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DESIGN OF AN EFFICIENT CHARGE CONTROLLER USED IN A SOLAR PV CHARGING STATION

MASTER'S THESIS

USMAN ALI

Department of Electrical and Electronics Engineering
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Thesis Advisor: Prof. Dr. NEDİM TUTKUN

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DECLARATION

I declare that all knowledge in this document has been achieved and presented with academic rules and moral standards. I proclaim that, in accordance with the requirements of these rules and management, I have fully quoted and recommended all data and results that are not related to this thesis.

Usman Ali

FOREWORD

First of all, I would like to thank the ALLAH Almighty for all the help, and blessings, throughout my life and specially while completing this thesis. Secondly, I would like to thank my family, especially my parents for their interminable support and prayers. Without their support it won’t be done. I dedicate my desertion work to my family whose prayers blended in my hard work.

Special thanks to Prof. Dr. Nedim Tutkun, head of Electrical and Electronic Engineering at Istanbul Aydin University, for developing technical and practical skills that empowered me to explore various fields of Electrical Engineering. Without his assistance and dedicated involvement in every step throughout the process, this thesis would have never been accomplished. I would like to thank you very much for your support and understanding over these past years.

Finally, I would like to thank all my friends, colleagues, and my family in Pakistan, for supporting me throughout these years.

May 2020 **Usman Ali**

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ABBREVIATIONS

MPPT	: Maximum Power Point Tracking
PV	: Photovoltaic
PWM	: Pulse Width Modulation
SOC	: State of charge
STC	: Standard test condition
CCM	: Continuous conduction method
DCM	: Discontinuous conduction method
P&O	: Perturb and Observe
ICM	: Incremental Conductance Method
VRLA	: Value regulated lead acid
AGM	: Absorbed glass mat
SC	: Silicon crystalline
MPP	: Maximum Power point
FF	: Fill factor
Si	: Silicon
A-Si	: Amorphous Silicon

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DESIGN OF AN EFFICIENT CHARGE CONTROLLER USED IN A SOLAR PV CHARGING STATION

ABSTRACT

Solar photovoltaic (PV) systems are of great interest for electricity generation in recent days due to depletion of fossil-fueled energy sources, global warming and clean environment. The use of these systems is mainly encountered in many applications that have been common in our daily life. These applications can be on-grid and off-grid power generation, charging stations for various electric vehicles (EVs) such as plug-in EVs, electric forklift, electric motor bike, golf carts etc. This investigation proposes an approach to design an efficient charge controller used in a solar PV charging station for charging EVs with various energy capacities. In such charging stations, maximum power point tracking (MPPT) plays major role in improving efficiency and there are few ways to do that, one is to employ a dc-dc converter based on switching mode devices. For the implementation of the charge controller, a dc-dc buck converter is considered to integrate a MPPT system in which the real coded genetic algorithms technique is employed rather than using deterministic iterative methods to rapidly and precisely find the maximum power point under varying environmental conditions. The designed system is simulated by MATLAB/Simulink and initial findings are consistent and promising, and will be given more in the full paper.

Keywords: *Solar photovoltaic, global warming, fossil-fuelled energy sources, charging stations, maximum power point tracking.*

SOLAR PO ŞARJ ISTASYONUNDA ŞARJ KONTROLÖRÜ ASAD'IN TASARIMI

ÖZET

Fosil yakıtlı enerji kaynaklarının tükenmesi, küresel ısınma ve temiz bir çevre nedeniyle son günlerde elektrik üretimi için güneş fotovoltaik (PV) sistemleri büyük ilgi görüyor. Bu sistemlerin kullanımı, ağırlıklı olarak günlük hayatımızda yaygın olan birçok uygulamada karşımıza çıkmaktadır. Bu uygulamalar, şebekeye bağlı ve şebekeden bağımsız güç üretimi, çeşitli elektrikli araçlar için şarj istasyonları (elektrikli araçlar, elektrikli forkliftler, elektrikli motosikletler, golf arabaları vb.) Olabilir. Bu araştırma, verimli bir tasarım yaklaşımı önermektedir. EV'leri çeşitli enerji kapasitelerine sahip şarj etmek için solar PV şarj istasyonunda kullanılan şarj kontrolörü. Bu tür şarj istasyonlarında, maksimum güç noktası izleme (MPPT), verimliliği artırmada önemli bir rol oynar ve bunu yapmanın birkaç yolu vardır, biri, anahtarlama modu cihazlarına dayalı bir dc-dc dönüştürücü kullanmaktır. Şarj denetleyicisinin uygulanması için, bir dc-dc buck dönüştürücünün, değişen çevresel koşullar altında maksimum güç noktasını hızlı ve kesin bir şekilde bulmak için deterministik yinelemeli yöntemler kullanmak yerine gerçek kodlanmış genetik algoritmalar tekniğinin kullanıldığı bir MPPT sistemini entegre ettiği düşünülmektedir. . Tasarlanan sistem MATLAB / Simulink tarafından simüle edilmiştir ve ilk bulgular tutarlı ve ümit vericidir ve tam metin olarak daha fazla verilecektir.

Anahtar Kelimeler: *Güneş fotovoltaik, küresel ısınma, fosil yakıtlı enerji kaynakları, şarj istasyonları, maksimum güç noktası takibi*

1. LITERATURE REVIEW & SCOPE

1.1 Introduction

Photovoltaic solar power has gained considerable attention over the past years. In 2019, installed power capacity grew by more than 200 gigawatts (GW) that make another record in renewable energy field. It is because of steady decline in the cost of photovoltaic modules over the past years. We see that, in near future old-fashioned energy will be diminish. Due to growth in population and industrialization, the commercial use of electricity is increasing. The increasing pollution around the world has formed a threatening situation due to our colossal dependence on old-fashioned energy sources. The growing call for power cannot be met with conservative energy sources. So, it is stage to start using renewable energy sources to produce electricity. Solar energy has become one of the leading renewable energy sources all over the world because of its new structures. Solar energy is becoming an alternative source for overcoming energy shortages. The main benefits of solar energy are natural, environmentally friendly, abundant, and require less maintenance. The way of converting sunbeams energy into electrically powered energy is done by PV scheme. A quantity of electrically linked solar chambers installed in a supporting assembly or mount is called PV units. A solar PV system can be divided into two types, one is a Standalone PV system and the other is Grid Connected PV system. During the day, when solar energy is easily accessible, energy will store in battery that power can be used to feed the loads or the DC micro-grid in darkness or in cloudy weather. The solar control regulator used to charge the batteries in electric vehicles such as golf carts, tractors, etc. DC-DC converter topology use to distribute power among photovoltaic module and battery to be charged. DC-DC converter alters DC input voltage into DC output voltage, with size of smaller or greater than the input voltage. Much work has been done in the past years to design and build high-efficiency DC-DC converters that can be used in domestic solar systems. Battery control regulator and MPPT follower contains in a solar based MPPT control regulator. Maximum power point tracker senses the extreme output of the photovoltaic array and conveys it to the battery control regulator. The controller controls the battery via multi-stage charging approach in order to keep the battery in charging state effectively deprived of scarring it from excessive charging gas and overheating. The most commonly used type is the valve-regulated lead-acid battery (VRLA) because it is inexpensive, maintenance-free, and highly efficient. Although the cost of battery installation is relatively low compared to PV, the cost of battery life is significantly increased due to the limited-service time. The whole budget of the system can be compact by using appropriate battery charge/discharge control techniques that allow the battery to remain at a high state of charge and longer age.

1.2 Literature Review

A lot of work has been done in the past years on the production and performance of highly optimized DC-DC converter used for domestic solar systems. H.J Chiu et al. offered low voltage equipment, low current, and high optimized DC-DC converter technique for sustainable energy systems that can produce controlled output voltage from low scale voltage power supply (Chiu, 2009). Rodney H.G Tan offered the circuit design of PV based MPPT lead-acid battery charge regulator for the small and medium-sized standalone system to achieve an average general charge regulator adeptness roundabout to 98.3% that is compatible to viable PV based MPPT charge regulator product conditions (Tan, 2020). Xinggui Wang design a 6kw photovoltaic system. In this, he proposes the voltage can be analyzed by adjusting the temperature. He has been improved the utilization of solar energy and to increase the battery life the constant voltage charge held the voltage around the float voltage (Wang, 2010). Matthew Wells offers a variety of approaches to help implement this idea and help analyze the performance of a smart solar grid in the residential market. In particular, the implementation of such a system allows users to program the switching between two solar batteries and possibly independently controlled, which allows optimal charging of the batteries according to the electrical performance of the panels (Wells, 2011). Mihir Pathare proposes the method of MPPT to extract the maximum power from the PV module and to protect the battery from overcharging. MPPT protects the battery from overcharging and also works as an energy meter. He designs a simple, inexpensive, and efficient photovoltaic solar power generation system for small dc loads (Pathare, 2017). Severus Olteanu developed trivial photovoltaic control algorithm to exploit the produced energy. His aim is to improve a mathematically easy way to apply the DC-DC buck converter control method. The basic idea is to make an enhance box to control the extreme energy position based on current energy and heat, and utilize its production as a locus for a polynomial regulator to generate PWM signal (Olteanu, 2017). B. Preetha Yesheswini implements a solar system to set up a charging station for EV applications. The charging station uses multi-port charging by providing a constant voltage DC bus. Charge controllers work with the concept of power balance and charging at constant current and constant voltage. This leads to exploration for alternative and cleaner energy sources for charging electric vehicles (Yesheswini, 2020). Bidyadhar Subudhi discusses different types of converter for each MPPT technique. It provides a breakdown of the available MPPT methods based on the number of related control variables, types of control strategies, schemes, and application costs, which may be useful for selecting the MPPT method for a particular application. He has also discussed MPPT techniques for unsuitable conditions such as partial spillage, lack of uniformity in the temperature of PV panels, dust occurrence, damage to the panel glass, and so on (Bidyadhar Subudhi, 2013). Manoj R. Hans discussed the design of a solar-based wheelchair for disabled persons. He offers that the wheelchair system is self-driven and it is very useful. Recently the wheelchair system used grid supply for charging the batteries and it is not affordable for a common man but the solar photovoltaic system it's cheap, less noisy, highly efficient, and doesn't need any extra maintenance (Hans, 2018). Azfarul Islam provided the designs and features of the hybrid solar net scheme with the MPPT. Integrating the solar structure with the grid-iron is very complicated and affluent. The production of the duty control is associated to the feedbacks of diode changing circuit. This diode conversion cycle determines what rate of solar power sent to output. We are promoting green energy uses with this simple hybrid system (Islam, 2016). E. Koutroulis proposed a battery charging system for a standalone photovoltaic system. He presented a better use of the photovoltaic energy available with the maximum power point (MPPT) tracking method used in the control algorithm, a longer battery life due to a higher charge level, and the charge control process. It is independent of the accuracy of the battery current measurement, which reduces the sensitivity impact of the current sensor to final SOC of battery (Koutroulis, 2004). H.S. Kim offered serial assembly of an integrated unit of DC / DC converter with a photovoltaic plate associated to the load side capacitor of flying-back converter, this technique decreases the DC / DC converter influence size and improves power conversion efficiency in comparison to conventional DC/DC converter (Kim, 2009). In (Lee, 2009), J. P. Lee et al. anticipated the development and management of new topology of high-efficiency photovoltaic DC / DC converter in a wide range of loads that can significantly diminish nominal power and improve the effectiveness of the photovoltaic arrangement. Karima Boudaraia studies and verifies the execution efficiency of the MPPT method. To achieve maximum extraction power, a DC / DC buck converter is used that adapts the voltage to the appropriate value. A new method (novel analysis) for analyzing a photovoltaic system is performed in various atmospheric conditions. The analysis of the open circuit of the photovoltaic circuit allows mining the extreme energy commencing the photovoltaic system (Boudaraia, 2016). Parag C. Atri presents a comprehensive study of various Maximum Power Point Tracking (MPPT) methods for solar charge controller applications with various converter topologies. For solar battery chargers, Fractional Open Circuit Voltage, Perturb and Observe algorithm, and Incremental Conductance method are used. The system contains a photovoltaic panel, a DC-DC converter, a duty control, and a battery-operated. For electrical vehicles such as bikes and cars, this system can be used (Atri, 2020). Anshuman Sharma proclaims an inventive MPPT technology, which can withdraw the extreme accessible energy from a solar system irrespective of solar temperature, heat, and output variances. To accomplish this objective, DC-DC converter is used to withdraw maximum energy from the system and to control the battery state of charge. He proposed that energy gained from the PV system is joint with the battery energy to confirm that the coupled load obtains full energy (Sharma, 2019). Ankur Bhattacharjee designed a three-stage battery charger control for an independent photovoltaic system. The three-stage charging method is useful for constant current charging in terms of charging time. Three-stage charging is also compared to two-stage charging, and decide that the three-stage charging requires more time for charging as compared to two-stage charging, but the three-stage charging technique for battery safety is a more useful technique in two-stage charging, since two-stage charging charges the battery with a high initial current, while three-stage charging initially delivers a small current called tickle current to the battery up to a certain voltage called threshold voltage and then the high charging currents are provided in the next stage called bulk charging (Bhattacharjee, 2012). M. LokeshReddy introduces a new PV control regulator that includes a sequence, parallel control regulator. For series charging and discharging, lead-acid batteries will be used because of its properties. He also suggested that the production of control regulator effectiveness is been modified, and value of the system decreases by using fewer switches. It is best suited to optimizing power crisis in countryside spaces to reasonable amount (LokeshReddy, 2017). Chihchiang Hua studies and designs numerous types of DC-DC regulators in PV energy for the efficiency check of the converter. A simple method is used to track the maximum power point (MPP) of the solar panel, which combines discrete time control and PI compensator. The system is sustained close to the MPPT, thus achieving the extreme potential energy transmission from the PV panel (Hua, 1997). Deepak Pullaguram introduces a smart and cost-effective approach to photovoltaic systems and DC batteries. It offers a reverse DC-DC conversion circuit for a standalone PV system that can serve a variety of home appliances, eliminating the need for an inverter system. He proposed that the load-side converter adjusts the load power by adjusting the load voltage within certain limits, without significantly affecting the load characteristics (Pullaguram, 2017). In (Dehedkar, 2018) deals with the role and possibility of maximum power with a control unit in a solar cell system to introduce simulation and modeling with optimization and analysis. Madhura N. Dehedkar examines their adequacy in a single-phase network connected to a PV system. To achieve maximum PV module usage and maximum solar energy recovery, a distributed MPPT pattern can be used for a PV system, enabling control of each intermediate circuit voltage.

1.3 Thesis Purpose

Our thesis purpose is to simulate and design a significant controller for PV charging station. There are several types of maximum power point technique such as incremental conductance method and perturb and observe algorithm. I use perturb and observe method because it is easy to implement and there is no frequent collapse of PV power. In this, the battery charge controller charges the battery in three stages that include bulk charge, absorption charge, and float charge. This system will be used for home-based photovoltaic systems and electric vehicles such as tugs, golf carts. The performance analysis in the following sections shows that MPPT can significantly improve the efficiency of a photovoltaic system. The analysis and design of these techniques are implemented in MATLAB/Simulink.

1.4 Problem Statement

Photovoltaics plays significant part in the use of solar power to produce electricity around the world. The proficiency of solar compartments (cell) is essentially central parameters to affirm this knowledge in souk. First solar panel was produced in the late 1950s and then used in satellites in earth-orbiting satellites. The effectiveness of the monocrystalline silicon solar cell presented brilliant development yearly. Initially the efficiency is just 15% in the 1950s and eventually rises to 17% in 1975, and grows steadily. Due to the limit of natural resources, the world is switching to the solar energy system. Nowadays, research work is continuing to reduce technology costs and increase operational efficiency. Such issues may include, improving the energy efficiency of PV modules, developing standardized PV management procedures to maximize efficient operation and longevity, developing heat recovery techniques to protect panels from the growth of operating temperatures. The main objective of this investigation is to increase and maintain the efficiency of the charge controller using MPPT techniques (perturb and observe algorithm) for better performance.

2. CONVERTERS & PHOTOVOLTAIC SYSTEM

2.1 DC-DC Converters

A DC-DC converter is a type of power electronic circuit that will convert the unregulated DC voltage to regulated DC output voltage and regulation is achieved by PWM at a fixed frequency. Power BJTs, MOSFETs, and IJBT is generally used as switching device. In order to maximize the efficiency, the minimum frequency of the oscillator should be approximately 100 times greater than the switching time of the transistor. This restriction is due to the loss of the transistor. Due to the increase in switching frequency the switching loss of transistor increases and as a result efficiency of the converter decreases. The output voltage contains harmonics and a DC filter is used to reduce the ripples. It consists of voltage source input, a switching network, a dc-dc filter is used to limit the ripple and load as output. The main component of the MPPT device is a DC-DC switching mode converter. MPPT use the regulator to adjust input voltage to solar maximum power point and ensure the output corresponding for extreme power transmission.

DC-DC converter substitute into distinct types of methods. The most common topologies for DC-DC regulators are:

I. DC-DC Buck (Regulator) Converter
II. DC-DC Boost (Regulator) Converter
III. DC-DC Buck-Boost (Regulator) Converter

In this chapter, we will discuss the DC-DC Buck converter and its operation. Our Input Voltage is high and we need low voltage at output that's why we use Buck converter. In a photovoltaic system buck converter is used for charging the batteries. Block Diagram of DC-DC converter is shown in Figure 2.1,

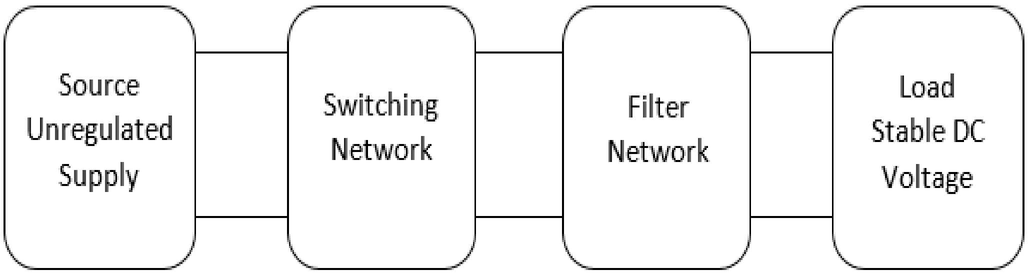

Figure 2. 1 : DC-DC Converter Block Diagram

2.2 DC-DC Buck (Regulator) Converter

A step-down converter or dc-dc buck regulator converts the dc input voltage to regulated dc output voltage whose value is less than the input. The converter has a dc bias current and single voltage that allows controlling the output voltage that is lower than the input voltage level. By controlling the duty cycle of switching we can maintain the dc stable output voltage. The dc output is having some squared wave characteristics. The Figure 2.2, shows the general diagram of the DC-DC buck regulator.

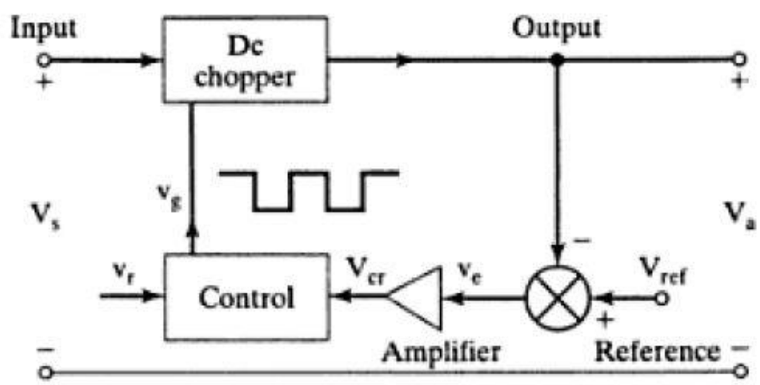

Figure 2. 2 : Block Diagram of DC-DC Buck Converter

Buck converter consists of DC voltage source, filter capacitor C, buck inductor L, diode D, controlled switch S, and the battery or load resistor R as shown in Figure 2.3. Buck converter operation divide into two modes, initially, the regulator is in open condition. When regulator is locked (closed) for first time the diode acts as an open circuit and the current starts to increase across the inductor after some time current starts to decrease and voltage also decreases so at that interval energy will be stored in shape of magnetic field with the support of inductor. Initially the regulator is undefended the power stowed in inductor release energy across RC circuit.

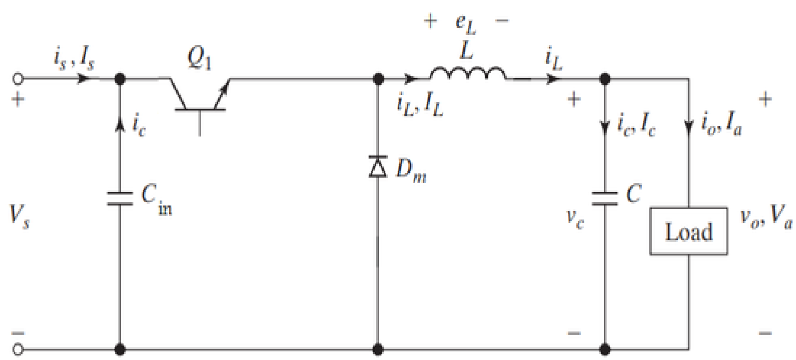

Figure 2. 3 Buck Converter Circuit Diagram

2.3 Analysis of CCM and DCM of Buck Converter

2.3.1 Continuous Conduction Mode:

Initially the circuit switch is in locked state as shown in Figure 2.4:

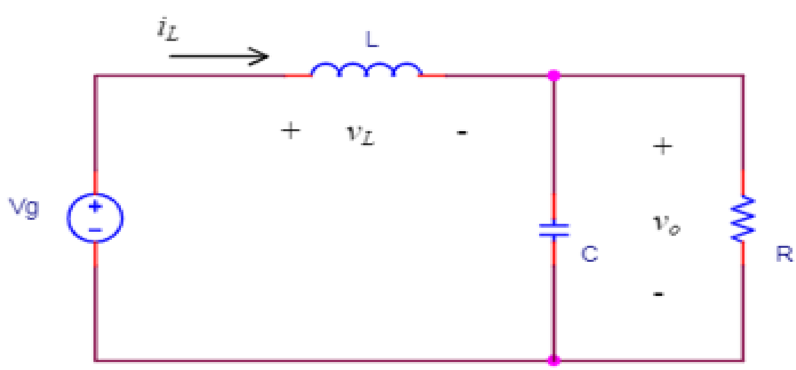

Figure 2. 4 : On-State Diagram of Buck Converter

When the power switch is on, the total sum of inductance voltage and source voltage appears as a load voltage. The current at input side increases and moves across the storing device (inductor, filter capacitor) and finally the load device.

A buck converter works in continuous mode if the current through the inductor never drops to zero during switching cycle. When the switch is closed (on-state), the inductor voltage becomes,

$$V_L = V_i - V_o \tag{2.1}$$

The inductor current increases gradually. Due to the voltage source V the diode operates in reversed biased condition, so no current will flow. The diode operates in forward biased condition when we open (off-state) switch and the current through inductor decreases. In off-state, the inductor voltage becomes,

$$V_L = -V_o \tag{2.2}$$

The rate of change of inductor current can be calculated by,

$$V_L = L\frac{di}{dt} \tag{2.3}$$

During the on time our $t_{on} = DT$ and during the off time our $t_{off} = (1 - D)T$, for the steady state operation we equate the values,

$$D = \frac{V_o}{V_{in}} \tag{2.4}$$

Above equation verifies that the voltage at output side changes according to duty ratio. Whereas D is changing ratio whose value varies between 0 and 1. And also our output voltage is less than input voltage that's why we call this converter as step down converter. Current, voltage and switch state of buck converter in continuous mode is given in Figure 2.5,

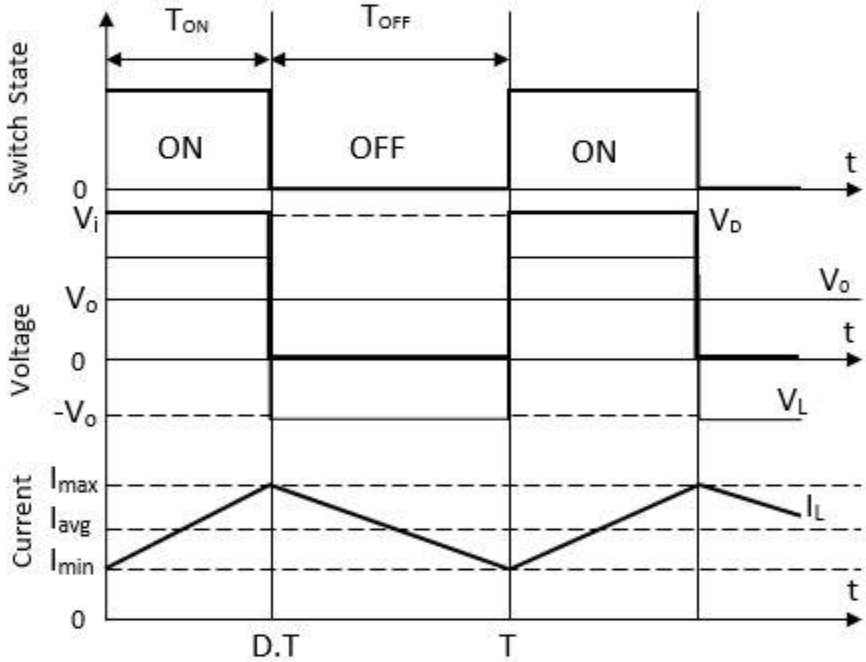

Figure 2. 5 : Buck Converter at CCM

2.3.2 Discontinuous Conduction (OFF-State) Mode:

When the circuit is open (in off state) the circuit shown in Figure 2.6:

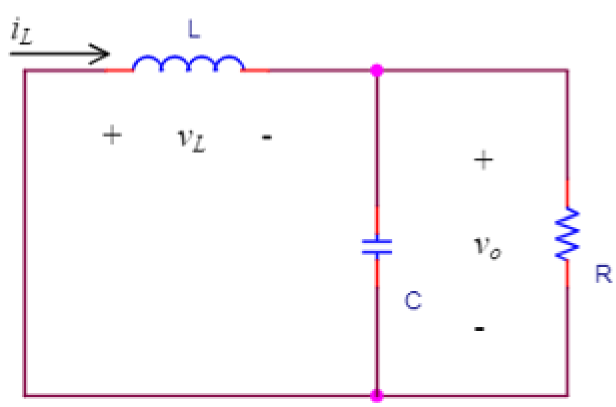

Figure 2. 6 : Off-State Diagram of Buck Converter

The diode D_m acts as freewheeling diode conducts due to the energy stored in the inductor during off state. The inductor current can also be discontinues depending upon the switching frequency, filter inductance and capacitance. Current, voltage and switch state of buck converter in discontinuous mode shown in Figure 2.7,

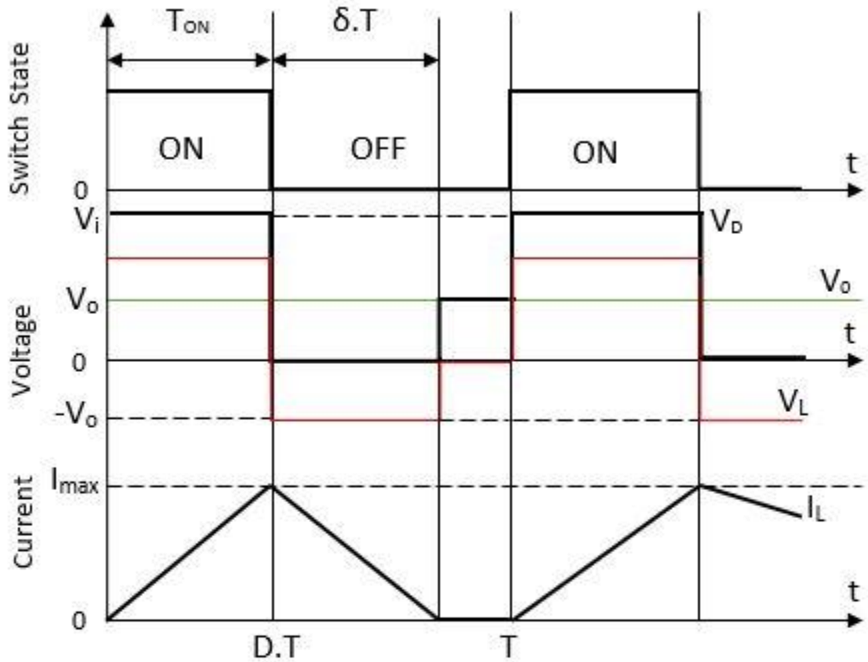

Figure 2. 7 : Buck Converter at DCM

Conditions for continues Inductor current and capacitor voltage are given by:

$$L_c = \frac{(1-k)}{2f} \qquad \textbf{(2.5)}$$

$$C_c = \frac{(1-k)}{16Lf^2} \qquad \textbf{(2.6)}$$

Where k is duty cycle and L_c and C_c are critical value the capacitors and inductor for continuous inductor current and capacitor voltage. Critical values are the maximum cut-off point if they exceed our circuit will operate in discontinuous mode.

For a good estimation we calculate the inductor value by following equation:

$$L = \frac{V_{out}(1-k)}{f_{sw}\Delta I_L} \qquad \textbf{(2.7)}$$

Where,

V_{out} = Desired Output Voltage

k = Duty cycle

ΔI_L = Estimated inductor ripple current

F_{sw} = Switching frequency

We can calculate the value of output capacitor for output voltage by following equation,

$$C_{out(min)} = \frac{\Delta I_L}{8 f_{sw} \Delta V_{out}} \quad \textbf{(2.8)}$$

$C_{out(min)}$ = Minimum output capacitance

ΔV_{out} = Desired Output Voltage ripple

ΔI_L = Estimated inductor ripple current

F_{sw} = Switching frequency

2.4 Photovoltaic System

A photovoltaic topology that converts energy from sun into electrical powered energy with help of semiconductor cells. The photovoltaic word can break into two parts, photo and voltaic, photo means light and voltaic means voltage. A photovoltaic system based on different components like solar panels, inverters, batteries, electrical components, controllers, wires, and other accessories.

A photovoltaic system is efficient, easy to use, reasonable price and it's a source of clean energy because there is no need for fuel to generate electricity. PV systems can be available in various forms of applications like PV-powered tugs, bikes, standalone system's and in grid connected system.

Figure 2. 8 : Photovoltaic Structure

Solar PV system available in divergent categories which are mostly divided into two parts off-grid photovoltaic energy system and standalone photovoltaic energy system shown in Figure 2.9,

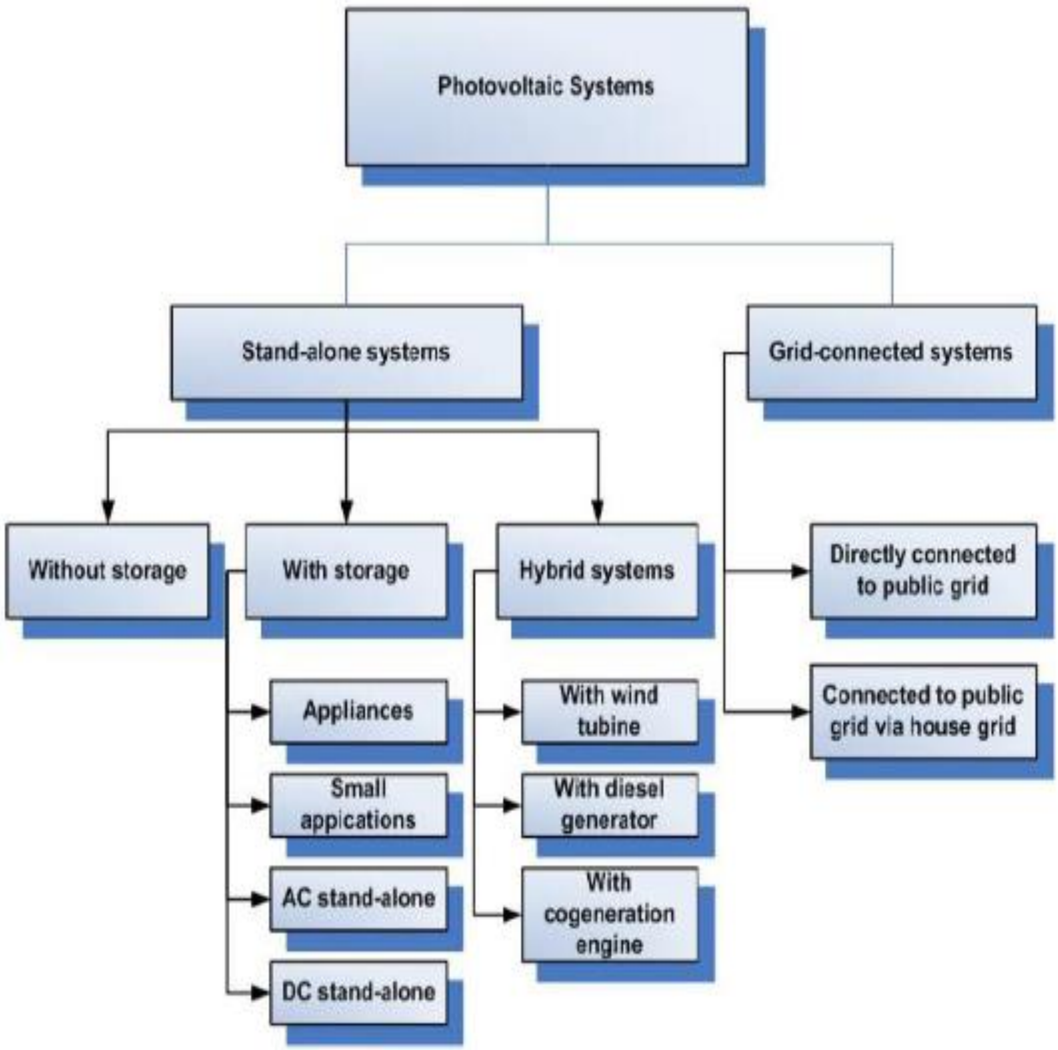

Figure 2. 9 : Types of Solar PV System

2.5 Photovoltaic Structure

2.5.1 PV Cell Model

A photovoltaic cell is a technology that uses the phenomena of the photovoltaic effect to convert solar energy into electrical energy. Solar cell or PV cell is made of semiconductor material. Silicon Crystalline (SC) is used as a semiconductor material. PV cells are connected in series or parallel to produce high current, voltages, and power. The age of PV cells is more than 30 years. PV cells that are used in Residential areas formed by combining the P-type and N-type semiconductor material that is separated by depletion layer or junction which is called pn junction. PV cell is shown in Figure 2.10,

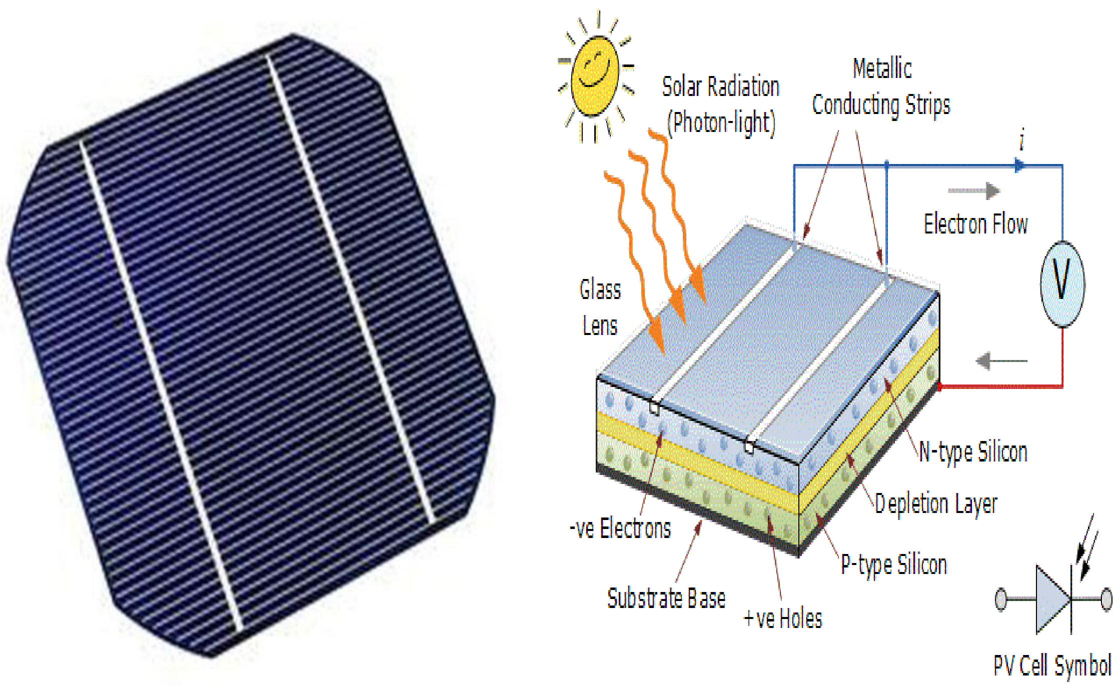

Figure 2. 10 : Photovoltaic Cell

2.5.2 PV Module, Panel, Array

Solar PV Module is a combination single PV cells that are connected together in series or parallel to produce high current, voltage and power. A number of PV modules also called PV panels. An assembly of solar panels connected together sort a PV array. Mostly PV arrays are used on rooftops of buildings, schools, and homes to meet the energy requirement. To increase the voltage at our output we connect the PV array in series and to increase the current at our output we connect the PV array in parallel. The flexibility of PV array allows engineer to develop PV systems that encounter a variation of electrical goods, either it is on large scale or small scale. The performance of solar module and array is usually evaluated according to their maximum power output under standard test conditions (STC), which is a radiation of 1 kW / m2, a cell temperature of 25 ℃ with an air mass of 1.5. The process of making PV array shown in Figure 2.11,

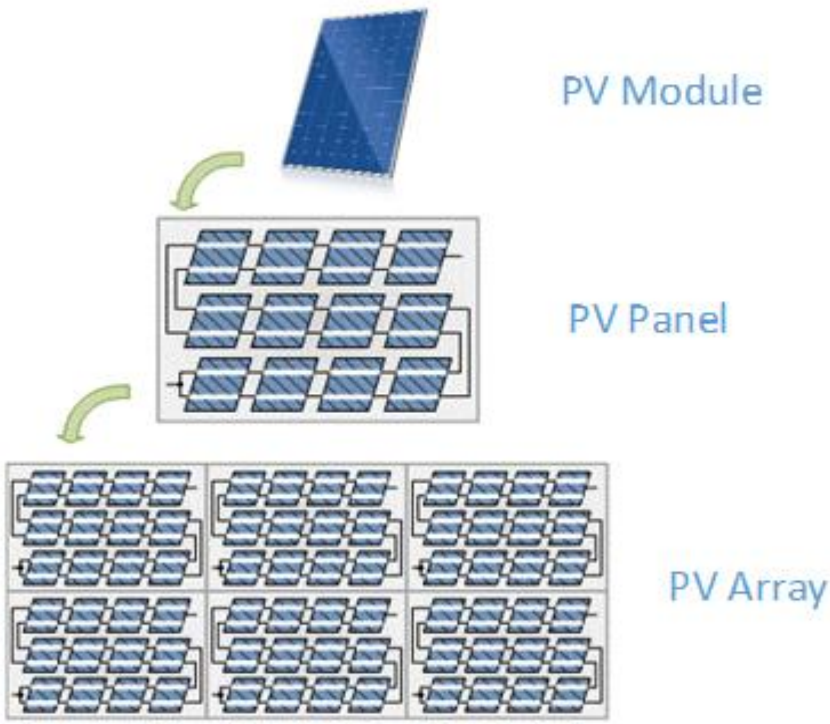

Figure 2. 11 : PV Array

2.6 Photovoltaic Characteristics

Photovoltaic cells are made of semiconductor material under certain conditions. The most common semiconductor material is silicon and to increase its conductivity it is often mixed with some other material.

The connection between the voltage and current at output side is encapsulate to known the characteristic of photovoltaic panel. The quantity and strength of solar heat regulate the quantity of current (I) at output, and the temperature of solar compartment effect the voltage (V) at output of the solar panel.

Figure 2.12 shows the current versus voltage and P-V features of solar cells. I-V bend shows the connection between the current and voltage under states of irradiance and temperature, and the P-V bend used to locate the maximum power point (MPP).

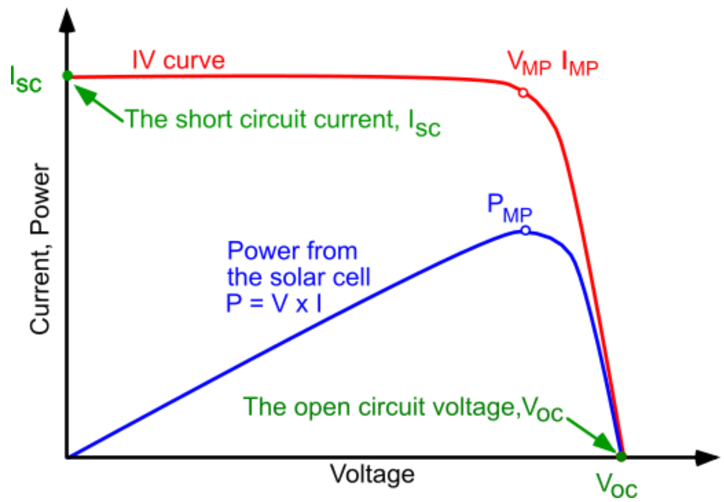

Figure 2. 12 : Characteristic of PV Compartment (Cell)

To design the solar cell we use some parameters that are:

Voltage at Open Circuit (V_{oc}): the maximum value of voltage in photovoltaic panel where the current across the load is zero. The output ends are not connected to each other.

$$V\,(@\,I = 0) = V_{oc} \qquad \textbf{(2.9)}$$

Current at Short Circuit (I_{sc}): The maximum value of current in solar panel where the voltage across the output is zero.

$$I\,(@\,V = 0) = I_{sc} \qquad \textbf{(2.10)}$$

Maximum Power point (MPP): maximum position at current voltage curve where the multiplication value of voltage and current is maximum across the load.

$$MPP = V_{mp} * I_{mp} \qquad \textbf{(2.11)}$$

Fill Factor (FF): is the link among the determined power at standard operational point to the result of V_{oc} into I_{sc}. Normally the value of the fill factor (FF) is 0.7 – 0.8.

$$\textit{Fill Factor (FF)} = \frac{V_{mp}}{I_{mp}} \qquad \textbf{(2.12)}$$

Efficiency: is the relationship between the maximum powers to the input radiation power. The efficiency of mostly cells are 13 % - 17 %.

$$\eta = \frac{Voc*Isc*FF}{P_{in}} \qquad \textbf{(2.13)}$$

Solar cells are mainly divided into three different parts.

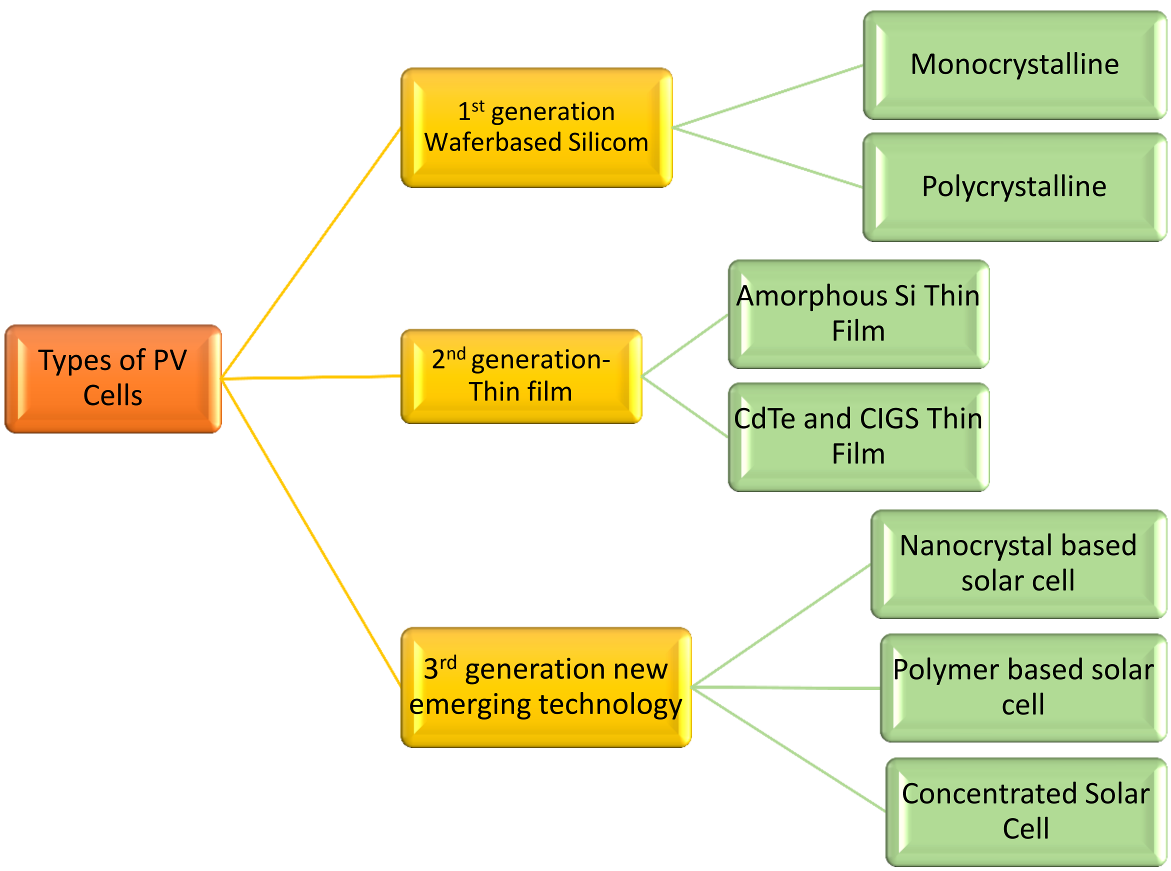

Figure 2. 13 : Types of PV Cells

2.7 PV System Types

2.7.1 1st Generation PV cell

First-generation solar cells are dependent on silicon (Si) PV cells. In spite of the fact that this innovation has high transformation effectiveness however the accessibility of Silicon is mind-boggling in light of its significant expense. Likewise, the manufacturing cycle of the silicon based sun powered cell is complex. First-generation silicon cell divides into two parts, polycrystalline and monocrystalline. The first generation solar cell is based on wafer boards.

Figure 2. 14 : First Generation Solar Cell

2.7.2 2nd Generation PV Cell

2nd generation solar compartments are dependent to amorphous silicon (A-Si) PV cells. The efficiency of the second-generation solar cell is better than the first generation. It is cheap in comparison to silicon based PV cell. Second-generation solar cell types are amorphous Si thin film, CdTe, and CIGS thin film. One disadvantage of a second-generation PV cells is its material is hard to find. Thin-film solar cells work efficiently at lower irradiance.

Figure 2. 15 : Second Generation PV Cell

2.7.3 3rd Generation Photovoltaic Cell

3rd generation solar compartment based on Nano crystalline, polymer, and concentrated solar cell. These types of cells are still in the research phase. The main purpose of the concentrated cell is to focus the huge quantity of solar heat on small place where solar chamber available. The main goal of third generation photovoltaic cell is to create photovoltaic cell energy more efficient and less expensive.

Figure 2. 16 : Third Generation PV cell

2.8 Standalone (Off-grid) PV System

Standalone PV systems are autonomous of the electric grid. They are intended to operate definite DC loads and DC/AC loads. The main parts of standalone systems are PV array, controller, batteries, and inverters. The simple type of this system is the Direct-coupled PV system. This type of system straight linked to DC loads, so batteries are not necessary. Direct-coupled PV system fed energy to DC load during sunlight. When the sunlight isn't available then the PV array stores the energy in the battery and converts this electrical energy from DC to AC by using an inverter and fed to the AC loads. Batteries are the main component of the standalone PV systems, they store energy in DC form and use this energy when the sun isn't available. The charge controller uses to regulate the output power and prevents batteries from over charging and discharging. Figure 2.17 shows the schematic diagram of the standalone PV system.

Figure 2. 17 : OFF-Grid Photovoltaic System

2.9 Grid Connected PV System

This type of plant is used for the bigger areas. The main part of this type of system is to convert the DC power of the PV array to AC power according to the requirement of the utility grid. The utility grid is connected in parallel with the inverter as shown in Figure 2.18. The clients use this system where they want to save the energy and the excess energy store into the battery for future use and we also called this system battery Backup PV system. If the energy produced by the solar array in the excess form it will send to the service grid, if enough energy isn’t produced by the PV array then we can take power from the utility grid. DC type grid-connected PV system includes switches, meters, and AC wiring which connects the PV generator to the house distribution panel.

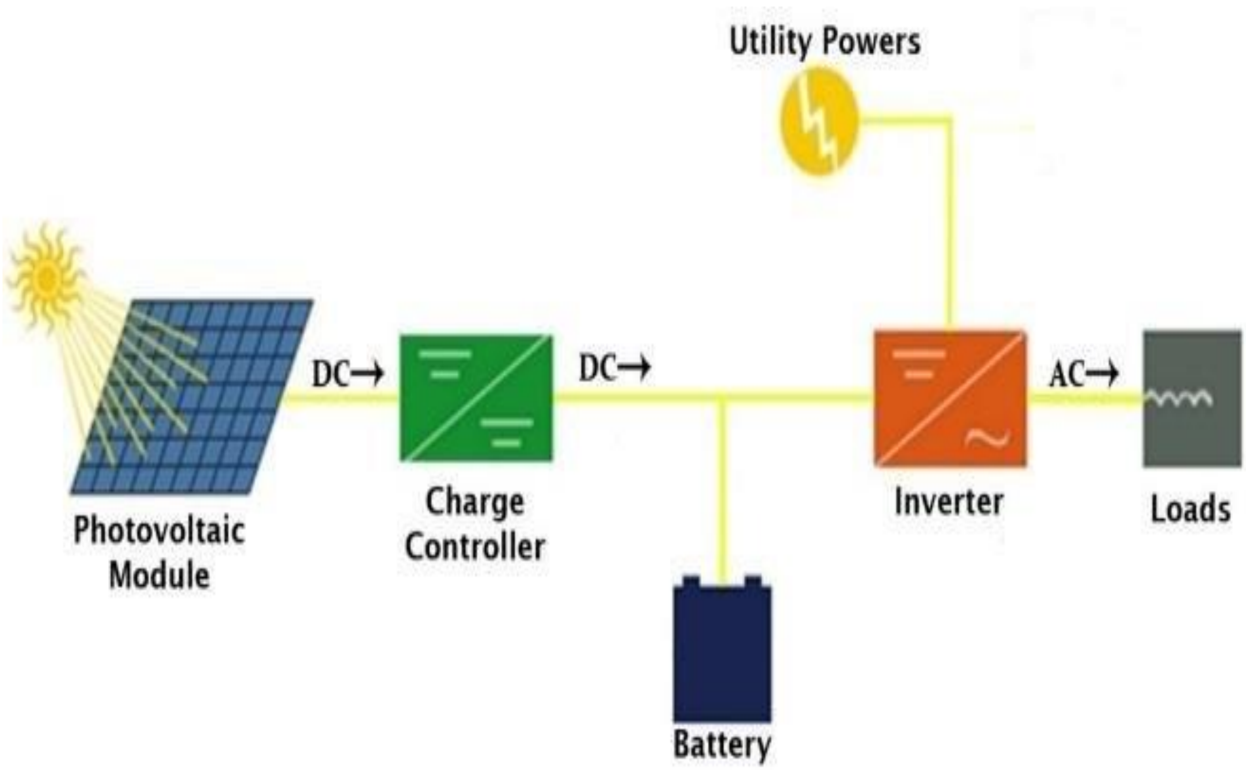

Figure 2. 18 : Grid-Connected PV System

3. MAXIMUM POWER POINT TRACKING & BATTERIES

3.1 Maximum Power Point Tracking

In solar panels, there is a peak point where the voltage and current is on their peak value that specific point is called the maximum power point of solar panel. In a photovoltaic system, the current-voltage curve varies with respect to irradiance and temperature. When the environment is changed like most cloudy and sunny the temperature and irradiance also change. We can extract the maximum power by tracking the maximum voltage and current. To withdraw the maximum power of the PV system, mostly maximum power point tracking algorithm is used. By using perturb and observe method, MPPT based efficient regulator will design.

The maximum value of current and voltages are related to the load resistance. We can find the load resistance by using Ohm's Law R=V/I. The power is calculated by P=V*I. The point where the voltage and current values are maxima known as the "knee" of the curve.

3.2 MPPT Algorithm Methods

In current applications, most of times load require extra energy than the system can distribute. MPPT substitute into diverse methods to draw out extreme power. In this chapter, we discuss about the "Perturb and Observe method". Some of the methods are given below:

1. Constant Voltage Method (CVM)
2. Open Circuit Voltage Method (OCVM)
3. Short Circuit Current Method (SCCM)
4. Perturb and Observe Method (P & O)
5. Incremental Conductance Method (ICM)

3.2.1 Hill Climbing (P&O) Method

In MPPT, Perturb and observe method is used to extract the maximum power from the system. In this method, due to a small increase in power change in the photovoltaic module. The output power is measured and compared with the old power and check if the system is reached to maximum point otherwise it increases the power until the maximum point is achieved. This is a commonly used method due to the ease of its implementation. In this method, perturbation is given to the PV array. If the PV module voltage is increased or decreased we can see the power is increased or decreased. If the voltage is increasing and the power is also increasing the operating point is on the left side of the MPP so to reach the MPP more perturbation is needed towards the right. If the voltage is increasing and power is decreasing then the operating point is on the left side of the MPP and to reach the MPP further perturbation is needed to the left side as shown in Figure 3.1.

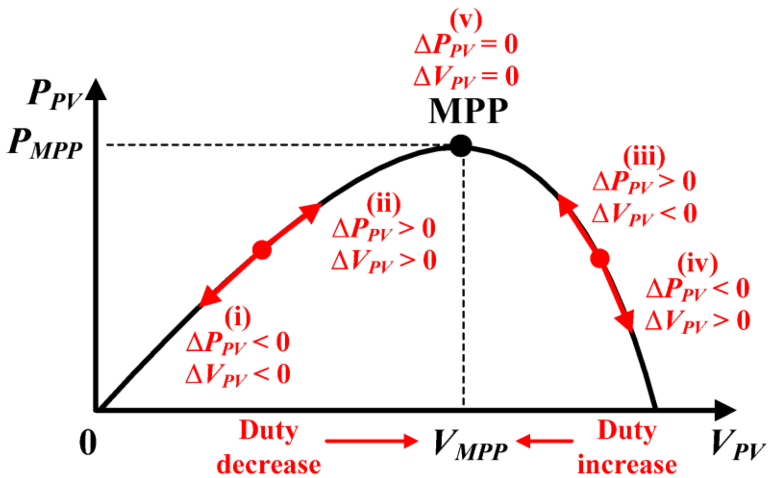

Figure 3. 1: Power with P&O Method

In Figure 3.2, the process of MPPT based (P&O) method is presented. The MPPT duty controller is connected to the center of the PV array and battery. It measures the PV array and battery voltages. MPPT controller check battery voltages and see battery is fully charged or not. If the charging of the battery is reached its maximum point then the charge controller stops the charging to prevent battery overcharging. If the battery is not fully charged then the regulator charges the battery by using DC-DC converter. By measuring the voltage and current charge controller measures the new power and compares it with the old power. If the new power is bigger than the old power, to draw out the extreme power from PV plate we increase PWM based duty cycle. If new power is smaller than the old power then we decrease the duty cycle so we can achieve our maximum point. Perturb and observe method is very simple to use and available at low cost with high precision.

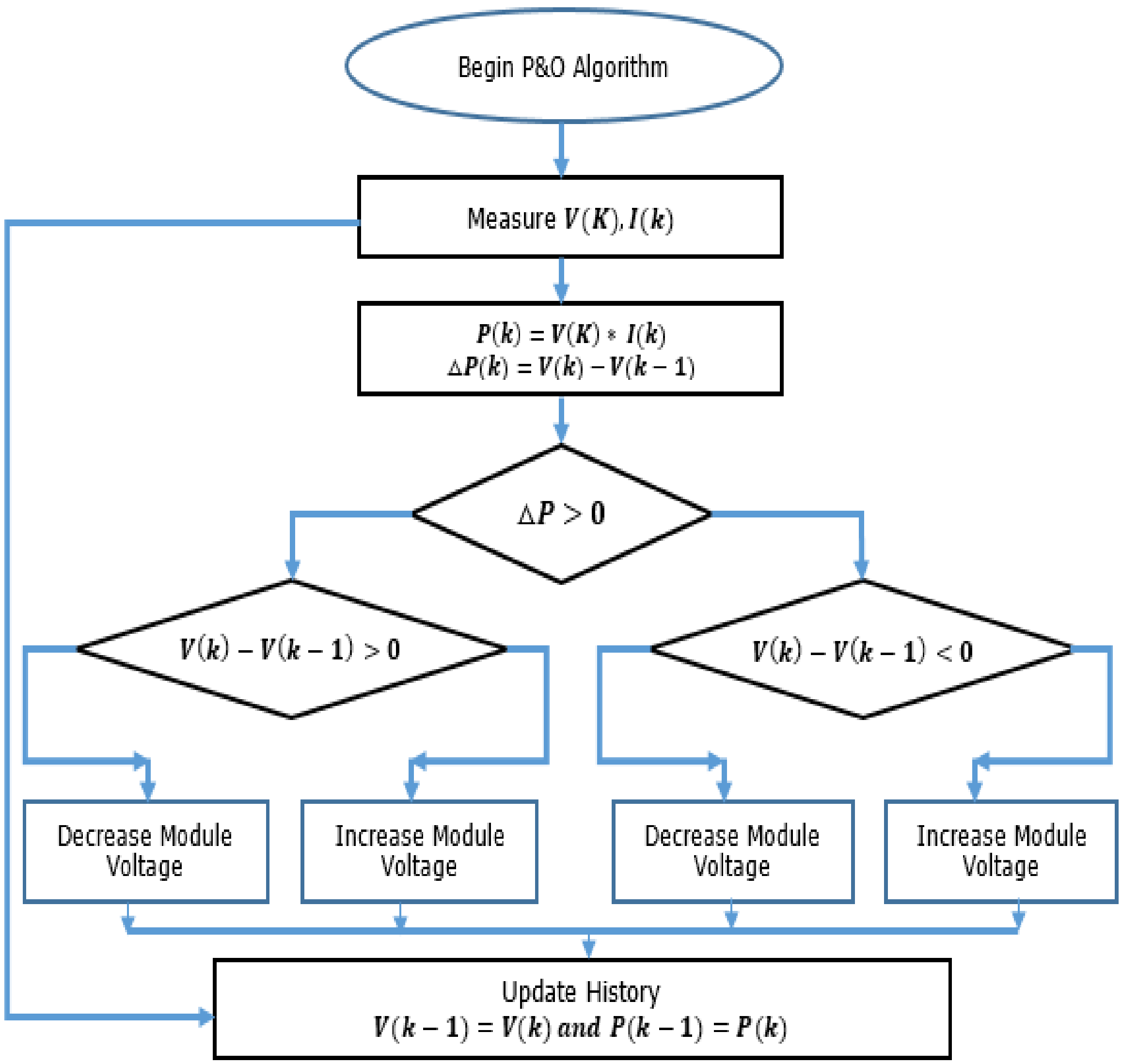

Figure 3. 2 : Flow Chart of P&O Method

3.3 Batteries

Rechargeable batteries are energy-storing devices that transforms the one type of energy into another form. Nowadays, societies are using additional storage batteries instead of disposable equivalents for the reason of cost and environmental changes. In a standalone PV system, there is a need to store a huge amount of energy for this we have to apprehend the diverse types of batteries, and choose 1 respectively. In a home-based energy PV Systems, power generation produces during the day, and without any energy storage facility, PV systems will not be able to meet the resident's demands because there is a peak energy consumption in the evening. Energy-saving technologies such as batteries are developing to measure the inconsistency scheme between the demand and production. A big battery power system is made from battery banks as shown in Figure 3.3.

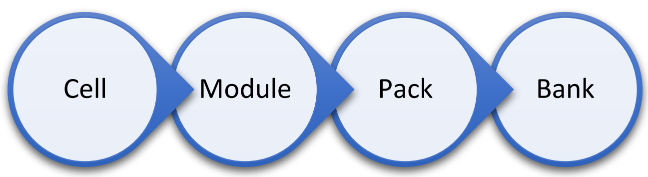

Figure 3. 3 : Battery Power System Formation

We note that battery discharges by itself and it depends on the battery temperature and type. We also saw that the life cycle or age of the battery is short and it depends on the battery charging and discharging, temperature, battery type, and how we use the battery. There are different types of batteries that are commonly used:

1. Lead-acid Battery
2. Lithium-ion Battery
3. Nickel-cadmium Battery
4. Sodium-ion Battery

3.3.1 Lead-acid Battery

Lead-acid batteries frequently utilize due to its ease of use and cheap cost. That’s why these types of batteries utilize for vehicles as a support power storage. Lead-acid batteries consist of dilute sulfuric-acid and for electrolyte and plate lead will use. Lead-acid battery categorize into two types: flooded & sealed. In most application sealed modules are used. VRLA, AGM and gel types are included in sealed type batteries. Lead-acid batteries types are described in Table 3.1.

Table 3. 1 : Types of Lead-Acid Battery

Flooded Batteries	In this type of battery, liquid electrolyte move freely through cell division. When the battery dries up, the user can easily approach the individual cells and add distilled water. The absorption voltage range for this type of battery is 14.4 to 14.9V.
Sealed Batteries	The function of this type of battery is the same as a flooded type battery. In this user doesn’t have any approach to cell section, the main difference is that the constructor verifies that there is enough amount of acid in the battery to support chemical reaction under standard conditions.
VRLA Batteries	VRLA stands for valve-controlled lead-acid battery. VRLA is impenetrable battery. The valve adjusting technique allows hydrogen and oxygen gases to escape safely during charging. The absorption voltage range is 14.2-14.5V.
AGM Batteries	The structure of absorbed glass mat accede the electrolyte to hang near the active ingredient of plate. The efficiency of charging and discharging increases in this type of batteries. The float voltage range is 13.2-13.8V.
GEL Batteries	Gel battery is alike AGM battery in that the electrolytes are suspended. The electrolyte in gel cell battery contains silica additive that cause them to harden. In deep cycle application this type of batteries are best. The absorption voltage range is 14 to 14.2 volt.

Figure 3. 4 : Lead-Acid Battery Types

3.3.2 Lithium-Ion Battery

Lithium battery has received attention and is growing exponentially because of its important advantages like extraordinary energy concentration per component size. In Lithium battery, 3.6 volt is the rated voltage capacity and typically higher. The automatic discharging time of lithium battery is less than the nickel metal hydrate battery. In lithium ion cells, cobalt acid normally activates the positive electrode, while highly crystalline like carbon activates by the negative electrode. The ions move in a negative direction and ionizes due to Lithium cobalt oxide material. In between of discharging state, ions travel towards the cathode side and convert in original material. Ascendancy of lithium-ion battery means that these are significantly utilize in shipping fleet & moveable electrical gadgets.

Figure 3. 5 : Lithium-ion Battery

Table 3. 2 : Application of Lithium-ion Battery

Power Store Device	Lithium-ion batteries are used in fixed, solar, standalone and self-consumption systems.

E-Traction	Lithium-ion batteries are used in airplane, marine, industrial vehicles, golf tugs, and in robotics.
Mobile Energy	Lithium-ion batteries are used as portable batteries like an auxiliary power unit for different type electrical apparatus.

4. RESULTS AND DISCUSSION

4.1 System Modeling

In this thesis our main focus is to design an efficient charge controller that will use in photovoltaic charging system. For this, we have to define our system parameters. In this system, irradiation falls on the solar panel, solar panel absorb the sunlight and with the help of electrons it convert the sun energy into electrical energy. This energy fed to our load. To withdraw the extreme power we use MPPT based (P&O) method and with help DC-DC converter we can achieve our required voltage and current that will use for charging the battery. In Figure 4.1, general diagram of our system is explained,

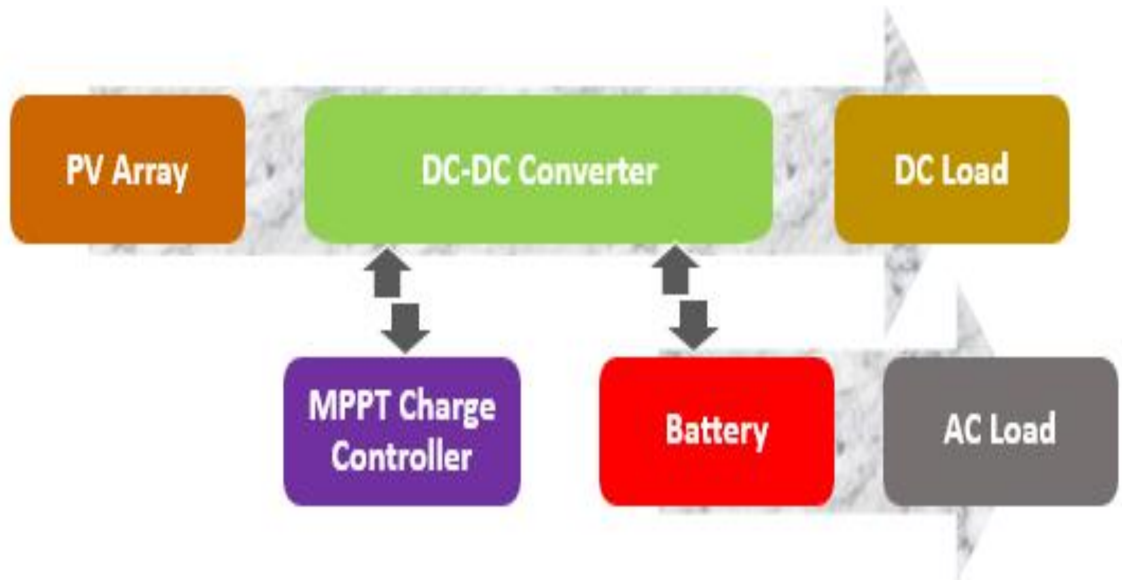

Figure 4. 1 : General Block Diagram

4.1.1 Specification of PV Array

PV Array that will use in this system is Grape solar GS-S 190W-Fab3. We use 2 series modules and 10 parallel modules. The specification of PV module is give in Table 4.1,

Table 4. 1 : PV Array

Maximum Power (P_{MP})	190 Watt
Module Cells	72
OC Voltage (V_{OC})	45.4 Volt
SC Current (I_{SC})	5.44 Amp
MPP Volt (V_{MP})	36.2 Volt
MPP Current (I_{MP})	5.25 Amp
Voc @ Temperature coefficient	-0.34401 %/^{o}C
Isc @ Temperature coefficient	0.052996 %/^{o}C

The ideal power, voltage, and current at maximum power point is shown in Figure 4.2. At 900 W/m^2, the voltage at MPP is72.29 V and the current at MPP is 47.19A, and the power at MPP is 3411W. At 1000 W/m^2, the voltage at MPP is72.4 V and the current at MPP is 52.5A, and the power at MPP is 3801W.

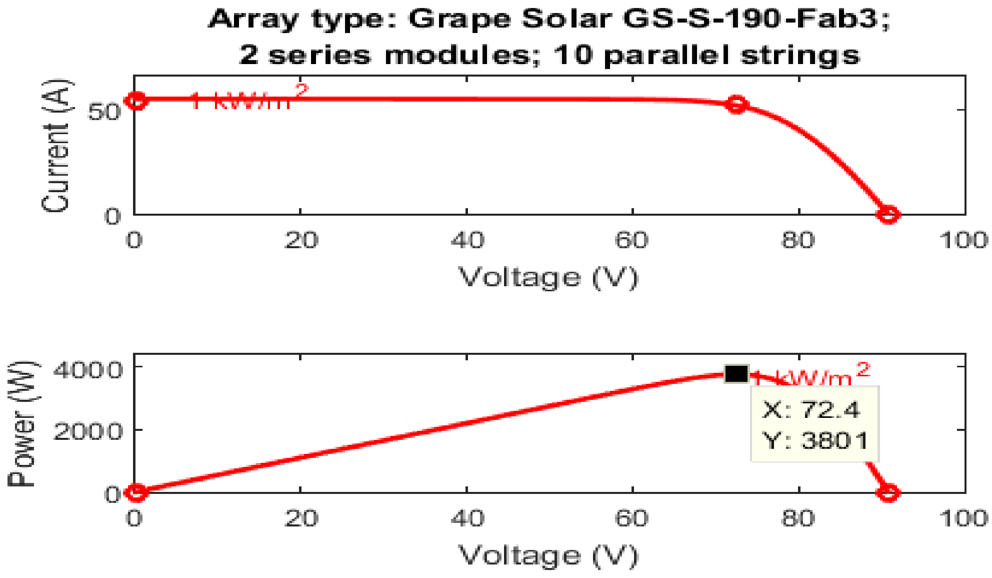

Figure 4. 2 : PV output at 1000 W/m^2

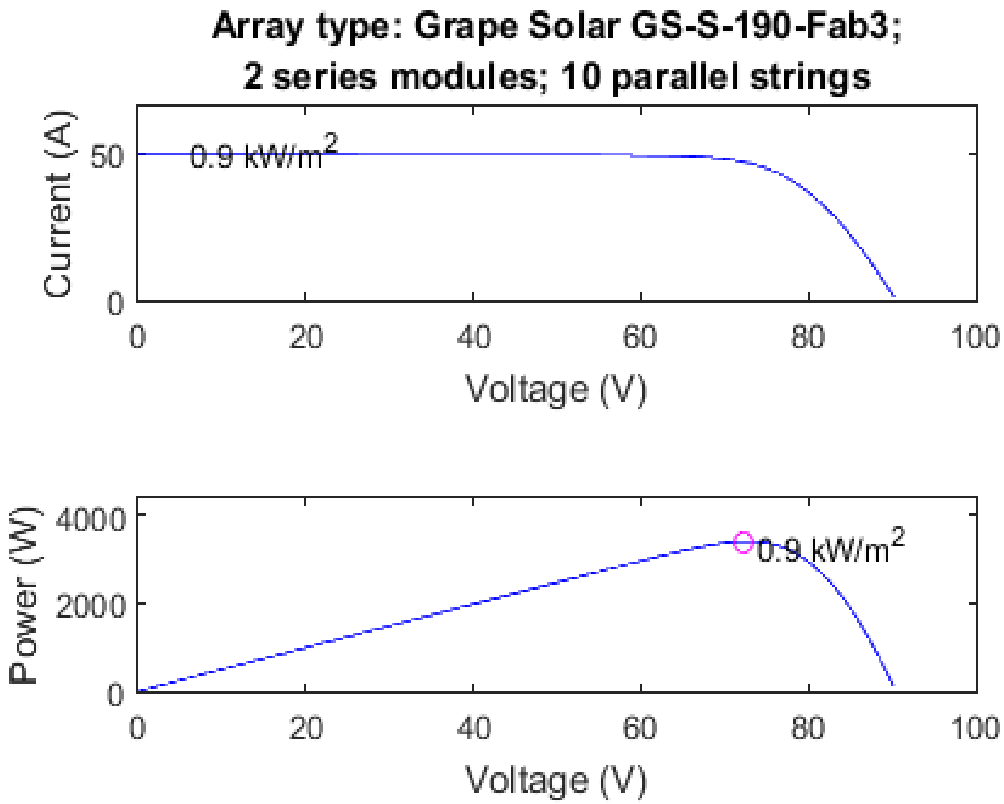

Figure 4. 3 : PV output at 900 W/m^2

4.1.2 PV with MPPT

As we see in above Figures, the power is different at different irradiance. To extract the maximum power at different irradiance from PV panel, MPPT method will use. MPPT categorize into various technique, we use perturb and observe method because of its accuracy and easy to use. For this we connect the boost converter with PV panel and PV panel is connecting to photovoltaic based (Perturb and observe) method. In Figure 4.4, Simulink model of (P&O) method is displayed. Boost converter details is mention in given Table 4.2,

Table 4. 2 : Boost Converter Specifications

Input Capacitor (C_{IN})	3mF
Inductor (L)	50μH
Output Capacitor (C_{OUT})	2200μF
Output Resistance	5Ω

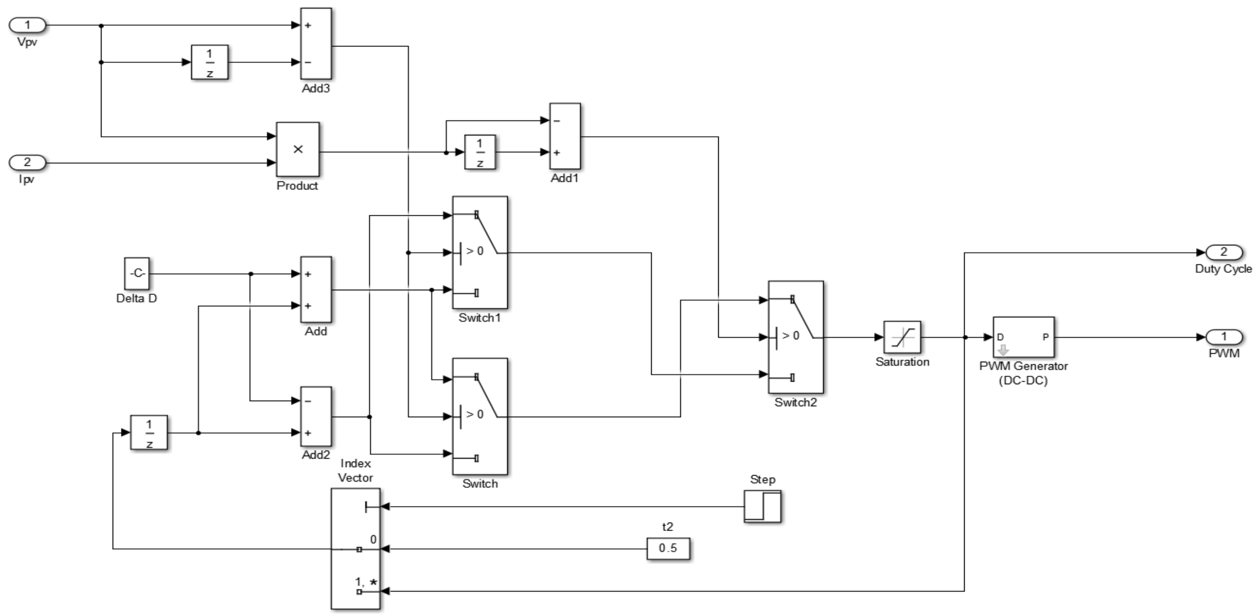

Figure 4. 4 : Perturb and Observe Method

At 1000 W/m^2, the output waveform of V_{PV}, I_{PV}, and P_{PV} is shown in below Figures, we also see that we reached our maximum value but there are ripple in voltage and current, we can reduce these ripple by changing the value of capacitor and inductor.

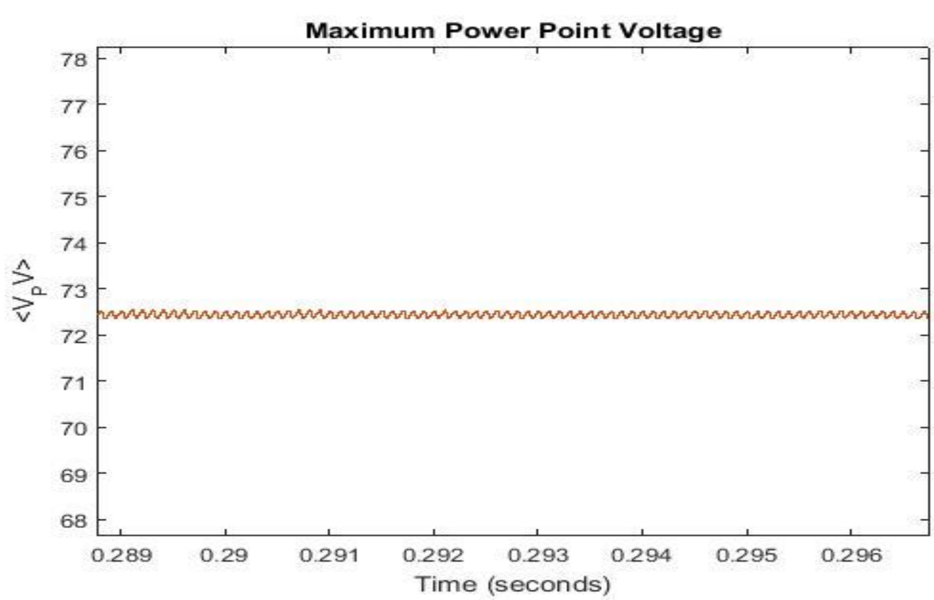

Figure 4. 5 : V_{MP} at 1000 IRR

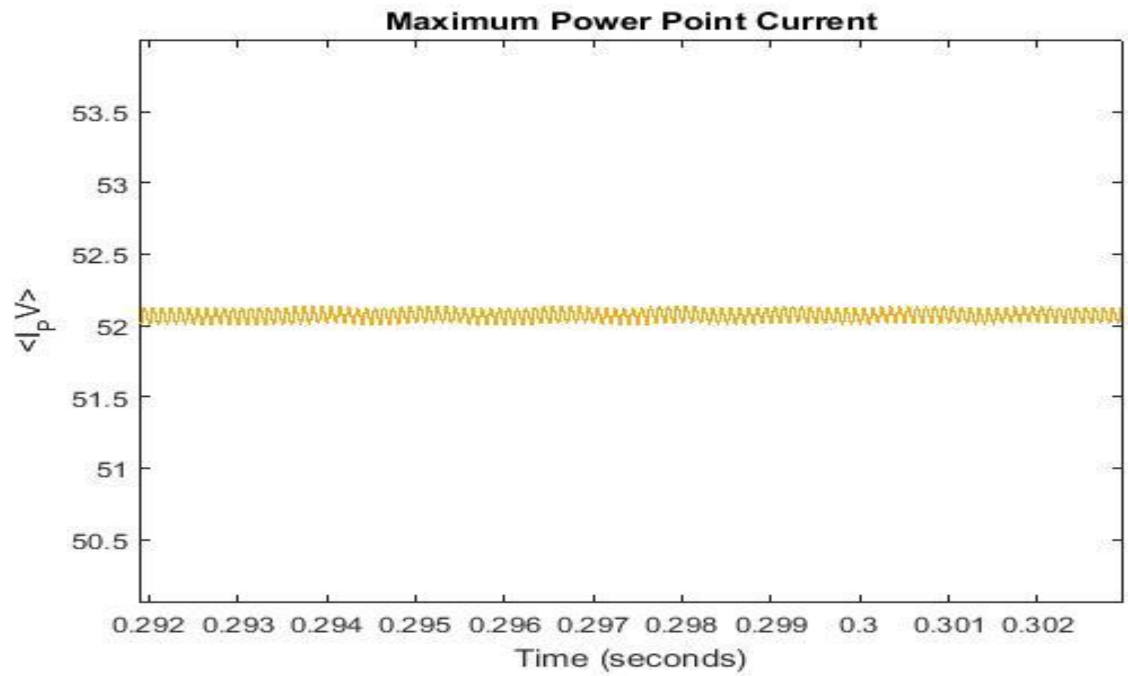

Figure 4. 6 : I_{MP} at 1000 IRR

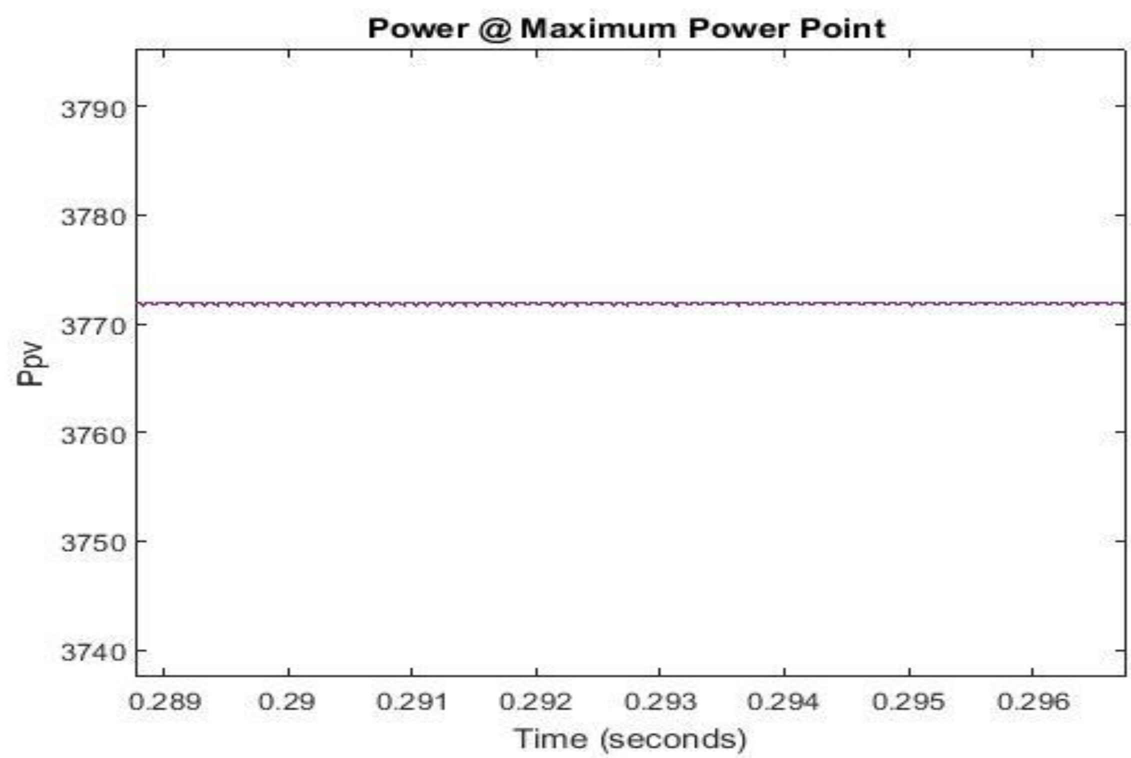

Figure 4. 7 : P_{MP} at 1000 IRR

4.1.3 PV with Buck Converter

As I explain MPPT based (P&O) method used to withdraw the extreme power from system by using boost converter. In this, buck converter use to lower the boost converter voltage, to accomplish our desire output so we can charge the battery. We design a controller that can provide a PWM signal to the DC-DC buck converter. In this controller, first we compare our output voltage with reference voltage by using a comparator. The comparator output is a fault signal which is improved by using a gain amplifier. The output is assimilated but the integrator retune by using timepiece pulse, the clock pulse frequency will be the sawtooth carrier wave frequency. Since constant assimilation results in a gradient function, to convert this function to sawtooth wave, we must repeat the integration using the integrators zero resets after each period time. Integration is completed with an intrinsic constant, where the integral perpetual is selected as forty thousand. It depends on the frequency of shift. A general rule is to choose an intrinsic constant that is four times greater than your switching frequency. Another comparator compares the saw tooth upsurge with the locus voltage and in response PWM signal is generated. Relay digitized the message i.e. in binary version zero (0) or one (1). Controller is given in Figure 4.8,

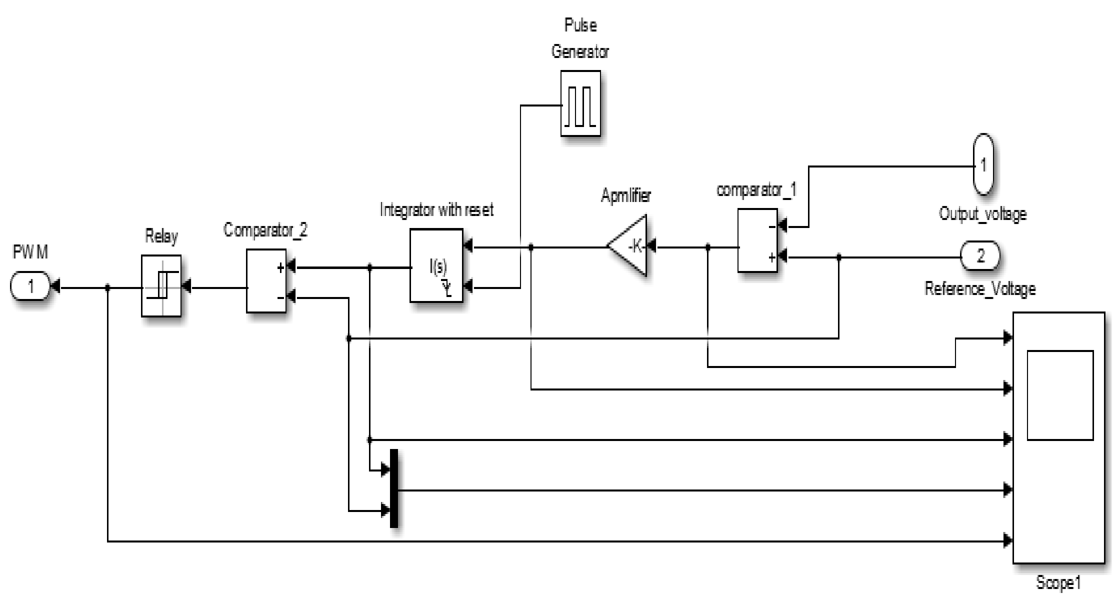

Figure 4. 8 : Buck Converter Controller

Specification of DC-DC buck converter is given in Table 4.3,

Table 4. 3 : Buck Converter Specification

Inductor (L)	500mH
Capacitor (C)	1F
Resistance (R)	0.001ohm
V_out	12.98V
Frequency (fsw)	10,000Hz

4.1.4 PV with Battery

After connecting the PV system with buck converter, we connect the remaining circuit with lead-acid battery with the help of circuit breaker. We also connect the diode to prevent the reverse current in circuit. The circuit break is controlled by Battery charge controller. Initially our battery state of charge (SOC) is 0% mean it's empty. In charge controller, we compare the SOC with relational operator and check if our SOC is less than 100 and also check if our output voltage is greater than 12V than battery will start charging. If one of the condition is not satisfied or the battery is fully charged then circuit breaker disconnect and battery stops charging. The battery specification is given in Table 4.4. By using this value our battery need 3060Wh energy required so battery took 5hr to reach in full charging state. Battery charge controller is given in Figure 4.9.

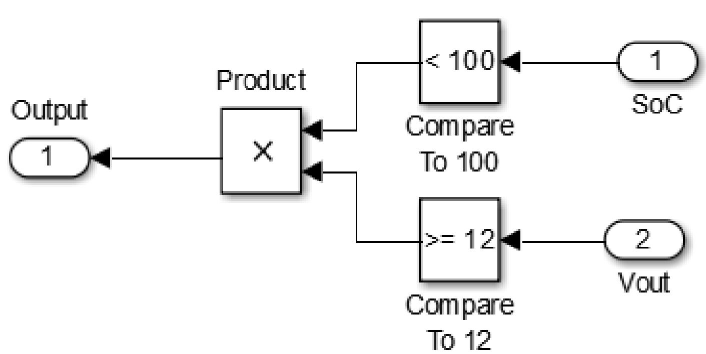

Figure 4. 9 : Battery Charge Controller

Table 4. 4 : Lead-Acid Battery Rating

Nominal Voltage	12V
Rated Capacity	255Ah
Initial SOC (%)	0
Maximum Capacity	265.625Ah
Fully Charged Voltage	13.06V
Nominal Discharge Current	51A
Battery Response Time	1s
Series Resistance	0.25ohm

4.2 Results

In circuit diagram of standalone PV system, we see that PV panel is connected with MPPT and boost converter and then that boost converter link with buck converter to step down the input voltage to achieve our required voltage and that buck converter is connected with battery. In below results, we see that when we run the circuit our voltage and current start increasing and our SOC of battery is at 0.01%. At time 0.7 sec our circuit reaches the require value like $V_{\_out}$=12.98V and I_{out}= 50A and after that it takes time to stable the voltage and current. At 1.8 sec our required voltage and current is steady (constant) after sometime then battery starts charging and the value of SOC start increasing. The circuit Diagram of standalone PV system is given in Figure 4.10,

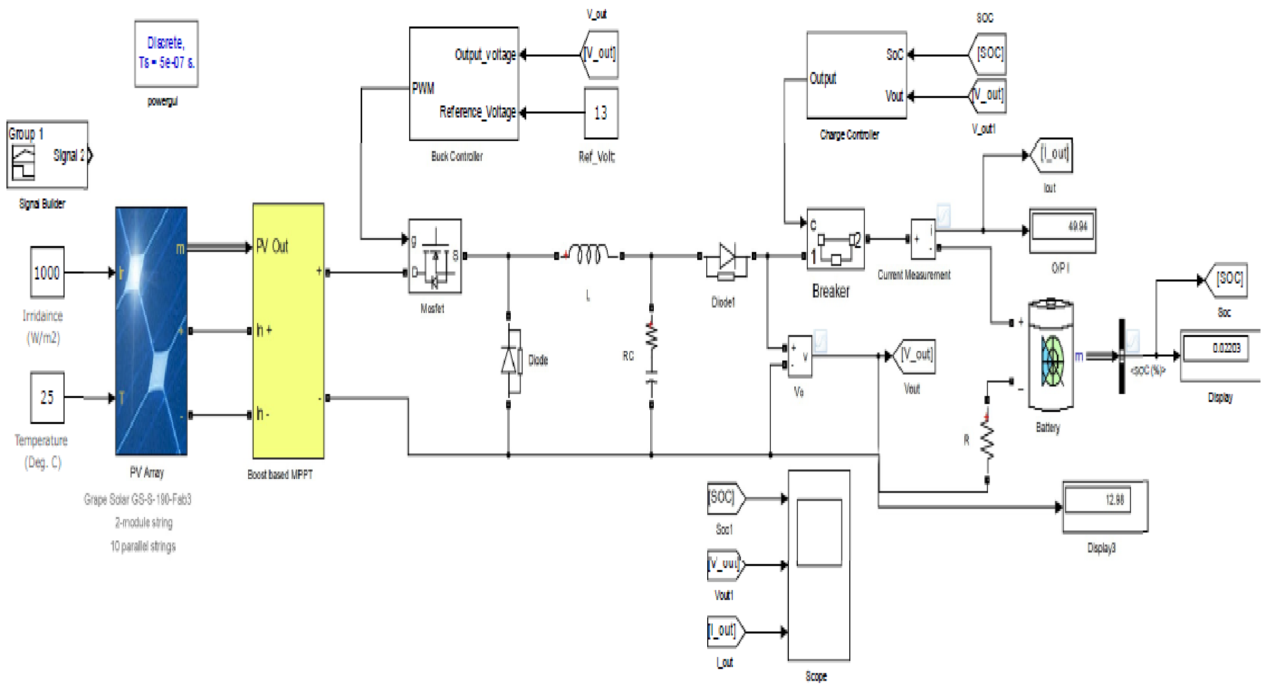

Figure 4. 10 : PV Charging Station

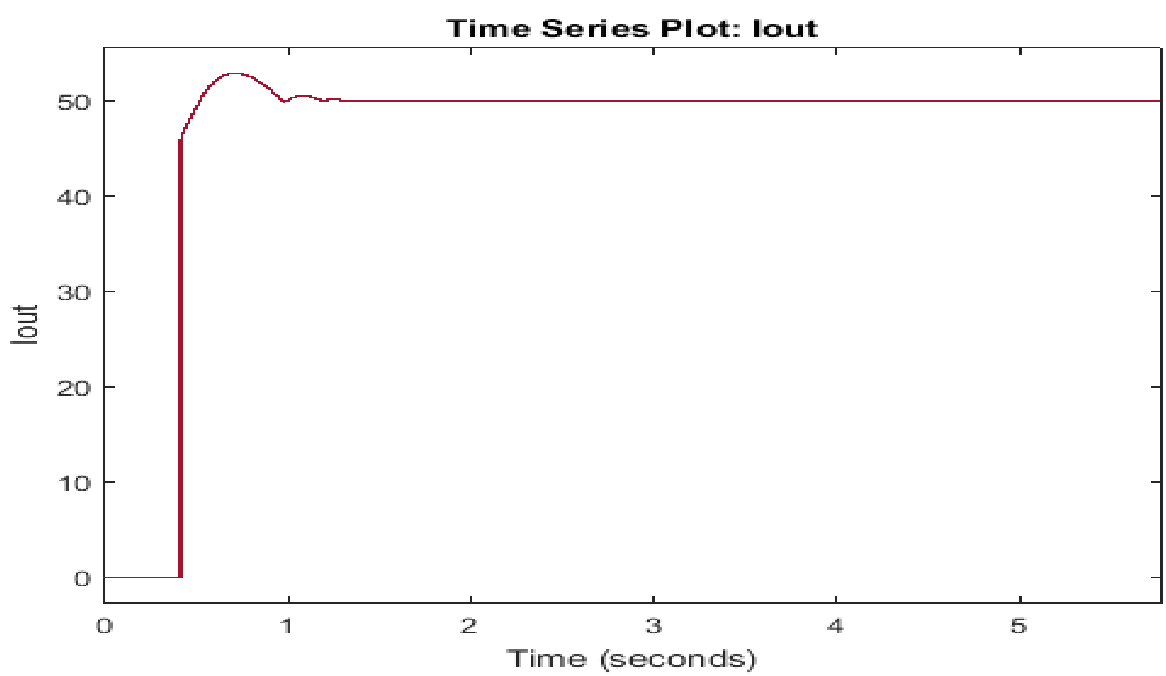

Figure 4. 11 : I_out @ 1000 IRR

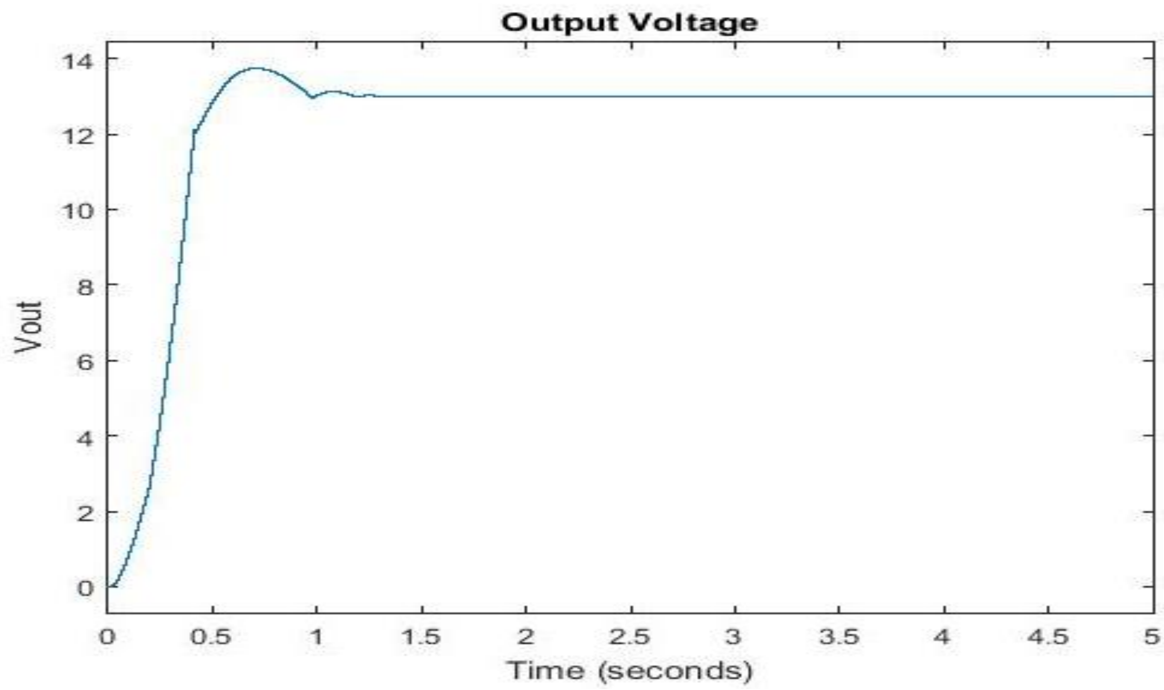

Figure 4. 12 : V_out @ 1000 IRR

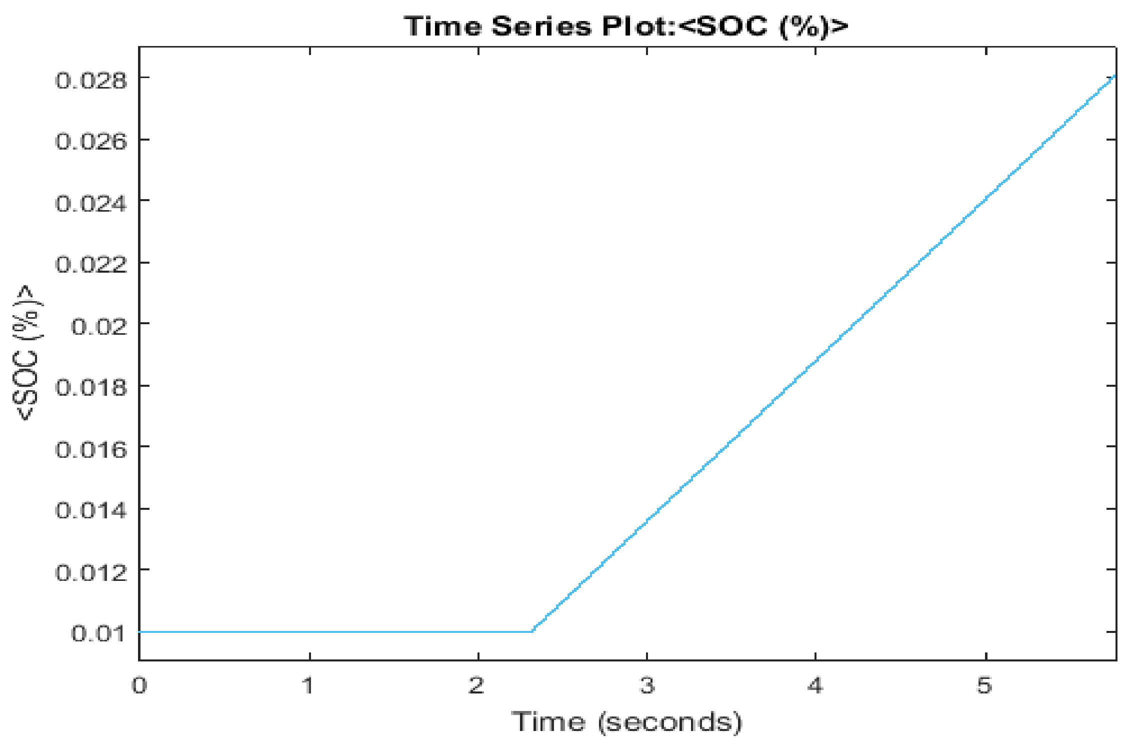

Figure 4. 13 : SOC @ 1000 IRR

We know that, lithium battery is used for static, and standalone PV system. Lithium battery also used for emergency holdup. We relate the Lead acid battery state of charge with lithium ion battery state of charge in Figure 4.14. We perceive that lithium battery charge fast as liken to lead acid but as relate to cost lithium batteries are affluent. So, that's why we use lead acid battery in our system. Lithium battery specification show in Table 4.5,

Table 4. 5 : Lithium Battery Description

Rated Voltage	12V
Esteemed Capacity	255Ah
Primary SOC (%)	0
Extreme Capacity	255Ah
Entirely Charged Voltage	13.9678V
Minimal Discharge Current	110.8696A

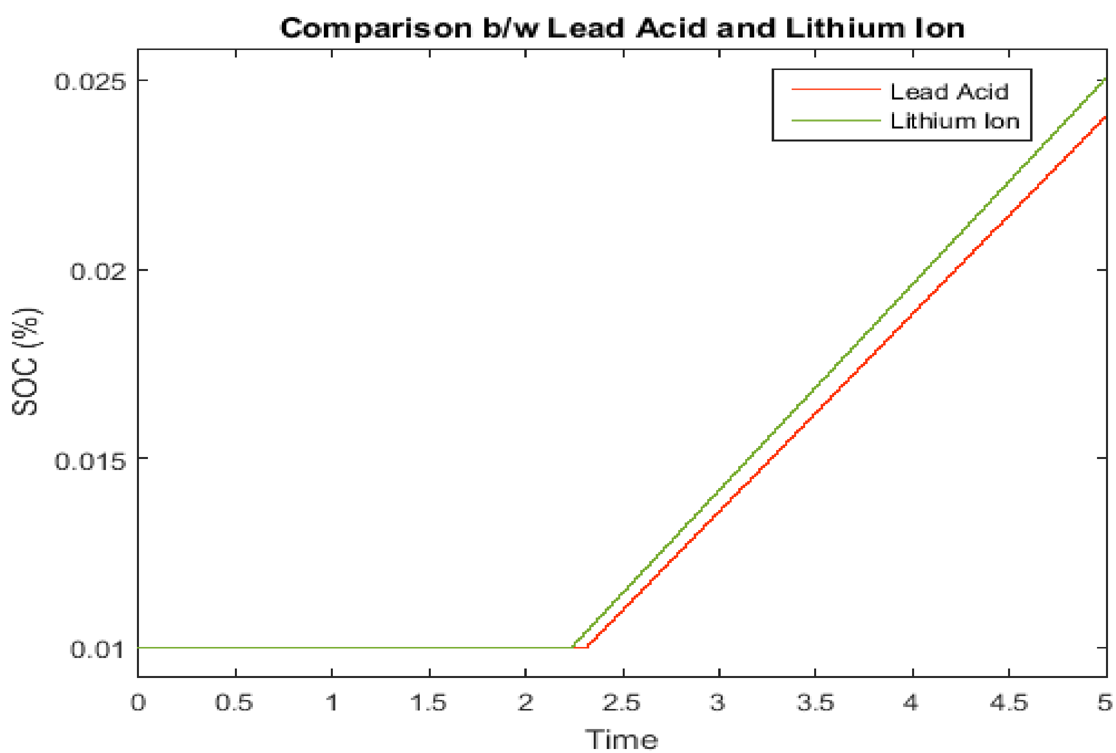

Figure 4. 14 : Lead Acid associate with Lithium Ion

In Figure 4.15, lead acid battery relates to nickel-cadmium battery and we proverb that nickel cadmium battery takes extra time to charge as liken to lead acid battery. The performance of lead acid battery is better than nickel cadmium battery. Ratings of nickel cadmium battery is shown in Table 4.6,

Table 4. 6 : Nickel-Cadmium Battery Measurements

Rated Voltage	12V
Esteemed Capacity	255Ah
Primary SOC (%)	0
Extreme Capacity	289.7727Ah
Entirely Charged Voltage	13.7301V
Minimal Discharge Current	51A

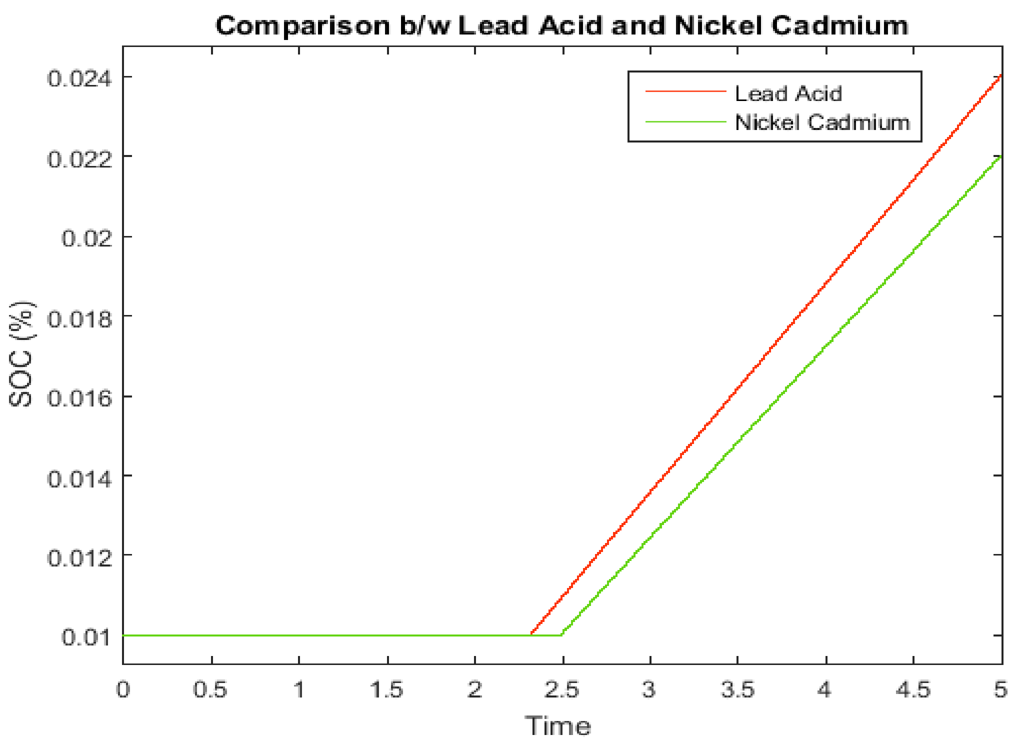

Figure 4. 15 : Lead Acid SOC Relates to Nickel-Cadmium SOC.

5. CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

In recent days, due to the depletion of natural resources solar energy becomes more popular. In this thesis, our main goal is to design an efficient charge controller that can charge our battery. First we design a solar panel according to our circuit requirements. That solar panel plates detects sun arrays at different irradiation and convert that irradiation into electrical form and deliver it to charge controller. From PV panel, maximum power will extract by using Perturb and Observe MPPT method. Initially when I design a circuit and run it I saw that our charging current is not stable so that's why our output is not stable. Then I decided to design a controller that can help our circuit in charging at constant voltage and constant current. The suggested method is capable of charging the battery at different Irradiation. Initially when we run the simulation, we observe that our voltage and current increasing linearly but at certain time it stops increasing because our battery needs 50A for charging. At certain point, where our voltage and current stop increasing, we say that our circuit is in a stable state and the battery will start charging. Also, we put some condition at battery end when this condition satisfied then our battery starts charging otherwise not. By results, we verify that at constant current and at constant voltage our battery is charging. The design system is simulated in MATLAB/Simulink R2015a. This system will be used in home-based PV system, golf carts and electric bike.

5.2 Future Scope

Our objectives were to minimize energy costs and carbon dioxide and pollutant emissions while maximizing the capacity. It is concluded that charging stations can also perform a function in peak-load shaving and valley-filling. The economic value of the foregoing is mainly reflected by efficient management of charging and discharging of a large number of PV station and the coordination of intermittent renewable energy sources can improve the capacity of the electrical system to accommodate these power supplies and thereby improve the cost-effectiveness of system operation. In other words, although the electricity grid has a limited capacity to accept intermittent renewable energy sources.

For instance, if several magnitudes of charging power, charging locations, and battery capacities are modelled by the same work, then such will provide a more accurate model that reflects the different requirements of various homebased PV system and EVs. Future research on PV charging station based electric vehicle and management of charging and discharging can aid in identifying a compromise between the requisites of vehicle owners and power grid stability.

The high penetration of PV and EVs in the electricity market requires more research. Further studies on the response of PV based vehicle owners to the requirements of grid operators should be implemented; benchmarking research, which evaluates both the produced power costs and charging costs, must be explored.

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