Direct Power Control (DPC) of Three Phase PWM Rectifiers

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Abstract .
This paper presents a new method, applied to three phase PWM rectifiers, based on virtual flux called Direct Power Control (VF DPC). The Principle of this control is based on the instantaneous active and reactive power control loops. The results show the excellent advantages, particularly provide a good power factor and low distortions.
***Keywords*—Power quality, Direct Power Control, PWM rectifiers.**

I. INTRODUCTION

The increasing use of non linear loads during this last decades induces severe problems on electrical power systems. The problem consists on the distortion in current and voltage wave forms.

Several harmonic cancellation methods were proposed; the typical one was the connection on the ac side of shunt passive filters. However they are bulky, expensive and resonant. Recently, active filtering and PWM conversion (rectification) are taking their places in industry plants.

Research interest in three-phase Pulse Width Modulated (PWM) rectifiers (AC/DC converters) has grown rapidly over the past few years due to some of their important advantages such as: power regeneration capabilities, control of DC bus voltage, low harmonic distortion of input currents and high power factor (usually near unity). In recent years different strategies have been proposed [1-4] for controlling PWM converter. The main goal of these control strategies is to obtain the high power control and sinusoidal current estimated flux signal is used in the control system. waveforms. Therefore their principles are different. One of these methods the Voltage Oriented Control (VOC), guarantees high dynamics and static performance via an internal current control loops; several papers are published in this field. Consequently, the final configuration and performance of this control largely depends on the quality of the applied current control strategy [3]. The classical Direct Power Control (DPC) is based on the instantaneous active and reactive power control loops. In this method, there are no internal current control loops and no PWM modulator block, because the converter switching states are appropriately selected by a switching table based on the instantaneous errors between the commanded and estimated values of active and reactive power.

Therefore, this method requires a good estimate of the active and reactive powers.

This paper presents a another method of voltage sensorless power estimation based on a duality with the PWM inverted induction motor where the

The use of Virtual motor Flux (VF) signal for power estimation leads to the following advantages of the VF-DPC:

Comparing to the conventional DPC: lower sampling frequency, simpler voltage and power estimation algorithm.

II. POWER ESTIMATION BASED ON VIRTUAL FLUX

The aim of Virtual Flux (VF) approach is to improve the VOC [1], [12]. Here it will be used for instantaneous power estimation. The Simplified representation of a three-phase PWM rectifier system is given by Fig. 1, where the phases of line are presented by the virtual induction motor.

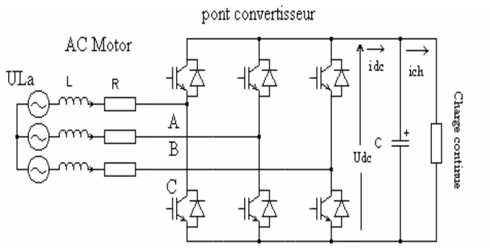

Fig.1. Simplified representation of a three phase PWM rectifier system for bi-directional power flow

Thus, R and L represent respectively the stator resistance and the stator leakage inductance of the virtual motor. Uab, Ubc, Uca are phase-to-phase line voltages induced by a virtual air gap flux, With another words the integration of the phase to-phase Voltages leads to a virtual line flux vector in stationary αβ coordinates (Fig. 2).

With the definitions:

$$\underline{\Psi}_L = \int \underline{u}_L dt \qquad (1)$$

where:

$$\underline{u}_L = \begin{bmatrix} u_{L\alpha} \\ u_{L\beta} \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & 1/2 \\ 0 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} u_{ab} \\ u_{bc} \end{bmatrix} \qquad (2)$$

$$\underline{\Psi}_L = \begin{bmatrix} \Psi_{L\alpha} \\ \Psi_{L\beta} \end{bmatrix} = \begin{bmatrix} \int u_{L\alpha} dt \\ \int u_{L\beta} dt \end{bmatrix} \qquad (3)$$

$$\underline{i}_L = \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 3/2 & 0 \\ \sqrt{3}/2 & \sqrt{3} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \end{bmatrix} \qquad (4)$$

$$\underline{u}_S = \underline{u}_{conv} = \begin{bmatrix} u_{S\alpha} \\ u_{S\beta} \end{bmatrix} =$$

$$\sqrt{2/3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} u_{AM} \\ u_{BM} \\ u_{CM} \end{bmatrix} \qquad (5)$$

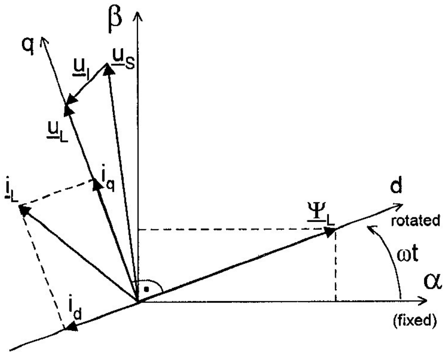

Fig.2. Reference coordinates and vectors $\underline{\Psi}_L$ – virtual line flux vector, $\underline{u}_S$ *converter voltage vector* $\underline{u}_L$ line voltage vector,– $\underline{u}_I$ inductance voltage Vector, $\underline{i}_L$ – line current vector

The voltage equation can be written as

$$\underline{u}_S = R\underline{i}_L + \frac{d}{dt}\left(L\underline{i}_L + \underline{\Psi}_L\right)$$

(6)

Usually, R can be neglected, which gives

$$\underline{u}_S = \frac{d\underline{i}_L}{dt} + \frac{d}{dt}\underline{\Psi}_L = L\frac{d\underline{i}_L}{dt} + \underline{u}_L$$

(7)

With the complex notation, the instantaneous power can be obtained as follows:

$$p = \mathrm{Re}(\underline{u}_L . \underline{i}_L^*)$$
$$p = \mathrm{Im}(\underline{u}_L . \underline{i}_L^*) \tag{8}$$

where * denotes the conjugate line current vector. The line voltage can be calculated by, the virtual flux:

$$\underline{u}_L = \frac{d}{dt}\underline{\Psi}_L = \frac{d}{dt}(\Psi_L e^{jwt}) = \frac{d\Psi_L}{dt}e^{jwt} + jw\Psi_L e^{jwt} = \frac{d\Psi_L}{dt}e^{jwt} + jw\underline{\Psi}_L \tag{9}$$

where $\underline{\Psi}_L$ denotes the space vector and Ψ_L its amplitude. For the virtual flux oriented d-q coordinates (Fig.2), $\underline{\Psi}_L = \Psi_{Ld}$, and the instantaneous active power can be calculated from (8) and (9) as:

$$p = \frac{d\Psi_{Ld}}{dt} i_{Ld} + w\Psi_{Ld} i_{Lq} \tag{10}$$

In the case of sinusoidal and balanced line voltages equation (11) is reduced to:

$$\frac{d\Psi_{Ld}}{dt} = 0 \tag{11}$$

$$p = w\Psi_{Ld} i_{Lq} \tag{12}$$

Which means that only the current components orthogonal to the flux $\underline{\Psi}_L$ vector, produce the instantaneous active power. In the same way, the instantaneous reactive power can be calculated

as: $q = -\frac{d\Psi_{Ld}}{dt} i_{Lq} + w\Psi_{Ld} i_{Ld}$ (13)

and with (11) it is reduced to:

$$q = w\Psi_{Ld} i_{Ld} \tag{14}$$

However, to avoid coordinate transformation into d-q coordinates, the power estimator for the DPC system should use stator-oriented quantities, in α–β coordinates (Fig.2).

Using (8) and (9):

$$\underline{u}_L = \left.\frac{d\Psi_L}{dt}\right|_\alpha + j\left.\frac{d\Psi_L}{dt}\right|_\beta + jw(\Psi_{L\alpha} + j\Psi_{L\beta}) \tag{15}$$

$$\underline{u}_L \underline{i}_L^* = \left\{ \begin{array}{l} \left.\frac{d\Psi_L}{dt}\right|_\alpha + j\left.\frac{d\Psi_L}{dt}\right|_\beta + \\ jw(\Psi_{L\alpha} + j\Psi_{L\beta}) \end{array} \right\}(i_{L\alpha} - ji_{L\beta}) \tag{16}$$

That gives:

$$p = \left\{ \left.\frac{d\Psi_L}{dt}\right|_\alpha i_{L\alpha} + \left.\frac{d\Psi_L}{dt}\right|_\beta i_{L\beta} + w(\Psi_{L\alpha} i_{L\beta} - \Psi_{L\beta} i_{L\alpha}) \right\} \tag{17}$$

and

$$q = \left\{ -\left.\frac{d\Psi_L}{dt}\right|_\alpha i_{L\beta} + \left.\frac{d\Psi_L}{dt}\right|_\beta i_{L\alpha} + w(\Psi_{L\alpha} i_{L\alpha} + \Psi_{L\beta} i_{L\beta}) \right\} \tag{18}$$

For sinusoidal and balanced line voltage the derivatives of the flux amplitudes are null. The instantaneous active and reactive powers can be computed as:

$$p = w.(\Psi_{L\alpha} i_{L\beta} - \Psi_{L\beta} i_{L\alpha}) \tag{19}$$

$$q = w.(\Psi_{L\alpha} i_{L\alpha} + \Psi_{L\beta} i_{L\beta}) \tag{20}$$

III. BLOCK SCHEME OF DIRECT POWER CONTROL (DPC)

The basic block scheme of the VF-DPC system is given by Fig. 3. The converter voltages are estimated in the block (Virtual flux estimator) as follows:

$$u_{S\alpha} = \sqrt{\frac{2}{3}} U_{dc}\left(S_a - \frac{1}{2}(S_b + S_c)\right)$$
$$u_{S\beta} = \frac{1}{\sqrt{2}} U_{dc}(S_b - S_c) \tag{21}$$

Where Udc is DC link voltage and SA, SB, Sc. switch states of converter.

After that, the virtual flux components are calculated from the (7)

$$\underline{\psi}_{L\alpha(est)} = \int (u_{S\alpha} + L\frac{di_{L\alpha}}{dt})dt \qquad (22)$$

$$\underline{\psi}_{L\beta(est)} = \int (u_{S\beta} + L\frac{di_{L\beta}}{dt})dt \qquad (23)$$

The instantaneous power active and reactive are estimated in the block (Power estimator) by measurement of line currents ia,, ib and the estimation of the virtual flux components $\Psi_{L\alpha}, \Psi_{L\beta}$. The command reactive power q^* and (delivered from the outer PI-DC voltage controller) active power p^* values are compared with the estimated q and p values, in reactive and active power hysteresis controllers, respectively.

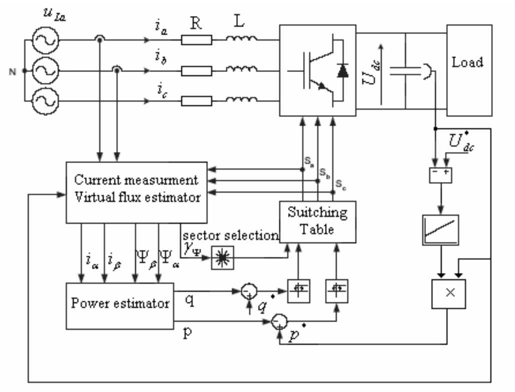

Fig. 3. Block scheme of VF-DPC

The digitized output signal of the reactive power controller is defined as:

$q < q^* - H_q$ for $d_q = 1$

$d_q = 0$ for $q > q^* + H_q$

and similarly of the active power controller as

$p < p^* - H_p$ for $d_p = 1$

$d_p = 0$ for $p > p^* + H_p$

where:

H_p & H_q are the hysteresis band. Table I shows the switching table for VF_DPC control.

Table.1. Switching table for 12 sectors

d_p	d_q	**Sector A**	**Sector B**
0	1	**VB**	**V7**
0	0	**V0**	**V7**
1	1	**VB**	**VB**
1	1	**VA**	**VA**

With:

V0=V0(000),V7(111)

VA=V1(100),V2(110),V3(010),V4(011) , V5(001), V6(101)

VB=V6(101),V1(100),V2(110),V3(010), V4(011), V5(001)

The figure 4 shows the 12 sector voltage plane for switching table.

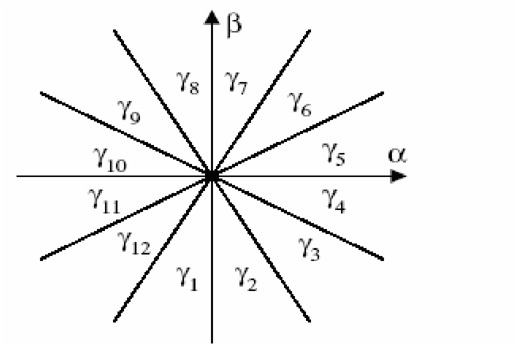

Fig.4. Virtual flux plane with 12 sectors

In this figure region of the voltage is divided in to twelve sectors, the area between adjoining vectors contain two sectors. Sector A is located closer to UA and sector B closer to UB.

IV. SILULATION RESULTS

To study the operation of the virtual flux based DPC/PWM rectifier, it is implemented in SIMULINK / MATLAB environment. The simulation results obtained for different conditions and shown in fig.5 to 13. The DC link voltage response is shown in figures 5.and Fig.6. The line current is shows in Fig.7. As shown in this figure the line current is approximately sinusoidal

In figure 8 we find the curves of active and reactive power in ac line. As shown in this figure the reactive power is approximately equal to zero.

The effect of dc side load on the operation of system is shown in figures 10 to 11 As shown in these figures the change in load don't affect DC link voltage and only change the amplitude of the line current and the line side active power. The line current phase and reactive power will remain constant.

Finally fig.11 and fig.12 show the influence of the band of hysteresis on the vector voltage and duration of their aplication.

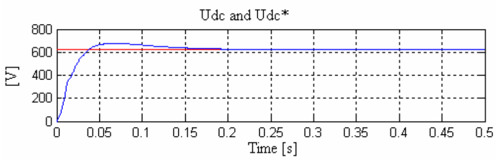

Fig.5 DC link voltage and reference.

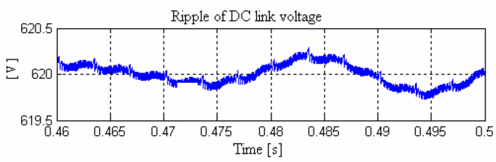

Fig 6 Ripple of DC link Voltage.

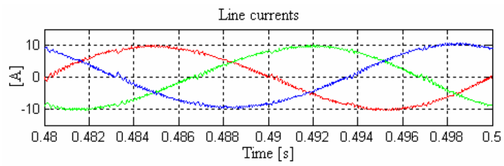

Fig. 7 Line currents

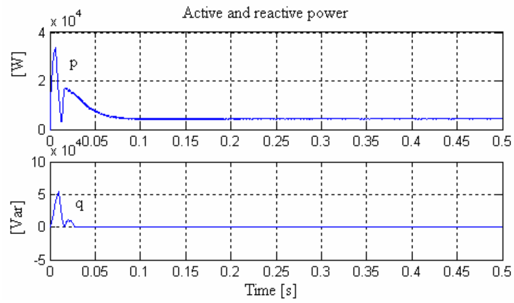

Fig. 8 Instantaneous power active and reactive

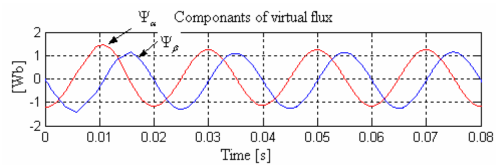

Fig .9 Components of virtual flux.

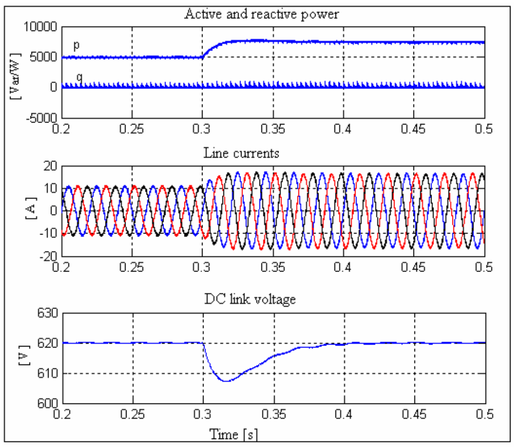

Fig. 10 Transient test results of the power step change of p=5kw to 8kw

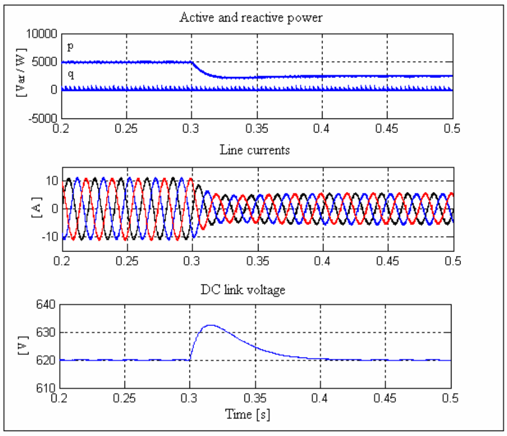

Fig 11.Transient test results of the power step change of p=5kw to 2.5kw

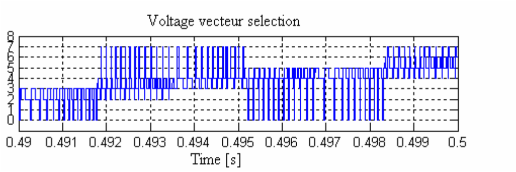

Fig 12.Vector selection during for a half period
Hq=Hp=100 [VAR / W].

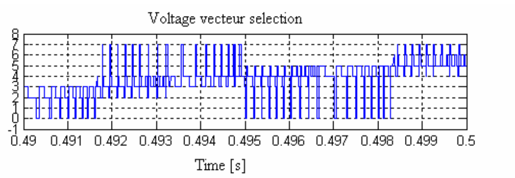

Fig. 13 Vector selection during for a half period
Hq=Hp=150 [VAR / W].

Conclusion

Regarding the advantages of PWM rectifier, in this paper a new control strategy of PWM rectifiers is presented and discuted. To predict behavior of DPC /PWM rectifier in different load, dynamic model is implemented in SIMULINK/MATLAB.
Simulation results show that DPC/PWM rectifier, not only keep regulated DC-link voltage, but also improve power quality indexes.

It is an important advantage of this converter particularly in speed control drive system that the operation of drive should be robust for line voltage disturbed conditions. As simulation results show, the reactive power is programmable in this system and can be set to obtain unity power factor. Also the line current have sinusoidal wave form and because of high switching frequency,

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