Direct Power Control Strategy for PWM Rectifier with the function of an Active Power Filter Based on a Novel Virtual Flux Observer

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Abstract ─

For improving the quality of the energy transfer from the power supply to the load, and reducing the harmful effects of the harmonics generated by nonlinear load. We propose a new multi-function converter (MFC) as an efficient solution to improve the power quality. This paper presents a new DPC strategy based on virtual flux Observer and Space vector Modulation to control PWM rectifier achieving by this unit power factor and reducing the harmonic current of the non linear load. The good dynamic and static performance under the proposed control strategy is verified by simulation and experiment.
Index Terms ─ Harmonics, Three phase APF, IP controller, pulse width modulated, PWM rectifier, DPC, virtual line flux linkage observer, SVM.

I. INTRODUCTION

The current generation of variable speed drives is typically based around the real-time digital generation of pulse-width modulated (PWM) waveforms using either microprocessors or application-specific integrated circuit.
The ideal Pulse Width Modulation strategy for a power electronic converter is one that can achieve the maximum possible voltage or current transfer ratio for a given converter, whilst generating a minimum of low order harmonics and creating minimum switching losses. It should also be computable in real-time for effective and ease implementation. The two major alternative modulation schemes that have been explored to satisfy these objectives are variations of symmetric or asymmetric regular sampled PWM [l, 2,3, 4 and 5].
the previous mentioned method (PWM method) controls each phase current separately using a linear controller and a comparison between a triangular carrier and a phase reference signal, hence a complex analog circuitry are required [6]. The space vector modulation (SVM) strategy controls the three phase currents or voltages together using a single space vector reference entity. It is based on the application of the two adjacent voltage vectors to build the desired voltage vector.

This paper presents a new control method entitled direct power control (DPC) strategy based on a virtual flux observer and Space vector Modulation to control PWM rectifier with the function of an active filter.

II. CONTROL OF PWM RECTIFIER WITH ACTIVE FILTERING FUNCTION

A) Control Method of PWM Rectifier (Virtual Flux)

The aim of Virtual Flux (VF) approach is to improve the VOC [2]. Here it will be used for instantaneous power estimation. The simplified representation of a three phase PWM rectifier system is given by Fig .2, where the phases of line are represented by the virtual induction motor.

Thus, R_f and L_f represent respectively the stator resistance and the stator leakage inductance of the virtual motor. U_{ab}, U_{bc}, U_{ca} are phase to phase line voltages induced by a virtual air gap flux. In another words the integration of the phase to phase Voltage leads to a virtual line flux vector in stationary $\alpha\beta$ coordintes (fig .3)

With these definitions [7]:

$$\underline{\varphi_f} = \int \underline{U_f}\, \mathrm{dt} \tag{1}$$

Where

$$\begin{bmatrix} U_{f\alpha} \\ U_{f\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} U_{ab} \\ U_{bc} \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} \varphi_{f\alpha} \\ \varphi_{f\beta} \end{bmatrix} = \begin{bmatrix} \int U_{f\alpha}\, \mathrm{dt} \\ \int U_{f\beta}\, \mathrm{dt} \end{bmatrix} \tag{3}$$

$$\begin{bmatrix} i_{f\alpha} \\ i_{f\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{2}{3} & 0 \\ \frac{\sqrt{3}}{2} & \sqrt{3} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \end{bmatrix} \tag{4}$$

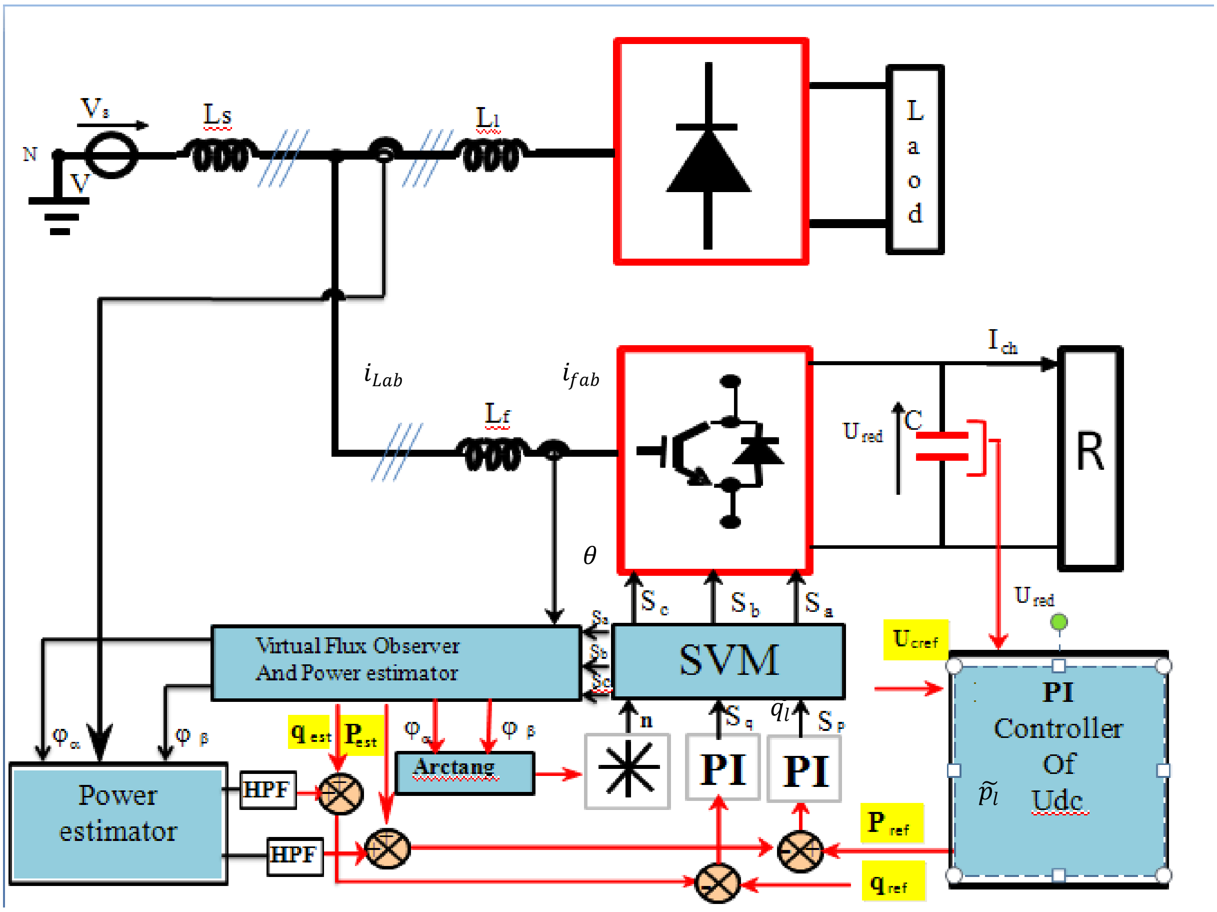

Fig. 1: Control of PWM Rectifier With Active Filtering Function

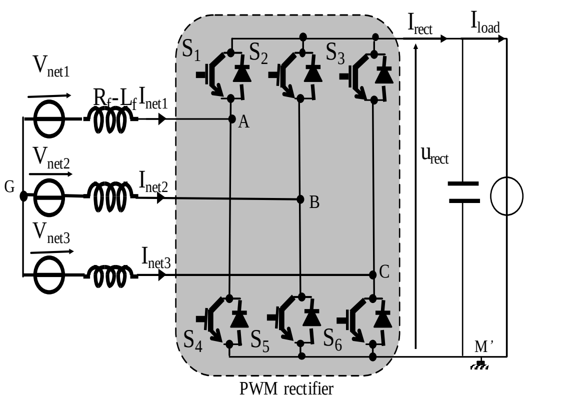

Fig .2. Simplified representation of a three phase PWM rectifier system

$$\begin{bmatrix} U_{s\alpha} \\ U_{s\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} U_{AM} \\ U_{BM} \\ U_{CM} \end{bmatrix} \quad (5)$$

Virtual line flux vector u_s line voltage vector, u_f inductance voltage Vector $\underline{i}_f$ -line current vector

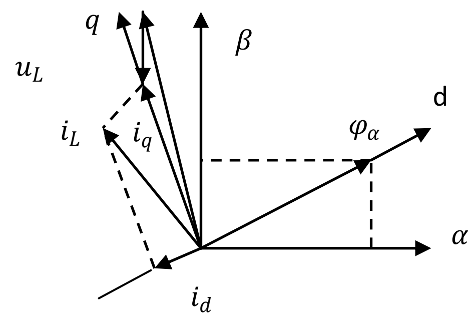

Fig.3. Reference coordinates and vectors φ_L

The voltage equation can be written as

$$\underline{u_s} = R\underline{i_f} + \frac{d}{dt}(L\underline{i_f} + \underline{\varphi_f}) \quad (6)$$

Usually R can be neglected which gives

$$\underline{u_s} = \frac{d}{dt}(L\underline{i_f} + \underline{\varphi_f}) \quad (7)$$

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

$$\text{P=Re}(\underline{u_f}, \underline{i^*_f})$$

$$\text{P=Im}(\underline{u_f}, \underline{i^*_f}) \quad (8)$$

Where * denotes the conjugate line current vector can be calculated by the virtual flux

$$u_f = \frac{d}{dt}\underline{\varphi_f} = \frac{d}{dt}(\varphi_f e^{jw}) = \frac{d\varphi_f}{dt} e^{jw} + jw\varphi_f e^{jw}$$

$$= \frac{d\varphi_f}{dt} e^{jw} + jw\underline{\varphi_f} \quad (9)$$

Where $\underline{\varphi_f}$ indicates the space vector and φ_L its amplitude. For the virtual flux oriented d-q coordinates (Fig.3.) $\underline{\varphi_f} = \varphi_{fd}$, and the instantaneous active power can be calculated form (8) and (9) as :

$$\text{P=}\frac{d\varphi_{fd}}{dt} i_{fd} + w\varphi_{fd} i_{fq} \quad (10)$$

Which means that only the current component orthogonal to the flux $\underline{\varphi_f}$ vector, produces the instantaneous active power. In the same way, the instantaneous reactive power can be calculated as :

$$\text{q=}-\frac{d\varphi_{fd}}{dt} i_{fq} + w\varphi_{fd} i_{fd} \quad (13)$$

However, to avoid coordinate transformation into d-q coordinates, the power estimator for the DPC system should use stator oriented quantities in $\alpha - \beta$ coordinates (fig .3.)

Using (8) and (9)

$$\underline{u_f} = \frac{d\varphi_f}{dt}\Big|_\alpha + j\frac{d\varphi_f}{dt}\Big|_\beta + jw(\varphi_{f\alpha} + j\varphi_{f\beta}) \quad (14)$$

$$\underline{u_f i^*_f} = \begin{Bmatrix} \frac{d\varphi_f}{dt}\Big|_\alpha + j\frac{d\varphi_f}{dt}\Big|_{\alpha\beta} + \\ jw(\varphi_{f\alpha} + j\varphi_{f\beta}) \end{Bmatrix} (i_{f\alpha} - ji_{f\beta}) \quad (15)$$

That gives :

$$\text{p=} \frac{d\varphi_f}{dt}\Big|_\alpha i_{f\alpha} + j\frac{d\varphi_f}{dt}\Big|_\beta i_{f\beta} + jw(\varphi_{f\alpha} i_{f\beta} + j\varphi_{f\beta} i_{f\alpha})$$
(16)

and

$$\text{q=} \frac{d\varphi_f}{dt}\Big|_\alpha i_{f\beta} + j\frac{d\varphi_f}{dt}\Big|_\beta i_{f\alpha} + jw(\varphi_{f\alpha} i_{f\alpha} + j\varphi_{f\beta} i_{f\beta})$$
(17)

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

$$p_c = w.(\varphi_{f\alpha} i_{f\beta} - \varphi_{f\beta} i_{f\alpha}) \quad (18)$$
$$q_c = w.(\varphi_{f\alpha} i_{f\alpha} + \varphi_{f\beta} i_{f\beta}) \quad (19)$$

Block Scheme of power Virtual Flux observer:

The Basic block scheme of the VF-DPC system is given by Fig.1. The converter voltages are estimated in the block as follows:

$$v_{f\alpha} = \sqrt{\frac{2}{3}}\text{U}_{\text{dc}}(S_a - \frac{1}{2}(S_b + S_c)) \quad (20)$$

$$v_{f\beta} = \sqrt{\frac{1}{2}}(\text{U}_{\text{dc}}(S_b - S_c)) \quad (21)$$

Where U_{dc} is DC link voltage and S_a $S_b S_c$ switch states of converter.
After that the virtual flux components are calculated from the (7)

$$\varphi_{f\alpha} = \int(v_{f\alpha}\text{dt} + \text{L}i_{f\alpha}) \quad (22)$$
$$\varphi_{f\beta} = \int(v_{f\beta}\text{dt} + \text{L}i_{f\beta}) \quad (23)$$

According to equation (22) and (23),the integrator can be used to estimate the virtual flux ,but the initial value of flux must be estimated firstly this makes simulation complex and DC offset could be produced easily [14].
The novel virtual line flux observer and the comparison of the observers are showed in fig 4 and fig 5 respectively, which distinctly shows that the novel algorithm responds faster than the traditional control.

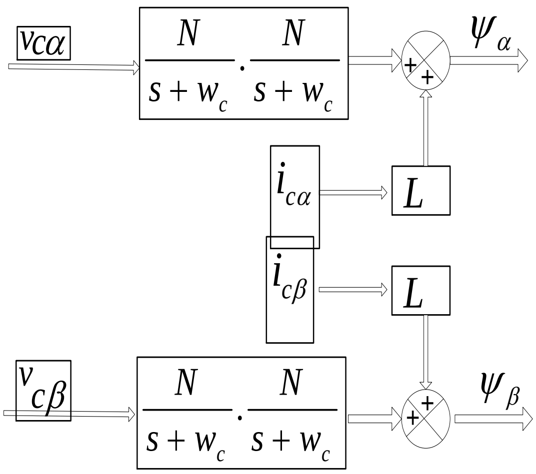

Fig 4 The novel virtual line flux linkage observer

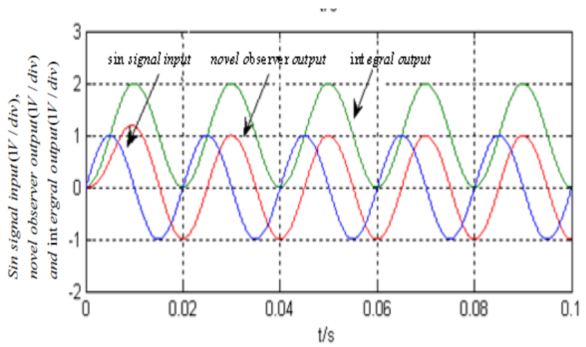

Fig 5 The comparison of the three observer.

The instantaneous active and reactive powers are observed in the block (power observer) by measurement of line current and the observation of the virtual flux components $\varphi_{f\alpha}, \varphi_{f\beta}$.

III. SPACE VECTOR PWM STRATEGY

The presented SVPWM strategy generates the specific sequence of states of the AC/DC converter without using a Park transformation. The reference voltage vector is defined as[3]:

$$\vec{u}_m = \frac{t_1}{T_m}\vec{u}_x + \frac{t_2}{T_m}\vec{u}_y + \frac{t_0}{T_m}\vec{u}_z$$

The vector $\vec{u}_m$ can take eight positions in the plane $\vec{u}_{m1}, \vec{u}_{m2}$ according to values of the phases 1,2,3 switching function S_a , S_b and S_c Fig.3 shows the eight possible configurations of the voltage vectors in the plane $\vec{u}_{m1}, \vec{u}_{m2}$. Vector v_1 ,v_6 divide the $\vec{u}_{m1}, \vec{u}_{m2}$. plane into six sectors. In each sector, the reference

voltage vector is generated by combining the two vectors v_x ,v_y limiting the sector, in addition to a zero sequence voltage v_z which is v_0 or v_7.

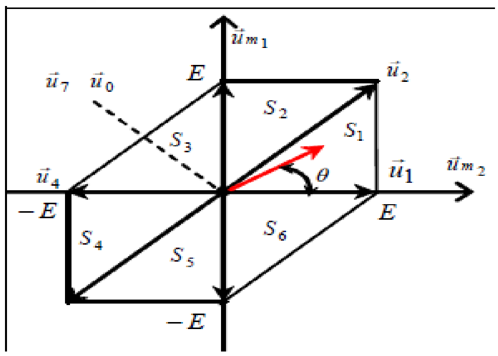

Fig.6. Space vector location into the frame

A. detection of sector

The plane $\vec{u}_{m1}, \vec{u}_{m2}$ is divided as it is shown in figure 3 to six sectors S_1 –S_6 Each sector is defined according the angle *between* the u_{m1} – axis and the reference voltage vector u_m.

$$\theta = arctg\frac{\Psi\alpha}{\Psi\beta}$$

$$if\ 0 < \theta < \frac{\pi}{4} \qquad S = 1$$

$$if\ \frac{\pi}{4} < \theta < \frac{\pi}{2} \qquad S = 2$$

$$if\ \frac{\pi}{2} < \theta < \pi \qquad S = 3$$

$$if\ \pi < \theta < \frac{5\pi}{4} \qquad S = 4$$

$$if\ \frac{5\pi}{4} < \theta < \frac{3\pi}{2} \qquad S = 5$$

$$if\ \frac{3\pi}{2} < \theta < 2\pi \qquad S = 6$$

IV. EXPERIMENTAL RESULTS

In this section, experimental results are shown to test the proposed controller using a prototype. For this purpose, the three-phase two-level power converter of Fig. 7 has been developed, with a digital implementation of the control algorithm that has been executed in a TMS320lf2407-40 MHz which has two high-resolution analog to digital (A/D) converters (0.8µs-10bit) provide very fast processing for fixed point calculations.

The electrical parameters of which are shown in Table II.

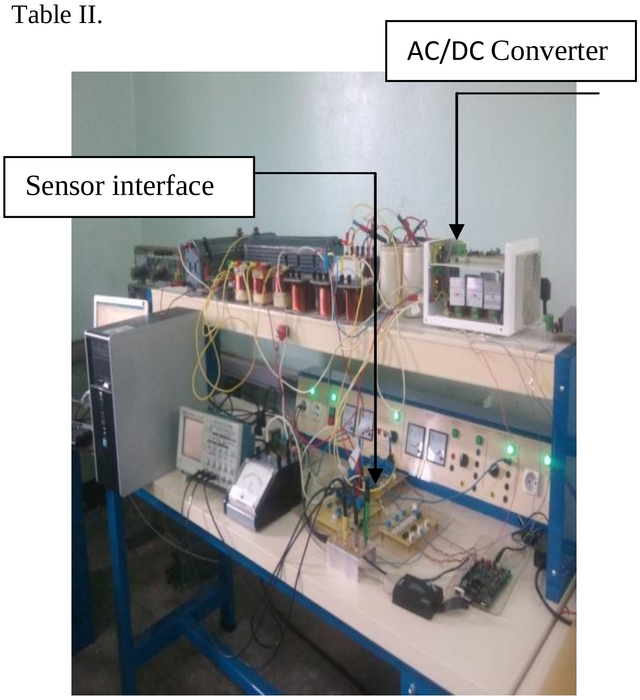

Fig.7. PWM Rectifier With the function of an Active Power Filter experimental test bench.

TABLE II
ELECTRICAL AND CONTROL PARAMETERS FOR THE EXPERIMENTAL SYSTEM

resistance of reactors	2.9 Ω
inductance of reactors	11 mH
resistance of reactors	2.5 Ω
inductance of reactors	7.5 mH
resistance of line	
inductance of line	
dc-link capacitor	4.7mF
phase voltage (RMS)	110 V
Dc-link voltage	300 V
PWM rectifier load:	110 Ω
diode rectifier load:	42 Ω
The hysteresis band was fixed	0.01

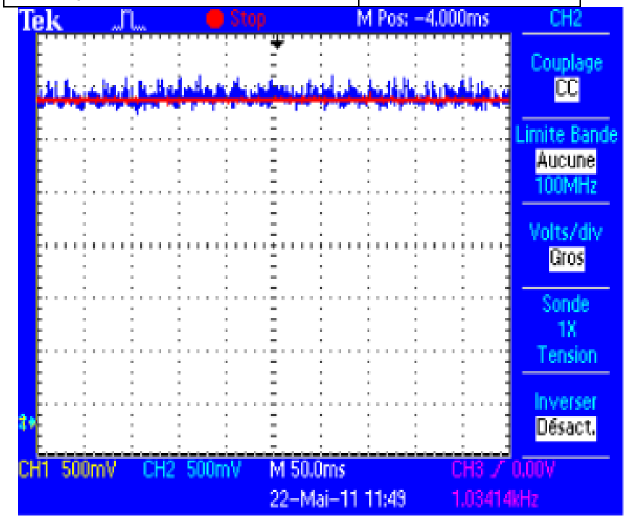

Fig 8. DC –link voltage

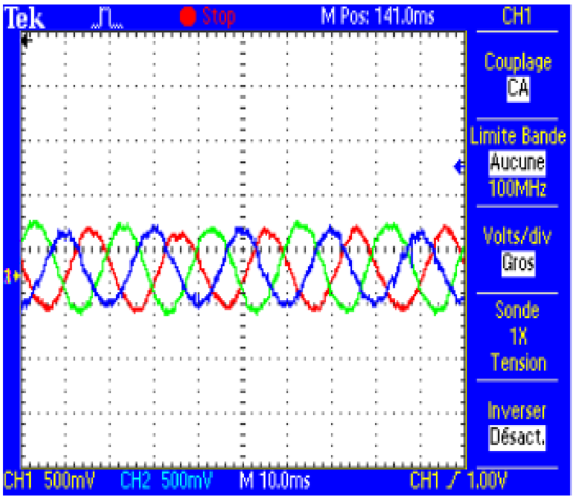

Fig 9. Operation of PWM Rectifier under grid current sag.

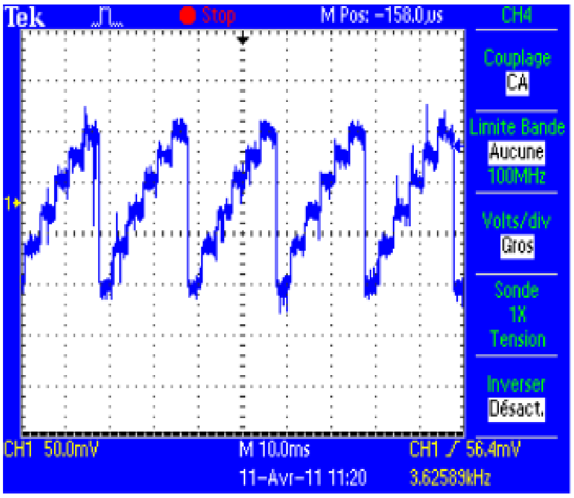

Fig 10 Experimental waveforms of Sector

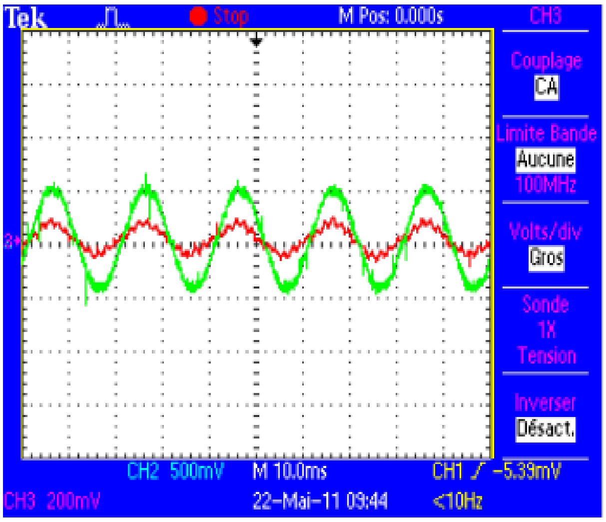

Fig 11. PWM rectifier operation without filtering operation [line voltage (v) and line current (i)].

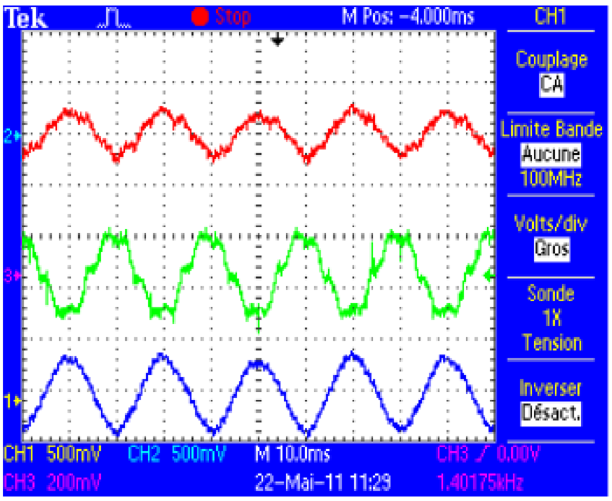

Fig 12. From top to bottom active filter current, load ac current and ac source current

Fig.8. Fig. 9. Fig 11. Presents the start up the PWM rectifier operation. It is noted the linear currents are sinusoidal and the control technique presents a very good dynamic behavior, Thais thanks to PI regulator behavior used control the DC-link voltage. Under APF operation, the line current becomes almost sinusoidal as well as in phase with line voltage, which gives near-to-unity power factor.

As Fig. 10 shows the waveform of the sector in which the reference voltage vectors can be located, which indicates that the DPC control strategy of PWM rectifier has a fast dynamic performance and excellent output performance

CONCLUSION

This paper has proposed Direct Power Control (DPC) strategy based on a novel virtual flux observer with Space vector Modulation to control PWM rectifier. The obtained results show that this control has a good dynamics, and it offers sinusoidal line currents (low THD) for ideal and distorted line voltage and compensates automatically the reactive power part to improve the main power factor to unity, the three-phase voltage-type PWM rectifier having also the function of an active power filter has been investigated and its effectiveness has been confirmed using a three-phase diode bridge rectifier with a smoothing reactor as a nonlinear load.

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