

# **PHOTOVOLTAIC POWERED COMMERCIAL LED LIGHTING SYSTEM**

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IN  
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SUBMITTED BY:

**ABHISHEK NEEM**

**Roll No- 2K12/C&I/033**

UNDER THE SUPERVISION OF

**DR. DHEERAJ JOSHI**



**DEPARTMENT OF ELECTRICAL ENGINEERING**

**DELHI TECHNOLOGICAL UNIVERSITY**

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

INDIA

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# **DEPARTMENT OF ELECTRICAL ENGINEERING**

## **DELHI TECHNOLOGICAL UNIVERSITY**

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

INDIA

### **CERTIFICATE**

I, Abhishek Neem, Roll No. 2K12/C&I/033 student of **M.Tech. (Control and Instrumentation)**, hereby declare that the thesis titled “**PHOTOVOLTAIC POWERED COMMERCIAL LED LIGHTING SYSTEM**” under the supervision of Dr.Dheeraj Joshi of Electrical Engineering Department Delhi Technological University in partial fulfilment of the requirement for the award of the degree of Master of Technology has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

**ABHISHEK NEEM**

Place: Delhi

Date:

**Dr. DHEERAJ JOSHI**

**SUPERVISOR**

Associate Professor

Department of Electrical Engineering

Delhi Technological University

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Place: Delhi

Abhishek Neem

Date:

M.Tech(C&I)

Delhi Technological University

## **ABSTRACT**

In this thesis the hardware prototype for solar powered LED lighting system is developed. Output of a Sepic convertor is regulated in closed loop for battery charging applications. The variation of output voltage is done by controlling the MOSFET using pulse width modulation (PWM) technique. The switching action of MOSFET is controlled by the Arduino microcontroller, which controls the duty ratio of MOSFET switch and consequently the convertor output voltage. The closed loop control is used having varying input and load conditions of the circuit.

Proteus 8.2 is used for the simulation purpose. Experimental results validate the simulated results in open as well as closed loop control of Sepic converter.

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## LIST OF SYMBOLES AND ABBREVIATION

S. NO	Symbol	Abbreviation
1	Gate	PWM out
2	$Fb$	Feedback to controller
3	$I_p$	Fault indication
4	$D$	Duty Cycle
5	$F_s$	Switching Frequency
6	$Q_{GD}$	Gate drain charge
7	$V_{TH(MIN)}$	Minimum threshold voltage
8	$R_{DS(ON)}$	Mosfet ON resistance
9	$V_{DS(MAX)}$	Maximum drain to source voltage

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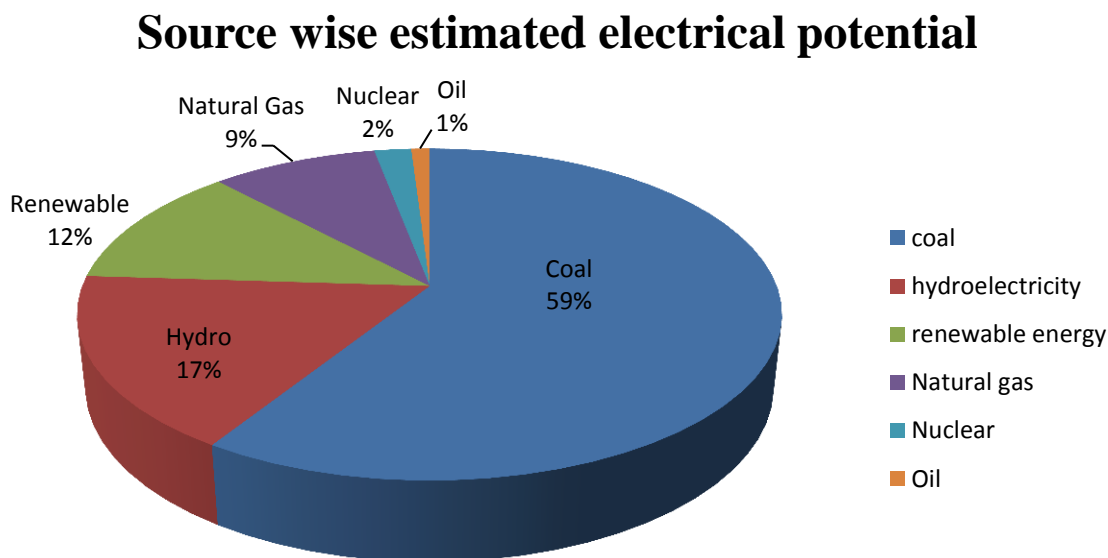
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# CHAPTER 1

## INTRODUCTION

### 1.1 General

India with the world's second largest population and fourth in terms of purchasing power is a rapidly emerging economy. India is sufficient in amount of primary energy sources such as fossil, renewable and other new energy sources. The share of coal is the highest in power sector industries and also in country's electricity mix with a robust 59% share, followed by hydroelectricity at 17%, Renewable energy at 12%, Natural gas at 9% and the remaining part is contributed by nuclear energy and oil which stands at 2% and less than 1% respectively. The distribution of the consumption patterns and production profile do not match in terms of primary sources, creating concerns about energy security. **Figure 1.1** shows the source wise estimated electricity potential.



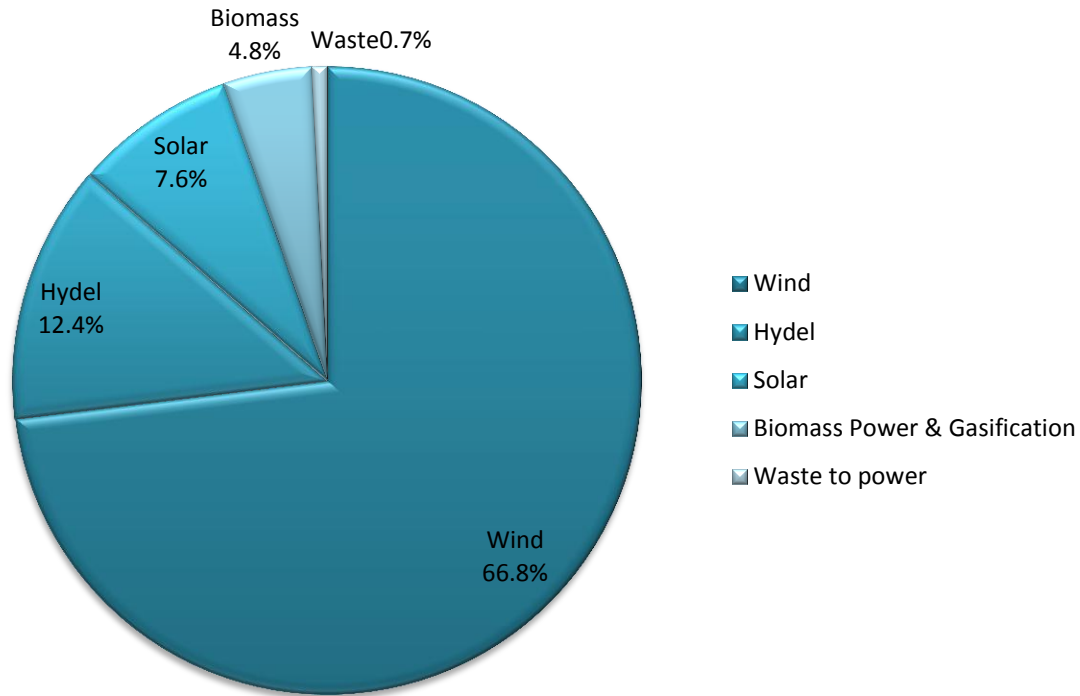
**Fig.1.1 Share of Different Energy Sources**

India's total electricity consumption per capita is around 778 KWh, and is much less than other countries or places in the world. About 80% of Indian rural areas are said to be getting electricity supply but in real terms around 33% houses in rural areas and around 6% of the urban areas do not get frequent electricity supply.

The energy demand is increasing day by day and non-availability of conventional sources for meeting the power demand day is increasing and causing great concern towards power sector. The non-stop exploitation of fossil fuels has resulted in huge reduction in their deposits and has led to increased global warming. Therefore, due to these global situations there has been an increase in demand of renewable sources of energy to be developed apart from conventional sources of energy to meet the power demand. Non-conventional energy sources like wind energy and solar energy are the most effectively utilized in this context. The photo Voltaic energy source is the vast energy resource that is a clean power and is gaining much significance as the world is shifting towards greener source to meet its power demand.

Out of the total 31,151.03 MW non-conventional power installed in India, 66.8% is shared by wind energy. Next major source of renewable energy is hydro power, which constitutes nearly 12.4% of total installed renewable energy. With huge potential & around 7.6% share of total installed renewable energy, solar power stands 3<sup>rd</sup> most important source of renewable energy in India. Other notable sources are power through biomass and waste as shown in **Fig.1.2**.

## Total Renewable Power-31,151.03 MW

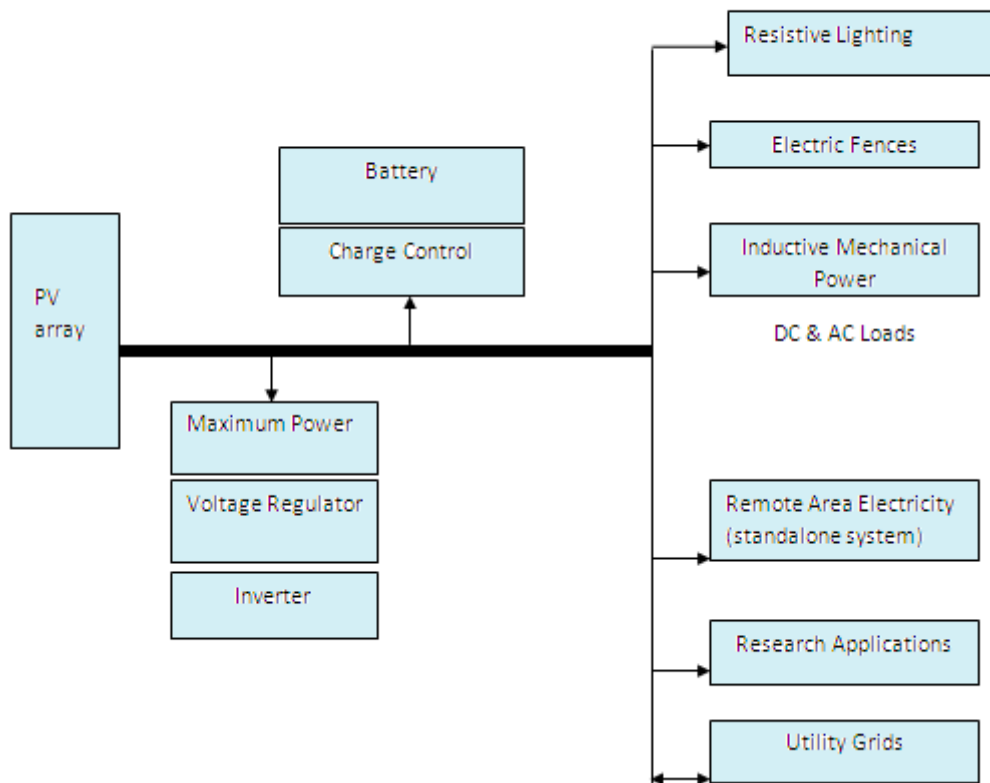


**Fig-1.2 Share of different Renewable energy sources**

India is blessed with abundance of solar energy if used in an efficient way, India's energy demands can be met to a great extent without much effort. On a regular sunny day, solar illumination is more than  $980\text{w/m}^2$  over Indian subcontinent. India is trying hard for increasing the % share power or electricity generation through non-conventional sources every year and has expected to reach to 16% by 2022. India's power sector is having a huge gap in demand and supply which can be easily met if various changes in current setup are made and emphasis is on greener sources of power generation is done.

Electrical power generation through solar or photovoltaic process is the process of converting light energy from sun, into electricity, based completely on solid state materials (i.e. semiconductors). This form of energy generation is cleaner and greener source of energy as there is no fuel required and pollutants are also not emitted. There are no rotational losses as there are

no moving parts. They can either be separate generation unit or can be grid connected generation unit (Distributed Generation). This depends on whether the nearby grid is available or not. Another major advantage of using solar power is the portability of plant wherever and whenever operation is required and least affected by environmental factors like snow, winds etc. However they do not produce electricity on cloudy days or during night, then other energy sources can be switched at that time.



**Fig-1.3 PV System Configuration**

## 1.2 PV system configuration-

**Fig-1.3** shows typical PV system. The system can be distinguished based on several factors like- depending on load type, i.e. AC or DC, depending on utility stand alone or grid connected system. Inverter configuration is mainly used for AC systems. Battery is used to deal with fluctuations and during non-availability. In order to tackle the present day energy crisis and



relatively high cost of photovoltaic generator, we have to modify the system in a manner such that maximum energy can be pumped out from solar radiations. Features such as low cost, and high energy efficiency convertor to enable its development where it is most needed. In this thesis work, we have thrown light on how the DC (direct current) current produced by the photovoltaic cell or array can be easily utilized to drive different types of electric loads. The simplest and least expensive way to convert solar energy to mechanical energy is to supply a DC motor from photovoltaic generator because they output DC (direct current). Since power generated by the Photovoltaic cells varies with the intensity of sun's rays falling on the panel, it must be used for charging the battery and then the battery should be used to drive the load. In recent development in led technology, led lights driven by its driver circuit and DC output from the converter have emerged in the market.

### **1.3 Thesis objective**

In this thesis work, we present a solar powered buck-boost converter with sepic topology with closed loop control for different type of domestic and commercial applications. The main characteristics of the work done in this thesis are as follows.

- 1) The correspondence between the PV system and AC and DC loads, power leds are examined as load.
- 2) Atmospheric non-uniform conditions perform a major role in power generation from PV module and it makes difference to the functioning of both DC and AC loads. To achieve this purpose, a closed loop microcontroller controlled buck buck-boost converter is designed which automatically adjusts the duty cycle of the converter to obtain constant voltage at the output to obtain maximum power from the PV module at varying atmospheric circumstances.
- 3) Designing of the sepic buck-boost converter is being is done in this thesis work, whose switching can be controlled by varying the duty ratio, in accordance with the output voltage reference.
- 4) Capacity of the circuit to practice the maximum switching pulse and load parameters.

### **1.4 Thesis outline**

The chapter wise description of this dissertation is given as under:

**Chapter-I** Gives the introductory view of the overall work that has been presented in this thesis.

**Chapter-II** Presents brief literature review of the PV fed system.

**Chapter-III** Discusses the main theory behind the work, details of different types of DC-DC converters have been discussed in detail.

**Chapter-IV** Presents system design and control scheme of the overall system.

**Chapter-V** Presents the modeling and analysis of the system.

**Chapter-VI** Presents the simulation, modeled and experimental results.

**Chapter-VII** Gives the main conclusion and future scope of the work.

# **CHAPTER II**

## **LITERATURE REVIEW**

### **2.1 General**

From the available literature, it is revealed that photovoltaic module can easily be used with a DC-DC converter for commercial and industrial use, the use of specific closed loop controllers has been used for enhancing the output power of the module which affects the performance of the system for a specific application. Arduino microcontroller is used here for generating and varying the duty cycle of the sepic converter in closed loop.

Sepic converter used is having minimum switching losses. Dedicated simulation software like Proteus professional has made the modeling and simulation of the system efficient and simple.

### **2.2 Literature review**

#### **2.2.1 Photovoltaic system-**

The complete thesis work can be sub divided into three works-understanding and selection of photovoltaic system, designing and modeling of sepic converter and selection of DC loads for the system. The existing literature survey available on understanding and selection of photovoltaic System, which is well described in the following works-

Analyzed the electrical circuit model of PV panel[1], it can be seen that solar output current depends mainly on solar irradiation, it also has discussed that Photovoltaic voltage is the function of junction voltage across the diode which is basic characteristic of the semiconductor.

Discussion on PV efficiency as a function of operating temperature of photovoltaic module (one sun commercial grade silicon-based solar cells/modules) [2].The efficiency and the output power of the photovoltaic is inversely proportional on the operating temperature.

Effect of light intensity on electron collection of Photovoltaic cells [3]. It shows that current is diminished in thin film cells under intense solar radiation due to increased recombination.

DC-DC/ DC-AC converter is used for converting solar power produced to AC system [4], which reduces the size of topologies comparatively. The losses are also reduced to great extent.

Step by step mathematical modeling of Photovoltaic Module with Simulink [5], which helps to have better viewpoint of I-V and P-V curve.

Tarak Salmi discussed on a Matlab/Simulink model of PV cell [6]. He has also discussed briefly the effect of varying Temperature, effect of varying series resistance of the cell  $R_s$ , effect of varying shunt resistance  $R_{sh}$  and effect of varying  $I_s$ . He has also discussed how PV cells can be connected to form module and then an array.

Patil Sahebrao N has presented a complete model of the PV system containing solar PV cell, DC-DC converter and MPPT control using Incremental Conductance method is simulated in Matlab [7]. The modeled DC-DC buck boost converter along with MPPT can be used as a reference for implementation of actual system. PWM signal generation is also discussed, that is used to control the duty cycle of converter.

### **2.2.2 Literature Review on DC-DC converters and their control-**

Veera Chary Mummadi has discussed the transient and steady state characteristics of DC motor solar powered [8] simple boost converter used for stepping up the DC voltage level.

P.Muthukrishnan & R.Dhanasekaran have discussed DC-DC boost converters with new coupled inductor for the solar power applications and by adjusting the turn's ratio of the coupled inductor and varying the capacitor with proper rating of all the parameters [9]. By this approach, converters with higher output voltage can be designed with smaller converter circuit.

Athira K Rajan, Rajan P Thomas & Neena Mani has proposed a bridgeless SEPIC converter with ripple-free input current. In this converter the input full-bridge diode is eliminated [10]. With the proposed gate driving method, the efficiency is improved.

Soumya Ranjan Behera & Thabir Kumar Meher has proposed the design of single ended primary inductor DC-DC converter [11] in continuous conduction mode. Sepic converter equations and component ratings with design specifications have been discussed [12]. Steady state analysis and simulation has been proposed by Texas Instruments [13].

Benefits of a coupled-inductor converter for sepic converter are discussed [14]. It shows how by varying the turn ratio of coupled inductor can result in variable output voltage, also it reduces the overall size and cost of the converter. The individual value of inductance needed in sepic converter is reduced to half by using coupled inductor. Comparison between coupled and non-coupled inductors has been shown.

A. Kalirasua, Shubhransu Sekhar Dashba has shown the implementation of an Embedded Controlled High Efficiency Improved Boost Converter for Solar Installation System [15]. By implementing the pulse width modulation (PWM) techniques on the boost converter, a stable output voltage from a non-stable input voltage can be obtained by changing the duty cycle of the switched input pulse.

Aditi Bajpai and Arvind Mittal has discussed solar powered DC to DC buck-boost converter [16] which can work in both buck mode and in boost mode according to the requirement with MPPT control and also by minimizing the losses in the converter.

Dr. B.J. Ranganath and Mr. Amurth R.T has proposed a DC/DC Buck-Boost Converter Charge Controller for Solar Power Applications [17]. The concept of buck-boost converter is implemented to extract the maximum power from solar panel during all-weather condition and Pulse Width Modulation (PWM) technique to achieve constant voltage battery charging and protects the battery from over current, short circuit by switching the solar system controller's power device.

Closed loop Boost Converter for Solar Powered LED Lighting System has been discussed by P.Sathya1 and Dr.R.Natarajan [18]. High performance closed loop Boost converter for solar powered HBLED lighting system is designed. The proposed system consists of solar photovoltaic module, a closed loop boost converter and LED lighting module. The closed loop boost converter is used to convert a low level dc input voltage from solar PV module to a high level dc voltage required for the load. To regulate the output of the converter, closed loop voltage feedback technique is used. The feedback voltage is compared with a reference voltage and a control signal is generated and amplified. The amplified signal is fed to 555 Timer which in turn generates a PWM signal which controls the switching of MOSFET. Thus by switching of MOSFET it would try to keep output as constant.

Maximum power point is obtained at different conditions possible by adjusting the duty cycle of the converter for optimization of the system is discussed by M. R. Banaei, M. R. Shirinabady and Mehdi Mirzaey [19]. A technique for efficiency extracting the maximum output power from a solar panel under varying meteorological conditions is presented. The methodology is based on connecting a pulse width modulated dc/dc SEPIC converter, which is controlled by MPPT unit [20]. The main difference between the method used in the proposed MPPT systems and other technique used in the past is that PV array output power is used to directly control the dc/dc converter thus reducing the complexity of the system. The resulting system has high efficiency, low cost and can be easily modified.

Literature survey of on chip dc converter is done by Snehal Raut [21]. Switched capacitor up converter and differential based voltage down converter is designed in UMC90. A new design for differential based voltage down converter is described to increase the efficiency of the converter. The converters designed have high efficiency and small layout area.

### **2.2.3 Literature Review on LED lighting and their characteristics-**

Cheng-Chih Hsieh has presented the analysis of LED Technologies for Solid State Lighting Markets [22]. This report focuses on the analysis of light emitting diode (LED) technology in the solid state lighting (SSL) market, that is, whether or not LED lighting products will replace incandescent bulbs and compact fluorescent lamps (CFLs).

Susan Walsh Sanderson and Kenneth L. Simons have presented the technology of the LED and its different types and growth of SSL industry [23]. This study draws lessons from the co - evolution of basic science, industrial technology, and niche applications that are stepping-stones to a mass market application. Development of today's SSL products required a maze of technology evolution, with false starts and unexpected turns.

Ater Amogpai presents the case studies on LEDs combined with solar panels in different DC lighting systems [24]. The work was done to find out the functionality of LED lighting combined with solar panels in developing countries and to find out the availability of solar energy in different geographical locations. Another aim of the work was to understand the advantages and disadvantages of photovoltaic (PV) systems and the optimum combination of PV systems for lighting. It also includes comparisons of incandescent lamp and compact fluorescent lamps (CFL) with LED light sources and the utilization of solar energy for electricity generation.

A.Wiedjaja a, S.Harta, L.Josses, Winardi and H.Rinda discussed MPPT technique to get maximum power output from the solar energy for LED street lighting system [25]. This research has developed a street light system for public area using solar panel and dried battery/cell as the energy storage. Energy efficiency to this system obtained by utilize solar panel to battery charging circuit using MPPT, and using LED and high efficiency LED driver circuit. The implementation of the MPPT technique in the solar panel to battery charging controller has power transfer efficiency up to 94.77%, they measured this from the maximum power that can be produced by the solar panel to energy for charging battery. Using white warm high power LED give us high efficiency energy transfer from electric to light, and LED driver circuit give efficiency up to 91.9% from input power to power LED.

Research on efficient LED driver using buck-boost converter have been done by Renbo Xu, Yongzhi Li, Lixin Zhong and Jiaming Liu [26]. Buck-Boost main circuit related characteristics are discussed, a new Buck-Boost power efficient double loop control strategy is built by using error amplifier and integrator control. It shows that the developed system has several advantages such as higher efficiency, faster response, strong anti -interference, better stability after analyses and simulations of its dynamic characteristics.

K.Sampath and S. China Venkateswarlu presents intelligent LED lighting system for energy efficiency [27]. The paper proposes an intelligent household LED lighting system considering energy efficiency and users satisfaction. The proposed system utilizes multiple sensors and wi-fi communication technology for controlling an LED light according to the user's state and the surroundings. The proposed LED lighting system can autonomously adjust the minimum light intensity value to enhance both energy efficiency and user satisfaction. The design and implementation of the proposed system in the test bed and measures total power consumption to verify the performance. The proposed LED lighting system reduces total power consumption of the test bed up to 21.9%.

LED-Professional November/December 2008 issue shows various types of LED, their applicable areas and characteristics in detail [28]. It presents different types of LED by different manufacturer have been compared in it with their efficiency, LED lighting technology fundamentals and measurement guidelines, LED source modeling method evaluations, simulation and optimization of optical systems have been discussed.

Ankit R Patel, Ankit A Patel, Mahesh A Patel and Dhaval R Vyas discussed the modeling and simulation of photovoltaic system combined with LED lighting [29]. This study analyzed the efficiency of each component of PV powered lighting systems to identify optimum system configurations for different applications. The efficiency of a grid connected hybrid power conditioning unit, which outputs dc power with the both ac(grid) and dc(PV) input powers, was evaluated through an experiment. The power conditioning unit draws power from the ac grid when the amount of dc power collected from the PV panels is not sufficient to meet the needs of the lighting system [30].

Yimin Gu and Nadarajah Narendran have discussed the use of light guides for LED lighting fixtures [31]. Conference room light fixtures using an LED light guide system were analysed through computer modeling. A rectangular light guide with diffused reflective surfaces provided the necessary cosine beam distribution, also a more sophisticated surface treatment was required on the light extracting surface of the light guide to create the batwing beam distribution. The system efficiency was found out to be quite low, only 55%. The highest light loss occurred in



creating the batwing distribution. The overall system efficiency must be greater than 80% for this type of fixture to become a viable solution.

## **2.3 Conclusion**

This literature review provides a basic knowledge of the area. It provides a knowledge about types of control algorithms already implemented in past, there advantages, disadvantages, etc. this review provides a knowledge about what are those parameters which can be controlled to provide better performance of the system.

## CHAPTER III

# INTRODUCTION TO DC-DC CONVERTERS AND THEIR CONTROL

### 3.1 General

Several methods exist to achieve DC-DC voltage conversion. Each of these methods has its specific benefits and disadvantages, depending on a number of operating conditions and specifications. Examples of such specifications are the voltage conversion ratio range, the maximal output power, power conversion efficiency, number of components, power density, galvanic separation of in- and output, etc. Here we will discuss about different types and select one for our system.

### 3.2 Comparison of different types of DC-DC converters

There are mainly two types of DC to DC converters

#### 1. DC to DC converters without isolation

These DC to DC converters does not have any isolation transformer between input and output stages. Some of the commonly used DC to DC converters with isolation are

- a. Buck converter
- b. Boost converter
- c. Buck-boost converter

The buck converter is step down converter where input voltage  $>$  output voltage whereas Boost converter is a step up converter where input voltage  $<$  output voltage. The buck-boost converter is derived from step up and step down converters. The buck boost converter can be operated in both modes based on its duty cycle of switch ( $t_{on}/T_s$  where  $t_{on}$  is the duration for which switch is on and  $T_s$  is the switching time period). The Step down and step up converters are basic converter topologies based on which other converters are derived.

## 2. DC to DC converters with isolation

A transformer is provided in between input and output stages for isolation. The electrical isolation is an additional feature and is mainly useful in cases where the input voltage level ( $V_{in}$ ) and output voltage level ( $V_{out}$ ) differs significantly i.e. high or low values of  $V_{out}/V_{in}$ . The DC to DC converters with isolation is again divided into two types based on polarity of transformer core excitation as follows.

Unidirectional core excitation, the core is excited with forward currents of only one direction. In these DC to DC converters the isolation transformer core operates in only the positive part of B-H curve.

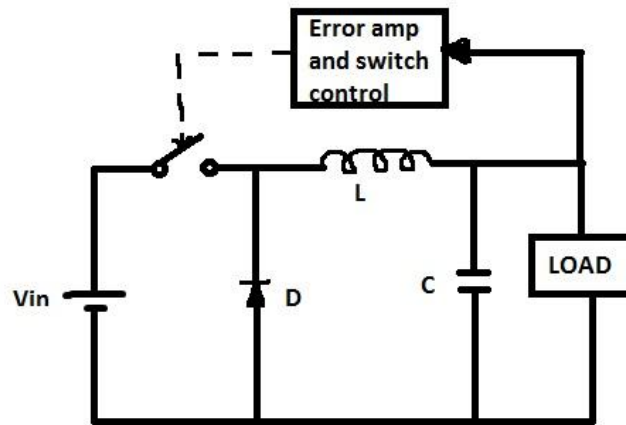
Bidirectional core excitation, core is excited with currents in either direction. In these DC to DC converters the isolation transformer core is operated alternatively in positive and negative portions of B-H curve.

Some of the commonly used DC to DC converters with isolation are

- a. Cuk converter (can be used in non-isolated mode also)
- b. Fly back converter
- c. Forward converter
- d. Full bridge converter
- e. Half bridge converter
- f. Push-pull converter etc.

### 3.2.1 Basic buck converter or regulator

The basic circuit for a buck converter consists of an inductor, diode, capacitor, switch and error amplifier with switch control circuitry as shown in **Fig.3.1**.



**Fig.3.1 Basic buck converter**

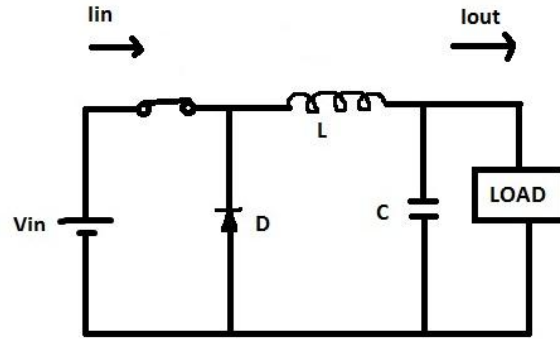
This circuit operates by varying the total amount of time in which inductor receives energy from the source, i.e. from the pulse width.

From the block diagram, it is found that the output voltage is sensed by the error amplifier and an error voltage is generated which controls the switch/mosfet duty cycle.

Usually the switch is controlled by a PWM generator, the switch remaining on of longer as more current is drawn by the load and the voltage tries to drop and usually there is a fixed frequency oscillator to drive the switch.

### **Buck converter operation**

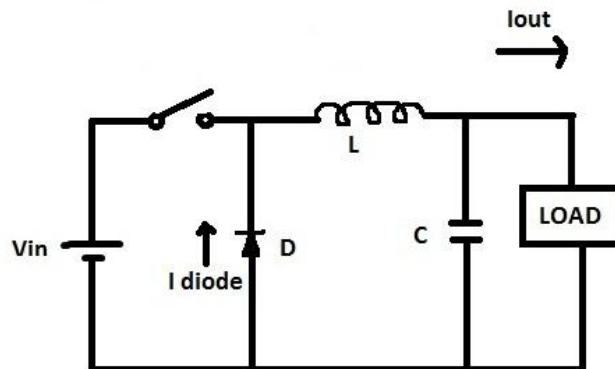
When the switch in the buck regulator is on as seen in **Fig 3.2**, the voltage which appears across the inductor is  $V_{in} - V_{out}$ . From the inductor equations, the current in the inductor will rise at a rate of  $(V_{in}-V_{out})/L$ . During this time the diode D is reverse biased and do not conduct.



**Fig.3.2 Basic buck converter ON state**

When the switch opens, i.e. OFF state as shown in **Fig.3.3**, current will still flow as the inductor tries to keep the same current flowing. As a result, load receives the current through the inductor. The diode, D forms the return path with current  $I_{diode}$  equal to  $I_{out}$  flowing through it.

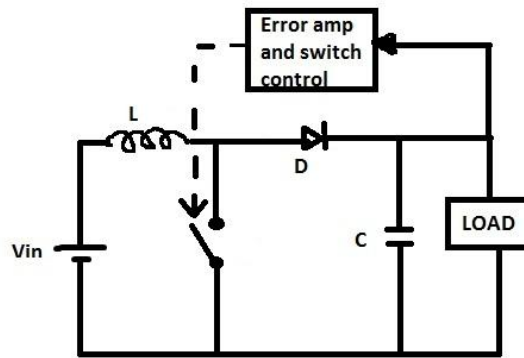
With the switch open, because of the reversed polarity on the inductor, current through the inductor decreases with a slope equal to  $-V_{out}/L$ .



**Fig.3.3 Basic buck converter OFF state**

### 3.2.2 Step-up or boost converter

The boost converter circuit has several similarities to the buck converter. But the circuit of the boost converter is slightly different. The fundamental circuit for a boost converter or step up converter consists of an inductor, diode, capacitor, switch and error amplifier with switch control circuitry as shown in **Fig.3.4**.



**Fig.3.4 Basic boost converter circuit**

This circuit operates by varying the total amount of time in which inductor receives energy from the source, i.e. from the pulse width.

From the block diagram, it is found that the output voltage is sensed by the error amplifier and an error voltage is generated which controls the switch/mosfet duty cycle.

Usually the switch is controlled by a PWM generator, the switch remaining on of longer as more current is drawn by the load and the voltage tries to drop and usually there is a fixed frequency oscillator to drive the switch.

### **Boost converter operation**

The operation of the boost converter is relatively straightforward. During the switch ON position, the inductor receives voltage  $V_{in}$  placed across it. The inductor current increases at a rate equal to  $V_{in}/L$ .

During switch in OFF position as shown in **Fig.3.5**, the voltage across the inductor changes and is equal to  $V_{out}-V_{in}$ . Current that was flowing in the inductor reduces at a rate equal to  $(V_{out}-V_{in})/L$ .

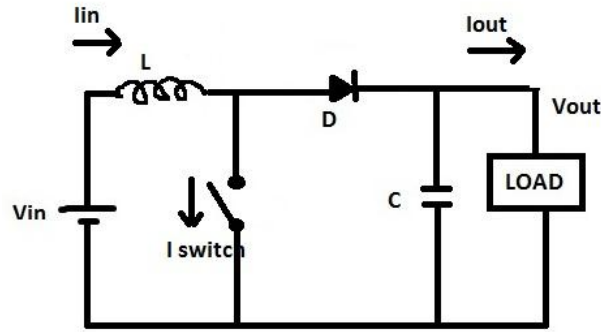


Fig.3.5 Basic boost converter switch OFF position

### 3.2.3 Buck-Boost Converter

The buck-boost DC-DC converter offers a greater level of capability than the buck converter or boost converter individually; extra components are to be required to provide the required functionality.

There are several types that can be used for buck-boost converters:

- **Positive  $V_{in}$ , Negative  $V_{out}$ :** This type of a buck-boost converter as shown in **Fig.3.6**, has same number of component count as the simple buck or boost converters. However this converter produces a negative output for a positive input. While this may be required by a limited number of applications, thus it is not normally the most conveniently used format.

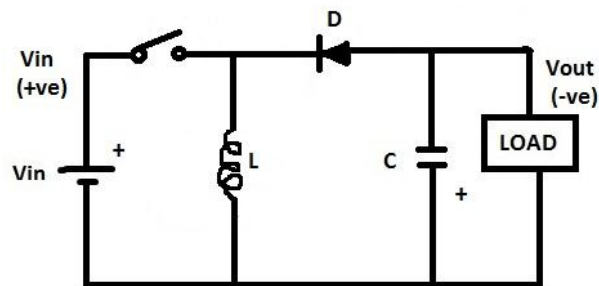
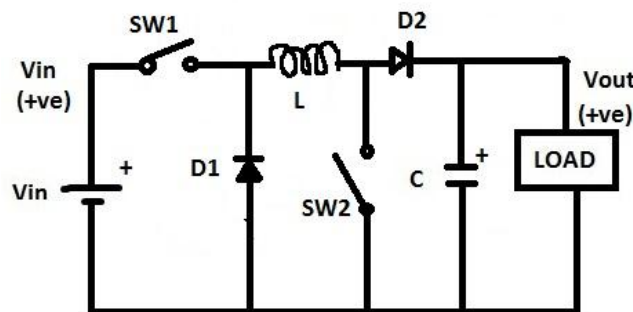


Fig.3.6 Basic buck-boost converter circuit with  $-ve$   $V_{out}$

When the switch is closed position, current builds up through the inductor. When the switch is opened the inductor supplies current through the diode to the load. The polarities (including the diode) within the buck-boost converter can be reversed to provide a positive output voltage from a negative input voltage.

- **Negative  $V_{in}$ , Positive  $V_{out}$ :** This topology of buck-boost converter circuit allows both input and output to be of same polarity. To achieve this, more components are required than regular converter. The circuit for this buck boost converter is shown below in **Fig.3.7**.



**Fig.3.7 Basic buck-boost converter circuit with +ve  $V_{out}$**

In this circuit, both switches are operated at the same time, i.e. both are closed or open. When the switches are open, the inductor current builds. At a required point, the switches are opened. The inductor then supplies current to the load through both diodes, D1 and D2.

In recent researches, two new converters have been developed known as cuk and sepic converter. They have several advantages over conventional buck-boost converters.

The advantages and disadvantages of three basic non-isolated converters can be summarized as given below.

**(i) Buck converter**

- Takes pulsed input current and requires input filter.



- Continuous output current results in lower output voltage ripple.
- Output voltage is always less than input voltage.

**(ii) Boost converter**

- Takes continuous input current and eliminates input filter requirement.
- Produces pulsed output current and increases output voltage ripple.
- Output voltage is always greater than input voltage.

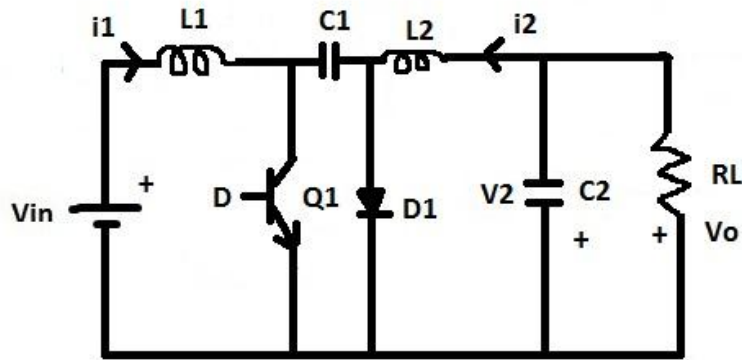
**(iii) Buck - Boost converter**

- Takes pulsed input current and requires input filter.
- Produces pulsed output current and increases output voltage ripple
- Output voltage can be either greater or smaller than input voltage.

### **3.2.4 Cuk converter**

The Buck converter can be seen as a Voltage to Current converter, the Boost as a Current to Voltage converter, the Buck-Boost as a Voltage-Current-Voltage and the CUK can be seen as a Current-Voltage-Current converter as shown in **Fig.3.8**. All other switching converter **MUST** fall into one of these configurations, if it does not increase the switching stages further, for example into a V-I-V-I converter which is difficult to realize through a single controlled switch. By looking into advantages & disadvantages of previous converters, it will be desirable to combine the advantages of these basic converters into one converter. CuK converter is one such converter. It has the following advantages:-

- Continuous input current.
- Continuous output current.
- Output voltage can be either greater or less than input voltage.



**Fig.3.8 Basic cuk converter circuit**

The Cuk converter is a step-down/step-up converter based on boost-buck topology. The cuk converter is composed of two sections, an input stage and an output stage. The input voltage  $V_{in}$  is given to the circuit through inductor  $L1$ . When transistor  $Q1$  is on, current  $i1$  builds the magnetic field of the inductor. The diode  $D1$  is reverse biased, and energy dissipates from the storage elements in the output stage. When  $Q1$  turns off, inductor  $L1$  tries to maintain the current flowing through it by reversing polarity and sourcing current as its magnetic field reduces. It thus provides energy to the output of the circuit thru capacitor  $C1$ . The inductor currents are the input and output currents, therefore, if the principle of conservation of energy is applied:

$$\frac{V_o}{V_{in}} = \frac{D}{1 - D}$$

Where  $D$  is the duty cycle of the switch:

$$D \triangleq \frac{T_{on}}{T_{on} + T_{off}}$$

The voltage ratio of a Cuk converter is the same as that of a buck-boost converter, but its main advantage over other converters is that the input and output inductors gives a filtered current on both sides of the converter, while buck, boost, and buck-boost converters have a pulsating current on at least one side of the circuit i.e. either on input side or output side. By adjusting the

duty cycle of the switch, the output voltage  $V_o$  can be controlled and can be made either higher or lower than the input voltage  $V_{in}$ . By using a controller to automatically vary the duty cycle during operation, the circuit can also be made to deal with disturbances.

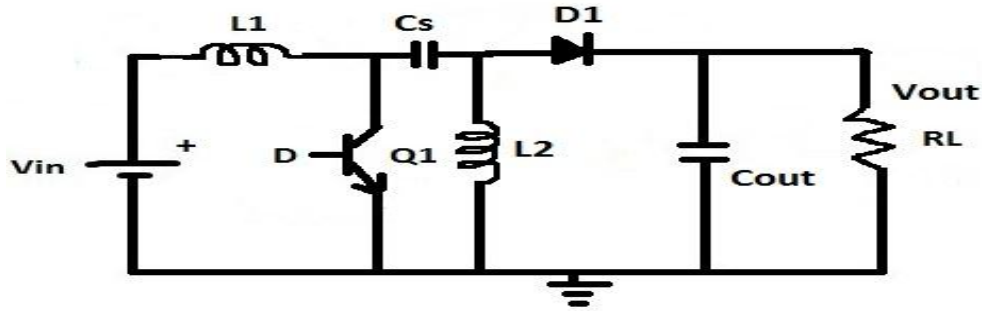
The main limitation of cuk converter is that it gives negative voltage at the output, which limits its applications in several areas, to overcome this problem, a new converter has come, known as sepic converter.

### **3.2.5 Sepic converter**

SEPIC is a DC to DC converter which is capable of operating in both, step up or step down mode and widely used in battery operated equipment, by varying duty cycle of gate signal of the MOSFET. For duty cycle  $D$  above 0.5 it will step up and  $D$  below 0.5, it will step down the resulting output voltage. Previous converter topologies like buck, boost, and buck-boost used to step up or step down voltage has some limitation like pulsating input and output current, inverted output voltage, in case of buck converter floating switch make it unreliable for different application. So it is not easy for conventional power converter design to maintain high efficiency especially when it step up or step down voltage. All these characteristics are obtained in SEPIC DC to DC power conversion. Different designs are used using active and passive components. Non- inverted output ,low equivalent series resistance(ESR) of coupling capacitor minimize ripple and prevent heat built up which make it reliable for wide range of operation.

#### **Circuit operation**

Single-ended primary inductor converter (SEPIC) is a type of DC-DC converter, that allows the voltage at its output to be more than, less than, or equal to that at its input. The output voltage of the SEPIC is controlled by the duty cycle of the MOSFET. A SEPIC is similar to a traditional buck-boost converter, but has advantages of having non-inverted output, by means of coupling energy from the input to the output is via a series capacitor. When the switch is turned off output voltage drops to 0 V. SEPIC is useful in applications like battery charging where voltage can be above and below that of the regulator output.



**Fig.3.9 Basic sepic converter circuit**

### **Continuous conduction mode**

A SEPIC converter is said to be in continuous-conduction mode if the current through the inductor L1 never falls down to zero value as shown in **Fig.3.9**. During SEPIC's steady-state operation, the average voltage across the capacitor Cs ( $V_{Cs}$ ) equals to the input voltage ( $V_{IN}$ ). Because of Cs which blocks direct current, the average current across it ( $I_{Cs}$ ) is zero, making inductor L2 the only source of load current. Hence the average current through inductor L2 is the average load current and hence independent of the input voltage. From the average voltages, the following can be concluded:

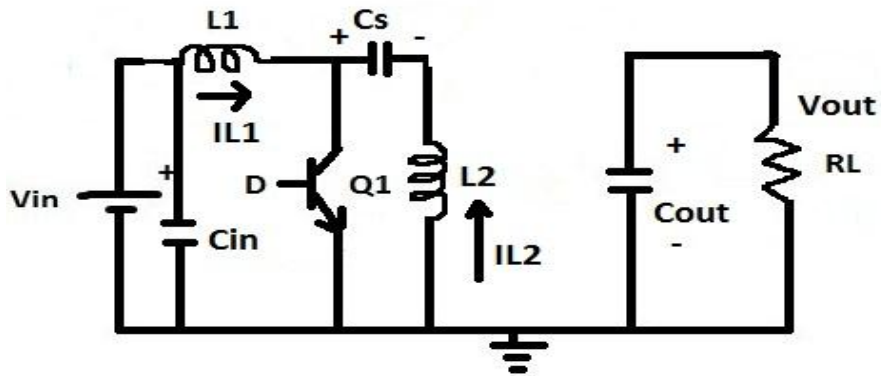
$$V_{in} = V_{L1} + V_{Cs} + V_{L2} \quad (3.1)$$

Because the average voltage of  $V_{Cs}$  is equal to  $V_{in}$

$$V_{L1} = -V_{L2}. \quad (3.2)$$

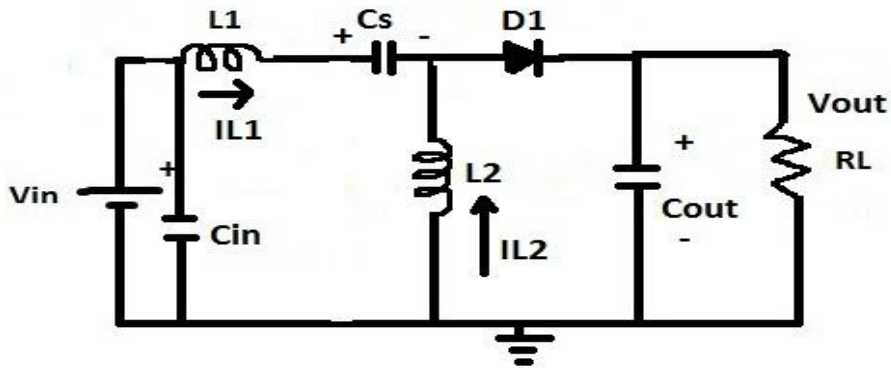
For this reason, the two inductors L1 & L2 can be wound on the same core. Since the voltages are the equal in magnitude, their mutual inductance effect will be zero if the polarity of the coil is correctly determined. As the voltages are the equal in magnitude, the ripple currents of the two inductors will be equal in magnitude. The average currents can be summed as follows:

$$I_{D1} = I_{L1} - I_{L2} \quad (3.3)$$



**Fig.3.10 SEPIC on state (continuous conduction mode)**

When switch Q1 is turned on as shown in **Fig.3.10**, current  $I_{L1}$  increases in positive and the current  $I_{L2}$  increases in the negative direction. The energy to increase  $I_{L1}$  comes from the input source  $V_{in}$ . Since Q1 acts as a short while closed, and the instantaneous voltage  $V_{Cs}$  is approximately  $V_{in}$ , the voltage  $V_{L2}$  is approximately  $-V_{in}$ . Therefore, the capacitor  $C_s$  supplies the energy to increase the magnitude of the current in  $I_{L2}$  and thus increase the energy stored in  $L_2$ .



**Fig.3.11 SEPIC off state (continuous conduction mode)**

When switch Q1 is turned off as shown in **Fig.3.11**, the current  $I_{Cs}$  becomes the same as the current  $I_{L1}$ , as the inductors will not allow instantaneous changes in current. Current  $I_{L2}$  will continue in the negative direction, or we can say that it never reverses its direction. It can be seen from the figure that a negative  $I_{L2}$  will add to the current  $I_{L1}$  to increase the current supplied to the load. By Using Kirchoff's Current Law

$$I_{D1} = I_{Cs} - I_{L2}. \quad (3.4)$$

So while Q1 is in off condition, power is delivered to the load from both L2 and L1. Coupling capacitor (Cs) is charged by L1 during this off cycle, and will recharge L2 during the on cycle. The boost and buck capabilities of the SEPIC converter are possible because of the coupling capacitor Cs and inductor L2. Inductor L1 and switch Q1 forms a standard boost converter, which generates a voltage (VQ1) that is higher than Vin. The magnitude of which is determined by the duty cycle of the mosfet Q1. Since we have found that the average voltage across Cs equals to Vin, the output voltage (Vout) is

$$V_{out} = V_{Q1} - V_{in}. \quad (3.5)$$

Hence it can be seen from above equation that if VQ1 is less than double of Vin, then the output voltage will be less than the input voltage. And if VQ1 is be greater than double of Vin, then the output voltage will be greater than the input voltage.

Thus it can be concluded that a SEPIC converter is similar to a traditional buck-boost converter, but has several advantages such as having non-inverted output (the output voltage is of the same polarity as the input voltage) while in case of buck-boost the output voltage is of opposite polarity with respect to the input voltage.

### 3.3. Conclusion

**Table.3.1. Comparison of different types of DC-DC converters**

<b>Buck</b>	<b>Boost</b>	<b>Buck-Boost</b>	<b>Cuk</b>	<b>Sepic</b>
Pulsed input current	Pulsed input current	Pulsed input current	Continuous input current	Continuous input current
requires input filter	requires input filter	requires input filter	Requires more components	No input filter
Continuous output current	Continuous output current	Pulsed output current	Continuous output current	Pulsed output current
Same output polarity	Reverse output polarity	Reverse output polarity	Reverse output polarity	Reverse output polarity
Highest	High efficiency	High efficiency	High efficiency	Coupled inductor

efficiency				can be used
Only step down applications	Only vin and step up applications	Can be used for both, but –ve Vout	Can be used for both, but –ve Vout	Can be used for both step up and downa

After studying all of the types of DC-DC converters, we have chosen Sepic topology for our system because of its advantages and application point of view. Modeling, designing and system will be designed according to sepic converter in further chapters.

## CHAPTER IV

### DESIGN AND CONTROL OF SEPIC CONVERTER

#### 4.1 Design of Sepic Converter

##### 4.1.1 Design Specifications:

A SEPIC converter is used in various applications in power electronics field. Given below specification are used here for charging a 12V battery for LED lighting system:

Input voltage range ( $V_{IN}$ ) = 4-20 V

Output voltage ( $V_{OUT}$ ) = 15V

Output current ( $I_{out}$ ) = 500mA

Voltage drop across diode = 0.5V

Output ripple current = 30% of load current

Output ripple voltage = 3% of load voltage

Switching frequency ( $F_s$ ) = 10 kHz

##### Power stage filter design from ripple specifications:

##### 4.1.2. Duty cycle considerations:

For a SEPIC converter operating in a continuous conduction mode (CCM), the duty cycle is given by:

$$D = \frac{V_{out} + V_d}{V_{in} + V_{out} + V_d}$$

$V_d$  is the forward voltage drop of the diode, here it is considered as 0.5V. The maximum duty cycle is:

$$D_{max} = \frac{V_{out} + V_d}{V_{in(min)} + V_{out} + V_d}$$



$$D_{min} = \frac{V_{out} + V_d}{V_{in(max)} + V_{out} + V_d}$$

Here for our designed converter,

$$D_{max} = \frac{15+0.5}{4+15+0.5} = 0.8, \text{ i.e. } 80\%$$

$$D_{min} = \frac{15+0.5}{20+15+0.5} = 0.43, \text{ i.e. } 43\%$$

#### 4.1.3. Inductor Selection:

A good rule for determining the inductance is to allow the peak-to-peak ripple current to be approximately 30-40% of the maximum input current at the minimum input voltage. The ripple current flowing in equal value inductors L1 and L2 is given by: -

$$\Delta I_L = I_{IN} \times 40\% = I_{OUT} \times \frac{V_{OUT}}{V_{IN(min)}} \times 40\%$$

The inductor value is calculated by:

$$L1 = L2 = L = \frac{V_{IN(min)}}{\Delta I_L \times f_{sw}} \times D_{max}$$

Fs is the switching frequency and Dmax is the duty cycle at the minimum Vin. The peak current in the inductor, to ensure the inductor does not saturate, is given by:

$$I_{L1(peak)} = I_{OUT} \times \frac{V_{OUT} + V_D}{V_{IN(min)}} \times \left(1 + \frac{40\%}{2}\right)$$

$$I_{L2(peak)} = I_{OUT} \times \left(1 + \frac{40\%}{2}\right)$$

If L1 and L2 are wound on the same core, the value of inductance in the equation above is replaced by 1/2L due to mutual inductance. The inductor value is calculated by:

$$L1' = L2' = \frac{L}{2} = \frac{V_{IN(min)}}{2 \times \Delta I_L \times f_{sw}} \times D_{max}$$

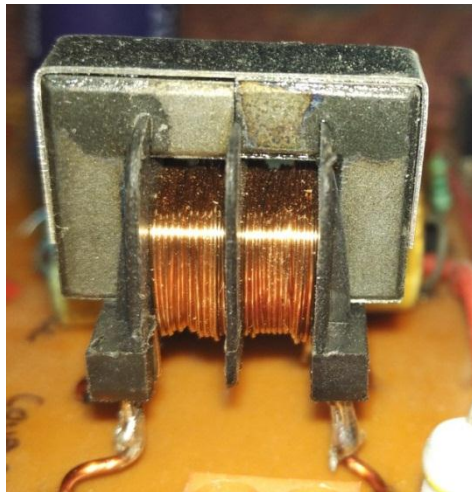
The input inductor L1 ripple current is:

$$\Delta I_L = I_{out} \times \frac{V_{out}}{V_{in(min)}} \times 30\%$$

$$\Delta I_L = 0.5 \times \frac{15}{4} \times 0.3 = 0.56 \approx 0.5$$

$$L1' = L2' = L \approx 320\mu H$$

The closest standard value of an off-the-shelf inductor is 326 $\mu$ H.



**Fig.4.1 Chosen 326 $\mu$ H \* 2 coupled inductor**

The peak inductor current is:

$$I_{L1}(\text{peak}) = 2.325\text{A}$$

$$I_{L2}(\text{peak}) = 0.6\text{A}$$

#### 4.1.4. Coupling Capacitor Selection:

The selection of coupling capacitor  $C_s$  depends on the RMS current and is given by

$$I_{cs(rms)} = I_{OUT} * \sqrt{\frac{V_{OUT} + V_d}{V_{IN(MIN)}}} \quad (4.1)$$

The coupling capacitor must be rated for a large RMS current relative to output power. This property makes the SEPIC much better suited to lower power application; here the RMS current through the capacitor is relatively small. The voltage rating of the  $C_s$  must be greater than the Maximum input voltage. Electrolytic capacitor work well for through whole application, where the size is not limited and they can accommodate the required RMS current rating. But for safer operation, unpolarized film capacitor is selected here.

The peak to peak ripple voltage on  $C_s$  is

$$\Delta V_{cs} = \frac{I_{OUT} * D_{MAX}}{C_s * F_s} \quad (4.2)$$

A capacitor that meets the RMS current requirement would mostly produce small ripple on  $C_s$ . We have selected 10 Micro Farad non polarized film capacitor. Hence the peak voltage is typically close to input voltage

from (4.1) and (4.2):

RMS current through coupling capacitor =  $I_{C_s} = 0.98A$

Peak to peak reverse voltage on  $C_s = 4V$

**Fig.4.2** shows the selected capacitor for converter design.

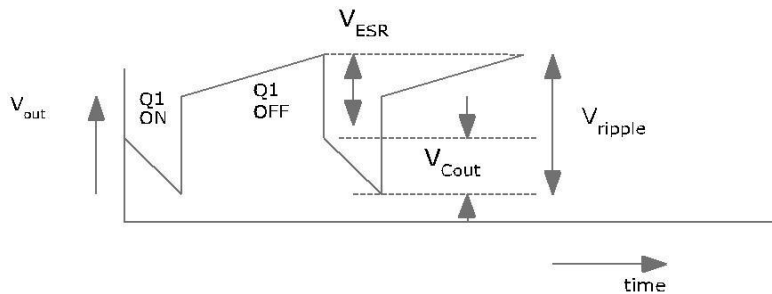


**Fig.4.2 Chosen 10mfd 100V unpolarized film capacitor**

#### 4.1.5. Output Capacitor Selection:

In a SEPIC converter, when the mosfet switch  $Q_1$  is turned on, the inductor starts charging and the output current is supplied by the output capacitor, as a result capacitor sees large ripple currents. Thus the selected output capacitor must be capable of handling maximum RMS current. The RMS current in output capacitor is given by:

$$I_{OUT(rms)} = I_{OUT} * \sqrt{\frac{V_{OUT} + V_d}{V_{IN(MIN)}}} \quad (4.3)$$



**Fig.4.3 Sepic Output Ripple Voltage**

The ESR, ESL and the buck capacitance of output capacitor directly control the output ripple. As shown in **Fig.4.3**, we assume half of the ripple is caused by the ESR and where other half is caused by amount of capacitance. So,

$$C_{OUT} \geq \frac{I_{OUT} * D}{V_{ripple} * 0.5 * F_{SW}} \quad (4.4)$$

$$ESR \leq \frac{V_{ripple} * 0.5}{I_{L1(peak)} + I_{L2(peak)}} \quad (4.5)$$

By calculating using (4.3), (4.4) and (4.5)

RMS current in output capacitor= $I_{C(OUT)}=0.98A$

$$ESR \leq 50m \text{ Ohm}$$

$$C_{OUT} \geq 267\mu F$$



**Fig.4.4 Chosen 470mfd 200V polarized capacitor**

#### 4.1.6. Input Capacitor Selection:

Input current waveform is continuous and is triangular in nature. The inductor ensures that the input capacitor observes fairly low ripple current. The RMS current in the input capacitor is given by:

$$I_{CIN(rms)} = \frac{\Delta I_L}{\sqrt{12}} \quad (4.6)$$

The input capacitor should be capable of handling the RMS current. The input capacitor is not much important in a SEPIC application, a 2200 Micro Farad or higher value good quality capacitor would prevent impedance interaction with the input supply. **Fig.4.5** shows the selected input capacitor for the designed SEPIC converter.



**Fig.4.5 Chosen 2200mfd 50V polarized capacitor**

So from (4.6), The RMS current in input capacitor is:

$$I_{Cin(rms)} = 0.144 \text{ A}$$

## Switch Selection:

There are mainly two switching element in SEPIC converter. That is diode and the MOSFET.

### 4.1.7. Power Mosfet Selection:

The parameters governing the selection of the MOSFET are:

Minimum threshold voltage  $V_{TH(MIN)}$

The on resistance  $R_{DS(ON)}$

Gate drain charge  $Q_{GD}$

Maximum drain to source voltage =  $V_{DS(MAX)}$

The peak switch voltage is equal to  $V_{IN} + V_{OUT}$  (4.7)

The peak switch current is given by

$$I_{Q1(peak)} = I_{L1(peak)} + I_{L2(peak)} \quad (4.8)$$

The RMS current through MOSFET is given by

$$I_{Q1(rms)} = I_{OUT} \sqrt{\frac{(V_{OUT} + V_{IN(MIN)})^2 + V_{OUT}^2}{V_{IN(MIN)}^2}} \quad (4.9)$$

The MOSFET power loss  $P_{Q1}$  is approximately:

$$P_{Q1} = I_{Q1}^2 \cdot R_{DS(ON)} \cdot D_{MAX} + (V_{IN(MIN)} + V_{OUT}) \cdot I_{Q1(peak)} \cdot \frac{Q_{GD} \cdot F_{sw}}{I_G} \quad (4.10)$$

$P_{Q1}$  includes conduction loss and switching loss. The  $R_{DS(ON)}$  value should be selected at maximum operating junction temperature and is typically given in MOSFET data sheet. conduction loss plus switching loss never exceed the package rating or exceed the overall thermal budget.

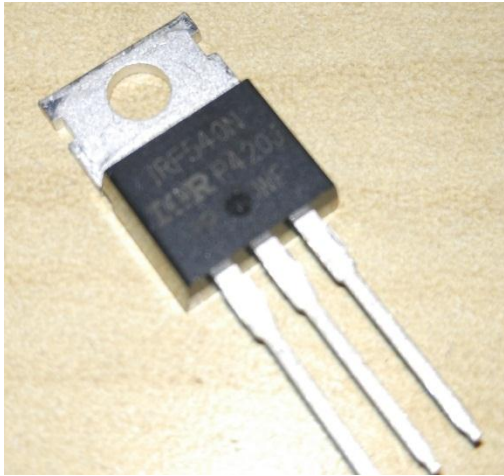
From equations (4.7),(4.8) and (4.9) :

$$\text{Peak swing of voltage} = V_{IN} + V_{OUT} = 35 \text{ V}$$

$$\text{Peak swing current} = I_{Q1(peak)} = I_{L1(peak)} + I_{L2(peak)} = 2.925 \text{ A}$$

$$\text{RMS current through switch} = I_{Q1(rms)} = 2.11 \text{ A}$$





**Fig.4.6 Selected Mosfet switch**

Thus IRF540N is selected as seen from **Fig.4.6**. It is sufficiently rated for our designed converter requirements.

#### 4.1.8. Diode Selection:

The output diode must be selected to handle the peak current and the reverse voltage. In a SEPIC converter, the diode peak current is the same as the mosfet switch peak current  $I_{Q1 \text{ peak}}$ . Thus the minimum peak reverse voltage the diode should withstand is given by:

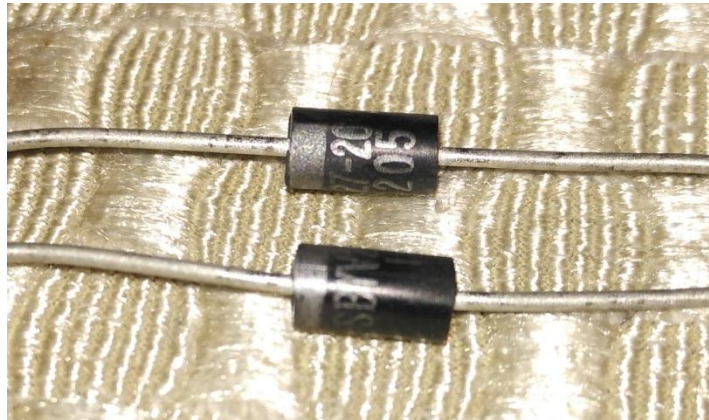
$$V_{RD1} = V_{IN(\max)} + V_{OUT(\max)} \quad (4.11)$$

The power dissipation in diode is equal to the output current multiplied by the forward voltage drop of the diode. Ultra-Fast Avalanche Sinter glass Diode (Byv27) is used, as shown in **Fig.4.7**, because of its low forward voltage drop and ultra-fast recovery time.

Diode peak current = 1.775A

Minimum peak reverse voltage the diode must withstand is =  $V_{RD1}$

$$= V_{IN(\max)} + V_{OUT(\max)} = 35V$$



**Fig.4.7 Selected Diode for sepic converter**

## 4.2 PCB Designing and circuit designing.

PCB for the circuit is designed using ExpressPCB software.

### About ExpressPCB

ExpressPCB is a circuit board layout program which is very easy and convenient to learn and use. Laying out PCBs is easy, even for the first time user. Following are the steps in designing a PCB via ExpressPCB software:

**Step 1 Selecting the Components** – The layout starts by adding the components. We can easily select the parts from the Component Manager Dialog box. Many components (such as connectors) include component part numbers are there for ease.

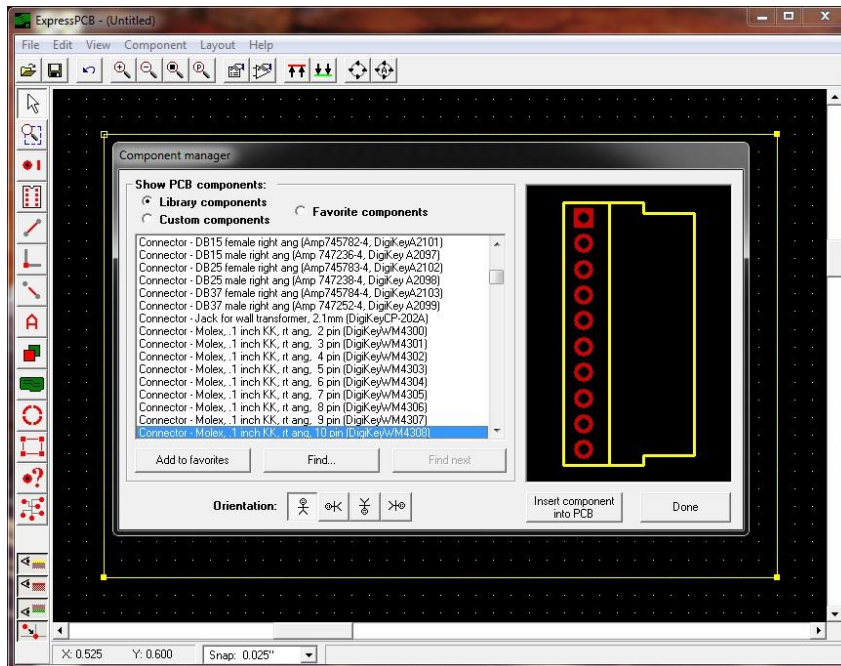
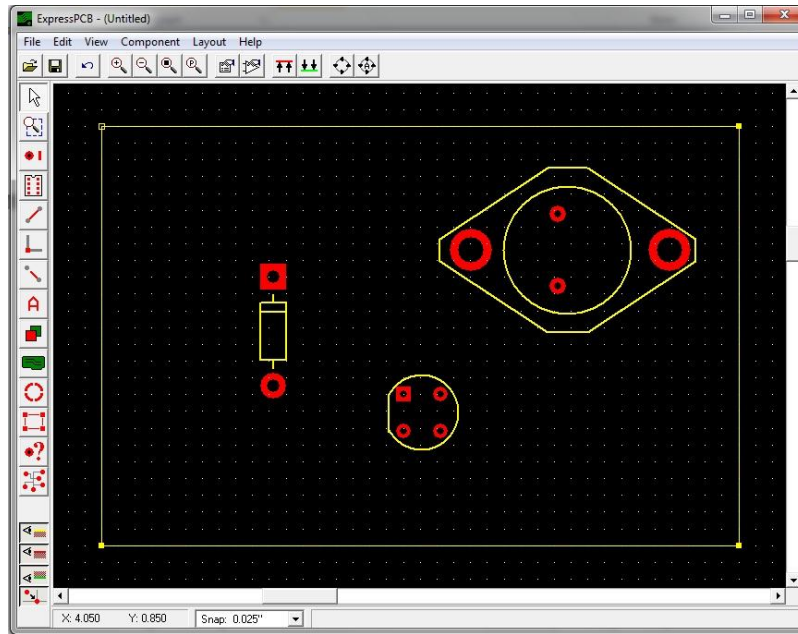


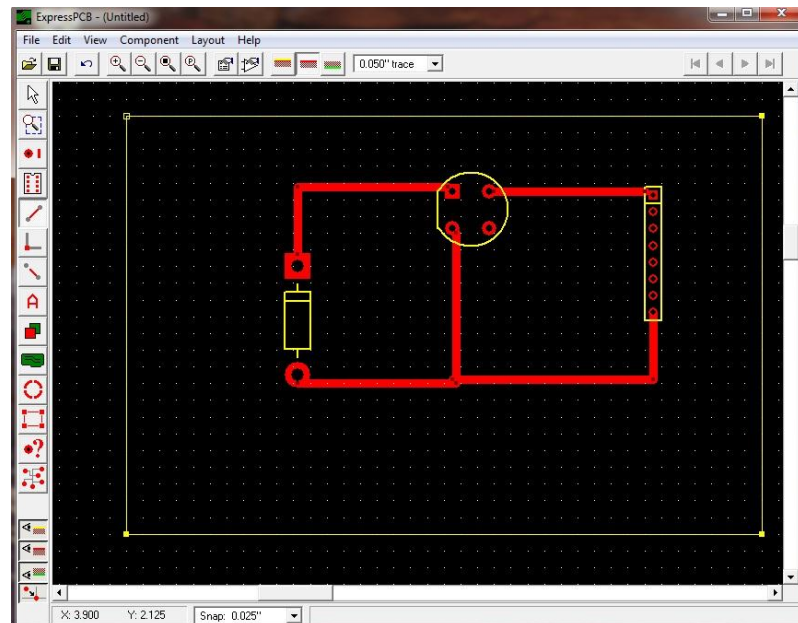
Fig.4.8a ExpressPCB component selection

**Step 2 Positioning the Components** – By dragging each component to its desired place on the mapped board.



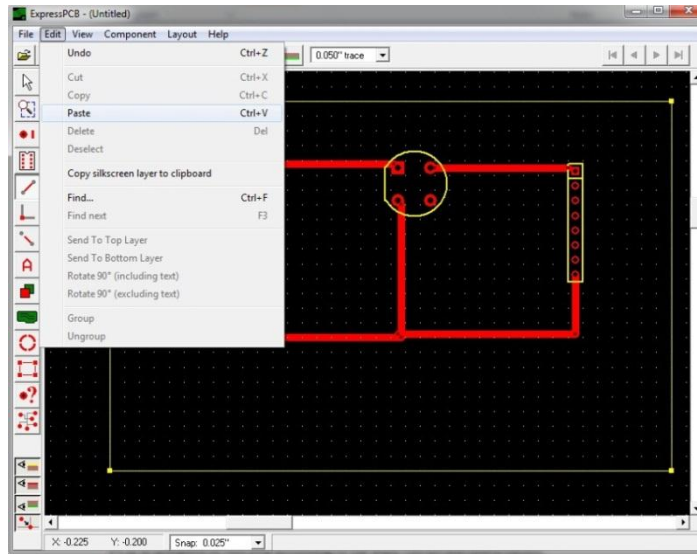
**Fig.4.8b Component layout**

**Step 3 Adding the wiring/connections** – Now connect each component wiring according to the designed circuit by clicking on the pin of a component and dragging to another pin.



**Fig.4.8c Wiring the components**

**Step 4 Final editing of the PCB** – Simple commands such as Copy, Cut and Paste can be used to properly arranging and adjusting the layout. Rearranging the parts can also be done by dragging and dropping them with the mouse. Traces don't break while moving them; they stay connected to their pins, even when you move things around.

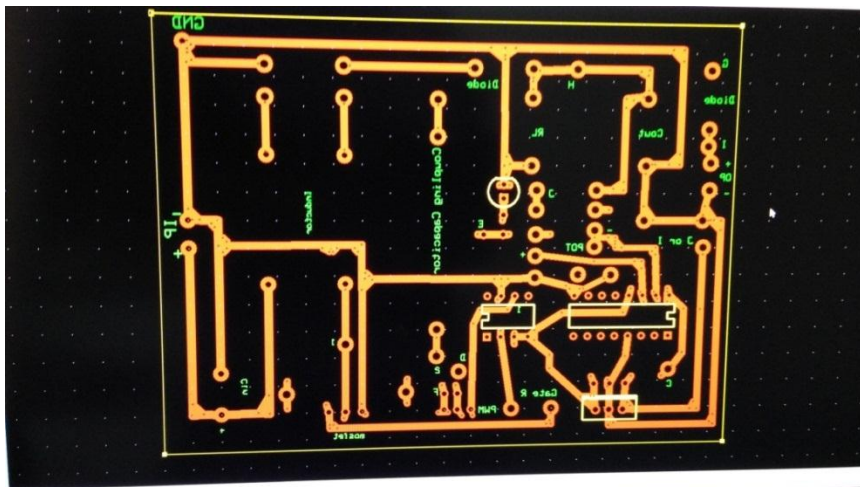


**Fig.4.8d Final adjustments in PCB**

**Stepwise PCB designing for our designed SEPIC converter**

1. Designing the PCB in express PCB software according to the circuit.

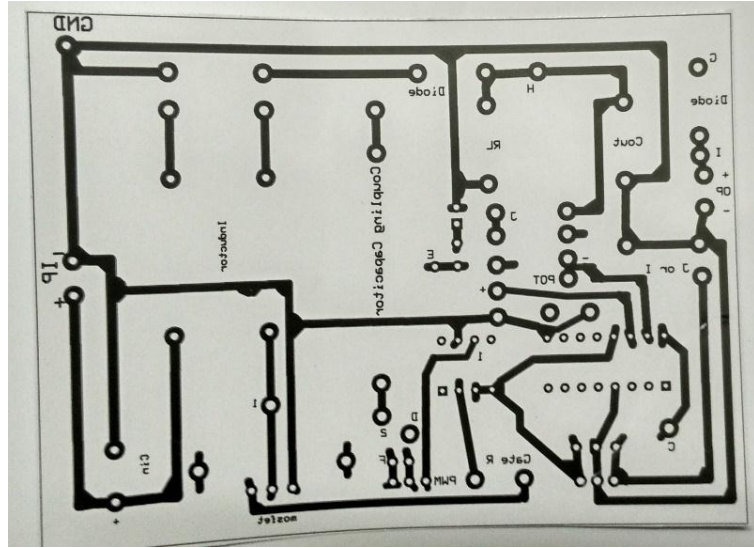
PCB is designed in this step according to the sepic circuit designed earlier. **Fig.4.9** shows the final prepared PCB schematic in the software.



**Fig.4.9 PCB schematic made in ExpressPCB**

2. Printing the Designed schematic on special paper

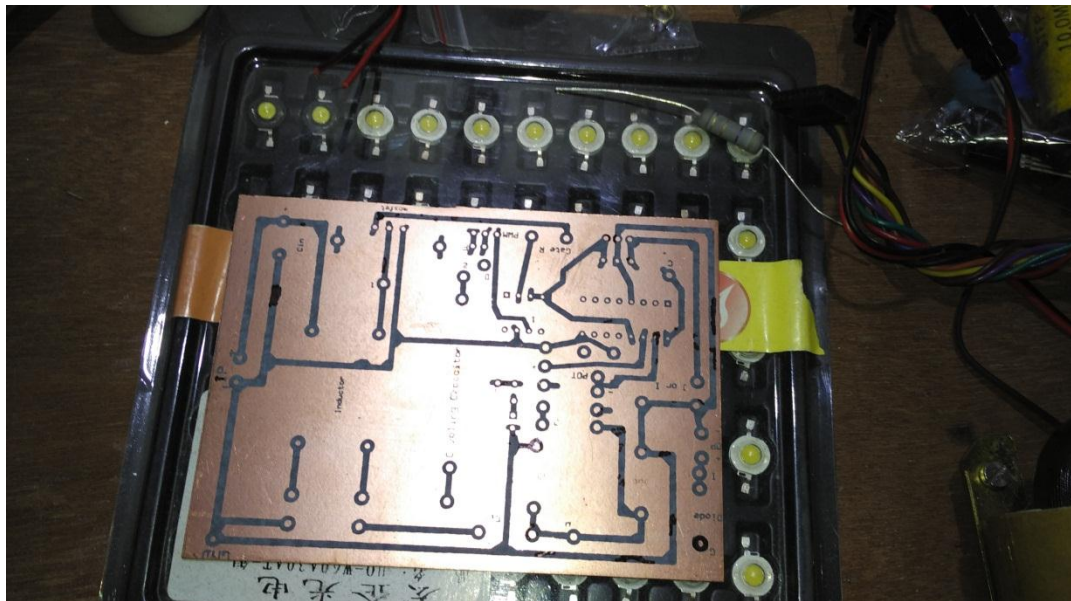
The Schematic is then printed on a special type of paper known as toner transfer paper using a laser printer as shown in **Fig.4.10**.



**Fig.4.10 PCB schematic printed on toner paper**

3. Transferring the print onto copper clad PCB

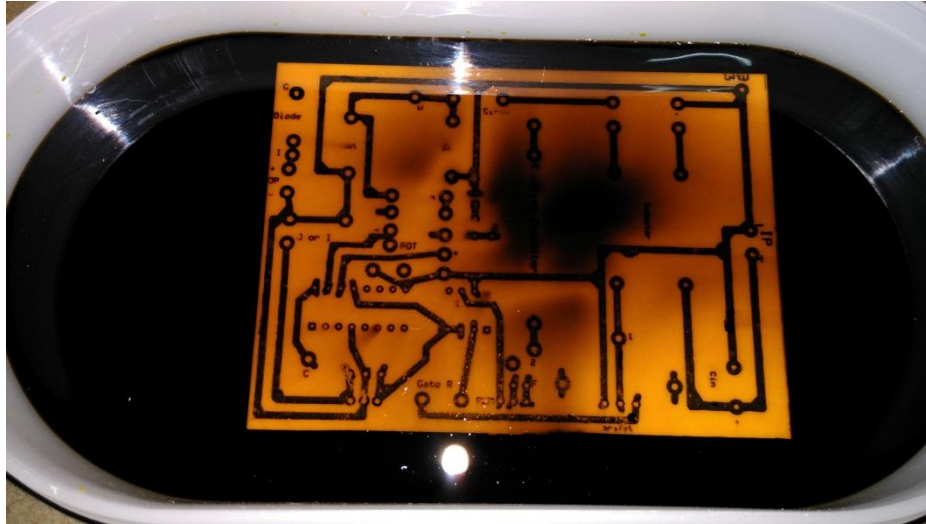
In this step the printed paper is pressed and heated onto the PCB so that all the ink on paper gets transferred onto the PCB as we can see the transfer after completion in **Fig.4.11**.



**Fig.4.11 PCB schematic after transferring on PCB**

#### 4. Soaking the PCB in etching chemical

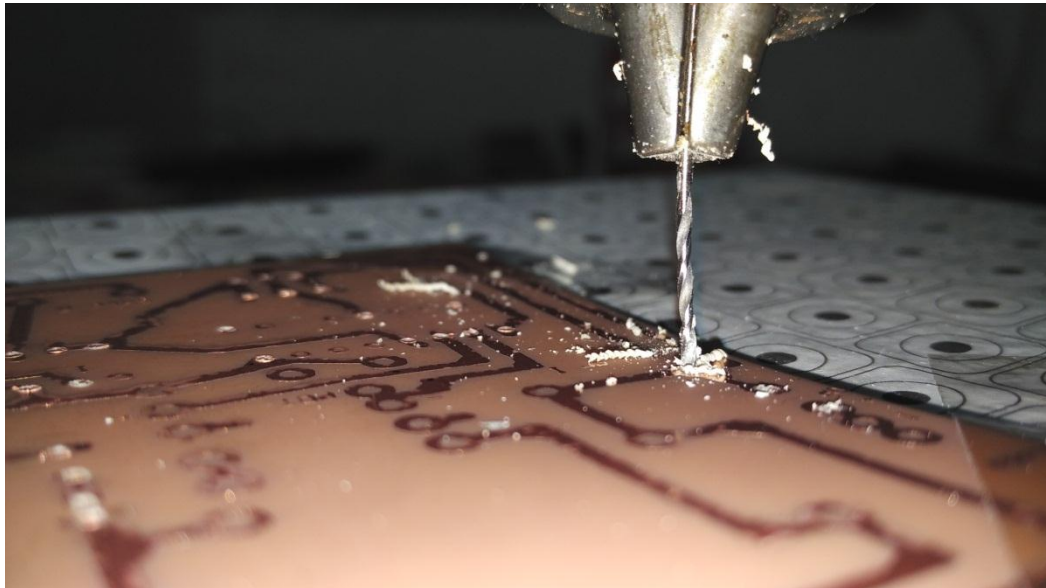
After print transfer, the PCB is soaked in ferric chloride solution for 10 minutes, so that all the copper on non-printed area gets dissolved into the solution as shown in **Fig.4.12**.



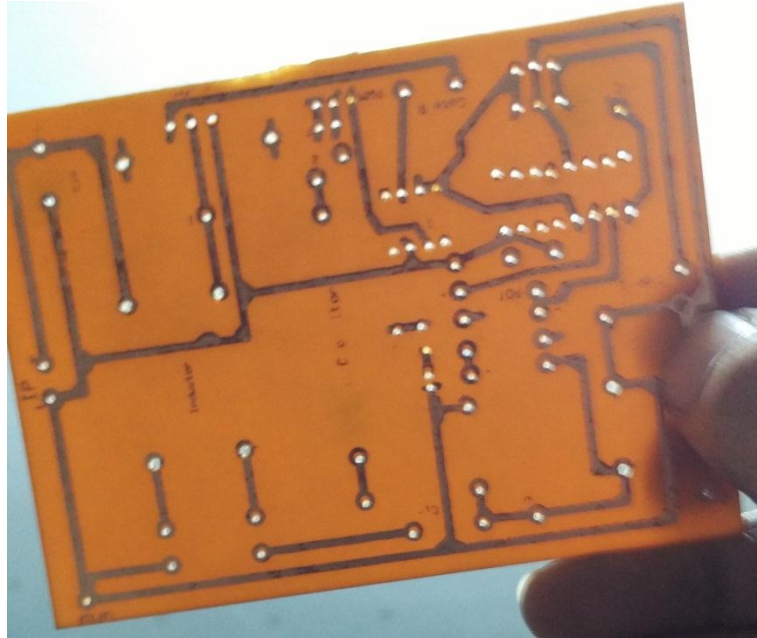
**Fig.4.12 Soaking the PCB in etching chemical**

#### 5. Drilling Holes for component placement

The PCB prepared in previous step is then drilled with 1mm drill bit for component placement holes as we can see from **Fig.4.13a** & **Fig.4.13b**.



**Fig.4.13a Drilling holes in prepared PCB**



**Fig.4.13b PCB after drilling holes for components**

6. Soldering the components onto the prepared PCB

All the designed and selected components are finally soldered onto the PCB for testing the circuit for proper operation after proper inspection and checking the circuit before connecting it to power source as shown in **Fig.4.14**.



**Fig.4.14 PCB after soldering all components**



### 4.3 Led selection and driver design

The specifications of the LED selected are given below: -

**Model:** HQ-W60A30AT

**Color temperature:** 6000-6500K

**Luminance:** 70-80Lm

**Voltage:** 3.4-3.6V

**Current:** 350mA

We will use series and parallel combinations of these leds' to achieve desired luminance, voltage and current specifications. As we will be charging a 12 volt battery at the converter output, we will use 3 of these leds' in series and use the module in parallel to achieve required luminance. The selected LEDs' in series are shown in **Fig.4.15**.

Therefore,

Applying  $V=IR$

Battery voltage = 12V

$$R = \frac{V}{I}$$

$$R = 12/0.35 = 35 \text{ ohm}$$

For 3 series LEDs, R value is approximate 35 ohm.



**Fig.4.15 Selected power LEDs with heat sink**

## **4.4 Arduino Microcontroller**

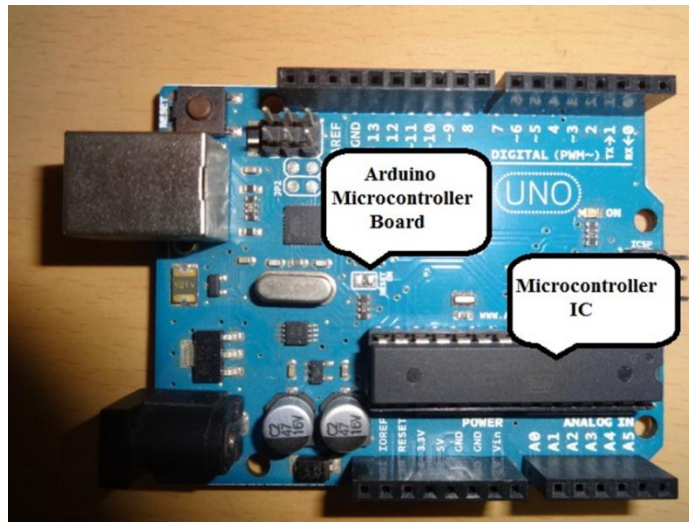
The atmega328PU is a low-power 8-bit microcontroller based on CMOS technology and AVR RISC(Reduced Instructions Set Computing) architecture. Processing speed versus power consumption is achieved in a single clock cycle by applying powerful instructions by the microcontroller.

The method proposed to maintain output voltage of the converter at steady state is called as the Pulse Width Modulation (PWM). In the PWM method, by modulating the pulse applied to the controlling switch i.e. the Mosfet, the duty cycle of the mosfet is controlled according to the compared voltage reference from battery and the converter output voltage, which is done by the LM324 op amp as a voltage comparator. The digital output from LM324 is then given as input to the Arduino microcontroller which in turn regulates the output PWM according to the program code written in the memory of the controller.

The Arduino application program is a freeware available for download and is an open source project.

There are three timers Timer 0, Timer 1, Timer 2 used by atmega328PU. All the three timers have two output compare registers each, and controls the width of PWM for the output of two timers. The timer output is toggled, when the output signal value attains the compare register value. The default PWM frequency on most of the pins of Arduino UNO

is only 490Hz excluding 2 pins having 980Hz PWM frequency. But to design an efficient converter, we needed higher frequency PWM which was achieved by using PWM library available online as it is an open source. By using the PWM library, the user can easily set the desired frequency of PWM with small changes in the program code. **Fig.4.16** shows an Arduino UNO microcontroller board.



**Fig.4.16**Arduino UNO microcontroller board

Usually the analog Read() and analog Write() instruction are written to generate PWM in basic mode of Arduino's programming language. The duty cycle can be varied from 0 to 255, 0 for 0% PWM out and 255 for 100% PWM. In the Arduino UNO microcontroller there are 6 pins at which we can observe PWM simultaneously at the same time. Pins (3, 5, 6, 9, 10, and 11) are the 6 pins where we get the output as PWM. The advantage of getting these 6 PWM's is that we can operate 6 different setups where PWM is needed by a single Arduino microcontroller board. The disadvantage of analog Write is that it does not have any control of frequency, it only provides interface to the hardware.

For example:-

`analogWrite(Pin, 255)` will write 100% duty PWM, i.e., always ON signal on the Pin specified by the user, but at a fixed frequency of either 490 or 980 Hz according to the pin selected as output.

To obtain the higher frequency duty cycle using PWM library, user just need to add following code and replace analogWrite() function with pwmWrite() function.

```
#include <PWM.h>

int gate = 9;          //PWM out at pin 9
int32_t frequency = 10000; //set frequency (in Hz)

void setup()
{
  InitTimersSafe();
  bool success = SetPinFrequencySafe(gate, frequency);
  if(success)
  {
    pinMode(13, OUTPUT);
    digitalWrite(13, HIGH); //Sets high if frequency is set successfully.
  }
}
```

### **Program Steps**

- Easy programming only in two steps

1. Void setup
2. Void loop

The void set up consists of all these input, output and variable parameters used in the program operation so that it can be read by the program. In void loop, programming codes for their different operations with their looping instruction are defined.

- For adding Delay in ATMEGA328

### **Program code-**

Delay (time ms) or DelayMicroseconds(time in microseconds) for adding delay in microseconds

## 4.5 Program Code for our system

The program code was written in Arduino software which is an open source application.

```
#include <PWM.h>

int gate = 9;
int i = 109;
int FB = 12;
int Ip = 10;
int V1=0;
int32_t frequency = 10000; //frequency (in Hz)
void setup()
{
  InitTimersSafe();
  bool success = SetPinFrequencySafe(gate, frequency);
  if(success)
  {
    pinMode(13, OUTPUT);
    digitalWrite(13, HIGH);
    pinMode(FB,INPUT);
    pinMode(10,OUTPUT);
  }
}
void loop()
{
  V1= digitalRead(FB);
```

```

if(i<=205)
{
  if(V1==HIGH)
  {
    i=i+1;
    delayMicroseconds(300);
    pwmWrite(gate, i);
  }
else if(V1==LOW)
{
  i=i-1;
  delayMicroseconds(300);
  pwmWrite(gate, i);
}
}
else
digitalWrite(Ip,HIGH);
}

```

The `pwmWrite()` function used above writes the PWM at specified pin in the range of 0-255.

Thus according to calculated  $D_{min}$  and  $D_{max}$ , we have used them as 109 and 205.

#### 4.6 Flow chart of the system

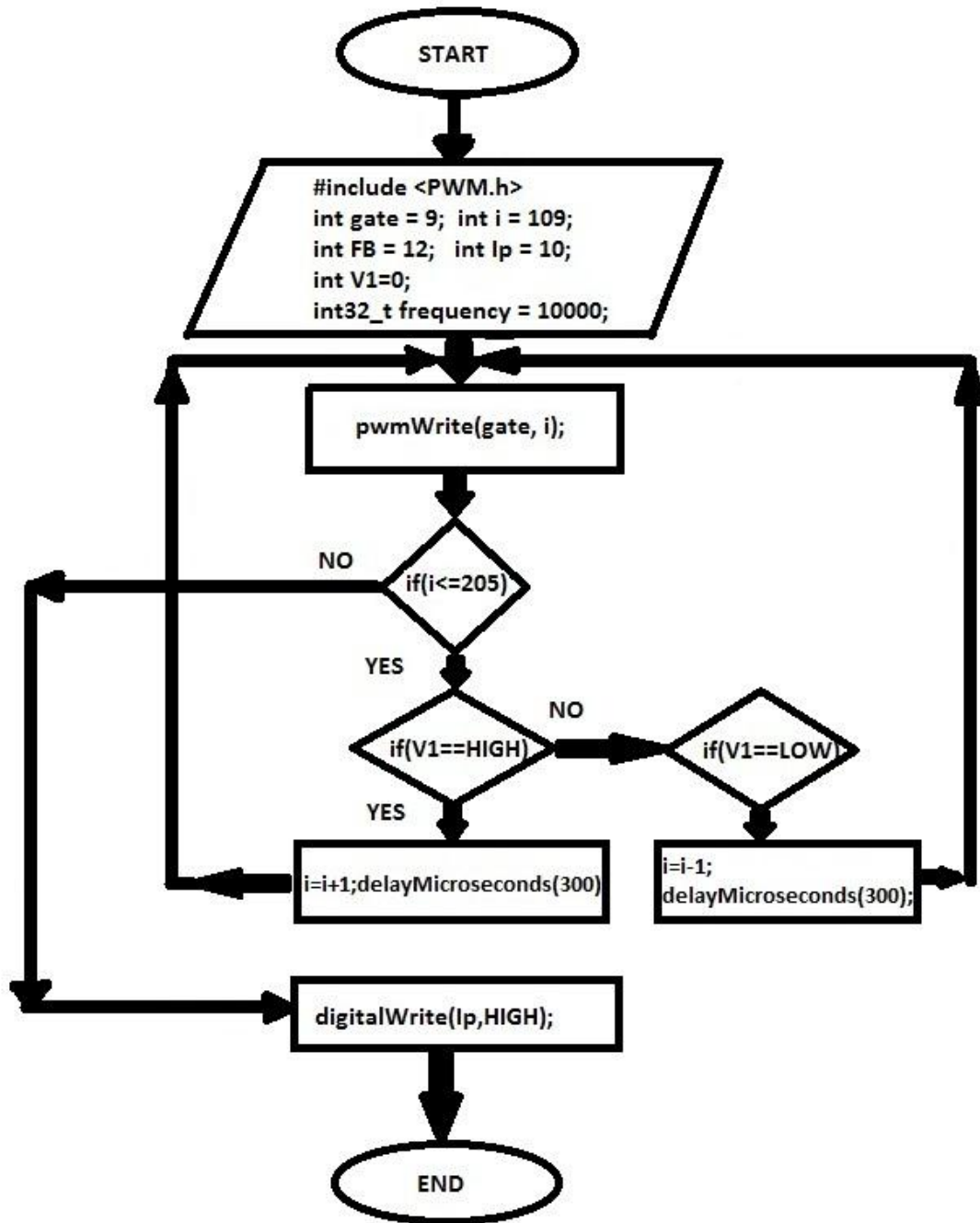


Fig.4.17 Flow chart for PWM generation

#### 4.7 Block diagram of the system

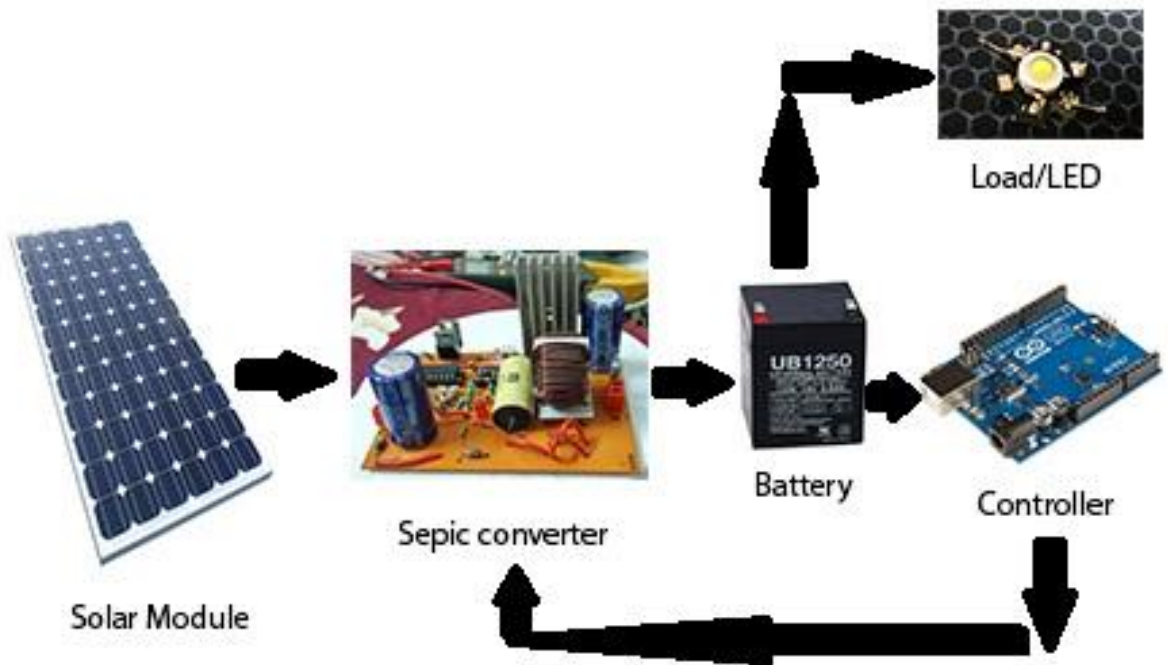


Fig.4.18 Block diagram of the DC system



## CHAPTER V

# MODELLING OF SOLAR POWERED LED LIGHTING SYSTEM

### 5.1 GENERAL

Solar powered systems are now days are boon in industrial as well as remote area applications like pumping, lighting etc. The fossil fuels are now becoming extinct, which has led to emergence of renewable sector especially photovoltaic in the economy. They require solar energy as input which is free of cost and also available in plenty. Modeling of solar powered lighting system is performed using matlab. The results of the modeling and practical are discussed later in Chapter VI. The Matlab code for modeling results is also discussed in this chapter.

### 5.2 State space analysis of sepic converter

For close loop system we have to know the transfer function of the system.

During  $0 < t < DT_s$  interval (when MOSFET is turn on) in fig (3.10)

$$V_{in} + L_1 \frac{dI_{L1}}{dt} = 0 \Rightarrow \frac{dI_{L1}}{dt} = -\frac{V_{in}}{L_1} \quad 5.1$$

$$L_2 \frac{dI_{L2}}{dt} - V_{cs} = 0 \Rightarrow \frac{dI_{L2}}{dt} = \frac{V_{cs}}{L_2} \quad 5.2$$

$$C_{cs} \frac{dV_{cs}}{dt} + I_{L2} = 0 \Rightarrow \frac{dV_{cs}}{dt} = -\frac{I_{L2}}{C_{cs}} \quad 5.3$$

$$C_{out} \frac{dV_{c(out)}}{dt} + \frac{V_{c(out)}}{R} = 0 \Rightarrow \frac{dV_{c(out)}}{dt} = -\frac{V_{c(out)}}{RC_{out}} \quad 5.4$$

During  $DT_s < t < (1-D)T_s$  interval (when MOSFET is turns off) in fig(3.11)

$$V_{in} + L_1 \frac{dI_{L1}}{dt} + V_{cs} + V_{c(out)} = 0 \Rightarrow \frac{dI_{L1}}{dt} = -\frac{V_{cs}}{L_1} - \frac{V_{c(out)}}{L_2} + \frac{V_{in}}{L_1} \quad 5.5$$

$$L_2 \frac{dI_{L2}}{dt} + V_{c(out)} = 0 \Rightarrow \frac{dI_{L2}}{dt} = - \frac{V_{c(out)}}{L_2} \quad 5.6$$

$$C_s \frac{dV_{c(s)}}{dt} - i_1 = 0 \Rightarrow \frac{dV_{c(s)}}{dt} = \frac{I_{L1}}{C_s} \quad 5.7$$

$$C_{out} \frac{dV_{c(out)}}{dt} - I_{L1} - I_{L2} + \frac{V_{c(out)}}{R} = 0 \Rightarrow \frac{dV_{c(out)}}{dt} = - \frac{V_{c(out)}}{RC_{out}} + \frac{I_{L1}}{C_{out}} + \frac{I_{L2}}{C_{out}} \quad 5.8$$

So when MOSFET is on state space equation is

$$\begin{bmatrix} \frac{dI_{L1}}{dt} \\ \frac{dI_{L2}}{dt} \\ \frac{dV_{c(s)}}{dt} \\ \frac{dV_{c(out)}}{dt} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{1}{L_2} & 0 \\ 0 & -\frac{1}{C_1} & 0 & 0 \\ 0 & 0 & 0 & -\frac{1}{RC_2} \end{bmatrix} \begin{bmatrix} I_{L1} \\ I_{L2} \\ V_{c(s)} \\ V_{c(out)} \end{bmatrix} + \begin{bmatrix} \frac{1}{L_1} \\ 0 \\ 0 \\ 0 \end{bmatrix} [V_{IN}] \quad 5.9$$

$$\text{So } A_1 = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{1}{L_2} & 0 \\ 0 & -\frac{1}{C_1} & 0 & 0 \\ 0 & 0 & 0 & -\frac{1}{RC_2} \end{bmatrix} \quad 5.10$$

$$B_1 = \begin{bmatrix} \frac{1}{L_1} \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad 5.11$$

When MOSFET is off, the state space equation is

$$\begin{bmatrix} \frac{dI_{L1}}{dt} \\ \frac{dI_{L2}}{dt} \\ \frac{dV_{C(S)}}{dt} \\ \frac{dV_{C(OUT)}}{dt} \end{bmatrix} = \begin{bmatrix} 0 & 0 & -\frac{1}{L_1} & -\frac{1}{L_1} \\ 0 & 0 & 0 & -\frac{1}{L_2} \\ \frac{1}{C_1} & 0 & 0 & 0 \\ \frac{1}{C_2} & \frac{1}{C_2} & 0 & -\frac{1}{RC_2} \end{bmatrix} \begin{bmatrix} I_{L1} \\ I_{L2} \\ V_{C(S)} \\ V_{C(OUT)} \end{bmatrix} + \begin{bmatrix} \frac{1}{L_1} \\ 0 \\ 0 \\ 0 \end{bmatrix} [V_{IN}] \quad 5.12$$

Where

$$A_2 = \begin{bmatrix} 0 & 0 & -\frac{1}{L_1} & -\frac{1}{L_1} \\ 0 & 0 & 0 & -\frac{1}{L_2} \\ \frac{1}{C_1} & 0 & 0 & 0 \\ \frac{1}{C_2} & \frac{1}{C_2} & 0 & -\frac{1}{RC_2} \end{bmatrix} \quad 5.13$$

$$B_2 = \begin{bmatrix} \frac{1}{L_1} \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad 5.14$$

$$V_{OUT} = [0 \quad 0 \quad 0 \quad 1] \begin{bmatrix} I_{L1} \\ I_{L2} \\ V_{C(S)} \\ V_{C(OUT)} \end{bmatrix} \quad 5.15$$

So

$$C=[0 \ 0 \ 0 \ 1] \quad 5.16$$

For state space average model, we have to consider

$$A=DA1+ (1-D) A2 \quad (5.17)$$

$$B=DB1+ (1-D) B2 \quad (5.18)$$

For SEPIC converter the large signal input to output relationship and associated large signal state relationship can be represented as:

$$\frac{V_{out}}{V_{in}} = \frac{D}{1-D}$$

$$I_{L1} = \frac{D^2 V_{in}}{(1-D)^2 R}$$

$$V_{C(s)} = V_{in}$$

$$I_{L2} = -\frac{DV_{in}}{(1-D)R}$$

$$V_{C(out)} = \frac{DV_{in}}{(1-D)} \quad 5.19$$

So Duty cycle to output relationship can be expressed as

$$\frac{V_{out}}{D}(S) = \frac{A_1 S^3 + A_2 S^2 + A_3 S^1 + A_4}{A_5 S^4 + A_6 S^3 + A_7 S^2 + A_8 S^1 + A_9} V_{in} \quad 5.20$$

$$A_1 = -L_1 C_s L_2 D$$

$$A_2 = L_1 C_s R D^2$$

$$A_3 = -D^2 L_1$$

$$A_4 = D^2 L_1$$

$$A_5 = (1 - D)^2 L_1 C_s L_2 C_{out} R$$

$$A_6 = (1 - D)^2 L_1 L_2 C_s$$

$$A_7 = (1 - D)^2 R (L_1 C_s (1 - D)^2 + L_2 C_{out} (1 - D)^2 + L_2 C_s (1 - D)^2 + L_1 C_{out} D^2)$$

$$A_8 = (1 - D)^2 (L_2 (1 - D)^2 + L_1 D^2)$$

$$A_9 = (1 - D)^4 R$$

Input to output voltage relationship can be described as

$$\frac{V_{out}}{V_{in}}(S) = \frac{B_1 S^2 + B_2}{B_3 S^4 + B_4 S^3 + B_5 S^2 + B_6 S^1 + B_7} V_{in} \quad 5.21$$

Where

$$B_1 = L_2 C_s R (1 - D)$$

$$B_2 = R D (1 - D)$$

$$B_3 = L_1 L_2 C_s C_{out} R$$

$$B_4 = L_1 L_2 C_s$$

$$B_5 = R (L_1 C_s (1 - D)^2 + L_2 C_{out} (1 - D)^2 + L_1 C_{out} D^2 + L_2 C_s (1 - D)^2)$$

$$B_6 = L_1 D^2 + L_2 (1 - D)^2$$

$$B_7 = R (1 - D)^2$$

Put the calculated value of inductance, capacitance and resistance in equation (5.20) and (5.21) respectively. We consider duty cycle is 0.5, so

$$\frac{V_{out}}{D}(S) = \frac{-2 \cdot 10^{-8} S^3 + 4.8 \cdot 10^{-4} S^2 - 1.6 S^1 + 75000}{1.41 S^4 + 10^{-8} S^3 + 1.152 \cdot 10^{-2} S^2 + 8 \cdot 10^{-1} S^1 + 75000} V_{in} \quad 5.22$$

$$\frac{V_{out}}{V_{in}}(S) = \frac{9.6 \cdot 10^{-4} S^2 + 75000}{5.78 \cdot 10^{-10} S^4 + 4.1 \cdot 10^{-8} S^3 + 4.6 \cdot 10^{-2} S^2 + 3.2 S^1 + 75000} V_{in} \quad 5.23$$

For better transient and steady state response of the system a feedback path given to the system. We are using LM354 as a voltage comparator for feedback. Because proportional controller reduce the rise time, hence transient response is better. We are selecting Arduino micro controller as it reduce the steady state error, so that a better output response will come. In close loop we can change the output by changing the reference signal.

### **5.3 Matlab code for obtaining modeled transfer function responses.**

The following code is formed to obtain and study the response of the system according to mathematical model. Different plots are obtained for different duty cycles of the converter, the amplitude of the plots will be used to obtain output voltage as result by multiplying input voltage with the amplitude and results will be discussed in chapter VI.

#### **Matlab code**

```
>> clear all

>> clc

>> num1=[1.09*10^-3 0 73530];

>> den1=[5.78*10^-10 4.1*10^-8 4.71*10^-2 3.26 97470];

>> H1s=tf(num1,den1)

>> num2=[9.6*10^-4 0 7.5*10^4];

>> den2=[5.78*10^-10 4.1*10^-8 4.6*10^-2 3.2 7.5*10^4];

>> H2s=tf(num2,den2)

>> num3=[8.64*10^-4 0 74250];

>> den3=[5.78*10^-10 4.1*10^-8 4.62*10^-2 3.23 60700];

>> H3s=tf(num3,den3)

>> num4=[7.68*10^-4 0 72000];
```

```

>> den4=[5.78*10^-10 4.1*10^-8 4.74*10^-2 3.32 48000];

>> H4s=tf(num4,den4)

>> num5=[6.72*10^-4 0 68250];

>> den5=[5.78*10^-10 4.1*10^-8 4.96*10^-2 3.48 36750];

>> H5s=tf(num5,den5)

>> num6=[5.76*10^-4 0 63000];

>> den6=[5.78*10^-10 4.1*10^-8 5.25*10^-2 3.71 27000];

>> H6s=tf(num6,den6)

>> num7=[3.84*10^-4 0 48000];

>> den7=[5.78*10^-10 4.1*10^-8 6.13*10^-2 4.35 12000];

>> H7s=tf(num7,den7)

>> step(H1s) //for duty cycle =0.43

>> step(H2s) //for duty cycle =0.50

>> step(H3s) //for duty cycle =0.55

>> step(H4s) //for duty cycle =0.60

>> step(H5s) //for duty cycle =0.65

>> step(H6s) //for duty cycle =0.70

>> step(H7s) //for duty cycle =0.80

```

# CHAPTER VI

## RESULTS AND DISCUSSIONS

### 6.1 General

In this chapter result of the various simulations in MATLAB/Simulink and Proteus and their relevance are discussed. The simulation is carried out in different parts- simulation of sepic converter with and without load, results from mathematical modeling of the converter. Various results are obtained at different duty cycles given to the MOSFET switch.

**The results are obtained in following manner–**

- 1 OPEN LOOP SIMULATION RESULTS
- 2 OPEN LOOP EXPERIMENTAL RESULTS
- 3 CLOSED LOOP SIMULATION RESULTS
- 4 CLOSED LOOP EXPERIMENTAL RESULTS
- 5 MODELLED TRANSFER FUNCTION RESPONSES
- 6 RESULTS FROM DEVELOPED MODEL
- 7 COMPARISONS OF RESULTS

### 6.2 Open loop simulation test results

We generated wide range of input voltages and pwm combinations to test the circuit as shown in results in **Table 6.1**.

**Table 6.1. Open loop simulation test of the sepic converter**

Input Voltage ( $V_{in}$ )	PWM (%)	Output Voltage ( $V_{out}$ )
20	43	18
15	50	15
12.5	55	14.7



10	60	14.2
7.5	65	13.1
5	70	10.7
4	80	14.3

### 6.3 Open loop experimental test results

The open loop test will be conducted for different input voltages and duty cycles as done in simulation and will be compared later on. **Table 6.2** shows the experimental results.

**Table 6.2. Open loop test of the sepic converter**

Input Voltage ( $V_{in}$ )	PWM (%)	Output Voltage ( $V_{out}$ )
20	43	16.1
15	50	14.9
12.5	55	15.2
10	60	14.8
7.5	65	13.2
5	70	10.7
4	80	15.1

### 6.4 Closed loop Simulation test results

Closed loop simulation is done using the output battery as voltage reference and converter output voltage as other voltage reference, both the reference are compared by a voltage comparator and an error signal is sent to microcontroller which adjusts the duty cycle of the converter. A 12V battery is selected for charging and as voltage reference for the comparator. **Table 6.3** shows the obtained results for the same.

**Table 6.3. Closed loop simulation test of the sepic converter**

Input Voltage ( $V_{in}$ )	Output Voltage ( $V_{out}$ )
----------------------------	------------------------------

20	13.8
15	13.5
12.5	13.5
10	13.2
7.5	14
5	13.5
4	14.3

### 6.5 Closed loop experimental test results

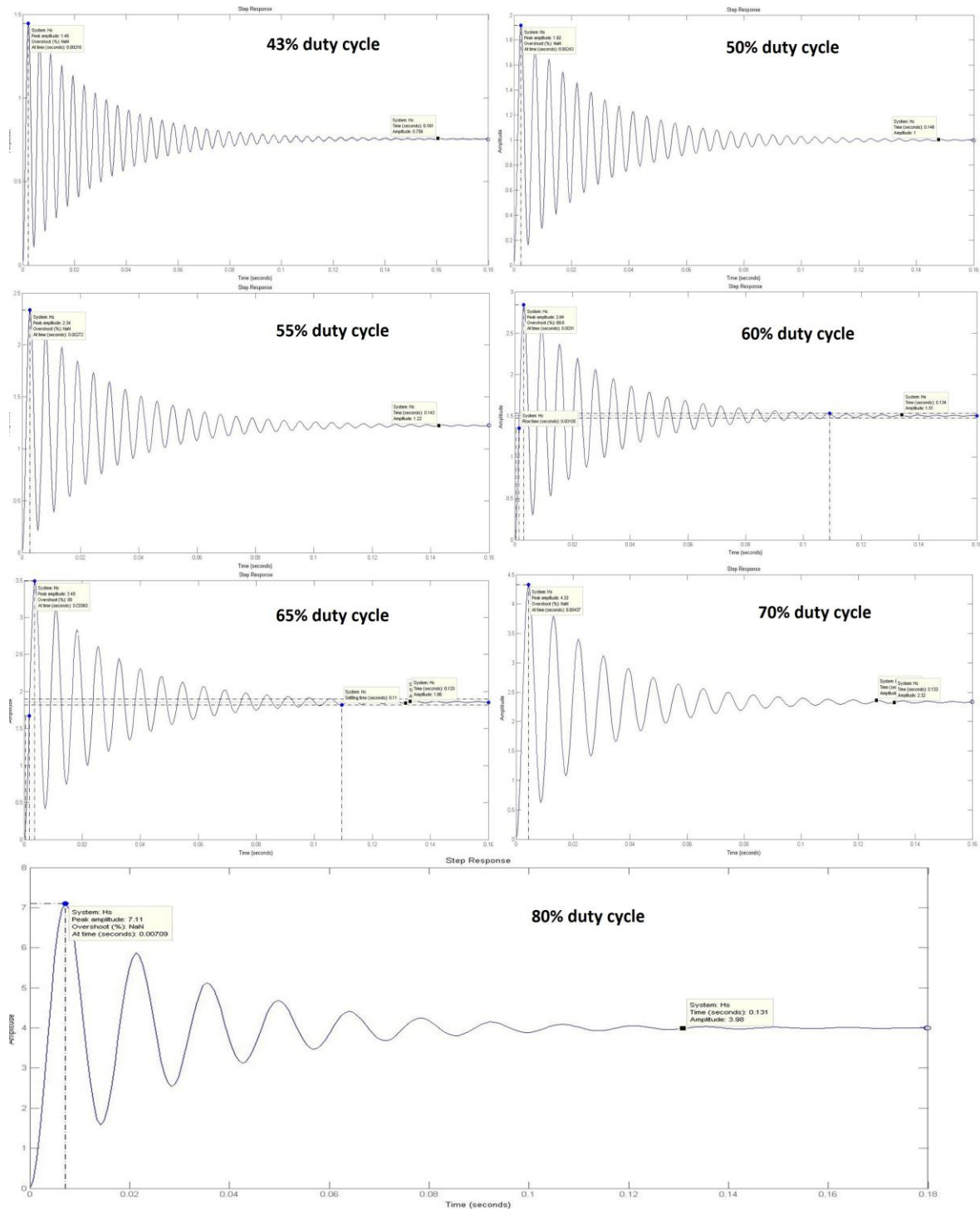
The voltage comparator and the microcontroller take the reference signal and automatically adjust the output voltage to desired level. **Table 6.4** shows the obtained results. A 12V battery is selected for charging and as voltage reference for the comparator.

**Table 6.4. Closed loop test of the sepic converter**

Input Voltage ( $V_{in}$ )	Output Voltage ( $V_{out}$ )
20	13.7
15	13.6
12.5	13.5
10	13.5
7.5	13.8
5	13.6
4	14

### 6.6 Modeled transfer function responses

The input to output relationship transfer function was modeled in Matlab and step responses were obtained for different duty cycles of the converter as shown in **Fig.6.1**.



**Fig6.1 Step responses for different duty cycles**

### 6.6.1 Results of developed model

The amplitude of the plots is used to obtain output voltage as the result by multiplying input voltage with the amplitude. **Table 6.5** shows the results obtained from modeling.

**Table 6.5. Results from modeling of the sepic converter**

Input Voltage ( $V_{in}$ )	PWM (%)	Output Voltage ( $V_{out}$ )
20	43	15.12
15	50	15
12.5	55	15.25
10	60	15.1
7.5	65	13.95
5	70	11.6
4	80	15.92

## 6.7 Comparisons of results

### 6.7.1 Comparison of output voltage

All the results obtained from modeling in matlab, simulation in proteus and experimental results are shown in **Table 6.6** for easy interpretation of all results.

**Table 6.6. Comparison of all the results of the sepic converter**

Input Voltage ( $V_{in}$ )	PWM (%)	Output Voltage ( $V_{out}$ ) from Modeling in Matlab	Output Voltage ( $V_{out}$ ) from Simulation in Proteus	Output Voltage ( $V_{out}$ ) Experimental
20	43	15.12	18	16.1
15	50	15	15	14.9
12.5	55	15.25	14.7	15.2

10	60	15.1	14.2	14.8
7.5	65	13.95	13.1	13.2
5	70	11.6	10.7	10.7
4	80	15.92	14.3	15.1

### 6.7.2 Comparison of percent error

**Table 6.7** shows the comparison of % error from modeling and simulation compared with experimental results. The following formula is used to calculate the percent error:-

$$\% \text{ Error from simulation} = \frac{\text{Experimental results} - \text{Simulated results}}{\text{Experimental results}} \times 100$$

$$\% \text{ Error from Modelling} = \frac{\text{Experimental results} - \text{Modelling results}}{\text{Experimental results}} \times 100$$

**Table 6.7. Comparison of % error of the results of the sepic converter**

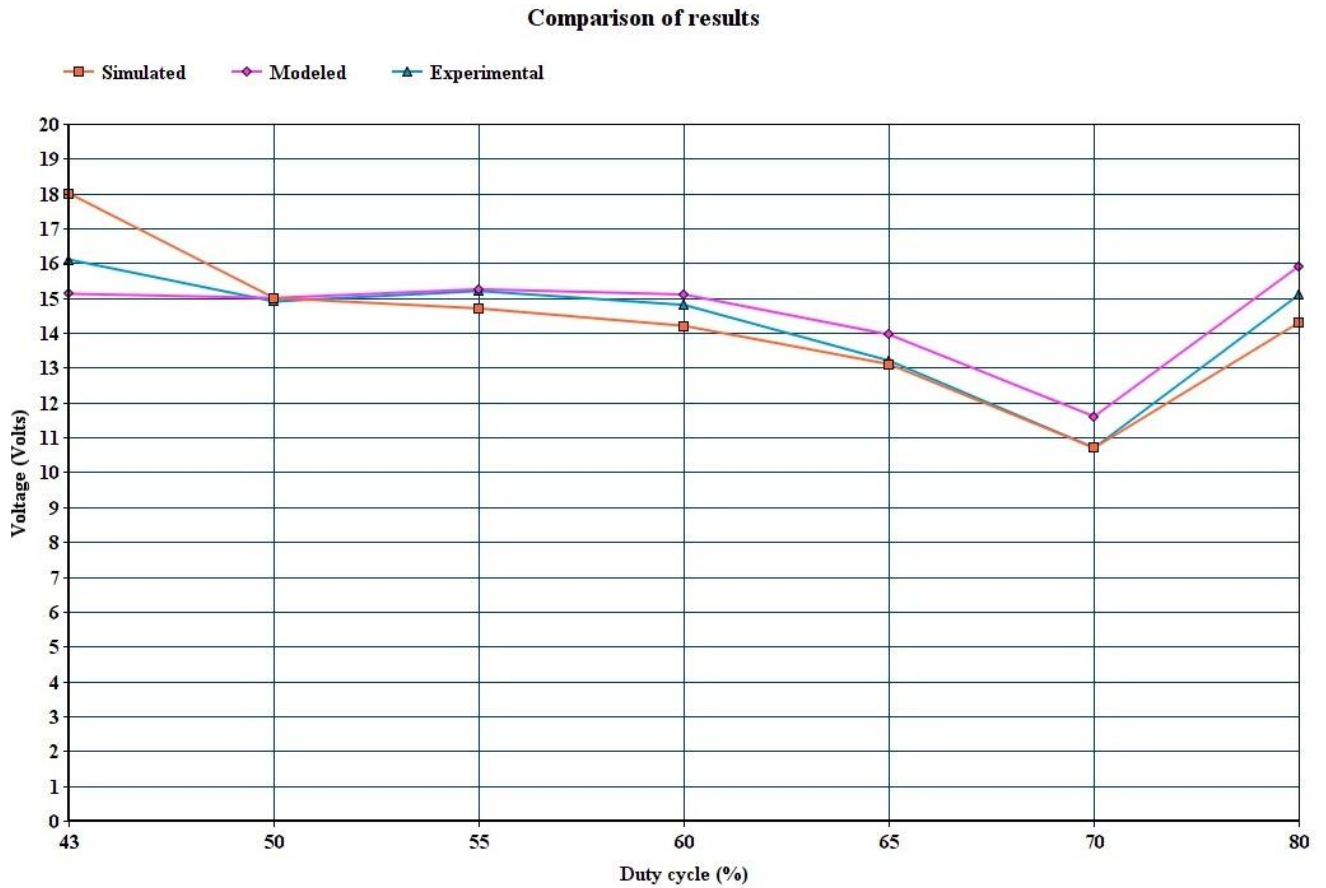
Input Voltage ( $V_{in}$ )	PWM (%)	% error from mathematical modeling results	% error from simulation results in proteus	Output Voltage ( $V_{out}$ ) Experimental
20	43	5.5	-11.8	16.1
15	50	-0.6	-0.6	14.9
12.5	55	-0.3	3.2	15.2
10	60	-2	4	14.8
7.5	65	-5.6	0.7	13.2
5	70	-8.4	0	10.7
4	80	-5.4	5.2	15.1

### 6.7.3 Graphical comparison of results

The graphical comparison of results is also done for easy understanding of the obtained results.

#### Open loop results comparison

Fig.6.2 shows the graphical comparison of simulated, modeled and experimental results.

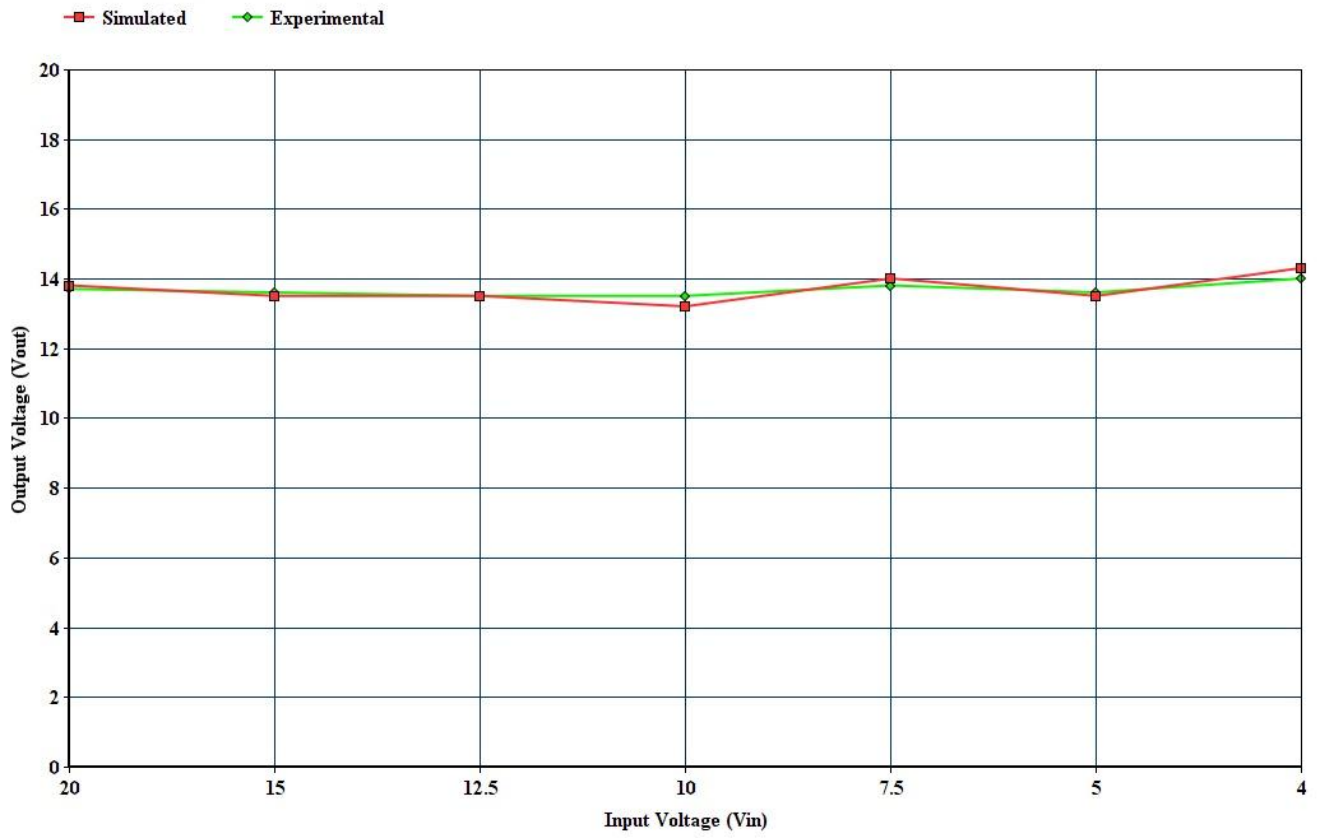


**Fig.6.2 Open loop results in the form of graph**

#### Closed loop results comparison

Fig.6.3 shows the graphical comparison of simulated and experimental results in closed loop.

### Comparison of results



**Fig.6.3 Closed loop results in the form of graph**

As we can see from the results, despite of varying input voltage conditions, the output of the convertor is almost constant in the specified range.

## **CHAPTER VII**

### **MAIN CONCLUSION AND FUTURE SCOPE OF WORK**

The proposed scheme of microcontroller controlled sepic converter for solar lighting. It is found to be an effective technique, and is helpful for application even in remote areas. All the design parameters and procedure have been discussed in detail in previous chapters. From the results it becomes clear that simulated and experimental results are almost same and can be used in the application system as discussed. The output voltage of the Sepic converter was found to be almost constant with varying input voltage according to designed parameters of the converter.

The future scope of this thesis work is to apply the following techniques-

1. Developing the system for 230-volt AC and DC applications.
2. Connect the system in Distributed Network grid.
3. To design efficient LED driver for current market power LED lighting system.



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## APPENDIX A

### Closed loop control parameters

For closed loop control, the parameters for controlling the output voltage in specified range are as shown below: -

S.NO	Control	Parameter	Action
1	Battery voltage	Duty cycle	Output voltage
2	Converter voltage	Duty cycle	Output voltage

### Parameter specification of PV module

Maximum power	$P_m$	5watt
Maximum voltage	$V_m$	17.5 Volt
Current at max power	$I_m$	0.3 Amp
Open circuit voltage	$V_{oc}$	21 Volt
Short circuit current	$I_{sc}$	0.35 Amp

### Parameter specification of converter

Input voltage range ( $V_{IN}$ ) =4-20 V

Output voltage ( $V_{OUT}$ ) =15V

Output current ( $I_{out}$ ) = 500mA

Voltage drop across diode = 0.5V

Output ripple current=30% of load current

Output ripple voltage=3% of load voltage

Switching frequency ( $F_s$ ) =10 KHz

## APPENDIX B

**Table B.1. Open loop simulation test of the sepic converter**

<b>Input Voltage (<math>V_{in}</math>)</b>	<b>PWM (%)</b>	<b>Output Voltage (<math>V_{out}</math>)</b>
20	43	18
15	50	15
12.5	55	14.7
10	60	14.2
7.5	65	13.1
5	70	10.7
4	80	14.3

**Table B.2. Open loop test of the sepic converter**

<b>Input Voltage (<math>V_{in}</math>)</b>	<b>PWM (%)</b>	<b>Output Voltage (<math>V_{out}</math>)</b>
20	43	16.1
15	50	14.9
12.5	55	15.2
10	60	14.8
7.5	65	13.2
5	70	10.7
4	80	15.1

**Table B.3. Closed loop simulation test of the sepic converter**

<b>Input Voltage (<math>V_{in}</math>)</b>	<b>Output Voltage (<math>V_{out}</math>)</b>
20	13.8
15	13.5
12.5	13.5
10	13.2

7.5	14
5	13.5
4	14.3

**Table B.4. Closed loop test of the sepic converter**

Input Voltage ( $V_{in}$ )	Output Voltage ( $V_{out}$ )
20	13.7
15	13.6
12.5	13.5
10	13.5
7.5	13.8
5	13.6
4	14

**Table B.5. Results from modeling of the sepic converter**

Input Voltage ( $V_{in}$ )	PWM (%)	Output Voltage ( $V_{out}$ )
20	43	15.12
15	50	15
12.5	55	15.25
10	60	15.1
7.5	65	13.95
5	70	11.6
4	80	15.92

**Table B.6. Comparison of all the results of the sepic converter**

Input Voltage ( $V_{in}$ )	PWM (%)	Output Voltage ( $V_{out}$ )	Output Voltage ( $V_{out}$ )	Output Voltage ( $V_{out}$ )
----------------------------	---------	------------------------------	------------------------------	------------------------------

		<b>from Modeling in Matlab</b>	<b>from Simulation in Proteus</b>	<b>Experimental</b>
20	43	15.12	18	16.1
15	50	15	15	14.9
12.5	55	15.25	14.7	15.2
10	60	15.1	14.2	14.8
7.5	65	13.95	13.1	13.2
5	70	11.6	10.7	10.7
4	80	15.92	14.3	15.1

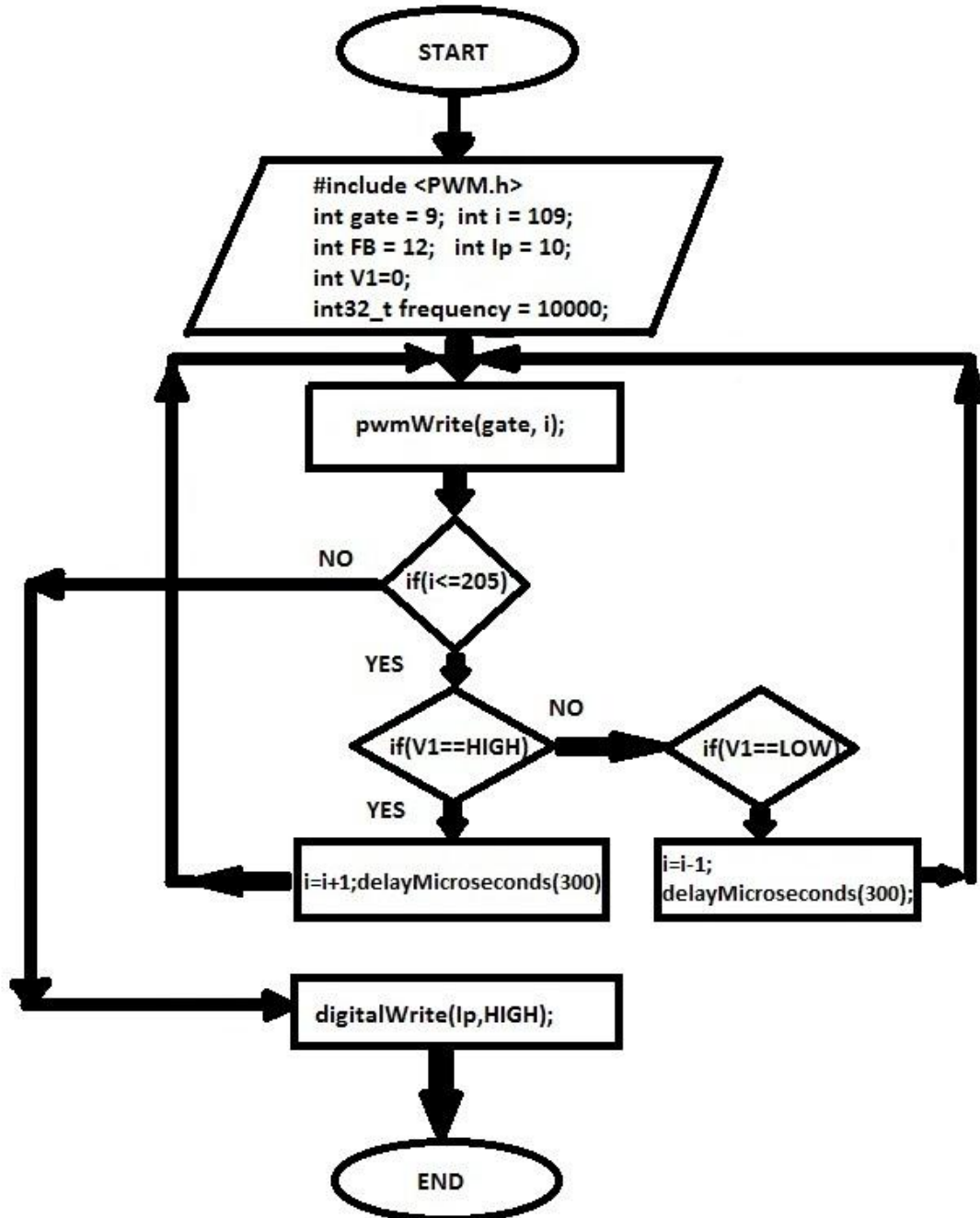
**Table B.7. Comparison of % error of the results of the sepic converter**

<b>Input Voltage (<math>V_{in}</math>)</b>	<b>PWM (%)</b>	<b>% error from mathematical modeling results</b>	<b>% error from simulation results in proteus</b>	<b>Output Voltage (<math>V_{out}</math>) Experimental</b>
20	43	5.5	-11.8	16.1
15	50	-0.6	-0.6	14.9
12.5	55	-0.3	3.2	15.2
10	60	-2	4	14.8
7.5	65	-5.6	0.7	13.2
5	70	-8.4	0	10.7
4	80	-5.4	5.2	15.1



# APPENDIX C

## C.1 Flow chart for PWM generation



## C.2 Pin diagram of Arduino328P Microcontroller

ARDUINO FUNCTION reset	PC6	1	15	PC5	ARDUINO FUNCTION analog input 5
digital pin 0 (RX)	PD0	2	16	PC4	analog input 4
digital pin 1 (TX)	PD1	3	17	PC3	analog input 3
digital pin 2	PD2	4	18	PC2	analog input 2
digital pin 3(PWM)	PD3	5	19	PC1	analog input 1
digital pin 4	PD4	6	20	PC0	analog input 0
	VCC	7	21	GND	
	GND	8	22	AREF	analog ref
crystal	PB6	9	24	AVCC	
crystal	PB7	10	24	PB5	digital pin 13
digital pin 5 (PWM)	PD5	11	25	PB4	digital pin 12
digital pin 6(PWM)	PD6	12	26	PB3	digital pin 11(PWM)
digital pin 7	PD7	13	27	PB2	digital pin 10(PWM)
digital pin 8	PB0	14	28	PB1	digital pin 9(PWM)

## C.3 Features of Arduino Microcontroller

- Low power 8-bit microcontroller with 28 pins
- 20MHz crystal frequency
- 32K Bytes self-programmable program memory
- 1K Byte EEPROM
- 2KB internal Static RAM
- 6 PWM channels (pin-3,5,6,9,10,11)

- Power on reset
- Internally calibrated oscillator
- 23-programmable I/O pins

Operating volt: (1.8-5.5)V

- Temperature range:

-40°C to 85°C

- Three ports (PB0-PB7),(PC0-PC6),(PD0-PD7)

Ports B, D are input-output ports having internal pull-up registers of 8-bit bidirectional

Ports C is/are input-output ports having internal pull-up registers of 7-bit bidirectional

## **C.4 Simulation setup of the circuit**

The simulation of the whole circuit is done using Proteus 8.2 professional, which offers wide components and live circuit simulations.

### **About Proteus**

Proteus is a software package for computer-aided design, simulation and design of electronic circuits. It consists of two main parts, the *ISIS*, the circuit design environment that even the simulator *VSM* includes, and the *ARES*, the PCB -Designer. Developer and manufacturer of the software package is the company Labcenter Electronics.

### **ISIS (Intelligent Input Schematic System)**

The *ISIS*, **I**ntelligent **S**chematic **I**nterface **S**ystem is the environment for the design and simulation of electronic circuits.

Its component library includes claims to more than 10,000 circuit components with 6000 Prospective simulation models. Own components can be created and added to the library.

ISIS includes a base-VSM engine with support for the following functionality:

- DC / AC voltmeter & ammeter, oscilloscopes, logic analyzers
- Analog signal generators, Digital Pattern Generator
- Timer functions, protocol analyzers (eg RS232, I2C, SPI)

### **VSM (Virtual Modelling System)**

The VSM, **Virtual System Modeling** , provides a graphical SPICE circuit simulation and animation directly in the ISIS environment. It may microprocessor-based systems are simulated. With the VSM-Engine can interact during the simulation directly to the circuit. Changes of buttons, switches or potentiometers are queried in real time as well as LED indicators, LCD display and "Hot / Cold" -Wires displayed.

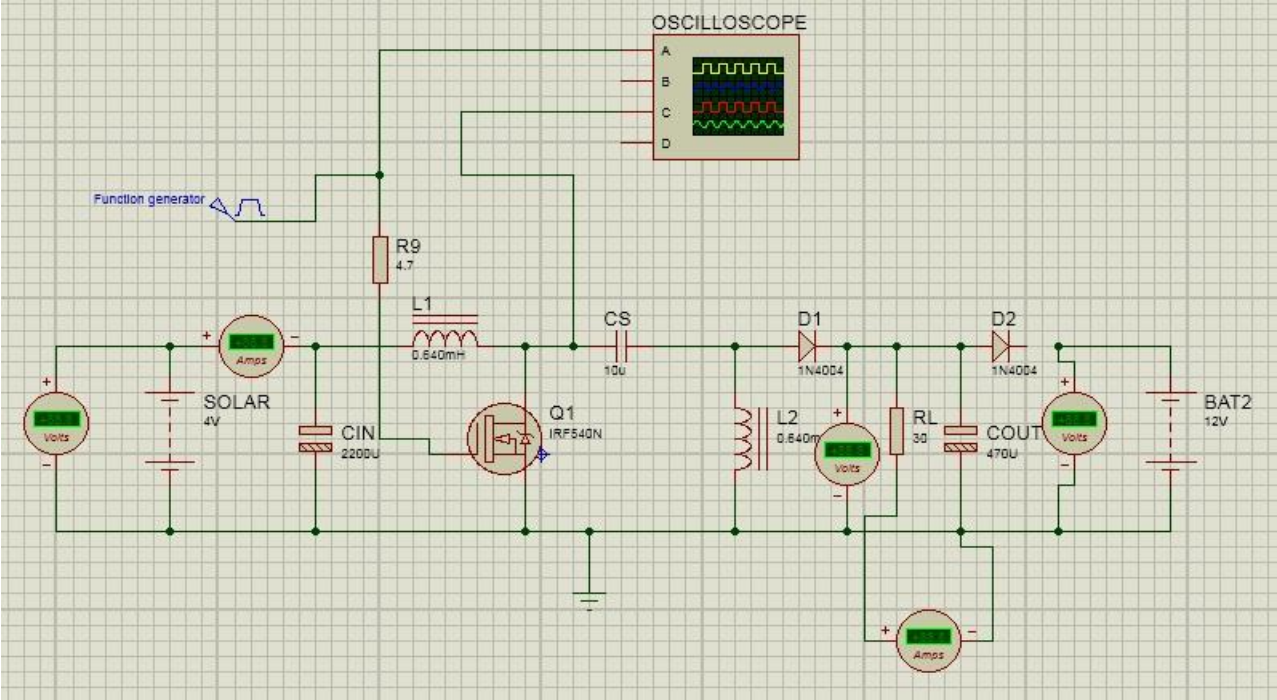
### **Proteus VSM for microcontrollers**

- PIC12 / PIC16 / PIC18
- PIC24 / PIC33
- HC11
- 8051/8052
- BASIC Stamp
- ATMEL AVR
- 8086
- MSP430

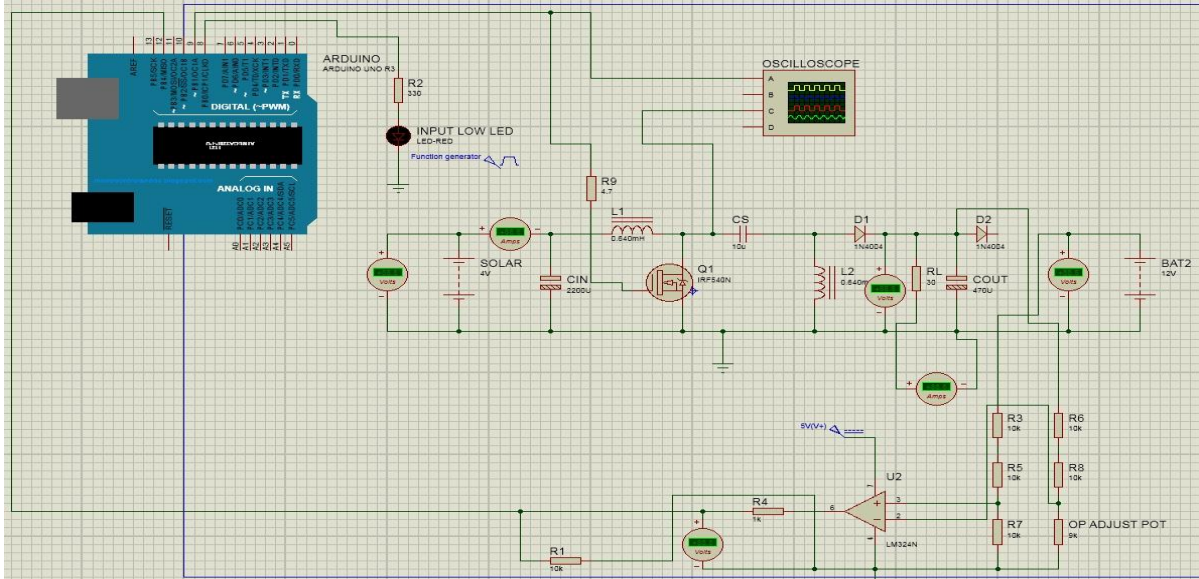
It also includes a debugging environment for the program code of the microcontroller. To simulate the .HEX and .COF file of the compiled software are necessary. The clock is also simulated in real time.

**Simulation setup for sepic converter**

The simulation of the circuit is done in two phases, i.e. in open loop and closed loop. The simulation of the system is done in Proteus 8.2 professional, and the screen setup for open loop simulation looks like as shown below in **Fig.C.1.A & B**



**Fig.C.1A Open loop Simulation setup in Proteus**

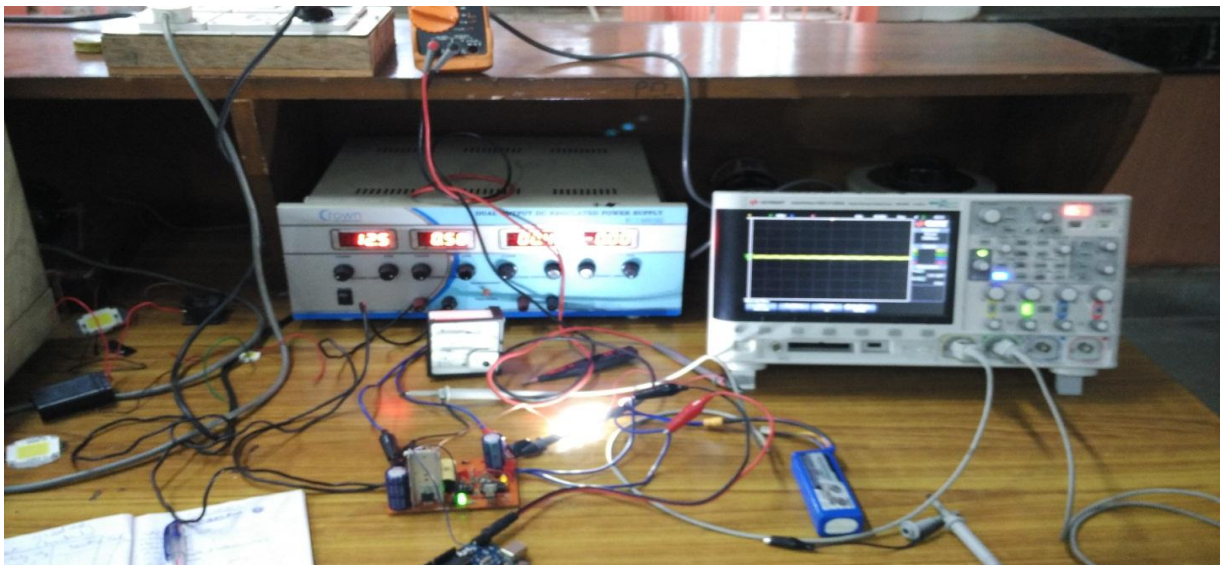


**Fig.C.1B Closed loop Simulation setup in Proteus**

A function generator will be used for open loop simulation and Arduino microcontroller and an op amp as voltage comparator will be used for closed loop simulations.

### **C.5 Experimental setup of the circuit**

The hardware mainly consists of sepic converter circuit, microcontroller board, variable input voltage source and the output battery to be charged, as shown in the figure below.



**Fig.C.2 Hardware setup for circuit testing**