Simulation and Analysis of Power Factor Correction in Electric Control System for Metal Halide High Intensity Discharge Lamps

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Abstract

Metal Halide High Intensity Discharge lamps are becoming popular because of its high efficacy. The operating characteristic of Metal Halide High Intensity Discharge (HID) lamps is complex as it has several stage of operation. So electric control system is required to control the operation of metal halide high intensity discharge lamps. Electric control system involves a number of non linear devices which reduce the power factor. Therefore power factor correction circuit is essential to get better voltage regulation and increase capacity to serve power requirements. The objective of this paper is to design an active power factor correction circuit using boost converter. The circuit is based on the modification of boost converter using active devices. Adaptive switching frequency control technique is used to regulate the output voltage. In this technique two control loops are used, outer loop is voltage loop that senses the output voltage while inner loop is current loop that senses the inductor current. PI Controller is used to stabilize the performance of control loops. Not only the proposed circuit requires few components for its implementation but also size and cost can be effectively reduced. The capacitor and inductor with voltage and current ripple with minimum ripple values was designed and to absorb sinusoidal input current to reduce total harmonic distortion (THD) in the input current with output voltage regulation. PSIM simulation software is used to do this analysis.

Keywords: Metal Halide HID Lamps, Boost Converter, Control Technique, PI Controller, PSIM.
1. Introduction
Metal halide HID lamps are appropriate for many application due to its long life and high luminous efficacy [1]-[2]. Since MH lamps have the characteristics of negative incremental impedance, electric control system is required to stabilize the lamp current. With the fast development in power electronics, electric control system for metal halide HID lamps has replaced largely the traditional magnetic control system. Electric Control System provides the reduction in size of the control system and improved quality performance.

Moreover, the non easy MH lamp behaviour also increases the complexity of the control circuit because these lamps have different operating phases, which can be classified as follows.

a) Lamp starting—the lamp has very high impedance before ignition and a pulse of approximately 3 kV is necessary to start a cold lamp.

b) Lamp heating—the heating process takes from tens of seconds to minutes. The lamp starts presenting small impedance that increases as long as the lamp is warmed up. This stage must be as short as possible in order to avoid the detrimental effect of the glow current.

c) Steady state—after the lamp heating, the lamp reaches the steady state and parameters like (lamp power or current) must be controlled.

As electric control system is complex in nature, therefore shape of input current with respect to input voltage is changed. In order to comply with the more stringent regulations on current harmonics such as IEC 61000-3-2 standards and to improve the power factor, ac/dc converter that performs as a power factor corrector (PFC) is required in electric control system.

![Fig. 1: Block Diagram of Power Factor Corrector Circuit.](https://example.com/block-diagram.png)
Boost converter is preferred here to serve as a PFC because component requirement is less [3]-[5]. Adaptive Switching Frequency Scheme is used to operate the single switch of boost converter. In this scheme duty cycle of the wave given to single switch of boost converter is automatically changes as input voltage varies. Fig.1 shows the block diagram of power factor corrector circuit. The proposed power factor corrector circuit improves the power factor of overall circuit when it is cascaded with electric control system for metal halide HID lamps. Boost Converter is designed for power factor correction circuit and satisfactory performance is obtained from the simulation results.

![Fig. 2(a) Basic Boost Converter](image1)

![Fig. 2(b) Mode1](image2)

![Fig. 2(c) Mode2](image3)

This paper is organized as follows. Working of boost converter is shown in section 2. Section 3 shows the design consideration of Boost Converter. Control technique and simulated circuit diagram are presented in Section 4. Simulation results are shown in section 5.

### 2. Working of Boost Converter

Boost converter is shown in Figure 2a. Following condition should be satisfied for proper operation of boost converter when it is used in power factor correction.

(a) Boost converter should operate in continuous conduction mode.

(b) The switching frequency is much higher than the line frequency.

Working of Boost converter is divided into two modes.

#### 2.1. Mode1

When switch ‘S’ is closed, in this mode of operation the switch is in on state. The current flows through switch and inductor, so the energy is stored in the inductor. At the same time, the capacitor discharges and supplies current to the load. Mode1 is shown in Fig. 2b.
2.2. Mode2
When switch ‘S’ is open, in this mode of operation the switch is in off state and current flows through inductor, diode and the capacitor with the load and return to main. Mode 2 is shown in Figure 2c.

3. Design Consideration
If output voltage is represented as \( V_o \) and input voltage is represented as \( V_{DC} \), the duty ratio (D) of a typical boost converter is given by:

\[
D = \frac{(V_o - V_{DC})}{V_o}
\]  

(1)

The inductor shown in fig.2 can be designed using the equation (2).

\[
L = \frac{R.D.(1-D)^2}{2.f}
\]  

(2)

Where \( f \)=switching frequency and \( R \)= Load Resistance.

The value of capacitance is given by.

\[
C = \frac{V_o.D}{f.AV.R}
\]  

(3)

Where \( \Delta V \) is output voltage ripple.

Table 1: Simulation Parameter of Boost Converter.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Voltage ((V_{DC}))</td>
<td>220V</td>
</tr>
<tr>
<td>Output Voltage ((V_o))</td>
<td>400V</td>
</tr>
<tr>
<td>Duty Ratio((D))</td>
<td>0.45</td>
</tr>
<tr>
<td>Inductor ((L))</td>
<td>1mH</td>
</tr>
<tr>
<td>Capacitance((C))</td>
<td>120uF</td>
</tr>
<tr>
<td>Load Resistance((R))</td>
<td>1000ohm</td>
</tr>
<tr>
<td>Switching Frequency((f))</td>
<td>68Khz</td>
</tr>
</tbody>
</table>

4. Control Technique
Two Control loops are used to maintain the output voltage constant and also make the power factor unity.

4.1 Voltage Control Loop
The error is estimated from the DC output voltage measurement. The DC output voltage control loop maintains the capacitor voltage at a set reference value using feedback action. The error at the DC output is regulated by a PI controller (voltage compensator or Integrator) and the PI controller output is added to the current control loop to vary the duty ratio to maintain the DC output voltage constant.
4.2 Current Control loop
The current control techniques have gained importance in ac to dc converters used for high performance applications, where fast response and high accuracy are important. Various current control methods have been proposed and classified as hysteresis control, predictive control, linear control and timer controller with constant switching frequency. Here hysteresis control method is used for current control loop.

4.3 Proposed Adaptive Switching Frequency Technique
The control technique (hysteresis control) is designed so that the inductor current follows the shape of the rectified ac line voltage. To regulate the load, comparator senses the variation between the output voltage and the fixed dc reference. This error voltage is multiplied with the sensed rectifier line voltage to control the inductor current amplitude. The advantages of the control are that one has no need of compensation ramp, converting a voltage source into a fast-acting current source, the inductor is easy to design, operating switching frequency is high and low distorted input current waveforms with fixed load. Fig. 3 shows Bang-Bang hysteresis current control technique to generate the switching pulse [6]-[10].

Fig. 3 Bang- Bang Hysteresis Current Control Technique.

Fig. 4 Simulated Circuit Diagram.

Fig. 4 shows the implementation of Bang-Bang Hysteresis current control strategy on boost converter. Output voltage is sensed and is given to summing node, other input
of summing node is connected to reference voltage, and the resultant output of summing node is given to multiplier through PI controller. The output of multiplier is connected to inverting terminal of op amp comparator and non inverting terminal is connected to sensed inductor current. The output of op amp comparator generates the switching pulse for the single switch of boost converter. Fig. 5 shows the pulse width modulated wave that is connected to switch S of boost converter. In this way constant output is obtained and also input current follows the shape of input voltage.

![Fig. 5 Gate Signal for Switch S](image)

5. Simulation Results

Fig. 6 shows the simulated waveform of supply or input voltage and input current when input voltage is 220V. Here $V_{ac}$ represents the input voltage and $I_{ac}$ represents the input current. From the figure it is clear that the shape of input current is same as supply voltage. So nearly unity power factor is achieved by this circuit. Proposed Power Factor Corrector Circuit improves the power factor of Electric control System for metal halide lamps when it is cascaded with the electric control system. Output voltage $V_o$ is shown in Fig. 7.

![Fig. 6 Supply Voltage and Supply Current](image)
6. Conclusion
Proposed adaptive switching frequency (Hysteresis) control for ac-dc converter PFC method based on the boost topology is used here. Advantage of adaptive switching frequency technique is that one has no need of ramp compensation, low distortion input current waveform. By using this proposed adaptive switching frequency (Hysteresis) control technique, the duty cycles required to achieve closer to unity power factor with the switching frequency of (50 - 80) kHz is generated. This power factor correction circuit removes drawback such as converting a voltage source into fast-acting current source. The design equations for selecting capacitance and inductance have been presented. Simulation results show that the proposed strategy works well and near unity power factor can be achieved. This type of power factor corrector circuit provides good result when it is cascaded with electric control system for metal halide lamps and the overall control system achieves nearly unity power factor.

References


