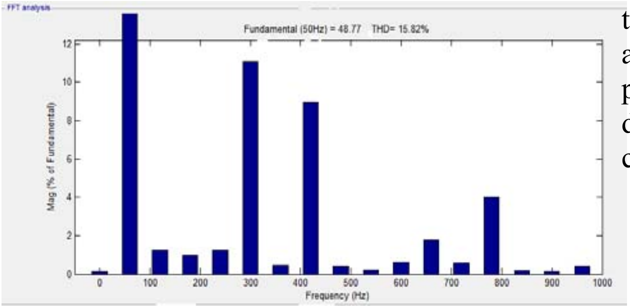

Fig.9 Total harmonic distortion (THD) for VOC

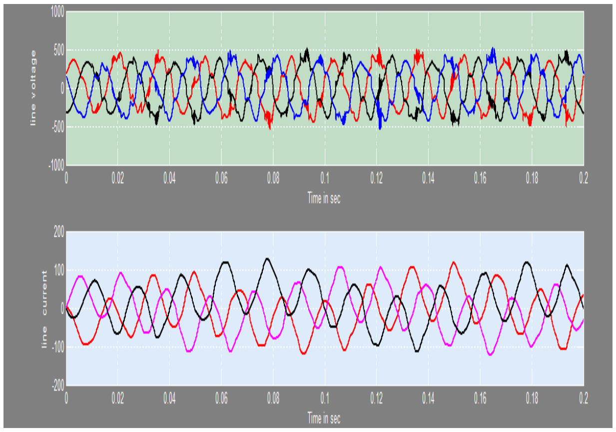

Fig.10 Wave forms of line voltage (top), line current(bottom) for VF-DPC

IV. PERFORMANCE COMPARISON

Performance Comparison of PWM Rectifiers
From the simulations of the Control strategies for PWM Rectifier i.e the virtual flux based Direct Power Control (VF-DPC), coordinates having a novel line voltage estimator, Total Harmonic Distortion, Dynamic performance and Parameter sensitivity of these control strategies are compared

A. Total Harmonic Distortion

From the spectrum analysis, total harmonic distortion for Virtual flux Direct Power Control (THD = 2.66 %) is progressed when compared to conventional Voltage Oriented Control (THD = 15.82 %) .The THD forV-DPC is also better than VOC and VFOC.

B. Parameter sensitivity

From the simulations it is understood that the value of the line inductance affect the value of THD. The VOC technique is insensitive to these variations, because the line inductance affects only the predicted angular position of the line voltage or virtual flux vectors. Therefore, it influences the input power factor but not theTHD of the current. To the contrary, within the DPC schemes, the line inductance right away affects the estimated active and reactive power values, which in the closed control loop define switching instants and, consequently, the current THD.

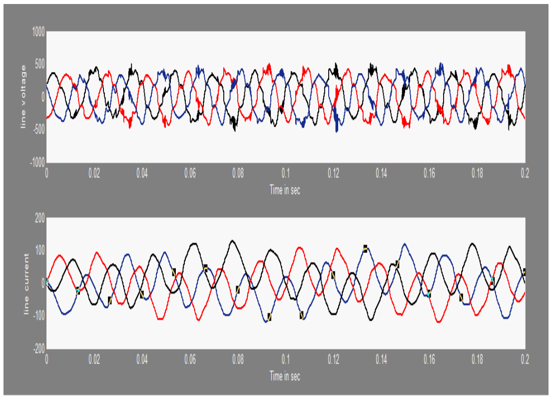

Fig 11. Wave forms of line voltage(top) line current(bottom) for VOC

V.CONCLUSION

In this paper, different control strategies for PWM rectifiers are compared to observe their performance with reference to circuit complexity, robustness, reliability, dynamic response, parameter sensitivity and total harmonic distortion. The VF estimation is far less noisy than that of the line voltage. Moreover, a line voltage or virtual flux estimator can replace AC-line voltage sensors without deterioration in protection and performance of PWM rectifiers. Therefore, taking into account all operational features, the Virtual Flux Based Direct Power Control (VF - DPC) approach seems to be the most advantageous of all as it has simpler algorithm, no current control loops, coordinate transformation and PI controllers are not required, no distinct PWM voltage modulation block, decoupled active and reactive power controls, good dynamic performance compared to VOC

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AUTHORS:

S.Md.Mazhar-ul-haq is a research scholar in JNTU college of Engineering, Hyderabad and he is a faculty in Electrical & Electronics Engineering department of Malla reddy group of institutions, Hyderabad, India, with 10 years of rich experience in teaching, training and research. His research interest is in FACTS devices, power electronics and drives. He published 5 papers in international journals and 3 papers in international and national conferences.

Dr. S.S.Tulasi Ram received B.Tech, M.Tech and Ph.D degrees in Electrical Engineering from JNTU College of Engineerig, Kakinada Currently, he is working as Professor of Electrical& Electronics Engineering in JNTU

College of Engineering, Hyderabad, with three decades of rich experience in teaching, training, research, projects and administration. His area of interest include high Voltage engineering, power system analysis and control. He published 15 research papers in reputed international & national journals and 39 papers in international and national conference

Dr. JBV Subrahmanyam is a Doctorate in Electrical Engineering from JNTU Hyderabad, India, currently he is working as principal and professor of Electrical & Electonics Engineering Department of Teegala Krishna Reddy Engineering College, Hyderabad with two decades of rich experience in teaching, training, research, industry, projects and consultancy. He published 25 research papers in reputed international journals and 20 papers in international and national conferences. His research interest is in automation of power systems. He is an expert in condition monitoring of industrial equipment through modern diagnostic techniques.He implemented the latest GPS and GIS technologies in many power utilities in India successfully. He executed many international and national level technical project seffectively funded by Power Finance Corporation, Ministry of Power Government of India, APDRP,DRUM,USAID and DFID-UK. Optimal Location for Fixing Fuel Cells in a Distributed Generation