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Buck Converter Based LED Driver

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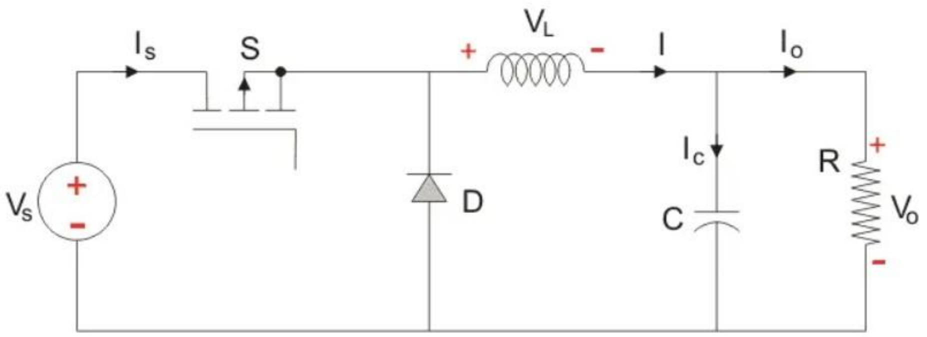
I. Introduction

Nowadays there are two groups of converters used for driving LEDs - converters with and without a transformer. The total efficiency and mass/volume parameters are better for AC/DC/DC drivers without a transformer. Conventional voltage mode control and the peak-current mode control are analyzed in order to compare its output current ripple responses. A practical comparison of circuit topologies suitable for passive LED drivers is presented in with energy efficiency of 92–94 % at 50 W consumption.

Dimmable light-emitting diode (LED) driver with adaptive feedback control is introduced in suitable for low-power lighting applications. The converter is applicable for street, home, and automotive lightning applications. Two topologies for LEDs Street lighting are investigated and high-power factor is reported. The converters are supplied with an alternative source (battery) during the peak load time. A two-stage LED driver achieving high efficiency over a wide load range is based on a buck converter as the first stage and a multichannel constant current CLL resonant converter as the second stage. A novel bias supply scheme for LED controller is considered based on buck converter.
A typical Buck converter is shown below.

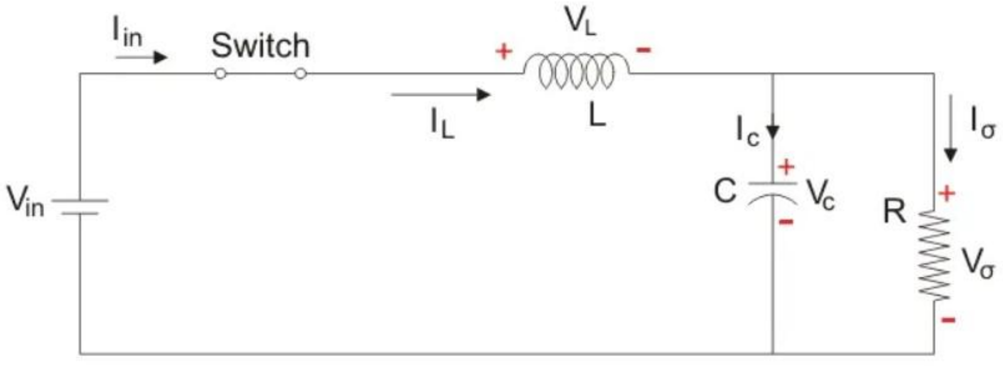


The input voltage source is connected to a controllable solid-state device which operates as a switch. The solid-state device can be a Power MOSFET or IGBT. Thyristors are not used generally for DC-DC converters because to turn off a Thyristor in a DC-DC circuit requires another commutation which involves using another Thyristor, whereas Power MOSFET and IGBT can be turned off by simply having the voltage between the GATE and SOURCE terminals of a Power MOSFET, or, the GATE and COLLECTOR terminals of the IGBT go to zero.

The second switch used is a diode. The switch and the diode are connected to a low-pass LC filter which is appropriately designed to reduce the current and voltage ripples. The load is a purely resistive load.

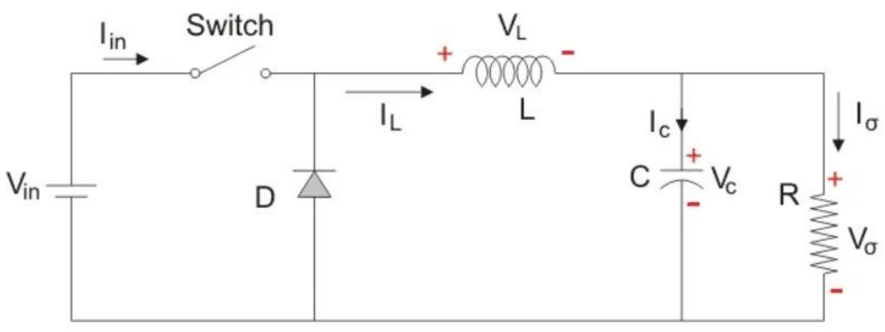
The input voltage is constant and the current through load is also constant. The load can be seen as current source.

The Buck converter has two modes of operation. The first mode is when the switch is on and conducting.
Mode I: Switch is ON, Diode is OFF:



The voltage across the capacitance in steady state is equal to the output voltage.
Let us say the switch is on for a time TON and is off for a time TOFF. We define the time period, T, as
$T = T_{ON} + T_{OFF}$
and the switching frequency,
$f_{switching} = \frac{1}{T}$
Let us now define another term, the duty cycle,
$D = \frac{T_{ON}}{T}$
Let us analyse the Buck converter in steady state operation for this mode using KVL.
$\therefore V_{in} = V_L + V_0$
$\therefore V_L = L\frac{di_L}{dt} = V_{in} - V_0$
$\frac{di_L}{dt} = \frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{DT} = \frac{V_{in} - V_0}{L}$

Since the switch is closed for a time TON = DT we can say that Δt = DT.
$(\Delta i_L)_{closed} = (\frac{V_{in} - V_0}{L})DT$
Mode II: Switch is OFF, Diode is ON:
Here, the energy stored in the inductor is released and is ultimately dissipated in the load resistance, and this helps to maintain the flow of current through the load. But for analysis we keep the original conventions to analyse the circuit using KVL.



Let us now analyse the Buck converter in steady state operation for Mode II using KVL.
$\therefore 0 = V_L + V_0$
$\therefore V_L = L\frac{di_L}{dt} = -V_0$
$\frac{di_L}{dt} = \frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{(1-D)T} = \frac{-V_0}{L}$

Since the switch is open for a time
$T_{OFF} = T - T_{ON} = T - DT = (1-D)T$
we can say that Δt = (1- D)T.
$(\Delta i_L)_{open} + (\frac{-V_0}{L})(1-D)T$

It is already established that the net change of the inductor current over anyone complete cycle is zero.

$\therefore(\Delta i_L)_{\text{closed}} + (\Delta i_L)_{\text{open}} = 0$

$(\frac{V_{in} - V_0}{L})DT + (\frac{-V_0}{L})(1\text{-}D)T = 0$

$\frac{V_0}{V_{in}} = D$

Now, an LED driver is a self-contained power supply which regulates the power required for an LED or array of LEDs. The light emitting diodes are low energy, lighting devices with a long lifespan and low energy consumption, hence the requirement for specialized power supplies.

LEDs require drivers for two purposes:

1. LEDs are designed to run on low voltage (12-24V), direct current electricity. However, most places supply higher voltage (120-277V), alternating current electricity. An LED driver rectifies higher voltage, alternating current to low voltage, direct current.
2. LED drivers also protect LEDs from voltage or current fluctuations. A change in voltage could cause a change in the current being supplied to the LEDs. LED light output is proportional to its current supply, and LEDs are rated to operate within a certain current range (measured in amps). Therefore, too much or too little current can cause light output to vary or degrade faster due to higher temperatures within the LED.

In summary, LED drivers convert higher voltage, alternating current to low voltage, direct current. They also keep the voltage and current flowing through an LED circuit at its rated level.

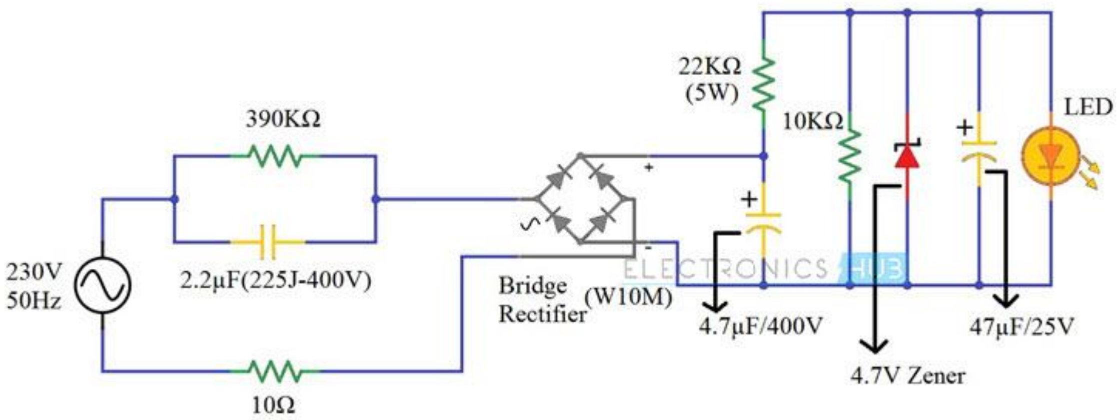
LED Driver Circuit Principle

The basic principle behind the 230V LED Driver circuit is transformer less power supply. The main component is the X-rated AC capacitor, which can reduce the supply current to a suitable amount. These capacitors are connected line to line and are designed for high voltage AC circuits.

The X – Rated Capacitor reduces only the current and the AC voltage can rectified and regulated in the later parts of the circuit. The high voltage and low current AC is rectified in to high voltage DC using a bridge rectifier. This high voltage DC is further rectified using a Zener diode to a low voltage DC.

Finally, the low voltage and low current DC is given to an LED.

LED Driver Circuit Diagram



Advantages

- With the help of this LED Driver Circuit, we can drive LEDs directly from the main supply.
- This project is based on a Transformer Less Power Supply. Hence, the final build won't be a large one.

Applications of LED Driver Circuit

1. This circuit can be used for home lightening systems.
2. It can be used as an indicator circuit.
3. One can fix this circuit with the doorbell to give indication.

Limitations of LED Driver Circuit

1. Since 230V AC supply is being directly used here, this circuit can be dangerous.
2. This circuit is best suited for domestic applications using single phase supply. This is because, in case of three phase supply, if any of the phases accidently touches the input terminal, it can prove to be quite dangerous.
3. The capacitor can produce spikes at mains fluctuations.

II. Objective

This Project studies a buck converter-based LED driver with a current control method. A wide input voltage range is considered as well as the power factor of the circuit. To improve the efficiency soft switching conditions are provided. Simulations and experimental investigation are carried out to obtain the converter performance relations. An advanced inductor design is applied in order to reduce the eddy current losses in windings due to air gap fringing field. Combined Litz wire - full wire approach is considered to reduce the effect of air gap fringing field. Experimental results and measurements confirm the simulation results and performance of the investigated converter.

III. Literature Review

The expeditiously growing internet has opened new horizons for development in various fields. It has become a topic of interest of many people around the globe.

The purpose of the optimization of a dc-dc buck converter is to guarantee the output parameters of the device. This produces better quality converters than those with conventional design methods. Initially, a tolerance analysis was used to understand the influence of the circuit element's tolerances on the characteristics of the circuit. Then, based on the mathematical model, optimization has been carried out with a certain reference curve to obtain improved values of the circuit elements. The comparison with the influence of the tolerances of the circuit elements in optimization and non-optimized scheme is made. Switched-mode dc-dc converters are used to regulate dc voltages or currents at a certain desired level. Due to inherent switching action, currents and voltages in the circuit tend to oscillate around a given average value, as the output values present some ripple in steady-state condition. The low-frequency output current ripple (OCR) is a key parameter for design considerations when a light-emitting diode (LED) string load is considered. In order to compare their ripple magnitudes under distinct conditions regarding a buck-based LED driver operating in continuous conduction mode (CCM), this paper analyzes the conventional voltage mode control as well as the peak-current mode control in order to compare its OCR responses by the classical control theory. The methods are implemented considering the same control bandwidth so that a proper comparison can be established.

A practical comparison on a range of circuit topologies suitable for passive LED drivers. These circuits consist of passive components and do not require any semiconductor-controlled switches, auxiliary power supply and control integrated circuits. The power loss components, the energy efficiency and the output current ripple are examined. These passive LED drivers are particularly suitable for outdoor applications such as street lighting in which extreme weather conditions including lightning and wide temperature range, and maintenance issues are major concerns but the size of the LED drivers is not critical. With extremely simple and reliable circuitry, these passive LED drivers achieve remarkably high energy efficiency. Energy efficiency of 92-94% has been achieved for LED systems of 50W in this study.

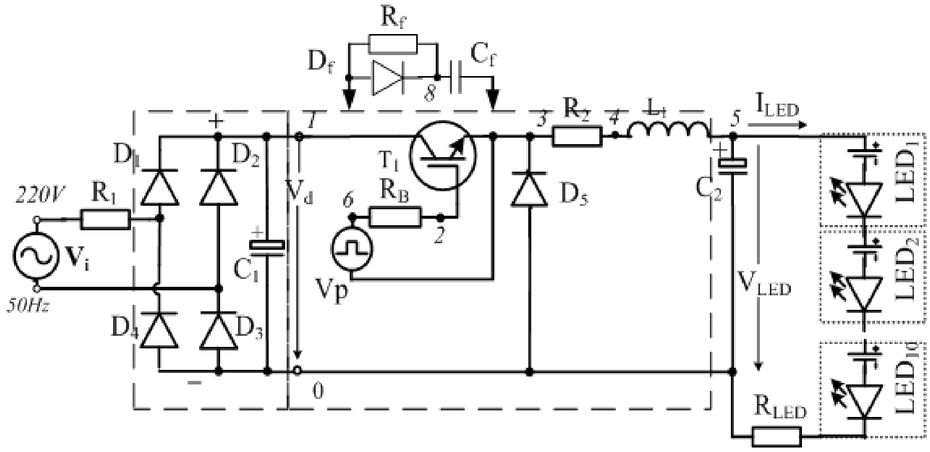
IV. Methodology / Description Of The Project

The purpose of the current Project is to investigate the performance main indicators of an industrial unregulated AC/DC/DC converter without transformer in nominal operational mode and the deviations (improvements) based on it in order to verify the quality indicators and search for solutions to improve them.

The tasks to be solved are:

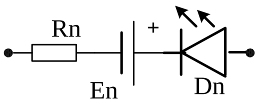
1. Choosing a mass production LED illuminant with built in buck converter.
2. Creating a laboratory setup and investigation of the selected sample.
3. PSIM simulation of equivalent circuit of the selected driver circuit.
4. Analysis of the results and investigation of improved circuits.

V. Block Diagram / Circuit Diagram:



Investigated converters for driving LEDs

The investigated LED illuminant consists of 18 high-power diodes that are connected in series. The LED bulb type is bubble ball bulb. The equivalent schematic of the illuminant is acquired from. It consists of a diode D_n, voltage source E_n (48 V) and resistor Rn (3 - 4 Ω). This equivalent schematic explains the obtained current and voltage values of the examined LED illuminant that acts like a non-linear element.



The investigated simulation model consists of 3 parts with different functions:

- I part – grid rectifier with smoothing capacitor;
- II part – DC/DC buck converter;
- III part – equivalent schematic of LED illuminant.

The duty ratio δ range of variation is defined by:

$\delta=\frac{U_{LED}}{U_D}$ =48/310=0.16 -(1)

The elements from the simulation model have the following values:

- Transistor Z1 - IXGH40N60A
- R1 = 0,1 Ω,
- C1 = 1 µF,
- R2 = 0.2 Ω,
- L1 = 435 µH,
- C2 = 10µF,
- VLED = 50 V,
- f_{op} = 50 kHz.

The auxiliary group elements have the following values:
R_f= 30 Ω, C_f = 0.030 µF
and D_f is a fast Schottky diode.

DETAILS OF COMPONENTS REQUIRED
FOR MAIN CIRCUIT:

- AC Voltage source
- Resistance
- Diodes
- Capacitors
- Inductor
- Transistor
- Pulse Generator

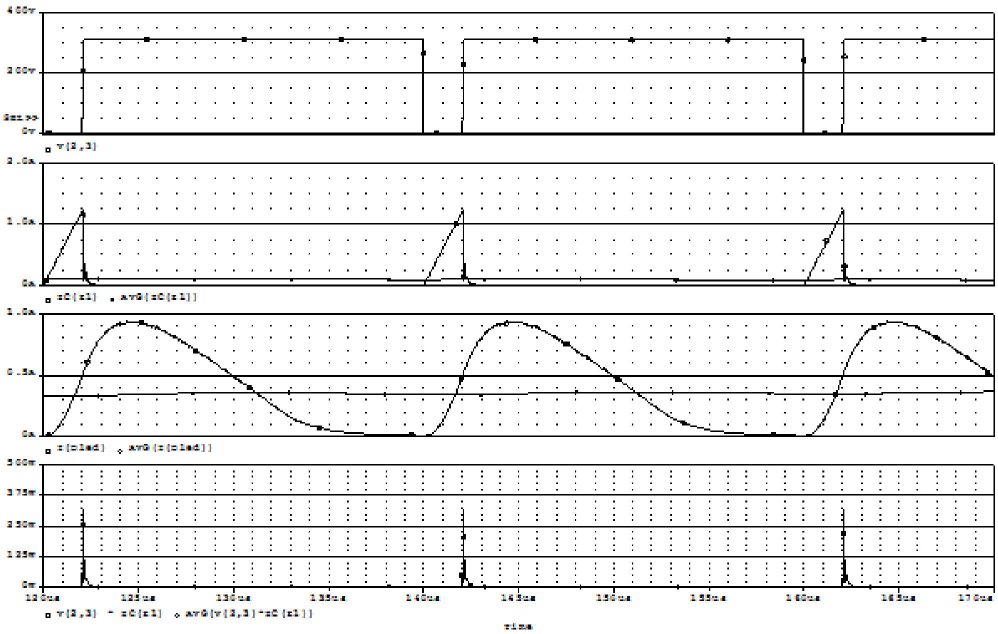
- LED Drivers

FOR FEEDBACK CIRCUIT:
- Resistance
- Fast Schottky Diode Diode
- Capacitor

FOR SIMULATION:
- PSIM SOFTWARE

RESULTS and OUTPUT

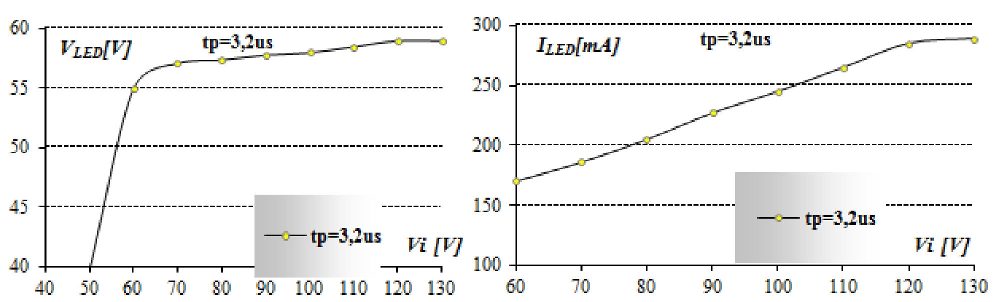
Operating diagrams of the buck converter (simulations), voltage across the switch, diode current, average load current, switching losses of the transistor without feedback



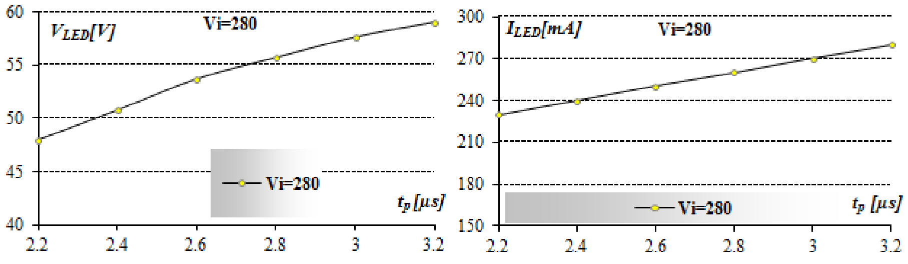
The results from the simulation of the investigated power converter for LED illuminant are given in Figure above:
transistor T1 voltage and current U_{ec} = 310V, I_C = 1.2A,
load current and average current value I_{LEDavg} = 280 mA.

RESULTS and OUTPUT

Voltage V_{LED} and current I_{LED} of the LED as a function of the input voltage RMS value, V_i



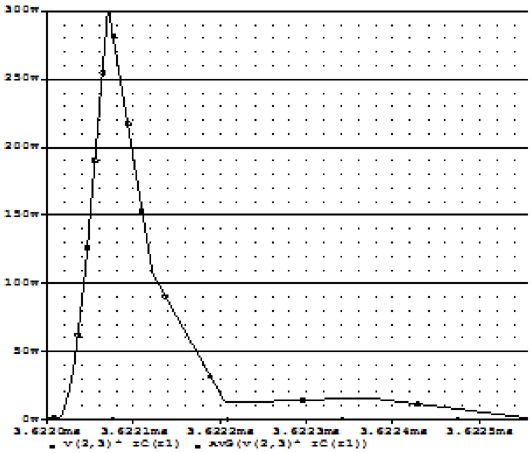
Voltage V_{LED} and current I_{LED} of the LED as a function of the ON interval of the transistor (t_p)



The simulation results for the studied LED parameters at voltage range 0 to 240 V are given in figures above. The presented results lead to the following 4 conclusions:

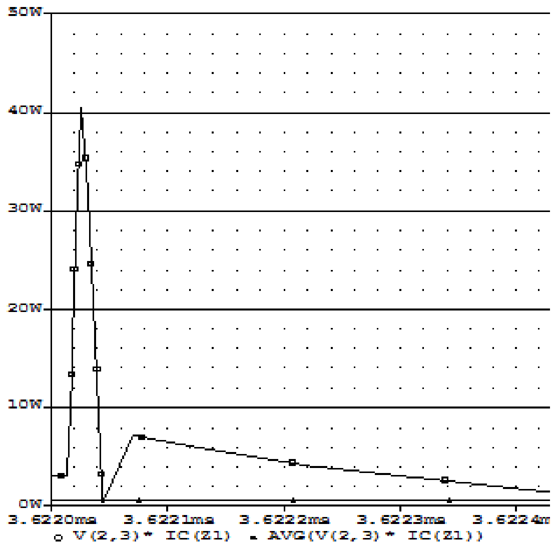
1. The LED voltage and current variations are observed for the input voltage range 50 - 120V because the buck converter output is stable in the range 120 - 240 V.
2. The regulation of the light flux is outside the stabilization range of the DC/DC converter and is in a narrow range.
3. The investigated converter has increased switching losses when turning off the transistor.
4. The Power factor cosφ of the converter depends on the selection of proper values of the reactive elements of the AC/DC/DC converter.

RESULTS and OUTPUT



Transistor switching losses without an auxiliary circuit

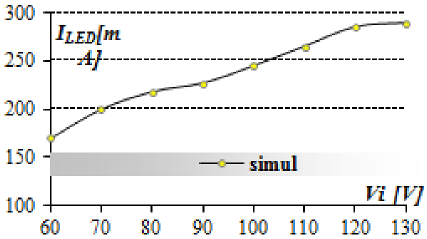
Transistor switching losses with an auxiliary circuit - obtained soft switching



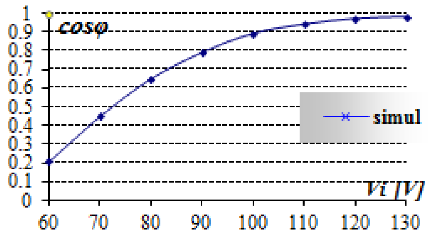
RESULTS and OUTPUT

U_i	*[V]*	60	70	80	90	100	110	120	130	140
U_d	*[V]*	*57*	*57.7*	*57.9*	*58*	*58.2*	*58.4*	*58.7*	*58.7*	*58.7*
I	*[mA]*	170	210	210	220	230	240	260	260	260
Light	*[Lux]*	1140	1250	1250	1600	2000	2500	3000	3600	3600
cos□		0.21	0.7	0.8	0.84	0.88	0.94	0.98	0.98	0.98
P	*[W]*	9.7	12.1	12.2	12.8	13.4	14.0	153	15.3	15.3

SIMULATION RESULTS, LOW SUPPLY VOLTAGE



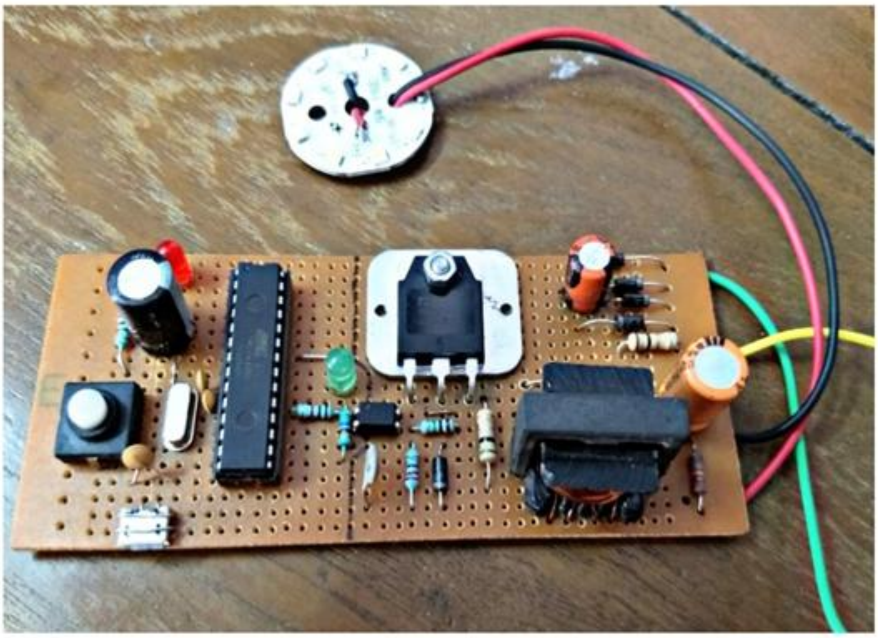
Current I_{LED}, measurements and simulations



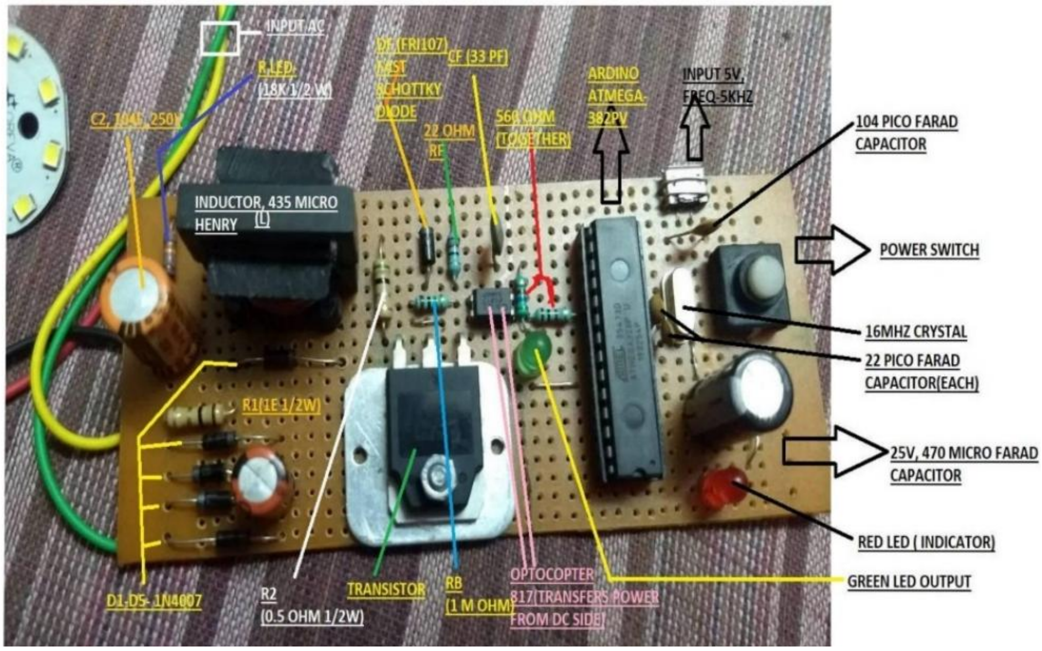
Measured and simulations obtained power factor (cos□) of the total LED driver circuit

PHOTOGRAPH OF ACTUAL PRODUCT:

HARDWARE CIRCUIT:



CIRCUIT WITH VALUES:



VI. Conclusions And Future Scope

This paper studies a buck converter used for LED driver with a current control method. A wide input voltage range is considered as well as the power factor of the circuit. Further improvement of PF (power factor) can be obtained by reducing the input filter capacitor value.

To improve the efficiency soft switching conditions are provided. An auxiliary circuit including components R_f, C_f, D_f is used to obtain soft switching conditions for the power switch, thus reducing the switching losses more than 2 times.

Experimental measurements confirm the simulation results and performance of the investigated converter concerning the efficiency, power factor (cosφ) and flux of the studied LED driver circuit.

Acknowledgement

We would like to express our gratitude to our mentor Mrs. Sukanya Dasgupta as it would not have been possible without her kind support and constant inputs to complete this project. We are highly indebted to our departmental teachers for their guidance and constant supervision as well as for providing necessary information regarding the project and also for their support in completing the project

We would like to express our sincere regards to our Head of the Department, Dr. Sujit Kumar Biswas for letting us to do this project where we got to know the functioning of every component involved and also helped us to formulate a systematic approach to a problem guided by empirical formulae and practical guidelines.

Last but not the least our regards and appreciation also goes to our colleagues, friends and parents in developing the project who have willingly helped us out with their abilities and encouragement.

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