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Power Factor Improvement of LED by Using Buck-Boost Converter for Residential Load

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Abstract- *This paper presents Buck-Boost converter which operates in continuous conduction mode (CCM). The proposed methodology improves power factor (PF) by using buck boost converter through pulse width modulation. To reduce the harmonics in Light Emitting Diode (LED), improved switching topology of DC to DC converter is proposed. This methodology has been simulated in MATLAB for verifying results. The various parameters of LED based power quality (PQ) has been evaluated. This proposed technology gives satisfactory results for PF improvement.*

Keywords- *Buck Boost converter, CCM, Harmonics, LED, power quality, pulse width modulation, power factor.*

I. Introduction

In residential, commercial, industrial and in street lightning LED lights are getting very popular because energy efficient, high luminous efficiency, long life and environmentally friendly. Recent research claims that LEDs have achieved efficacy more than 100 lumens per watt and their life is more than 100,000 hours. The default method for driving light source is controlling the DC forward current through the resistor, but this kind of approach is considered as less efficient to glow the lighting source due to excessive power loss in the resistor. Moreover, such circuits introduce power quality issues like poor power factor and higher harmonic contents in the AC mains current as well as poor efficiency. The driving circuit design for multiple LEDs should provide constant current with improved efficiency. LED lamp needs AC-DC converter when fed from AC mains. But such circuit induces power quality issues like high crest factor, low PF and high total harmonic distortion (THD) of AC mains current [1][2].

The driver circuit is essential for this, it is necessary to ac to dc converters. Generally harmonics distortion varies according to the type LED but only 3rd, 5th & 7th harmonic components are predominant which will increase overall THD [3][4][5]. Different manufacturers of LED lamps use diverse ballast technologies to reduce harmonic. These driver circuit use different DC-DC converter topologies to improve PF [6]. As per literature survey also harmonics reduced by using compensator which compensates harmonics by switching the half controlled H bridge converter or dual boost PFC rectifier until the THD becomes within the required level [7][8]. Some other ballast uses first-stage isolated current-fed power factor correction (PFC) pre-regulator that puts the short-lifetime high-voltage storage capacitor to the secondary, thus extending the overall system lifetime [9][10].

II. Measurement of Thad

$$v = \sqrt{2}\ \mathrm{V}_1 \sin(wt - \alpha_1) + \sqrt{2} \sum_{h \neq 1} V_h\ \sin(hwt - \alpha_h) \quad (1)$$

$$i = \sqrt{2}\, \mathrm{I}_1 \sin(\mathrm{wt} - \beta_1) + \sqrt{2} \sum_{h \neq 1} I_h \sin(\mathrm{hwt} - \beta_\mathrm{h}) \quad (2)$$

h =Harmonic order
1 =Fundamental Component of voltage and current

$$V_{rms} = \sqrt{V_1^2 + \sum_{h\neq 1} V_h^{\ 2}} \tag{3}$$

$$I_{rms} = \sqrt{I_1^2 + \sum_{h\neq 1} I_h^{\ 2}} \tag{4}$$

The total harmonic distortion of voltage is defined as:

$$THDv = \frac{V_H}{V_1} = \sqrt{\frac{V^2}{V_1^2} - 1} \tag{5}$$

The total harmonic distortion of current is defined as:

$$THDi = \frac{I_H}{I_1} = \sqrt{\frac{I^2}{I_1^2} - 1} \tag{6}$$

III. Problem Definition

In today's scenario single phase non- linear loads are increasing in residential and commercial building. This loads usually includes hospital, Educational Institute and small commercial shops etc. Most of the load in single phase are lightning load. The replacement of incandescent and tube lights by CFL or LED leads to energy saving, but these energy saving devices produce lots of harmonics into the supply. The harmonics creates extra losses in neutral due to third harmonics. The single phase loads are having distributed in nature, so it is difficult to analysis the harmonics. Due to this nature of distributed harmonics filter implementation is very difficult at particular point [11][12]. The solution of this single phase distributed harmonics is to implement PF improvement capability within the driver circuit itself. The driver circuit includes AC power supply which is converted into DC by rectification. After rectification this DC supply given to the LEDs. This conversion of AC to DC uses non-linear semiconductor switches, which distort the supply current and decreases the PF. The general circuit diagram of LED and their THD has been shown in figure 1 and 2.

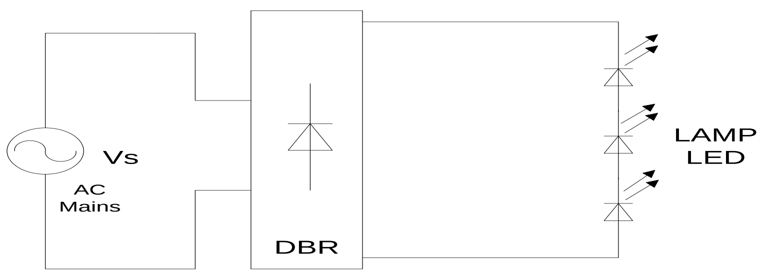

Fig.1 Circuit diagram of LED

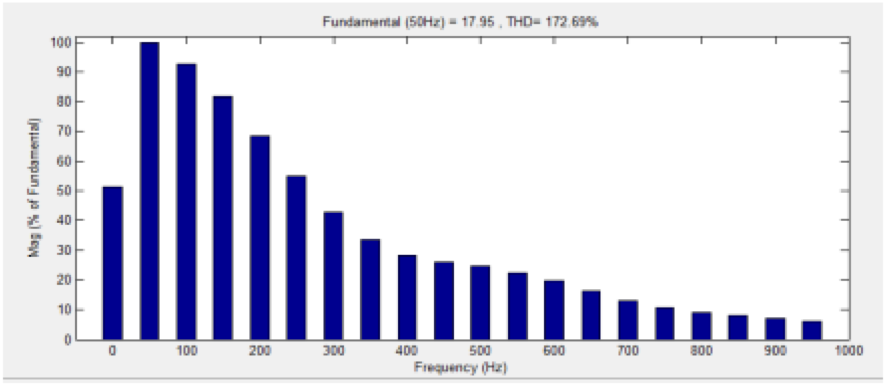

Fig.2 THD of LED

IV. Proposed Methodology

In the process of AC to DC rectification the power factor of input is very low in the range of 0.4 to 0.6 and high THD% as shown in Fig.2. Hence it is essential to use lamp driver circuit to improve the PQ performance of LED. The schematic circuit diagram of Lamp driver, which consist of Diode bridge rectifier (DBR), Buck-boost converter and feedback element with PWM generation has been shown in fig.3. Current of LED is sensed by feedback element and then compared with set reference current, which will generate error signal and act as reference current for PWM. For getting better switching performance MOSFET is used as a switch. This reference current is then compared with buck boost inductor current which will generate error to produce PWM signals to drive the MOSFET.

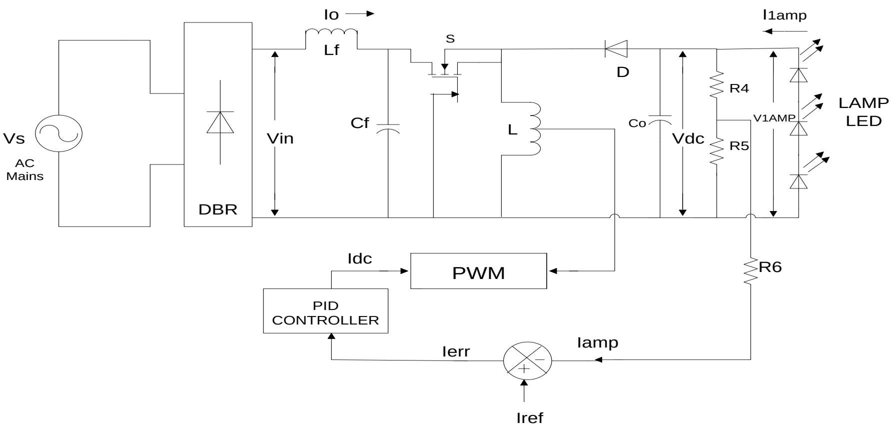

Fig.3. Circuit diagram with proposed topology

V. Design Consideration and Control Strategy

5.1 *Current feedback element*

LED lamp current (i_l) is sensed and compared it with set reference current (i_{ref}) which produce error (i_{err})

$$I_{err}(t) = i_l(t) - i_{ref}(t) \qquad (7)$$

5.2 PI controller

It is the sum of the instantaneous error over time and gives the accumulated offset that should have been corrected previously. Output of PI current controller is given as,

$$I_{dc}(t) = K_p i_{err} + K_i \int i_{err} \qquad (8)$$

Where Kp and Ki proportional and integral gains respectively.

5.3 *PWM generation*

Less switching power losses is the main feature of using PWM in the circuit. This buck-boost inductor current error is the difference of reference current (I_{dc}) and sensed inductor current (I_{dc}^{*}). Then current error is compared with PWM oscillator and output of the error amplifier is used to generate PWM signals required to turn-on power MOSFET of the converter.

VI. Simulation Performance

The MATLAB model of the proposed buck-boost Converter based LED lamp driver is developed with the help of SIMULINK tool as shown in Fig. 4 The lamp is considered as a resistor under the running condition. The proposed topology is modelled in MATLAB Simulink environment using Proportional Integral (PI) regulator with current multiplier approach for operating it in continuous condition mode (CCM). The operating frequency to turn on the MOSFET of PFC boost front end converter is maintained constant at 66 kHz for PWM generation. These component values along with PI controller gain parameters are provided in Appendix. The various waveforms of lamp current, error signal and PI control signal has been shown in fig.6 and fig.7. Reduction in THD% is shown in Fig.5.

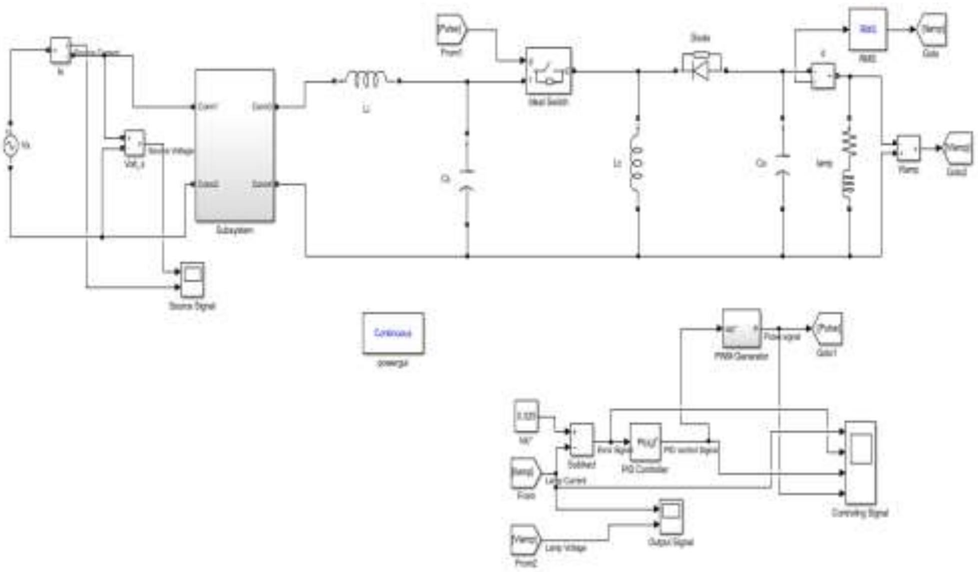

Fig.4. Matlab Simulation OF LED Driver circuit

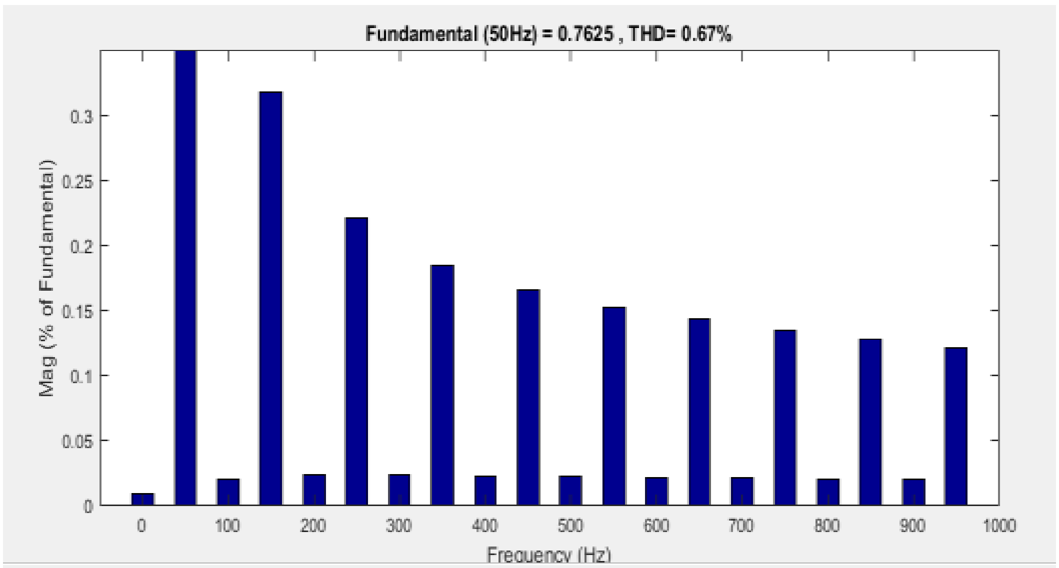

Fig.5. THD of LED with proposed methodology

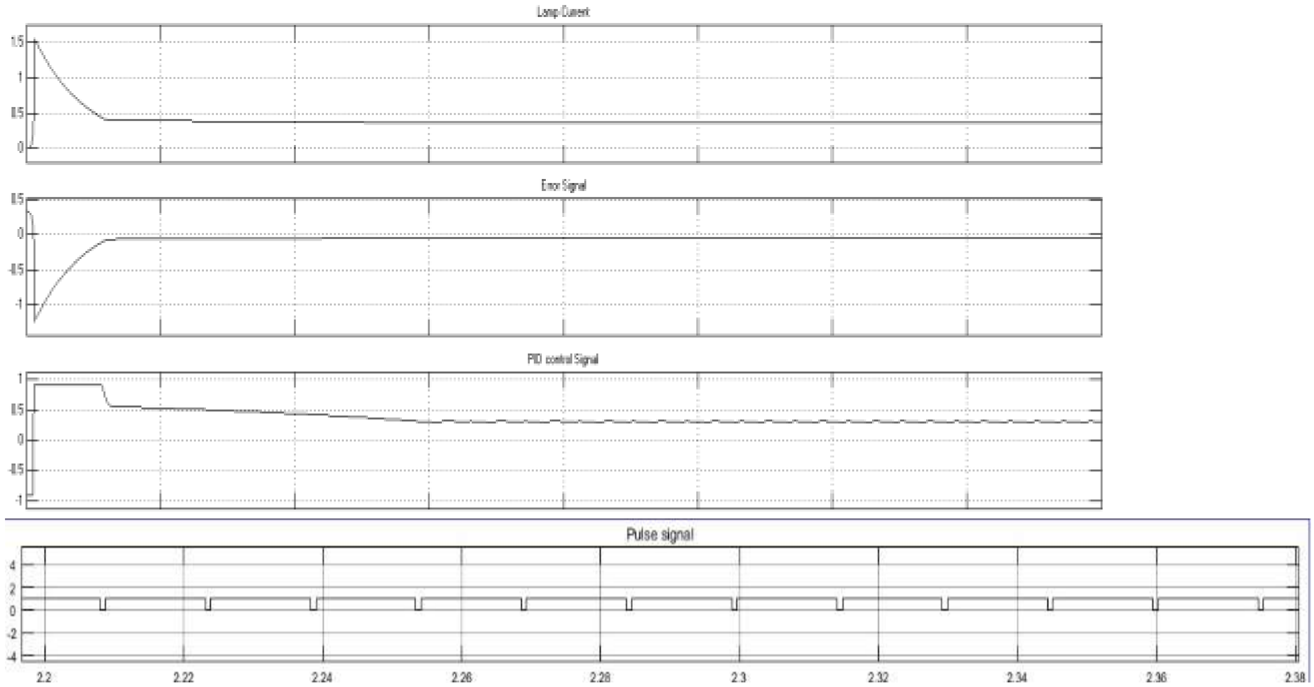

Fig.6 Controlling Signal

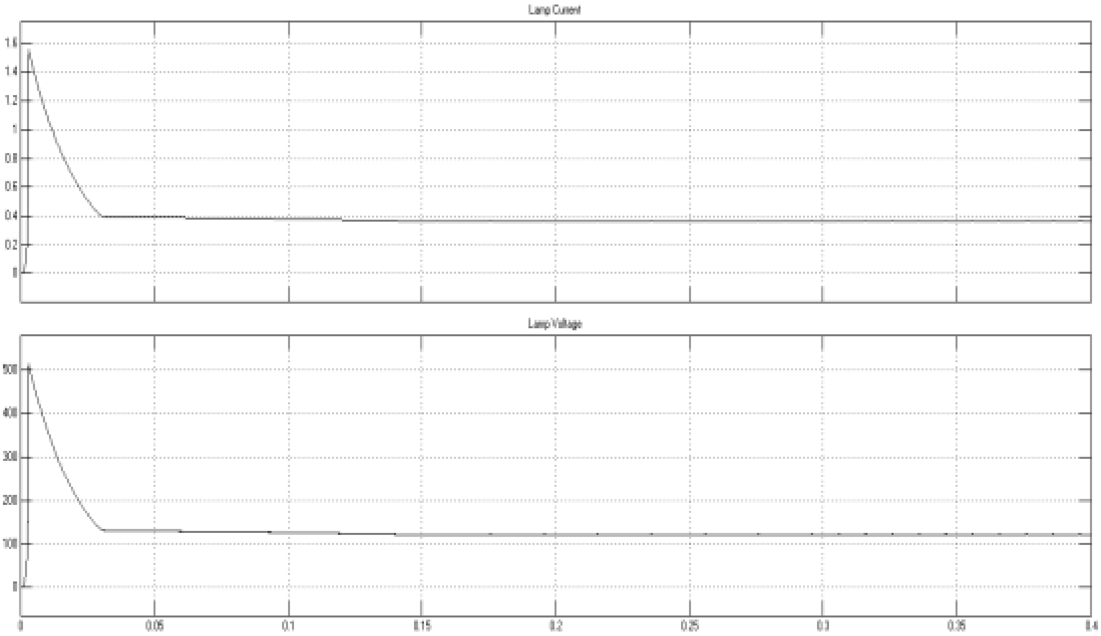

Fig.7. Lamp current and Voltage

VII. Results

In the LED of 18W 325mA, 110V has been used for simulation in MATLAB with proposed methodology. By using this topology, the power factor is improved from 0.6 to 0.995 which ultimately decrease the THD.

VIII. Conclusion

The above buck-boost converter using LED drive shows improved power quality for non-linear residential load and improved PF of 0.995, reduces the harmonics. As per results shown, it is necessary to implement some rules and regulation or guideline to manufacturer for implement the driver circuit with low

THD and high PF in energy efficient loads. Implementation of LED drive for improving PQ is important for residential and commercial load in future.

IX. Appendix

Reference current: 325mA, Lamp current: 325mA, lamp voltage: 100 V, switching frequency of PFC switch (fs): 66 kHz, PI controller gains (Kp): 8.2, (Ki): 1.28, Boost inductor (Lb): 1.1mH, DC link capacitor (Co): 60μF

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