A Lyapunov Approach Based Higher Order Sliding Mode Controller for Grid Connected Shunt Active Compensators with a LCL Filter

MHD. A. E. Alali* and J-P Barbot**

* QUARTZ LABORATORY, EA7393, ENSEA,

** QUARTZ Laboratory, EA7393, ENSEA, and Non-A, INRIA

6 Avenue du Ponceau,

95014 Cergy-Pontoise, Paris, France

Tel.: +33 / (1) – 30736241

Fax: +33 / (1) – 30736667

E-Mails: mohamad-alaa-eddin.alali@ensea.fr, barbot@ensea.fr

URL: <http://www.ensea.fr>

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Abstract

A Lyapunov approach based homogeneous higher order SM-Controller (HOSMC) is considered here, for grid connected three phases three wires shunt active filter (SAF) via LCL filter. This nonlinear controller is an alternative solution to overcome phase shift caused by a linear controller and a chattering effect caused by a 1st order sliding mode controller that is supposed to be of relative degree 1. The last fact requires a special sliding variable design that yields asymptotic convergence of the tracking error to zero versus a finite time convergence provided by HOSMC.

On the other hand, it is well known that VSI based SAFs compensate for the main types of current perturbations in the electrical power systems, while generate some undesired components caused by switching frequency. In order to avoid the spreading of these components to the grid side, a VSI connected to the grid via a LCL output filter is largely proposed, but for renewable energy systems, where the component to be injected into the grid is only the fundamental. Unfortunately, when the currents to be generated by SAF include both fundamental and harmonics, and for a LCL output filter associated to linear controllers, a phase shift appears, between the identified harmonics current and the injected current, and impacts negatively, harmonic current filtration of the SAF.

In this article, a PWM-HOSMC is proposed to operate in a fixed frequency without chattering, preventing a variable switching frequency effects. In addition, this article proposes a solution for the non-robustness drawback, from disturbances point of view, of the used control method. The rapidity, tracking and effectiveness of this proposed controller, within the SAF, are validated by simulations carried out by Matlab, Simulink, Simscape-SimPower System code.

Introduction

The electric systems and machines of the modern world, depend more and more of the power electronics, to operate effectively and sustainably. In this context, voltage source inverters (VSI) are used for energy conversion from a DC source to an AC output, either in a standalone mode or when connected to the utility grid. A filter is required between a VSI and the grid, reducing harmonics of the output current and imposing a current-like performance for feedback control. A simple series inductor (first order output filter) can be used [1], but the attenuation of high frequency components, due to switching frequency, is not very pronounced. In addition, a high voltage drop is produced and the inductor, required in the design, is very bulky [2]. Commonly a high-order output LCL filter (called also T-filter) has been used in place of the conventional L-filter, for smoothing the high frequency output currents from a VSI [2]. Indeed, LCL filter provides, in comparison with the first order one, higher attenuation

of high frequency components as well as cost savings, in term of overall weight reduction and the size of the components.

In this context, a grid connected VSI with LCL filter is mainly proposed for the renewable energy (photovoltaic and wind) systems [3]; the grid-connected VSIs have to inject to the grid, in this case, only fundamental components.

On the other hand, shunt active compensators are becoming, in most industrial countries, an alternative solution to compensate for all current perturbations in electrical installations, such as harmonic, unbalance and reactive currents. In this case, current control loop, of the shunt active compensator, has to ensure a good compensating performance over all harmonic frequencies of the bandwidth, including the fundamental. For this purpose, a PWM-VSI with an adapted linear controller (such as RST: Robust Roots Locus) is proposed [4], [5]. However, this controller cannot guarantee good compensation. Indeed, although the tracking of the magnitude of identified perturbation currents was quite good, a phase shift between the reference and the injected currents appears in the current control loop, degrading the compensation performance and limiting consequently the integration of the LCL filters in the structure of the shunt active compensator [5]. In order to overcome the phase shift effects over the entire bandwidth for LCL grid connected shunt active compensator, an advanced RST controller is proposed, called RSTimp [5]. Despite the fact that the high compensating performance ensured by this improved method in the continuous domain, this method is largely limited in the discrete domain [4]. Indeed, Shannon theorem, Nyquist frequency, sampling delay and other constraints, imply very high switching and sampling frequencies, what are still limited by VSI power rating components and costs.

To overcome these problems, a conventional structure of the VSI (two levels system configuration) associated to LCL filter, along with adapted nonlinear controllers, as the classical first order sliding mode control (FOSMC) [6], is proposed. This technic provides strong sensitivity against uncertainties disturbances, satisfying the well-known matching condition, i.e., uncertainties and perturbations affecting the system through the same channels as the control input. FOSMC is easy to implement and reduce the order of the state equations. However, it also has some disadvantages. For instance, it is restricted to systems having relative degree equal to one (which would be equal to three in the case of the LCL filter) and it yielded chattering effect, which degrade the performance of the controlled system and could cause zeno phenomena, which could destroy the inverter.

It is important to mention that other compensation solutions were focused to build the least polluting load. In this context, loads of sinusoidal consumption are proposed for harmonics and reactive power cancelling [7], [8]. However, these solutions involve additional costs and do not solve the problems caused by all the polluting loads, that already exist on the market.

In this research, a Lyapunov approach based homogeneous higher order sliding mode (HOSM) controller is proposed to control the injected current of the grid connected shunt active filter (SAF) via LCL output filter. In this case, a grid connected SAF via LCL could be universal, by compensating (without injecting frequency switching components) all current perturbations as reactive, unbalance and harmonic currents. In addition, A PWM-HOSM-Controller will allow to operate in a fixed frequency, preventing a variable switching frequency effects. Moreover, a solution for the non-robustness drawback, in the presence of high disturbances, of this control method is proposed. Finally, the speed, tracking and robustness of the proposed controller, operating within the SAF, will be validated by simulations carried out by Matlab, Simulink, Simscap-Sim_Power_System code.

Shunt active filter structure

General basic structure

In the distribution electrical power systems, most power quality problems are associated with voltage harmonics, unbalanced voltages and reactive power. These disturbances are usually generated by unbalanced and inductive consumption and by non-linear loads. Therefore, shunt active compensators are generally proposed to cancel the current perturbations and subsequently reducing the voltage perturbations of the same nature [9], [5]. Fig. 1 shows a conventional structure of shunt active filter within its power environment, such as the three-wire power network and the non-linear load. The shunt active filter is generally composed of a control part and a power part. The power part includes a PWM voltage source inverter (VSI), a DC capacitive storage system and an output filter. The control part

consists of a current perturbations identification block, a current control block and a driving VSI block for the injected currents into the grid.

Fig. 1: Basic structure of shunt active compensators

Output current control loop

A PWM three-phase voltage source inverter (VSI) is used to generate the current to be injected to the network supply. The VSI is connected to the electrical network via a passive output filter. The output filter must be designed to block the components of the switching frequency, generated by the PWM-VSI, without affecting the SAF dynamics.

State space models of the LCL output filter

A single phase equivalent circuit of the LCL output filter is shown in previous Fig. 2. Where L_{f1} is the inverter side inductor, L_{f2} is the grid-side inductor, C_f is a capacitor with a series R_f damping resistor, R_{f1} and R_{f2} are inductors resistances, L_s and R_s are grid inductor and resistor respectively. $V_f(s)$ is the inverter output voltage and $V_s(s)$ is the PCC network voltage, which is considered as a disturbance. Currents I_f , I_c , I_{inj} are inverter output current, capacitor current, and grid injected current, respectively and V_c is capacitor voltage.

Fig. 2: A single phase model of LCL output filter

The state space model of the single phase LCL output filter is [10]:

$$\begin{aligned} \frac{dv_c}{dt} &= \frac{i_f - i_{inj}}{C_f} \\ \frac{di_f}{dt} &= \frac{1}{L_{f1}}(v_f - v_c - R_f(i_f - i_{inj}) - R_{f1}i_f) \\ \frac{di_{inj}}{dt} &= \frac{1}{L_{f2}}(v_c - R_f(i_f - i_{inj}) - v_s - R_{f2}i_{inj}) \end{aligned}$$

The equations show no cross-coupling terms as indicated by the matrix expression:

$$\begin{bmatrix} \frac{di_f}{dt} \\ \frac{di_{inj}}{dt} \\ \frac{dv_c}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{R_{f1} + R_f}{L_{f1}} & \frac{R_f}{L_{f1}} & -\frac{1}{L_{f1}} \\ \frac{R_f}{L_{f2}} & -\frac{R_{f2} + R_f}{L_{f2}} & \frac{1}{L_{f2}} \\ \frac{1}{C_f} & -\frac{1}{C_f} & 0 \end{bmatrix} \begin{bmatrix} i_f \\ i_{inj} \\ v_c \end{bmatrix} + \begin{bmatrix} \frac{1}{L_{f1}} & 0 \\ 0 & -\frac{1}{L_{f2}} \\ 0 & 0 \end{bmatrix} \begin{bmatrix} v_f \\ v_s \end{bmatrix} \quad (1)$$

$$x = Ax + \hat{B} v_f + P v_s \quad (2)$$

Control method

Linear control Algorithm

The control strategy is based on, detecting the current perturbations (current reference I_{ref}) by means of an identification method, and then to drive the VSI by a PWM technology, in order to generate these references as injected currents (I_{inj}) in the grid.

In order to ensure a good tracking between I_{ref} and I_{inj} , the control strategy integrates a current control loop. Fig. 3 shows a general block scheme of the current control algorithm, with $B_1(s)/A(s)$ is the transfer function model of the controlled system (LCL filter) and $B_2(s)/A(s)$ represents the disturbance model. In this scheme, a LCL grid connected PWM-VSI with a controller and an instantaneous power method, for current perturbations identification, are proposed; the voltage network V_s represents here external disturbance. In this article, the effects of this disturbance will be compensated by adding the same network voltage to the control signal (u).

Fig. 3: General block scheme of current control algorithm

Phase shift effect problems

The RST control method, as all linear controllers, are generally used when the reference to be tracked is either a constant or a single low frequency signal. In the low single-frequency case (i.e. unbalance or reactive power compensation), phase shift between reference (I_{ref}) and injected (I_{inj}) signals is acceptable. However, the phase shift is unacceptable when the reference signal includes multiple frequencies, as phase shift increases with frequency. Moreover, higher the order of the controlled system (the output filter here), the higher the phase shift is. Fig. 4 illustrates the phase shift effect for the structure presented in Fig. 3. From Fig. 4, it is simple to noticed that the distorted current (I_{Load}), is not correctly compensated for (I_{real} : compensation with phase shift), compared to the ideal form (I_{ideal} : compensation without phase shift).

Fig. 4: Phase shift effects on compensation quality

Higher order sliding mode (HOSM) controller

The higher order sliding mode technique has been developed to deal with the drawback of the first order SM technic [11]. Elimination of the restriction of the relative degree equal to one, better accuracy with respect to discrete sampling time and chattering effect reduction are achieved with HOSMC [11]. Recently, new families of the homogenous HOSM controllers derived by the concept of Lyapunov functions (CLFs) are proposed [6]. Notable features of the proposed families are their capacity of

reducing high frequency transient response of the state trajectories of the controlled system and providing good convergence rate [6].

Some recalls on higher order sliding mode

It is well known that it is not necessary to have a discontinuous dynamic in order to obtain finite time convergence, let us consider the following academic example:

$$\dot{x} = -x^{\frac{1}{3}}$$

which have as solution:

$$x(t) = \left(\frac{-2t}{3} + C\right)^{\frac{2}{3}} \text{ with } C = x(0)^{\frac{2}{3}} \text{ for } t \in \left[0, \frac{3x(0)^{\frac{2}{3}}}{2}\right] \text{ and } x(t) = 0 \text{ for } t > \frac{3x(0)^{\frac{2}{3}}}{2}$$

For an introduction to finite time convergence for continuous but non-Lipschitzian system see [12]. But this kind of finite time convergence does not ensure an exact cancellation of the disturbances effects, even if the disturbance is matching [13]. It is why, high order sliding mode control based on the homogeneity was introduced by A. Levant [11]. Moreover, this type of control overcome the restriction of the relative degree equal to one and ensures the finite time convergence of the full state. Since this seminal article, many researchers were worked on this subject [14], [15], [16]. In order to design a homogeneous finite time control, and this for any relative degree, which ensures the finite time convergence, Lyapunov control function (LCF) are used [17], [18]. These LCF are based on the well-known Backstepping method [19]. For the seek of the presentation simplicity, let us consider only the following second order system:

$$\begin{aligned} \dot{x} &= x_2 \\ \dot{x}_2 &= u + p(t) \end{aligned} \tag{3'}$$

with for all $t > 0$, $|p(t)| < D$. So for this, an expected x_{2d} is designed with respect to the following finite time dynamic:

$$\dot{x}_1 = -\lambda_1 [x_1]^\alpha := x_{2d} \tag{4'}$$

where $\alpha \in [0,1)$ and $[\cdot]^\alpha$ denotes $|\cdot|^\alpha \text{sign}(\cdot)$.

Unfortunately, this equation is not differentiable at $x_1 = 0$. Thus, in order to overcome the singularity at $x_1 = 0$, the following equivalent equation is used:

$$[\dot{x}_1]^{\frac{1}{\alpha}} + \lambda_1^{\frac{1}{\alpha}} x_1 = 0 \tag{5'}$$

Thus $S_d := [\dot{x}_1]^{\frac{1}{\alpha}} + \lambda_1^{\frac{1}{\alpha}} x_1$ is equivalent to $S = \dot{x}_1 + \lambda_1 [x_1]^\alpha$ with respect to the x_1 behavior when $S_d = S = 0$. Now, let us consider the first step of the backstepping and set the following partial Lyapunov function (only function of x_1)

$$V_1 = \int_0^{x_1} [\sigma]^\alpha d\sigma = \frac{1}{\alpha+1} |x_1|^{\alpha+1}$$

Then the time derivative of V_1 with respect to (3) gives:

$$\dot{V}_1 = |x_1|^\alpha \text{sign}(x_1) x_2 = [x_1]^\alpha x_2$$

Setting $z = x_2 - (-\lambda_1 [x_1]^\alpha)$ where $-\lambda_1 [x_1]^\alpha = x_{2d}$ the expected value of x_2 , the previous equation becomes:

$\dot{V}_1 = [x_1]^\alpha \text{sign}(x_1) (z - \lambda_1 [x_1]^\alpha)$ Which is equal for $z = 0$: $\dot{V}_1 = -\lambda |x_1|^{2\alpha}$ and can be rewritten only in function of V_1 :

$$\dot{V}_1 = -\lambda ((\alpha+1)V_1)^\beta \tag{6'}$$

with $\beta = \frac{2\alpha}{1+\alpha}$ which verifies $\beta \in (0,1)$, then when $z = 0$, x_1 converges in finite time to zero. Now, the second step of the backstepping procedure consists to choose a new Lyapunov function:

$$V_2 = \int_{-\lambda_1 [x_1]^\alpha}^{x_2} ([\sigma]^{\frac{1}{\alpha}} + \lambda_1^{\frac{1}{\alpha}} x_1) d\sigma + \gamma V_1 \tag{7'}$$

Where γ is a strictly positive free parameter and the integral term is positive definite and equal to:

$$\int_{-\lambda_1|x_1|^\alpha}^{x_2} ([\sigma]^{\frac{1}{\alpha}} + \lambda_1^{\frac{1}{\alpha}} x_1) d\sigma = [\frac{\alpha}{1+\alpha} |\sigma|^{\frac{1}{\alpha}+1} + \lambda_1 x_1 \sigma]^{x_2} - \lambda_1 |x_1|^\alpha$$

Then V_2 becomes:

$$V_2 = \frac{\alpha}{1+\alpha} |x_2|^{\frac{1+\alpha}{\alpha}} + \lambda_1^{\frac{1}{\alpha}} x_1 x_2 - \frac{\alpha}{1+\alpha} |-\lambda|^{\frac{1+\alpha}{\alpha}} |x_1|^{\alpha+1} + \lambda_1^{\frac{1+\alpha}{\alpha}} |x_1|^{\alpha+1}$$

which is equal to:

$$V_2 = \frac{\alpha}{1+\alpha} |x_2|^{\frac{1+\alpha}{\alpha}} + \lambda_1^{\frac{1}{\alpha}} x_1 x_2 + \frac{1}{1+\alpha} |\lambda|^{\frac{1+\alpha}{\alpha}} |x_1|^{\alpha+1} + \gamma \alpha |x_1|^{\alpha+1} \quad (8')$$

Considering the following dilation: $\Delta_\varepsilon^{r_1, r_2} x := (\varepsilon^{r_1} x_1, \varepsilon^{r_2} x_2)^T$, with $r_1 = \frac{1}{\alpha+1}$ and $r_2 = \frac{l\alpha}{1+\alpha}$, then V_2 verifies:

$$\begin{aligned} V_2(\Delta_\varepsilon^{r_1, r_2} x) &= \frac{\alpha}{1+\alpha} |\varepsilon^{r_2} x_2|^{\frac{1+\alpha}{\alpha}} + \lambda_1^{\frac{1}{\alpha}} \varepsilon^{r_1+r_2} x_1 x_2 + \frac{1}{1+\alpha} |\lambda|^{\frac{1+\alpha}{\alpha}} |\varepsilon^{r_1} x_1|^{\alpha+1} + \gamma \alpha |\varepsilon^{r_1} x_1|^{\alpha+1} \\ V_2 &= (\Delta_\varepsilon^{r_1, r_2} x) = \varepsilon^l V_2(x) \end{aligned} \quad (9')$$

Consequently, the function V_2 is an homogeneous function. Moreover, the time derivative of V_2 with respect to (3) is:

$$\dot{V}_2 = ([x_2]^{\frac{1}{\alpha}} + \lambda_1^{\frac{1}{\alpha}})(u + p(t)) + \lambda_1^{\frac{1}{\alpha}} x_2^2 + \rho [x_1]^\alpha x_2$$

As $\rho = \lambda_1^{\frac{1+\alpha}{\alpha}} + \gamma(\alpha+1)\alpha$, it is possible to choose $\gamma > 0$ such that $\rho = \lambda_1^{\frac{1+2\alpha}{\alpha}}$ and $\dot{V}_2$ becomes:

$$\dot{V}_2 = S_d(U + p(t)) + S x_2 + \lambda [x_1]^\alpha x_2 \quad (10')$$

As the set $\{\frac{x}{S_d} = 0\}$ is included in $\{\frac{x}{S x_2} = 0\}$ from technical homogeneous arguments (see [18]) there exists $\theta_{min} > 0$ such that for all $\theta > \theta_{min}$, $(S x_2)^2 - \theta S_d \leq 0$, so it is always possible to design the control $u(t)$ as follow:

$$u(t) = -U_{max} [S_d]^0 = -U_{max} \text{sign}(S_d) \quad (11')$$

with U_{max} sufficiently large to cancel, for x_2 bounded, the matching disturbance $p(t)$ [13] and x_2 . Now what appends in vicinity of $S_d = 0$, then $x_2 = -\lambda_1 [x_1]^\alpha$ and $\dot{V}_2$ becomes :

$$\dot{V}_2 = -\lambda_1 [x_1]^{2\alpha} \quad (12')$$

By continuity and homogeneity arguments and LaSalle theorem [20], these imply that the control (11') ensures the finite time convergence of (3').

Now, we are able to present a homogeneous control dedicated to our problem, for this we will, in this paper use one of the controller analyzed in [6] and we will explain why we have chosen this control.

Higher order sliding mode controller design

Considering the system in state space representation with: $y := i_{inj}$ as output, $u := v_f$ as input and $w := v_s$ as disturbances and $R_f = 0$, equation (2) becomes:

$$\begin{aligned} \dot{x} &= Ax + Bu + Pw \\ y &= Cx, C = [0 \ 1 \ 0] \end{aligned} \quad (3)$$

$$\text{with } x = \begin{bmatrix} \frac{di_f}{dt} & \frac{di_{inj}}{dt} & \frac{dv_c}{dt} \end{bmatrix} \text{ and: } A = \begin{bmatrix} -\frac{R_{f1}}{L_{f1}} & 0 & -\frac{1}{L_{f1}} \\ 0 & \frac{R_{f2}}{L_{f2}} & \frac{1}{L_{f2}} \\ \frac{1}{C_f} & -\frac{1}{C_f} & 0 \end{bmatrix}, B = \begin{bmatrix} \frac{1}{L_{f1}} \\ 0 \\ 0 \end{bmatrix}, P = \begin{bmatrix} 0 \\ -\frac{1}{L_{f2}} \\ 0 \end{bmatrix}$$

From (3), it is obvious that the relative degree of the system is equal to three ($CB = CAB = 0$ and $CA^2B = \frac{1}{(L_{f1}L_{f2}C_f)}$) and that the matching condition [13] is not verified, but as the disturbance is at least

$\mathbb{C}^2$, with $v_s, \frac{dv_s}{dt}, \frac{d^2v_s}{dt^2}$ bounded, then we can use a high order sliding mode of order three. It is not necessary to introduce a terminal sliding manifold technics or to reduce the chattering, this is done by the PWM. In [6] some High-order sliding mode control based on Lyapunov function was analyzed and compared, for our study we have chosen a new NSC sliding mode of the following one:

$$u(t) = K_3 \left(\left[\frac{d^2(i_{inj} - i_{iref})}{dt^2} + 1.5 \lambda \left[\frac{d(i_{inj} - i_{iref})}{dt} \right]^{\frac{3}{2}} + \lambda (i_{inj} - i_{iref}) \right]^{\frac{1}{3}} \right)^0 \quad (4)$$

Where $[\cdot]^k$ denotes $|\cdot|^k \text{sign}(\cdot)$ and $K_3 \geq (L_{f1} L_{f2} C_f) (3.32 \lambda^2 + D)$, with $D=380$ and $\lambda = 7$. We have chosen this control law for its tuning simplicity, only one parameter λ and its implementation simplicity.

Disturbance rejection

As it is previously mentioned, the drawback of this control method is its limitation in the presence of high disturbances, which could deteriorate severely the filtering quality of the active filter. Indeed, from equation (1), the network voltage V_s is considered as disturbance, which could contains both fundamental and harmonic components. If these disturbances have not been enough rejected, they will disturb the performance of the proposed method, by adding disturbing components into the injected current, especially at fundamental frequency. This will result in over-rating and performance degradation of the active filter.

In order to eliminate the effect of these disturbances, we add the network voltage (with an opposite sign with relation to the network voltage) to the controller output $u(t)$, as shown in the Fig. 3. This new branch will support disturbances mitigation and consequently keep the possibility of applying this control method on active harmonic filtering.

Simulation results

The studied network is made up of a sub-transformer 20/0.4 kV, 1 MVA, ucc=4%, supplied by an upstream network of 500 MVA of short-circuit power. The non-linear load is a 130 kVA six-pulse diode rectifier with R/C load. The performance of the shunt active filter used to eliminate harmonics, generated by the nonlinear load, will be tested using Matlab, Simulink, Simscap-Sim_Power_System. In these simulations, the shunt active filter has a LCL output filter while the injected current is controlled by the HOSM-Cntroller. The sign function is approximated, for computation reason, by a hysteresis function, with very small band (10^{-16}).

The system rating values, considered in the general structure, are given in Table I.

Table I: Electrical network characteristics

Electrical Network	
Ssc=500 MVA, 20kV, Transformer: 1 MVA, 20/0.4 kV, ucc=4% Rs=0.25 mΩ, Ls=19.4 μH	
Shunt Active Filter	
Output LCL filter	Lf1=100 μH, Rf1= 5 mΩ, Lf2=100 μH, Rf2= 5 mΩ Cf= 130 μF
Storage capacity	Vdc=840 V
LCL Cut-off frequency	2000 Hz
PWM switching Frequency	16 kHz

Simulation with disturbances rejection

In this first case, network voltage disturbances are rejected by adding the network voltage to the controller output $u(t)$ as mentioned above and as shown in Fig. 3. In this first case, the active filter is cutted-on after 5 operating periods (≈ 0.1 s). The Fig. 5 shows results, in time domain for phase 1, of network current (I_s) before and after compensation, the identified and injected harmonic currents I_{ref} and I_{inj} respectively superimposed and the total harmonic distortion of current (THD- I_s) at network side, before and after compensation. From this figure, it is noticed that, despite the presence of the LCL filter, there is no phase shift between reference current and injected current. Thus, the current pattern, in the network side is a perfect sinusoidal (with a neglected transient time), without any presence of high

frequency components. This results are confirmed by an important decrease of current THD (THD-Is) at the network side, from almost 24% before compensation to almost 1.6% after compensation.

Fig. 5: Time domain simulation with disturbances rejection

In order to confirm this good result, a spectrum analyze is made for line current at the network side, before and after filtering, as shown at Fig. 6 and Fig. 7 respectively. From Fig. 6, it could be noticed that the current harmonics to be filtered are 5th, 7th, 11th, 13th...etc, the maximum value of fundamental current is 273.3 A and the THD of current before filtering is 24.29%. After filtering and via the Fig. 7, the large mitigation of harmonics (for the same fundamental current component as the case before filtration) can be noticed. This witnesses the good performance of the proposed nonlinear control method associated to voltage disturbance rejection branch.

Fig. 6: spectrum analysis of network current before filtration (with disturbances rejection)

Fig. 7: spectrum analysis of network current after filtration (with disturbances rejection)

Fig. 8: spectrum analysis of the network current after filtration (without disturbances rejection)

Simulation without disturbances rejection

In this second case, we will study the performance of the same control method, but without disturbances rejection; in this case, the added branch of network voltage is disconnected, from the output of $u(t)$. Previous Fig. 8 shows spectrum analysis of the network current after filtration. From this figure, it can

be can observed that the injected current contains fundamental and other supplementary harmonics components. Indeed, the maximum value of fundamental current, injected to the network, is now 294.8 A with a real increase of THD to 2.58%; the network current before filtering stays unchanged. This result demonstrates the limitation of the proposed method in the presence of high disturbances, which could result in over rating and deterioration of the performance of the shunt active filter.

Conclusion

In this paper, we proposed a Lyapunov approach based homogenous higher order SM-Controller, for grid connected three phases three wires shunt active filter (SAF) via LCL filter. The active filter is a very good solution for current perturbations elimination, especially harmonic currents. The proposed method is an alternative solution to linear controllers, which are limited (in presence of LCL output filter) by a phase shift between identified and injected harmonics. The limitation of this control method by high disturbances (represented in this case by the network voltage) is solved in this article by adding the same network voltage to the controller output.

The very fast and accurate filtration of the active filter (with HOSM-Controller, associated to disturbances rejection branch) is proved via two simulations, carried out in time and frequency domains. A second simulation demonstrated the inaptitude of this control method in presence of high disturbing voltage, which is not a matching disturbance; this could lead to an over rating of the SAF with degradation of filtration quality.

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