Direct Power control for tree phase active parallel power filter using Sliding mode technique

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Abstract— **In this work, we are considering the problem of controlling the three-phase active power filter (APF). We consider the control goal is compensation of the reactive power absorbed by the linear load, in other words, the load and the (APF) to behave like a resistive load, the (APF) must ensure the reactive power absorbed by the load, and prevent the exchange of active power between him and the grid. We are proposing Direct Power Control (DPC) using Sliding mode technique, the system is present in the α-β frame for to simplify the study. We're using the averaging approach to surmount the problem of switching functions of the switches. The theoretical results are evaluated by simulation using Matlab/Simulink.**

***Keywords*— Three phase active power filter connected to the grid, direct power control, reactive power compensation, Sliding mode control**

I. Introduction

The disadvantages of the circulation of the reactive power in the electrical networks are numerous, which requires a production of the reactive power as close as possible to the load (reactive power compensation). The fixed compensation of the reactive power in the medium and high voltage installation becomes very limited because of the brutal burdening of the loads, which requires an instantaneous compensation[1], The topologies of the compensation devices that have spread in the reactive energy compensation and the harmonics, is the active parallel filters based on voltage source inverter (VSI)[2], The control strategy used is the control of the images of the powers which are currents in the dq frame. In this work, we proposed a new control strategy, direct power control (DPC) used for controlling the circulation of the active and reactive power in between direct voltage source and grid Through (VSI)[3]. We have developed the control laws using the sliding mode technique.

This paper is organized as follows: Firstly, we have developed the dynamic model in (abc) frame and we converted the model in **α-β** frame, after that we have developed a new decoupled control for DPC control in section 2. The control law is elaborated in section 3. The validation of the proposed strategy control is confirmed by the simulation and the discussion of the results presented in section 4.

II. Topology and System Modelling of (APF)

A. Switched model

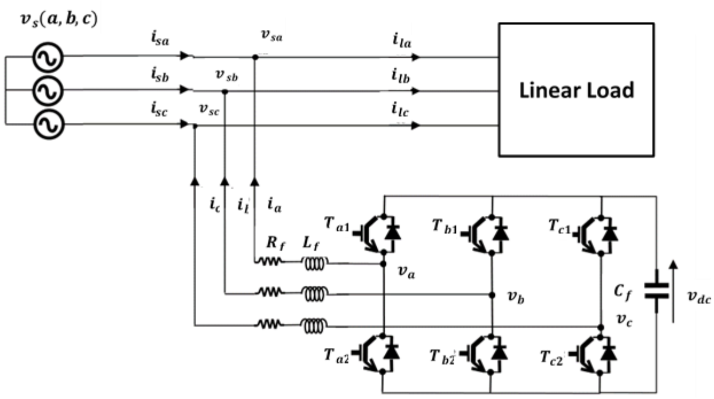

Fig. 1 Representation of three phases (APF) connected to the grid

μ_i : Is a switching function, $i = (a,b,c)$

$$\begin{pmatrix}\mu_a\\ \mu_b\\ \mu_c\end{pmatrix} = \begin{pmatrix}\begin{cases}1\ if\ T_{a1}\ ON\ and\ T_{a2}\ OFF\\ -1\ if\ T_{a2}\ ON\ and\ T_{a1}\ OFF\end{cases}\\ \begin{cases}1\ if\ T_{b1}\ ON\ and\ T_{b2}\ OFF\\ -1\ if\ T_{b2}\ ON\ and\ T_{b1}\ OFF\end{cases}\\ \begin{cases}1\ if\ T_{c1}\ ON\ and\ T_{c2}\ OFF\\ -1\ T_{c2}\ ON\ and\ T_{c1}\ OFF\end{cases}\end{pmatrix} \tag{1.1}$$

The application of Kirchhoff's laws on the circuit gives us the followings equations[4]:

$$L_f\frac{d}{dt}\begin{pmatrix}i_a\\ i_b\\ i_c\end{pmatrix} = -R_f\begin{pmatrix}i_a\\ i_b\\ i_c\end{pmatrix} + \begin{pmatrix}v_a\\ v_b\\ v_c\end{pmatrix} - \begin{pmatrix}v_{sa}\\ v_{sb}\\ v_{sc}\end{pmatrix} \tag{1.2}$$

$$\frac{dv_{dc}}{dt} = \frac{-1}{2*C}\left[\mu_a i_a + \mu_b i_b + \mu_c i_c\right]$$

The voltage source inverter (VSI) output and grid wave form defined by:

$$\begin{pmatrix}v_a\\ v_a\\ v_a\end{pmatrix} = \frac{v_{dc}}{6}\begin{pmatrix}2 & -1 & -1\\ -1 & 2 & -1\\ -1 & -1 & 2\end{pmatrix}\begin{pmatrix}\mu_a\\ \mu_b\\ \mu_c\end{pmatrix} \tag{1.3}$$

$$\begin{pmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{pmatrix} = \hat{v} \begin{pmatrix} \sin(\omega t) \\ \sin\left(\omega t - \frac{2\pi}{3}\right) \\ \sin\left(\omega t + \frac{2\pi}{3}\right) \end{pmatrix} \quad (1.4)$$

Where $\hat{v}$ is the magnitude of the grid voltage, $\omega = 2 * \pi * f$, and f his frequency.

The model (1.2) and (1.4) in $\alpha - \beta$ frame becomes:

$$\frac{d}{dt}\begin{pmatrix} i_\alpha \\ i_\beta \end{pmatrix} = \frac{-R_f}{L_f}\begin{pmatrix} i_\alpha \\ i_\beta \end{pmatrix} + \frac{v_{dc}}{2 * L_f}\begin{pmatrix} \mu_\alpha \\ \mu_\beta \end{pmatrix} - \frac{1}{L_f}\begin{pmatrix} v_{s\alpha} \\ v_{s\beta} \end{pmatrix} \quad (1.5)$$

$$\frac{dv_{dc}}{dt} = \frac{-1}{2 * C}\left[\mu_\alpha i_\alpha + \mu_\beta i_\beta\right]$$

$$v_{s\alpha} = \sqrt{\frac{3}{2}} * \hat{v} * \sin(\omega t) \quad ; \quad v_{s\beta} = -\sqrt{\frac{3}{2}} * \hat{v} * \cos(\omega t) \quad (1.6)$$

P and Q are the instantaneous output active and reactive powers of the (VSI)[5].

$$P = v_{s\alpha} i_\alpha + v_{s\beta} i_\beta \quad ; \quad Q = v_{s\beta} i_\alpha - v_{s\alpha} i_\beta \quad (1.7)$$

The expressions of the instantaneous active, reactive powers and grid voltage derived with respect to the times, give us:

$$\frac{dP}{dt} = x_\alpha \frac{dv_{s\alpha}}{dt} + v_{s\alpha}\frac{dx_\alpha}{dt} + x_\beta \frac{dv_{s\beta}}{dt} + v_{s\beta}\frac{dx_\beta}{dt} \quad (1.8)$$

$$\frac{dQ}{dt} = x_\alpha \frac{dv_{s\beta}}{dt} + v_{s\beta}\frac{dx_\alpha}{dt} - \left[x_\beta \frac{dv_{s\alpha}}{dt} + v_{s\alpha}\frac{dx_\beta}{dt}\right]$$

$$\frac{dv_{s\alpha}}{dt} = \sqrt{\frac{3}{2}} * \omega * \hat{v} * \cos(\omega t) = -\omega * v_{s\beta} \quad (1.9)$$

$$\frac{dv_{s\beta}}{dt} = \sqrt{\frac{3}{2}} * \omega * \hat{v} * \sin(\omega t) = \omega * v_{s\alpha}$$

We replace (1.5) and (1.9) into (1.8), give us:

$$\frac{dP}{dt} = \frac{-R_f}{L_f} P - \omega\, Q + \frac{v_{dc}}{2 * L_f}\left[v_{s\alpha} u_\alpha + v_{s\beta} u_\beta\right] - \frac{3}{2 * L_f}\hat{v}^2 \quad (1.10)$$

$$\frac{dQ}{dt} = \omega P - \frac{R_f}{L_f} Q + \frac{v_{dc}}{2 * L_f}\left[v_{s\beta} u_\alpha - v_{s\alpha} u_\beta\right]$$

Where ***x*α**, ***x*β**, ***u*α**, and ***u*β** denote respectively the average values, over cutting periods of the signals ***i*α**, ***i*β**, ***u*α**, and ***u*β**.

We define two states as:

$$x = \begin{bmatrix} x_1 & x_2 \end{bmatrix}^T = \begin{bmatrix} P & Q \end{bmatrix}^T \quad (1.11)$$

And two laws decoupled control of the new system:

$$u_P = v_{s\alpha} u_\alpha + v_{s\beta} u_\beta \quad (1.12)$$

$$u_Q = v_{s\beta} u_\alpha - v_{s\alpha} u_\beta$$

$$u_\alpha = \frac{v_{s\alpha} u_P + v_{s\beta} u_Q}{\frac{3}{2} * \hat{v}^2} \quad ; \quad u_\beta = \frac{v_{s\beta} u_P - v_{s\alpha} u_Q}{\frac{3}{2} * \hat{v}^2} \quad (1.13)$$

We obtain the new average model:

$$\dot{x}_1 = \frac{-R_f}{L_f} x_1 - \omega\, x_2 + \frac{v_{dc}}{2 * L_f} u_P - \frac{3}{2 * L_f}\hat{v}^2 \quad (1.14)$$

$$\dot{x}_2 = \omega\, x_1 - \frac{R_f}{L_f} x_2 + \frac{v_{dc}}{2 * L_f} u_Q$$

III. DEVELOPMENT OF THE CONTROL LAW USING THE SLIDING MODE TECHNIQUE

From the new average model (1.14), we're going to develop two control laws for the active and reactive power using sliding mode technique[6].

A. *Control law for the active power*

The control objective in this part is to converge the variable state *x1* to follow the reference value *x1,ref*. For this goal we consider the sliding surface is the error tracking for the active power.

$$s_1 = z_1 = x_1 - x_{1,ref} \quad (2.1)$$

The control law can be defined as follow:

$$u_P = u_{P,eq} + u_{P,n} \quad (2.2)$$

Where *uP,eq* is the equivalent control law whose enforce the surface attractive[6].The Equivalent control law is a way to determine the system performance when restricted to the surface:

$$s_1 = z_1 = 0 \quad \text{Which implies:} \quad \dot{s}_1 = \dot{z}_1 = 0 \quad (2.3)$$

$$u_{P,eq} = \frac{2 * \left[L_f\left(\dot{x}_{1,ref} + \omega\, x_2\right) + \frac{3}{2} * \hat{v}^2 + R_f * x_1\right]}{v_{dc}} \quad (2.4)$$

And *uP,n* is the Normal control law whose can secure the convergence condition, for this goal we choose the candidate Lyapunov function:

$$v_1 = \frac{1}{2} * z_1^{\,2}$$

$$\dot{v}_1 = \dot{z}_1 z_1 = -k_1 sign(z_1) * z_1 \quad (2.5)$$

$$u_{P,n} = -k_1 * sign(z_1) \quad (2.6)$$

Such as *k1* is a positive constant, and *sign (z1)* function is defined by:

$$sign(z(t)) = \begin{cases} 1 & if \quad z(t) \succ 0 \\ 0 & if \quad z(t) = 0 \\ -1 & if \quad z(t) \prec 0 \end{cases} \quad s(2.7)$$

Finally we obtain the control law for the active power loop by:

$$u_P = u_{P,eq} + u_{P,n} \quad (2.8)$$

$$u_P = \frac{2 * \left[L_f\left(\dot{x}_{1,ref} + \omega x_2\right) + \frac{3}{2} * \hat{v} \; + R_f x_1\right]}{V_{dc}} - k_1 * sign(z_1) \quad (2.9)$$

B. Law control for reactive power

The control objective in this part is to enforce the variable state *x2* to follow the reference value for the reactive power *x2,ref*.

The sliding surface defined by:

$$s_2 = z_2 = x_2 - x_{2,ref} \quad (2.10)$$

$$s_2 = z_2 = 0 \quad \text{This implies:} \quad \dot{s}_2 = \dot{z}_2 = 0$$

$$u_{Q,eq} = \frac{2*\left[L_f\left(\dot{x}_{2,ref} - wx_1\right) + R_f * x_2\right]}{v_{dc}} \quad (2.11)$$

$$v_2 = \frac{1}{2} * z_2{}^2$$

$$\dot{v}_2 = \dot{z}_2 z_2 = -k_2 sign(z_2) * z_2 \quad (2.12)$$

$$u_{Q,n} = -k_2 * sign(z_2) \quad (2.13)$$

$$u_Q = u_{P,eq} + u_{P,n} \quad (2.14)$$

We follow the same procedure as the previous section and we obtain the control law of the reactive power:

$$u_Q = \frac{2*\left[L_f\left(\dot{x}_{2,ref} - wx_1\right) + R_f * x_2\right]}{v_{dc}} - k_2 * sign(z_2) \quad (2.15)$$

IV. SIMULATION AND RESULTS:

To illustrate the performance of the system with the proposed control, two different loads have been proposed inductive (RL) and capacitive (RC), with the MATLAB/Simulink environment. The values of the parameters of the proposed circuit are presented in Table I below:

TABLE II
SYSTEMS PARAMETERS USED IN THE SIMULATION

Parameter	**Symbol**	**Value**
Filter	R_f L_f C_f	$5*10^{-3}$ (Ω) $5*10^{-3}$ (H) $2000*10^{-6}$ (F)
Grid	$\hat{v}$ f	220 (V) 50 s^{-1}
Load	L C R	$100*10^{-3}$ (H) $1000*10^{-6}$ (F) 5 (Ω)
Regulator	k_1 k_2	$5*10^{10}$ $5*10^{10}$

A. Inductive load RL:

For a change value of the load inductance from 0 to 100 (mH) at time $t = 0.5s$ shown in Fig.2, the reference value of the reactive power change from 0 to 2250 (var) Fig.3. It can be seen that the state variable *x2* follows its set point trajectory instantly with the undulations ± 55 var around *x2*.the reactive power provide from the grid reached the steady state at $t = 0.115s$, After that it has not affected by the changing in the inductance of the load Fig.5.

In the Fig.4, We can observe the pursuit of the variable state of the active power *x1*, with response time $t = 0.35s$, and static error -20 (w) caused by conduction losses[1].

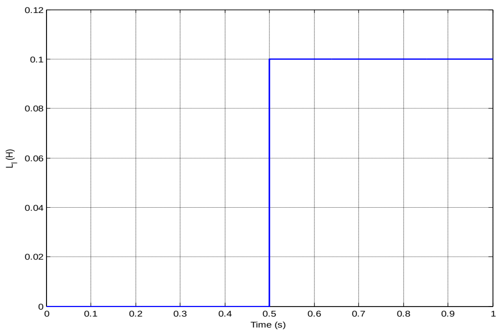

Fig. 2 Load inductance L

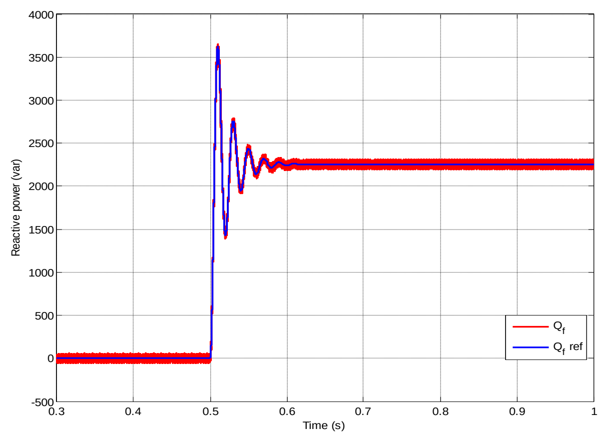

Fig. 3 Reactive power filter *x2*

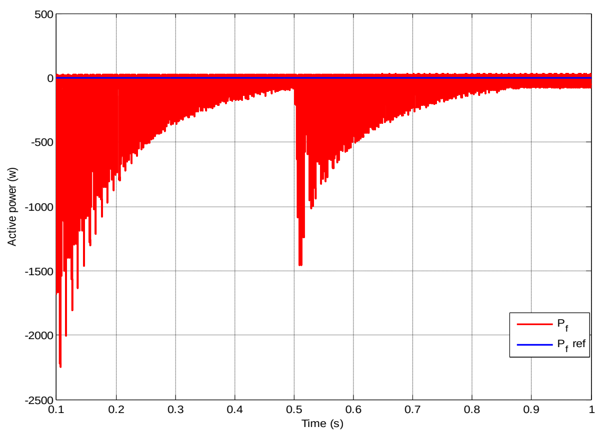

Fig. 4 Active power of the filter *x1*

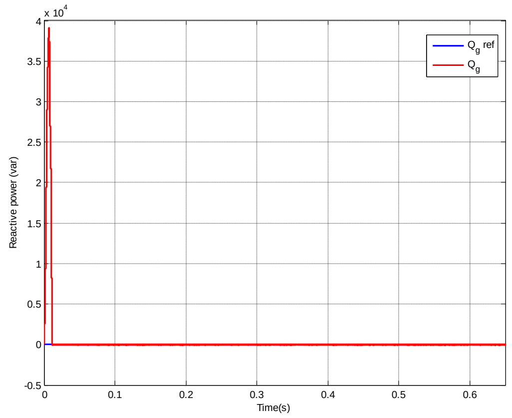

Fig. 5 Reactive power of the grid Q_g

B. *Capacitive Load RC:*

We changed the load to the capacitive, and we varied the value of the capacity of the load at the moment $t = 0.5s$ from 0 to 1 (mF) Fig .6. We can see in figure.7. The reactive power of the filter *x2* follow the reference value *x2,ref*

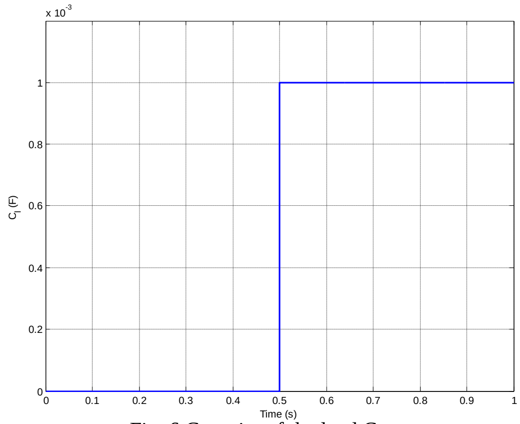

Fig. 6 Capacity of the load C

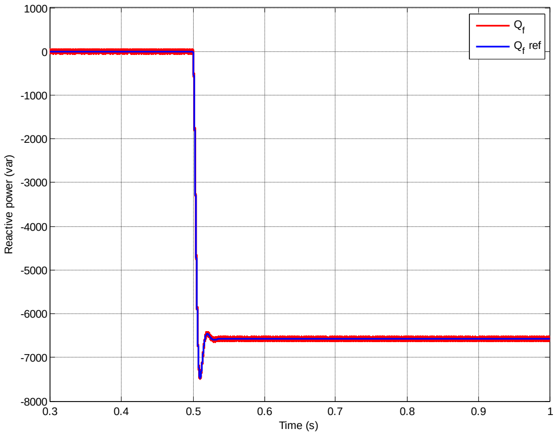

Fig. 7 Reactive power of the filter *x2*

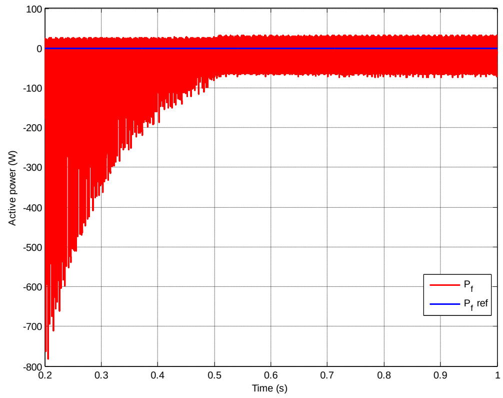

Fig. 8 Active power of the filter *x1*

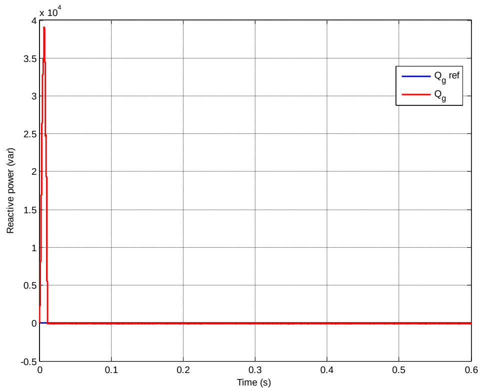

Fig. 9 Reactive power of the grid Q_g

V. Conclusions

The proposed method of control in this work, proved his performance since the underlined objective of the reactive power is reached with a good response time Fig.3&7. Although, the response of the active power reaches its set point with a nonzero static error Fig.4&8.

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