



# Unity power factor Converter based on a Fuzzy controller and Predictive Input Current



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## ABSTRACT

This paper proposes analysis and control of a single-phase power factor corrector (PFC). The proposed control is capable of achieving a unity power factor for each DC link voltage or load fluctuation. The method under study is composed of two intelligent approaches, a fuzzy logic controller to ensure an output voltage at a suitable value and predictive current control. The fuzzy controller is used with minimum rules to attain a low cost. The method is verified and discussed through simulation on the MATLAB/Simulink platform. It presents high dynamic performance under various parameter changes. Moreover, in order to examine and evaluate the method in real-time, a test bench is built using dSPACE 1104. The implantation of the proposed method is very easy and flexible and allows for operation under parameter variations. Additionally, the obtained results are very significant.

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## 1. Introduction

Recently, power converters have been employed in a wide range of industrial sectors and energy conversions. Due to increasing energy demands and the appearance of renewable energy (photovoltaic and wind), studies regarding power converters have become a topic of interest. Moreover, more than 60% of utility power is dissipated before it is finally consumed due to: network pollution, harmonic distortion and the insufficiency of power supplies; for these reasons, many countries around the world have created laws to limit energy dissipation. One of these laws enforces that electronic appliances produced must have high-performance with low harmonic distortion. To fulfill these goals, power factor correctors (PFC) appear to be an enabling technology for the improvement of power supplies. A switching mode operation in the latest power converts has improved the efficiency and speed of their performance. This operation includes two states (ON/OFF) and has been developed due to new inventions in semiconductor technologies [1].

In the literature, there are many types of power converters. Among these converters, the boost converter is currently the most popular and is used in a wide range of electronic appliances.

To ensure the converted AC/DC, usually a bridge of diodes is used; this tends to have a non-sinusoidal current and a low power

factor, nearly 0.6, due to the nonlinear behavior of the circuit. To solve this problem, one possibility is to add a PFC circuit. Moreover, the global cost of devices will be increased by 10 to 25%; however, the cost of the energy saved will cover the cost of the PFC.

Active PFCs have increasingly been used in the last few years in a wide range of industrial power supplies. This involves a pre-regulator between the rectifier and the load (Fig. 1) [2]. By controlling the applied switching, the current will take a sinusoidal shape like the source voltage; also, the total harmonic distortion (THD) will be decreased. Several control strategies have been proposed for the control of boost converters, such as PI control [3], neural networks [4], predictive control [5–8], fuzzy logic control [9] sliding mode control [2], and others [10–11]. Taking into account the efficiency of devices, they ensure conversion with less weight and cost. The fuzzy logic with predictive method can be a suitable solution.

Fuzzy logic is considered a solution when a high nonlinearity and ambiguity of the system have been considered. It is used in many areas, such as: identification, control and diagnostic of a complex system [12]. Fuzzy logic was created by Zadeh in 1963 [13]. Construction and understanding are very easy because the controller does not need mathematical modeling. According to Zadeh's concept, the system behavior is converted to linguist rules; these rules are used to develop a control strategy [14]. The application of fuzzy logic for a power factor corrector can yield improvements [9] because it can enhance the performance of the system and can offer good responses during the variation of load values or output voltage reference value. There are several works

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that use fuzzy logic for APFC, but these works apply a high number of rules, which will exhibit an additional cost and decrease the rapidity of devices. Thus, in this work, we try using FLC with a small number of rules compared to previous works. Meanwhile, the predictive control has been introduced to the current control; this later has been extended for a wide range of power converters and electric devices. This type of control allows the system to present good robustness.

The primary task of this work is to develop a new method based on predictive control and Takagi Sugeno Fuzzy logic for single-phase active power factor correction in order to supply a sinusoidal current in phase with the grid voltage. The simulation in MATLAB/Simulink and its implementation in real-time by using dSPACE1104 are carried out to improve the efficiency and possibility of commercialization for this technique in the future. Additionally, several robustness tests have been conducted by the changing load values and the output voltage reference.

### 2. Mathematical modeling

The basic conception of the boost converter is illustrated in Fig. 1. According to the state of the switch, two function modes are founded. The first mode of operation is shown in Fig. 1b; in this case, the switch S is turned on (S=1), and the current will accumulate. Additionally, the energy has been saved in the inductor, and the capacitor supplies the load. In the second mode of operation, shown in Fig. 1c, the switch S is turned off (S= 0). The quantity of stored energy in the inductor and the source energy will both be transferred to the output (capacitor-load). Moreover, the power circuit has been changed for this mode. The model of the boost PFC can be represented by Eqs. (1) [2,3,9].

$$\begin{cases} C \frac{dv_o}{dt} = (1-S)i_L - i_o \\ L \frac{di_L}{dt} = v_{in} - (1-S)v_o \end{cases} \quad (1)$$

To get a sinusoidal current in phase with the source voltage, a control law has been introduced to achieve a manner by which the resistive load is made equal to the ratio of  $v_{in}$  and  $i_L$ .

### 3. Predictive current control

Predictive control has become increasingly popular over a period of decades, but its application for power electronics is rather new. Due to its attractive characteristics, the predictive control changes the concept of a classical controller, which unable or less able to achieve good performance if it's integrated with the new power converters that use a switching mode operation. In this work, predictive control has been used for control of the converter switch. Taking into account the state of the switch from the circuit shown in Fig. 1, the equations of the current of inductor  $i_L(t)$  for each state can be expressed as [8]:

For the case in which switch S is turned on:

$$L \frac{di_L}{dt} = v_{in}(t) \text{ for } t(k) \leq t < t(k)+d(k).T_s \quad (2)$$

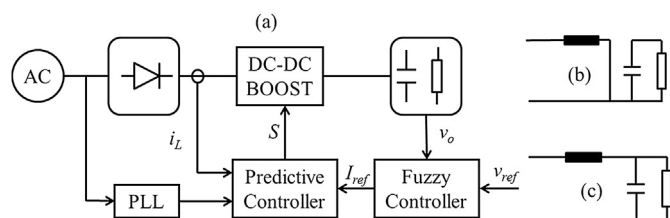


Fig. 1. PFC pre-regulator.

For the case in which switch S is turned off:

$$L \frac{di_L}{dt} = v_{in}(t) - v_o(t) \text{ for } t(k)+d(k).T_s \leq t < t(k+1) \quad (3)$$

where  $t(k)$  and  $t(k+1)$  are the starting time of the  $k^{th}$  and  $(k+1)^{th}$  switching cycle, respectively, and  $d(k)$  and  $T_s$  are the duty cycle and switching period, respectively.

Since the switching period is more than the input voltage frequency, Eq.(3) and Eq.(4) can be rewritten as:

$$L \frac{i_L(t(k)+d(k).T_s) - i_L(t(k))}{d(k).T_s} = v_{in}(t(k)) \quad (4)$$

$$L \frac{i_L(t(k+1)) - i_L(t(k)+d(k).T_s)}{(1-d(k)).T_s} = v_{in}(t(k)) - v_o(t(k)) \quad (5)$$

The diagram shown in Fig. 2 presents the inductor current during one switching cycle [8].

At the instant  $t(k)+d(k).T_s$ , the inductor current can be derived as (6):

$$i_L(t(k)+d(k).T_s) = i_L(t(k)) + \frac{1}{L} v_{in}(t(k)).d(k).T_s \quad (6)$$

At the start time of the  $(k+1)^{th}$  switching cycle, the inductor current can be derived as follow:

$$i_L(t(k+1)) = i_L(t(k)+d(k).T_s) + \frac{1}{L} (v_{in}(t(k)) - v_o(t(k)).(1-d(k)).T_s \quad (7)$$

Substituting (6) and (7), the inductor current can be derived as:

$$i_L(t(k+1)) = i_L(t(k)) + \frac{1}{L} v_{in}(t(k)).T_s - \frac{1}{L} v_o(t(k)).(1-d(k)).T_s \quad (8)$$

The discrete form of (8) can be expressed as

$$i_L(k+1) = i_L(k) + \frac{v_{in}(k).T_s}{L} - \frac{v_o(k).(1-d(k)).T_s}{L} \quad (9)$$

According to (9), the inductor current at the next switching cycle is calculated by the inductor current at the present switching cycle.

To calculate the duty cycle,  $d(k)$ , Eq. (8) can be rewritten as:

$$d(k) = \frac{L}{T_s} \cdot \frac{i_L(k+1) - i_L(k)}{v_o(k)} + \frac{v_o(k) - v_{in}(k)}{v_o(k)} \quad (10)$$

Through the boost circuit parameters, such as input voltage, output voltage and inductor current, the duty cycle  $d(k)$  for the actual switching cycle has been calculated.

For designing the boost converter with APFC, the inductor current  $i_L(k+1)$  has been forced to follow this reference  $i_{ref}(k+1)$ , which has a sinusoidal form.

Substituting  $V_o$ ,  $i_L(k+1)$  in (10) by his references, the duty cycle can be expressed as:

$$d(k) = \frac{L}{T_s} \cdot \frac{i_{ref}(k+1) - i_L(k)}{V_{ref}(k)} + \frac{V_{ref}(k) - v_{in}(k)}{V_{ref}(k)} \quad (11)$$

The reference current  $i_{ref}$  in (11) has been calculated as (12):

$$I_{ref}(k+1) = K_{fuzzy} \cdot \sin(\omega_{line} \cdot t(k+1)) \quad (12)$$

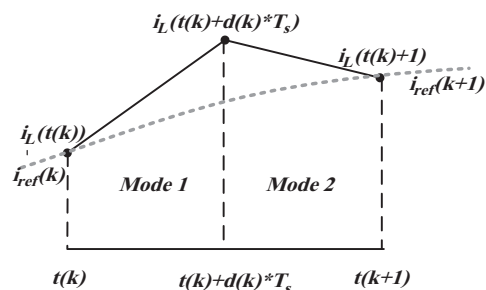


Fig. 2. Inductor current during one switching cycle.

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