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A Passivity Based-Sliding Mode Control Approach for the Regulation of Power Factor Precompensators[1]

G. Escobar
LSS,CNRS-SUPELEC, France
e-mail: escobar@lss.supelec.fr

H. Sira–Ramirez
Univ. de Los Andes, Venezuela
e-mail: isira@ing.ula.ve

Abstract

A controller design method which combines passivity based control and sliding mode control is presented for the feedback regulation of a class of switched power converters, addressed as "power factor precompensators" (PFP). Aside from load voltage regulation to a prespecified constant level, a vital additional control objective is to avoid reactive losses by keeping the input power factor close to unity. A passivity plus sliding mode control approach is proposed which forces the input current to follow a suitable reference signal which is in phase with the rectified supplied voltage. This results in approximately satisfying both control objectives for the converter. Simulation results are furnished for assessing the performance of the proposed feedback control laws.

1 Introduction

Despite their widespread use in DC-to-DC power regulation, the traditional DC-to-DC Power Converter topologies (such as the boost, the buck-boost, the Cúk) have shown several disadvantages when used in rectified AC-to-DC power conversion schemes. One of the major drawbacks is related to the low–input–power factor usually attained. Control strategies are sought which, simultaneously, enhance the low power factor to avoid reactive losses while efficiently regulating the output load voltage.

In this research, we propose a controller for the feedback regulation of a class of switched power converters, addressed as *"power factor precompensators" (PFP)* whose closed loop performance approximately achieves, in a simultaneous fashion, the above stated control objectives.

The controller design strategy is based on using a *passivity approach* in combination with a *sliding mode control* implementation. Passivity–based control, a concept first introduced by *Ortega & Spong* in 1987, has proven very successful in many control applications. The sliding mode aspect is added to handle the fact that the input lives in a finite set.

The boost converter topology is chosen for detailed illustration, but the approach is extendable to other traditional converter topologies as well. By defining a reference signal tracking problem on the input current of the converter, the power factor can be made very close to unity as long as the tracked signal is in phase with the rectified input voltage.

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2 Switch-regulated boost converter as a PFP

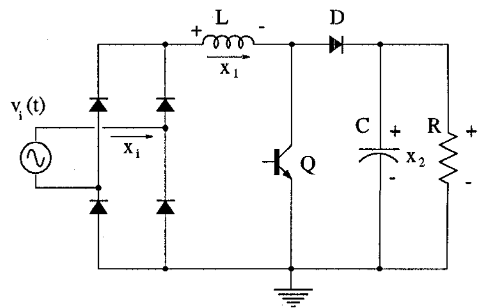

Figure 1: Switch–regulated PFP Boost circuit

The differential equations describing the circuit are given by,

$$\begin{aligned} L\dot{x}_1 &= -ux_2 + V|\sin(wt)| \\ C\dot{x}_2 &= ux_1 - \frac{1}{R}x_2 \end{aligned} \tag{1}$$

where x_1 and x_2 are the input inductor current and the output capacitor voltage variables, respectively; $V|\sin(wt)| > 0$ is the rectified voltage of the ac–line source; R is the nominal constant value of the output resistance; u, which takes values in the discrete set $\{0, 1\}$, denotes the switch position function, and acts as a control input.

3 Problem formulation

The *control objective* is twofold. First, the output x_2 should be driven to some constant desired value $V_d > V$. Second, in order to guarantee a power factor near unity, the inductor current x_1 should follow a rectified sinusoidal signal of the same frequency and also in phase with the ac–line voltage source.

It is well known that in this system the output x_1 yields a minimum phase system, while the capacitor voltage x_2, yields a non minimum phase system. For this reason control actions are geared to indirectly regulate x_2 through x_1.

4 Controller design

Consider the *auxiliary system,*

$$\begin{aligned} L\dot{x}_{1d} &= -ux_{2d} + V|\sin(wt)| + R_1(x_1 - x_{1d}) \\ C\dot{x}_{2d} &= ux_{1d} - \frac{1}{R}x_{2d} + R_2^{-1}(x_2 - x_{2d}) \end{aligned} \qquad (2)$$

where $R_1, R_2 \in \mathbb{R}^+$ and the terms containing R_1, R_2 are the damping injection terms.

In order to fulfill the two control objectives, namely, power factor close to unity and a constant output voltage level, we propose the following *switching policy,*

$$u = \frac{1}{2}(1 - \text{sign}(\sigma))$$

where $\sigma = x_{1d} - x_{1d}^*$ is the *sliding surface* on the auxiliary system, with x_{1d}^* given by,

$$x_{1d}^* = \frac{2V_d^2}{RV}|\sin(wt)| \qquad (3)$$

This switching policy locally creates a stable sliding regime on open sets of the form $wt \in [\beta + k\pi, (k+1)\pi), (k = 0, 1, .., n)$ providing,

$$wt \geq \arctan(\frac{2V_d^2 Lw}{RV^2}), \quad V_d \geq \sqrt{V^2 + \left(\frac{2V_d^2 Lw}{RV}\right)^2}$$

5 Power factor analysis

The *trajectory of the inductor current,* in steady state, is thus described as,

$$x_1(t) = \begin{cases} \frac{V}{wL}(1 - \cos(wt)), & 0 \leq wt \leq \beta \\ \frac{2V_d^2}{RV}\sin(wt), & \beta < wt \leq \pi \end{cases} \qquad (4)$$

with $\beta = 2\arctan(\frac{2V_d^2 wL}{RV^2})$

The *ac-line current signal* $x_I(t)$, in steady state, at the input of the diode rectifier has the alternate symmetrical form shown in fig. 2 and it is expressed as,

$$x_I(t) = x_1(t)\text{sign}(\sin(wt)) \qquad (5)$$

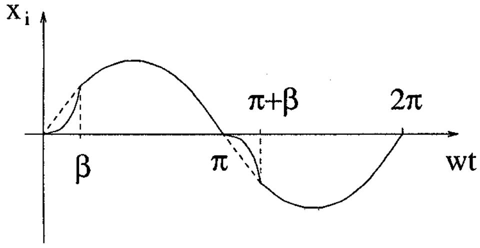

Figure 2: Input current time response.

For which the *power factor (PF)* is computed in the following manner,

$$PF = \frac{\left(\frac{\sin(\beta)}{\pi} + 1 - \frac{\beta}{\pi}\right)}{\left[\frac{V^4 R^2}{2V_d^4 \pi w^2 L^2}\left(\frac{3\beta}{2} - 2\sin(\beta) + \frac{\sin(2\beta)}{4}\right) + \left(1 - \frac{\beta}{\pi} + \frac{\sin(2\beta)}{2\pi}\right)\right]}$$

Notice that $PF \to 1$ as $\beta \to 0$

6 Simulation results

Digital computer simulations were performed for evaluating the proposed feedback controller. The *parameters* used for this simulations are, $R = 100\Omega$, $L = 10m$H, $C = 2200\mu$F, $V = \sqrt{2} \times 115$ Volts, $w = 2\pi \times (60)$ rad/sec, $V_d = 215$ Volts, $R_1 = 1$, $R_2 = 1$. For this example the power factor takes the value PF=0.999. The time responses for the capacitor voltages $x_2(t)$, $x_{2d}(t)$ and the inductor currents $x_1(t)$, $x_{1d}^*(t)$ are shown in fig. 3.

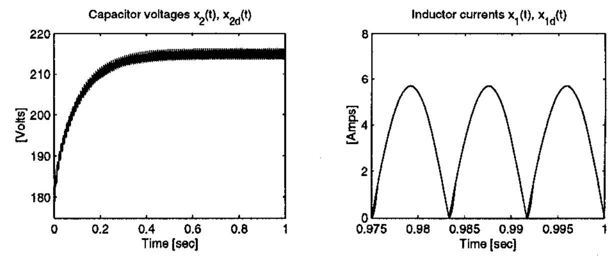

Figure 3: Time response for the Boost PFP

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