Understanding of boost-PFC circuit design for low cost electronic ballast

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Abstract:

This paper presents a simple design of Power Factor Correction (PFC) circuit for using in electronic ballasts circuit based on the boost topology which the suitable value of inductor, capacitor and switching frequency are selected. The improved design method has also been developed for increasing power factor and reducing harmonics of the system. The experiments and satisfactory results are demonstrated and presented.

KEYWORDS: PFC, THD, Boost-PFC, Electronic Ballast

I. INTRODUCTION

The high-frequency electronic ballast is an AC-to-AC power converter, converting line-frequency power from the utility line to high-frequency AC power in order to drive the fluorescent lamp. Figure 1 shows the circuit diagram of typical high-frequency electronic ballast that uses the half-bridge series-resonant parallel-loaded inverter [1]. The AC/DC rectifier contains four diodes and one bulk capacitor. This simple rectification scheme is still widely used because of its lower cost. However, it has very poor line side power factor (p.f.) and large Total Harmonic Distortion (THD). The low PF increase the reactive power and the large THD pollute the utility line.

In electronic ballast, the ac utility input voltage is converted to dc with a rectifier circuit, as shown in Figure 1. This circuit has the advantages of simplicity, low cost, high reliability, and no need of control. But, it also has the disadvantages of low power factor (p.f.) due to the presence of rich harmonics and high peak current magnitude, as shown in Figures 2(i) and (ii). The input voltage and input current waveforms in Figure 2(i) are obtained by PowerSim simulation tool and normalized to the peak values. The harmonic spectrum of the input current is shown in Figure 2(ii). Their magnitudes are normalized to the fundamental component that is 50Hz in this case.

The input p.f. is defined as the ratio of the real power over apparent power as,

$$\text{Power Factor} = \frac{\text{Real Power}}{\text{Appearant power}} \qquad (1)$$

$$= \frac{V_{rms} I_1 \cos\phi}{V_{rms} I_{rms}} = \frac{I_1 \cos\phi}{I_{rms}} \qquad (2)$$

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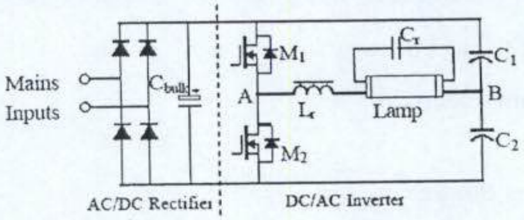
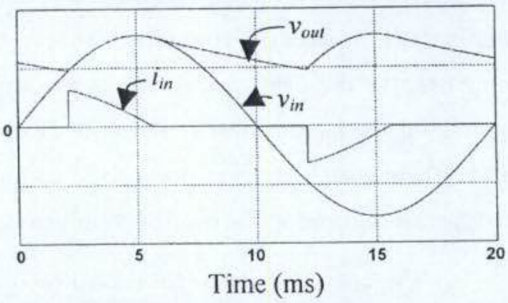


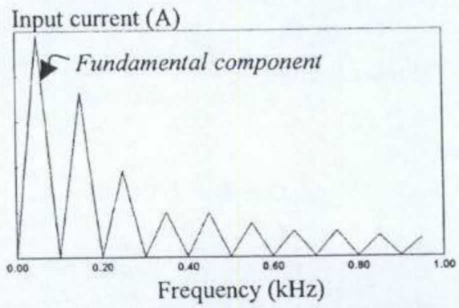
Figure 1: Typical topology for electronic ballast.

In order to solve this problem, this paper will present the rectifier circuit with boost-PFC: some time, we call active PFC rectifier. The design of Inductor and capacitor are shown with many constraints of simple electronic ballast used the criteria operation to choose operating frequency.

This paper is organized as follows. Section 2 introduces the principle of PFC circuit with rectifier circuit. Design the PFC for electronic ballast is presented in section 3. In section 4, the simulation results are shown and the experimental results are summarized in section 5. Finally, in section 6, conclusion and discuss the further works are given.



(i) Normalized input ac voltage and current



(ii) Normalized harmonic spectrum of input current

Figure 2: An example of current harmonic content in diode rectifier circuit with bulk capacitor.

II. BASIC OPERATION OF BOOST-PFC CIRCUIT

PFCs reshape the distorted input current waveform to approximate a sinusoidal current that is in phase with the input voltage. There are several effective techniques for achieving a sinusoidal input current waveform with low distortion. Two typical techniques for PFCs are passive correction and active correction. In this study, only the single-phase input circuitry is considered. Passive PFC techniques [2,3] shape the input current waveform by using a passive input filter consisting of inductors and capacitors. Because it operates at the line frequency of 50Hz, passive filters require relatively large fixed-value inductors and capacitors to reduce the low frequency harmonic currents. These filters use resonant pass or resonant trap circuits sensitive to both frequency and load. It is difficult to achieve near unity power factor with passive filters.

Also, very large currents may circulate in the filter. However the passive filter is an effective PFC solution in cases where the line frequency, line voltage and load are relatively constant. An active PFC performs much better and is significantly smaller and lighter than the passive PFC circuit. The active PFC circuits operate at a higher switching frequency than the line frequency to allow a large reduction in the size and cost of passive filter elements. Their function includes active waveshaping of the input current, filtering of the high frequency switching, feedback sensing of the source current for waveform control and feedback control to regulate output voltage. Buck, boost, flyback and other converter topologies are used for the active PFC circuits. The boost circuit-based PFC topology is the most popular and is employed in this study. The boost-PFC circuit is an economical solution to comply with the regulations. It can be implemented with a dedicated single chip controller, making the circuit relatively simple with a minimum number of components. The boost inductor in the boost PFC circuit is in series with the ac power line. Therefore, the input current does not minimize the conducted EMI at the line.

The output voltage of a boost-PFC circuit should be higher than the peak value of the maximum input voltage. Although this is a simple topology, it must be designed to handle the same power as the main power converter. Only the single-phase boost-PFC circuit operating in the continuous inductor current mode is discussed in this study and the simplified block diagram of the boost-PFC circuit is shown in Figure 3.

III. DESIGN OF BOOST-PFC CIRCUIT

The voltage and current ratings of the switch, diodes and passive components for the boost PFC Circuit discussed in many publications. Based on the obtained ratings for major power components, the loss equations are derived. The PFC stage is at least rated to the maximum input power rating of the electronic ballast system given by,

$$P_f(\max) = \frac{P_O(\max)}{\eta_B \eta_C} \quad (3)$$

where $P_f(max)$ is the maximum power rating of the PFC stage, $P_o\ (max)$ is the maximum output power of the electronic ballast, η_B is the efficiency of the electronic ballast and η_C is the efficiency of the corresponding converter or inverter.

3.1 Input Rectifier Bridge Diode

The peak input current occurs at the minimum input line voltage with the maximum output power. The peak input current is expressed as,

$$I_{in}(pk) = \frac{\sqrt{2}P_f(\max)}{\eta_f V_m(\min)}, \text{ A} \quad (4)$$

where η_f is the efficiency of the PFC stage.

The current flowing through each diode is a half-wave rectified sine wave. Therefore the average current through each diode is

$$I_{bd}(ave) = \frac{2I_{in}(pk)}{\pi}, \text{ A} \quad (5)$$

And the minimum voltage rating for the input rectifier diode is $V_{in}^{pk}(\min)$.

3.2 Boost Switch

The minimum voltage rating of the boost switch is the output voltage of the PFC stage. The peak current rating is the same value as in the input rectifier bridge diode case shown in equation (4). The rms boost switch current is expressed as:

$$I_{sw}(rms) = I_{in}(pk)\sqrt{\frac{1}{2} - \frac{4V_{in}(pk)}{3\pi V_O}}, \text{ A} \quad (6)$$

3.3 Boost Diode

The minimum voltage and current ratings of the boost diode have the same value as in the boost switch case. The rms current of the boost diode is given by,

$$I_{sw}(rms) = 2I_{in}(pk)\sqrt{\frac{V_{in}(pk)}{3\pi V_O}}, \text{ A} \quad (7)$$

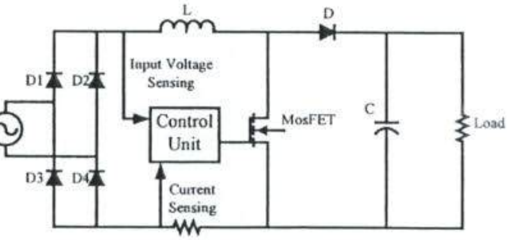


Figure 3: *A simplified of block diagram of single phase Boost-PFC circuit.*

3.5 Boost Inductor

The inductor value is based on the current in the boost inductor, which is usually chosen as a fraction of I_{in}^{pk}. The inductance value is expressed as,

$$L = \frac{2 \cdot \left[\frac{V_O}{\sqrt{2}} - V_{in}^{pk}(min) \right] V_{in}^{pk}(min)}{f_S \cdot V_O \cdot I_{in}^{pk}}, \text{H} \quad (8)$$

where V_{in}^{pk} (min) is the peak minimum input voltage, f_s is the switching frequency, The rms boost inductor current is expressed as:

$$I_L(rms) = \frac{I_{in}(pk)}{\sqrt{2}}, \text{A} \quad (9)$$

3.6 Output Capacitor

The output capacitance for a given output voltage ripple is obtained by integrating the charging current into the capacitor over the entire switching period. The output capacitance is,

$$C_O = \frac{I_O(max)}{4\pi f_l \cdot \Delta V_{or} \cdot \eta_f}, \quad \text{F} \quad (10)$$

where $I_O(max)$ is the maximum output current, f_l is the line frequency and ΔV_{or} is the output ripple voltage.

From equation (1)-(10), we can design the parameter that use in electronic ballast with Boost-PFC by using electrical system specification in Thailand [6].

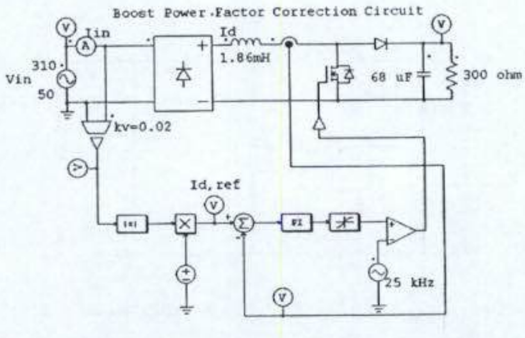


Figure 4: Block diagram of Boost-PFC circuit.

Table 1 Specification of Boost-PFC Circuit

Input Voltage, Vrms	220
Output Voltage, Vdc	600
Output Current, A peak	1.708
Switch Device	IRF740
Diode	1N4007
Inductor, mH	1.86
Output capacitor, μF	68
Switching frequency, kHz	25

IV. SIMULATION RESULTS

Figure 4 shows a simulation Boost-PFC circuit and Figure 5 shows a simulation result by choosing the frequency of 1.5 kHz which we want to see the behavior of Boost-PFC circuit with low switching frequency. The input voltage is sinusoidal waveform and input current have a large ripple because the low switching frequency.

We tested a boost-PFC circuit for electronic ballast by using the specification as Table 1. Figure 6 and 7 shows a waveform of Boost-PFC circuit and choose the frequency of 25 kHz and harmonic spectrum of input current, respectively. If we compare the harmonic spectrum with figure 2(ii), we can reduce the harmonic currents on 2[nd]-9[th] harmonic orders.

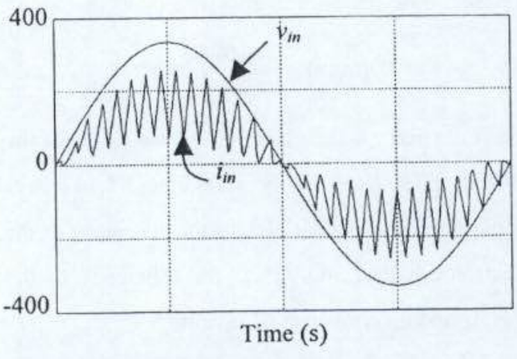


Figure 5: waveform of input voltage and current at 1.5 kHz.

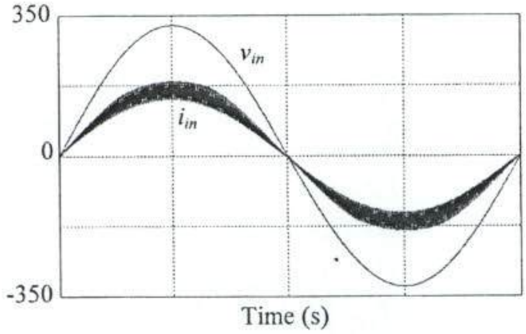


Figure 6: *waveform of input voltage and current at 25 kHz.*

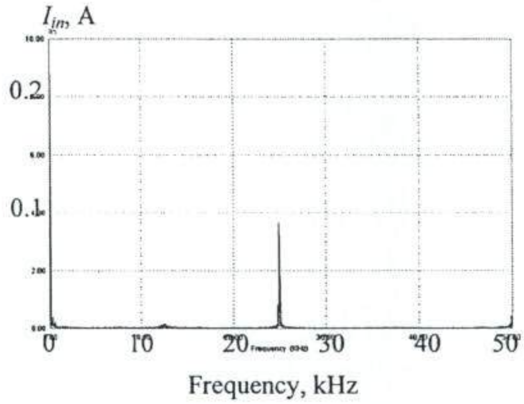


Figure 7: *Harmonic spectrum of input current.*

V. EXPERIMENTAL RESULTS

Figure 8 shows a tested Boost-PFC circuit by using IC-MC33260 controller. The IC received the output current and input voltage from Boost circuit and controls the operating frequency. When we compare the input voltage and input current waveform in Figure 9 and 10, the input current waveform in Figure 9 is similar sinusoidal wave than Figure 10. Besides that the harmonic spectrum of input current is shown in Figure 11. From the simulation results and experimental results, we can improve the power factor up to 0.95 and reduce the current harmonic of electronic ballast to 17%.

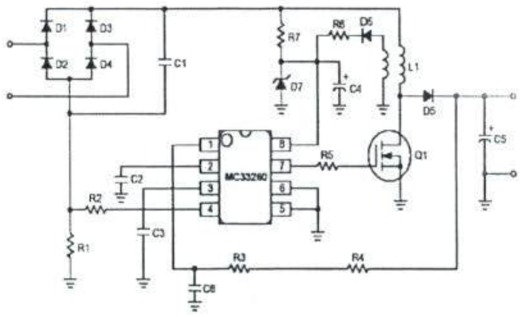


Figure 8: *Boost-PFC circuit.*

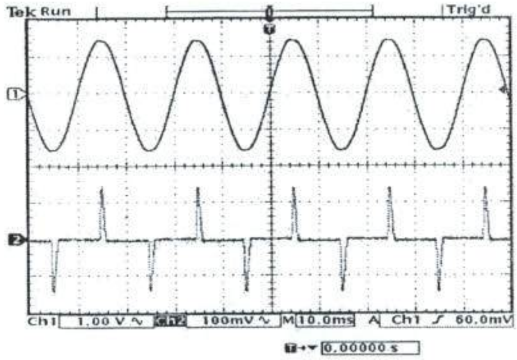


Figure 9: *Waveform of input voltage and current without Boost-PFC circuit.*

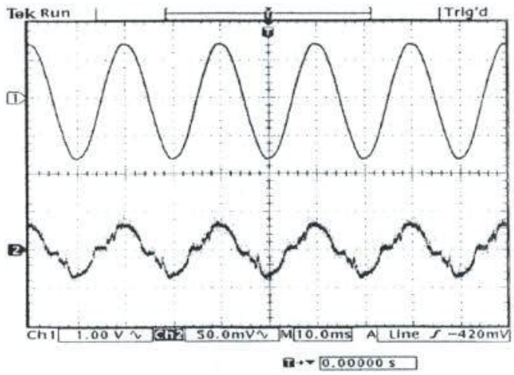


Figure 10: *Waveform of input voltage and current with Boost-PFC circuit.*

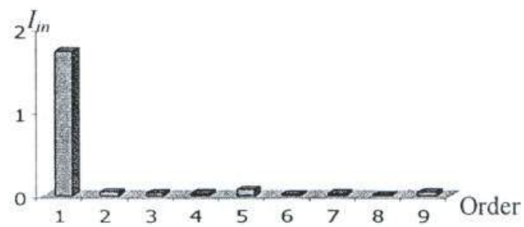


Figure 11: *Harmonic spectrum of input current.*

VI. CONCLUSION

A Boost-PFC circuit has been developed which incorporates all of the necessary ballast function. An improved PFC control method has been developed which gives good performance and easier to manufacture. The simulation results and experimental results are guarantee the performance of this understanding design which a higher reliability.

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