

# An Improvement of Predictive Control for Single Phase Voltage Fed Power Factor Correction Converters

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**Abstract** - Harmonic contamination and low power factor in power systems caused by power converters have been a great concern. The effect of harmonics in current due to lagging power factor are the increase in current flow in the capacitors which results in additional heating of the capacitors and reduce its life, increased magnitudes of neutral currents in three phase systems, over-heating in transformers and induction motors. To overcome these problems several converter topologies and control schemes have been proposed in recent years. This work is proposed to identify the power converters with low cost/small size/high efficiency for single phase systems and also to study the control techniques for such converters to improve the Power Factor (PF) and reduce total harmonic distortion (THD) in the input current with output voltage regulation. This work has very high potential for UPS, motor drives and other industrial applications. A predictive control strategy for power factor correction of AC - DC converter is to maintain the unity power factor. Its basic idea is that all of the duty cycles required to achieve unity power factor in a half line period are generated in advance by using a predictive control topologies. It can be based on the average output voltage in the previous half line period, the duty cycles in the current half line period can be calculated by the predictive control topologies. The operation, analysis and design of control technique for high performance rectifier are investigated and verified through simulation.

**Key words:** System Configuration, Mathematical Modeling of PFC Converter, Predictive Control for Single -Phase Converter and Simulation Results.

## I. INTRODUCTION

In most power electronic applications, the power input is of 50 or 60 hertz AC voltage provided by the electric utility. It further converted to a DC voltage for various applications. The inexpensive rectifiers with diodes convert AC to DC and the output voltage is uncontrolled. The controlled rectifiers are used for providing variable/ constant output voltage. The dc output voltage of a controlled/uncontrolled rectifier should be ripple free [1]. Therefore a large capacitor is connected as a filter on dc side. Due to this, controlled/uncontrolled rectifier has the following drawbacks; these rectifiers draw highly distorted current from the Utility and Power factor is very low. To take the

edge off these drawbacks, High performance rectifiers is proposed in this paper.

One of the authors has proposed a digital controller-based predictive instantaneous current control scheme for the single-phase voltage-fed rectifier [2] and its modified analogue version [3]. Although the control schemes obtain a sufficient performance, further simplification is necessary to realise an economical PFC converter system in practice. In this paper propose a simplified analogue controller-based predictive instantaneous current control scheme for single-phase voltage fed PFC converters, which is obtained from further modification of the original digital scheme. As a result, a simple predictive instantaneous current control scheme for single-phase voltage-fed PFC converters is obtained.

In this paper, the predictive control methods for PFC are reviewed and their system configuration is highlighted in section II. The principles of the predictive control algorithm are discussed in the section III. The further improvement with single- phase PFC converter proposed in same section. In section IV, the simulation results are presented in this section. The conclusion is drawn in the last section.

## II. CONFIGURATIONS

### A. Classification of different Topology

Improved power quality converters are classified on the basis of topology and type of converter used. The topology-based classification is categorized on the basis of boost, buck, buck-boost, multilevel, unidirectional and bidirectional voltage, current, and power flow. The converter type can be step-up and step-down choppers, voltage source and current-source inverters, bridge structure, etc[4]. These converters are developed in such vastly varying configurations to fulfill the very close and exact requirement in variety of applications. Some of these improved power quality converters are improved to provide better performance from primitive configurations.

### B. Current Control Techniques for PFC converters

The current control techniques have gained importance in ac to dc converters used for high performance applications [2]. Where the fast response and high accuracy are important. Various current

control methods have been proposed and classified as hysteresis control, predictive control and linear control. Principle of these methods are briefly described and discussed below.

C. System Configuration

The topology of Boost converter is shown in Fig.1. The proposed predictive control PFC algorithm is derived based on the following assumptions [1]:

- (a) Boost converter operates at continuous conduction mode
- (b) The switching frequency is much higher than the line frequency. So the input voltage  $V_m$  can be assumed as a constant during one switching cycle.

Figure 1. Shows the configuration of such converter to improve the power quality at ac mains and dc output, reduced losses and noise, enhanced compactness by drastically cutting their weight and volume. In principle, it is a combination of diode bridge rectifier and step-up dc chopper with filtering and energy storage elements[5]. High-frequency PWM and predictive control techniques are used in the closed-loop controllers in outer voltage-fed loop of these converters to provide fast response and high level of power quality at input ac mains and dc output.

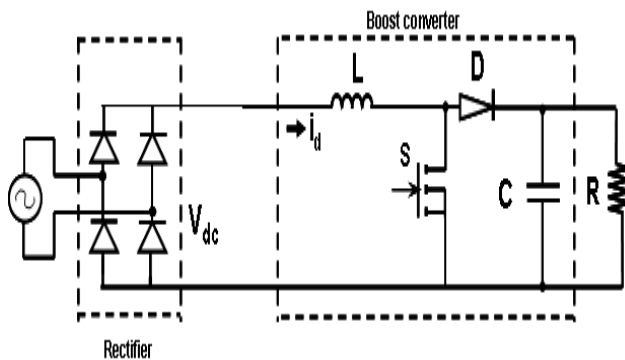


Figure. 1 Diode Bridge Boost Converter

III. MATHEMATICAL MODELING OF PFC CONVERTER

The proposed PFC Converter system comprise single-phase ac supply, power converter circuit, and control scheme. In this section modeling equation of various components of the converter system are formulated separately to develop a comprehensive model for their performance simulation. Under normal operating conditions the supply system can be modeled as a sinusoidal voltage source of amplitude  $V_m$  and frequency [5]. The instantaneous voltage is given as:

$$v_s(t) = V_m \sin \omega t \tag{1}$$

Where,  $\omega = 2\pi f_s t$  electrical rad/s and  $t$  is instantaneous time.

From sensed supply voltage, a template  $u(t)$  is estimated for converter topologies with ac side inductor.

$$u(t) = v_s(t)/V_m \tag{2}$$

$u(t)$  for converter topologies with dc side inductor is obtained from:

$$u(t) = |v_s(t)|/V_m \tag{3}$$

The closed loop arrangement of the boost converter based ac to dc converter topology with predictive control is shown in Figure.3. presented as follows. The switch voltage reference ( $V_{ref}$ ) at  $(k+1)^{th}$  instant is predicted at  $k^{th}$  instant itself for the circuit shown in Figure.3. by means of (4).

$$V_{ref}(t) = V_{dc}(t) - L [i_{dc}^*(t) - i_{dc}(t)]/T_s \tag{4}$$

Where,

$V_d$  – rectified voltage

$i_d$  – inductor current

$T$  – modulation period (inverse of switching frequency)

To implement the parameters at the  $k^{th}$  instant can easily be sensed, expect the current  $i_d$  at  $(k+1)^{th}$  instant. For that the reference signal  $i_d^*$  which has been derived from the rectified voltage as shown in Figure.3. has been phase shifted by a modulation period of  $(t_{(k+1)}-t_k)$  and it has been used in the (4) as  $i_d^*(k+1)$  instead of  $i_d(k+1)$ . So the control law has been modified as (5)

$$V_{ref}(k) = V_{dc}(k) - L [i_{dc}^*(t_{k+1}) - i_{dc}(t_k)]/T_s \tag{5}$$

Since the switching frequency is very high the modulation period is very small. The current  $i_d$  at  $(k+1)^{th}$  instant will be approximately equal to the current  $i_d$  at  $k^{th}$  instant. So the eqn (4) is modified to eqn.(5)

$$V_{ref}(k) = V_{dc}(k) - L [i_{dc}^*(t_k) - i_{dc}(t_k)]/T_s \tag{6}$$

The same control law has been written in Analog domain as (6). It is implemented in the circuit shown in Figure. 3 to obtain the reference switch voltage  $V_{ref}(t)$ .

$$V_{ref}(t) = V_{dc}(t) - L [i_{dc}^*(t) - i_{dc}(t)]/T_s \tag{7}$$

The reference switch voltage is compared with the carrier whose amplitude is varying according to the load voltage and it is given to the switch S. The operation of the switch results in Sinusoidal current and unity power factor [1]. PI-controller has been used externally to regulate the output voltage.

It should be noted that there are still two approximations in the predictive algorithm (7). First, the average current in every switching cycle should follow the reference current in Figure.2. Here, it is the instantaneous current  $i_L(k)$  and  $i_L(k+1)$  that are forced to track the reference current  $i_{ref}$ . Second, the instantaneous current  $i_L(k)$  is used in (7) to calculate the voltage drop across the inductor resistance and the on resistance of switch.

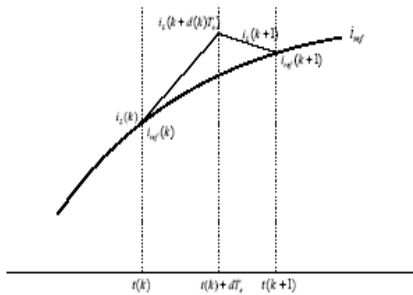


Figure. 2 Inductor current controlled by the directly calculated duty cycles

In fact, the average current in one switching cycle should also be used to calculate the voltage drop. Because the inductor current ripple can be neglected, these two approximations are reasonable in the proposed predictive control PFC algorithm. This condition of approximation is easier to be satisfied at high load than that at low load. power factor at low load is a little bit less than that at high load because of this approximation. The digital controlled Boost PFC based on the predictive algorithm is shown in Figure.3. The duty cycles are generated by the predictive algorithm. The input voltage  $v_{in}$  is sensed for the predictive algorithm (7). The reference current  $i_{ref}$ , is from the multiplier. Its amplitude is determined by the output of the PI controller in the voltage loop. The output voltage  $V_o$  is controlled by the closed loop with a PI regulator. In this predictive control system, the feedback signals are  $v_o$  and  $V_{in}$ . The output is the gate signal for the switch  $S$ . Because no current loop is needed in the calculation of the duty cycle, all the duty cycles required to achieve unity power factor in a half line period can be generated in advance with this predictive control strategy[1][2].

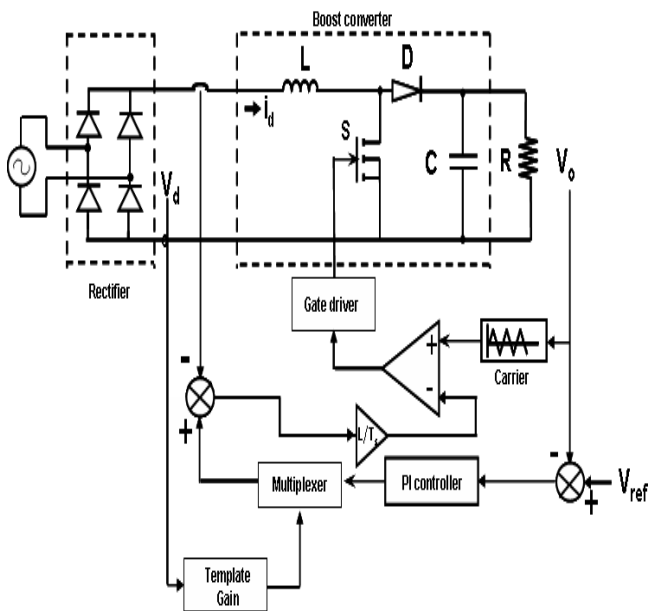


Figure.3. Predictive Control for single-Phase Boost PFC Converter

C. Determination of the objective function

The significant subject of the predictive control PFC method is how to determine the objective function when the predictive control algorithm is implemented. In this paper, Total Harmonic Distortion (THD) of the input current is chosen as the objective function[2]. The objective of the predictive control PFC algorithm is to achieve a high power factor. The ideal situation is unity power factor. The power factor define as

$$PF = \frac{(averagepower)}{(RMSvoltage) \times (RMScurrent)} \tag{8}$$

In the rectifier cascaded by a PFC circuit, the displacement factor is one. So if the distortion factor approaches one. Unity power factor is realized. The relation between distortion factor and THD is expressed by

$$DistortionFactor(DF) = \frac{1}{\sqrt{1+(THD)^2}} \tag{9}$$

If the THD of line current is minimum, the distortion factor is maximum and the power factor become maximum too. Zero THD means unity power factor. Therefore, the THD of input current can be used as the objective function in the predictive control PFC algorithm. Table.1. Shows summary of performance evaluation.

Input voltage (V)	Input current (A)	Power factor	Input power (Watts)	Load Voltage (V)	Load current (A)	Output power (Watts)	Input THD	Input voltage THD	Efficiency %
90	50.08	0.997	5143	398.6	7.48	2950	0.03128	0.0037	57.35
110	38.95	0.9950	4239.4	398.5	7.483	2981.9	0.0377	0.0088	70.33
130	25.77	0.997	3372	400	7.51	3013	0.0502	0.0004	89.3

Table.1. Summary of performance evaluation

IV. SIMULATION RESULTS

Simulation is performed by MATLAB/Simulink to verify the proposed Predictive Control algorithm. Figure.5. is the input current of the PFC Boost circuit under 3kw load (full load) with 130V (RMS) input voltage. The THD of the current is 5 %. The predictive PFC control strategy can achieve very high power factor (0.997). It is shown that, with 130V input voltage, the power factor is over 0.997 under the range from 25% to full load. The power factor at the low load is a little bit less than that at the high load due to the approximation in the derivation of predictive algorithm (7).

Figure.5. shows the comparison of carrier signal with the PI current controller of the single phase circuit. The carrier signal has the frequency of 200KHz. This gives the gate pulse waveforms as shown in figure.6. which controls the Boost Converter circuit. The supply current and voltage waveforms of a single phase circuit are shown in figure.7. In this figure.7. it shows that the supply voltage and current are in phase with each other and has a power factor of 0.997 (approximately unity power factor) under full load. Figure.8. Shows output voltage of Boost Converter across resistor of 53 ohms having the voltage of 400V and is operating at a constant d.c. voltage.

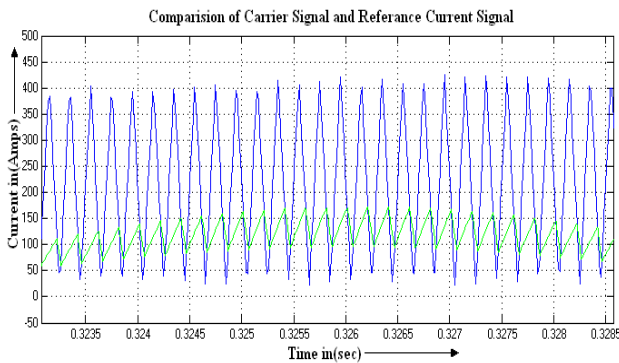


Figure. 5. Comparison of carrier and PI-Controller

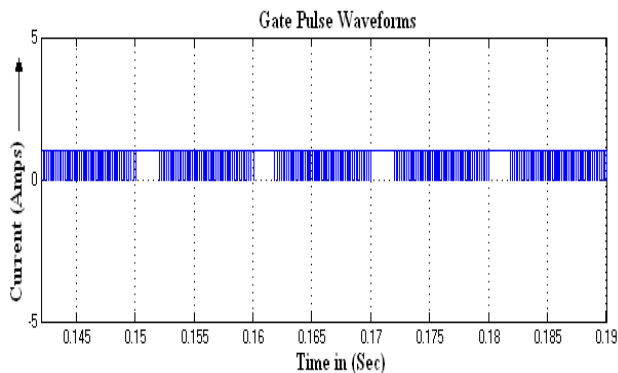


Figure. 6. Gate signals waveforms

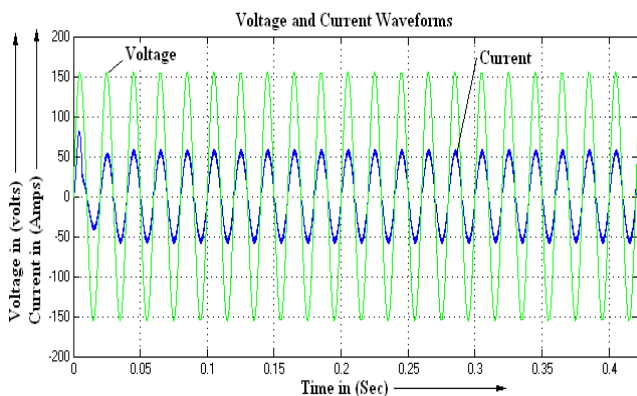


Figure.7. Simulation results for single-phase converter

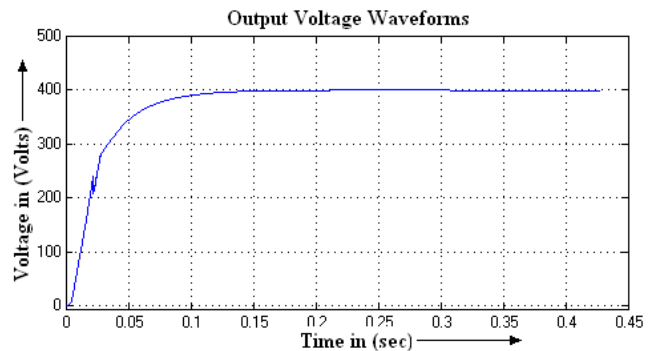


Figure.8. Output voltage of a single-phase Boost converter

Figure.9. shows the comparison of carrier signal with the PI-controller of the three phase circuit. The carrier signal has the frequency of 200 KHz.

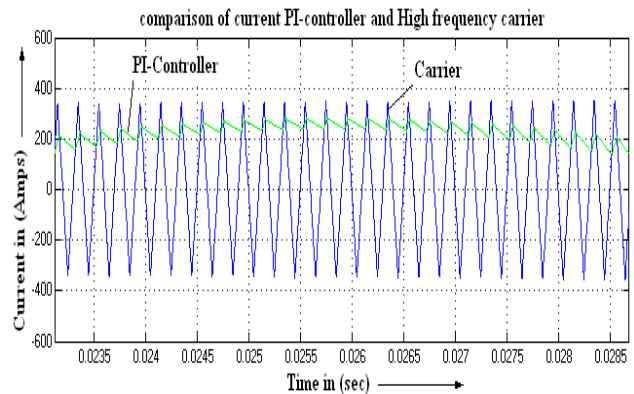


Figure. 9. Comparison of carrier and PI-Controller for three-phase circuit.

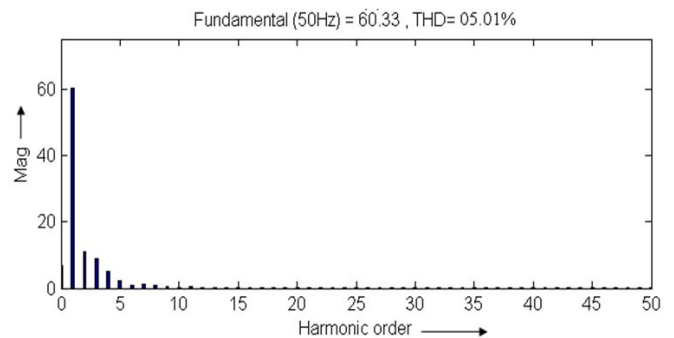


Figure.10. Simulation results for Input current THD Response

#### IV. CONCLUSION

A predictive control algorithm is proposed for ac-dc Boost converter PFC method. Based on the Boost topology, the predictive control algorithm is derived in detail. By using this predictive control algorithm, all the duty cycles required to achieve unity power factor in a half line period are generated in advance. That means the switching frequency of the PFC is no longer directly dependent on the processing speed of the

Predictive controller. The predictive control is incorporated into further improve the performance of the three-phase ac-dc Boost PFC converter. Simulation results show that the proposed strategy works well and unity power factor can be achieved over wide input voltage and load current variation range.

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