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SLIDING MODE OBSERVER OF A GRID CONNECTED PHOTOVOLTAICGENERATION SYSTEM WITH ACTIVE FILTERING FUNCTION

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Sliding Mode Observer of a Grid Connected Photovoltaic Generation System with Active Filtering Function

A. Djerioui [α], K. Aliouane [σ] & F.Bouchafaa [ρ]

Abstract - The first problem in our third millennium is energy. For this raison, we try to find a new solution to develop different ways of distribution and energy use. This article presents the design of a sliding mode controller using sliding mode observation technique which aims to simplify the control procedure. For ameliorating the quality of the energy transferred from the power supply to the load, and minimizing the harmful effects of the harmonics generated by nonlinear load. The virtual grid flux vector estimated in the sliding-mode observer yields robustness against the line voltage distortions. We propose a new multi-function converter as an efficient solution to improve the power quality. The good dynamic and static performance under the proposed control strategy is verified by simulation.

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I. Introduction

The widespread use of power electronics in domestic and industrial applications had induced power line losses and electrical interference problems, which resulted in low power factor, efficiency and bad quality of the power electrical distribution system.

Classical solutions use passive filters, made up of capacitors and inductors, to reduce line current harmonics and to compensate reactive power. But these filters have several drawbacks: risk of parallel and series resonance with the AC source, bulky passive components, and low flexibility due to fixed compensation characteristics.

Active filters can be connected in series or in parallel to the nonlinear loads. Shunt active filters are the most important and widely used industrial processes for active filtering The main purpose of shunt filters is to cancel the load current harmonics fed to the supply, so that the power supply needs only to feed the fundamental active current component.

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In this frame, photovoltaic generation systems have the opportunity to be as much as suitable for their important advantage being able to produce electrical energy very close to the electric loads. In this way the transmission losses are avoided and it is also possible to satisfy the daily load diagrams' peaks since they supply the maximum power quite in correspondence to the maximum request.

The sliding mode control (SMC) is one of the popular strategies to deal with uncertain control systems [9]. The main feature of SMC is the robustness against parameter variations and external disturbances. Various applications of SMC have been conducted, such as robotic manipulators, aircrafts, DC motors, chaotic systems, and so on [10]

The motivation for this work was to design a digitally controlled, combination active filter and photovoltaic (PV) generation system.

Sliding Mode Control of a Grid Connected Photovoltaic Generation System with Active Filtering Function

The motivation for this work was to design a digitally controlled, combination active filter and photovoltaic (PV) generation system. This work focuses on a proposed control scheme for the dual function system and on the effects of delay on the control of an active filter. The scheme of the proposed multi-function converter is shown in Fig.1

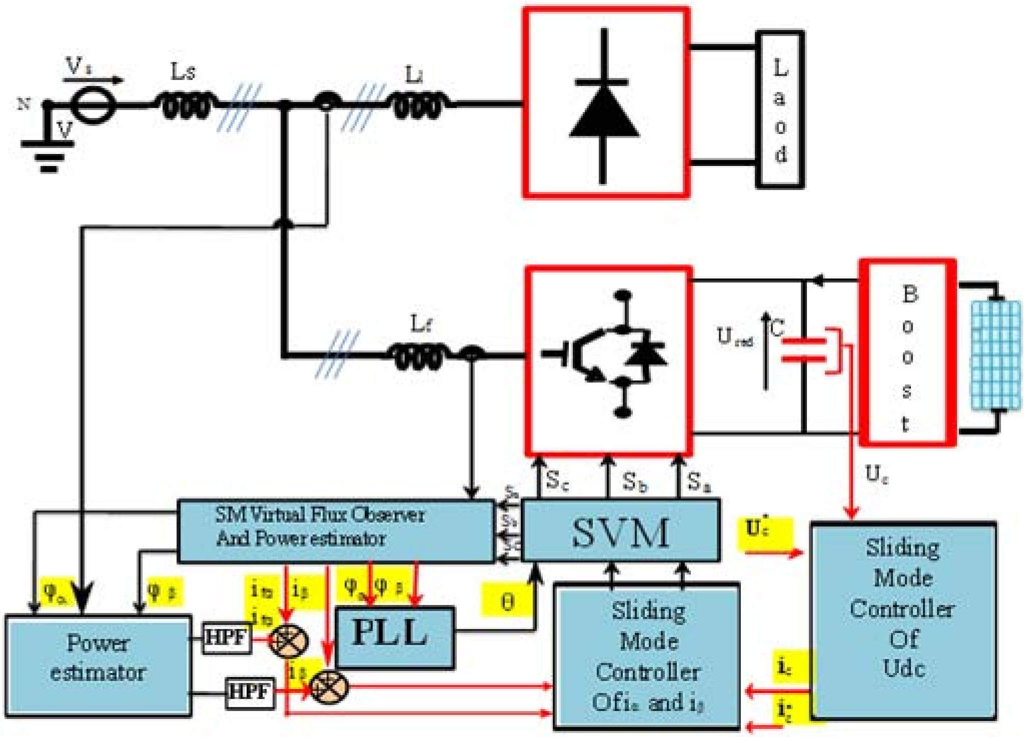


Figure 1 : Scheme of the multi-function converter

a) Modelling of the PVG

The mathematical model of the PVG is given by model 1.

$$I = I_{sc} - I_0\left[\left(e^{\frac{(V+IR_s)}{nkT_c/q}} - 1\right)\right] - \frac{V+IR_{sr}}{R_{sh}} \qquad (1)$$

With I and V are respectively the PV current and voltage, I_0: leakage or reverse saturation current, q: electron charge, *n:* Ideality factor, K is the Boltzman's constant ($1.38.10^{-23}$ J/K), R_{sr} :series cell resistance, R_{sh}:shunt cell resistance.

b) Boost converter

The Boost converter shown in Figure 2, it has step-up conversion ratio. Therefore the output voltage is always higher than the input voltage. The converter will operate throughout the entire line cycle, so the input current does not have distortions and continuous. It has a smooth input current because an inductor is connected in series in with the power source. In addition the switch is source-grounded; therefore it is easy to drive.

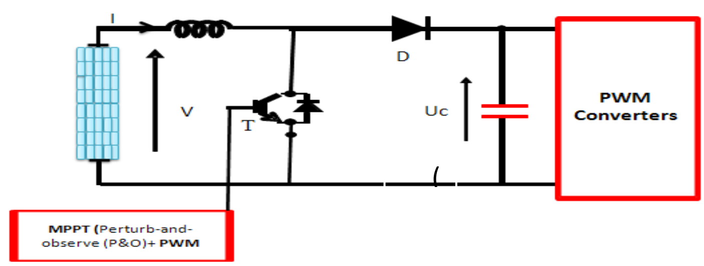


Figure 2 : Boost Converter

c) Mathematical Model of PWM Converters

A three phase voltage inverter is used to interface the PVG with the grid by converting the dc power generated by the PVG into AC power to be injected to the grid. The dynamic model of a PWM DC-AC Converter can be described in the well known (d-q) frame through the Park transformation as follows [1], see appendix:

$$\begin{aligned} \frac{di_{fd}}{dt} &= \frac{-R_f}{L_f} i_{fd} + w i_{fq} + \frac{1}{L_f} v_{fd} - \frac{v_{sd}}{L_f} \\ \frac{di_{fq}}{dt} &= \frac{-R_f}{L_f} i_{fq} + w i_{fd} + \frac{1}{L_f} v_{fq} - \frac{v_{sq}}{L_f} \\ \frac{dU_c}{dt} &= \frac{d_d}{C} i_{fq} + \frac{d_q}{C} i_{fd} \end{aligned} \qquad (2)$$

Where

d_d,d_q d- Axis and q- axis switching state functions,

$\hat{v}_{sd}$ and $\hat{v}_{sq}$ - d- Axis and q- axis supply voltages.

The bi-directional characteristic of the converter is very important in this proposed photovoltaic system, because it allows the processing of active and reactive power from the generator to the load and vice versa, depending on the application. Thus, with an appropriate control of the power switches it is possible to control the active and reactive power flow.

$$\begin{bmatrix} \hat{v}_d \\ \hat{v}_q \end{bmatrix} = \frac{1}{i_{fd}^{\;2} + i_{fq}^{\;2}} \begin{bmatrix} i_{fd} & -i_{fq} \\ i_{fq} & i_{fd} \end{bmatrix} \begin{bmatrix} P \\ q \end{bmatrix} \quad (3)$$

Where $\hat{v}_d$ and $\hat{v}_q$ are the estimated main line

d) The Regulators Synthesis

The state equations are shown in (4) and summarized as (5)

$$\begin{bmatrix} \frac{di_{fd}}{dt} \\ \frac{di_{fq}}{dt} \end{bmatrix} = \begin{bmatrix} \frac{-R_f}{L_f} & w \\ -w & \frac{-R_f}{L_f} \end{bmatrix} \begin{bmatrix} i_{fd} \\ i_{fq} \end{bmatrix} + \begin{bmatrix} \frac{1}{L_f} \\ \frac{1}{L_f} \end{bmatrix} \begin{bmatrix} v_{fd} \\ v_{fq} \end{bmatrix} - \begin{bmatrix} \frac{v_{sd}}{L_f} \\ \frac{v_{sq}}{L_f} \end{bmatrix} \quad (4)$$

$$\dot{I} = AI + Bu - G \quad (5)$$

The sliding surfaces (S) are equal to the error of state variables, which can be express as:

$$S = K_{SMP} E_f + K_{SMI} \int E_f dt \quad (6)$$

Where

$$S = \begin{bmatrix} S_d \\ S_q \end{bmatrix}; E_f = I^* - I; I^* = \begin{bmatrix} i^*_{fd} \\ i^*_{fq} \end{bmatrix}; K_{SMP} = \begin{bmatrix} k_{SMPd} & 0 \\ 0 & k_{SMPq} \end{bmatrix}; K_{SMI} = \begin{bmatrix} k_{SMid} & 0 \\ 0 & k_{SMiq} \end{bmatrix} \quad (7)$$

Where k_{SMPd}, k_{SMPq}, k_{SMid} and k_{SMiq} 3 are positive constants And consequently, their temporal derivatives are given by:

$$\dot{S} = K_{SMP} \dot{E}_f + K_{SMI} E_f \quad (8)$$

The equivalent control can be calculated from the formula $\dot{S} = 0$, and the stabilizing control is given to guarantee the convergence condition (5).

$$\dot{S} = K_{SMP} \dot{I}^* + K_{SMI} E_f - K_{SMP}(AI + Bu - G) = 0 \quad (9)$$

The equivalent control u_{eq} is deduced by imposing the sliding regime condition $\dot{S}$ obtaining:

$$u_{eq} = \begin{bmatrix} u_{eqd} \\ u_{eqq} \end{bmatrix} = (K_{SMP} B)^{-1} \left[K_{SMI} E_f - K_{SMP}(AI + Bu - G + \dot{I}^*) \right] \quad (10)$$

Finally, the control law is given by:

$$u = u_{eq} + u_{dis} = \begin{bmatrix} u_{eqd} + u_{disd} \\ u_{eqq} + u_{disq} \end{bmatrix} = \begin{bmatrix} u_{eqd} + k_{sd}\, sign(S) \\ u_{eqq} + k_{sq}\, sign(S) \end{bmatrix} \quad (11)$$

For the sliding mode DC-link voltage controller based on integrator can be determined by substituting the reference line current, is chosen to determine switching surface functions:

$$S_{dc} = K_{SMPC}(U^*_c - U_c) + K_{SMIC} \int (U^*_c - U_c) d \quad (12)$$

And consequently, their temporal derivative is given by:

$$\dot{S}_{dc} = K_{SMPC}(\dot{U}^*_c - \dot{U}_c) + K_{SMIC}(U^*_c - U_c) = 0 \quad (13)$$

Finally, the control law is given by:

$$i_{ceq} = C\left(\frac{K_{SMIC}}{K_{SMPC}}(U^*_c - U_c) + \dot{U}^*_c\right) + K_{SC}\, sig\, (U^*_c - U_c) \quad (14)$$

The sliding mode observer uses the system model with model with the sign feedback function. The continuous time version of the SMO is described by Equation (15).

$$\frac{d}{dt}\begin{bmatrix} i_{f\alpha} \\ i_{f\beta} \end{bmatrix} = \frac{1}{L_f}\left(\lambda.sign\left(\begin{bmatrix} i_{f\alpha} - i_{f\alpha est} \\ i_{f\beta} - i_{f\beta est} \end{bmatrix}\right) - R_f \begin{bmatrix} i_{f\alpha} \\ i_{f\beta} \end{bmatrix} - \begin{bmatrix} v_{f\alpha} \\ v_{f\beta} \end{bmatrix}\right) \quad (15)$$

The estimated values of the grid voltage are obtained from the law-pass filter:

$$\begin{bmatrix} v_{s\alpha estSMO} \\ v_{s\beta estSMO} \end{bmatrix} = LPF\left(\lambda.sign\left(\begin{bmatrix} i_{f\alpha} - i_{f\alpha est} \\ i_{f\beta} - i_{f\beta est} \end{bmatrix}\right)\right) \quad (16)$$

While the (α–β) components of the virtual grid flux are calculated as follows:

$$\begin{bmatrix} \varphi_{\alpha est} \\ \varphi_{\beta est} \end{bmatrix} = (\lambda.\int sign(\begin{bmatrix} i_{f\alpha} - i_{f\alpha est} \\ i_{f\beta} - i_{f\beta est} \end{bmatrix} dt) + \begin{bmatrix} \varphi_{\alpha est0} \\ \varphi_{\beta est0} \end{bmatrix} \quad (17)$$

Hence the structure of the virtual grid flux sliding-mode observer presented in Fig.3.

The sliding surface representing the error between the measured and references courrents are given by this relation.

$$\begin{bmatrix} \sigma_{\alpha} \\ \sigma_{\beta} \end{bmatrix} = \begin{bmatrix} i_{f\alpha} - i_{f\alpha est} \\ i_{f\beta} - i_{f\beta est} \end{bmatrix} \quad (18)$$

The sliding mode will exist only if th following condition

$$\dot{\sigma}_{\alpha\beta}\sigma_{\alpha\beta} < 0 \quad (19)$$

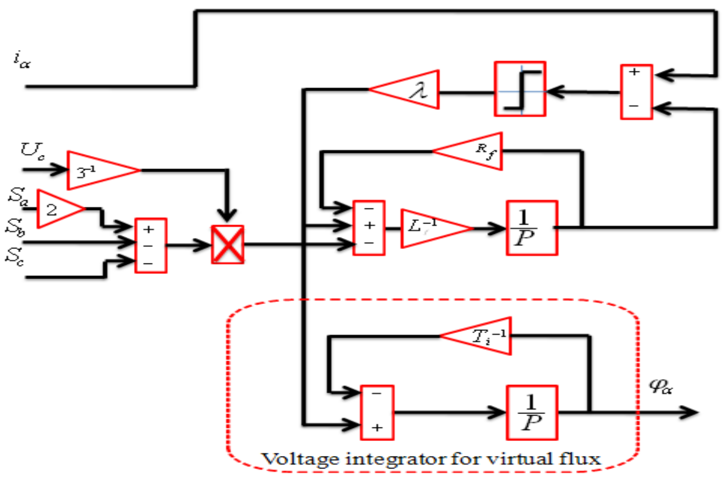
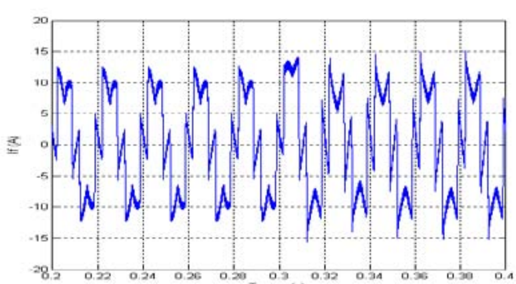


Figure 3 : Sliding-mode current observer for virtual grid flux

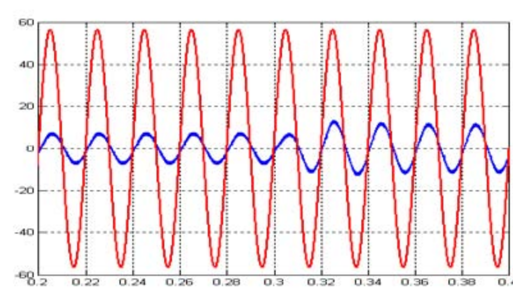
II. Simulation Result

In simulation part, power system is modeled as 3wired 3-phase system by an RL load with uncontrolled diode rectifier. In the circuit, the ac source with frequency of 50Hz. The grid side line voltage is 220V. The line resistor is 0.25Ω. The line inductance of each phase is 1mH. The dc capacitor is 5000μF; the dc voltage is set to be 700V. The switching frequency for three-phase is 15 kHz.

The Pv model applied in simulation is as Fig .4. Whose parameters are regulated for normal condition (25^0 C Temp. and sun radiation G=1kW/m).



A)



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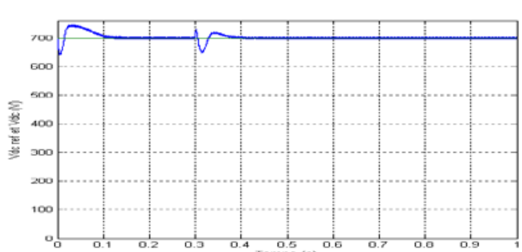
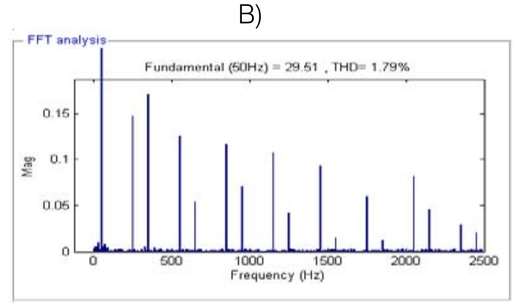


C)



D)

Fig.7. Simulated responses for a step change in the load resistor: A) Harmonic currents injected by the active power filter, Load change at 0.3 s. B) Source voltage, source current. C) DC side capacitor voltage and filter D) Current spectrum harmonic: Grid in Phase 1.

a) Sliding mode control of a grid connected photovoltaic generation system with active filtering function

The current reference of the active filter and the generated one are superposed in the same Fig.7.A

The Fig. 7.B. shows the behavior of the current and voltage in Phase 1 of the grid,. It is noted the linear currents are sinusoidal and the control technique presents a very good dynamic behavior, almost sinusoidal as well as in phase with line voltage, which gives near-to-unity power factor.

Fig .7.D shows simulation results for the DC bus voltage controller. The voltage vdc on the DC side of the inverter is stable and regulated around its reference. The THD before filtering for the first line is 27.46 % and becomes 1.79% after filtering.

III. Conclusion

This paper outlined the modeling and development of the control system for the active filter/PV generation system with sliding mode controller based on a Sliding Mode Observer. The results verify the validity of the proposed control scheme. Unity power factor is achieved, active and reactive current are decoupled controlled in the synchronous reference frame and the objective of maintaining balanced voltages in DC-link capacitors is carried out effectively with the proposed SVM, and it offers sinusoidal line currents (low THD) for ideal and distorted line voltage .

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