

Direct Power Control based on PI controller for PWM voltage source converters

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Abstract—in this paper, the DPC strategy is proposed to control PWM voltage source converters under various loads. This strategy is used to reduce the current 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. Simulation results are presented and interpreted.

Keywords—DPC, PI controller, PWM voltage source converter, performances, pwer quality, improvement.

1. INTRODUCTION

Harmonics distortion cause several problems in electrical networks and grid. They have negative influence on the control and automatic power electronic equipments, protection systems, and other electrical loads. Traditional method of current harmonic compensation involves passive filters. These filters are used to eliminate lower order harmonics such as 5th, 7th, 11th, and 13th, however, these passive present many disadvantages such as series and parallel resonances [1, 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 [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]. 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. 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 (L_c), 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 [5]. 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 [6]. This paper is dedicated to this specific type of rectifiers using DPC strategy, shown in Figure. 1.

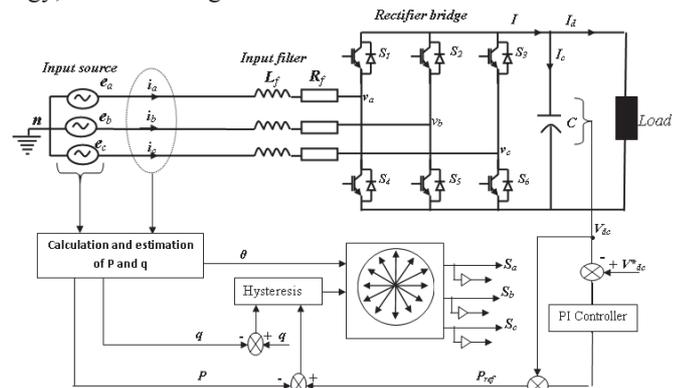


Fig. 1. Three-phase PWM voltage source converter

The instantaneous voltages of AC source and the fundamental line current [5,7] are expressed as:

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

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

V_m : is the amplitude source voltage,

I_m : is the amplitude of the phase current,

φ : is the angular phase.

With assumption:

$$i_{AN} + i_{AN} + i_{AN} = 0 \quad (3)$$

α - β input voltages are:

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

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

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

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

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

$$\begin{aligned} v_{sa} &= v_{ca} + Ri_{ca} + L \frac{di_{ca}}{dt} \\ v_{sb} &= v_{cb} + Ri_{cb} + L \frac{di_{cb}}{dt} \\ v_{sc} &= v_{cc} + Ri_{cc} + L \frac{di_{cc}}{dt} \end{aligned} \quad (7)$$

And additionally for currents

$$C \frac{du_{dc}}{dt} = S_a i_{ca} + S_b i_{cb} + S_c i_{cc} - i_{dc} \quad (8)$$

2. DIRECT POWER CONTROL

The basic principle of the Direct Power Control (DPC) was proposed by Noguchi [8], 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 [9-11]. In this case, active and reactive instantaneous powers represent the controlled variables. In this technique, there are no internal current control loops and no PWM modulator block [6], because the PWM voltage source converters switching states are appropriately selected by a lookup table based on the instantaneous errors between the commanded (the reference) and measured values of the active and reactive powers are defined as:

$$p = v_{an}(t) \cdot i_a(t) + v_{bn}(t) \cdot i_b(t) + v_{cn}(t) \cdot i_c(t) \quad (9)$$

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

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

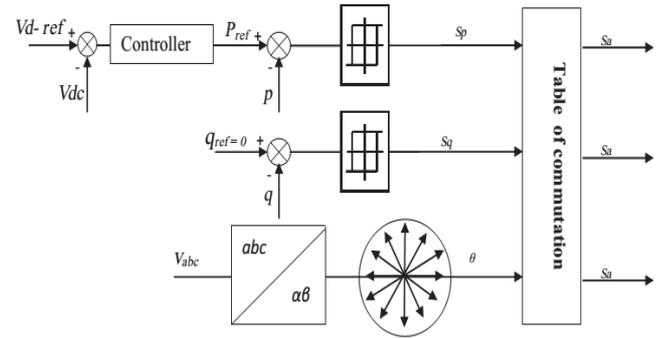


Fig.2. DPC based on the instantaneous active and reactive power control

3. 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:

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

Where:

h_p and h_q designate the hysteresis band.

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

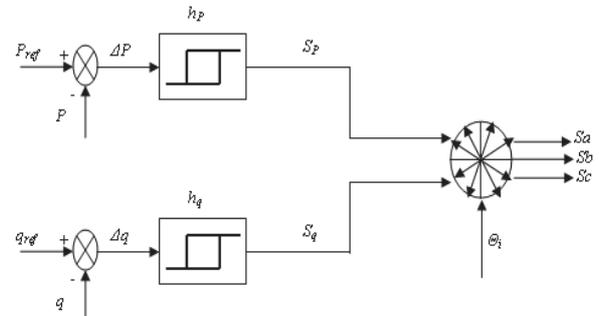


Fig.3. Block diagram of the PWM converter state selection

4. SWITCHING TABLE

The principle of DPC is to select a sequence of switching commands (S_a , S_b , S_c), 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 [6,]. The input voltage can be estimated by the following equation:

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

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

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

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

θ_n : is the voltage vector position is obtained as follows, is shown in figure 4.

Where:

$$\theta = \arctg\left(\frac{v_\alpha}{v_\beta}\right) \quad (14)$$

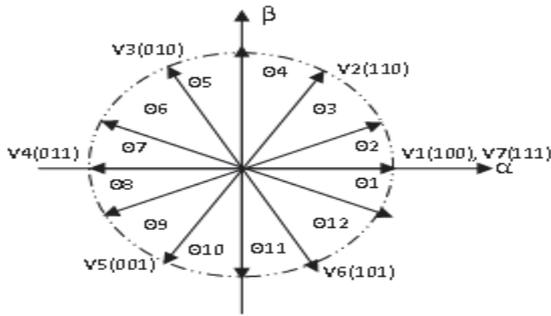


Fig.4. Voltage vectors generated in α - β coordinate

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 powers 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 | θ_1 | θ_2 | θ_3 | θ_4 | θ_5 | θ_6 | θ_7 | θ_8 | θ_9 | θ_{10} | θ_{11} | θ_{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 | v_5 | 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 [8-11]. 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 [12-13] is given by Figure. 4 . The closed loop transfer function is given by:

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

We have:

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

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:

$$F(s) = \frac{\omega_c^2}{s^2 + 2\xi\omega_c s + \omega_c^2} \quad (17)$$

So,

$$k_p = 2C\xi\omega_c$$

$$k_i = C\omega_c$$

The reference dc current is

$$I_c = I_{dc} - I_l \quad (18)$$

And the referenced active power is given by:

$$P_{ref} = I_{dc} \cdot V_{dc} \quad (19)$$

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

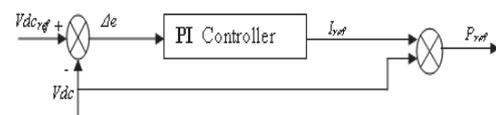


Fig.5. DC capacitor voltage regulation

6. SIMULATION AND DISCUSSION

To validate the effectiveness of the control strategy studied in this paper, The PWM rectifier was examined through simulations using Matlab/Simulink. All spectrum analysis harmonic figures are below the levels imposed by international standards recommendation IEEE 519-1992, in terms of total distortion harmonic (THD). The system parameters studied in this paper are given 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 R=50 Ω, L=30mH |
| DC voltage | 600V and 750V |

Figure 6 shows superposition of the input current and the input voltage. We can see that the input current is sinusoidal and nearly in-phase with the respective phase voltages due the presence of DPC technique based on PI controller. Figure 7 shows, the evolution of line current phase. The THD (Total Harmonic Distortion) at 1,73 %, that is within the limit of the harmonic standard, shown as figure 8.

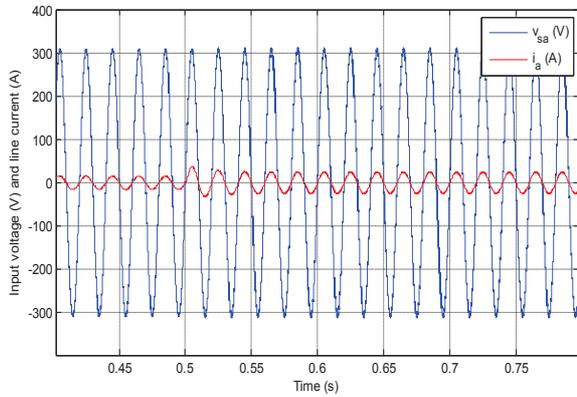


Fig.6. Line current in phase with input voltage

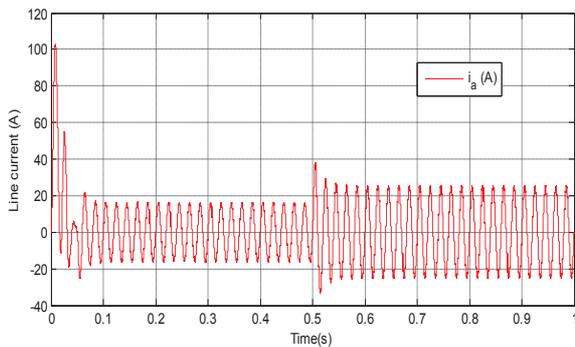


Fig.7. Line sinusoidal current

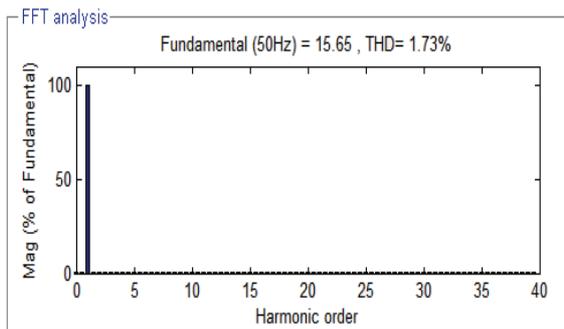


Fig8 line current spectrum harmonic

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 0.7 we introduced author load (see figure 9).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.

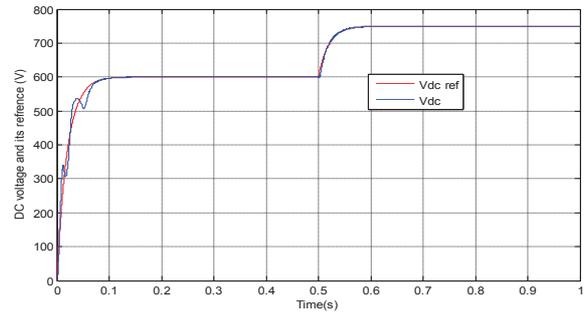


Fig.9. DC capacitor voltage and its reference

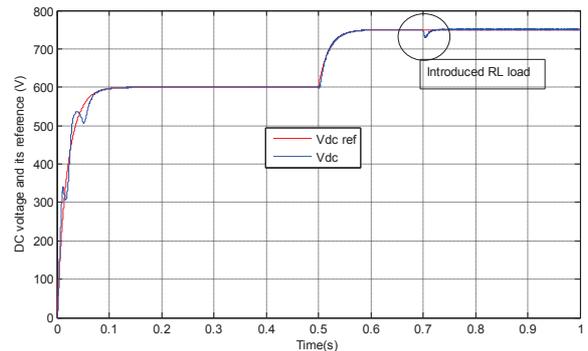


Fig.10. DC capacitor voltage and its reference in various load

Figure 11 presents the evolution of the instantaneous active and reactive power. We can see that the reactive power flow is small, what is very beneficial for the system performances and thus the power-factor is almost equal to unity, shown in figure 12.

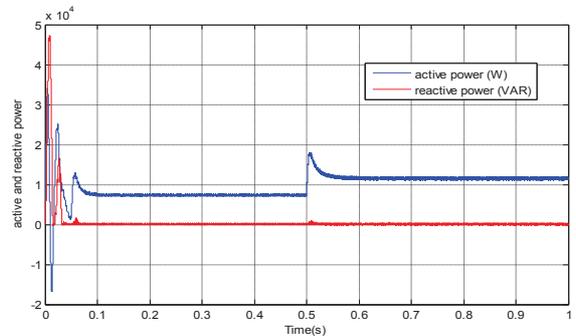


Fig.10 Active and reactive powers

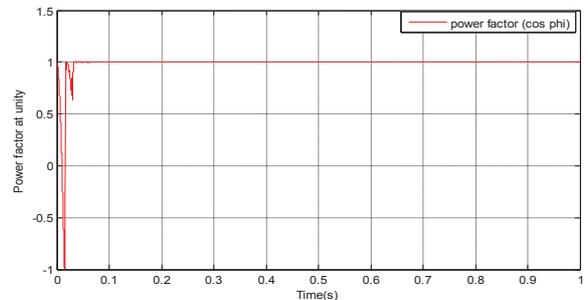


Fig.12: Power factor correction

7. CONCLUSION

In this article we presented a control strategy for a PWM rectifier. It concerns the use of the direct power control based on PI controller. The simulation results obtained showed that the DPC technique improves the system performances. These improvements affect the performances of the system response on the DC side capacitor voltage, power-factor correction, sinusoidal line current and power quality improvement.

8. REFERENCES

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