MAYNOOTH UNIVERSITY

ME EMBEDDED AND WIRELESS SYSTEMS THESIS

Design and Simulate a Hybrid Solar and Wind Power System

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Declaration

I declare that the thesis titled' Design and Simulate a Hybrid Solar and Wind Power System' under the supervision of Dr. Bob Lawlor, is my work and is submitted for assessment by the Department of Electronics Engineering as part of the course' ME in Embedded and Wireless Systems.' Additionally, I have consulted various resources and references to finish the thesis, and all the references have been acknowledged in the bibliography provided.

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Abstract

Energy is critical to all country's economic and social growth. Indigenous energy resources must be designed to the optimum level, subject to cultural, environmental, and social constraints, to reduce their dependence on imported fuels. This led to an increase in research and development and innovation in the renewable energy sector, in order to find ways of meeting energy demand and rising reliance on fossil fuels. Because of the abundance, affordability and accessibility of electricity production, Wind and solar energy is becoming common.

Purpose-oriented and environmentally sustainable renewable energy systems are crucial in the future. Solar and wind energy options are alternatives to each other that have the ability to meet the demand for electricity. Nonetheless, the wind energy system might not be technologically feasible at all locations because of its low wind speed and more volatile than solar energy. Hence,this is increasingly appealing to the integrated use of these renewable energy sources and is commonly seen as an alternative to the oil-producing technology known as 'Hybrid Renewable Energy Systems.'

In remote power applications, the innovations in renewable energy technology and the drastic rise in the prices of fossil fuels have made these hybrid power systems popular. This thesis provides an overview of the design and implementation of the renewable hybrid energy system. This thesis also highlights the strategies of optimization that can maximize the economic strategy of the system.

Keywords: Hybrid System, MATLAB, Solar PV, Boost Converter, Efficiency

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Chapter 1

Introduction

The world has a wide variety of sources of energy, which can be easily utilized to produce and consume electricity in two different types, renewable and non-renewable. Non-renewable energy is divided into four classes, including coal, crude oil, natural gas, and nuclear power whereas, Wind, Solar, Hydro, Geothermal, and Biogas are classified as renewable sources. Below Figure 1.1 displays the flowchart of energy resources used for applications.

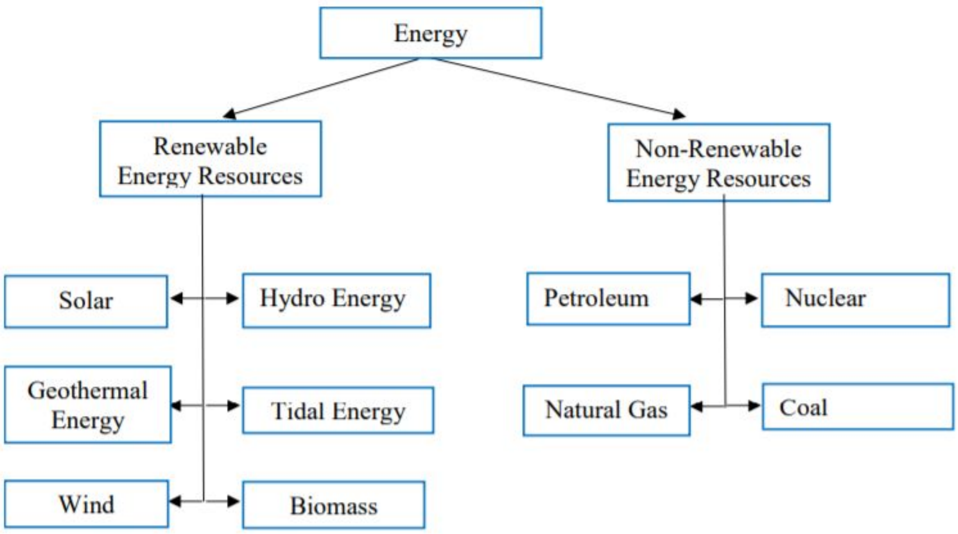

Figure 1.1: Flowchart of energy sources

Burning fossil fuels has been providing much of the electricity used to drive our vehicles, power our industries, and keep the lights on in our homes for more than a century. Figure 1.2 shows the energy sources consumption of the world [Net, 2020]. Oil, coal, and gas still provide around 80 percent of our energy needs today. The use of fossil fuels for energy has caused an enormous toll on humankind and the environment – from air and water pollution to global warming. Figure 1.3 shows the energy sources consumed by the world each year [Net, 2020]. They pollute the environment; they are non-renewable and unsustainable, and drilling them is a difficult process. That is far above the harmful impacts of materials dependent on petroleum, such as plastics and chemicals. Such 'add-ons' of non-renewable resources to the global energy system represent increasingly positive trends towards higher standards of living, rising world poverty, and expanded livelihoods. Increased fossil fuels are the principal cause of global climate change rising many important environmental challenges. The global energy system will have to undergo a renewable energy transition to address these challenges, replacing energy sources generating greenhouse emissions with cleaner sources.

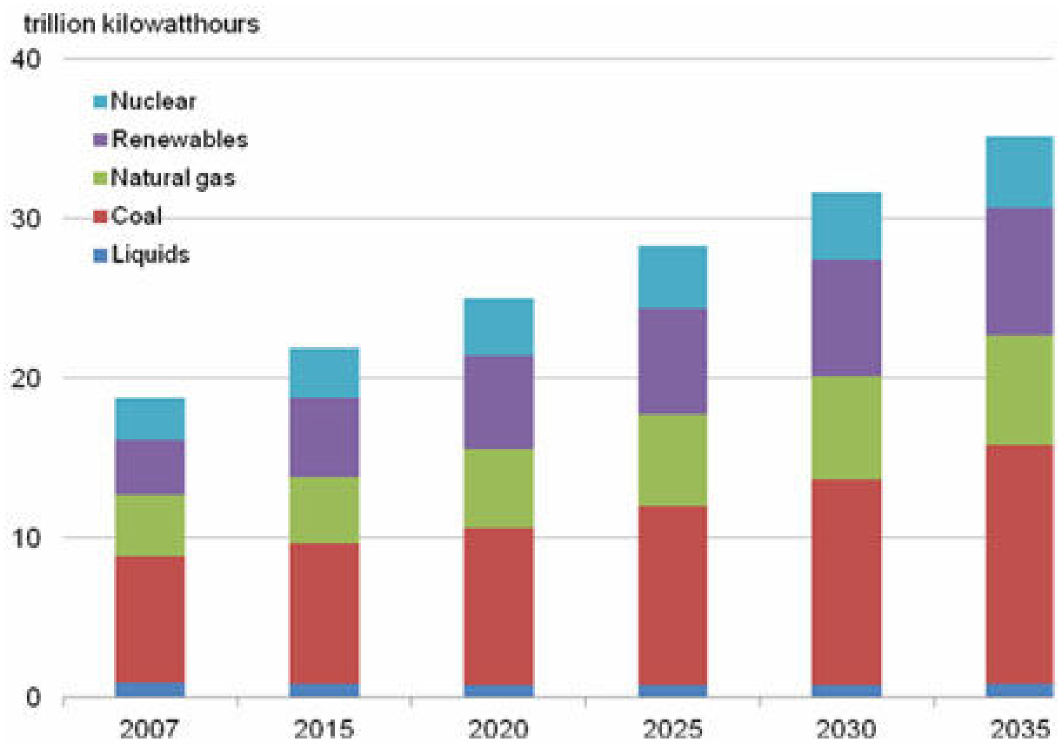

Figure 1.2: Energy Sources Consumption

With the rise of the scarcity of fossil fuel in a world today, renewable energy systems like solar and wind energy, biomass, and micro-hydro systems is seen as a suitable alternative for conventional life because of their sustainability. This latest technology is a hybrid system that consists of multiple renewable sources incorporated as a power plant. It has been discovered that it can produce electricity without limitation in a rural area in particular. The energy resources for solar PV and wind have proven to be more promising, technologically viable, and economically feasible. In several countries around the world, they are used as a hybrid power network, using a single source. The renewable hybrid power system is a device designed to produce and use more than one source of electric power, subject to at least one source being renewable.

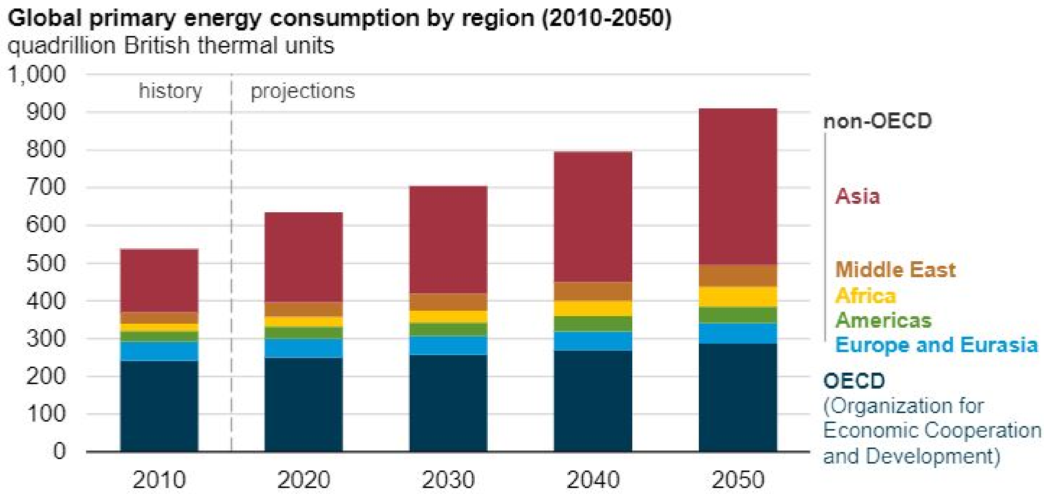

Figure 1.3: Energy Consumption of the World

Motivation

This project will be mainly focusing on the solar energy system. Over the years, the accessiblity of sufficient solar sources and the ease of use in the building of photovoltaic (PV) systems to meet the energy needs have been explored by Ireland's researchers and consumers. In 2018, Ireland had 29MW installed solar photovoltaic power. It is projected that by 2022 1,500 MW will be achieved, representing 5% of Ireland's electricity demand. The ISEA estimates that 2GW of solar energy will generate more than 7,000 jobs and meet 7 percent of the country's electricity demand. A 20sq m solar photovoltaic (PV) system costs around 5000 euros and could create more than 40% of the annual demand for electricity in the typical Irish home [Sol, 2019].

The IEA (International Energy Agency) forecasts that by 2020 the market for prime energy would fall for petroleum ("– 9%"), coal ("– 8%"), natural gas ("– 5%"), and nuclear ("– 2%") while renewable energies would increase by 1%

[Sol, 2019]. The DCCAE (Department of Communications, Climate Action, and Environment) has acknowledged the advantages of solar photovoltaics to Ireland's energy mix and has welcomed the technology as part of the RESS (Renewable Electricity Support Program), issued in July 2018. The scheme will support green energy initiatives in Ireland while improving energy efficiency and sustainable growth.

Figure 1.4: Solar PV System

Figure 1.4 shows general Solar PV Sytem [Sol, 2019]. Solar PV is one of the newly developed, most flexible technology. In reality, its flexibility has been recognized as a key driver for more extensive future technology deployment, and the government recognized the possibility of 1.5 GW grid solar in Ireland by 2030, as part of the Climate Action Plan. Solar PV is an ideal contender for urban energy projects as it positions itself as a technology that can also be integrated into the built environment. On the other hand, the non-intrusive nature of technology is also appropriate for use in large rural projects. Figure 1.5 displays solar energy generation across the world [Tverberg, 2020]. Solar power increased from less than 0.01% of the energy supply for the world in 2008 to more than 2% in 2018. Before 2040, solar will produce more than 20 percent of the world's energy in various scenarios.

Objectives

In this project, we will mainly focus on Hybrid Solar Power System. It discusses the related basic concept and component development of a solar system in three steps:

1. Designing a domestic hybrid power system which is less than 10kW
2. MATLAB / Simulink dynamic simulation for optimal hybrid power system PV system component with battery integration
3. Testing the simulation and presenting it along with the simulation results

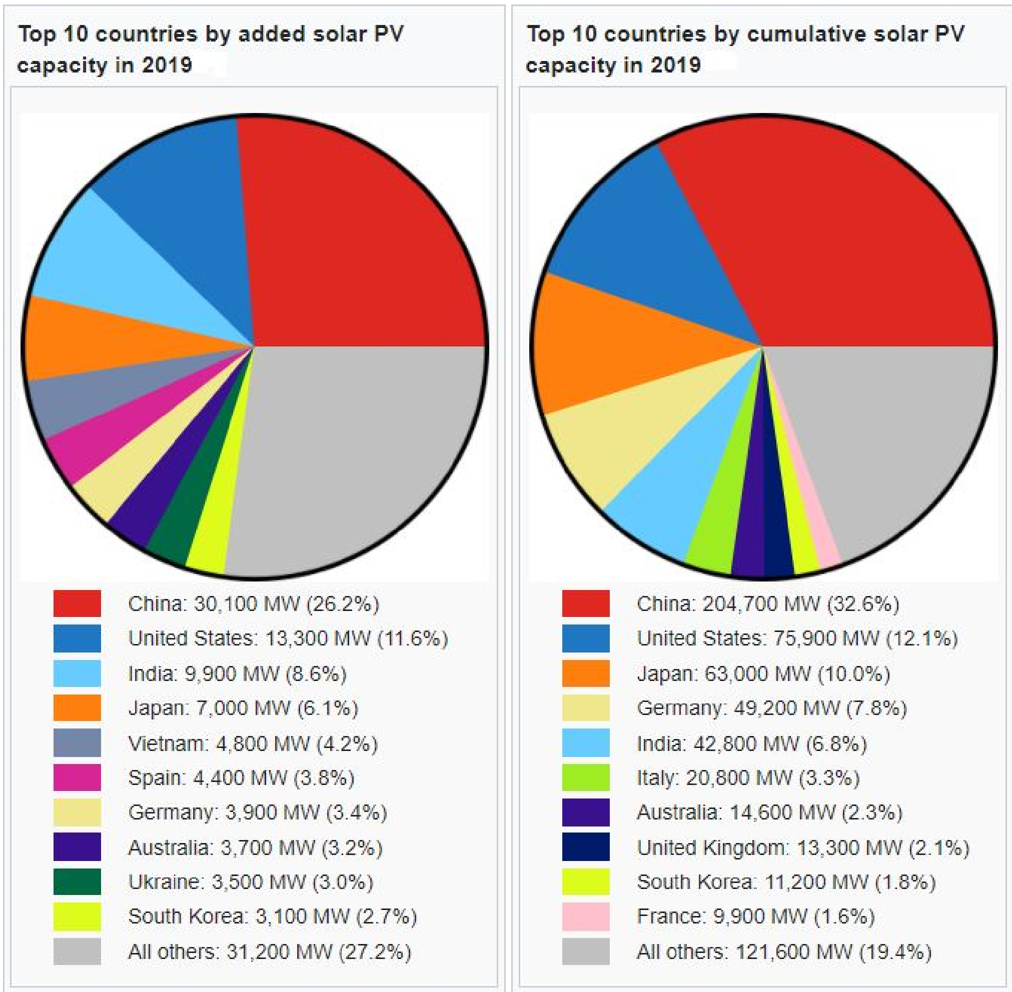

Figure 1.5: Solar energy generation across the world

The project's purpose is to design a solar energy system that consists of solar PV, which is integrated with the battery using the MATLAB Simulink tool. The goal is to create a framework with the objectives:-

1. Energy Saving: Solar uses energy-efficient like LED / CFL, lower electronics, etc., not getting the same power as traditional electrical devices. Initially, the LEDs are powered by 12 VDC and require electrically operated AC adapters. They work efficiently with DC power for LEDs by lighter and less heat. Electricity may be saved in this way.

2. Eco-Friendly: To build an atmosphere that enables solar technology to expand throughout the country's mission goal. It is promoting green economic development, thus resolving the problems of national energy stability.

3. Easy Installation: Solar PVs are simple to mount and easy to keep them safe. Solar lighting systems provide solar power at the top of the pole in most installation systems and finish off all the electrical material required. For simple installation, solar power systems can require a bit more. However, low voltage DC power can be operated with more safety than standard electrical systems.

4. Battery Reinforcement: Many solar systems use a backup batteries that allows more retention of power to stay in operation for more days.

5. Available Anywhere: Even if the power is in the shade, solar can still be installed. Whatever the case, if there is a sunny spot next to the solar, it can be installed remotely.

6. Green energy: Green energy is the new trend, but it is also a way of looking to our planet's future also reducing the repercussion of fossil fuels

In Ireland, the deployment of solar energy will diversify the renewable generation portfolio across the country over ten years from 2020 to 2030, with a focus on economic efficiency and results. The utility of photovoltaic solar systems, which can be installed in roof-mounted or ground installed systems, has been stressed as an approach that enables a Irish citizen to assume responsibility for energy generation and consumption.

Chapter 2

Background

2.1 Literature Review

A literature review aims to explain and present knowledge in the form of a written article, current studies, and discussions about a given subject or study field. Below are some of the papers where this thesis has compared their approach of designing and simulating Solar Power systems and my proposal towards this approach.

Bica and Dumitru [Bică et al., 2009] have defined the modeling process for an autonomous solar-wind hydropower system and are simulated for service in Simulink / MATLAB.

Yang et al [Yang et al., 2003] developed hybrid wind / solar models to calculate optimized combinations of photovoltaic modules, wind generating turbines, and battery banking parameters for a certain power loss probability. The study does not contain factors such as the height of a wind turbine and the photovoltaic angle [Yang et al., 2009]. Ekren et al Ekren et al. [2009] studied the optimal scale process for a related procedure in Turkey.

Elhadidy [Elhadidy and Shaahid, 2004] evaluated the viability of generating electricity also satisfying the load requirements of a standard building using a combined hybrid energy system; searched various combinations of wind power systems, photovoltaic battery storage panels and diesel power storage network.

Bakos and Tsagas[Bakos and Tsagas, 2003] studies on the technical and cost-effectiveness of using a grid-connected hybrid wind / solar network to meet the energy demands of a typical residence in the Greek city of Xanthi through electrical and heat energy generation.

Dihrab and Sopian [Dihrab and Sopian, 2010] proposed a hybrid PV / wind network to be used as a power source for grid-connected applications in three Iraqi cities. A model simulation has been performed at the MATLAB, where meteorological data from the three sites as well as wind turbines and PV arrays determined the input parameters. Their results showed that their hybrid system would provide ample electricity for the villages.

A genetic algorithm was employed by Yang et al [Yang et al., 2008]to establish an optimum size approach in order to optimize its configurations by using battery bench systems for the Hybrid wind / solar system. The ideal size method was then used to predict optimal system configurations to achieve a certain probability of power loss.

Ahmed et al [Ahmed et al., 2008] implemented a system which included solar-wind power generating the cell. The fuel pellet system was used in solar and wind systems as the key sources of electricity for backup option. The results show that the device is efficient and able to provide the load with high-quality power even if the wind and the sun are not present. Onar et al [Onar et al., 2008]also developed solar and wind-energy fuel cell systems that are suitable for grid-independent applications.

Celik [Celik, 2003] suggested a new method to dimension hybrid battery storage wind / solar power systems which would include both the fraction of the system's time to fulfill the load and costs for the device, as design parameters.

Now, some of the above publications have calculated the requirements for energy for their hybrid energy system drafted by measuring the requirements for power of each unit in the house and by evaluating the average number of hours each energy consuming unit will use electricity in one day [Ele, 2020]. The problem with this approach is that it does not take into account the form and scale of electricity equipment sites, construction materials, the house orientation and dimensions, or heat loss through the walls, windows, doors, or towers of the house. The downside of these papers is that due to the inability to model the interactions between components of the circuit, they sometimes over-size or under-size the entire device, meaning it often produces very little energy. On the other hand, the numerical method in the above articles is a complex approach prone to faults because it involves several variable calculations [Ele, 2020].

2.2 Photovoltaic (PV) Cells

When the sun rays strike a PV cell, the sun's photons are absorbed, causing the electrons within the cell's atoms to migrate to the cell's holes[Ashley, 1992]. This is the act of adjusting the physical location of electrons and holes that generate electricity[Fahrenbruch and Bube, 2012]. In other words, the photovoltaic effect is called the physical process involving the conversion of sunlight into electricity through the PV cell. A single PV cell can provide up to 0.5 to 0.8 volts, i.e., 2 watts of power and cannot provide power to a pocket calculator or wristwatch either as they require minimum of 1 to 2 volts. However, the power output can be increased by linking several PV cells together to form a module. This can be generated in larger units called solar panels. Many panels are connected and known as arrays. Photovoltaic cells are also referred to as solar cells[Nguyen and Lehman, 2006].

2.2.1 PV Structure

The arrangement of the PV cells is relatively basic. As shown in Figure 2.1, there are six different material layers. Secondly, due to the support of the glass surface of the black cover, photon absorption capacity improves, and the glass protects the cell from atmosphere elements. Via anti-reflective coating, the loss of reflection in photons is reduced to less than 5%. The distance between the Photon and the semicircle was decreased by the touch grid. The nucleus of the photovoltaic system is made up of two thin layers of semiconductors p and n. Eventually, the back touch tends to enhance driving[Luque and Hegedus, 2011].

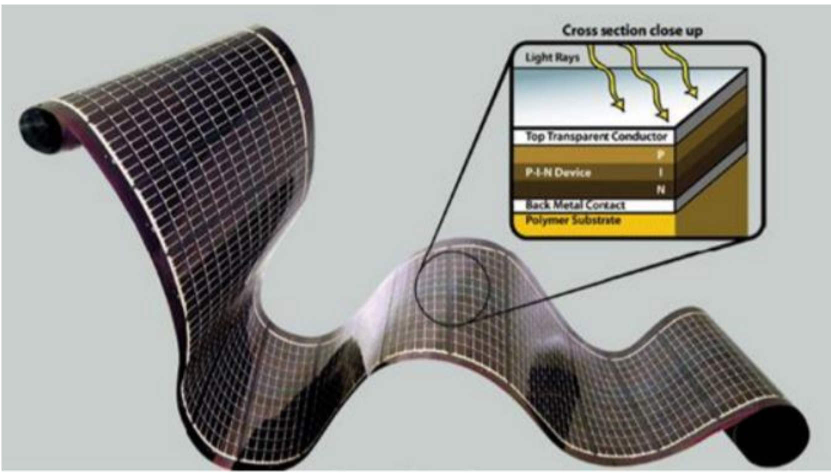

Figure 2.1: Silicon Photovoltaic Cell

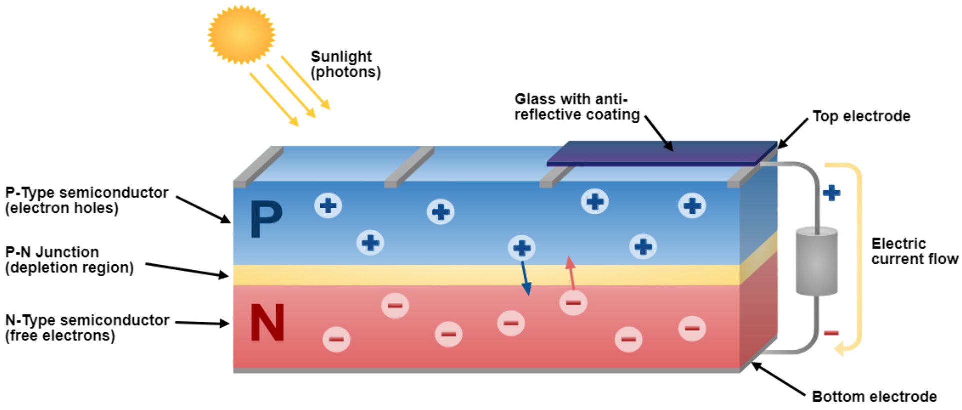

Figure 2.2: Schematic diagram

2.2.2 Principles of Solar Cell

Conversion of solar energy into photovoltaic cells consists of two crucial steps[Razykov et al., 2011]. Figure 2.2 shows the schematic diagram of PV Cell. First, a pair of electron-holes produces the absorption of light. The structure of the semi-conductor chip then isolates the electron and the hole. The electrons are split into negative terminals while the holes are divided into positive terminals. As the devices remain fixed, the hole rotates. Thus, an electron exits its hole and passes into the empty position of another hole, and the same goes for potential electrons. At this point, the solar cell becomes a conductor and therefore absorbs electricity from the silicon wafer [Baeg et al., 2013]. The existence of the solar cell does, however, depend on the dopants, which are impure atoms. Boron and Phosphorous are the most common dopants used by PV cells. The Silicon Solar Cell is a negative type (n-type) if doped with Phosphorous, while Boron Positive (p-type), when doped with cell remains a negative type [Cotter et al., 2006].

2.2.3 Photovoltaic Effect

In the photovoltaic cell, electrons from one semiconductor flow to the other to produce electric current. Moreover, if a reinforced 'Si' surface and an anti-reflective surface coating are used, it will probably increase the photon absorption in the photovoltaic cell. Further, if the current is seen to be the minimum (zero) value, there is infinite resistance on the circuit and maximum voltage, there is an open circuit voltage. When the circuit current exceeds the maximum value, the circuit resistance is zero; the short circuit is not permitted.

If the resistance ranges from infinite to 0, voltage, and current may also differ, the IV feature curve of the photovoltaic cell can be described [Tzanakis, 2006]. Here in this Figure 2.3, the photovoltaic cell's MPP (Maximum Power Point) is shown.

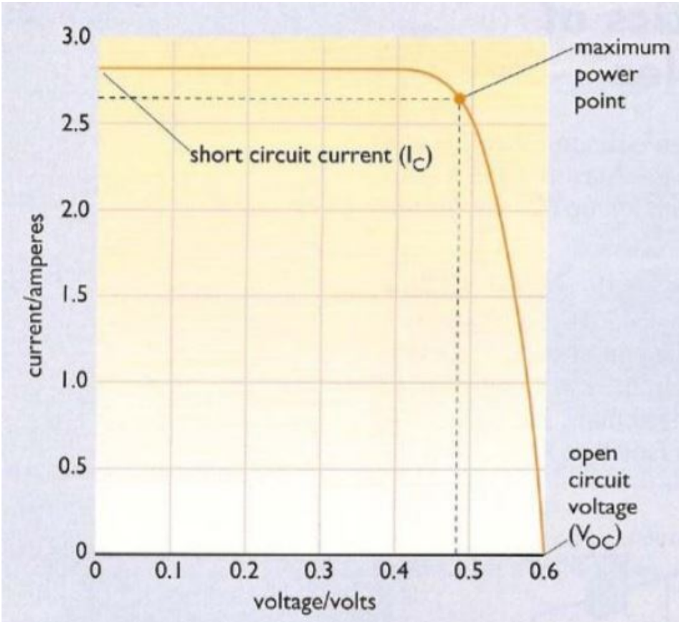

Figure 2.3: I-V Characteristic curve of a silicon PV

To measure the power output of PV cells, international standard test conditions are also defined. The air mass connection of 1.5 solar spectral irradiances and a cell juncture is 25° C with irradiance level defined as $1000W/m^2$.

2.3 Maximum Power Point Tracking Techniques

The point in Figure 2.3 above is called a maximum power point (MPP), which is mainly determined by panel temperature and irradiance. The radiation will sometimes shift because of clouds or the shadow of an object, and the MPP fluctuates. A dynamic operating point at the highest powerpoint is set by an algorithm that measures the operating point of the solar panel continuously. These are called MPPT (Maximum Power Point Tracking) algorithms [Kumaresh et al., 2014]. Figure 2.4 displays the circuit diagram of MPPT. Not only does the MPPT increase the load power, but the life span of the PV system will also improve. In [Bahgat et al., 2005], the duty cycle of the PWM-based dc-dc converter in MPPT is modified to reach the optimum power level.

Maximum power point (MPP) must be monitored continuously for optimum power output from the photovoltaic system. Maximum Power Point Tracking (MPPT) algorithms boost the efficiency of the PV system. The maximum power point of a photovoltaic unit varies with the radiance, temperature and load connected to the (PV) network.

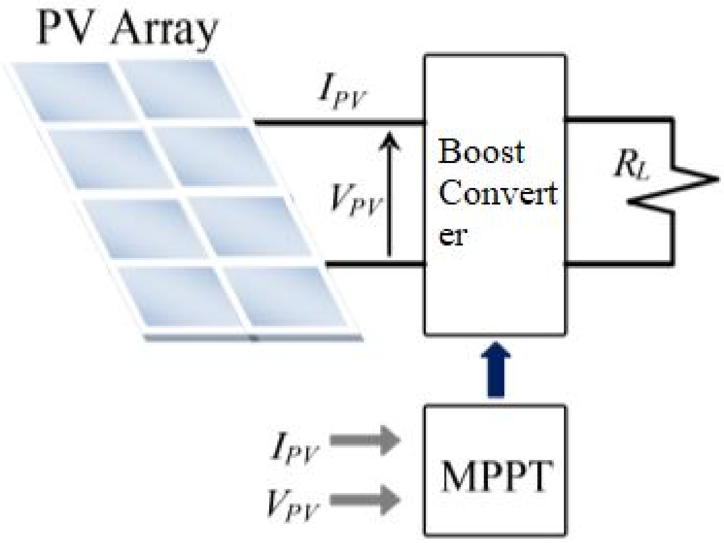

Figure 2.4: Schematic Diagram of MPPT

We find a wide variety of MPPT algorithms categorized according to their complexity, cost, number of sensors needed. This thesis includes a comparison of all the algorithms, which are P&O, Incremental Conductance, Ripple Correlation Control, Current Sweep, and some smart control algorithms such as ANN & Fuzzy logic and the application of Incremental conductance algorithm.

MPPT aims to control the actual PV panel voltage at the MPP level. MPPT changes the inverter or DC converter output power for this purpose. If the PV output voltage is higher than MPP voltage, the load or network power will be increased, otherwise, it will be reduced. Figure 2.5 shows the variation of MPP with diferent Solar radiation and temperature.

2.3.1 Applications of MPPT

Maximum power point tracking controllers are used for many applications to correct the variations in I-V curves and to regulate the current from the PV panel

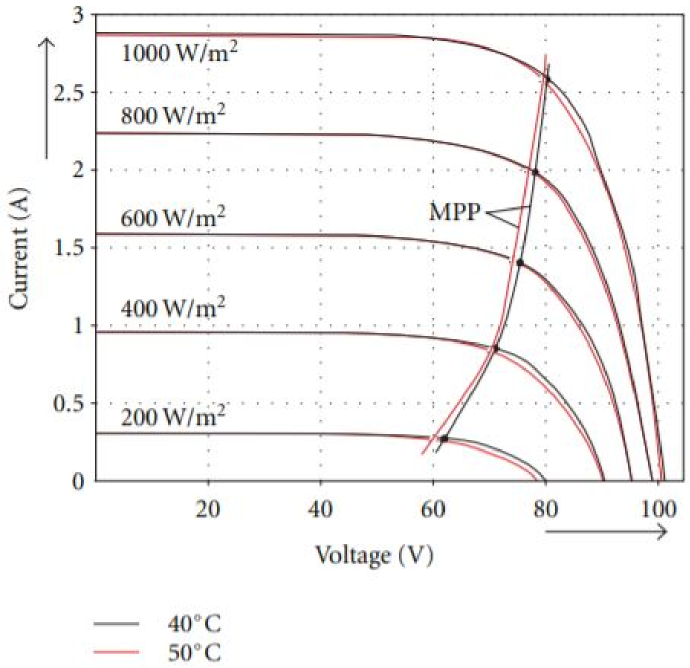

Figure 2.5: Variation of MPP

to the battery. The PV module also operates the battery to a voltage higher than the rated value. These methods are used predominantly to charge and unload the required batteries [Karami et al., 2017]. Thanks to its convergence speed, FLC (fuzzy logic control) and ANN (Artificial neural network) algorithms are used when searching for MPPs to monitor solar powered vehicles. Easy Constant Voltage and Open Circuit Voltage methods are employed to powering & releasing the battery and to drive LED street light during the day. In the PV method, the INC and P&O algorithms are used [Ezinwanne et al., 2017].

The Table 2.1 compares numbers of MPPT algorithms, which differ according to complexity, the required sensor, cost-effectiveness, convergence speed, efficiency range and the hardware for implementation [Mao et al., 2020].

2.4 Physical Intact of PV-Battery System

Installation costs for solar systems are one of the biggest costs. The installation can be optimized to make it more accessible by installing only one integrated unit directly on the roof of the household, minimizing human labor and, therefore, expense. The newly integrated system will include a PV module, dc/dc con-

MPPT Technique	PV Array Dependent	TRUE MPPT	Analog or Digital	Periodic Tuning	Convergence Speed	Implementation Complexity	Sensed Parameters
Hill-climbing/P&O	No	Yes	Both	No	Varies	Low	Voltage, Current
IncCond	No	Yes	Digital	No	Varies	Medium	Voltage, Current
Fractional V_{oc}	Yes	No	Both	Yes	Medium	Low	Voltage
Fractional I_{sc}	Yes	No	Both	Yes	Medium	Medium	Current
Fuzzy Logic Control	Yes	Yes	Digital	Yes	Fast	High	Varies
Neural Network	Yes	Yes	Digital	Yes	Fast	High	Varies
RCC	No	Yes	Analog	No	Fast	Low	Voltage, Current
Current Sweep	Yes	Yes	Digital	Yes	Slow	High	Voltage, Current
DC Link Capacitor Droop Control	No	No	Both	No	Medium	Low	Voltage
Load I or V Maximization	No	No	Analog	No	Fast	Low	Voltage, Current
dP/dV or Feedback Control	No	Yes	Digital	No	Fast	Medium	Voltage, Current
Array Reconfiguration	Yes	No	Digital	Yes	Slow	High	Voltage, Current
Linear Current Control	Yes	No	Digital	Yes	Fast	Medium	Irradiance
State-based MPPT	Yes	Yes	Both	Yes	Fast	High	Voltage, Current
OCC MPPT	Yes	No	Both	Yes	Fast	Medium	Current
BFV	Yes	No	Both	Yes	N/A	Low	None
LRCM	Yes	No	Digital	No	N/A	High	Voltage, Current
Slide Control	No	Yes	Digital	No	Fast	Medium	Voltage, Current

Table 2.1: Contrast of all MPPT Algorithms

verter, dc/ac microinverter, and battery. PV modules on the roof are associated with power conversion and management units within the house in standard PV battery systems. A predefined battery charging and download strategy are applied to the power conversion and management unit. At this point, the device is connected either to the grid or in stand-alone solutions to the load [Dunn et al., 2011].

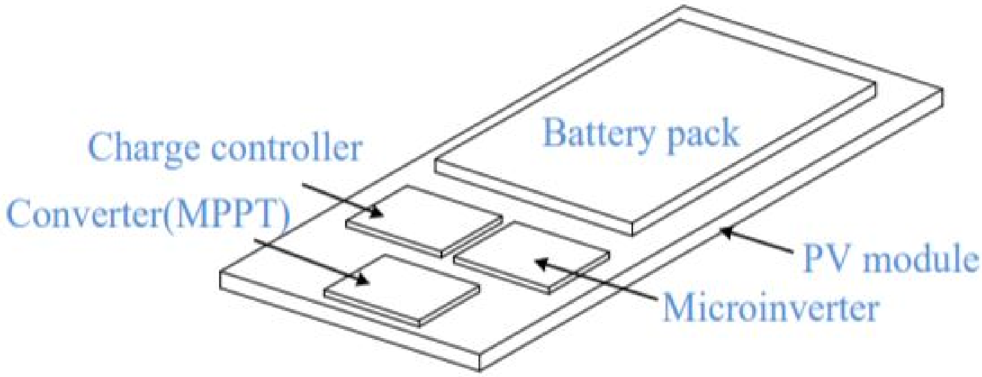

Figure 2.6: Physical Integration of Battery

The cost of system balance components may be reduced by economic size. For this, a single integrated PV-battery module is proposed. Figure 2.6 shows the concept of physical integration. Once a broad range of PV battery systems is integrated at the rear of the PV board, non-modular part costs can be minimized. The photovoltaic battery systems are complex and need guidance from technical experts. In terms of ease, a box with all the balancing system components incorporated could lead from a customer perspective to a product that could be appealing to the solar energy market [Arvizu et al., 2011].

Efforts have been documented to incorporate electronic power components directly on the back of PV modules. In [Wills et al., 1997] the photovoltaic module is integrated with the inverter, and in [Ačanski et al., 2010] a PV flexible DC/DC converter is proposed, while the authors have also developed a thermal model. Initially, [Reynaud et al., 2008] and [Reynaud, 2011] introduced and improved proposed physical integration of battery and electronic control systems.

Chapter 3

Methodology

In this project, I have explained each component and its function to the Maximum Power Point Tracking method.

3.1 Photovoltaic Array

Photovoltaics (PV) turn sunlight into electricity directly. A solar cell is a cross-sectional reverse current PN diode. Several photovoltaic modules have solar cells. The PV array consists of parallel module strings, each consisting of sequence-connected modules. The two main factors influencing PV production are temperature and irradiation. Irradiation and temperature shifts contribute to photovoltaic systems voltage, current change and power generation

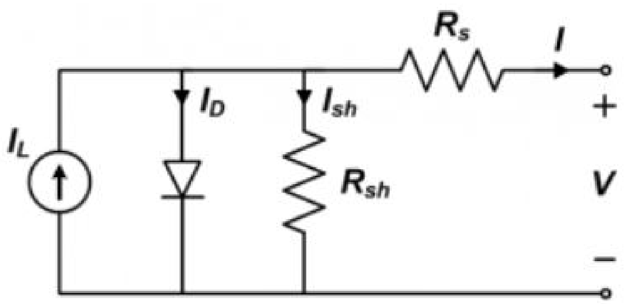

Figure 3.1: Circuit Diagram of a PV module

In Figure 3.1, the solar cellular model uses the current source I_L (light-generated current), a diode (I_0 and nI parameters), series resistance R_s, and shunt resistance

$$I_d = I_o[exp(\frac{V_d}{V_T}) - 1]$$

$$V_T = \frac{KT}{q} \times nI \times N_{cell}$$

R_{sh}. The I-V diode for a single module is defined by the I_d and V_T equations [Kazmi et al., 2009].

3.1.1 Photovoltaic Module Connection

A single-diode PV cell generates very low current and voltage. Interconnections between cells will form a module or array to increase voltage and current in PV cells [Wang and Hsu, 2011]. It has high accuracy and performance with uniform solar insolation.

The increased voltage and current from cells connected in series and parallel are obtained. Inter-connectable configurations likely be connected in series connection (SC), series-parallel (SP), overall tile-cross (TC), bridge-connected (BL), and bones (HC) between the 36 cell configurations [Villalva et al., 2009]. Based on their power extraction ability, TC, HC, and BL configurations are in investigation. In each SP cell, the MPP voltages are the same as the independent light; the power output is moderately affected by a little variance in the MPP voltages and temperature variations for the MPP voltages are slightly sensitive. Therefore, MPP from the SP relation can be traced precisely because there is a standard reference voltage of the shading patterns regardless of the current variations for each cell [Gao et al., 2009].

3.1.2 PV Controller Selection

A PIC is used in pv modules for measuring voltage and current and for utilizing an MPPT method between PV panels and DC / DC converters [Soon and Mekhilef, 2014]. For recognising and enhancing the voltage and current for PV modules, a proportional integrated derivative control is used to initiate the PWM duty cycle. Efficient real-time monitoring or computing should be investigated to track hardware and software system's operations. The control system's facility of implementation affects the process of selecting the MPPT, where it relies heavily on the user's ability. To guarantee the measurement precision and deliver immediate results, a real-time testing system is constantly modified.

For example, a DSP is designed for the application of PWM signals and the digitization of DC / DC converters and DC / AC inverters [Farhat et al., 2015].

DSP is a popular microcontroller, versatile, reliable, low cost, and high-speed controller.

3.2 Incremental Conductance MPPT

The I-V point at which the solar module is always present in the operating point and references to the precise irradiance (G) and temperature (T) geographic conditions. The operation module is mainly determined by line shifts and the load produced at its output by a module without electrical control. The I-V characteristic curve displays the generated and loaded energy. The solar module will therefore run at its peak power point (MPP). The module has to be run for full power output on the operating system. Modifications to G and T adjust the curve to remove the viability of the previous MPP and build a new MPP. With the new MPP called MPP Tracking Maximum Power Point (MPPT), the transformation in the curve must then be recorded at any time to provide MPP. This can be achieved with various algorithms.

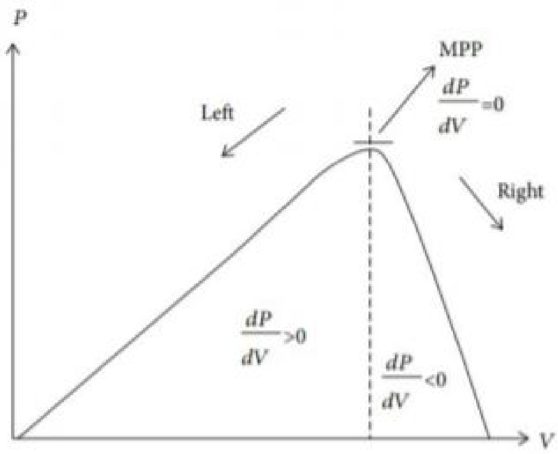

Figure 3.2: MPPT Process

Due to its efficiency and precision, the incremental conductance MPPT is chosen in this project. Figure 3.2 shows the graphical representation of the MPPT Process. The voltage and current from this algorithm are used to monitor the duty cycle of the DC-DC boost converter (D). The terminal voltage of the panel is instead altered according to its value with the MPP voltage [Kazmi et al., 2009].

This technique is based on the power-voltage characteristic, with the P-V curve slope at 0 at MPP, positive on the left and negative on the right side [Roman et al., 2006]. The IncCond technology recognizes the achievement of MPPT at MPP and prevents the voltage from distorting [Kazmi et al., 2009]. At this point, the operation of the array is continued until the output current (ΔI) is unchanged. The V_{ref} will increase or decrease in this process of monitoring the new MPP [Rai et al., 2016].

3.2.1 Operation

Full power point will be reached if the derivative is zero as set out in

$$\frac{dPpv}{dVpv} = 0 \quad \Rightarrow Ipv\frac{dVpv}{dVpv} + Vpv\frac{dIpv}{dVpv} = 0 \Rightarrow \frac{dIpv}{dVpv} = -\frac{Ipv}{Vpv}$$

where I_{pv} and V_{pv} are the PV array current and voltage respectively.

The following equation determines the position of the operating point in relation to the actual MPP by assuming $dV_{pv} \approx \Delta V_{pv}$ and $dI_{pv} \approx \Delta I_{pv}$[Wu et al., 2003]:

At MPP,

$$\frac{\Delta I_{pv}}{\Delta V_{pv}} = -\frac{I_{pv}}{V_{pv}}$$

Right side of MPP,

$$\frac{\Delta I_{pv}}{\Delta V_{pv}} < -\frac{I_{pv}}{V_{pv}}$$

Left side of MPP,

$$\frac{\Delta I_{pv}}{\Delta V_{pv}} > -\frac{I_{pv}}{V_{pv}}$$

In the flowchart Figure 3.3, the method and steps of the Incremental Conductance MPPT technique are described.

Once MPP has been achieved, the PV array will keep on working, and perturbation will stop unless a shift in ΔI_{pv} is noted. In this case, V_{ref} reduces or raises the function to suit the new MPP. The size of the change determines how easily the MPP is monitored. It is then theoretically possible to determine if the MPP is attained and then if the perturbation can be stopped using the IC algorithm. The IC method performs well under rapidly changing atmospheric conditions. The time taken to track the MPP in the IncCond scheme is based on the size of the increase in reference voltage (V_{ref}). For fast tracking, the large size increase

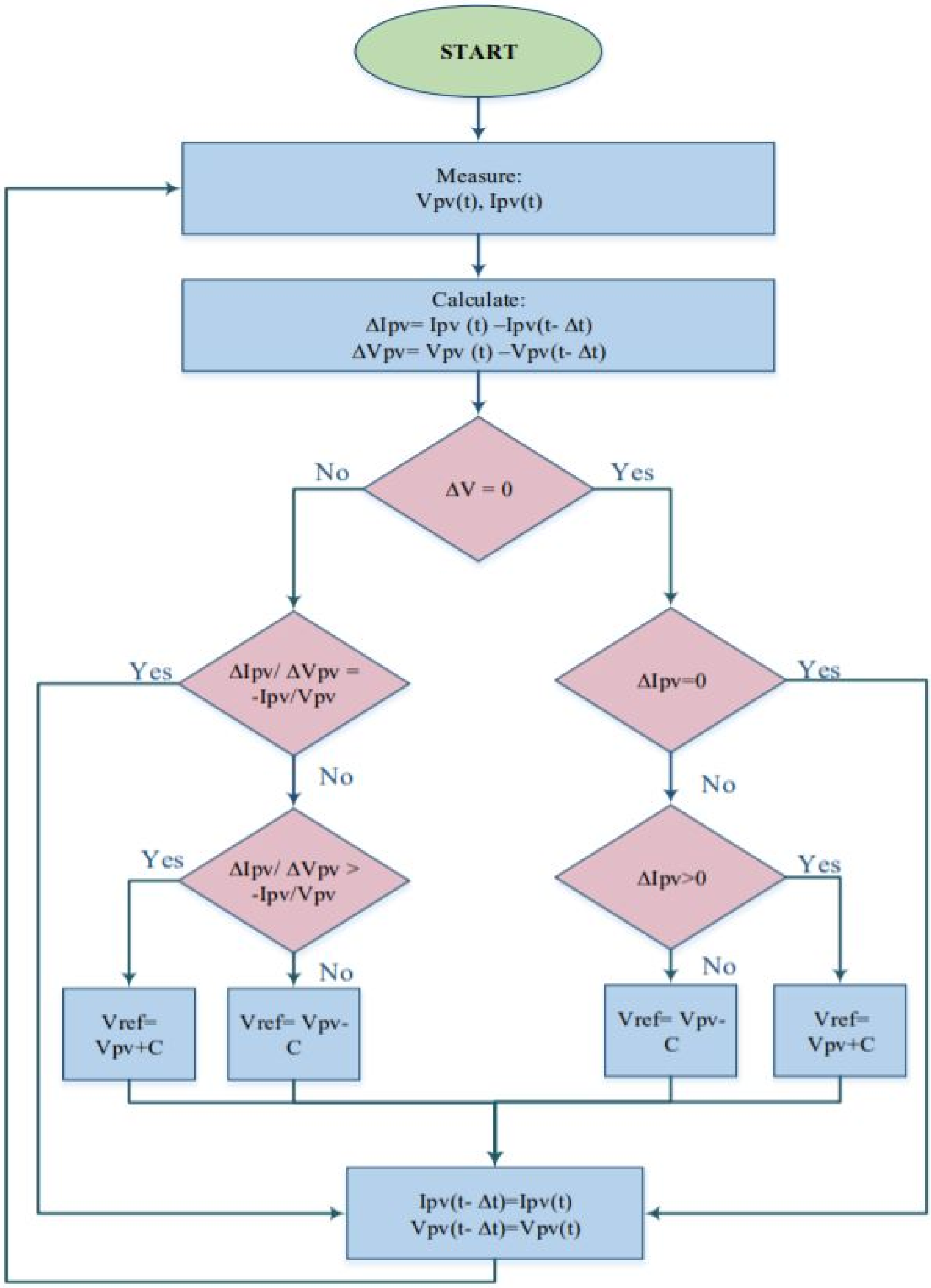

Figure 3.3: Flowchart of InCond algorithm

is used, and the device does not work in the MPP and oscillates over the MPP, which means that the system is never completely successful [Hohm and Ropp, 2000]. This can be resolved through the variable disturbance size, whereby the first step pushes the operating point near MPP and then uses IncCond. Exactly to reach the MPP, but this algorithm requires a complex and expensive control circuit. In often changing irradiance conditions, the algorithm is more efficient than P&O [Esram and Chapman, 2007].

The chart shows that Incremental Conductance (ΔV_{pv} / ΔI_{pv}) and instantaneous conductance (V_{pv} / I_{Pv}) are monitored simultaneously with the MPP [Ahmed and Shoyama, 2011]. The controller moves the operating point to the MPP in step C, depending on the active point location in the output function. The controllers' tracking speed depends primarily on the magnitude of the phase scale. A broad phase value helps to monitor the MPP quicker, but it oscillates across the MPP. In some experiments this problem has been solved by developing an InCond variable phase size process. For such techniques, the controller initially takes a large step in the estimated MPP area and then tracks exact MPP by a tiny step in the process. This approach improves the controller precision and prevents spinning around the MPP [Tey and Mekhilef, 2014].

3.2.2 Advantages of Incremental Conductance Algorithm

Incremental Conductance eliminates the drawback of the P&O method, i.e., Operating point oscillation under various irradiance conditions). This strengthens the P&O algorithm further. Moreover, as opposed to Short Current Pulse and Open Volatge techniques, P&O and IncCond methods do not need additional static switches, so the relative costs are not high. Because of its lack of tracking speed, the P&O approach has low reliability. Hence IncCond method has the greatest efficiency. Contrary to the P&O process, InCond's quick and responsive response to unexpected and rapid environmental changes is the most remarkable benefit [Ishaque and Salam, 2013]. Table 3.1 shows a contrast between the Incremental Conductance MPPT parameters.

3.2.3 Efficiency of MPPT

Efficiency (η_{MPPT}) is the main MPPT algorithm parameter. The efficiency of MPPT varied according to the cell temperature and the fill factor(FF) was derived from experimental studies. According to [Azli et al., 2008], the efficiency of MPPT increases with temperature, and only changes in FF affect output in constant temperature conditions about 4 percent.

Parameters/INC MPPTs	Adaptive INC	INR-Based INC	ST-Based INC	FC-Based INC	PI-Based INC	FLC-Based INC
Input variables	V_{pv}, I_{pv}	V_{pv}, I_{pv}	V_{pv}, I_{pv}	V_{pv}, I_{pv}	V_{pv}, I_{pv}	V_{pv}, I_{pv}
Control variables	D	I_{ref}	V_{ref}	R_{load}, D	D	R_{load}, D
Implementation cost	Low	Low	Low	Low	Low	Low
Controller types	PIC	Micro controller	Microprocessor	PIC	DSP	dSPACE
Converter types	Boost	Boost	Buck-Boost	SEPIC	Fly Back	CUK
Complexity	Simple	Simple	Complex	Simple	Complex	Average
System independence	High	High	High	High	High	High
Reliability in PSCs	Less	High	High	High	High	High
Convergence speed	Average	Fast	Fast	Fast	Medium	Fast
Oscillation around MPP	No	Less	No	No	No	Less
Periodic tuning	Yes	No	Yes	Yes	Yes	Yes
Power efficiency	Average	High	High	High	High	High
Tracking speed	Slow	Faster	Fast	Fast	Fast	Faster

Table 3.1: Comparison of IncCond algorithms

Efficiency of MPPT is calculated as below:

$$\eta_{\text{MPPT}} = \frac{\int_0^t P_{\text{MPPT}}(t)dt}{\int_0^t P_{\max}(t)dt}.$$

P_{MPPT} reflects the output power of PV with MPPT, and P_{max} is the maximum power output [Salas et al., 2009]. The performance of MPPT is related to environment and geographic area characteristics where the photovoltaic systems are based. MPPT is used in PV storage system to increase the battery charger; the rise will be greater than the loss of the device itself. There is no net profit otherwise. To evaluate the benefits of MPPT in different climatic conditions, a theoretical model was created.

3.3 Converter Selection

MPPT schemes drive the controller to optimize the load capacity of the PV system. This method is done by modifying the duty cycle or altering the function of the converter (current or voltage being analyzed). The MPP is measured with the help of a converter or a closed-loop system [Saravanan and Babu, 2015]. Figure 3.4 shoes the diagram of boost converter circuit diagram. DC/DC converters are attached to the load and PV array so that the load line is located on MPP's I-V characteristics curve. They are used in particular about maintaining the PV panel's output voltage as fixed under any weather conditions [Hsieh et al., 2012].

If a converter has PSCs or loads changes with a fixed duty cycle, output voltage and current differ. The converter's duty cycle is controlled by the controller only when there is change in solar insolation and load. The input and output of the converters must be continuous to ensure constant maximum power supply in PV panels and stable MPPT techniques with little vibration. However, this method creates a negative power output, including electrical resonance, heaviness, costs, & irregularity [El Khateb et al., 2014]. This is because of the need to connect the filter circuit (1000 hours worth of electricity) or large electrolytic condensers to store energy and to-secondary voltage and primary converter currents. Because of the rip current, a control device has less bandwidth than the conversion frequency; it can not enter an operating point near the MPP [Safari and Mekhilef, 2011].

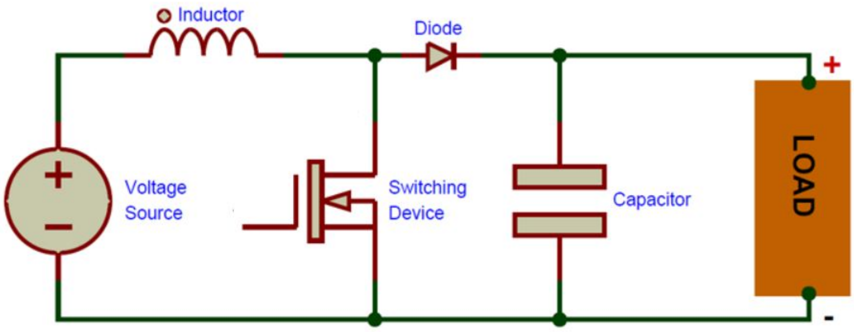

Figure 3.4: Boost Converter Circuit Diagram

The PV array is interfaced with the load resistance with a DC-DC boost converter. The maximum power produced by the standard PV array (STC) is about 299.3W. Five components have to be chosen for the DC/DC boost converter, including switching device, diode, inductor, capacitor and resistor. A typical power diode and the PowerMOSFET switching system is selected for the simulation as it is often used in low to medium power applications. After a compromise between the switching loss and the inductor capacity, the switching frequency is set at 20 kHz. Other components are selected as follows.

1. Resistor Selection: The relation between boost converter load resistance

(R_L) and optimum internal resistance (R_{MPP}) of the PV array at MPP can be expressed as

$$R_L = \frac{R_{MPP}}{(1 - D_{mpp})^2}$$

D_{mpp} is the maximum power point (MPP) converter duty cycle. To measure the maximum power, the load resistance of the boost converter has to be higher or equal to the PV internal maximum resistance in the MPP ($R_L >/ R_{MPP}$) since the duty ratio (D) range is 0 to 1. When the above condition is not met, the maximum power tracking fails [Nayak et al., 2017].

2. Inductor Selection: The boost value of the inductor is chosen based on the highest allowable power ripple of the MPP for the highest solar radiation ($1000W/m^2$). The higher the inductor frequency, the lower the output current and vice versa. The lower inductor value is superior to a low-cost converter because the inductor is the most expensive relative to the other components. The frequency of switching (f_s) is set to 20 kHz with the permissible ripple current (ΔI) set at 40% of the current. Therefore, the minimal inductor value is calculated as

$$L = \frac{V_{mpp} \times D_{mpp}}{2 \times \Delta I_{out} \times f_s}$$

For the MPPT's transient response study, the commercially available inductors of 1mH, 5mH, and 10mH are taken [Hauke, 2009].

3. Capacitor Selection: The 'Cin' & 'Cout' capacitor is chosen to fulfill the 0.2% voltage ripple requirement. The approximate expression is given for the necessary capacity.

$$C_{min} = \frac{V_{out} \times D_{mpp}}{2 \times \Delta V_{out} \times R \times f_s}$$

To test the impact of the condenser value in MPPT's transience response to the phase change in radiation, three realistic 250V voltage supporting capacitor values, i.e., $47\mu F$, $100\mu F$, and $220\mu F$ are chosen [Ishaque et al., 2011].

3.4 PV Inverter Selection

In the device where AC power output is needed, an inverter is used. The input value of the inverter will never be below the total watt of equipment. The inverter must be as small as battery. The inverter must be large enough to handle the total quantity of watts used concurrently. The inverter scale will be 25 to 30% greater than the total watts of equipment. In the case of an engine or compressor type, the inverter size should be a 3-fold minimum and add up to the inverter ability to control surge power during start-up.

The input value of the inverter should be the same for grid connection systems or grid linked systems as the PV array rating to ensure safe and effective operation.

3.5 Load

When the solar panel is mounted, load measurement is a necessary portion of the Solar System's reliability because it is considered an off-grid PV system, which often relies on the battery capacity corresponding to charging and backup periods during which the Sun is not usable. The load is what makes our machine trustworthy. If our load requires more power than the capacity of the system when the Sun is not available, the system performance is soon zero due to zero efficiency. This raises the load beyond the capacity requirements and battery life and module performance.

3.6 Battery

The idea is to combine all the required devices in a single PV battery system. The new system must perform the essential functions necessary for the standard PV battery: achieving a full output of PV power, intelligently charging/discharging the battery, providing stable dc and ac performance, and meeting the load requirement.

Several factors, for example, cycle length, physical power, thermal efficiency, shape, and health, guide the selection of battery technology. The cycle of batteries is related to the charging / discharging frequency and quantity energy supplied or processed. To achieve the high life of the integrated module, extended cycle life is required.

Since the battery packs are mounted at the back end of the PV module and the battery room is small, the selected batteries must be highly specific. All battery manufacturers define a precise operating temperature, which generally avoids high temperatures. The cell's shapes are critical as cylindrical shapes do not support for high packaging. The ratio between the ability to build a compact battery package and the surface area available for proper heat dissipation is another part of the consideration.

The capacity or size of the battery is related to the reasons for using energy storage (whether long or short periods). Short intervals will minimize grid reliance, reduce the power bill, and provide energy during blackouts. Long-term storage (several days) with only one integrated module is difficult to run, with the connection of multiple PBIM's, long times can be better controlled, but seasonal fluctuations can not be treated in areas where seasonal changes are dramatic.

3.7 Efficiency of the Solar PV System

A solar cell (PV) conversion efficiency represents the percentage of solar energy that is shining on an energy-used photovoltaic system. Improving this conversion efficiency is an important research goal that helps make PV systems cost-effective with traditional sources of energy.

Electric power is the current and voltage product. Current-voltage relationships measure the electrical characteristics of PV devices. If the two cell or module terminals are connected to a certain load resistance, the current and the emitted voltage must change according to Ohm's law (The current between the two points through a conduction driver is directly proportional to the potential difference between the two points). Efficiency is achieved by exposing the cell to a natural and constant light level while maintaining a constant cell temperature, as well as by testing current and voltage for different stress resistances.

3.8 Solar Photovoltaic System

The first phase in design, optimization, and performance analysis is dynamic modeling and simulation. Figure 3.5 shows the full MATLAB / Simulink model. In order to investigate the dynamic behavior in the proposed energy system in terms of power quality, harmonics, load impact and voltage transient of the PV-system elements, it has been simulated under various conditions in the MATLAB / Simulink system.

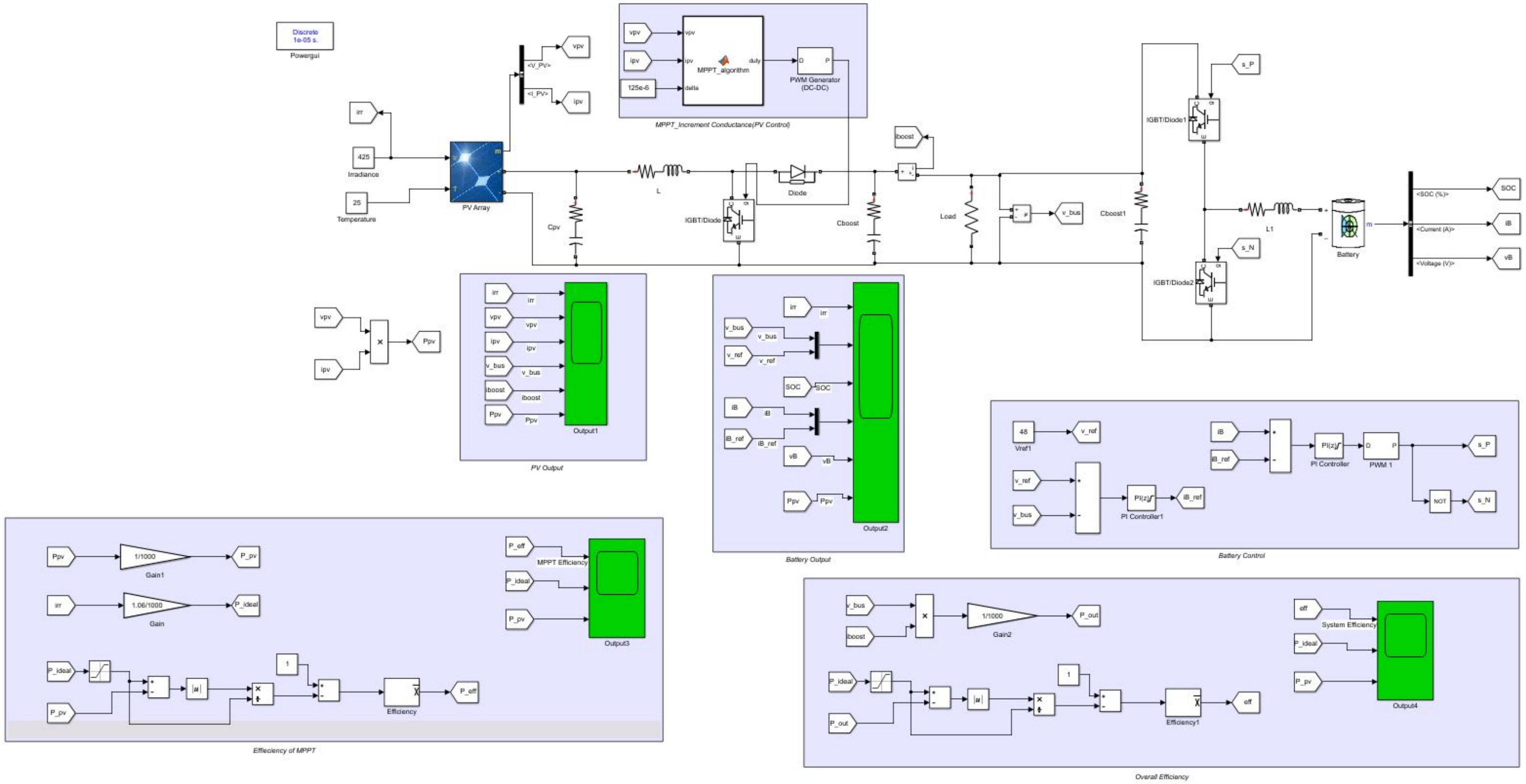

Figure 3.5: Solar Photovoltaic System

Chapter 4

Results and Discussion

4.1 Results

The principle of energy conversion from solar insolation to electrical energy is illustrated and analyzed in this chapter, showing the conversion in volts, amperes and power of solar energy into electricity with the application of MPPT technique. The numerical simulation here presented involves the variance of PV cell irradiance.

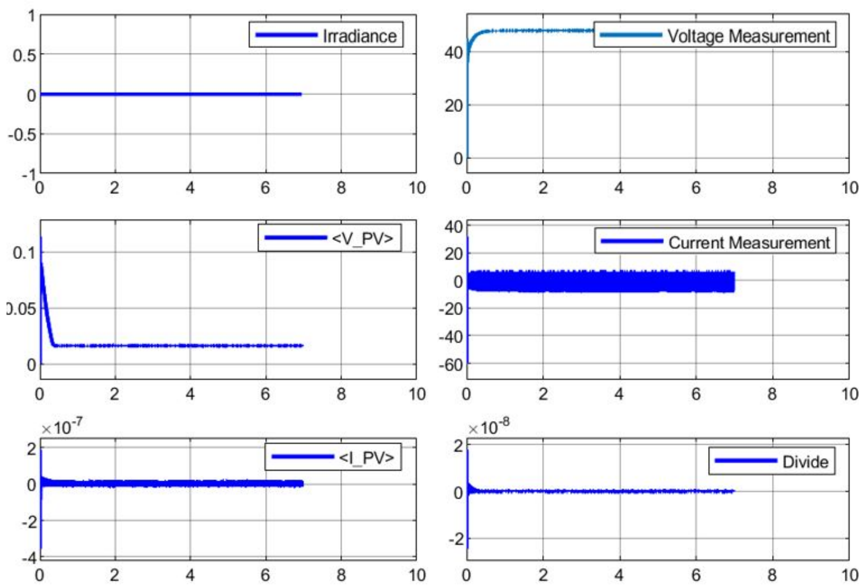

Figure 4.1: PV Output at '0' Irradiance

Figures 4.1 and 4.2 displays the most important dynamic simulation outcomes. These two figure shows the solar irradiance and the temperature of the photovoltaic array and the power generated. Figure 4.2 indicates the current state of charge (SOC) and the battery voltage (48V) and the PV device charges the battery for future use as seen in the SOC. The DC-DC boost converter exhibits the constant DC voltage output (48 V).

In the Figure 4.1, the irradiance given to the PV array is 0. 'V-PV' and 'I-PV' are the voltage and current output of the PV array respectively. 'Vref1' is the reference voltage i.e., 48V. By changing the periodic time, the frequency of output voltage and current is regulated. The input temperature given to the PV array is 25°C. 'Divide' is the power output parameter of the PV array.

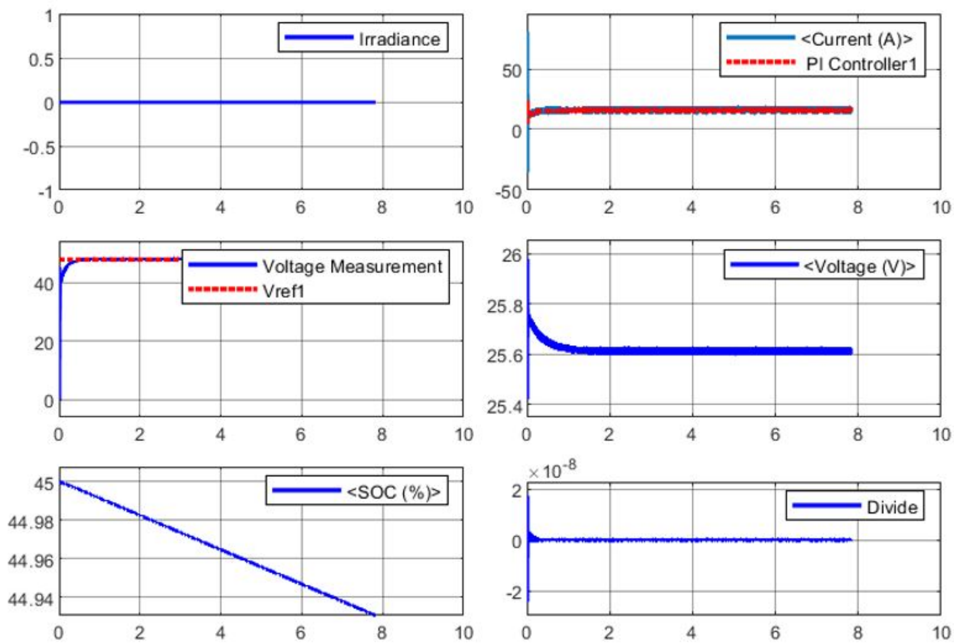

Figure 4.2: Battery Output at '0' Irradiance

In the Figure 4.2, as we can see, state of charge (SOC) is going down. This means that the battery is discharging. Voltage and Current values are both '0' as the solar irradiance is 0. Nowadays, the batteries engage in energy storage. The initial value of SOC is set to the necessary percentage, based on the high power available during this period. The batteries will not deeply discharge during this period, as their usable capacity never reduces their nominal capacity and stays at their full strength for long periods of time.

In the Figure 4.3 & 4.4, we can observe 2nd plots of both the Figures which

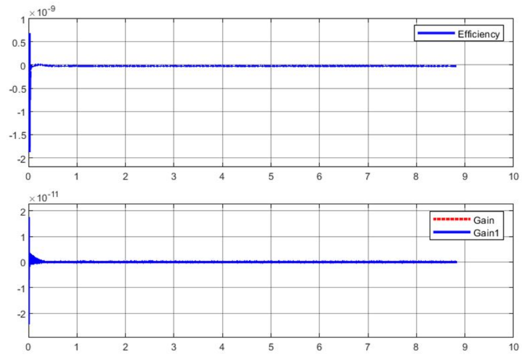

Figure 4.3: Efficiency of the MPPT Algorithm at '0' Irradiance

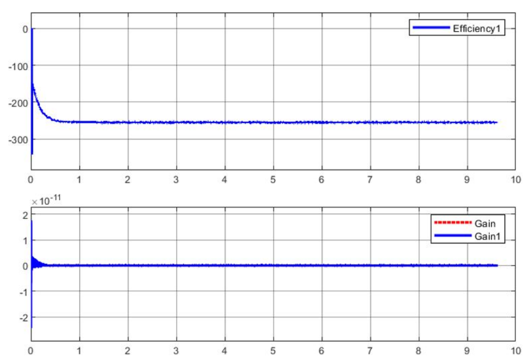

Figure 4.4: Efficiency of the System at '0' Irradiance

conclude that the ideal gain and gain of the respective system (MPPT system and overall system) are almost overlying. This means that the efficiency of both the MPPT algorithm and the overall system is higher.

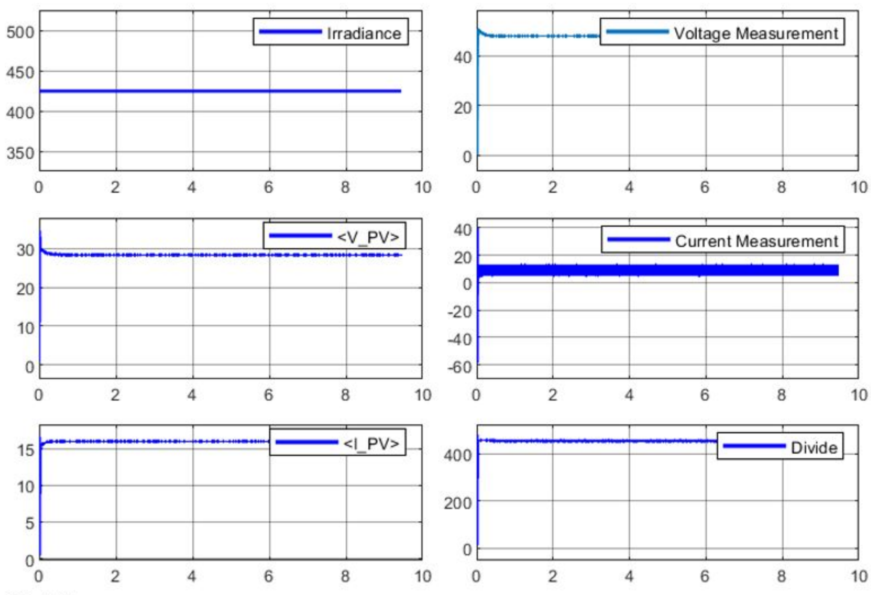

Figure 4.5: PV Output at '425' Irradiance

The Figure 4.5 shows the PWM generator characteristics according to the irradiation variance from $0W/m^2$ to $425W/m^2$. The PWM signal can then be used to monitor switches connected to a high voltage bus to replicate the signal at the required voltage. The implementation of an LC filter requires a close approximation of the PWM signal. The voltage of the PV changes to 29V and the current of the PV array is 17A.

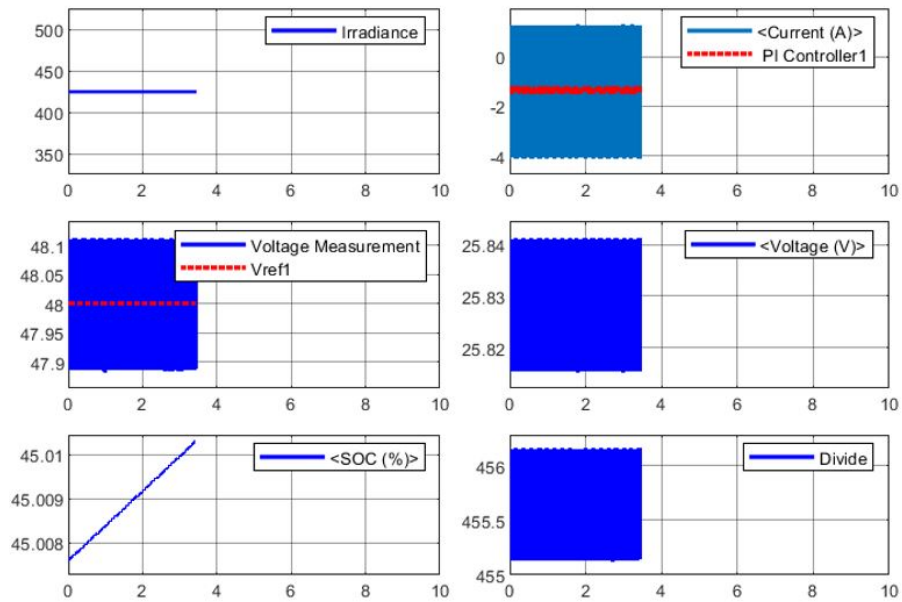

Figure 4.6: Battery Output at '425' Irradiance

In the Figure 4.6, as we can see, state of charge (SOC) is raising up. This means that the battery is charging.

4.2 Discussion

The research centered on developing a model to find the ideal system parameters for the design of a hybrid energy network. The intention was to meet the load of different applications with our energy system and to minimize cost. In the study of this model, there are good results about the changes in temperature, hence our model is reliable and accurate.

The simulation model will predict the behavior of the PV cell/module in uniform and differential insolation. To perform advanced power converter operation, the PWM power converter controller and the PV cell/module is designed using Matlab/Simulink because of the simplicity and accuracy of the program in the circuit design. The hybrid solar system model also acts as a good guide for future research in the field of maximum power point monitoring.

In the Figure 4.7, we can observe the same in the second plot which conclude that the ideal gain and gain of the respective system (MPPT system and overall

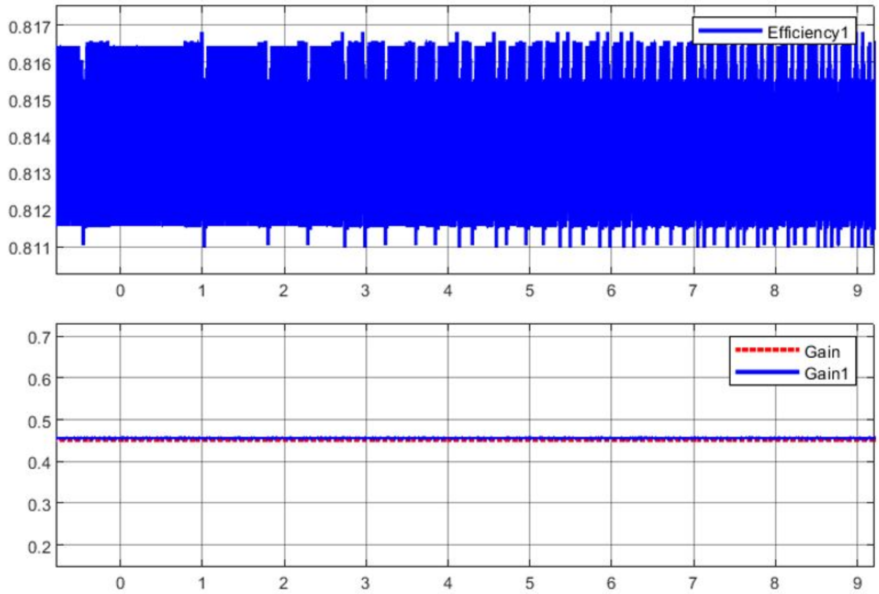

Figure 4.7: Efficiency of the System at '425' Irradiance

system) are almost overlying. This means that the efficiency of the system is above 90%.

Also, the results of the PV analysis showed that faster is a PV cell temp, the higher the solar radiation. As solar radiation increases, the electricity produced by the solar panel also increases and thus increases the output of energy. If solar radiation is strong and wind power is limited during summer, then the solar panels have the most electricity. In wintertime, when wind speed is higher and solar radiation is lower, the wind turbine provides more energy needed so that the relationship between the two sources is clearly conversely. When developing this energy system device, the ambient temperature where the equipment is situated will also take account of more Sun radiation, and this should also be well covered against environmental agents that can minimize the useful life of the equipment.

Chapter 5

Conclusion

The latest global developments contribute to energy protection and sustainable development worldwide. Therefore, the role of renewable energy has become increasingly relevant. The developing world is now on the way out of fossil-fuel era and primarily involves renewable energy and energy conservation technologies.

This project sums up the efforts made to combine PV panels, power electronics, and energy storage in one unit. The gaps and challenges to be addressed have been identified and analyzed. The advantages gained by power electronics must be taken into account to achieve higher efficiencies and to ensure a healthy operation of components in low-power integrated concepts. Although new integration ideas are promising, long-term testing like cycling analyzes its important to validate solution feasibility. For high-power devices, more information should be studied on the thermal stresses caused by outdoor conditions and their relationship to aging.

Various systems were simulated and techno-economic analysis were performed taking into account factors such as device sizes, system design, the suitability of other renewability choices, load-changing economics and cost of components, system life cycle, net current system costs, power costs for end users, maintenance and annual operating costs. The ideal hybrid electricity system involves a diesel generator and a photovoltaic solar panel. Prior to installing HyPV, the energy efficiency of loading equipment must be increased. Furthermore, the economic figures of the solar photovoltaic system would be significantly reduced if energy-efficient load equipment is used.

Dynamical simulation in the MATLAB / Simulink setting has been performed under diverse systems conditions to check the power efficiency, harmonics, load impacts, and voltage transients of the designed solar PV system portion of the hybrid power system. The simulated results demonstrate that the solar photovoltaic system can fully power the building and can serve as an alternative solution to the energy crisis.

5.1 Future Work

An improved inverter control system (e.g., voltage-oriented control, VOC) could be implemented in the battery control system (state of charge controller, SOC) in case of severe system disruptions such as sudden overload in the future to allow rapid response. Figure 5.1 shows the model of Hybrid Renewable Energy System. Future research can be carried out to change the design built in this study by further exploring building design for Hybrid Solar-Wind Energy System which uses maximum power point tracking method integrated with battery and also for grid-tied systems. Also, the current autonomous PV system is to be hardware-implemented for real-life testing.

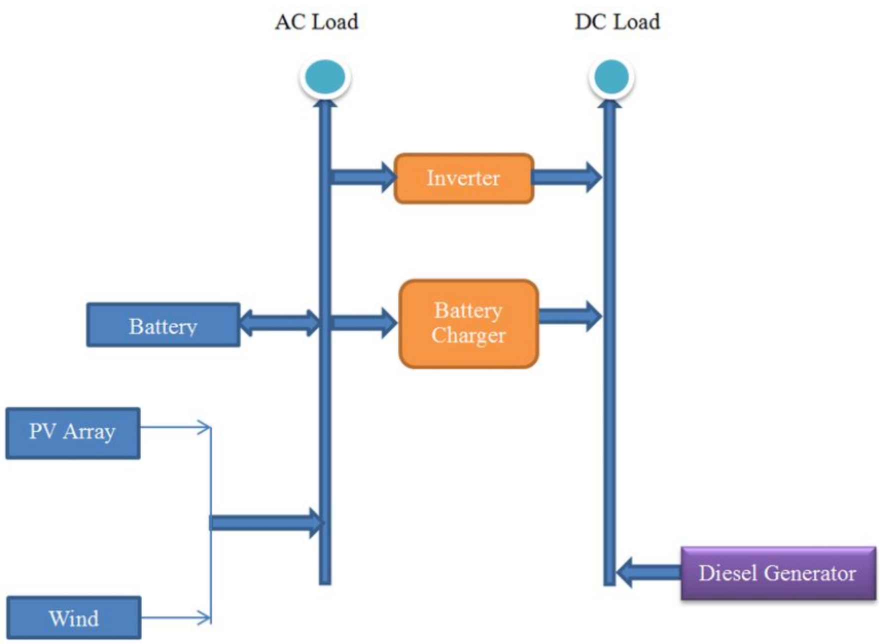

Figure 5.1: Model of Hybrid Renewable Energy System

5.2 Alternative Future Work

What if any window can easily be converted to a solar panel?

Solar window technology transforms any window or sheet of glass into a battery-integrated solar photovoltaic cell which uses MPPT algorithm.

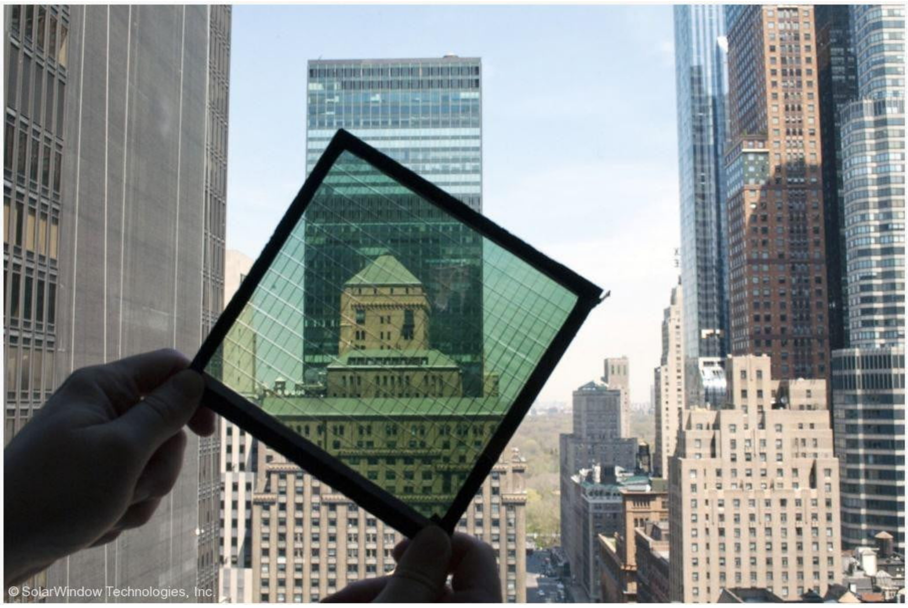

Figure 5.2: Embedded Solar Window

Figure 5.2 shows the Embedded Solar Window where the cells pick up part of the solar radiation selectively that the eyes can not see when normal visible light passes through. The infrared light emitted is directed to the edge of transparent plastic, where the solar photovoltaic cell strips turn into electricity. This application can be used with combination of wind power energy.

Appendix A

Appendix

The programming code for the MPPT algorithm described and analysed in this project is available at the GitHub repository: MPPT Algorithm for Design of Hybrid Solar Power System

"https://github.com/VarunNNayak/MPPT-Algorithm-for-Design-of-Hybrid-Solar-Power-System.git"

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