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An AC LED Driver with Improved Total Harmonic Distortion and Power Factor

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Abstract -In this paper, A Bridgeless Boost converter proposed for improving power factor (PF) and total harmonic distortion (THD) of an AC LED driver. The proposed topology is integration of Boost and Buck-Boost converter. In conventional LED driver there were a bridge rectifier with large value of inductor and capacitor but in proposed topology one inductor and one capacitor with a very small value are used. By which distortion as well as PF are reduce significantly. After performing experiments we got PF>0.98 and THD<2%.Simulation of proposed circuit is done by MATLAB SIMULINK. Controlling of proposed circuit is done by FPGA.

Index Term – AC LED, Boost, Buck-Boost, bridgeless, DC-DC Converter, Power Factor, and Total Harmonic Distortion

1. INTRODUCTION

In Today's world there is huge technology development in various fields. There are various problem arises with technology development such as environment pollution, energy storage problem, power dissipation in devices, lower efficiency and so on. Thus, the product efficiency is more important and their standard also important. For lightning application, the light-emitting diode (LED) in hold many advantage over the existing lightning system such as no Mercury(Hg) pollution, small in size ,life is more, luminous efficiency is very high, fast time response, low power consumption[1]etc. These are the advantages by which LED suitable for lightning application. As compare with traditional lightning sources such as incandescent lamp and fluorescent lamp LED have ability to reduce power dissipation by 81% to 92%.In lighting application , the current harmonics presents in line should satisfy the limits set by International Electro technical Commission(IEC) 61000-3-2 class C regulation And power factor should be higher than 0.9[2].
Since the LED is directly driven, so the AC-DC converter or DC-DC converter is used to transfer the input voltage to the required DC voltage to drive the LED.

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In general, the LED driver blocks shown in Figure 1. This is a traditional LED driver which is widely used. In this AC input voltage fed into bridge rectifier with a high capacitor value in parallel generates a pulsating DC. Now Pulsating DC fed into DC-DC converter which provides the stable DC to LED module.

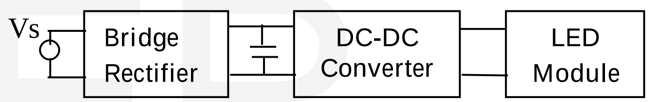

Fig. 1 Widely-used LED driver structure

This is a general structure of LED driver. Since Bridge rectifier whose output pulsating dc is not directly proportional to its input ac voltage due to diodes, distorted current is drawn from the AC source and Harmonics are introduce in lines. It is also draw spiky current. Bridge rectifier imparts High THD, Very Low PF and very low efficiency to the LED module [3]. These harmonic currents creates various problem such as voltage distortion, heating, noises, power dissipation etc. by which overall efficiency will reduce or very low and THD is significantly High. This lead to need of high power LED driver that can deliver and maintain LED current in a power efficient manner. Amid all kinds of LED drivers, switch mode power converters is widely used for high-power LED driver due to better efficiency [1].In general DC-DC PWM (Pulse –Width Modulation) converters for LED have three basic types: Buck, Boost and Buck – Boost. There are some other topologies like Fly-Back, Boost –Buck, Single –End Primary Inductance Converter (SEPIC). All design are developed from three basic topologies above [4] .Here first we will discuss some basic converter after that we will concentrate on proposed circuit. The proposed circuit is combination of Boost and Buck-Boost converter .This proposed circuit also called as Bridgeless Boost rectifier.

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2. EXISTING METHOD OF IMPROVING THD & PFC

There are various methods already introduced to improve PFC & THD. In paper [5] A Bridgeless Single-Stage Half-Bridge AC/DC converter method is used for improving the PFC of circuit. In paper [6] A Non-isolated LED converter method is used for improving PFC. In paper [7] they had not used capacitor and inductor in main power stage. They arrange the LEDs in efficient manner by which LED cannot dissipate more power.

Now we will see some basic topology and compare them. As discussed earlier there are three basic topology; Buck, Boost and Buck Boost.

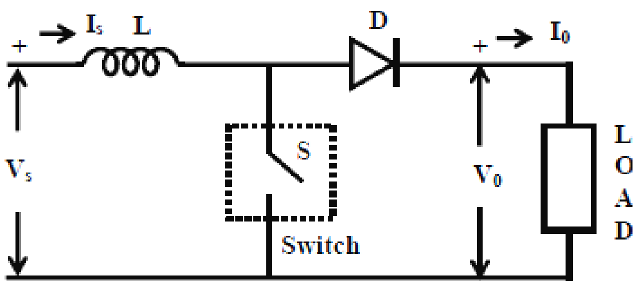


Fig. 2 Boost Converter

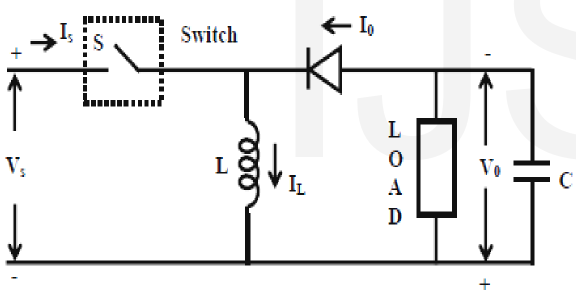
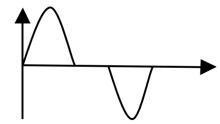
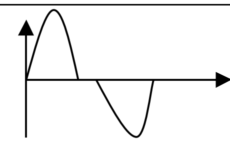
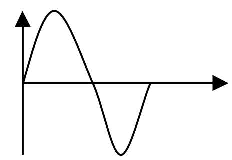


Fig .3 Buck-Boost Converter

These are the basic topology of DC-DC converter. Among these three we are using the Boost and Buck-Boost converter for proposed circuit. Buck converter usually use for low voltage operation because it convert the high input voltage to low output voltage. It is also called Step-Down chopper. In Boost converter output voltage is high compare to input voltage so it is also called Step-Up chopper. The comparisons between these of three are given below in table 1. These topologies are operates mainly in two Modes Continuous Conduction Mode (CCM) and Discontinuous Conduction Mode (DCM). Here from table we can see the Boost and Buck-Boost converter are good for DCM operation mode. Buck converter is not suitable for DCM mode. There are some advantages of DCM mode and CCM mode.

Table 1

Comparison of Basic converters

Basic Converter	Line current waveform	DCM self-PFC
Buck		Poor
Boost		Good
Buck-Boost		Excellent

In basic topologies rectifiers is essential. Input given to this topology is not pure dc. It is a pulsating dc comes from rectifier. This pulsating dc fed into basic circuit. Pulsating dc contain ripples and harmonic. Here ripples related with combination of AC and DC. As result PF will decrease and THD will increase. In proposed topology ac signal direct fed into input side. There is no need of rectifier. By doing this we can reduce the number of diodes and additional circuit. As a result THD as well as PF will improve. Proposed Bridgeless Boost rectifier shown below

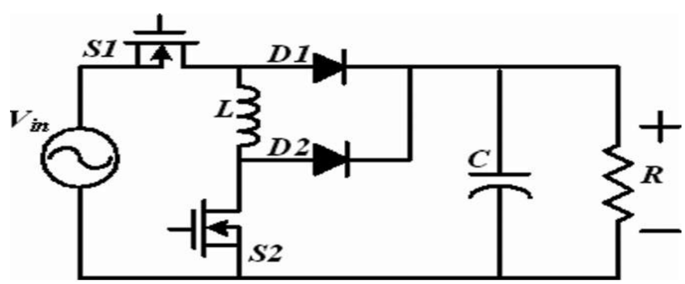


Fig.4 Proposed Bridgeless Boost Rectifier Circuit

Proposed circuit is combination of Boost and Buck-Boost topology so there are two modes of operation. Proposed topology can work for both cycles of input that is for positive half cycle as well as for negative half cycle. When positive half cycle is apply then switch 1(S1) is ON and D1 becomes reverse bias now circuit work as a Boost converter. When negative cycle is applied then S2 is ON and D2 become reverse bias now circuit work as a Buck-Boost converter. The detail operation of circuit discuss in following section. Switches are controlled by FPGA Spartan-3AN kit. This kit generate a waveform of 50MHz. Proposed circuit Boost the voltage level from 12 volt to 14 volt- 280 volt.

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3. METHODOLOGY

Hardware part describes the block diagram of proposed circuit and working of that circuit. Software part describes the control technique.

3.1 System Hardware

An AC LED module has taken as a load. AC LED module is operates at 14V dc signal. Bridgeless Boost rectifier takes input 12V at 50 Hz. After taking AC input, bridgeless Boost rectifier converts the ac voltage into dc voltage and Boost the voltage in range between 12V to 280V.
Fig 5 shows the block diagram of proposed circuit. In which Bridgeless Boost converter, One Driver circuit, One FPGA board for controlling (switching) and One LED of 14 Volt modules as a load.

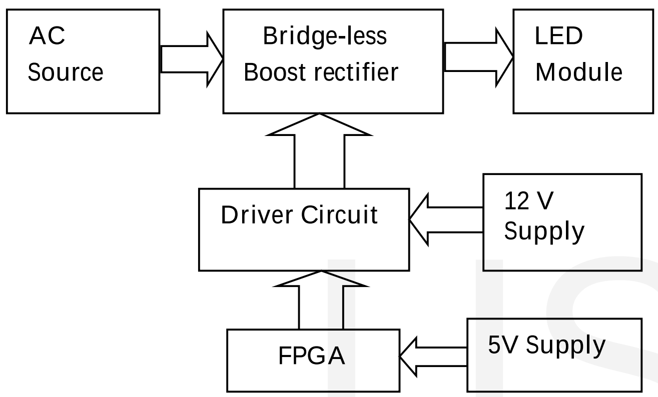

Fig. 5 Block Diagram of Proposed Method: Bridgeless Boost Rectifier

The proposed Bridgeless Boost rectifier's DCM operating modes shown in figure 6.
The proposed circuit operates mainly in 2 mode i.e. Boost mode and Buck-Boost mode. In Boost mode further circuit operate in 3 modes. This is shown in figure 6. Now we will elaborate each mode properly. First 3 modes are Boost mode for first positive half cycle of input. Last 3 modes are Buck-Boost mode for negative half cycle of input.

Mode I: This mode start with the first positive half cycle of input. In this mode both the switches S1 and S2 are in ON condition. When both the switches in ON condition the both the diode D1 and D2 are reverse biased. Since diodes are in reverse biased mode the inductor energized with the input voltage. Due to reverse bias of diode the capacitor decoupled from circuit.

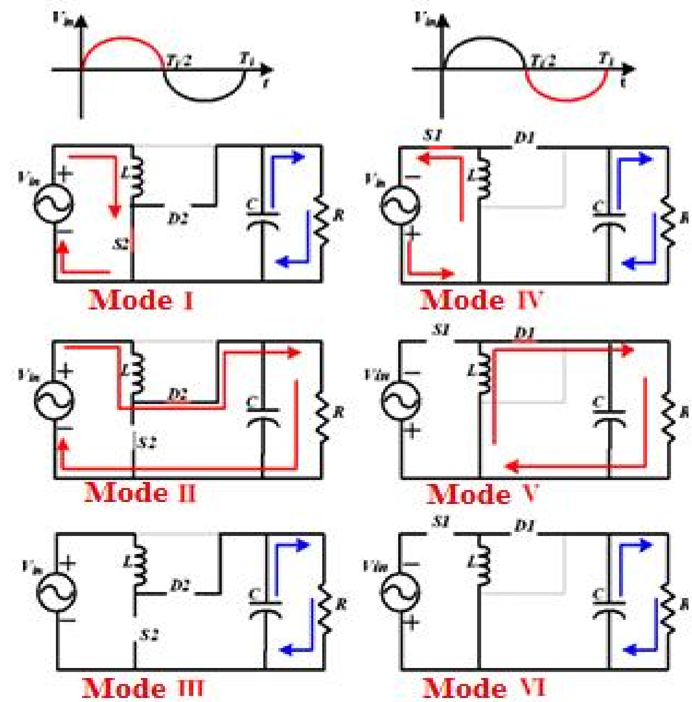

Fig. 6 Modes of operation in Bridgeless Boost Rectifier

Mode II: In this mode S2 is turn off and diode D2 is ON that is in forward bias. Now whatever energy stored in inductor during Mode 1 all energy transferred to load. For Boost mode operation d2 is the duty cycle.
Mode III: Now D2 is automatically off when inductor current becomes to zero. The capacitor will discharge through the load. S2 is again turned ON and circuit operates in Mode 1 if input voltage still in positive half cycle.
Mode IV: In this mode negative half cycle of input is apply. Switch1 (S1) starts conducting means S1 is turn ON. The energy once again transferred to inductor L and capacitor C again decoupled from the circuit. Both the switches S1 and S2 are conduct in this mode as mode 1.
Mode V: In this mode S1 become turn OFF. Whatever energy stored during Mode 4 across the inductor L transferred to load. The current across inductor decreases linearly. In this Mode some switching loss occurs due to diode D1 turn ON.
Mode VI: After some time when inductor current becomes zero or decrease to zero, D1 become turned OFF. Total voltage across the capacitor C transferred to the load.
There are some losses due to diodes ON time but it is very negligible. But by using high switching frequency we can reduce the switching losses.

3.2 System Software

In software MATLAB SIMULINK used for simulation of proposed circuit. Software XILLINX 10.1 used for coding to FPGA board. FPGA board generates the PWM signal. Here requirement of PWM signal is to provide the switching signal to MOSFETS by which circuit can perform the operation accurately. Simulation result of MATLAB shown in result part. Here we will see the flowchart of generation of pulses.

3.3 VLSI (FPGA) Part

Generally this is integration of Hardware and Software. In FPGA first we write the code in VHDL form and after that download that bit file in SPARTAN3AN kit.

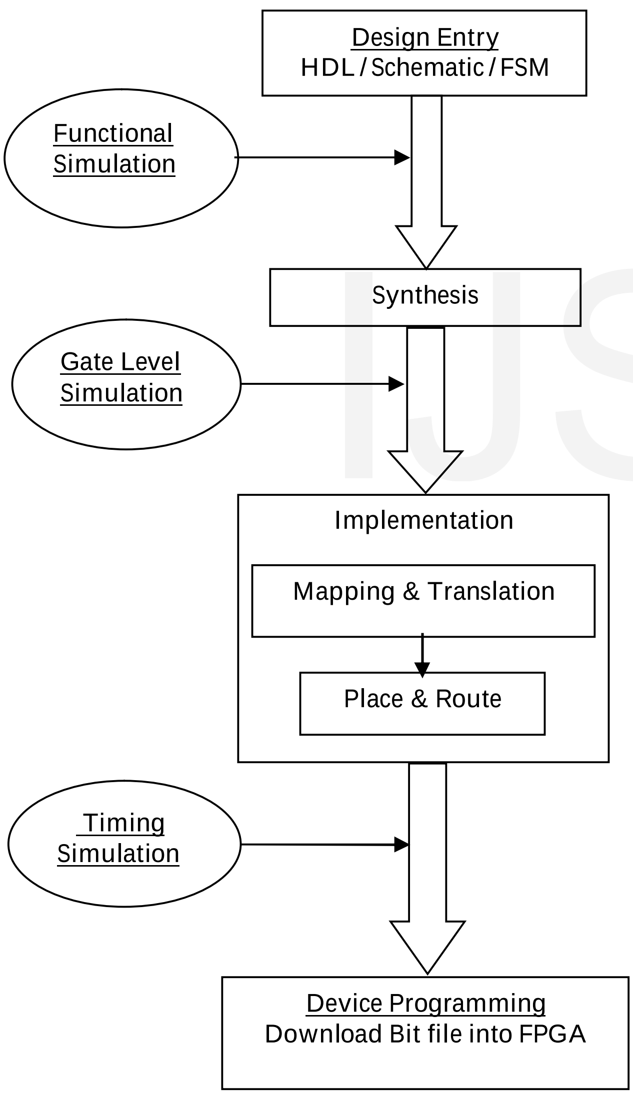

Fig. 7 Flow chart of processes in FPGA

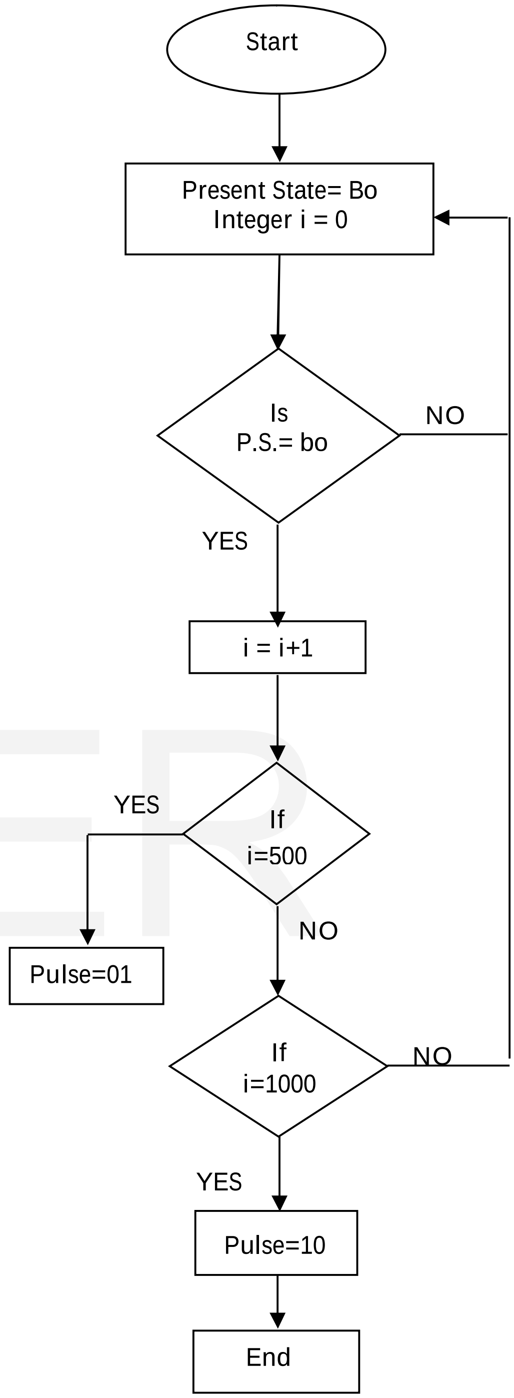

Fig. 8 Flow Chart of PWM signal generation for MOSFET switch

There are two switches used for controlling to our circuit. Hence there are two switching signal are required. From flow chart we can see that there are two different pulses one is 01 and another one is 10.

3.4 Theoretical Analysis

Here some assumptions are made for analyzing the steady-state behavior of proposed circuit in one switching cycle.

1) The value of output capacitor C takes large enough around 1000µf to maintain output voltage V0 constant.
2) The input to the circuit is sinusoidal voltage source. So switching frequency should be much higher than the input voltage frequency by which in each switching cycle input voltage look like a constant voltage source.
3) All internal resistance of passive component not taken into account for calculation convenience.

3.4.1 Input Output voltage relationship in Boost operation

According to operation of circuit as discussed earlier first 3 Modes are related with Boost mode.

In discontinuous conduction mode (DCM) inductor current falls to zero. At the beginning of cycle the inductor current is zero. Its maximum value at $t = D_1T$ is:

$$I_{Lmax} = \frac{V_i D_1 T}{L}$$

During OFF-period, Inductor current falls to zero after δT :

$$I_{Lmax} = \frac{(V_i - V_O)\delta T}{L} = 0$$

Output voltage gain is given as:

$$\boxed{\frac{V_o}{V_i} = 1 + \frac{V_i D_1^2 T}{2LI_O}}$$

3.4.2.Input Output voltage relationship in Buck-Boost operation

For Buck-Boost operation the input output voltage relation given as fallow-

At the beginning of cycle the inductor current is zero. Its maximum value at $t = DT$ is:

$$I_{Lmax} = \frac{V_i D_2 T}{L}$$

During OFF-period, Inductor current falls to zero after δT :

$$I_{Lmax} + \frac{V_O \delta T}{L} = 0$$

Output voltage gain can be written as:

$$\boxed{\frac{V_o}{V_i} = -\frac{V_i D_2^2 T}{2LI_O}}$$

Here minus(-) sign indicate the polarity of signal means when negative half cycle of input will come then the output voltage again become positive.

4. EXPERIMENTAL RESULT & LOSS ANALYSIS

Hardware setup of proposed circuit's shown in figure 9. In figure we can see there are SPARATAN3AN kit and one driver circuit to isolate the FPGA board and Bridgeless Boost rectifier.

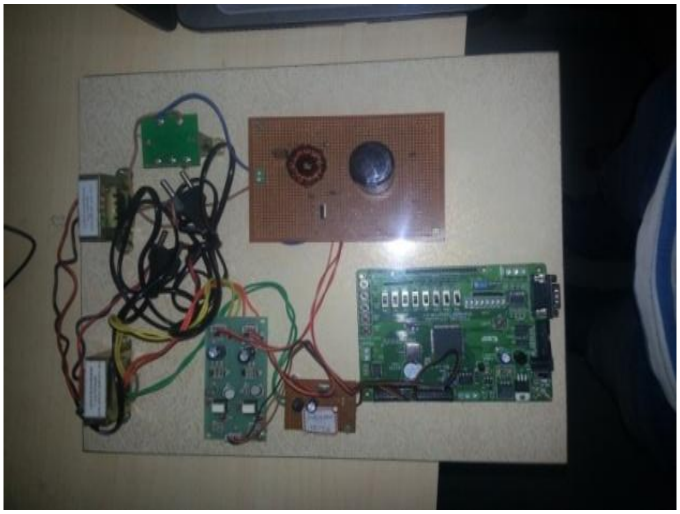

Fig. 9 Hardware setup for Bridgeless Boost Rectifier

TABLE 2
COMPONENT AND PARAMETERS IN THE BRIDGELESS BOOST RECTIFIER

Component	Parameter	Part Number
Vin(input voltage)	12V, 50Hz	-
Vo(output voltage)	14V-280V	-
Switching frequency	50MHz	-
Inductor L	1mH	-
Capacitor C	1000µf, 250V	C322Y020712
Power MOSFET	8A, 500V, 0.850Ω	IRF840
Diode	1.0A,1.1V	1N007

For Bridgeless Boost rectifier input voltage is 12V AC input. Output voltage of Bridgeless Boost rectifier is in range 14V to 280V at switching frequency 50MHz. The value of Inductor L, Capacitor C and Power MOSFET are taken respectively 1mH, 1000µf and 8A.

4.1. Comparison of THD between Conventional and Proposed Method

Simulation is performed by MATLAB SIMULINK. In simulation circuit we draw conventional circuit and take the value of component same as mention in Table 2. After performing simulation of conventional circuit we got THD near to 68.52% and PF near to .98. When we performed simulation of proposed Bridgeless Boost converter circuit we got the THD near to 0.93% and PF near about .991. Simulation result of proposed and conventional circuit in figure 10 and figure 11 respectively.

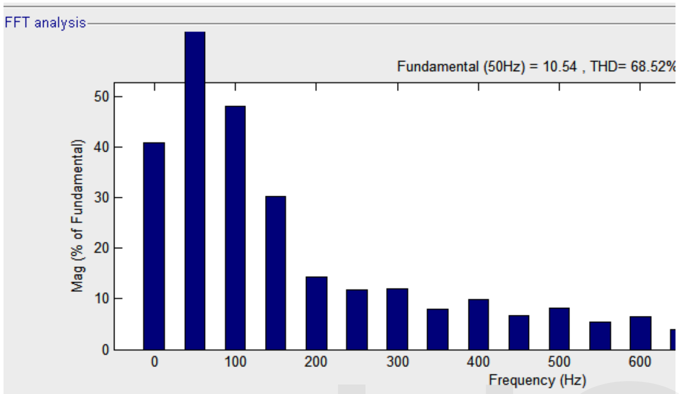

Fig.10 THD of Conventional Bridge Boost rectifier

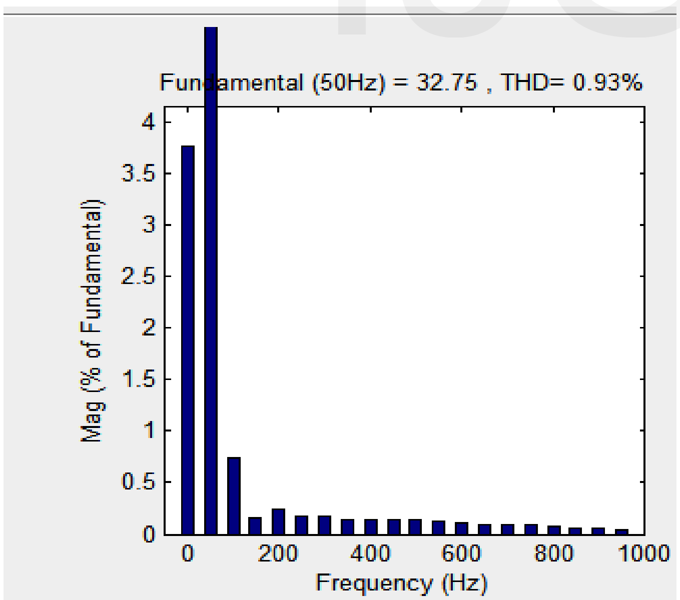

Fig. 11 THD of Proposed Bridgeless Boost rectifier

4.2. Comparison of PF between Conventional and Proposed Method

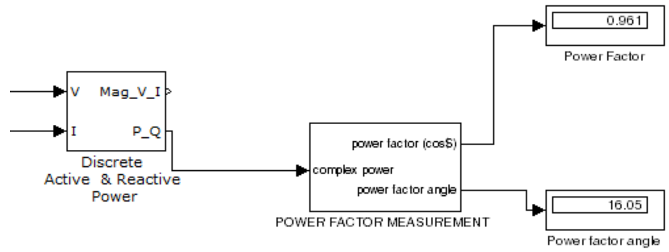

Fig.12 PF of Bridgeless Boost Rectifier

Fig. 13 PF of Conventional Circuit

4.3. Loss calculation in Proposed Bridgeless Boost rectifier and Bridge Boost Rectifier

There are some losses occurs in components during the operation of proposed Bridgeless Boost rectifier circuit. Losses from each and every component are calculated shown in table 3.

TABLE 3
LOSS CALCULATION OF CONVENTIONAL AND PROPOSED CIRCUIT

Category	Component		Estimated Loss	
	Bridge-less Boost Rectifier	Bridge Boost Rectifier	Bridge-less Boost Rectifier	Bridge Boost Rectifier
Topology	Inductor	Inductor	2.5mW	6.7mW
	Capacitor	Capacitor	0.09mW	1.2mW
	MOSFET	2 MOSFET	4.6mW	10mW
	Diodes	4 Diodes	4.9mW	20.3mW
Controller	SPARTAN3AN	PIC	1.2mW	2mW
Total Loss			13.29mW	40mW

5. CONCLUSION

A Bridgeless Boost rectifier for an AC LED driver is proposed in this paper. The proposed topology is combination of Boost and Buck-Boost topology. The Boost operation is performed by positive half cycle of input. The Buck-Boost operation is performed by negative half cycle of input. So proposed circuit operates for both cycle. In proposed topology only one inductor and one capacitor are required. Less passive components are used compare to conventional circuit. By doing so PF and THD of circuit significantly improved. We got PF>0.98 and THD<2%. Switching losses are dominant to the circuit at low level voltage application. So in future switching loss is main concern for this project.

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