Direct Power Control With Space Vector Modulation And Fuzzy DC-Voltage Control- PWM rectifier

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Abstract: - The study made in this paper concerns the use of the direct power control (DPC) of three-phase pulse width modulation (PWM) rectifier with constant switching frequency. This control method, called direct power control with space vector modulation (DPC-SVM), the uses of SVM technique for the converter switching signal generation, is based on the power control model of the converter in synchronous coordinates (dq), with the aim of ensuring a stable active power exchange, and providing line current very close to sinusoidal waveforms, and good regulation of DC-bus voltage is achieved using FUZZY controller. A digital simulation, in Matlab/Simulink/ SimPowerSystems and Fuzzy Logic Toolbox, was carried out. This showed clearly the effectiveness of the adopted control strategies.

Key-Words: - DPC, FLC ,Instantaneous active and reactive power, PWM-rectifier, Space vector modulation,THD

NOMENCLATURE

e_a, e_b, e_c: power source voltages.
u_{ea}, u_{eb}, u_{ec}: rectifier voltages
i_a, i_b, i_c: power source currents.
R, L, and C: line resistance, line inductance, and capacitor.
f: frequency.
ω: frequency pulsating.
S_a, S_b, S_c: Switching state of the converter.
φ : phase voltage.
V_{dc} : direct voltage.
i_d: load current.
h: the order harmanique.
R_d: load resistance.
G,G_e, $G_{\Delta e}$: gains of the Fuzzy controller.
P_{est} ,Q_{est}: active and reactive power estimation.
P_{ref} ,Q_{ref}: active and reactive power reference.

1 Introduction

Most of three-phase rectifiers, extensively employed in industrial fields and consumer products, use a diode bridge circuit[1][2]. That advantage of being simple and low cost. However, diode rectifier permits on unidirectional power flow, low power factor and high level of harmonic input currents. Therefore, a three-phase pulse width modulated (PWM) rectifier is interesting as a solution for various industrial applications, thanks to viable advantages such as bi-directional power flow, low harmonic distortion of line current, regulation of input power factor to unity, adjustment and stabilization of DC-link voltage [1].

Research interest in this type of PWM converter has grown rapidly over the past few years and various control strategies have been proposed in recent works[3]. They can be classified according to its use of current loop controllers or active and reactive power controllers.

The control by the loop current is a voltage oriented control (VOC) [4], it guarantees high dynamics and static performances via internal control loops. One main drawback of such a system is that the performance largely depends on the quality of the current control strategy. In recent years, emerging and interesting control technique is the direct power control (DPC). In DPC scheme, there are no internal control loops and the converter switching states are appropriately selected by a switching table based on the instantaneous errors between the controlled and estimated values of the instantaneous active and reactive powers and the voltage vector position. The major disadvantage of the DPC is that is variable switching frequency. To eliminate the above drawbacks, direct power control with space vector modulation (DPC-SVM), is presented in recent works [1][2][5]. Instead of the switching table, in DPC–SVM method, the switching states of the converter are generated by a SV-PWM modulator block operating with constant switching frequency..

This paper presents a direct power control with space vector modulation (DPC-SVM) of three phase PWM rectifier based on fuzzy logic control approach, which makes it possible to achieve unity power factor operation by directly controlling its instantaneous active and reactive power. The dc-bus voltage is regulated by controlling the active power using Fuzzy logic controller. Finally the developed fuzzy controller is shown via simulation results that the proposed controller based on fuzzy logic control gives a good performance, a good rejection of the impact load disturbances, a good dynamic behaviour output the voltage regulation and a low THD.

2 Principles of DPC-SVM based Fuzzy Controller

The schematic diagram of three phase PWM rectifier with DPC-SVM algorithm is shown in Fig.1. The AC source voltages are e_a, e_b , e_c . The AC current are i_a, i_b, i_c . the AC terminal voltages of the PWM are u_a, u_b, u_c. the DC-voltage is v_{dc}. The AC side impedance is modeled as an inductor L in series with a resistor R. The DC side capacitor is C and the DC load is R_d. The modulation signals of phase a, b and c are S_a , S_b and S_c

The voltage equation in the stationary abc frame is [6]:

$$\begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} = R\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + L\frac{d}{dt}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} \tag{1}$$

In the stationary frame αβ the voltage equation can be represented as [6]

$$\begin{bmatrix} e_\alpha \\ e_\beta \end{bmatrix} = R\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} + L\frac{d}{di}\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} + \begin{bmatrix} u_\alpha \\ u_\beta \end{bmatrix} \tag{2}$$

By transforming (2) into synchronous rotating frame dq, the voltage equation in the synchronous dq coordinates is derived as :

$$\begin{aligned} e_d &= Ri_d + L\frac{di_d}{dt} - \omega L i_q + u_d \\ e_q &= Ri_q + L\frac{di_q}{dt} + \omega L i_d + u_q \end{aligned} \tag{3}$$

The AC terminal voltages of the PWM rectifier u_a, u_b, u_c are commuted from the output DC-voltage and switching signals S_a, S_b and S_c as:

$$\begin{bmatrix} u_{ea} \\ u_{eb} \\ u_{ec} \end{bmatrix} = \frac{v_{dc}}{3}\begin{pmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{pmatrix}\begin{pmatrix} S_a \\ S_b \\ S_c \end{pmatrix} \tag{4}$$

The main idea of DPC is proposed by Noguchi [8] and it is similar to the well-known DTC for induction motors. Instead of controlling torque and flux, the instantaneous active and reactive powers are controlled. The controlled reactive power q_{ref} (set to zero for unity power factor operation) [2][7][8]

and active power P_{ref} (delivered from the outer FUZZY-DC voltage controller) are compared with the estimated Q_{est} and P_{est} values, respectively The errors are DC quantities that are delivered to PI controllers that eliminate steady state error[2][7][8]. The output signals from PI controllers, after decoupling operation and transformation to *αβ* coordinates system, are used for switching signals generation by SVM

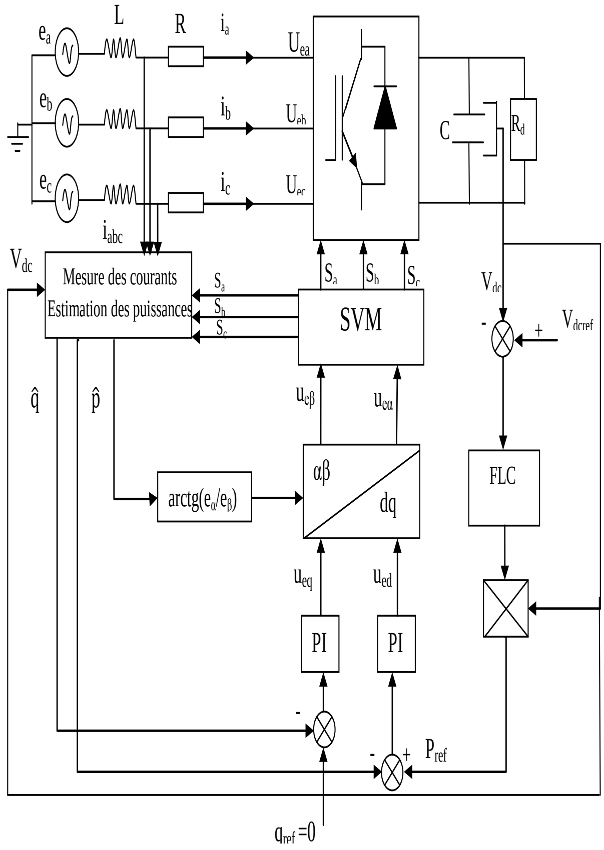

Fig. 1. Block diagram of DPC–SVM for three-phase PWM rectifier

2.1 Fuzzy DC voltage control

The principal scheme of the proposed fuzzy logic control is given by Fig.2 [3]. The dc bus voltage V_{dc} is sensed and compared with a reference value V_{dcref} the obtained error [4].

$$\varepsilon\,(k) = v_{dcref}\,(k) - v_{dc}\,(k) \tag{5}$$

and its incremental variation

$$\Delta\varepsilon(k) = \varepsilon(k) - \varepsilon(k-1) \tag{6}$$

The k^{th} sampling instant is used as inputs for fuzzy controller [3]. The output is the instantaneous active Pref. the dc bus voltage is controlled by adjusting the active power using fuzzy controller.

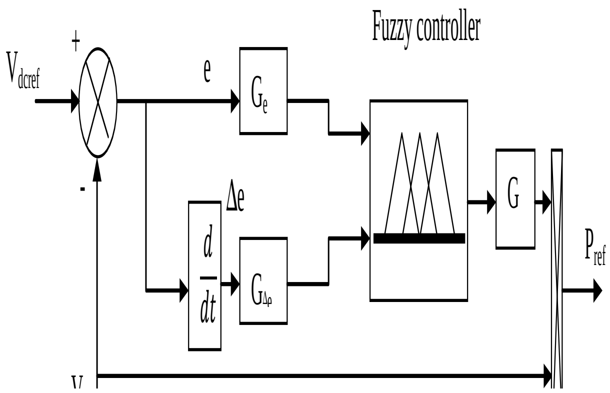

Fig 2. DC voltage fuzzy control

3 Simulation results

To validate the effectiveness of the control strategy studied in this paper, a digital simulation was carried out under MATLAB/SIMULINK environment. The DC voltage control system is tested as well as the DPC-SVM method following a DC voltage step variation occurred at t=0.5s from 300V to 350V. The effectiveness of the DC voltage fuzzy control is illustrated by Fig.3. We can see that the system became stable. The system response is very fast, and does not present any overshoot

Fig.4 shows that when the dc voltage reaches the new reference value, also the active power and consequently the line current increase.

In this case the power increase is limited, what avoids dangerous over currents for the system operation.

In Fig.5, we can see that the reactive power flow is small, what is very beneficial for the system performances, and provide the power factor.

In order to maintain the continuous bus charged, the DC voltage variation involves a reference variation in the instantaneous active power. Fig.4 and fig.5 shows that the DPC-SVM technique responds very quickly with regard to the power reference variation.

Fig 6 shows that the line voltage is in phase with the line current so a power factor is assured

The wave shape of the line current close to the sinusoid, and hence the THD (Total Harmonic Distortion) was reduced THD=1.862 (see fig.7)

The system parameters studied in this paper are given in Table.1.

Switching frequency	30 KHz
R	0.2 Ω
L	0.016 H
C	0.0045 F
R_{load}	100 Ω
Peak amplitude of line voltage	120 V
Source voltage frequency	50 Hz
DC-Voltage V_{dcref}	300 V

Table.1: systems parametres

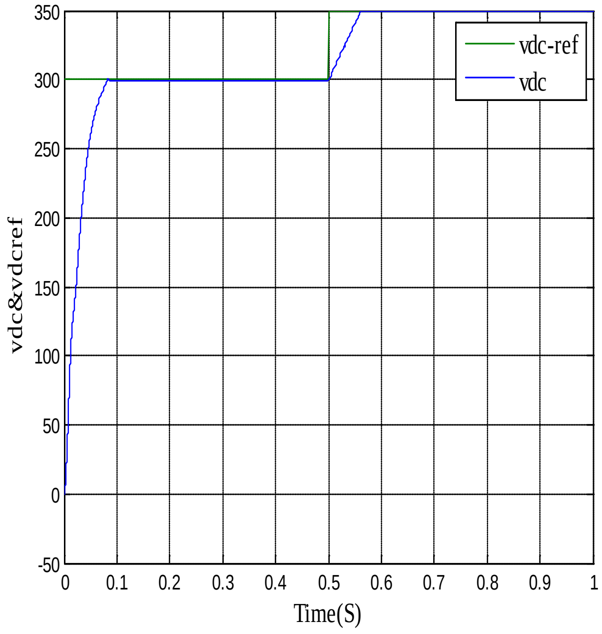

Fig. 3: Control system step response.

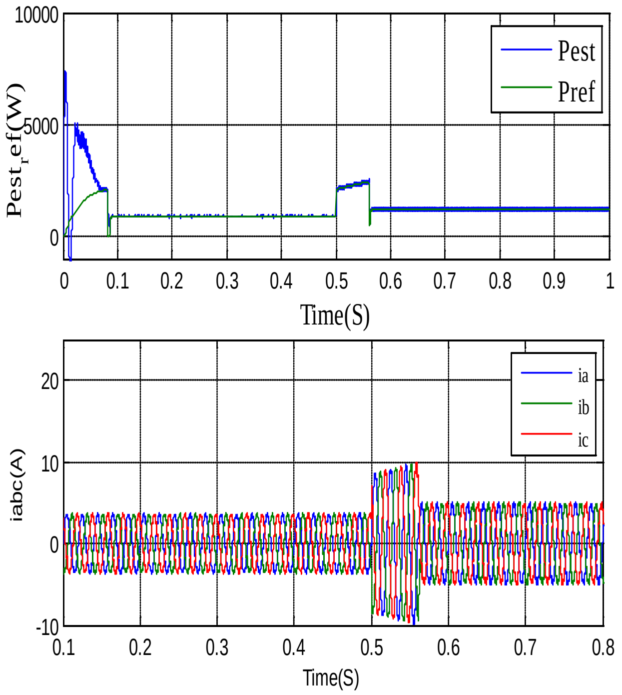

Fig. 4: Reference and estimation active power and line current

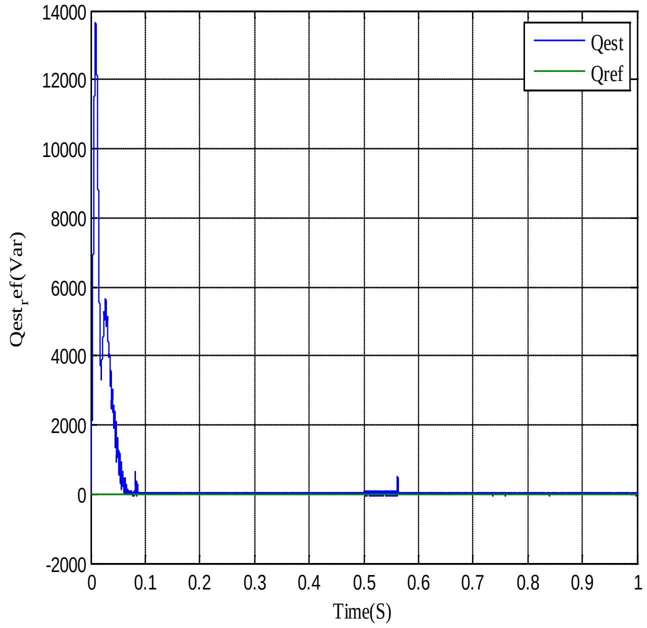

Fig. 5: Estimated and reference instantaneous reactive power.

Fig.6. shows that the current is in phase with the line voltage and the current is multiplied by a gain equal to 20

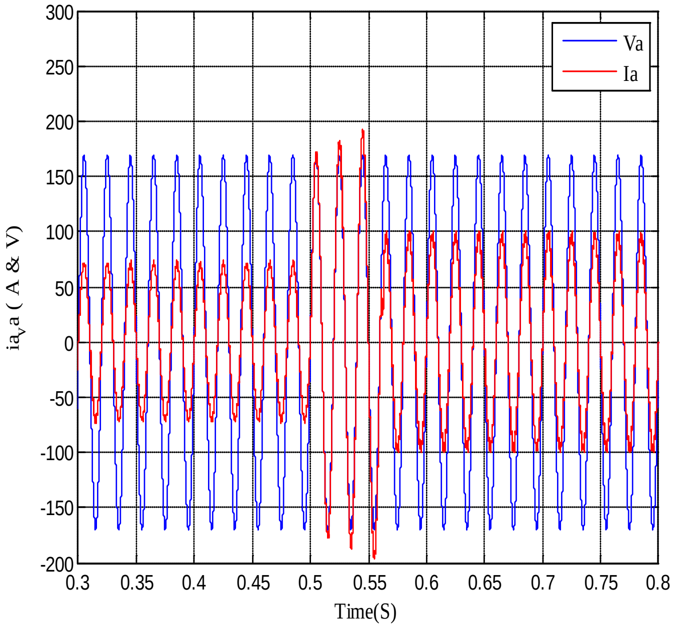

Fig.6. Line current and line voltage are in phase (cos(φ)=1)

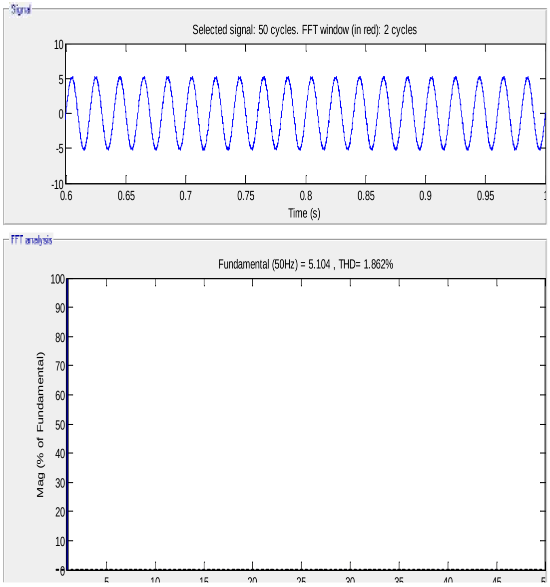

Fig.7. Harmonic spectrum and THD of the current with a fuzzy controller.

4 Conclusion

In this paper we presented a new control strategy for a PWM rectifier constant switching frequency. It concerns the use of the direct power control with space vector modulation (DPC-SVM) principle via a fuzzy control system on the DC side; it reduces the number of sensor used, and to offer a fast power response following a disturbance. In order to obtain a stable exchange of the active power flow between the converter and the electrical network, the dc voltage is controlled using a fuzzy regulator.
Simulation results showed that the DPC-SVM technique combined to a dc voltage fuzzy control improves the system performances.
These improvements concern the performances of the system response on the DC side (overshoot and response time), as well as the power-factor and the THD of the line current.

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