

Design and Implementation of a Solar Based Smart Street Lighting System

A dissertation submitted in fulfillment of the requirements for the Degree
of

MASTER OF ENGINEERING

in

Power Systems

Submitted By

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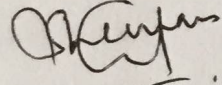
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DECLARATION

I hereby certify that the work which is presented in dissertation entitled, "*Design and Implementation of a Solar Based Smart Street Lighting System*", in fulfillment of the requirements for the award of the degree of **Master of Engineering in Power Systems**, submitted to Electrical & Instrumentation Engineering Department of Thapar University, Patiala is as authentic record of my own work carried under the supervision of **Mr. Shakti Singh**. It refers others researchers work which are duly listed in the reference section. The matter contained in this dissertation has not been submitted, neither in part nor in full to any other degree to any other university or institute except as reported in text and references.

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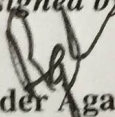
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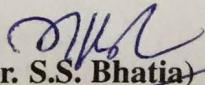
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ABSTRACT

Street lights are pervasive everywhere in almost every nook and cranny in a city. The conventional street lighting system administered physically offers many drawbacks such as high power consumption, high cost, wastage of power, no LDR (light dependent resistor) sensor, battery theft problem and there is no effective monitoring system. This work represents the performance of photovoltaic (PV) based smart street lighting system for energy storage and intensity control of light application. The system is controlled by a microcontroller unit STM8S003F3P6 by discerning the PV cell voltage and triggering pulse width modulation (PWM) wave to limit intensity based upon state of charge (SOC) of battery. Light emitting diodes (LED) lighting technology is used which offers many benefits like reduction in power consumption, environment friendly, long life time expectancy, high luminous efficacy and no toxic content. The cell type battery is used mounted on printed circuit board (PCB) which remains away from battery theft problem. This proposed design has advantages such as low power consumption, small size, effective monitoring, extend in service life of lighting equipment and high luminous efficacy.

Keywords: *Solar based smart street light, energy storage, intensity control, STM8S003F3P6, LEDs, PIC16F887.*

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LIST OF ABBREVIATIONS

DC	Direct Current
PV	Photo-Voltaic
PCB	Printed Circuit Board
PWM	Pulse Width Modulation
MCU	Micro-Controller Unit
AC	Alternating Current
CNG	Compressed Natural Gas
LED	Light Emitting Diode
LDR	Light Dependent Resistor
PCC	Peak Current Control
HCC	Hysteretic Current Control
SLA	Service Level Agreement
VRLA	Valve Regulated Lead Acid
VR	Variable Resistor
ADC	Analog to Digital Comparator
SOC	State of Charge
TIM2_ARR	Timer 2 Auto Reload Register
TIM2_CCR	Timer 2 Compare/Capture Register

Chapter 1

INTRODUCTION

1.1 Street lighting system

A street light is a raised source of light on the edge of a road or walkway. Monitoring and governing the street lights are of utmost importance in order to reduce the power consumption and to increase the life of the battery. The street lighting system offers many advantages such as prevent the road accidents, provides high safety, reduces the risk of pedestrians crashes. Globally, millions of dollars are spent each day on the incandescent bulb based street lights that requires high maintenance and replacement costs. The traditional street lighting system controlled manually has many disadvantages such as high power consumption, high cost, wastage of power and there is no effective monitoring system [1]. The simple and effective solution to this would be control of light intensity during off peak hours and depending on power available as well i.e. effective management of power known as smart street lighting system. Smart street light have the light sensitive photocells that activate automatically when light is or is not needed depending on dusk, dawn or the onset of dark weather [2].

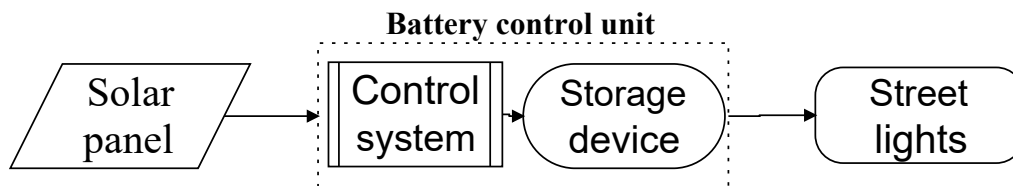


Figure 1.1: Layout of a conventional street light system

Fig. 1.1 shows complete layout of a conventional street light system. It consists of solar energy

source, storage device and street lights. It stores the solar energy in storage device through control system and feed the street light during night.

Light emitting diodes (LED) are used as street lights. It is a lighting system depending on p-n junction semiconductor material. It generates photons by effective recombination of charge carriers. The junction is formed by the combination of p type and n type material. The positive layer in p side represents the number of acceptors and the n side layer depicts the number of donors of charge carriers. When electric current flows, the electrons are energized from one layer to another layer to recombine with the holes hence, generating a photon [3]. This lighting technology offers many advantages such as:

- Reduction in power consumption
- Dimmable control
- Small in size and robust in design
- Long life time expectancy
- No toxic content and easy to recycle
- Has short start and re-starting time
- High luminous efficacy
- Low heat load

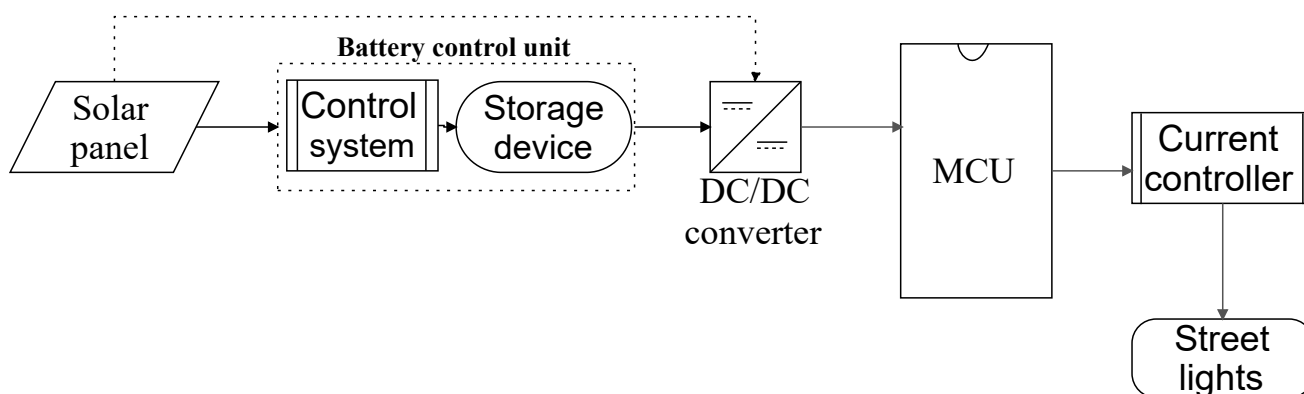


Figure 1.2: Layout of a smart street light system

Fig. 1.2 shows complete system layout of a solar based smart street lighting system. The proposed smart street lighting system designed consists of solar energy source, storage device, micro-controller, DC/DC (direct current) converter and street lights. The micro-controller senses the output of the DC/DC converter topology. For effective intensity control, pulse width modulation (PWM) is generated by the micro-controller unit based on charging and discharging rates of battery.

Features	Conventional street light system	Solar based smart street light system
Initial cost	Low	High because of high cost of solar panels, battery and LEDs
Overall maintenance cost	High because of high cost of electricity	Low because electricity is generated from sun
Ecosystem	Less ecofriendly because of more pollution and high toxic content	More ecofriendly as there is no pollution or emission of gases
Running cost	High	Low
Safety	Less as there is risk of short circuit of wires used	High as there are no wires used
Lifespan	Less	More
Size of battery	Greater which causes battery theft problem	Reduced to a level so as to prevent the system from battery theft problem
Electrical efficiency	low (30-50)%	High (85-95)%

Table 1.1: Comparison of conventional and smart street light system

1.2 Solar power generation

The various number of solar cells are combined to form solar panels. Solar panels convert the solar energy into usable power. The electricity generation from the solar module involves two process:

- Photoelectric effect: The energy is provided to electrons when photons hit the surface layer.
- Electrochemical process: The electric current is produced by rearranging the excited electrons in series, hence, generating electric potential [4].

We can store the power in batteries or use immediately or sell it to the utility grid based on the pervasive tariffs.

1.2.1 Distribution of solar energy

- Solar energy for utilities: The electricity is generated to sell to the power utilities. It is generated in large scale acquiring large area of land and high capital cost. Some plants have a agreement signed with the utility.
- Solar energy for customers: The electricity is generated to be used inside the premises itself. It requires lesser area and less capital cost. It consists of two parts:
 - Grid connected mode: The solar power plants are connected to the power utility. They either sell the power to the utility grid or use it for their own purpose and sell only surplus power to the grid.
 - Islanded mode: The solar power plants are not connected to the power utility. The whole generated electricity is used by themselves and surplus power is stored in batteries for future use.

1.2.2 Photo-voltaic (PV) based electricity generation

- Solar panels: Solar panels are the combination of various solar cells stacked together. These modules uses the photons energy to produce electricity. The bigger the size of panel, the higher is the generation capacity and vice versa based on the investment and location.

- DC/AC converter: The DC power produced by solar energy is converted into alternating current (AC) to sell it to the utility grid i.e., the converter behaves like a protection between solar system and the utility end.
- Storage batteries: The excess power generated is preserved in batteries for future use i.e., the excess power is not sold to the utility grid.
- Smart meter: The number of units of electricity produced is calculated. The calculation is required for the sale of electricity to the power utility.

1.2.3 Factors affecting solar power generation

The various factors that affect solar power generation are listed as follows:

- Location, tilt and orientation of solar panel
- Efficiency of battery
- Temperature
- Shading
- Efficiency of solar module

1.3 Literature survey

Now a days the majority of the energy is attained from fossil fuels like diesel, petrol, coal or compressed natural gas (CNG) which are present finitely. So, the renewable energy sources are achieving popularity in the world. Solar energy is the best apparent solution. The appealing characteristic of solar energy is its availability everywhere. It also has low set up cost than other forms of renewable energies. It is turning out to be more famous because it has many advantages like free pollution, low maintenance, and is noise free [4].

Solar energy is being harnessed to power street light. Latest LED lighting technology is used which offers many benefits like reduction in power consumption, environment friendly, long life time expectancy, high luminous efficacy and no toxic content. Remote control system uses zig

bee modules and simplifies management problem and maintenance problem [5]. Light dependent resistor (LDR) sensor is used which automatically switches ON and OFF lights when sunlight goes and comes visible to the eyes [2].

LEDs are current driven devices and are stacked in series to provide sufficient light output. Luminous intensity and chromaticity of a white LED is proportional to the forward current. Flyback converter and forward converter operates one active power switch. The converting power is transferred to obtain current regulation and PWM dimming. It attains high efficiency and dominates if we connect more number of LEDs in series [6]. The microcontroller and the DC-DC converter output drives the output LEDs. Each LED current is controlled independently. The efficiency can be raised by maintaining the drain voltage of MOSFET to minimum. It results in regulation of the duty cycle of PWM [7].

In [8], the author In-Hwan Oh has explained that if the input voltage varies widely, then current inaccuracy problem occurs. It causes major problem for driving high brightness power LEDs. Buck and buck boost converter uses peak current control (PCC) and hysteretic current control (HCC) method for accurate results. Hence, it can be concluded from observations that HCC method shows more accurate results as compared to PCC. In [9], the high power LEDs connected in parallel are driven using PWM dimming control method. The results are efficient enough if there is a change in step of peak driving current. The execution of the method can be upgraded by adjusting the output voltage of DC-DC SRC drivers. The AC-DC LED driver uses flyback converter to drive high brightness LEDs which has a long life span.

The reliability of the system is increased by injecting third and fifth harmonics into input. Hence, it lowers down the output peak to average ratio [10]. Either DC signal or pulsating signal applied to various topologies like the buck, boost or flyback converter is used to feed the LED strings. The use of an electrolytic filtered capacitor is also eliminated. We can also supply resonant operating drivers for LEDs without smoothing capacitor. The output current remains invariable eliminating the use of current sensor or back control circuit [11]. LED circuit contains many continuous current regulators as well as voltage pre-regulators. To attain the required current, the output voltage is maintained at a required lower level. The system was tested on multiple LED string consisting of eight LEDs in each string respectively and hence, resulted in 15% higher efficiency [12].

PWM dimming technique controls the intensity of street light and controls the output current. As the input voltage varies, it results in higher efficiency and power factor by using a coupled inductor power factor correction boost converter [13]. LED string is operated by using PWM dimming technique. It feeds one active power switch. A part of the converted power manages the current regulation. High efficiency is achieved when number of LEDs are connected in series [14]. Based on estimator, incandescent flux should be measured to attain an enriched continuous dimming control of the system. Once the estimator is authenticated by the PWM dimming technique, the electronic driver feeds the LEDs [15]. A lot of energy is wasted by using LDR as the light during night is too bright resulting in low consistency. So time control method and time optical control is used. It reduces labour intensity and labour cost and improves efficiency of street light control [16].

1.4 Research gap

It can be inferred from the literature survey that hardware design of solar based smart street lighting system needs to be investigated. In [5], the author utilize solar energy to power street lights and uses Zig bee modules for remote control systems. In [2-16], LDR sensor is used for automatic control of street lights but it leads to low reliability of the system as the night street lighting is too bright leading to wastage of energy. Hence, PWM dimming technique must be used for intensity control based on state of charge (SOC) of battery and time i.e. intensity must be high during peak load hours and reduces automatically with time. In [13-15], PWM dimming technique is used to drive LED lamp driver consisting of number of LEDs in series. This technique regulates the LED current and brightness for low power lighting applications. The AC-DC LED driver uses flyback converter to drive high brightness LEDs which has a long life span. The reliability of the system is increased by injecting third and fifth harmonics into input. Hence, it lowers down the output peak to average ratio [10]. LED circuit contains many continuous current regulators as well as voltage pre-regulators. To attain the required current, the output voltage is maintained at a required lower level. The system was tested on multiple LED string consisting of eight LEDs in each string respectively and hence, resulted in 15% higher efficiency [12]. Thus, there arises a need to design and implement solar based smart street lighting system by using latest LED technology and to

prevent battery theft problem by reducing its size.

1.5 Motivation and objective

It can be concluded from the literature survey that a very less work has been done on the design and implementation of solar based smart street lighting systems. The traditional street lighting system controlled manually has many disadvantages such as high power consumption, high cost, wastage of power and there is no effective monitoring system. A very limited work has been found in literature with respect to the intensity control of lighting system thus, considering the PWM dimming technique based on charging and discharging rates of batteries. So there is a need for hardware implementation of smart street lighting system by utilising the solar energy to save electricity and deteriorate pollution. Automatic ON or OFF of street lights must be made depending on darkness or light to diminish the manual work. Moreover, the latest LED technology to be used which offers many benefits like reduction in power consumption, environment friendly, long life time expectancy, high luminous efficacy and no toxic content.

1.5.1 Objectives

- Hardware implementation of smart street lighting system for effective intensity control based on charging and discharging rates of batteries.
- Design of smart street lighting system by using latest LED technology which are technologically advanced and energy efficient, thus minimizing the power consumption and lasts longer.
- To harness solar energy for automatic control of smart street lights for economizing the electricity as well as improving the performance characteristics of battery to ensure a stable operation of system.

1.6 Organization of thesis work

- **Chapter 1** displays the introduction of smart street light using solar energy, literature survey, research gap, motivation and objectives and organization of the research work.
- **Chapter 2** describes the system architecture, converter topology, PWM techniques and various rechargeable batteries.
- **Chapter 3** explains the methodology adopted for implementation of smart street lighting system.
- **Chapter 4** discusses about the results obtained by using lead acid battery and lithium ion battery.
- **Chapter 5** discusses about the conclusion of the research work and its future work.

Chapter 2

SYSTEM DESCRIPTION

The solar PV system feeding the street light, able to operate in both grid connected and islanded mode is considered. However, the main focus of the proposed work is on intensity control of street lights during off peak hours. The smart street light system consists of a PV unit for the purpose of electricity generation. To deal with the intermittent nature of generation units, the lithium ion rechargeable batteries are connected which get charged and discharged through the charge controller and buck converter. The number of LEDs are connected in series consisting of 16 strings in parallel. The string can be disconnected if the available power is less or is under maintenance. The intensity of light is automatically controlled based on PWM generation for enhancing the reliability of the system.

2.1 Smart street lighting system architecture

A complete schematic diagram of the smart street lighting module is demonstrated in Fig. 2.1. The solar panel is used as a source for power generation. When it receives energy during day time, it charges the battery via charge controller circuitry. The charge controller allows the current to flow in one direction only i.e. it opposes the reverse flow of current. The stored energy is used for lighting street lights. Automatic ON/OFF of street lights is done by a LDR sensor. Buck converter steps down the input voltage to feed to the microcontroller unit generating PWM signals. The street light intensity is controlled automatically based upon charging and discharging rates of battery and during off peak hours.

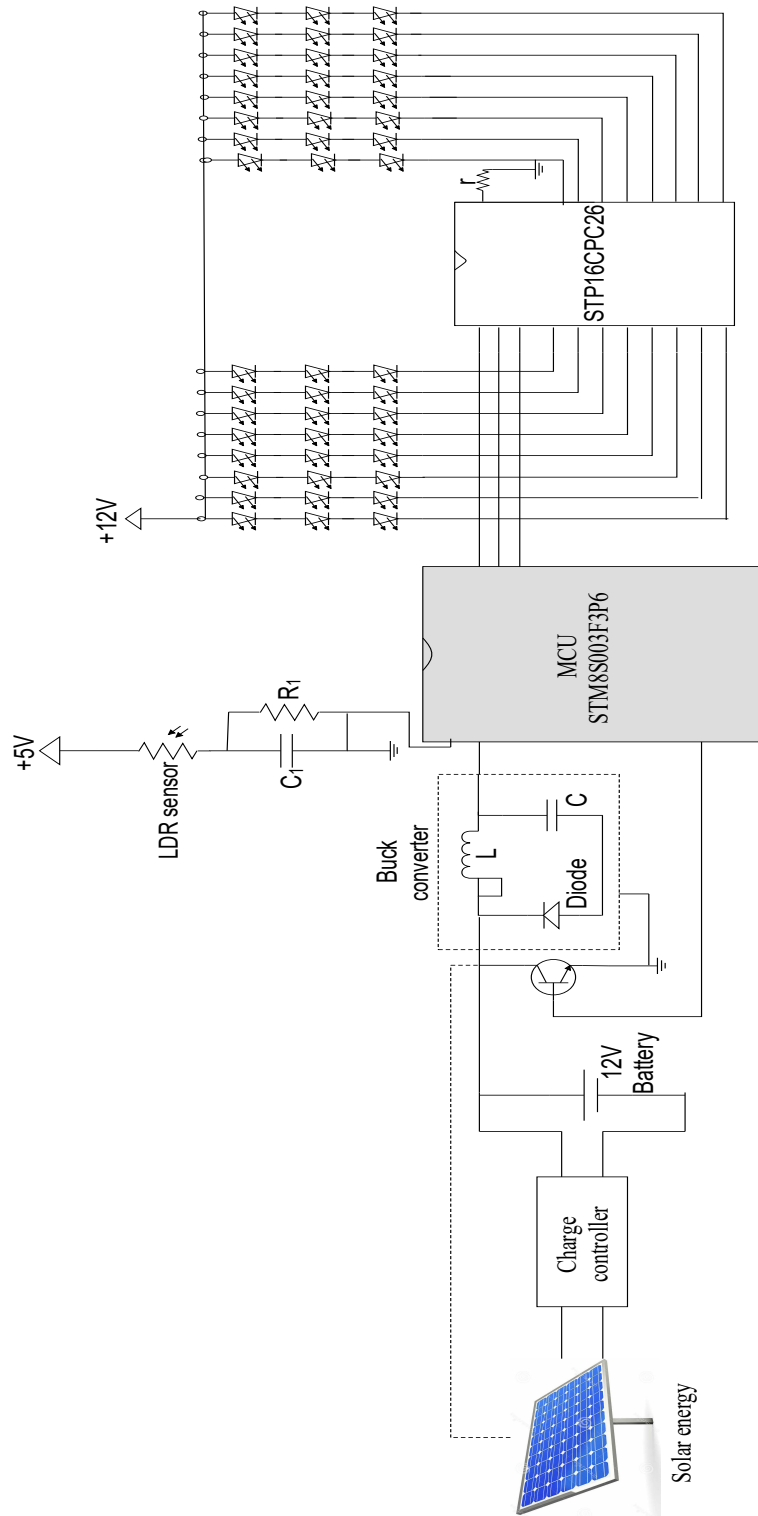


Figure 2.1: Schematic representation of the smart street lighting system

2.2 PV array characteristics

PV arrays consists of solar-voltaic material which converts the solar energy into electrical energy. Solar cells are used in PV based systems. It consists of various components like electrical and mechanical connections, various types of mountings and regulations required to modify the electrical output. We can directly feed small loads like lighting system or small DC motors with the help of power available. The solar cell behaves as a diode when there is no light present. The electric model of solar cell is depicted in Fig. 2.2 [4].

The output load current of a solar cell is represented in the following equation:

$$I_L = I_{se} = I_l - I_d - I_{sh} \quad (2.1)$$

$$I_L = I_l - I_S \left[\exp \left(\frac{V_L + I_{se} R_{se}}{V_T} \right) - 1 \right] - \frac{V_L + I_L R_{se}}{R_{sh}} \quad (2.2)$$

where, I_L and V_L are the output current and output voltage, I_l is current generated by light, I_S represents reverse saturation current of diode, V_T is the thermal voltage, R_{se} and R_{sh} series and shunt parasitic resistances.

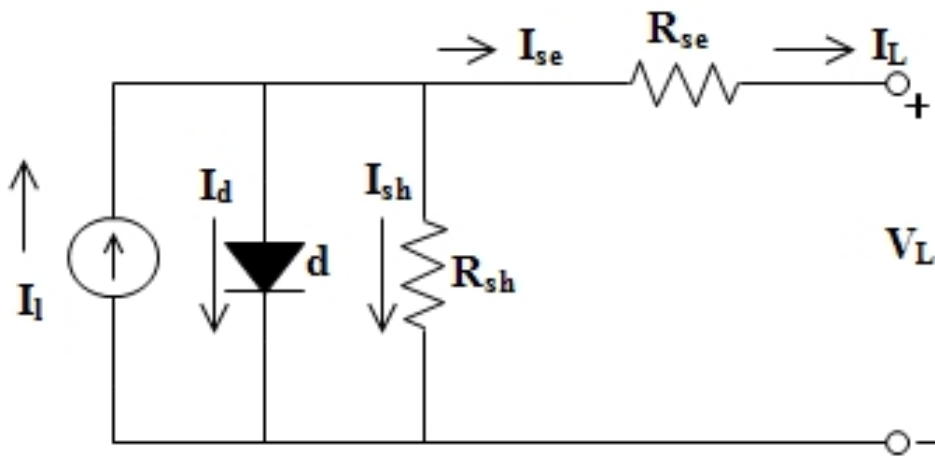


Figure 2.2: Electrical circuit diagram of a solar cell

2.3 Buck converter

A buck converter steps down the DC supply voltage from its input supply to its output load as represented in Fig. 2.3. It contains dc supply V_{in} , single pole single throw switch S , filter inductor L , pn junction diode D , ceramic capacitor C , and output resistive load R . The buck converter works in two of the following modes as represented in Fig. 2.4 and Fig. 2.5 [4].

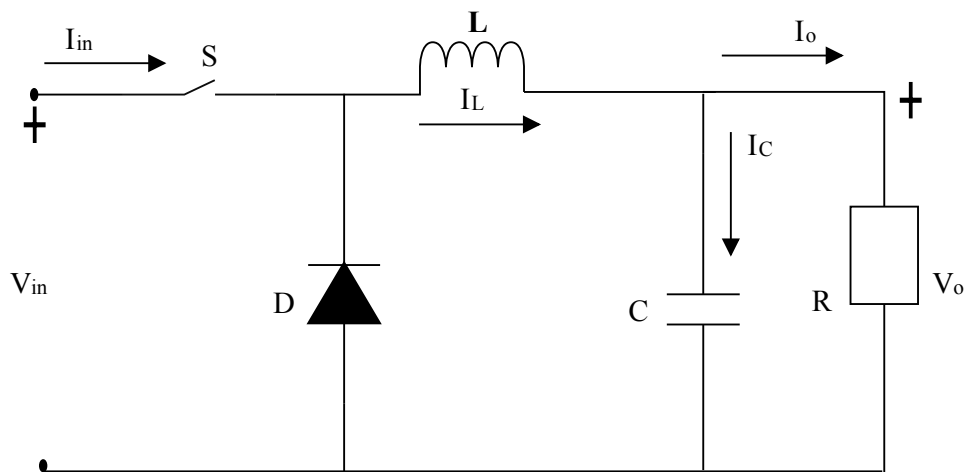


Figure 2.3: Equivalent model of a buck converter

Mode 1 operation: As the switch S is turned on, the amount of current that passes through the inductor L denies the rise in current and stores energy in its electromagnetic field. Diode D is reverse biased.

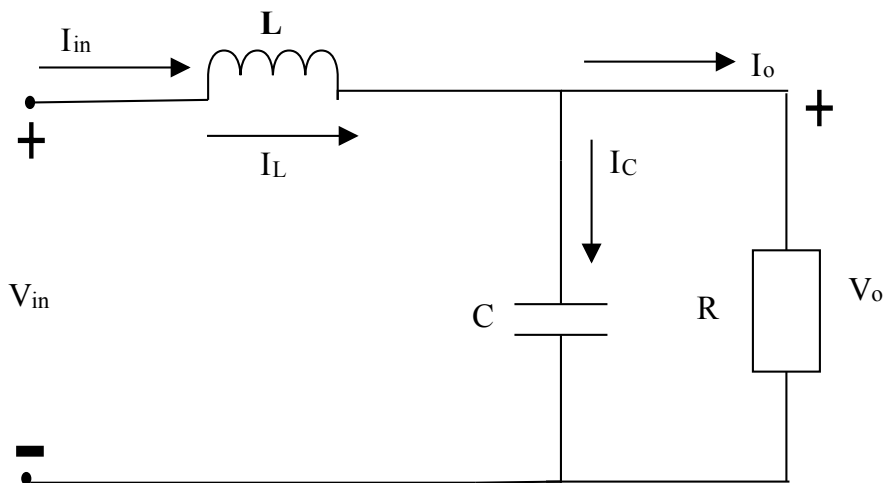


Figure 2.4: Buck converter mode 1 operation

It develops a positive voltage drop across inductor when there is a rise in its current. It results in lesser output in compared to the input supply. So, inductor behaves like a current source to the output resistive load [18].

Mode 2 operation: In Fig. 2.5, when switch S turns off, diode D is forward biased. The stored energy is contributed in inductor (magnetic energy) and capacitor (electric energy). A negative voltage drop is developed across the inductor when there is a fall in its current. As one end of inductor is grounded, so other end is at a higher potential generating the desired output voltage. The capacitor operates as a low pass filter. As the fluctuating current flows through the inductor, so output capacitor reduces the ripple in its output voltage [18]. Fig. 2.6 represents the output voltage V_L and output current I_L signal of inductor with respect to time.

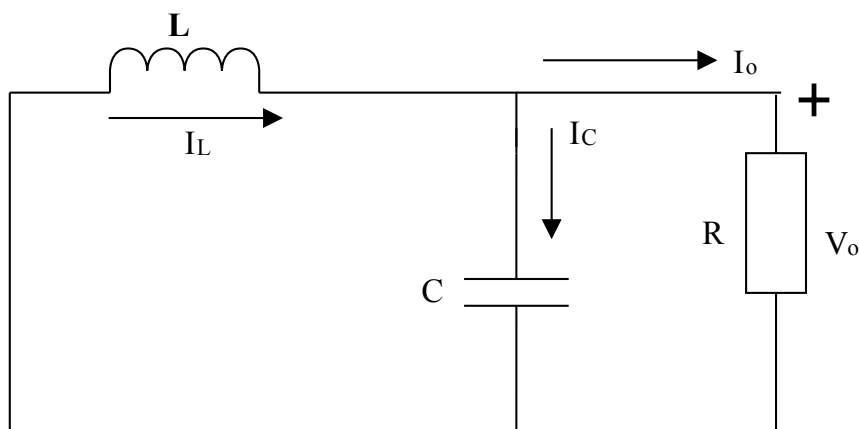


Figure 2.5: Buck converter mode 2 operation

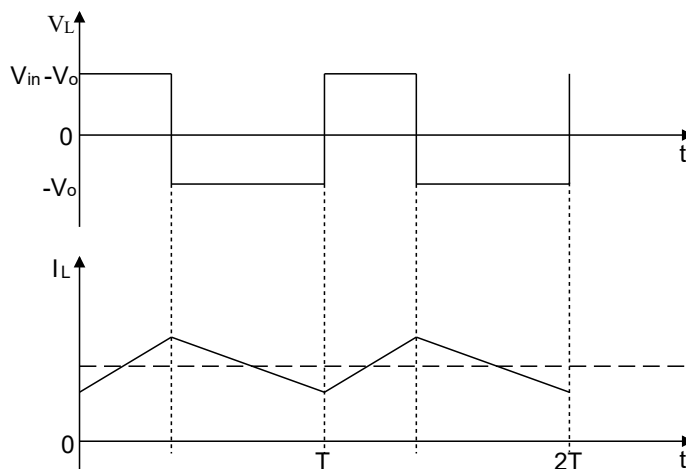


Figure 2.6: The output voltage V_L and current I_L signal of inductor with respect to time

2.4 PWM techniques

PWM technique is also called internal control method having constant frequency and magnitude and fluctuating pulse width. The pulse width fluctuates depending on the modulating signal. This method not only controls the voltage but all the specified harmonics are also reduced. Hence, it is very powerful technique. There are two types of PWM signals:

- **Symmetric PWM signal:** The output of symmetric PWM signal is always in symmetry wrt the centre of each pulse. Hence, it reduces the harmonic content in its output.
- **Asymmetric PWM signal:** The output of asymmetric PWM signal is having the same side alignment with one end of each signal.

The three types of PWM techniques are discussed below:

- **Single PWM:** It consists of two pulses in a complete cycle i.e., only one pulse in a half cycle. The output voltage is controlled by fluctuating the pulse width. The reference signal is compared with the modulating signal to generate the square wave signal as shown in Fig. 2.7.

The root mean square (rms) value of pulse width modulated output is:

$$V_{Orms} = V_S \sqrt{\frac{2d}{\pi}} \quad (2.3)$$

where V_S is the supply voltage, V_O is the output voltage, $2d$ represents the width of the pulse width modulated output.

The instantaneous value of PWM output is:

$$V_{on} = \sum_{n=1,3,5}^{\infty} \left[\frac{4V_S}{n\pi} \sin\left(\frac{n\pi}{2}\right) \sin(nd) \sin(n\omega t) \right] \quad (2.4)$$

The rms value of PWM output is:

$$V_{onrms} = \sum_{n=1,3,5}^{\infty} \left[\frac{4V_S}{\sqrt{2}n\pi} \sin\left(\frac{n\pi}{2}\right) \sin(nd) \right] \quad (2.5)$$

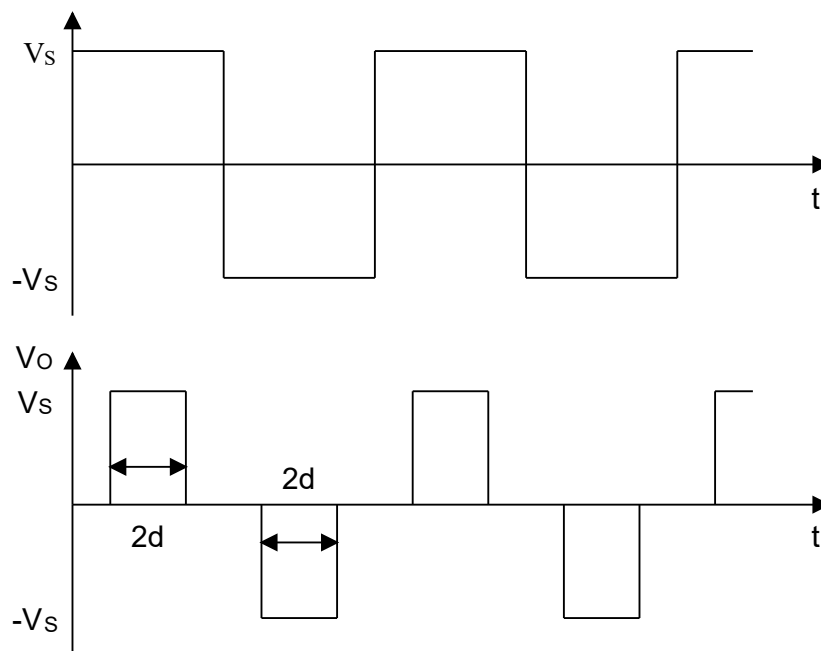


Figure 2.7: Gate signal generation by using single PWM

To eliminate the n^{th} order harmonics, put $nd = \pi$ in above equation.

Therefore, $V_{on} = 0$

$$d = \frac{\pi}{n} \quad (2.6)$$

By using this technique, the low order harmonics are easily eliminated. We can use filters to eliminate higher order harmonics because in this method, if order increases, pulse width decreases and hence, V_{Orms} decreases respectively.

- **Multiple PWM:** In this technique, there are two wave signals. One is carrier wave signal which is a triangular wave and other is reference wave signal which is a square wave. The two signals are compared in a comparator and sent to the trigger pulse generator which generates the pulses as shown in Fig. 2.9. Fig. 2.8 represents the block diagram of multiple PWM.

In Fig. 2.9, V_C is the amplitude of the carrier wave signal, V_R is the amplitude of reference signal, T_C is the carrier signal time period, T_R is the reference signal time period, f_C is the frequency of carrier signal, f_R is the frequency of reference signal, N is the number of pulses for half cycle m is the modulation index.

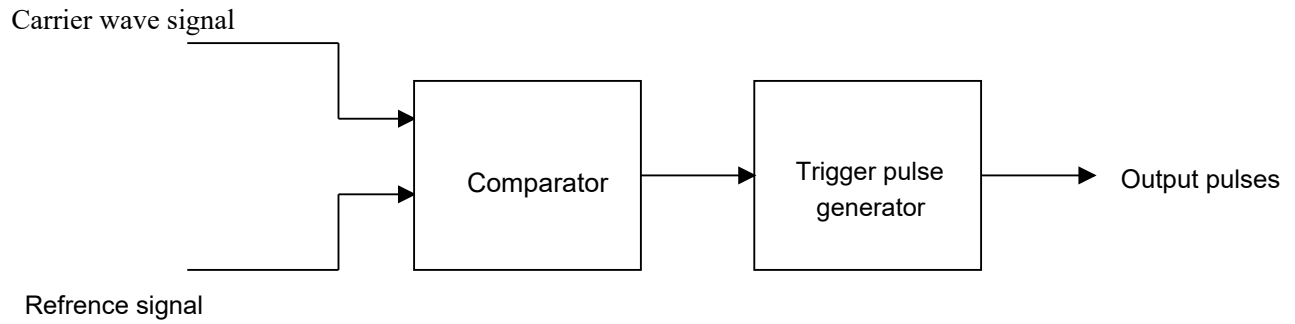


Figure 2.8: Block diagram of multiple PWM

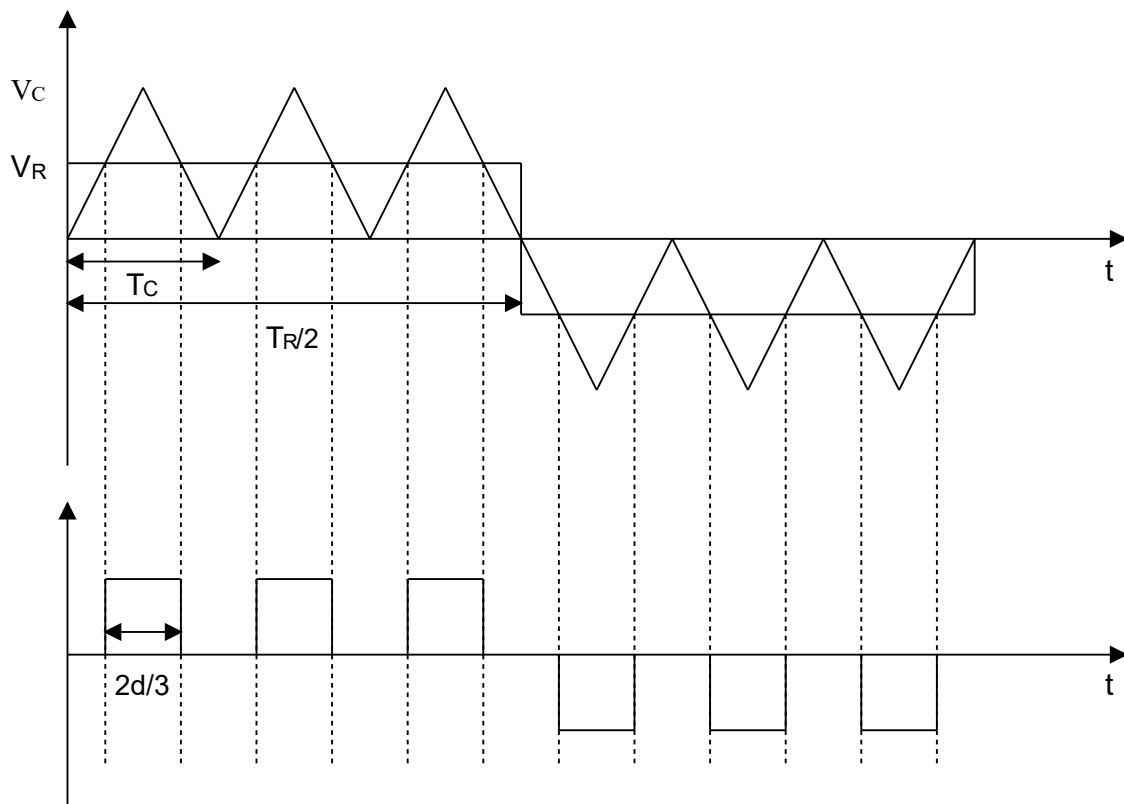


Figure 2.9: Gate signal generation by using multiple PWM

If $V_C \geq V_R$, pulse is generated as demonstrated in fig. 2.9.

$$\frac{T_R}{2} = 3T_C \tag{2.7}$$

$$N = \frac{f_C}{2f_R} \tag{2.8}$$

$$Pulsewidth = \left(1 - \frac{V_R}{V_C}\right) \frac{\pi}{N} \quad (2.9)$$

$$m = \frac{V_R}{V_C} \quad (2.10)$$

- **Sinusoidal PWM:** In this technique, there are two wave signals. One is carrier wave signal which is a triangular wave and other is reference wave signal which is a sinusoidal wave. The two signals are compared in a comparator and sent to the trigger pulse generator which generates the pulses as shown in Fig. 2.10.

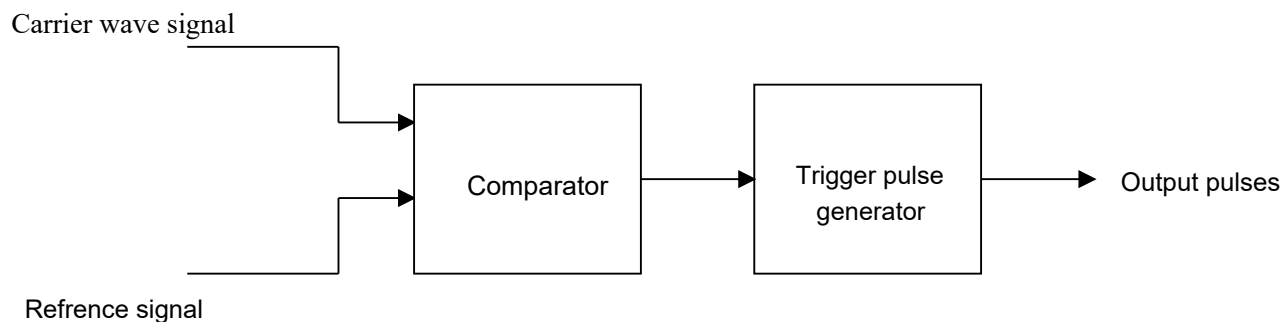


Figure 2.10: Block diagram of sinusoidal PWM

If the frequency of carrier signal increases, it leads to the increase in number of pulses generated for half cycle. There are two cases possible:

- **Case 1:** If the zero of carrier wave coincide with the zero of reference wave. The output pulse is generated if reference wave is greater than the carrier wave as shown in Fig. 2.11.

The number of pulses generated for half cycle are:

$$N = \frac{f_C}{2f_R} - 1 \quad (2.11)$$

- **Case 2:** If the peak of carrier wave coincide with the zero of reference wave. The output pulse is generated if reference wave is greater than the carrier wave as shown in Fig. 2.12.

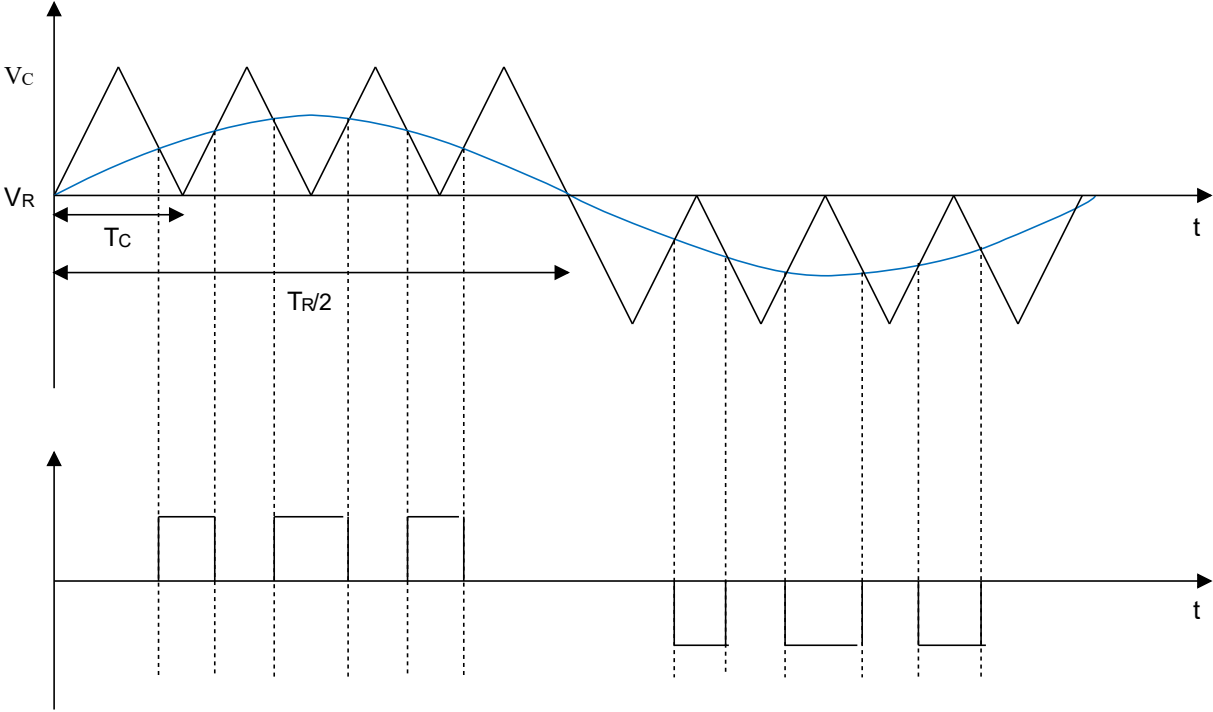


Figure 2.11: Gate signal generation by using sinusoidal PWM for case 1

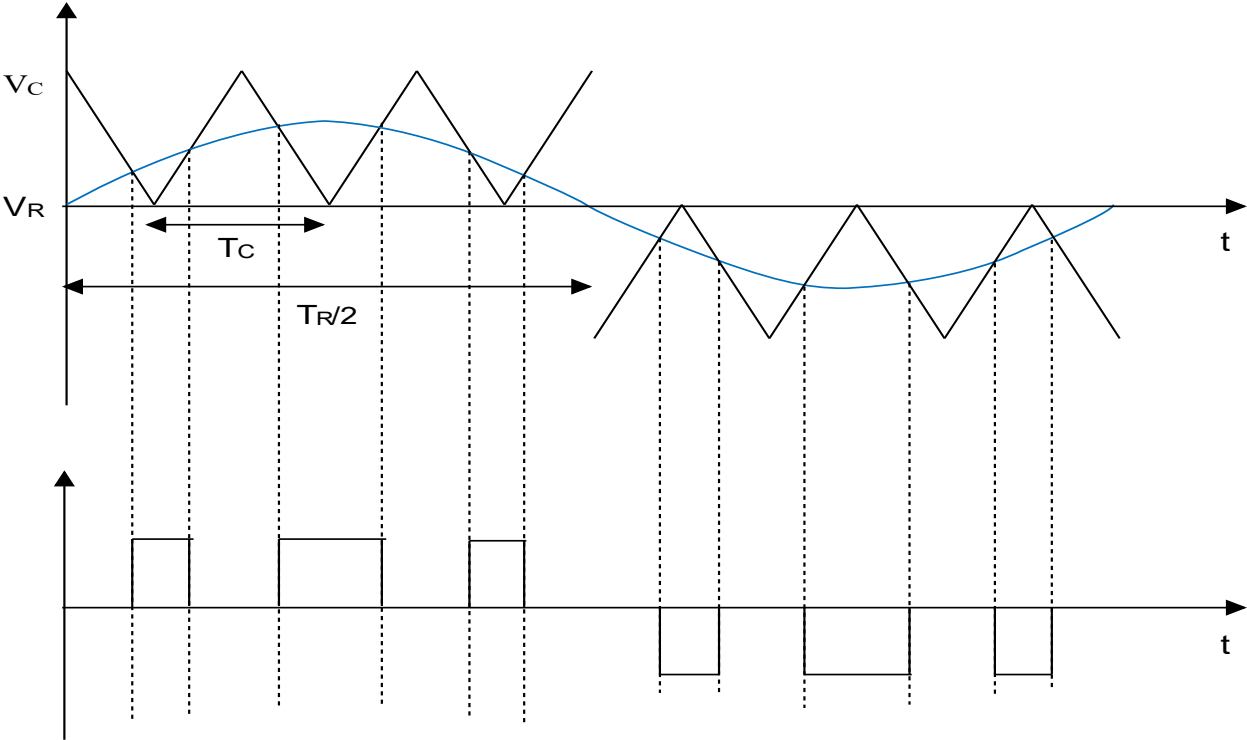


Figure 2.12: Gate signal generation by using sinusoidal PWM for case 2

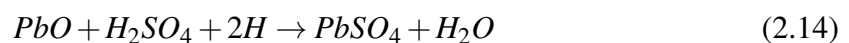
The number of pulses generated for half cycle are:

$$N = \frac{f_C}{2f_R} \quad (2.12)$$

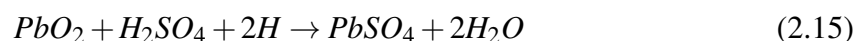
2.5 Rechargeable battery and its types

The storage battery is the one which can be charged through charge controller or discharged to feed the load. The storage battery reserve the energy in form of chemical energy. It can be converted in to electrical energy whenever required by connecting a external source battery. During charging, the electrical energy is converted into the chemical energy. During discharging, the chemical energy is converted into the electrical energy. The rechargeable batteries are more advantageous in comparison to the non-rechargeable batteries because of its low overall cost and its recharging nature i.e., we can recharge it again and again. The two types of rechargeable batteries are considered as explained below:

- **Lead acid battery:** Fig. 2.13 represents the working of lead acid battery. The materials required for making of a lead acid battery are lead peroxide PbO_2 , pure lead Pb and dilute sulphuric acid H_2SO_4 . One electrode consists of PbO_2 and other of pure lead Pb . The electrolyte is made up of H_2SO_4 . When the load is connected externally between plates, the electrolysis split to deposit the hydrogen ions H^+ on the anode i.e., PbO_2 plate and sulphate ions SO_4^{--} on the cathode i.e., Pb plate. The hydrogen ions on the anode attains electrons to form hydrogen atom which then combines with lead peroxide to form lead oxide and water. Also, the lead oxide reacts with dilute sulphuric acid to form lead sulphate and water. The chemical reactions are given as follows [19]:



The overall chemical reaction is



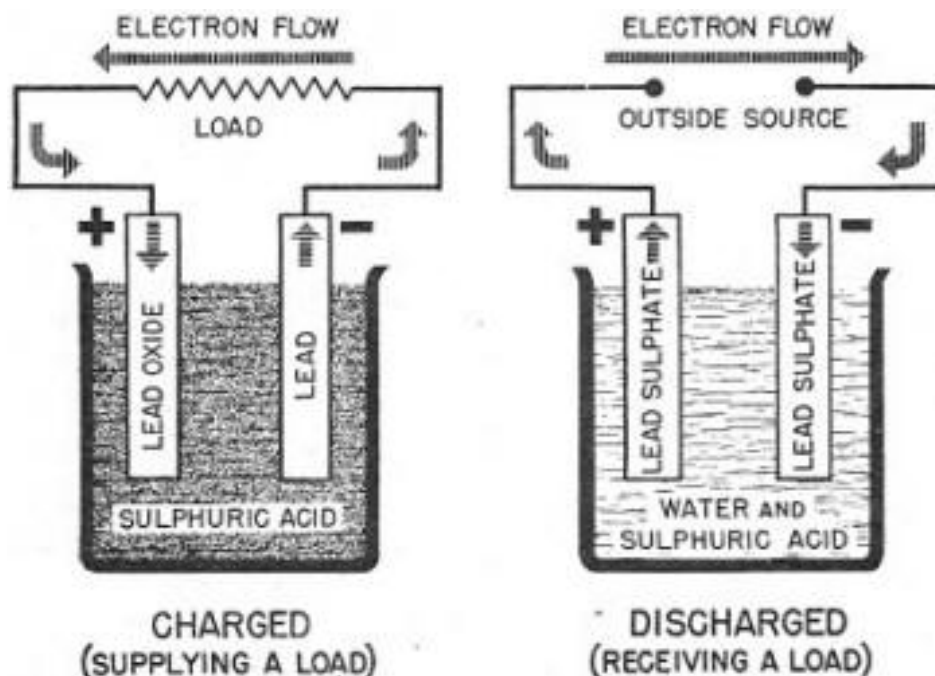
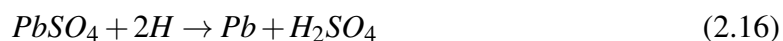


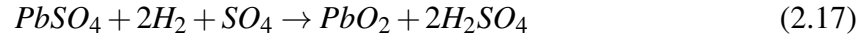
Figure 2.13: Working of lead acid battery [20]

Similarly, the sulphate ions move to the cathode externally through load. It combines to form SO_4 which further reacts with Pb to form $PbSO_4$. There is an imbalance of electrons on the two electrodes leading to the external flow of current which further balances the number of electrons. This process is called discharging of the battery.

During discharging, both plates are covered with $PbSO_4$. The water formation leads to the fall in specific gravity, and hence, the potential difference decreases between the two electrodes.

Now, the load is disconnected and a battery or a DC source is connected between electrodes. The positive end of the source is connected to the anode plastered with $PbSO_4$ and the negative end is connected to the cathode which is plastered with PbO_2 . So, the hydrogen ions in the electrolyte move to the cathode forming hydrogen atom which then recombines with lead sulphate to form pure lead and dilute sulphuric acid. The sulphate ions move to the anode forming SO_4 which further recombines with lead sulphate to produce lead peroxide and dilute sulphuric acid. The chemical reactions are shown below:

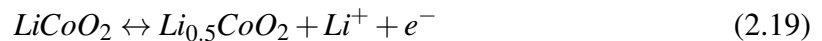




This process is called as charging process. The specific gravity of the electrolyte increases and hence, the potential difference increases respectively.

- **Lithium ion battery:** Fig. 2.14 represents the working of lithium ion battery. One electrode consists of $LiCoO_2$ and other of pure graphite carbon C . Now, the DC source is connected externally between plates. The positive end of the source is connected to the anode and the negative end is connected to the cathode. The lithium ions from the positive electrode move to the negative electrode through the electrolyte. Also, the electrons flow from anode to the cathode that mixes together to form lithium at cathode. This process is called as charging process. The flow of ions stops when the battery is fully charged. Now, when the battery discharges, the lithium ions advances from negative plate to the positive plate i.e., lithium cobalt oxide electrode. Also, the electrons flow from negative electrode to the positive electrode via external source. These ions and electrons are mixed together to form lithium at the anode. The flow of ions stops when the battery is fully discharged. At the positive electrode, lithium ions combine with graphite to form lithium carbide and vice versa. At the negative electrode, lithium cobalt oxide dissipates to give lithium ions and vice versa [21].

The chemical reactions taking place at the electrodes is given as:



The overall chemical reaction is

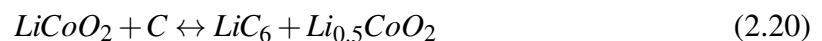


Table 2.1 shows the comparison of lead acid and lithium ion battery.

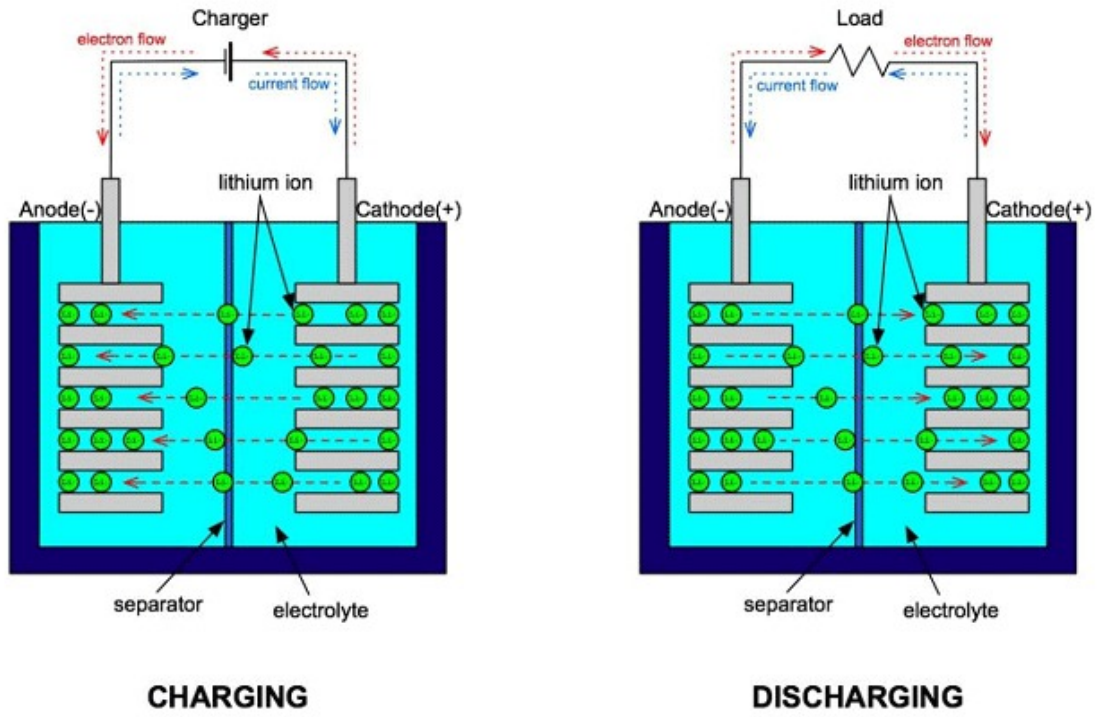


Figure 2.14: Working of lithium ion battery [22]

	LEAD ACID BATTERY	LITHIUM ION BATTERY
Nominal cell voltage	2V	3.7V
Specific energy (Wh/kg)	35-40	140-150
Energy density (Wh/litre)	70	400
Size of a 1KWh battery	14 litres	2.5 litres
Weight of a 1KWh battery	25 kg	6.7 kg
Recharging time duration	10 times the capacity	1 time the capacity
Recharge interval	needs recharge weekly	needs recharge every 6 months
Turn around charge η	75%	97%
Maintenance cost	SLA=2%, VRLA=10%	none
Air conditioning cost	8% f capacity	none
Replacement time frame	2 years	5-7 years
Over chargeability	Tolerant	Intolerant
Protection circuitry	Inexpensive	Expensive
Constant charging rate	0.07 C rate	C rate (10 times fast)
Temperature range of charge	-40°C to +27°C	-20°C to +55°C
Voltage profile	Sloping	Flat
Failure mode	will not accept charge	predicts based on cycles
Cycle life at 95% discharge	250	500
SOC measured by	voltage level	coulomb count

Table 2.1: Comparison of lead acid and lithium ion battery

Chapter 3

METHODOLOGY ADOPTED

3.1 Solar panels

A solar panel is connected to the charge controller for increasing the current in the panels required for glowing street lights. The ratings of the solar panels used under standard test condition is depicted in Table 3.1 [4].

Maximum power (P_{\max})	75W
Maximum power voltage (V_{\max})	24V
Maximum power current (I_{\max})	2.04A
Open circuit voltage (V_{oc})	45V
Short circuit current (I_{sc})	4.72A
Maximum system voltage	136.7V

Table 3.1: Solar panel specifications under standard test conditions

3.2 Charge controller

The energy saving solar inverter battery charge controller is depicted in Fig. 3.1 in which solar energy is harnessed from 24 volt solar panel to store power in 12V rechargeable battery. It automatically cuts down after battery is fully charged.

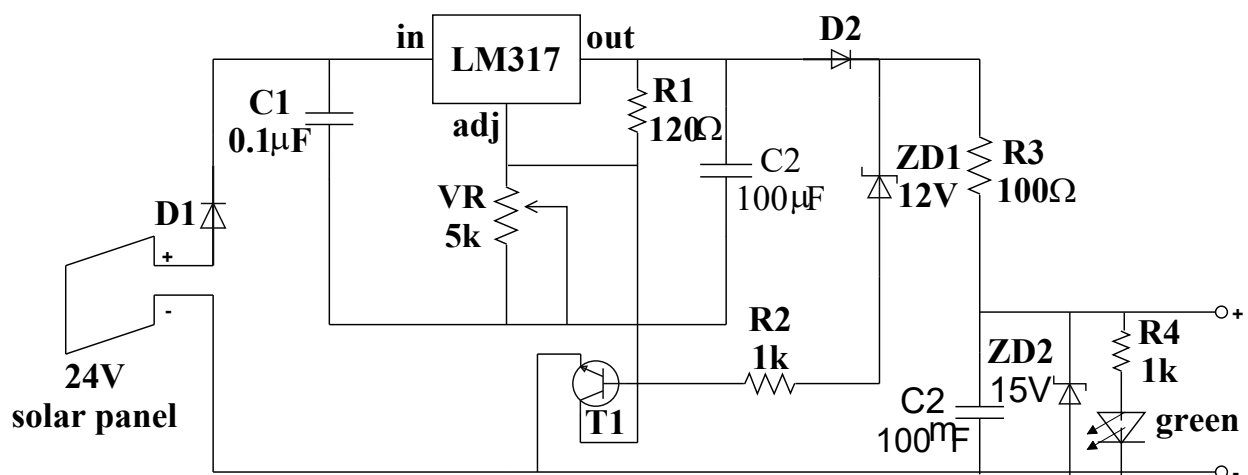


Figure 3.1: Charge controller

The output current of solar panel forward bias the diode D1. The regulator LM317 generates output voltage depending on the setting of variable resistor (VR). The regulator gives the steady output voltage of 16 volts and the output voltage is managed by VR. Output current passes through diode D2 and resistance R3. Zener Diode ZD2 conducts to restore charge in battery when output voltage is above 16 volt generating around 250 to 300 mA current. Charging current depends on the values of R1 and R3 and green LED depicts the charging status. When battery is fully charged, Zener Diode ZD1 starts conducting and TIP122 Transistor (T1) gets forward biased. The output current is withdrawn from LM317 through T1 and the charging process discontinues. ZD1 is reverse biased as the voltage of the battery dips below 12V and hence, the recharging process starts [17]. Fig. 3.2 represents the hardware design of charge controller.

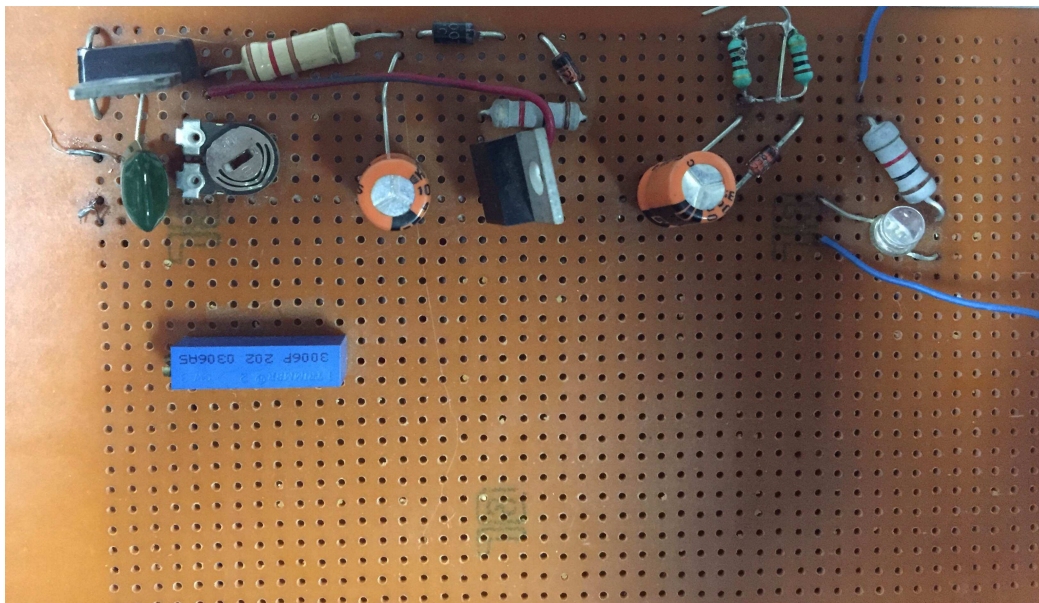


Figure 3.2: Hardware design of charge controller

3.3 Design of buck converter

The buck converter is used to drop down the DC input voltage. It contains input DC supply V_{in} , single pole single throw switch S , p-n junction diode, filter inductor L , ceramic capacitor C and output resistive load R . The output voltage V_o is proportional to the duty cycle D given by eq.(3):

$$V_o = D * V_{in}, 0 \leq D \leq 1 \quad (3.1)$$

The input voltage of the battery is fed as input to the buck converter that steps it down. The step down voltage is applied to the microcontroller STM8S003F3P6. The parameters L and C are obtained from peak to peak ripple voltage ΔV_C and current ΔI of L and C . The value of ΔI of inductor is obtained from the following equation [23]:

$$\Delta I = \frac{V_o(V_{in} - V_o)}{fLV_{in}} \quad (3.2)$$

where f is switching frequency of the output waveform.

The value of ΔV_C of capacitor is expressed as:

$$\Delta V_C = \frac{V_o(V_{in} - V_o)}{8LCf^2V_{in}} \quad (3.3)$$

Parameter	Value
Input voltage (V_{in})	12V
Output voltage (V_o)	5.5V
Switching frequency (f)	5KHz
Peak-to-peak ripple voltage (ΔV_C)	0.056V
Peak-to-peak ripple current (ΔI)	2.128A

Table 3.2: Buck converter design specifications

So the values of L and C can be calculated which depends on some parameters from eq.(4),(5) and Table 3.2 as follows: $L = 280\mu H$ and $C = 940\mu F$.

3.4 LEDs driven STP16CPC26

STP16CPC26 is a 16 bit LED driver having steady current mainly used in low voltage street lighting applications. This driver consists of 16 constant current output channels i.e., O_0 to O_{15} as depicted in Fig. 3.3. Each channel generates a 20V thereby, allowing to connect increased number of LEDs in series. It has input power supply V_{DD} of 3V-5.5V and adjustable output current in the range of 5mA-90mA. Serial interfacing is used for loading of data. We can adjust the LED brightness from 0%-100%. The thermal shutdown assures protection from over temperature events [24].

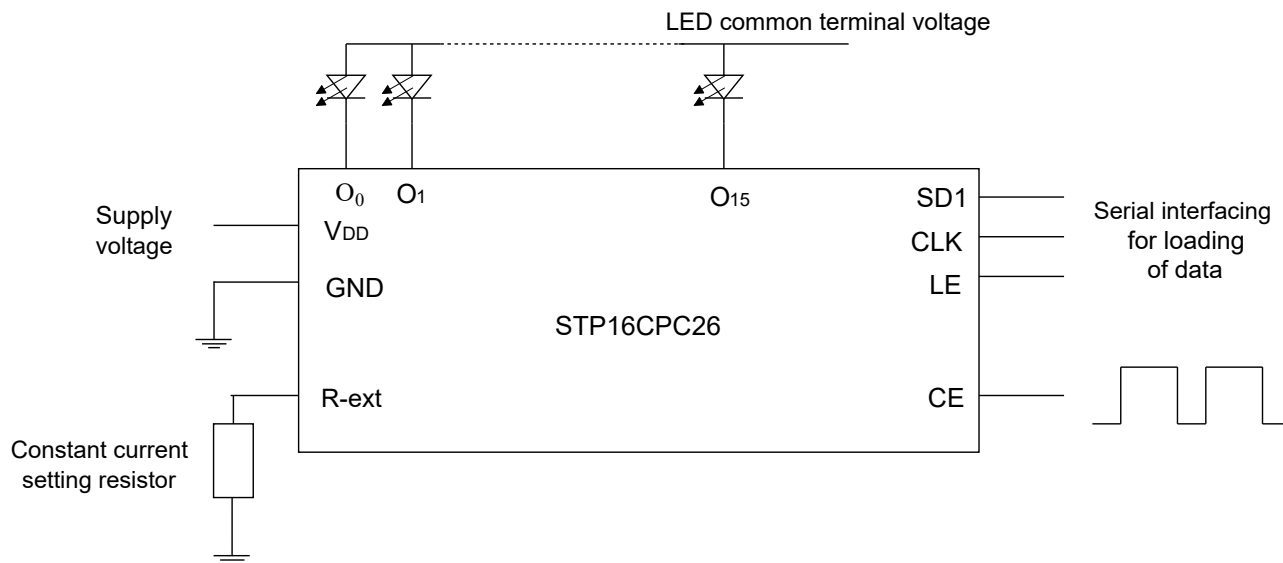


Figure 3.3: LED driven constant current controller

3.5 Lithium ion battery

The lithium ion rechargeable battery used in PV charge controller stores electrical energy in chemical form to operate the street lights. Li-ion battery has many applications such as electric vehicles, renewable energy systems, portable equipment and satellites. The lithium-ion battery is more advantageous in comparison to lead acid and nickel cadmium having some special features like higher energy densities, low self-discharge rate and long life cycle [25]. For a battery, when the SOC is less than SOC_{min} , the battery needs to charge first. However, when the SOC is higher than SOC_{min} and less than a certain predefined maximum limit SOC_{max} , the battery power can be used. SOC is a critical parameter for management of battery power and intensity of light is controlled respectively.

The SOC of the battery at any time t , can be given as follows:

$$SOC(t) = \frac{V_{oc}(t) - SOC_{min}}{SOC_{max} - SOC_{min}} \quad (3.4)$$

SOC_{max} is the instant when the battery is charged completely and SOC_{min} is when the battery charge is drained completely. Then, the SOC of the battery can be easily determined once we know the value of V_{oc} i.e. open circuit voltage of the battery at any instant.

The basic parameters of the lithium ion battery used are indexed in Table 3.3. The current rating of the battery is 2600mAh and its rated voltage is 3.7V [25].

Parameter	Value
Capacity	2600mAh
Nominal voltage	3.7V
Lower limit voltage	2.7V
Upper limit voltage	4.2V

Table 3.3: Specifications of the Li-ion rechargeable battery

Fig. 3.4 shows the equivalent circuit of a lithium ion rechargeable battery. The resistor R_d shows rapid voltage drop while battery charging/discharging process. Two RC network battery models are developed to provide higher efficiency as compared to one RC network model [23]. The R_a and C_a section depicts discontinuous transient response of battery, whereas, R_b and C_b , the continuous transient response. V_{OC} is the open circuit voltage and V_b is the battery end voltage. I_b represents the battery current [27].

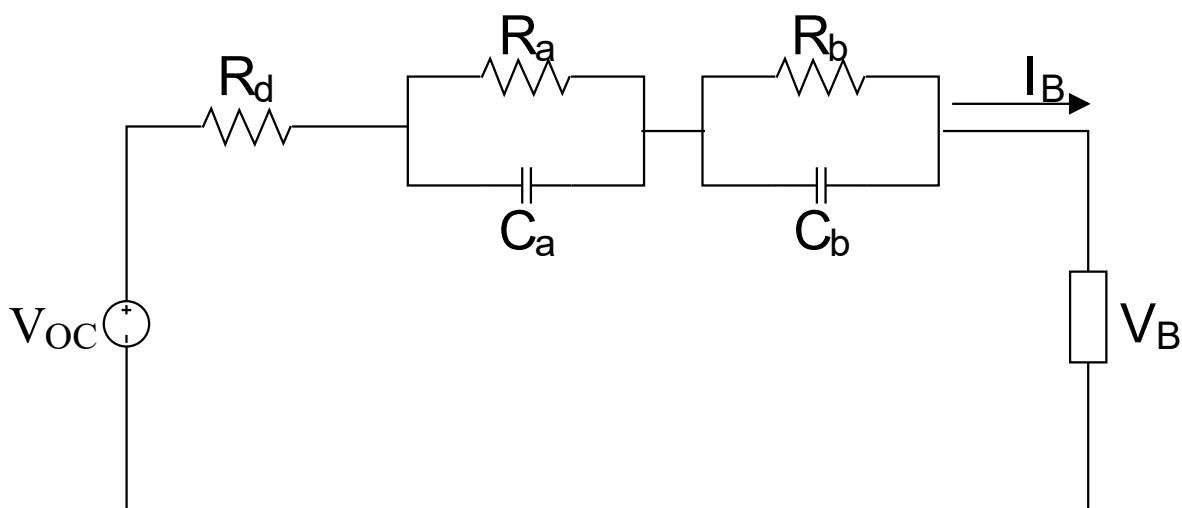


Figure 3.4: Equivalent circuit model of a Li-ion rechargeable battery

3.6 PWM signals using microcontroller STM8S003F3P6

PWM signal uses a digital signal as input to generate an analogue output signal required to control the intensity of street light. In this micro-controller, two register pairs are used one is the Timer-2 auto reload register $TIM2_ARR$ and the other is compare capture register $TIM2_CCRxx$. STM8S003F3P6 generates three PWM signals using $TIM2$ i.e. Timer 2 peripheral. Timer 2 starts counting from 0 to the ARR value (=999) depending on the $TIM2$ counter clock [28]. The duty cycle and frequency of the PWM signal is transformed by configuring $TIM2_ARR$ and $TIM2_CCRxx$ registers.

- When counter value equals timer 2 register $CCRxx$ value, then input channel is set to 0.
- When counter value equals timer 2 register ARR value, then input is set to 1.

The following equation helps to adjust the PWM output signal frequency:

$$PWM\ output\ signal\ frequency = \frac{TIM2\ counter\ clock}{TIM2_ARR + 1} \quad (3.5)$$

where, $TIM2$ counter clock frequency is 2MHz.

The channel x duty cycle based on timer2 compare/capture register can be calculated by following equation:

$$Duty\ cycle\ of\ input\ channel = \left[\frac{Timer2_CCRxx}{Timer2_ARR + 1} \right] * 100 \quad (3.6)$$

Algorithm 1 is designed to show the generation of the pulse width modulation signal for intensity control of the STM8S003F3P6 micro-controller. The auto reload register is substituted 999 value in hexadecimal. Then, compare capture register value is checked. The value of $TIM2_CCRxx$ is checked if its value is 750, then, it means the duty cycle of the signal is 75% and PD2 is turned ON which gives high output pulse of the signal. If the value of compare capture register $TIM2_CCRxx$ is less than 750, then, either of the two cases can happen which means either the value of this pair is between 250 and 750 or the register value is less than 250. When $TIM2_CCRxx$ value is between 250 and 750, its duty cycle is between (25-75)% then, PD3 is turned ON and when

Algorithm 1 Generation of PWM signals using microcontroller

Input: $TIM2_ARR$, $TIM2_CCRxx$ **Output:** *Output pulse*

```
1: Value of  $TIM2\_ARR = 999$ 
2: if  $TIM2\_CCRxx > 750$  then
3:   duty cycle is 75%
4:   Channel 2 i.e., PD2 ON
5:   Output pulse is high
6: end if
7: if  $TIM2\_CCRxx < 750$  then
8:   if  $TIM2\_CCRxx > 250$  then
9:     duty cycle is 25%
10:    Channel 3 i.e., PA3 ON
11:    Output pulse is high
12:   end if
13:   if  $TIM2\_CCRxx < 250$  then
14:     duty cycle lies between (25-75)%
15:     Channel 1 i.e., PD4 ON
16:     Output pulse is high
17:   end if
18: end if
```

this value is less than 250, it means its duty cycle is less than 25% and PD4 is turned on. The output pulse is high which control the intensity of load. Fig. 3.5 shows the flowchart of the generation of the PWM signals.

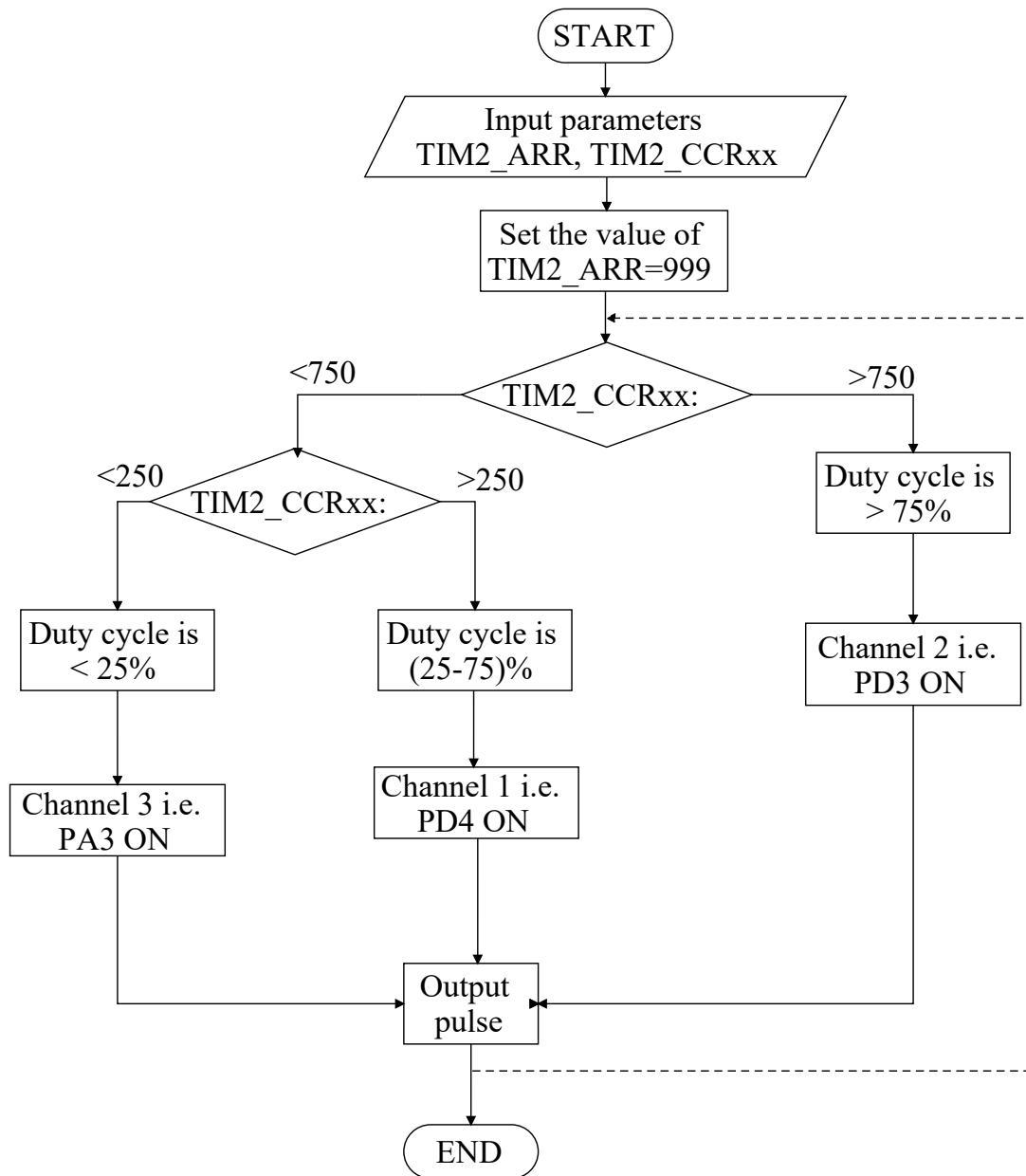


Figure 3.5: Flowchart for the PWM generation

Chapter 4

RESULTS AND DISCUSSIONS

4.1 Charging characteristics of lead acid battery

The efficacy of the smart street lighting system is validated through hardware implementation. The readings observed for different values are plotted below. The rechargeable lead acid battery used is considered to have the specifications of 12V and 3Ah respectively i.e., it has a maximum charging current of 0.3A if it is allowed to get discharged in 10 hours. So, the maximum rated capacity is 36W-h. The data is observed for charging the battery. Fig. 4.1 represents the plot between the charging voltage and the charging time. The maximum charged voltage can be as high as 12V ideally and 12.72V practically. It is charged by using the charge controller which absorbs solar energy during day.

The charging current observations are taken during day time based on the amount of solar radiation available. The charging current versus time observations are observed and plotted in Fig. 4.2. The variations between ideal and practical characteristics are also shown. It has three stages of charging. Stage 1 denotes the constant current charge i.e., the amount of current flow is same and tends to decrease in stage 2, i.e., topping charge. It decreases to a certain value which further decreases slightly in stage 3, i.e., floating charge. In stage 3, the charging current remains constant at its lower limit and does not decrease below it. The maximum capacity of a battery is 3Ah. The battery capacity reduces at night and tends to increase when the solar radiations are present. The capacity increases with time. The observations of capacity with respect to voltage are represented in Fig. 4.3. The observations of charging capacity with respect to time are shown in Fig. 4.4.

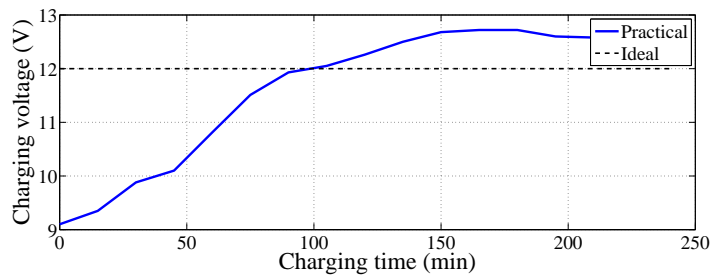


Figure 4.1: Charging voltage vs time for lead acid battery

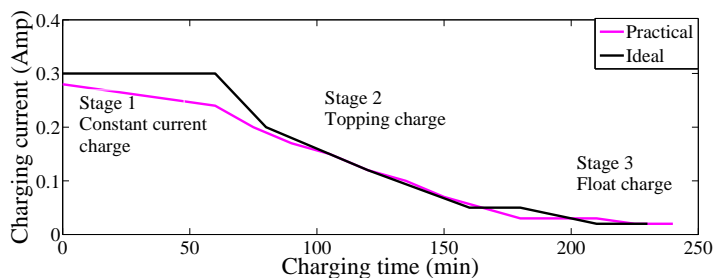


Figure 4.2: Charging current vs time for lead acid battery

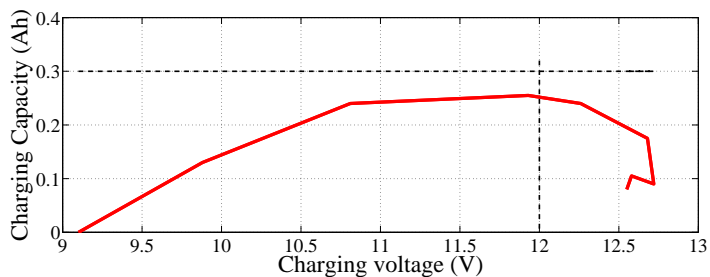


Figure 4.3: Charging capacity vs voltage for lead acid battery

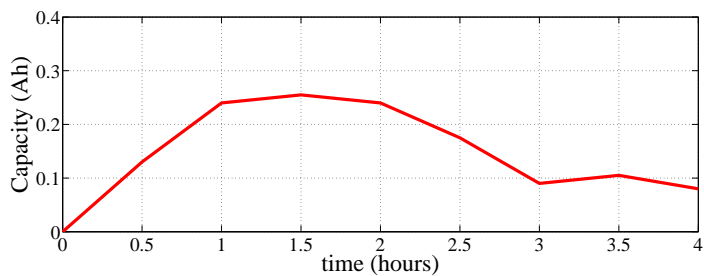


Figure 4.4: Charging capacity vs time for lead acid battery

4.2 Discharging characteristics of lead acid battery

The discharging characteristics are depicted for different parameters. When it becomes dark, the LDR sensor senses the battery voltage to turn on the street light. After the lights are on, the battery begins to discharge based on the capacity available. The system is initially provided with a turn off time of 33 seconds after LDR sensing. PWM generation occurs to control the intensity of light. PWM is generated depending upon the power available in battery. The intensity of light is automatically controlled based upon power available i.e., street lighting system is managed automatically. Fig. 4.5 represents the curve for the observations taken for solar radiation with respect to time. Fig. 4.6 represents the plot between discharge voltage with respect to time. The curve for discharging capacity with respect to discharging voltage is shown in Fig. 4.7. The observations for discharge current with respect to time are taken and plotted in Fig. 4.8. Fig. 4.9 represents the curve between discharging capacity with respect to time.

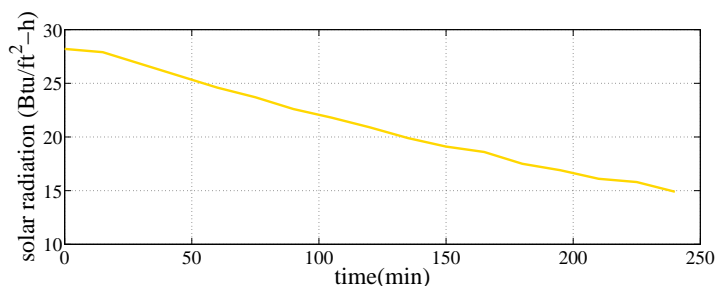


Figure 4.5: Solar radiation vs time for lead acid battery

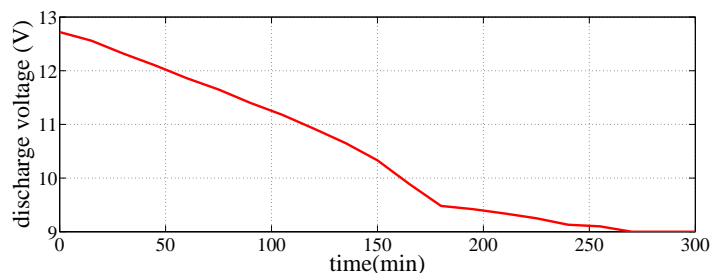


Figure 4.6: Discharging voltage vs time for lead acid battery

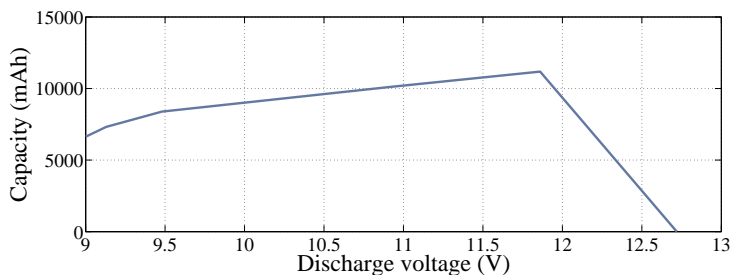


Figure 4.7: Discharging capacity vs voltage for lead acid battery

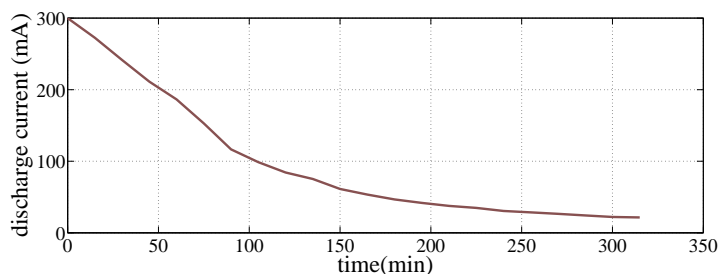


Figure 4.8: Discharging current vs time for lead acid battery

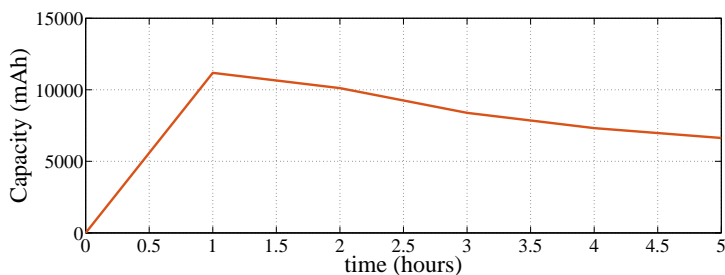


Figure 4.9: Discharging capacity vs time for lead acid battery

4.3 Charging characteristics of lithium ion battery

The observations are also taken with lithium ion battery having specifications of 3.7V, 5800 mAh. It is allowed to charge and discharge in 10 hours and has a maximum current of 0.58A. Three batteries are connected in series having ten parallel combinations of the batteries and following observations are made. Fig. 4.10 is the obtained curve between charging voltage and charging time. Fig. 4.11 represents the plot between charging current with respect to time. Similarly, Fig.

4.12 and Fig. 4.13 is the curve plotted between charged capacity with respect to time and voltage.

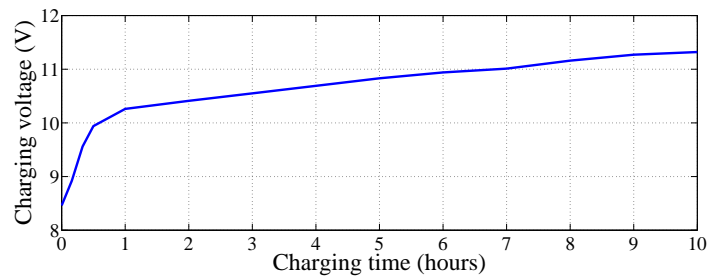


Figure 4.10: Charging voltage vs time for lithium ion battery

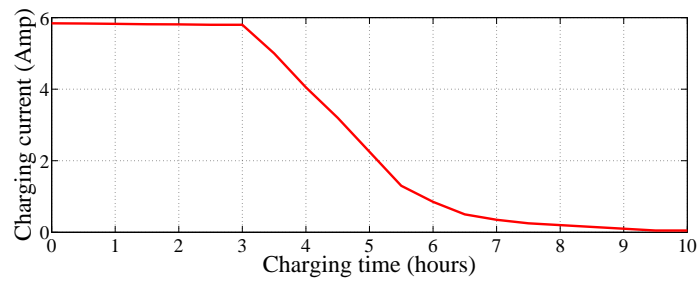


Figure 4.11: Charging current vs time for lithium ion battery

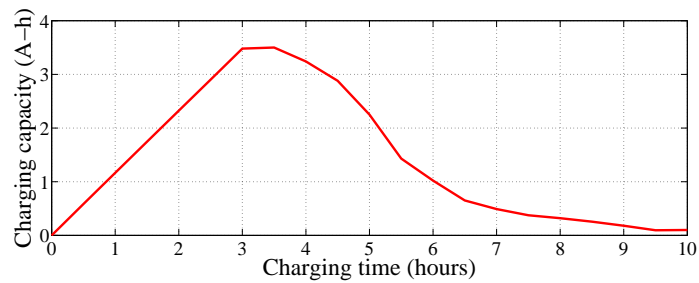


Figure 4.12: Charging capacity vs time for lithium ion battery

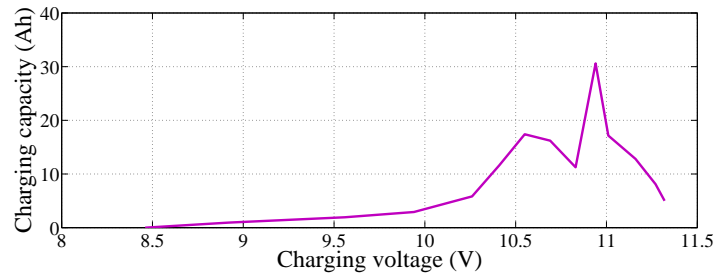


Figure 4.13: Charging capacity vs time for lithium ion battery

4.4 Discharging characteristics of lithium ion battery

The discharge characteristics of lithium ion batteries are observed. Fig. 4.14 and Fig. 4.15 are the curves plotted between discharge voltage and current with respect to time. Fig. 4.16 and Fig. 4.17 represents the plot between discharge capacity with respect to voltage and time.

The results obtained from lithium ion cells have many advantages as compared to lead acid battery. Lithium ion battery does not need saturation and a equalizing charger. It provides much more accuracy and is highly efficient and reliable. Its size is compact i.e., it is mounted on the printed circuit board (PCB) itself, so remains away from battery theft problem. It has long life cycle and does not need any maintenance. It has high capacity and is highly efficient. Also, it provides low self discharge, so, is preferred over lead acid battery.

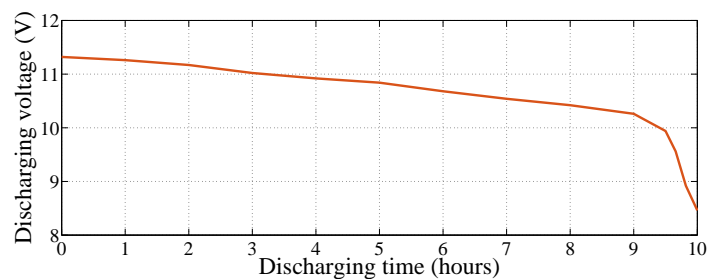


Figure 4.14: Discharging voltage vs time for lithium ion battery

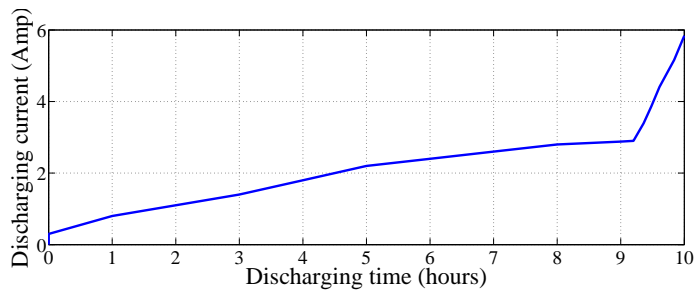


Figure 4.15: Discharging current vs time for lithium ion battery

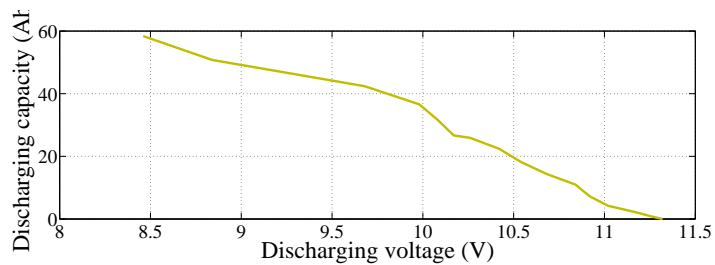


Figure 4.16: Discharging capacity vs voltage for lithium ion battery

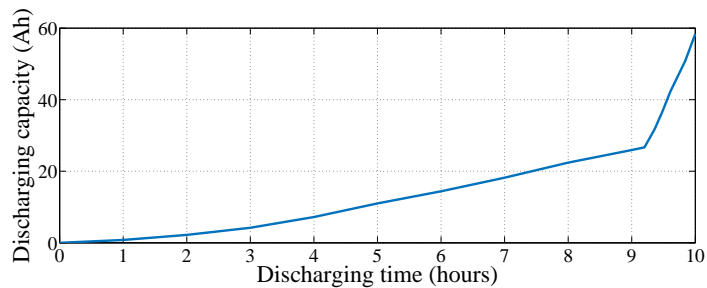


Figure 4.17: Discharging capacity vs time for lithium ion battery



Figure 4.18: Hardware design of charge controller using lead acid battery

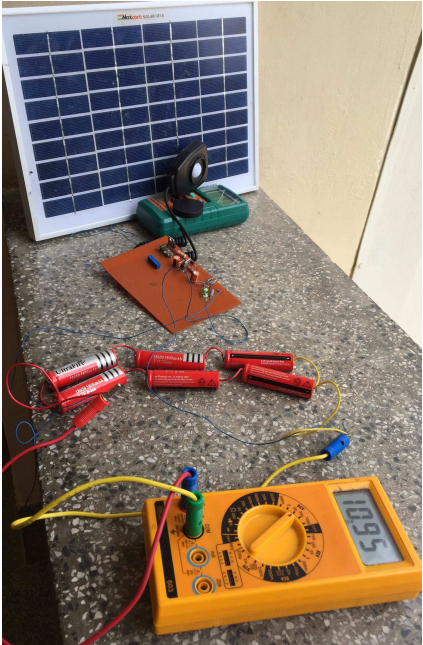


Figure 4.19: Hardware design of charge controller using lithium ion battery



Figure 4.20: Hardware design of smart street light using lead acid battery

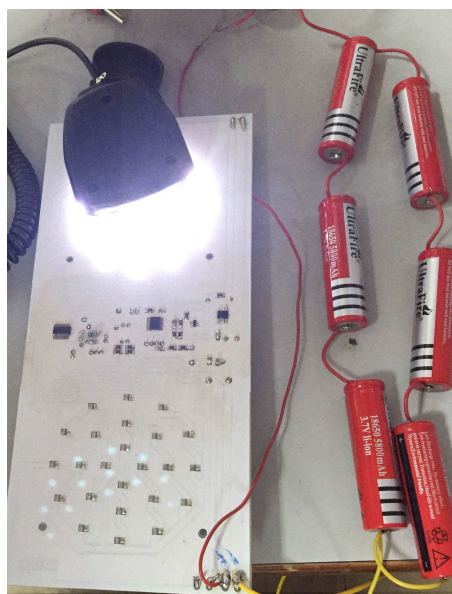


Figure 4.21: Hardware design of smart street light using lithium ion battery

Chapter 5

CONCLUSION AND FUTURE WORK

The traditional smart street lighting system has many disadvantages and results in lesser efficiency. To make the street lighting system smarter, it is implemented using solar energy. The rechargeable batteries are used to store the energy during day which lights up the system during dark. The lithium ion rechargeable battery is used over lead acid battery because of its compact size i.e., prevent the battery from battery theft problem and has long life cycle. The LDR sensor senses the dusk and turns on the street light. PWM signals are generated based on the amount of power available to automatically control the intensity of the smart street light. The micro-controller STM8S00F3P6 can efficiently control the intensity depending on power available and during off peak hours. LEDs are used which are driven by constant current controller STP16CPC26.

The future work will include the application of the proposed system in display panels i.e., LCD display of the percentage amount of charge available in battery using PIC16F887 micro-controller. The efficiency of the proposed system can be improved more by using this technique that tells us the amount by which battery can be charged or discharged. Zigbee communication can also be used in the system where internet of things can be implemented.

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