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# Performances Improvement of Three-phase Voltage Source Inverter Using Direct Power Control

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Abstract- ***This paper, deals with an improvement of the direct power control (DPC) for three-phase voltage source inverter named PWM rectifier, the DPC control strategy is proposed to control PWM voltage source inverter under various loads. The control strategy is especially designed to reduce the harmonics distortion, to maintain the DC side capacitor voltage at the required level, while the input currents drawn from the power supply should be sinusoidal and in phase with respective phase voltages to satisfy the unity power factor. The detailed operation principle and simulation results of the proposed technique for three-phase converter fed various load are also discussed.***

**Keywords:** Direct power control, three phase voltage source inverter, performances, improvement.

## 1. INTRODUCTION

The increasing use of static converters in industrial applications causes several problems in electrical networks and grid. These converters result in a deterioration of the control and automatic power electronic equipments, protection systems, and other electrical loads [1]. Traditional method of the current harmonic compensation involves passive filters. These filters are used to eliminate lower order harmonics, consequently, these passive present many disadvantages such as series and parallel resonances [2]. The use of the active power filters (APFs) was been one of the most competitive modern solutions to suppressing harmonic pollution, enhance power quality, and insure the better power distribution system. According to its procedure connection to the power system, there are two types of (APFs) as series active power filter and parallel (shunt) active power filter [2, 3]. The AC/DC conventional rectifiers converter such as Diodes Bridge have nonlinear loads nature, which absorb a no sinusoidal input current, consume sometimes reactive energy, and they generate harmonic currents in to the AC line power [4-6]. Researches and application show that the PWM voltage source converters (PWM rectifiers) are used in several industrial applications, the performance of the PWM converter depends on the design of the structure and the types of controllers to obtain the high performances [7,8]. In this paper, the DPC strategy is proposed to control PWM voltage source converters rectifiers. The PWM rectifier has six power transistors with anti-parallel diodes, which is used to carry out the PWM generation as well as the power bidirectional conversion. The converter is supplied by a three-phase source in series with coupling inductance (Lc), the PWM rectifier is supplying various loads connected in parallel with DC capacitor voltage. The advantage of PWM voltage source converter rectifier as non-polluting equipment, he has sinusoidal input currents with unity power factor with bi-directional power flow and the stabilization of output DC voltage. Several control strategies were proposed in recent works for the PWM rectifier, DPC strategy based on PI controller provides sinusoidal line current and lower harmonic distortion in to the AC line power. This paper is dedicated to this specific type of converter using DPC control strategy.

## 2. SYSTEM MODELING

The instantaneous voltages of AC source and the fundamental line current [9, 10] are expressed as:

$$\begin{cases} v_{an}(t) = V_m \cos(\omega t) \\ v_{bn}(t) = V_m \cos(\omega t - \frac{2\pi}{3}) \\ v_{cn}(t) = V_m \cos(\omega t - \frac{4\pi}{3}) \end{cases} \tag{1}$$

$$\begin{cases} i_a(t) = I_m \cos(\omega t + \varphi) \\ i_b(t) = I_m \cos(\omega t - \frac{2\pi}{3} + \varphi) \\ i_c(t) = I_m \cos(\omega t - \frac{4\pi}{3} + \varphi) \end{cases} \tag{2}$$

$V_m$ : is the amplitude source voltage,
$I_m$ : is the amplitude of the phase current,
$\varphi$ : is the angular phase.
With assumption:

$$i_{AN} + i_{AN} + i_{AN} = 0 \tag{3}$$

In α–β frame , the input voltages are:

$$\begin{cases} v_{s\alpha}(t) = \frac{\sqrt{3}}{2} V_m \sin(\omega t) \\ v_{s\beta}(t) = \frac{\sqrt{3}}{2} V_m \cos(\omega t) \end{cases} \tag{4}$$

Similarly, the input voltages in the synchronous d-q coordinates are expressed by:

$$\begin{cases} v_{sd}(t) = \frac{\sqrt{3}}{2} = \sqrt{v^2{}_{sd} + v^2{}_{sq}} \\ v_{sq}(t) = 0 \end{cases} \tag{5}$$

Line to line input voltages of PWM rectifier can be described as:

$$\begin{cases} v_{AB}(t) = (S_A - S_B) * V_{dc} \\ v_{BC}(t) = (S_B - S_A) * V_{dc} \\ v_{CA}(t) = (S_C - S_A) * V_{dc} \end{cases} \tag{6}$$

$$\begin{cases} v_{sa} = v_{ca} + Ri_{ca} + L\dfrac{di_{ca}}{dt} \\ v_{sb} = v_{cb} + Ri_{cb} + L\dfrac{di_{cb}}{dt} \\ v_{sc} = v_{cc} + Ri_{cc} + L\dfrac{di_{cc}}{dt} \end{cases} \tag{7}$$

And additionally for currents

$$C\frac{du_{dc}}{dt} = S_a i_{Ca} + S_b i_{Cb} + S_c i_{Cc} - i_{dc} \tag{8}$$

The structure of three-phase voltage source inverter is as shown in Figure 1.

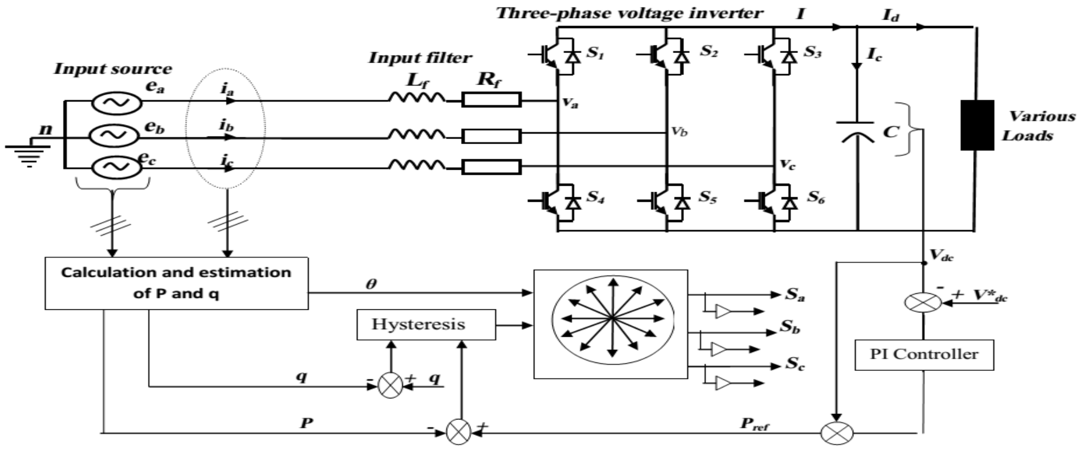



Figure 1 Three-phase PWM voltage source converter

## 3. DIRECT POWER CONTROL

The basic principle of the Direct Power Control (DPC) was proposed by Noguchi, [11]. This strategy was inspired from DTC is based on the concept of the direct control of the torque applied to the electric machines. The DPC strategy was developed for controlling PWM rectifiers connected to the network [12-15], it is based on the instantaneous active and reactive power control loops. In this technique, there are no internal current control loops and no PWM modulator block [4,15-17], because the PWM voltage source converters switching states are appropriately selected by a lookup table based on the instantaneous errors between the reference and measured values of the active and reactive powers are defined as:

$$p = v_{an}(t)\cdot i_a(t) + v_{an}(t)\cdot i_a(t) + v_{an}(t)\cdot i_a(t) \tag{9}$$

$$q = \frac{1}{\sqrt{3}}((v_{bn}(t) - v_{cn}(t))\cdot i_a + ((v_{cn}(t) - v_{an}(t))\cdot i_b + (v_{an}(t) - v_{bn}(t))\cdot i_c) \tag{10}$$

Figure 2 shows the configuration of the direct instantaneous active and reactive power controller for the PWM rectifier.

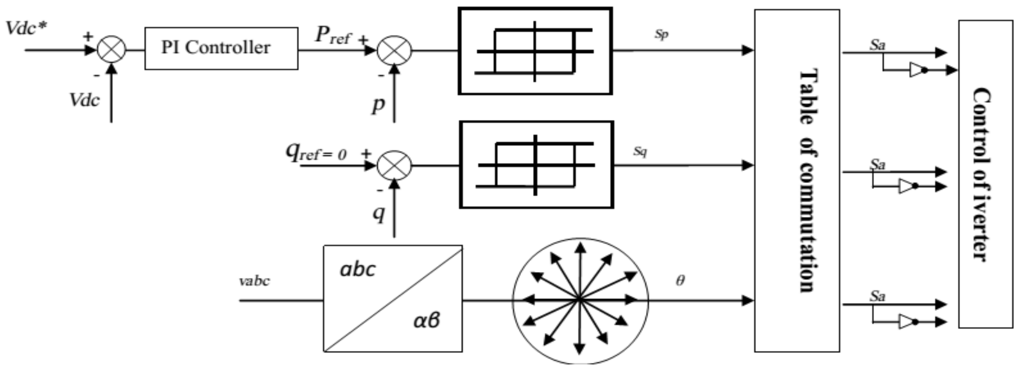



Figure 2 DPC based on the instantaneous P and Q power control

## 4. HYSTERESIS CONTROL

The regulators used are hysteresis comparators for errors instantaneous active and reactive power. The output switches determines the switching state of the converter, indicate higher or lower limits of powers errors according to the below logic are given by:

$$
\begin{aligned}
&S_P = 1 \ \ if \ \ P_{ref} - P > h_p \\
&S_P = 0 \ \ if \ \ P_{ref} - P < h_p \\
&S_P = 1 \ \ if \ \ q_{ref} - q > h_q \\
&S_P = 0 \ \ if \ \ q_{ref} - q < h_q
\end{aligned}
\qquad (11)
$$

Where:

$h_p$ and $h_q$ designate the hysteresis band.

Figure 3 shows the block diagram of the PWM rectifier state selection

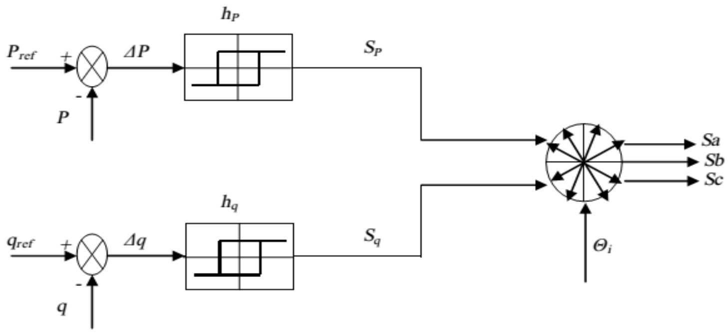



Fig.3. Block diagram of the PWM converter state selection

## 4. SWITCHING TABLE

The principle of DPC is to select a sequence of switching commands (Sa, Sb, Sc), from a switching table, according to the errors between of the active and the reactive powers as well as the angular position of the source voltage vector. This position is defined by the following relationship [4, 17, 21]. The input voltage can be estimated by the following equation:

$$
\begin{bmatrix} v_\alpha \\ v\beta \end{bmatrix} = \frac{1}{i^2{}_\alpha + i^2{}_\beta} \begin{bmatrix} i_\alpha & -i_\beta \\ i_\beta & {}_\beta i \end{bmatrix} \begin{bmatrix} \hat{p} \\ \hat{q} \end{bmatrix} \qquad (12)
$$

The knowledge of the estimated voltage sector is necessary to determine optimal switching states. Determination of the number sector is given by:

$$(n-1)\frac{\pi}{6} < \theta_n < (n-1)\frac{\pi}{6} \qquad (13)$$

Where, n is the sector number n=1,2,…12.

$\theta_n$ : is the voltage vector position is obtained as follows, is shown in figure 4.

With:

$$\theta = arctg(\frac{v_\alpha}{v_\beta}) \qquad (14)$$

Figure 4 shows the twelve sectors voltage plane :

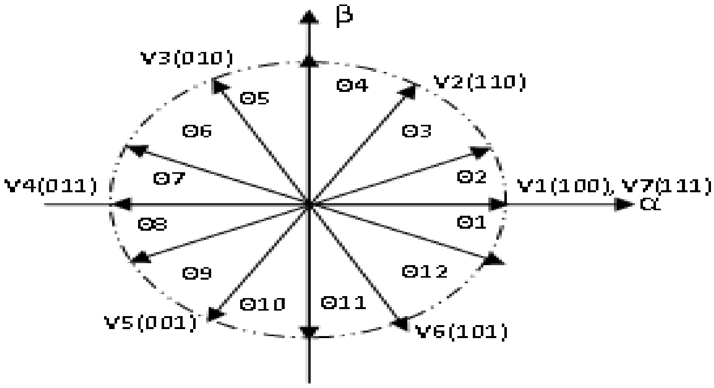



Figure 4 Voltage vectors generated in α-β coordinate

The switching table was determined in order to minimize the errors between the commanded and measured powers in each sampling period. Also to achieve a better performance, they proposed to divide the vector space into twelve sectors and then determine the position of the source voltage vector corresponding. Switching table for direct instantaneous power control illustrated by Table 1.

TABLE I

Switching table for the DPC technique

| $S_p$ | $S_q$ | $\theta_1$ | $\theta_2$ | $\theta_3$ | $\theta_4$ | $\theta_5$ | $\theta_6$ | $\theta_7$ | $\theta_8$ | $\theta_9$ | $\theta_{10}$ | $\theta_{11}$ | $\theta_{12}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | $V_5$ | $V_5$ | $V_6$ | $V_6$ | $V_1$ | $V_1$ | $V_2$ | $V_2$ | $V_3$ | $V_4$ | $V_4$ | $V_4$ |
| 1 | 1 | $V_3$ | $V_3$ | $V_4$ | $V_4$ | $V_5$ | v5 | $V_6$ | $V_6$ | $V_1$ | $V_1$ | $V_2$ | $V_2$ |
| 0 | 0 | $V_6$ | $V_1$ | $V_1$ | $V_2$ | $V_2$ | $V_3$ | $V_3$ | $V_4$ | $V_4$ | $V_5$ | $V_5$ | $V_6$ |
| 0 | 1 | $V_1$ | $V_2$ | $V_2$ | $V_3$ | $V_3$ | $V_4$ | $V_4$ | $V_5$ | $V_5$ | $V_6$ | $V_6$ | $V_1$ |

## 5. CONTROL OF DC VOLTAGE

The advantage control of DC voltage source of PWM converter arises suitable transit of supply power necessary added to power active fluctuate. The storage capacity C absorbs the power fluctuations caused by the compensation of the reactive power. In the normal conditioner, the real power supplied by the source should be equal to the real power demand of the load plus a small power to compensate the losses in the active filter [8-13]. Thus, the DC capacitor voltage can be kept at constant value and confirmed at a reference value. However, in the abnormal conditioner, In the presence of harmonics current, when the load changes, the real power balance between the source and the load will be disturbed. In this case, the real power poured most is compensated by the DC capacitor of inverter constructor of (SAPF). The changes of DC capacitor voltage from its reference most is regulate.

### A. *PI regulator*

The functional diagram of $v_{dc}$ voltage regulation based on a classical PI regulator is given by Figure. 4.

The closed loop transfer function is given by:

$$H(s)=\frac{R(s)G(s)}{1+R(s)G(s)} \tag{15}$$

We have:

$$H(s)=\frac{k_p s+k_i}{Cs^2+k_p s+k_i} \tag{16}$$

To order the closed loop system, it is necessary to choose the coefficients $k_i$ and $k_p$.

The transfer of a system of second order function is given by:

$$F(s)=\frac{\omega_C{}^2}{s^2+2\xi\omega_C s+\omega_C{}^2} \tag{17}$$

So,

$k_p=2C\xi\omega_c$ and $k_i=C\omega_c$ .

The reference dc current is:

$$I_c=I_{dc}-I_l \tag{18}$$

And the referenced active power is given by:

$$P_{ref}=I_{dc}\cdot V_{dc} \tag{19}$$

The control loop of the DC voltage is represented by the diagram of figure 5.

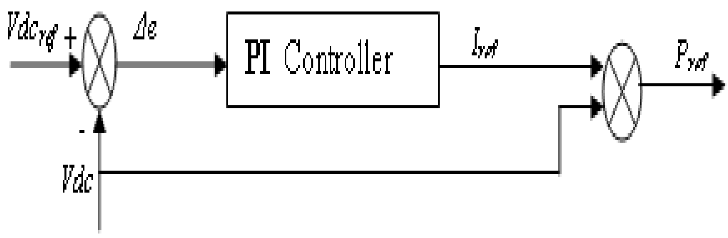



Figure 5 DC capacitor voltage regulation

## 6. Simulation and discussion

In order to verify the effectiveness of a proposed system and its control strategy was examined through simulations using Matlab/Simulink. All spectrum analysis harmonic figures are below the levels imposed by international standards recommendation, in terms of total distortion harmonic (THD). The system parameters are summarized in Table 2.

TABLE II
System parameters

| | |
|---|---|
| RMS supply phase voltage source | 380 V, 50Hz |
| Coupling inductance | R=0.1 Ω, L=12mH |
| Load rectifier bridge | R=100Ω<br>R=50 Ω, L=30mH |
| DC voltage | 600V and 750V |

Figure 6 shows the waveforms of the input voltage of three- phase voltage inverter.

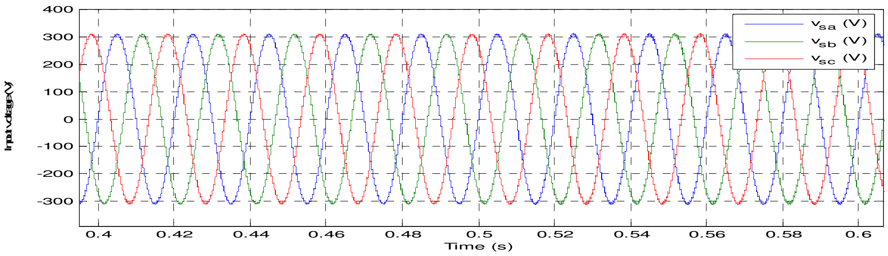
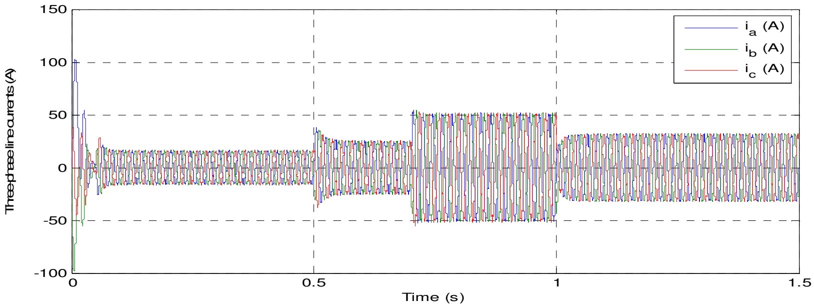
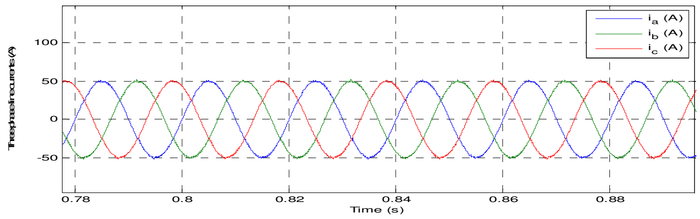



Figure 6 Line current in phase with input voltage

The three-phase line current and the harmonic spectrum of the first phase current are shown in Figures 7 and 8. The THD (Total Harmonic Distortion) at 1, 73 %, that is within the limit of the harmonic standard.




a) Three-phase line current




b) Zoom of three-phase line current

Figure7 Line currents

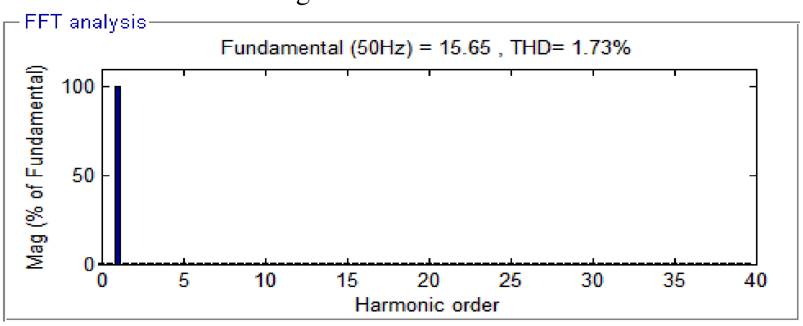



Figure 8 line current spectrum harmonic

Figure 9 shows superposition of the input current and the input voltage. We can see that the input current is sinusoidal and nearly in-shape with the respective phase voltages due the presence of DPC technique based on PI controller.

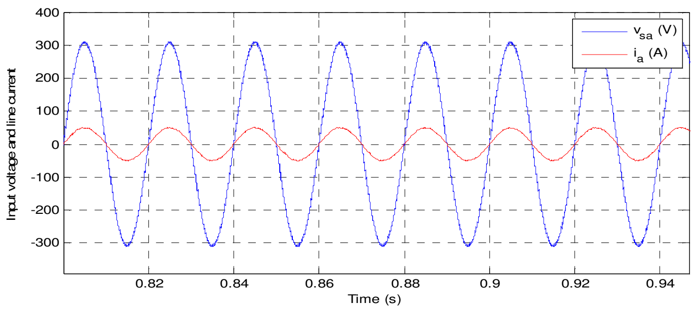



Figure 9 Input voltages and line current

In order to evaluate the system performance, The DC voltage control system is tested as well as the DPC method following a DC voltage step variation occurred at t=0.5s from 600V to 750V and at 1s from 600V. We introduced author load (see figure 10) at .The effectiveness of the DC voltage PI controller is illustrated by figure.10. We can see that DC value follows up its reference at 600V.We have changed the reference value in t= 0.5s at 750V, the DC voltage pursue its reference that system became more stable and more robust.

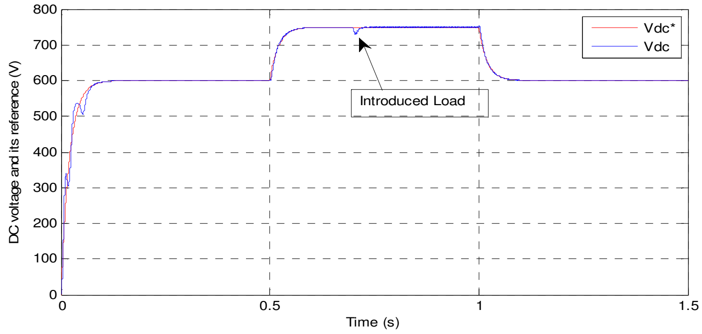



Figure10 DC capacitor voltage and its reference in various loads

Figure 11 presents the evolution of the instantaneous active and reactive power, it can be seen that reactive power is zero despite the load change what is very beneficial for the system performances and thus the power-factor is almost equal to unity, shown in figure 12.

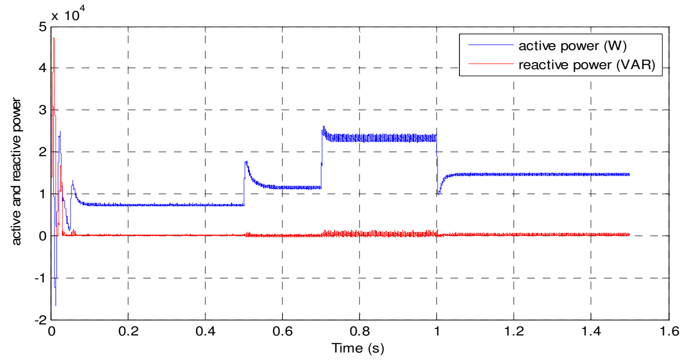



Figure11 Active and reactive powers

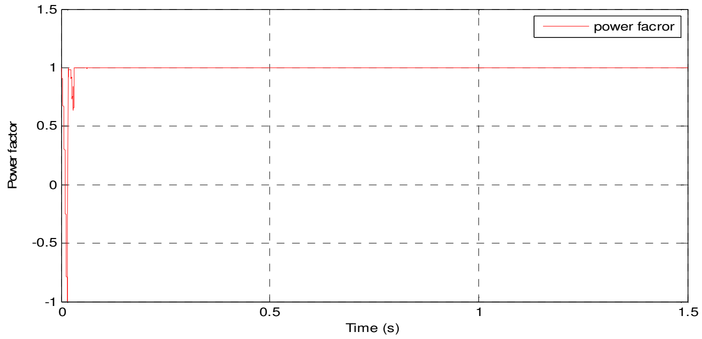



Figure12 Power factor correction

## 7. CONCUSION

This paper has presented an improvement of the direct power control strategy applied to the three-phase voltage source inverter. The simulation results obtained showed that the proposed control strategy improves the system performances. These improvements affect the performances of the system response on the DC side capacitor voltage, power-factor correction, and sinusoidal line current. The proposed DPC strategy presents good performances, demonstrating that this control technique is an alternative solution to the power quality.

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