ISA Transactions 55 (2015) 267–274

Contents lists available at ScienceDirect

ISA Transactions

journal homepage: www.elsevier.com/locate/isatrans

Design and real time implementation of single phase boost power factor correction converter

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ARTICLE INFO

Article history:
Received 5 May 2014
Received in revised form
24 September 2014
Accepted 10 October 2014
Available online 31 October 2014

Keywords:
Power factor correction
Higher order sliding mode controller
Predictive control
AC–DC Boost converter
dSPACE 1104

ABSTRACT

This paper presents a real time implementation of the single-phase power factor correction (PFC) AC–DC boost converter. A combination of higher order sliding mode controller based on super twisting algorithm and predictive control techniques are implemented to improve the performance of the boost converter. Due to the chattering effects, the higher order sliding mode control (HOSMC) is designed. Also, the predictive technique is modified taking into account the large computational delays. The robustness of the controller is verified conducting simulation in MATLAB, the results show good performances in both steady and transient states. An experiment is conducted through a test bench based on dSPACE 1104. The experimental results proved that the proposed controller enhanced the performance of the converter under different parameters variations.

1. Introduction

Recently, the power electronics components have gained popularity in the development of new static converters to supply domestic and industrial applications due to the introduction of the fast switches components and appearance of new types of control techniques. Moreover, the use of power converters for renewable energy (solar, wind) becomes more important in the world due to the energy crisis. The AC–DC converter is an important element of the power supplies. Indeed, it has numerous applications in different power levels; low power like chargers of mobile phones that need a few watts, high power like electric welding that need a few kW. The AC–DC converter includes various topologies such as; buck, boost and buck-boost, etc. [1,2]. Among these types, the AC–DC boost converter has interesting features, which are the lifting operation, simple structure and low cost. The development of semiconductor allows the appearance of new power converters use a switch mode operation. The nonlinear loads and switching losses lead to more energy losses. Furthermore, Due to increasingly use of boost converter in the large electronic equipment, intensive efforts have been devoted to adopt international standard such as IEC 1000-3-2, EN61000-3-2 in Europe and the IEEE 519 in USA [3]. To improve the power factor in the boost converter topology, there are two types of power factor correction methods, passive method used for old power converters, and active method used recently in the most of electronics components that shown in Fig. 1. Several researches have been done to improve and find an adequate control for the PFC converter, which can provide a better performance.

Commonly, the traditional regulators like PI and PID have been used to regulate the output voltage of the boost converter [4,5]. These types of controls are based on modeling of the system around a nominal point under constant parameters and disturbance, which provide an acceptable performance but if the parameters change, the system loses its performance and give a bad results. For this reason, various intelligent controllers have been introduced to get an optimal performance of the converter regardless of parameters variations. Among these controllers fuzzy logic [6,7], sliding mode [8–10], predictive technique [11,12], artificial neural network [13] are used.

The sliding mode control has attracted great research interest [14–17]. Several researches have used SMC for the control of nonlinear and multivariable systems due to its disturbance rejection [18–20]. However, the drawback of sliding mode controller is the high frequency oscillations (chattering phenomenon), which is a major obstacle for the implementation of standard SMC. For these reasons. The HOSMC is proposed to overcomes the main drawbacks of classical SMC, its provides a smooth control, good performance yielding to less chattering in real time implementation, and better convergence while preserving the robustness properties [21–24]. Among the existing algorithms, the super twisting algorithms has been designed and evaluated in this paper. It has interesting features and maintains the distinctive performances of the classical SMC. It provides a systematic method to

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http://dx.doi.org/10.1016/j.isatra.2014.10.004
0019-0578/

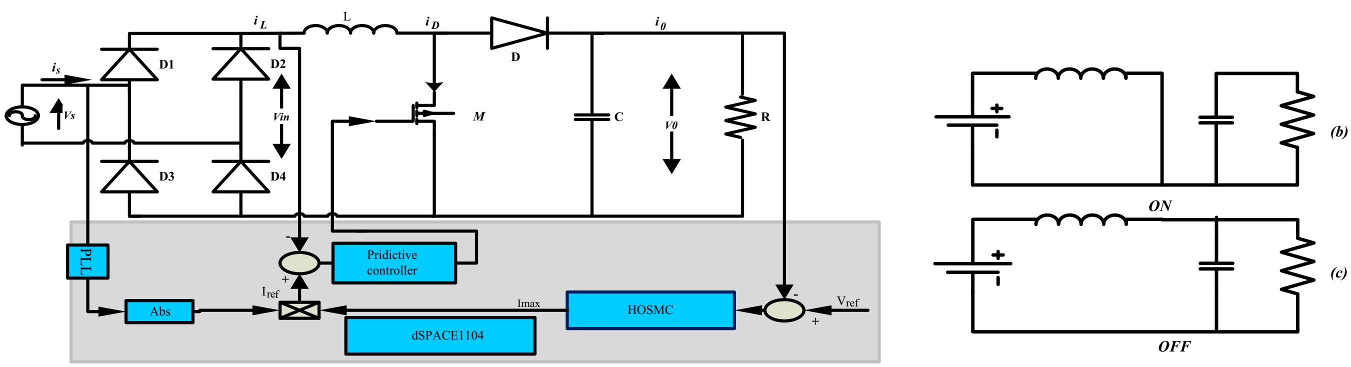

Fig. 1. PFC pre-regulator.

solve the stability and modeling imprecision problems in new electronic components. Moreover, his practical implementation is simple and assure in both the accuracy and convergence in finite time. Similarly, the predictive control has been employed in the industrial applications those need high specific performance, due to its reliability and disturbance attenuation [25,26]. The predictive technique has been used in this work to investigate its speed and implementation simplicity, which leads a fast dynamic response and better efficiency.

Generally, fast settling time leads to large overshoot; it is well known that these two important requirements are the most common problems in controller design, which are not desired in many practical applications. Hence the user is compelled to choose either fast response or low overshoot. This particular problem can be solved by using the proposed method. The main contribution of this paper is the real time implementation on dSPACE 1104 of a new robust hybrid controller, composed by HOSMC based on super twisting in the DC voltage loop, and predictive controller in the current loop, which takes into account a better steady state performance and transient response. To verify the controllers performance for steady and transient states, at first simulations have been carried out under different loading conditions along with different reference output voltages. Later an experimental test using the dSPACE 1104 board has been conducted to verify the simulations results. From both simulation and experimental results, the robustness of the proposed controller based boost converter for PFC has been verified and evaluated.

The paper is organized as follows. Section 2 describes the proposed control methods for the boost converter. Sections 3 and 4 present the simulation and the experimental results along with the discussion. In Section 5 a general conclusion has been drawn by focusing the significant point of the paper.

2. Description of proposed control method

2.1. Modeling of the system

The basic model of the boost converter is defined according to the state of switch M. When the switch M is turned on ($u=1$), the voltage across the transistor is equal to zero and the diode is closed. Fig. 1b shows the equivalent circuit of the boost converter in the ON state. As soon as the switch M is turned off ($u=0$), the voltage across the diode is equal to zero, Fig. 1c shows the equivalent circuit in this operation mode [4]. The state space model for the boost converter governed the real switched system can be expressed as follow [27].

$$\begin{cases} C\frac{dV_0}{dt} = (1-u)i_L - i_0 \\ L\frac{di_L}{dt} = V_{in} - (1-u)V_0 \end{cases} \tag{1}$$

When a non-controlled rectifier is connected to the source voltage to ensure the converted AC/DC as shown in Fig. 1, the current drawn from the source i_s will be very distorted (high THD) and not in phase with the input voltage Vs, which increases the reactive power and lead to a low input power factor. To solve this problem, one possibility is to add a PFC circuit using two control loops. The dc-bus voltage is sensed and compared with its reference value V_{ref}. The obtained error is used as input for the voltage loop controller, the output of the voltage loop controller I_{max} multiplied by $|\sin \omega t|$ obtained from PLL is the reference current i_{ref}, the reference current is compared with the inductor current i_L. The obtained error is used as input for the current loop controller that calculate the duty cycle.

2.2. Voltage loop controller

To regulate the output voltage, the high order sliding mode controller (the second) based on super twisting algorithm has been used which has a specific operating mode. A sliding mode is said "rth order sliding mode" if $S(t) = \dot{S}(t) = \ldots = S^{(r-1)} = 0$. In HOSMC, the idea is to force the error to move on the switching surfaces and to keep its $(r-1)$ first successive derivatives null. More specifically, SOSMC aims for $S(t) = \dot{S}(t) = 0$, which is, the controller's aim to steer to zero at the intersection of $S(t)$ and $\dot{S}(t)$ in the state space [28]. The main feature of the proposed method is that the system present a high robustness performance during the change of the parameters. The control is carried out based on the state variables used to build a switching surface, whose purpose is to force the dynamic system to follow this switching surface in finite time and reduce chattering effects.

Let us the following tracking error as:

$$e(t) = V_{ref} - V_0 \tag{2}$$

The aim of control is that;

$$\lim_{t\to\infty} \|e(t)\| = \lim_{t\to\infty} \|V_{ref}(t) - V_0(t)\| = 0 \tag{3}$$

Then we will have:

$$\frac{de(t)}{dt} = \frac{dV_{ref}(t)}{dt} - \frac{dV_0(t)}{dt} = \frac{dV_{ref}(t)}{dt} - \frac{1}{C}\left(i_L - \frac{V_0}{R}\right) \tag{4}$$

Thus we have

$$\frac{d^2e(t)}{dt^2} = \frac{d^2V_{ref}(t)}{dt^2} - \frac{d^2V_0(t)}{dt^2} = \frac{d^2V_{ref}(t)}{dt^2} - \frac{1}{C}\left(\frac{di_L}{dt} - \frac{1}{R}\frac{dV_0}{dt}\right) \tag{5}$$

Using Eq. (1) and Eq. (5), the second derivative rewrite as follow:

$$\frac{d^2e(t)}{dt^2} = \frac{d^2V_{ref}(t)}{dt^2} - \frac{1}{C}\left(\frac{1}{L}(V_{in} - V_0) - \frac{1}{RC}\left(i_L - \frac{V_0}{R}\right)\right) \tag{6}$$