Comparative Study of Two Virtual Flux DPC Methods applied to Shunt Active Filter

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Abstract— **The dynamic and static performance of the Shunt Active Filter depends strongly on adopted control methods. This paper deals with Virtual Flux Based Direct Power Control Methods for Shunt Active. Two commonly used VF-DPC algorithms (Fuzzy-DPC and classical DPC) are presented and discussed with respect to the resulting switching frequency, the harmonics compensation, the spectrum of the current source and the implementation complexity. The proposed control strategies for the active filter have been tested in the Matlab/Simulink environment. The simulation comparison results show that the Fuzzy DPC is more efficient.**

Index Terms—**Virtual Flux, Direct Power Control, Fuzzy logic, Shunt Active Filter, Harmonic Current.**

I. INTRODUCTION

In order to interface with the electrical network, modern power electronics uses diodes or PWM rectifiers that absorb non-sinusoidal currents [1, 2, and 3] and inject of harmonic currents into power distribution systems through the point of common coupling [4]. These harmonics damage (affect) the voltage waveform quality and disrupt the operation of the Electronic equipments by excessive overheat [2]. So, to improve the electric power quality, we have to eliminate some perturbations and reduce harmonics. The most used solution is the filter integration.

The conventional solutions to the harmonic distortion problems are unable be adapted to the changing system conditions [5].Thus, active power filters, in particular the shunt active power filter (SAPF), are introduced and used to compensate harmonics and reactive power,. Various control strategies have been proposed in literature on this type of SAPF [4]-[6]. Although these control strategies can achieve the same main goals, such as increasing the power factor, eliminating harmonic currents and improving current waveforms, their principles of running are different. Particularly, the voltage-oriented control (VOC), which guarantees high dynamics and static performance via internal current control loops, has become very popular and has constantly been developed and improved[7]-[8]. Consequently, the final configuration and performance of the VOC system largely depends on the quality of the applied current control strategy [9].

Moreover, another control technique, called Direct Power Control (DPC), was proposed. This technique is based on the instantaneous active and reactive power control loops. For the DPC technique [10]-[11], there are neither internal current control loops nor PWM modulator block, because the converter switching states are appropriately selected by a switching table. This table is based on the instantaneous errors between the commanded and estimated values of active and reactive power as well as on the angular position of the estimated voltage source vector. The key point in the DPC strategy is the fast estimation of the active and reactive line power [12]. Furthermore, the line voltage estimation by the virtual flux method was used to improve control for systems with nested loops and calculate the instantaneous power without requiring the AC-line voltage sensors.

The virtual flux based active and reactive power estimation (VF-DPC) present advantages compared to other control techniques and therefore can work with a smaller sampling frequency and to obtain the best performance when the network voltage is disturbed [12].

In this study, we propose two control Methods applied to a three-phase three-wire shunt active power filter. We speak about, in particular, the classical DPC and the DPC based on fuzzy logic. A comparative study is presented order to show the particularities and the performance of each of both control strategies.

II. SHUNT ACTIVE POWER FILTER SYSTEM

The Shunt active power filters consist of a power part and a command part. The power electronic circuit part is usually composed of a Voltage Source Inverter using IGBTs with anti-parallel diodes, controllable in priming and blocking, an energy storage circuit and an output passive filter as an interface between the grid and the inverter. Indeed, the SAPF is a modern and effective solution to reinstate the electrical network sinusoidal current when it is deformed by a non-linear load. The introduction of a shunt active power filter in an electrical network which lets compensate harmonics continuously, regardless of the changing of the applied loads.

Figure1 illustrates the application of the SAPF to harmonic current source type nonlinear load represented Norton's equivalent circuit. The current source, I_l, and the parallel impedance Z_L represent the equivalent current source. IL is the total current drawn by the load. The 3-phase AC supply is represented as a voltage source, V_S, and supply impedance, Z_S.

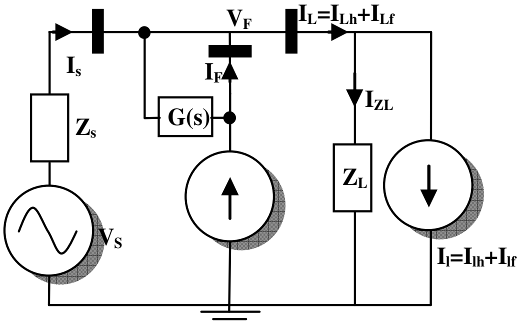

Fig. 1. Application of the SAPF to a harmonic current source type nonlinear load which is represented as Norton's equivalent.

Since the aim of the SAPF is to compensate the load current harmonics to provide sinusoidal line (supply) current, it is implemented as a harmonic current generator, which generates harmonic currents equal in magnitude and opposite in phase to that of the load current harmonics. Thus the PAF in the figure is represented as a current source of IF. The filter current is defined by the following equation:

$$I_F = G(s).I_s \tag{1}$$

Where G(s) is the transfer function of the SAPF.

By circuit analysis, the line current I_S and the total load current I_L are given as in (2) and (2) respectively.

$$I_s = \frac{Z_L}{Z_s + \frac{Z_L}{1-G(s)}} \cdot I_l + \frac{1}{Z_s + \frac{Z_L}{1-G(s)}} \cdot V_s \tag{2}$$

$$I_L = \frac{\frac{Z_L}{1-G(s)}}{Z_s + \frac{Z_L}{1-G(s)}} \cdot I_l + \frac{1}{(1-G(s)) \cdot \left(Z_s + \frac{Z_L}{1-G(s)} \right)} \cdot V_s \tag{3}$$

In an ideal SAPF, G(s) is equal to zero at fundamental frequency ($|G|^f = 0$) and approximately equal to unity at all harmonic frequencies, ($|G|^h = 1$). If G(s) is assumed to have a characteristic of a notch filter at the fundamental frequency, we will have:

$$\left| I \frac{Z_L}{1-G(s)} \right|_h \succ\succ |Z_s|_h \tag{4}$$

According the harmonic frequencies, Equations (1), (2) and (3) can be written as:

$$I_F \cong .I_{Lh} \tag{5}$$

$$I_{sh} = (1-G(s)) \cdot I_{lh} + \frac{1-G(s)}{Z_L} \cdot V_{sh} \cong 0 \tag{6}$$

$$I_{Lh} = I_{lh} + \frac{1}{Z_L} \cdot V_{sh} \tag{7}$$

Where the subscripts, "h" and "f" represent the harmonic components and the fundamental components, respectively.

III. DIRECT POWER CONTROL OF THREE-PHASE SAPF

The main idea of Direct Power Control (DPC) proposed in and next developed by is similar to the well-known Direct Torque Control (DTC) for induction motors. Instead of torque and stator flux the instantaneous active (p) and reactive (q) powers are controlled. The purpose of DPC is to treat directly the active and reactive power in a three-phase shunt active power filter connected to the voltage distribution systems, that is to say, the active and reactive powers are the control variables.

A. Approach VF-DPC

The main idea of the algorithm of the classical Virtual-Flux Based Direct Power Control (VF-DPC) is to maintain instantaneous active and reactive power in a desired band. This control is based on two level hysteresis comparators using as input the error signals between the reference values and estimated values of the active and reactive power ($\varepsilon_p = p_{ref} - p_{est}$ and $\varepsilon_q = q_{ref} - q_{est}$). Indeed, we note that the reference reactive power is considered to be zero in order to ensure, it's functioning with single power factor and that the reference active power is generated by the outer PI DC voltage controller.

The principle of VF is based on assumption that the voltages imposed by the line power in combination with the AC side inductors can be considered as quantities related to a virtual AC motor. Thus, R_s and L_s represent the stator resistance and leakage inductance of the virtual motor. Besides being present for synchronization, The Virtual Flux is also unused to deliver the instantaneous power to reduce the cost of the installation and working with a limited sampling frequency more. Based on the measured line currents (i_a and i_b) and VF components Ψ_α and Ψ_β, the instantaneous active and reactive power can be calculated by the expressions:

$$q = \omega \cdot (\Psi_{s\alpha} \cdot i_{s\alpha} + \Psi_{s\beta} \cdot i_{s\beta}) \tag{8}$$

$$p = \omega \cdot (\Psi_{s\alpha} \cdot i_{s\beta} - \Psi_{s\beta} \cdot i_{s\alpha}) \tag{9}$$

The outputs of both comparators are put at the state "1" when it is necessary to increase the control variable (p or q) and put at the state "0" when this variable must decrease or remain unchanged. The output levels and the membership sector of the estimated virtual flux vector constitute the inputs of a switching table. This table determines the switching state of the semiconductor. The digitized output signals of the reactive power controller are defined as:

$$dq = 1 \quad si \quad q \prec q_{ref} - H_q \tag{10}$$

$$dq = 0 \quad si \quad q \succ q_{ref} + H_q \tag{11}$$

And, similarly, of the active power controller as:

$$dp = 1 \quad si \quad p \prec p_{ref} - H_p \tag{12}$$

$$dp = 0 \quad si \quad p \succ p_{ref} + H_p \tag{13}$$

Fig. 2 shows the block diagram of classical VF-DPC.

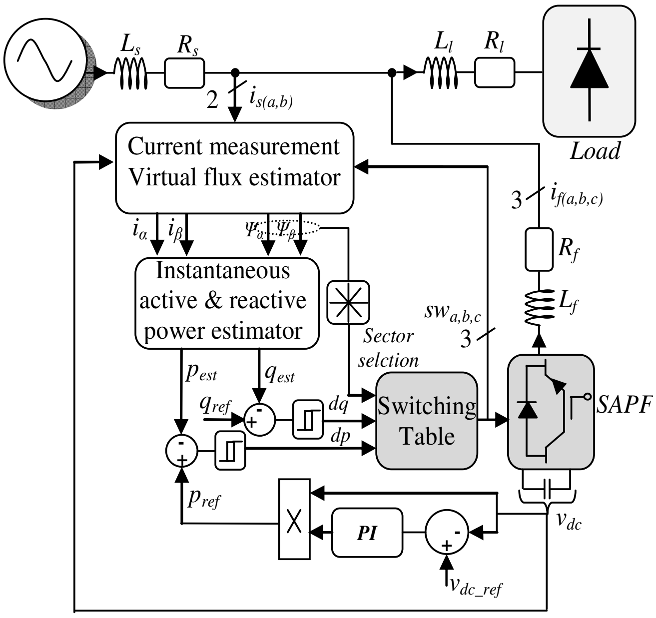

Fig. 2. Block scheme of classical VF-DPC.

B. Approach VF-DPC Based on Fuzzy Logic

The Virtual-Flux Based Direct Power Fuzzy Control (VF-DPFC) block diagram of the Shunt active power filter is presented in fig.3. In this approach, a fuzzy logic controller has been introduced to replace the classical hysteresis controllers and the switching table [13]. The estimated values of the active and reactive power are compared to their reference. The errors ε_p, ε_q and θ_n of the active power and reactive power and of the position angle, respectively, are fuzzified into several fuzzy set several fuzzy set using functions fuzzy memberships triangular shapes. However, the output of DPFC is also fuzzyfied using fuzzy singletons to select a voltage vector in order to force the active and reactive powers to reach their reference values, optimally, with a quick response of the active power. All the possible fuzzy rules are stored in a fuzzy rule base. Thus the DPFC takes the decision for the given input crisp variables by (firing) this rule base [14][15].

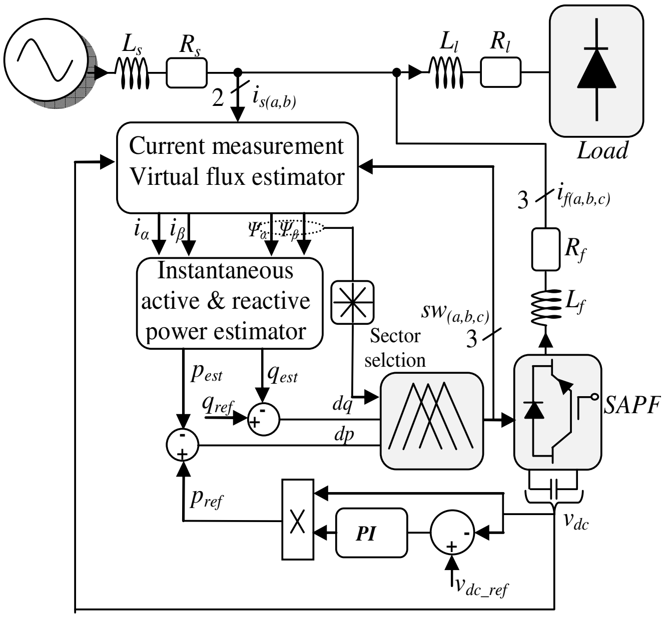

Fig. 3. Block scheme of VF-DPFC.

In our study case and for DPFC implementation, we chose:

- The universe of discourse of the input variables set between -1 and 1 by introducing gains called scaling factors for each input;
- The two inputs (ε_p and ε_q) are defined each by three subsets: N for Negative, EZ for Zero and P for Positive, such as triangular membership functions.
- θ_n is represented by the following Twelve linguistic values: $\theta_1 \rightarrow \theta_{12}$ which are defined by the triangular membership function.
- The DPFC output represented by eight singleton linguistic values, as V_1,V_2,V_3,V_4,V_5, V_6,V_7;

IV. COMPARISONS BETWEEN THE TWO TECHNIQUES

The aim of our present study is to compare our approach with the traditional one: Classic table and fuzzy table. The two comparison criteria are the harmonic distortion rate of the current source "THDi" and the adjusting precision of the continuous voltage of the bus.

The first scenario simulated in the Matlab environment is to vary the reference voltage of the continuous bus in the interval [450-680] for a fixed charge ($R_{load}=7\Omega$ and $L_{load}=1mH$). The comparison results obtained (Fig.4) show that the rate of harmonic current distortion obtained by the conventional table is even higher and it attains unacceptable values (THDi>8%). In addition, it increases with the rise of v_{dc_ref}. Moreover, we note that adjust setting the voltage v_{dc} becomes impossible for references superior to 600V. Concerning the technique based on fuzzy commutation table, we note that the rate harmonic distortion is acceptable and even very satisfactory (THDi<5%) over the entire range of v_{dc} variation.

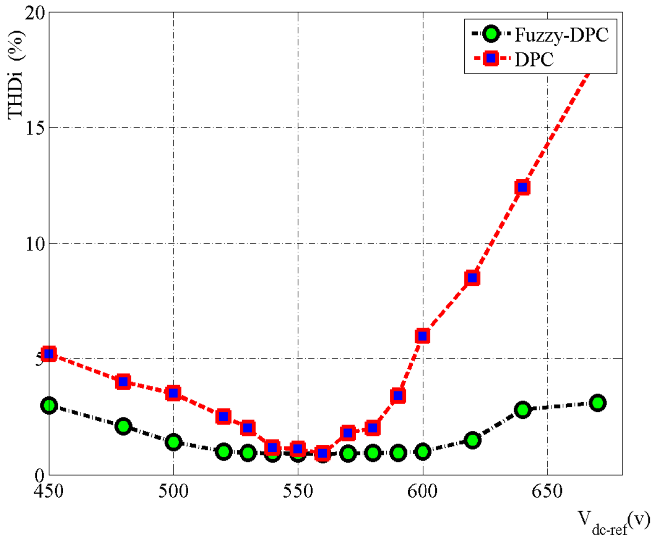

Fig. 4. v_{dc_ref} dependence of THDi.

For the second scenario, we envisaged the following: The reference of the continuous bus tension is maintained constant (v_{dc_ref} =560V), for the same load. We altered the value of the capacitance C (R_{load} =7Ω and L_{load}=1mH). For this case of simulation, the distortion rate of the current obtained with the fuzzy commutation table remains in the standards which fix the THDi to a value less than 5% over the entire range of variation of C. Furthermore, the THDi decreases as a function of the capacitor increase.

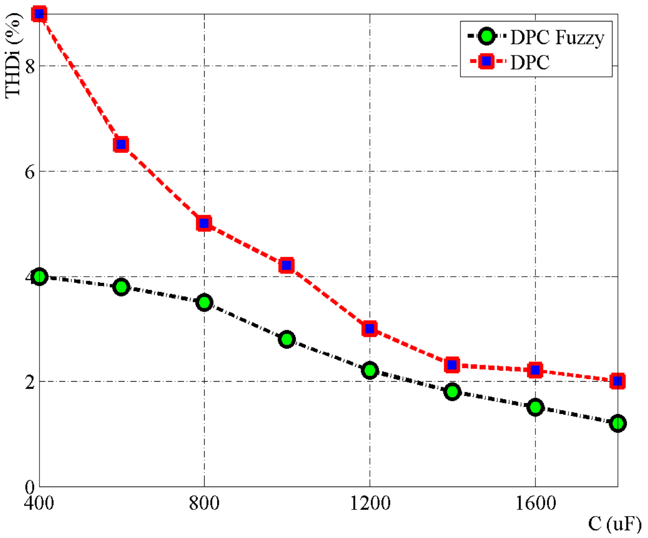

Fig. 5. Capacitor dependence of THDi.

For the 3rd scenario, the reference of the bus voltage is kept constant (v_{dc_ref}=560V), however, the impedance of the load is variable. Figure 6 shows the rate distortion evolution of the absorbed current. In this context, we note that the rate distortion of the current obtained with the fuzzy commutation table remains in the standards which set the THDi to a value less than 5% over the entire range of capacitor variation. Furthermore, the THDi decreases according to the rise of the capacitance C. Thus, we prove that the VF-DPFC method is much better compared to the classical VF-DPC technique.

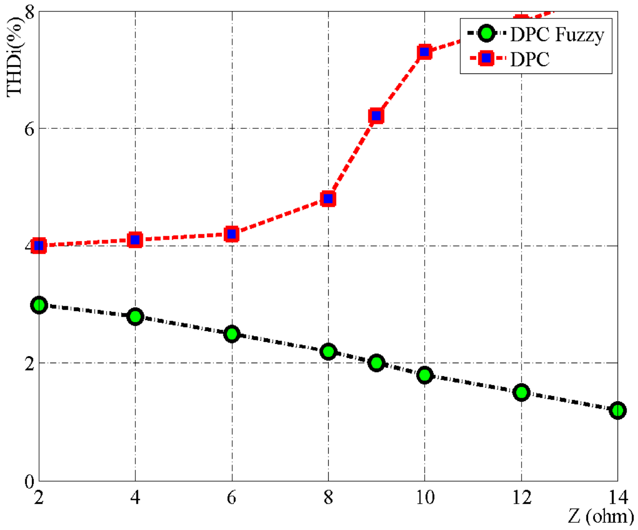

Fig. 6. Impedance dependence of THDi.

V. CONCLUSION

In the present paper, we studied and compared the DPFC strategy to the classical DPC Method. These two strategies have been formulated for the active shunt power filter connected to the grid in order to inject currents that eliminate the harmonics caused by the presence of non-linear loads. Our comparative study shows that the VF-DPFC method is better than the classical VF-DPC method based on the hysteresis comparators. In addition, we have shown that the approach of the Virtual-Flux Based Direct Power Fuzzy Control presents the best performance in terms of the elimination harmonic of the currents in the system and the improvement of the power factor.

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