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A Ripple-free High power factor Electrolytic Capacitor-less Grid connected LED Lighting System

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Abstract - In conventional grid connected LED drivers, three stages are present, namely rectification, power factor correction and harmonic elimination. In this paper, a configuration is presented which uses a fully controlled full bridge rectifier (FCFBR) for rectification as well as power factor correction (PFC). This eliminates the need for PFC converters like fly-back converter. A Buck converter is used to drive the LEDs. Two Hysteresis controllers are used separately for harmonic elimination and power factor correction. The proposed configuration uses less number of components and a simple technique to meet general requirement of grid connected LEDs. The performance of proposed configuration is verified with simulation results.

Keywords – LED driver, power factor correction, harmonic elimination, hysteresis control.

I. INTRODUCTION

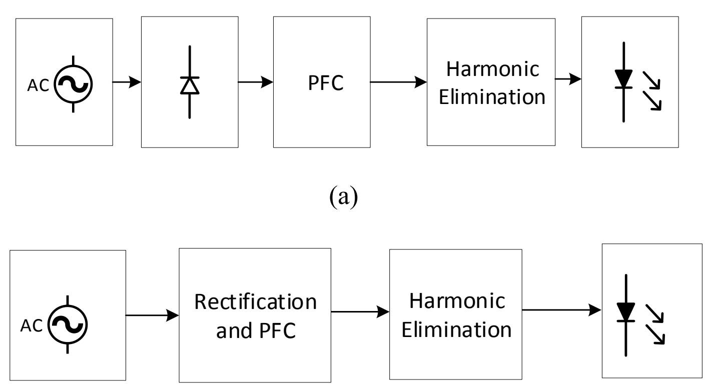
In Grid connected LED lighting systems, there are four major requirements. First, power factor of the source side should not be deteriorated. Second, the harmonics injected into the grid should be within the standard limits. Third, the current fed to the LED should be a maintained constant. Fourth, the lifetime of the driver should be high. When LEDs are fed from grid and connected directly through the rectifier, high level second order harmonics are present in the output current and voltages. The ac variation in the LED current will not affect the average illumination produced by LED [1]. Hence, an electrolytic capacitor-less single stage LED driver is proposed in [2]. But as stated in [3], prolonged use of such lights may be harmful for human eyes. Hence, the second order harmonics must be eliminated from the output current and voltage waveforms of LED driver. In order to meet the constant current demand of the LEDs, several harmonic elimination techniques are proposed in literature.

In [4-5], harmonics are removed by using magnetic storage elements. This leads to the increase in the size of the system. In [6], input current itself is distorted in such a way that very less amount of second order harmonics are present in the output side. In [7], a bidirectional buck-boost converter with small value of capacitor is used to eliminate harmonics in the load voltage. In [8], Asymmetrical Half Bridge converter is used to eliminate second order harmonics. This topology overcomes the disadvantages of the fly-back topology as post regulator.

As LEDs are non-linear loads, the input power factor of the source will be deteriorated. Hence, PFC must be incorporated in order to achieve high power factor and to meet standard harmonic limits e.g., IEC61000-3-2 [9]. Various techniques are used to maintain high power factor in the source side. In [8], Boost converter is used for PFC purpose. This gives very high efficiency but it is applicable for the low voltage output only. In [10], a fly-back/buck-boost LED driver is proposed which maintains high power factor by significant removal of the second order harmonics.

In this proposed system, on the source side PFC is achieved using fully controlled full bridge rectifier with hysteresis control and on the load side, second order harmonics are removed by driving LEDs through hysteresis controlled buck converter. Dimming control is also provided by proposed configuration.

II. PROPOSED SYSTEM



(a)

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Fig.1 a) Block diagram of conventional grid connected LED lighting system.
b) Block diagram of the proposed system

Fig.1.a shows the block diagram of the conventional grid

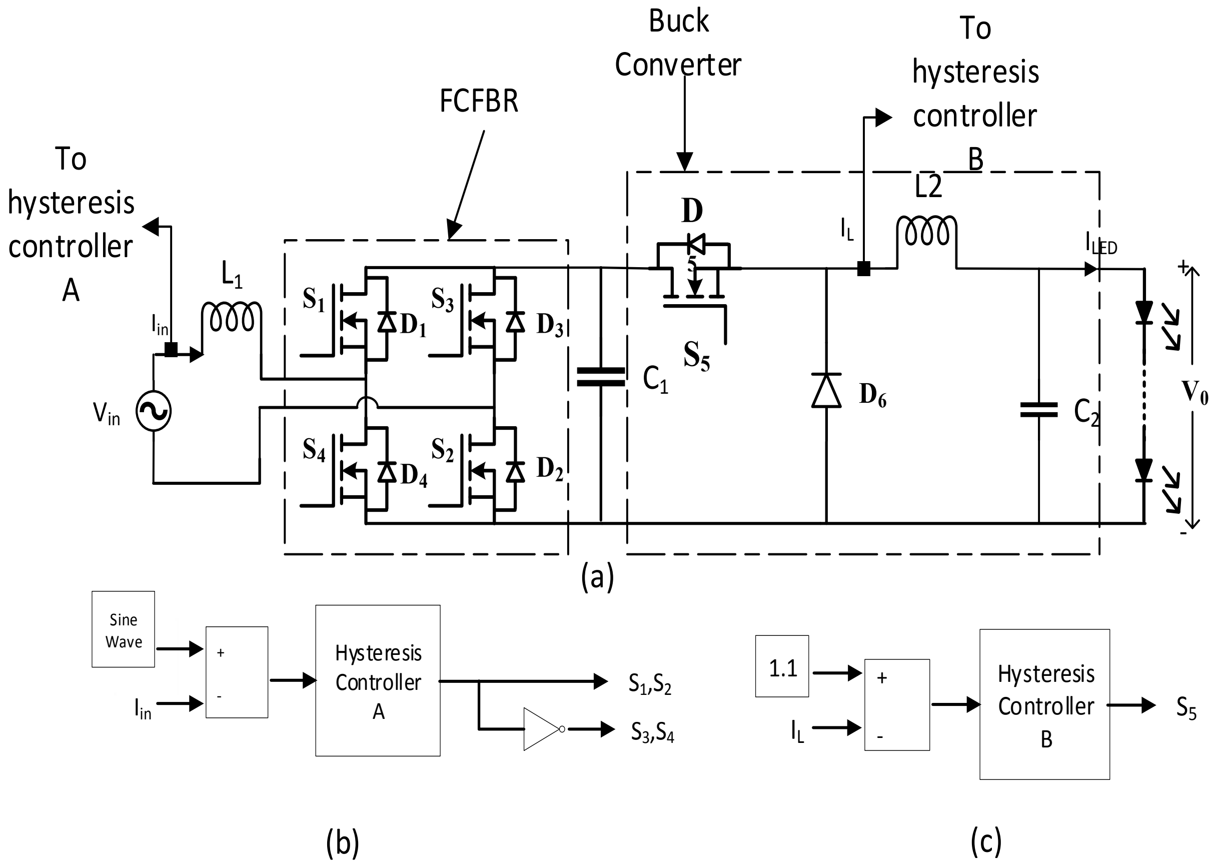


Fig. 2. a) Circuit diagram of proposed configuration. b) Hysteresis controller-A. c) Hysteresis controller-B.

connected LED lighting system. Here input ac voltage is rectified by an uncontrolled diode rectifier and power factor correction is done using converters like fly-back converter or DCM operated converters. This is followed by harmonic elimination stage. The block diagram of the proposed grid connected LED lighting system is shown in Fig. 1.b. Here the power factor correction and rectification are handled by a single block, FCFBR.

Fig. 2 shows the proposed grid connected LED lighting with PFC and harmonic elimination. LED load is connected through buck converter and the FCFBR to the grid. Here switching of the FCFBR is controlled by using hysteresis control such that input power factor is maintained at unity and harmonics injected in the grid are also maintained within the standard limits. Buck converter is used to drive the LED load as well as to maintain the load current at constant value by removing the harmonics. Conventionally, as shown in Fig. 1.a, uncontrolled rectifier, PFC circuit and harmonics removal circuit are present in the configurations. Whereas, in the proposed configuration, only PFC circuit and Harmonics removal circuit are present. As power factor correction is implemented through controlled full bridge rectifier, it rectifies the signal as well as maintains the power factor at unity. Hence, the number of components used in the proposed configuration is less compared to the conventional configurations.

III. PRINCIPLE OF OPERATION

As shown in Fig. 2, FCFBR is used for rectification as well as PFC. Two hysteresis controllers are used for PFC and harmonic elimination respectively. Hysteresis controller-A is employed for PFC. Fig. 3 shows the operation of hysteresis controller. Hysteresis band is defined in which the actual signal is maintained by proper switching. Upper and Lower limit of hysteresis band can be set to any desired value. For PFC, in Hysteresis controller-A, the input current is compared with the desired pure sinusoidal waveform which is the reference. After comparing both the signals, error signal is generated. This error is fed to the hysteresis controller. Whenever the input current deviates from the reference waveform, the appropriate gate pulses are generated by the hysteresis controller. These gate pulses are fed to the switches S_1 and S_2 and out of phase signal is applied to the switches S_3 and S_4. Whenever input current exceeds the upper limit of hysteresis band, S_1 and S_2 are turned off and S_3 and S_4 are turned on. This will bring back the input current in the desired band of the signal. When input signal goes lower than the lower limit if the desired band of the signal, switches S_1 and S_2 are turned on while S_3 and S_4 are turned off. This will bring back the input current again into the desired band. In this way, input power factor is maintained closer to unity.

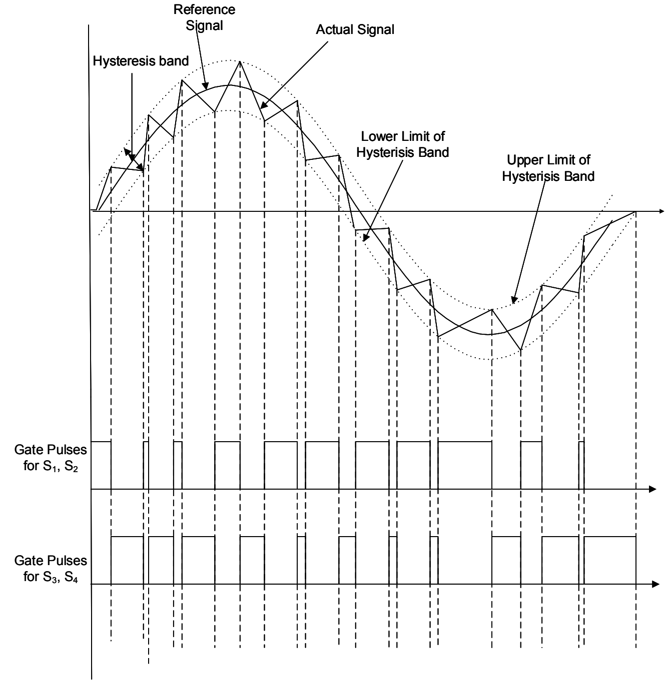


Fig. 3 Hysteresis controller operation

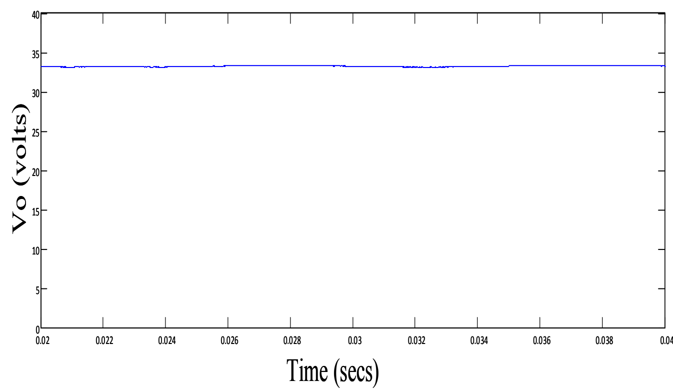
Output of the FCFBR is fed to the Buck converter. Buck converter is used to drive the LED load with desired value of constant current. Another Hysteresis controller (Hysteresis controller-B) is used to generate the pulses for the switch S_5. Here, inductor current (I_L) is compared to the desired load current reference value. After comparing both the signals, error signal is generated is applied to the hysteresis controller which generates switching pulses of S_5. Whenever the inductor current exceeds the defined band limit, S_5 will be opened. This brings back inductor current in the desired band limit. Whenever the inductor current goes lower than the lower limit of the band, S_5 is closed which brings back the inductor current in the desired limit. Hence, inductor current is maintained at constant value, which leads to constant value of the load current as output capacitor used is very small. In this way, the output load current is maintained at the desired constant value. Hence the output current fed to the LED load is constant and free from the harmonics.

IV. Dimming Control

Dimming control of LED lights is an important feature of LED driver. Here, the average current through LED is controlled by a low frequency dimming signal. This dimming feature is incorporated by ANDing a 100 Hz low frequency pulse with the switching pulse of the device S_5. Hence, average current and thereby brightness of each LED lamp is controlled. Simulation results for 60% and 80% dimming levels are shown in this paper.

V. Simulation Results

In the proposed system one LED lamp is used. It consists of two strings of LEDs connected in parallel. Each string contains 10 LEDs connected in series. Each LED is operated at 3.3 V, 550mA and 1.815 W and hence each LED lamp is operated at 33 V, 1.1A and 36.3 W. Values of inductors used are L_1=5mH and L_2=1mH. Values of Capacitors used are C_1=15μF and C_2=5μF.The simulation results are presented below:



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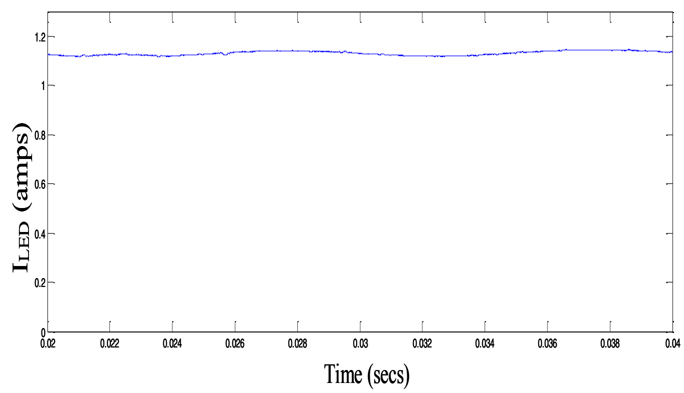

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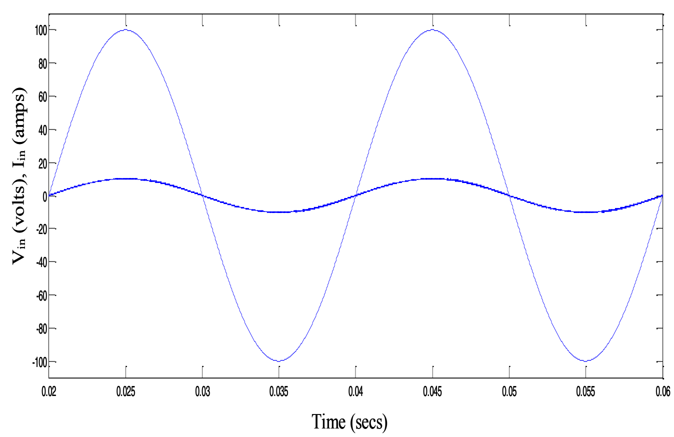

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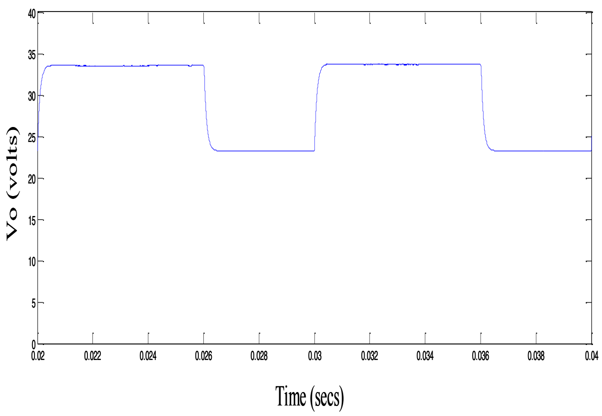
Fig. 4 Simulation results at rated LED current
a) Output voltage, V_o. b) Output Current, I_{LED}. c) AC input voltage (V_{in}) and current (I_{in}). (Current scale for input current is 1/10th of that shown)



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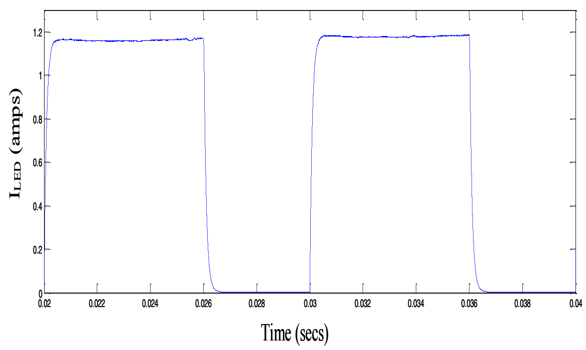

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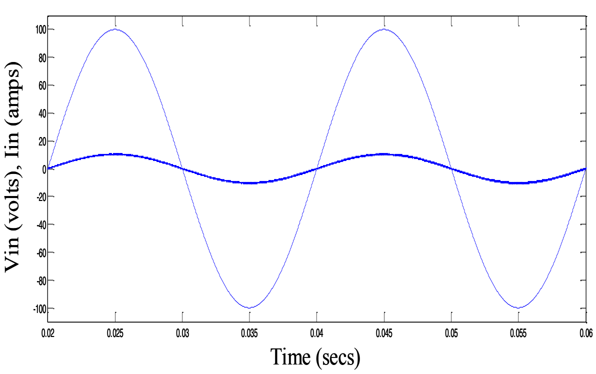
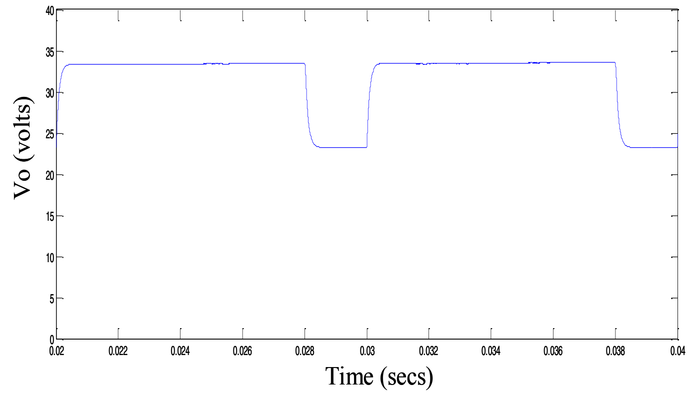


(c)

Fig. 5 Simulation results at 60 % dimming of LED
a) Output voltage, V_o. b) Output Current, I_{LED}. c) AC input voltage (V_{in}) and current (I_{in}). (Current scale for input current is 1/10th of that shown)



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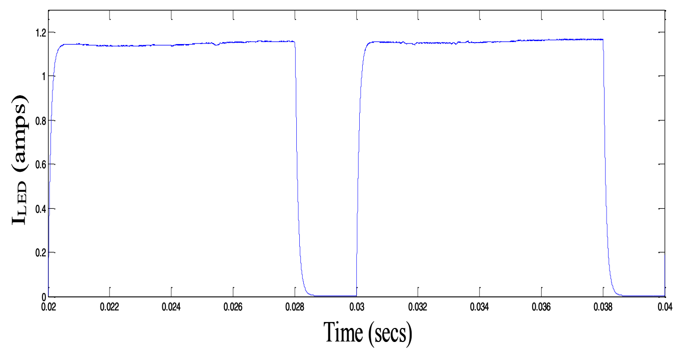

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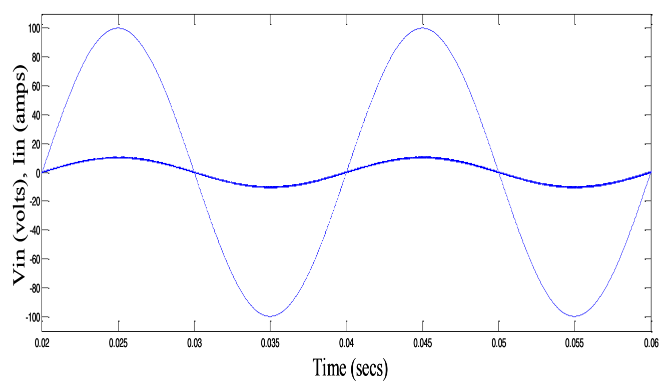
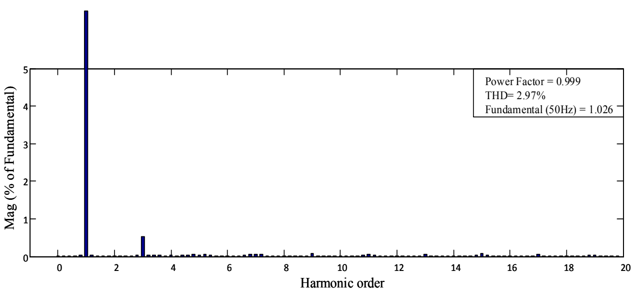


(c)

Fig. 6 Simulation results at 80 % dimming of LED
a) Output voltage, V_o. b) Output Current, I_{LED}. c) AC input voltage (V_{in}) and current (I_{in}). (Current scale for input current is 1/10th of that shown)

Fig. 4 shows the simulation results at rated LED current i.e., is at full illumination level. Output voltage, V_o and output Current, I_{LED} are shown in Figs. 4.a and 4.b respectively. From these figures, it can be observed that the output voltage and current have negligible amount of ripples and second order harmonics are removed completely. Corresponding ac input voltage and current waveforms are shown in Fig. 4.c. The corresponding harmonic spectrum of the input current is shown in Fig. 7.a. It can be observed from these figures that the input power factor is nearly unity and THD is also less.

Fig. 5 shows the simulation results at 60 % dimming level. Output voltage, V_o and output Current, I_{LED} are shown in Figs. 5.a and 5.b respectively. From these figures, it can be observed that when LEDs are 'on', the current is maintained constant and only the average current changes. Corresponding ac input voltage and current waveforms are shown in Fig. 5.c. The corresponding harmonic spectrum of the input current is shown in Fig. 7.b. It can be observed from these figures that during dimming control also the input power factor is maintained nearly at unity and THD is also less. Fig. 6 shows the simulation results at 80 % dimming level. Output voltage, V_o and output Current, I_{LED} are shown in Figs. 6.a and 6.b respectively. Corresponding ac input voltage and current waveforms are shown in Fig. 6.c. The corresponding harmonic spectrum of the input current is shown in Fig. 7.c. It can be observed that the input power factor is maintained nearly at unity and THD is also less.



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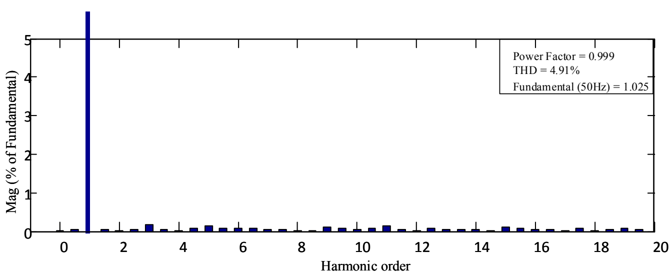

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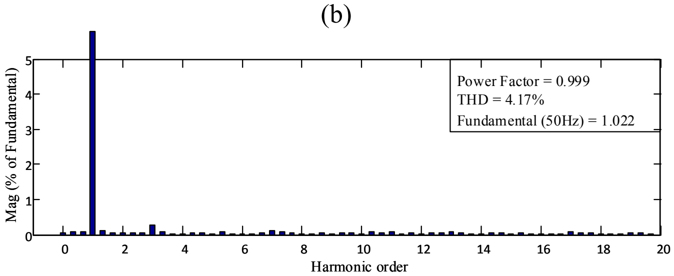

(c)

Fig. 7 Harmonic spectrum of supply current
a) At rated LED current. b) At 60 % dimming of LED. c) At 80% dimming of LED.

VI. Conclusion

A Ripple-free High power factor Electrolytic Capacitor-less Grid connected LED Lighting System has been designed. Its performance has been verified through simulation results. In the source side PFC is achieved using fully controlled full bridge rectifier with hysteresis control and on the load side, second order harmonics are eliminated by driving LEDs through hysteresis controlled buck converter. Dimming control is also provided. From simulation results, it is observed that the power factor at the input side is maintained at unity and nearly constant current is fed to the LEDs as per the requirements. No electrolytic capacitor is required as significant harmonics are removed. The proposed system uses less number of components as compared to conventional configurations. It employs a simple control technique.

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