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# Design and implementation of FPGA-based high power LED lighting system for ships

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Light emitting drive system used in ships induce less input side power factor with highly distorted line (AC) current which brings down the quality of AC power supply system. To suppress these limitations, futuristic ANFIS tuned PI controller operated modified SEPIC rectifier is designed and the effective analysis and results are presented in this paper. More desirable power quality is achieved with ANFIS tuned PI controller when compared with PI/fuzzy tuned PI controller in ship's LED light module. LED driver module of 48 V, 100 W power rating is built and its upgraded operating performance is accomplished by the execution of controller in FPGA Spartan–6 platform. The satisfactory result of 2.927%-line current harmonic distortion and supply side 0.9991 power factor (within IEEE-516 standard) is attained. Steady state study involving 0.09 s, rise time with zero overshoot is acquired.

**[Keywords:** Fuzzy logic controller; Light emitting diode; Power factor; Modified SEPIC rectifier; Total harmonic distortion; Anfis tuned PI controller]

## Introduction

In recent times, LED lamps are widely preferred in lighting technologies. Enhanced quality of light, highly stable, improved energy efficiency, long lasting features of LED find its applications in lighting of industrial buildings, street walkway lighting, and decorate/kitchen lighting[1,2,3,4]. Therefore LED lighting module substitute fluorescent lights and incandescent lamps. Low-cost development of ships is the key target of ship builders. They can achieve it by using LED lights for whole ships, since ships size and amount of light are directly propositional. Also, no hazardous elements are involved in LED. Increased



in turn minimizes the cost. Affirmation of more economic factor with money back of 150 million dollars is given by Navy with the implementation of LED lamp lights. Still having lot of merits, the driver system of LED lamps pollutes the AC power supply by injecting high harmonic content with poor supply side power factor due to the presence of switching components.

More researches have concentrated on effective design and construction of LED lights[5,6,7]. Yet few researches focused on power quality enhancement with the usage of LED driver system[8,9,10]. Nowadays, AC-DC converters with large gain for driver circuit of LED lamps are finding more attention of researchers. Traditionally, regulated DC output is obtained with the help of filter capacitors in AC source rectification[11]. Due to this rectification process, high peak current wave causes poor power factor at input, more harmonic content, deficient power factor etc[12,13]. These terrible distortions must be taken into account especially when multiple kind of loads/driven modules are supplied by a single source. Hence, pre-suppose of power factor correction is highly recommended[14,15]. Renewable energy applications involving SEPIC converter are able to generate very

pply[16]. Henceforth, it is recommended to operate single phase PWM rectifiers which should maintain source current THD and supply side power factor within the endorsed limits. For that purpose, control loops involving load voltage/inductor current wave shaping are used[17]. Modified SEPIC rectifier operating in continuous conduction mode produces less stress in comparison to typical SEPC rectifier. Here, further addition of capacitor and diode are involved in modified SEPIC converter for enhanced gain. This improved version of SEPIC converter suits well for operating LED driver to exhibit minimized harmonic distortion, improved power factor along with decreased ripple content of output voltage.

Prominent ANFIS tuned PI controller is apt for generating gate pulse for the controller. The automatic tuning of PI controller gain constants produces excellent steady state response[18,19]. Benefits of both neural and fuzzy are integrated in single unit which operates on Sugeno inference system. Optimization techniques like GA, PSO etc are adapted to tune gain parameters of PI widely used for controlling non-linear process[20,21]. Multilevel inverter is preferred for high voltage electric ship propulsion set-up[22]. Multilevel converter controlled by FLC is employed in marine LED lamp lighting[23,24,25]. This paper describes the eminent performance of modified SEPIC rectifier operated by ANFIS tuned PI controller along with traditional PI and fuzzy tuned PI controller. Efficient DC voltage regulation is achieved by all the above three voltage controllers and supply current is brought into good shape with the help of typical PI current controller. Comparative analysis is made for the results obtained for controller combinations operated modified SEPIC rectifier fed LED lamp driver.

## Organization of modified SEPIC fed LED Lighting Assembly for Ships

The schematic configuration of modified SEPIC fed LED driver is represented (Figure 1). The static gain of the converter is significantly uplifted with the help of $C_M/D_M$ (multiplier capacitor & diode).
The switches are designed to operate at 10 kHz frequency. Provided with the supply voltage of 16 V, the converter is designed to produce 100 W DC power with 48 V as output voltage. Undergoing continuous conduction mode operation, bi-operational modes are possible in this converter.

*Operating Mode (a)*

In this mode, MOSFET is turned OFF (Figure 2) and the LED driver is supplied from inductors ($L_{1i}$,$L_{i2}$). And also, $C_M$ gets charged through $D_M$ from the energy supplied from $L_{i1}$.

*Operating Mode (b)*

Mode (b) is represented (Figure 3) in which the power switch is turned ON. Both the diodes ($D_1$, $D_2$) got reverse biased and the LED driver is supplied from $C_{01}$. Here, inductors ($L_{i1}$,$L_{i2}$) gets charged from the supply. Design values of modified SEPIC LED driver parameters are given (Table 1).

## Modified SEPIC LED Drives Control Circuit

Schematic representation of modified SEPIC LED driver's control circuit is given (Figure 4). Voltage and current controller for modified SEPIC rectifier is chosen as ANFIS tuned PI controller and PI controller, respectively. Switching 'ON' and 'OFF' of MOSFET's can be controlled by gating pulse from the current controller. Current controller

Table 1 — Design values of modified SEPIC LED driver parameters

| | |
|---|---|
| AC supply voltage | 16 V |
| Operating frequency of MOSFET | 10 kHz |
| LED driver voltage | 48 V |
| LED driver current | 2 A |
| Power rating of LED driver | 100 W |
| Capacitor ($C_M$) | 16 µF |
| Inductances ($L_{i1}$, $L_{i2}$) | 1.5 mH |
| Series Capacitor ($Ci_1$) | 100 µF |

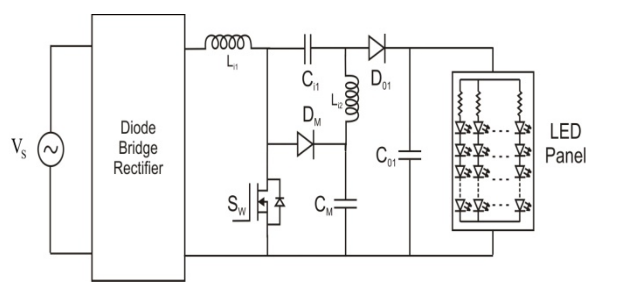


Fig. 1 — Arrangement of two-stage LED driver fed by modified SEPIC

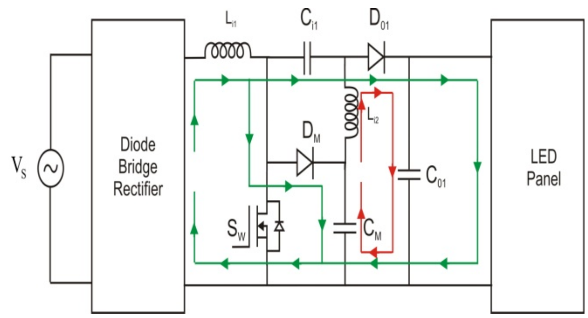


Fig. 2 — First mode of operation

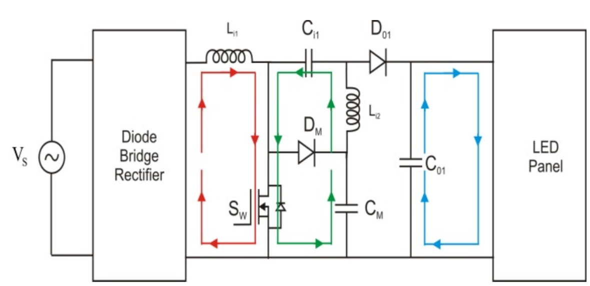


Fig. 3 — Second mode of operation

processes the error current signal, which is the deviation of actual current value from reference current value. ANFIS tuned PI output is magnified with rectified sinusoidal signal, which creates reference current. This control module is able to operate the converter effectively under steady state and dynamic conditions.

## Simulation Study and Analysis

(Figure 5) It is deduced that both the current and voltage waveforms are harmonic, free and flows with same phase and hence input power factor closer to unity is attained. It may be noted that THD of 1.12% is presented in AC source current (Figure 6). With the combination of ATPIC plus PI controllers, regulated LED driver voltage is obtained at the converter's output terminals (Figure 7). There is zero overshoot produced in the output waveform.

Figures 8a and 8b describe the analysis of LED driver performance with different levels of LED load power for three different combinations of controller (ATPIC-PI, FTPIC-PI, PI-PI). Among these, ATPIC-PI combination is proven to be the best by producing unity power factor with very less supply current harmonic distortions. At rated LED load power, THD of 1.12% and supply side power factor of 1 is achieved in addition to THD of less than 5% attained for different levels of LED load power (Figure 8a). Also, power factor is maintained almost nearer to unity for all levels of LED load power (Figure 8b).

The time domain specifications are measured and tabulated for different controllers (Table 2).

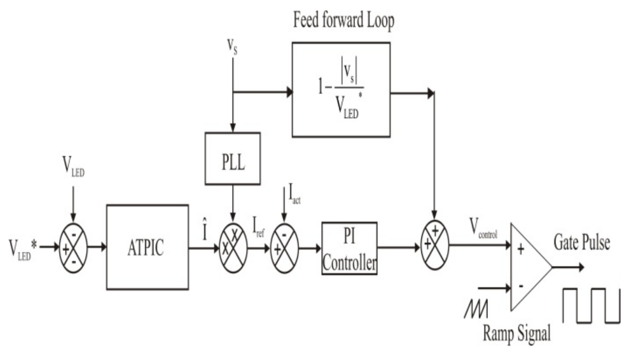


Fig. 4 — Schematic representation of modified SEPIC LED driver's control circuit

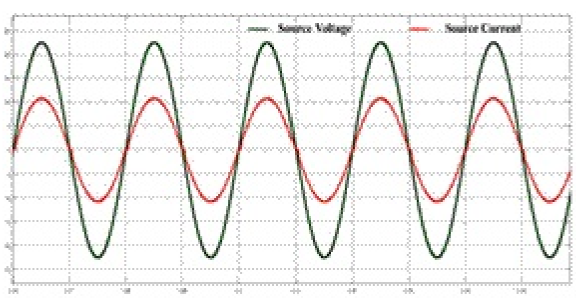


Fig. 5 — AC voltage/current waveforms of the proposed LED driver with ATPIC plus PI current controller

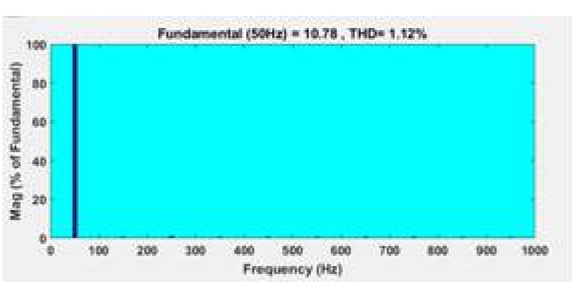


Fig. 6 — Input AC current's harmonic spectrum

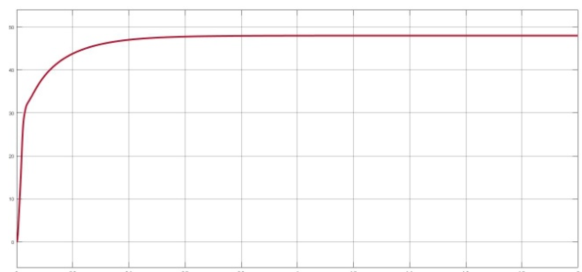

Fig. 7 — LED driver voltage waveform

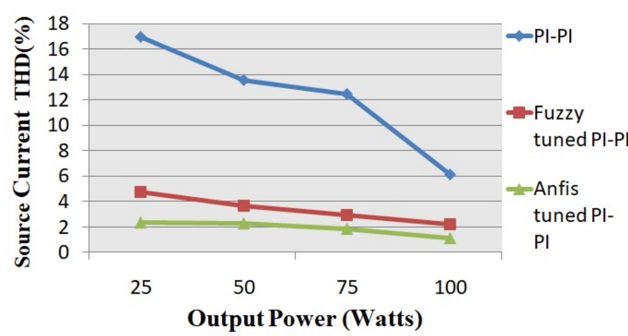


Fig. 8a — Analysis of LED driver performance with different levels of load power (THD)

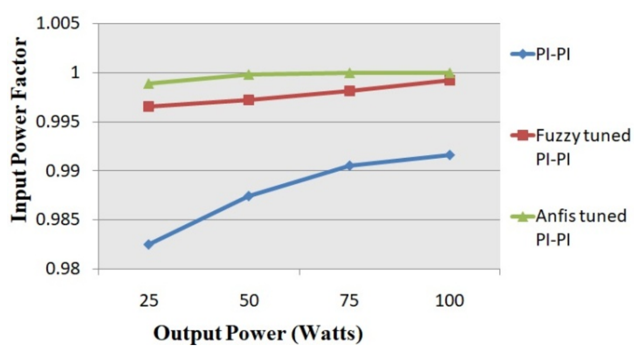


Fig. 8b — Analysis of LED driver performance with different levels of load power (Power factor)

## Real-Time Implementation of Modified SEPIC Rectifier Fed LED Driver

### *Hardware implementation and analysis of modified SEPIC LED driver*

Block diagram representation of hardware implementation (Figure 9). For investigation of results, ATPIC-based modified SEPIC LED driver is developed and tested in the laboratory (Figure 10). The ATPIC-PI controller is implemented using Xilinx software in FPGA platform.

The devices/components involved in the hardware assembly are IRF 250 switches, HCPL-7840 voltage sensor, WCS 2705 current sensor, MUR360 rectifier, and LED lamp 100 W. Performance of ATPIC plus PI current controller for modified SEPIC LED driver under rated and 25% of load power is depicted, respectively (Figure 11a and 11b). The corresponding THD values of 2.927% and 3.645% are obtained for rated and 25% of LED load power.

The experimental gate pulse and output voltage waveforms of ATPIC plus PI current controller for modified SEPIC LED driver under rated conditions is depicted (Figures 12 and 13). Comparative analysis chart for LED driver performance with ATPIC-PI controller under simulation and experimental study is provided (Figure 14). Comparative analysis chart for

Table 2 — Relative analysis between ATPIC, FTPIC and PI controllers operated modified SEPIC LED driver

| Controller | Rise time (s) | Peak overshoot (%) | Source current THD (%) | Power factor |
|---|---|---|---|---|
| Conventional PI controller | 0.7 | 2.08 | 6.14 | 0.9920 |
| Fuzzy tuned PI controller | 0.5 | 1.3 | 2.21 | 0.9992 |
| Pioneer ANFIS tuned PI controller | 0.09 | - | 1.12 | 1 |

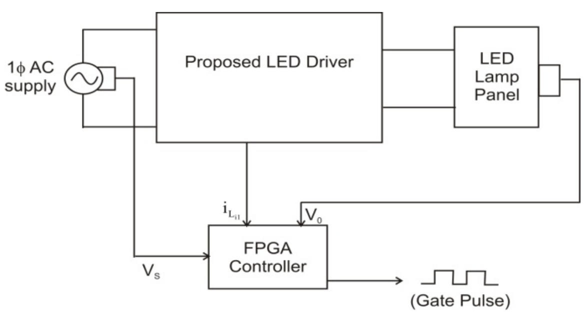


Fig. 9 — Hardware block diagram

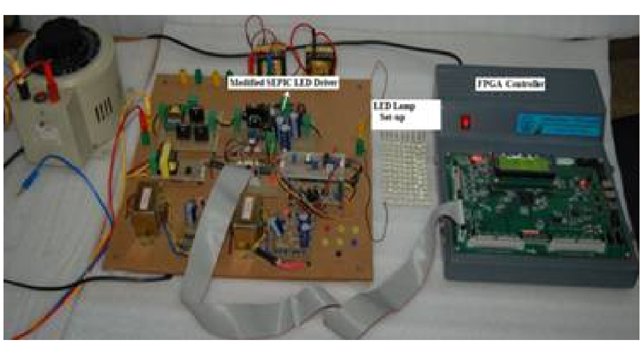


Fig. 10 — Modified SEPIC based LED driver implemented in laboratory

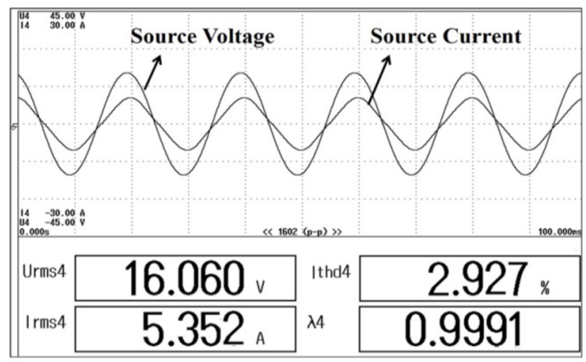


Fig. 11a — Power quality investigation along with supply current-voltage waveforms for rated LED load power

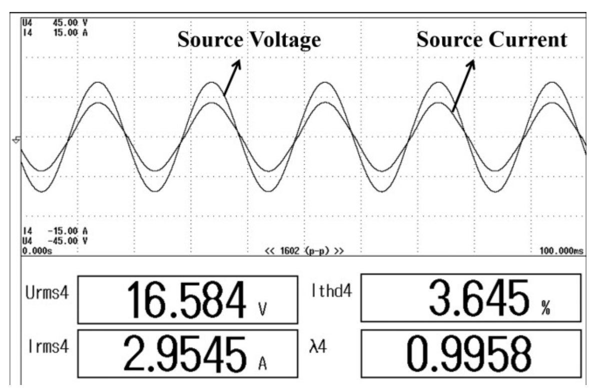


Fig. 11b — Power quality investigation along with supply current-voltage waveforms for 25% LED load power

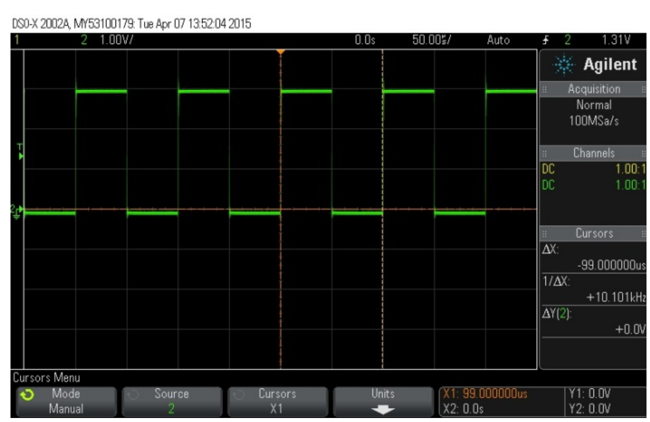


Fig. 12 — Experimental gate pulse waveform

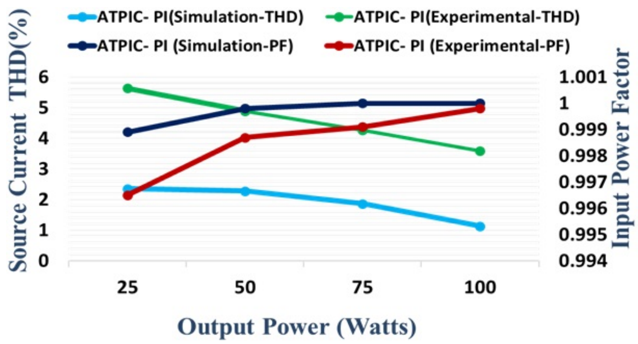


Fig.14 — Comparative analysis of LED driver performance with different levels of load power

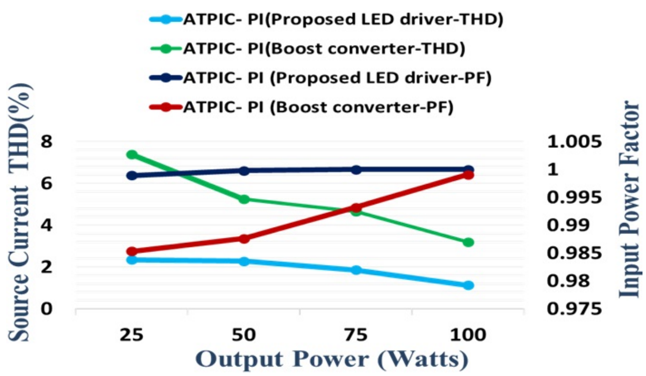


Fig. 15 — Comparative analysis of LED driver performance with conventional boost converter

proposed LED driver performance with the conventional boost converter is depicted (Figure 15).

## Conclusion

Key features of LED light module like usage of non-hazardous material, long lasting nature, high luminous intensity, and limited consumption fuel are taken into account and the LED driver is positioned in ships for supplying light to entire cruiser. Improved power quality, well-regulated DC load voltage, better values of time domain specifications are achieved while using modified SEPIC LED driver for ships operated by ANFIS tuned PI controller. Typical PI and fuzzy tuned PI controller-based modified SEPIC rectifier also simulated and the results compared with the prominent ANFIS tuned PI based modified SEPIC rectifier. The prime ANFIS tuned PI controller based modified SEPIC fed LED driver is implemented in hardware (FPGA Spartran-6) platform and the better result of 2.927% THD with input power factor of 0.9991 is achieved for marine LED lighting.

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