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In the aim obtaining of

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Domain: Sciences and Technology

Option: Mechanical engineering

Specialty: Electromecanic

THEME

Implementation of a system for measuring the conformity and electrical quality of solar panels

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بسم الله الرحمن الرحيم

﴿ رَبَّنَا لاَ تُؤَاخِذْنَا إِن نَّسِينَا أَوْ أَخْطَأْنَا رَبَّنَا وَلاَ تَحْمِلْ عَلَيْنَا إِصْرًا كَمَا حَمَلْتَهُ عَلَى الَّذِينَ مِن قَبْلِنَا رَبَّنَا وَلاَ تُحَمِّلْنَا مَا لاَ طَاقَةَ لَنَا بِهِ وَاعْفُ عَنَّا وَاغْفِرْ لَنَا وَارْحَمْنَا أَنتَ مَوْلاَنَا فَانصُرْنَا عَلَى الْقَوْمِ الْكَافِرِينَ﴾ **سورة البقرة : الآية286 .**

" صدق الله العظيم"

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First and foremost, we thank God Almighty for giving us strength

*To reach our endeavours, as well as the courage to overcome all difficulties. Thank you very much to the doctor. **LAPIUD Shoaib**, Professor at El-Wad University, my thesis supervisor, for the confidence he gave us by agreeing to be the supervisor of this work. We were able to appreciate his scientific skills and he knew how to make us benefit from his experience and fruitful guidance. We also thank the members of the jury for their interest in our research. We also extend our sincere thanks to all the teachers of the Department of Electromechanical Engineering who participated in our training.*

DEDICATION

In the name of God the Merciful Praise be to Allah Almighty

We dedicate this humble work as respect, appreciation and thanks:

To our dear fathers, mothers and brothers who helped us from near and far.

To all our family that bears the name of Bebboukha, Mosbahi and Medekhel

To everyone who contributed to the development of this humble work and

All these are dear to us.

Abstract

Résumé

الملخص

Abstract

One of the most common problems with solar panels is the incompatibility of the electrical quality of solar panels. For this reason, this project addresses this problem by implementing a system that allows measuring the properties of solar panels and measures the compatibility of the displayed properties compared to the measured properties.

In this project, the characteristics of solar panels will be studied by simulating a virtual model on Matlab, and then an algorithm is proposed that allows determining the necessary characteristics to determine the compatibility and effectiveness of solar panels.

After being able to simulate, the project will be implemented using voltage and current sensors with the programming of the controller (Arduino) in order to implement the proposed algorithm and determine the necessary characteristics.

Finally, the model will be tested and verified for its effectiveness on the various available kinds of solar panels .

Keywords: The electrical quality, solar panels, voltage, current sensors, simulating.

Résumé:

L'un des problèmes les plus courants avec les panneaux solaires est l'incompatibilité de la qualité électrique des panneaux solaires. Pour cette raison, ce projet aborde ce problème en mettant en œuvre un système qui permet de mesurer les propriétés des panneaux solaires et de mesurer la compatibilité des propriétés affichées par rapport aux propriétés mesurées.

Dans ce projet, les caractéristiques des panneaux solaires seront étudiées en simulant un modèle virtuel sur Matlab, puis un algorithme est proposé qui permet de déterminer les caractéristiques nécessaires pour déterminer la compatibilité et l'efficacité des panneaux solaires.

Après avoir pu simuler, le projet sera mis en œuvre à l'aide de capteurs de tension et de courant avec la programmation du contrôleur (Arduino) afin de mettre en œuvre l'algorithme proposé et de déterminer les caractéristiques nécessaires.

Enfin, le modèle sera testé et vérifié pour son efficacité sur les différents types de panneaux solaires disponibles.

Mots clés : La qualité électrique, les panneaux solaires, la tension, les capteurs de courant, la simulation.

الملخص

من أكثر المشاكل شيوعا في الألواح الشمسية هي عدم التوافقية للجودة الكهربائية الألواح الشمسية لهذا السبب هذا المشروع يعالج هذا المشكل المطروح من خلال انجاز نظام يسمح بقياس خصائص الألواح الشمسية ويقيس مدى توافقية الخصائص المعروضة مقارنة بالخصائص المقاسة.

في هذا المشروع سيتم دراسة خصائص الألواح الشمسية من خلال محاكاة نموذج افتراضي على الماتلاب ثم يتم اقتراح خوارزمية تسمح بتحديد الخصائص اللازمة لتحديد مدى توافقية وفعالية الألواح الشمسية.

بعد التمكن من المحاكاة سيتم تنفيذ المشروع بإستخدام حساسات التوتر والتيار والكهربائية مع برمجة المتحكمة الذكية من أجل تنفيذ الخوارزمية المقترحة وتحديد الخصائص اللازمة.

وفي الأخير سيتم تجريب وتحقيق النموذج على مختلف أنواع الألواح الشمسية المتوفرة.

الكلمات المفتاحية: الجودة الكهربائية، الألواح الشمسية، الجهد، أجهزة الاستشعار الحالية، المحاكاة.

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CHAPTER II : The Role of Converters in Extracting Data from Solar Panels.

Abbreviations

Abbreviations

Symbol	Designation	Unit
I	Total current	A
Iph	photocurrent	A
I_d	Dark current	A
I_s	Saturation current	A
q	Charge of an electron (approximately 1.6 x 10^-19 coulombs).	Coulombs
V_{oc}	Open-circuit voltage	V
N_s	Emission coefficient of the diode	/
K	Boltzmann's constant(approximately 1.38 x 10^-23 joules per kelvin)	J/K
A	Diode area	/
To	Temperature of the diode	K
Irs	Reverse saturation current	A
Tr	Reference temperature	K
Eg	This is the energy bandgap of the semiconductor material used in the diode.	/
S	Swich	/
v_c	Voltage across the capacitor	V
Rc	Series resistance	Ω
i_L	Current through the inductor	A
c	Capacitance	F
L	Inductance	H
E	External voltage	V
$\frac{di_L}{dt}$	Rate of change of current with respect to time	A/s
V_s	DC voltage used to power the component or circuit	V
D	Duty cycle	/
i_s	Source current	A
$\frac{dV_s}{dt}$	Represents the rate of change of the source voltage with respect to time	V/s

General Introduction

General Introduction

Renewable energy has gained increasing importance in recent years as we strive to address the challenges of climate change and reduce our reliance on traditional energy sources. Among the various forms of renewable energy, solar energy stands out as one of the most promising and rapidly growing technologies. Solar panels, which are essential components of solar energy systems, play a crucial role in harnessing and converting solar energy into electricity. However, there are several challenges associated with solar energy, particularly related to the efficiency and quality of solar panels.

The first chapter of this thesis provides an overview of renewable energy and focuses specifically on solar energy and the problems associated with it. It explores the importance of maintaining the electrical quality and conformity of solar panels to achieve optimal performance. This involves ensuring that solar panels are manufactured to the highest quality standards and operate within established electrical specifications. The chapter also discusses the role of electronic converters in solar panels and how different types of converters can impact overall efficiency. It highlights the use of transistor driving techniques in electronic converters to improve solar panel performance. Additionally, the chapter emphasizes the significance of accurately measuring solar panel efficiency using specialized tools such as pyranometers and spectroradiometers.

The second chapter delves into the characteristics of solar panels and the importance of efficient DC/DC converters in optimizing the performance and power extraction from photovoltaic (PV) systems. It discusses different types of DC/DC converters used in PV systems and explores maximum power point tracking (MPPT) techniques for solar PV. The chapter also presents a proposed technique for extracting data from PV solar using a DC/DC converter. Furthermore, it introduces solar PV modeling and simulation techniques to facilitate accurate data extraction.

The third chapter focuses on the components and design aspects of a solar panel metering system. It covers important elements such as the gate drive of a DC/DC boost converter, measurement sensors, design process, PCB design and fabrication, circuit board fabrication, Arduino programming algorithm, and the interface of an Android application with the system. The chapter highlights the significance of measurement sensors for capturing accurate data and discusses the role of the gate drive of the DC/DC boost converter in ensuring efficient operation. It provides a comprehensive understanding of these components, their functions, and their importance within a system. Additionally, the chapter explores the PCB design and fabrication process, circuit board fabrication, Arduino programming algorithm, and integration with an Android application.

The content of these chapters is based on various sources, including academic papers, theses, and books. Some of the key references used include A. B. Arostegi's thesis on photovoltaic generators with high conversion efficiency, Kalogirou's book on solar energy engineering, and various papers on power electronics and photovoltaic applications.

By studying these chapters, readers will gain valuable insights into the factors that impact solar panel efficiency and how to optimize solar energy systems effectively.

Chapter I

Importance of Measuring Electrical Quality and Conformity in Renewable Energy

I.1. Introduction

Renewable energy has become increasingly important in modern times, as we strive to address the challenges of climate change and reduce our reliance on traditional energy sources. Among the various forms of renewable energy, solar energy is one of the most promising and rapidly growing technologies. Solar panels are essential components of solar energy systems, and optimizing their performance requires consideration of several factors.

Maintaining electrical quality and conformity is critical in achieving optimal solar panel performance. This involves ensuring that solar panels are manufactured to the highest quality standards and operate within established electrical specifications. Electronic converters are another essential component of solar panels, and different types of converters can impact overall efficiency. Transistor driving techniques are used in electronic converters to improve solar panel performance.

Accurately measuring solar panel efficiency is also crucial in determining the effectiveness of solar energy systems. Specialized measuring tools, such as pyranometers and spectroradiometers, are necessary to accurately assess solar panel efficiency.

This chapter draws on various sources, including A. B. Arostegi's thesis on photovoltaic generators with high conversion efficiency, kalogirou's book on solar energy engineering, and various academic papers on power electronics and photovoltaic applications. These sources offer valuable insights into the different factors that impact solar panel efficiency and provide a foundation for understanding how to optimize solar energy systems.

I.2 Overview of Renewable Energy Importance:

The term renewable energy expresses energy that is continuously generated and renewed through natural phenomena without human intervention. There are different types in nature such as sunlight, geothermal energy, wind, ocean waves, flowing water energy and biomass energy in its various forms. One of the most important advantages of renewable energy is that it is free and clean energy. With regard to the concept of alternative energy, the term alternative energy refers to any energy source that can be used as an alternative to fossil fuels, and often refers to unconventional energy sources that do not affect nature as much as burning fossil fuels.[1]

These sources and technologies include solar and wind power, hydro and mini-hydro, tidal power, biomass power (including biofuels), and geothermal power.[2]

Renewable energy sources are inexhaustible and evenly distributed over a large geographical area, these resources are quickly replenished through a natural process. It will not cause any pollution problem. The main advantage of using renewable raw materials is that they are available all year round. With a one-off investment, we can generate energy for many decades without harming the environment, which we mention below: [3]

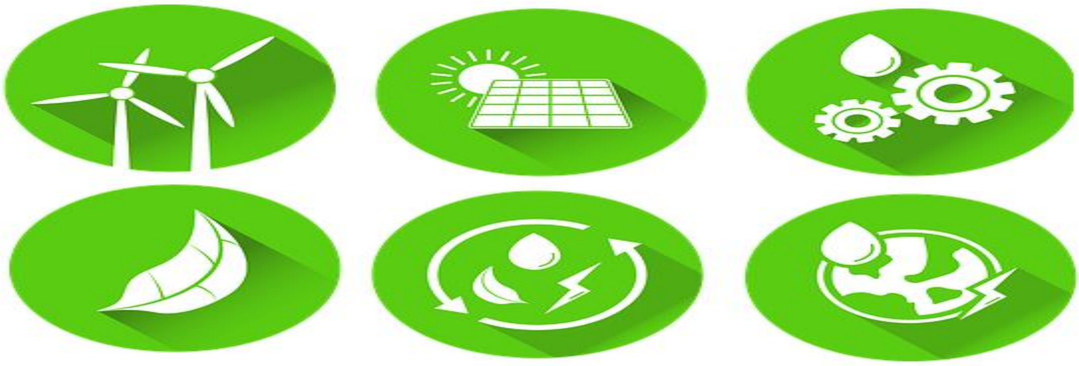


Figure I.1: Different renewable energies

I.2.1 Solar Energy:

Figure I.2: Solar Energy

Solar energy is an alternative to traditional fossil fuels. Available in large quantities at our scale and distributed over the earth's surface, it can recover up to 1000 W/m2 in temperate zones. Both in an urban environment and, on the contrary, in a remote place, this energy can be recovered and used in thermal or electrical form, there are different types of solar energy:[4]

I.2.1.1. Solar thermal energy:

Involves the use of solar panels to capture the energy of solar radiation in a liquid, sometimes air but mostly water [5]. Because of this, we can use the recovered energy for water heating, swimming pool and apartment heating, grain drying, the principle of operation of water heating based on solar thermal energy is shown in Figure I.3.

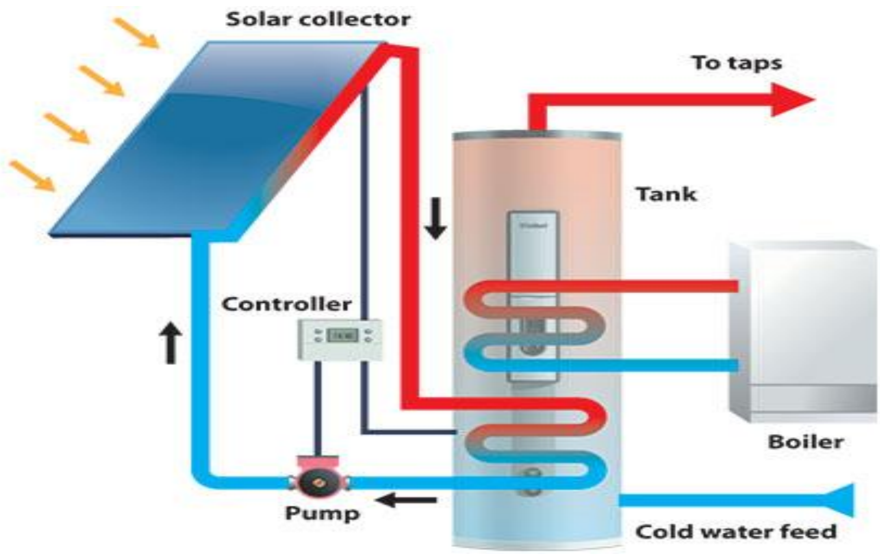


Figure I.3: The production of hot water based on solar thermal[6]

The solar collector consists of a dark body, a cooling system, an insulator and a transparent cover [7].

There are two types of solar collectors, one that uses a liquid (water or antifreeze) and another that uses air as the heat transfer fluid.

I.2.1.2. Photovoltaic solar energy:

It is a form of renewable energy that generates electricity by converting solar radiation through a photovoltaic cell. Several cells are interconnected to form a photovoltaic module [8]. The functional principle of the power supply of a house based on a photovoltaic system is shown in Figure I.4.

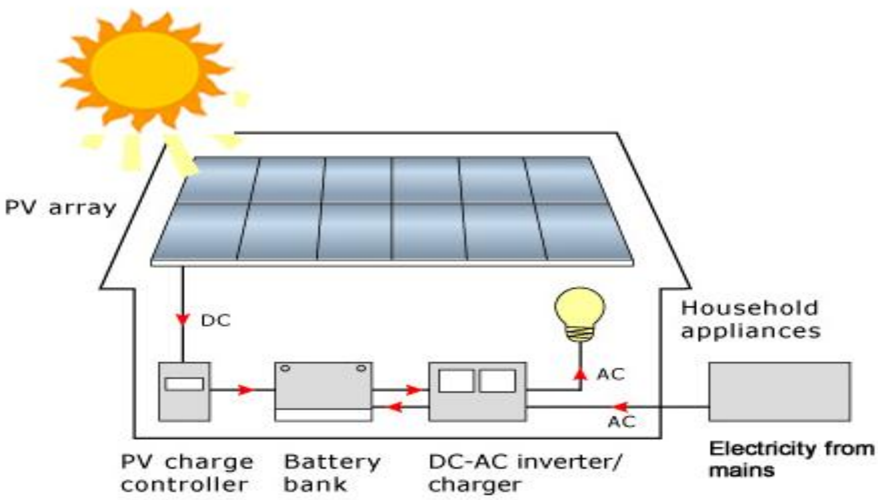


Figure I.4:The supply of a residence based on the photovoltaic system [9]

- **Monocrystalline solar modules:**

Have a better efficiency (12% - 16%), are mainly used where little space is available.

- **Polycrystalline solar modules:**

Are the most used in terms of quality and price. They have a good yield (10% - 13%) and an interesting lifespan (more than 35 years).

- **Amorphous solar modules:**

Are commonly used in calculators and watches. They are characterized by low consumption (they work even in low light conditions), so these types of photovoltaic panels do not have very high yields, only between 5 and 7%.

- **Modules made of composite materials:**

This solution is intended to replace existing technology, so the idea was to replace metal to build a device that's both smaller and lighter, but just as effective.

I.2.2. Thermodynamic energy:

Thermodynamic solar power plants are installations that produce electricity from solar thermal energy. There are three main types of thermodynamic solar power plants, namely tower power plants, cylindrical-parabolic mirror power plants and Fresnel mirror power plants, which use different configurations of mirrors to focus the sun's rays onto the solar collector. To ensure efficient and reliable electricity generation, the operation of solar thermal power plants requires careful planning and regular maintenance. It is also important to have back-up power sources, such as diesel generators, to ensure a continuous power supply in the event of outages or emergencies.

Figure I.5: Thermodynamic energy

I.2.2.1 Technical explanation:

The liquid first flows through the regulator and gets very cold. To keep it less cold, it then flows to a thermodynamic solar panel. Once the liquid is in the plate, it sucks up all the heat it can find. It sucks in heat from the sun, rain, and even ambient air. The liquid then goes to the compressor. Compressing a liquid makes it hot. This compression and warm-up is an important step. When the liquid is hot, it circulates in a coil inside the hot water tank. From there, the warmth goes to the content of your thanks and gives you hot water. The process is now complete and the liquid flows through the expansion valve again to continue the cycle.[10].

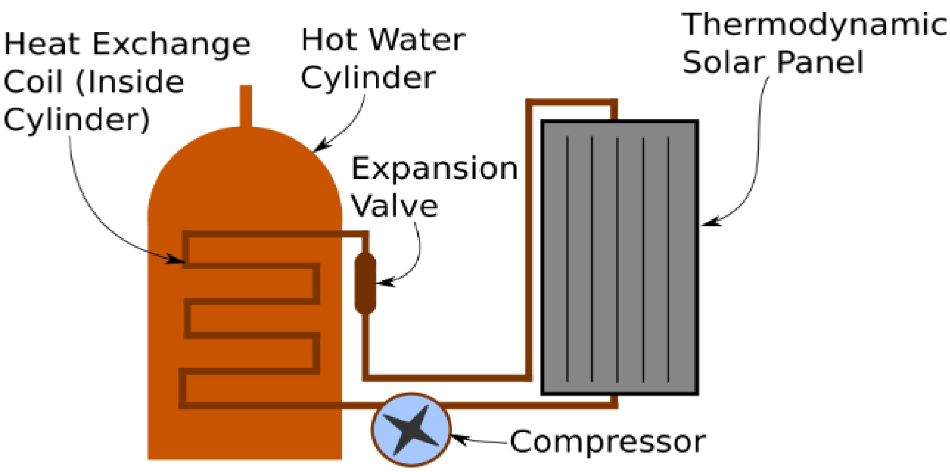


Figure I.6: Thermodynamic solar panel schematic [10]

I.2.3. Wind energy:

Wind energy is one of the most important and promising renewable energy sources in the world in terms of development because, unlike other conventional energy sources, it does not pollute the environmentIt depends directly on the wind.[11]

Figure I.7: Wind Power

The sun heats the earth unevenly, creating distinct temperature and atmospheric pressure zones around the globe. From these pressure differences arise air movements, called wind. It makes it possible to produce electricity, also called aerogenerator, thanks to the force of the wind. There are two families of wind turbines, horizontal axis and vertical axis such as Darrius and Savonius. Figure I.8 shows the different shapes of the blades of axis wind turbines vertical.

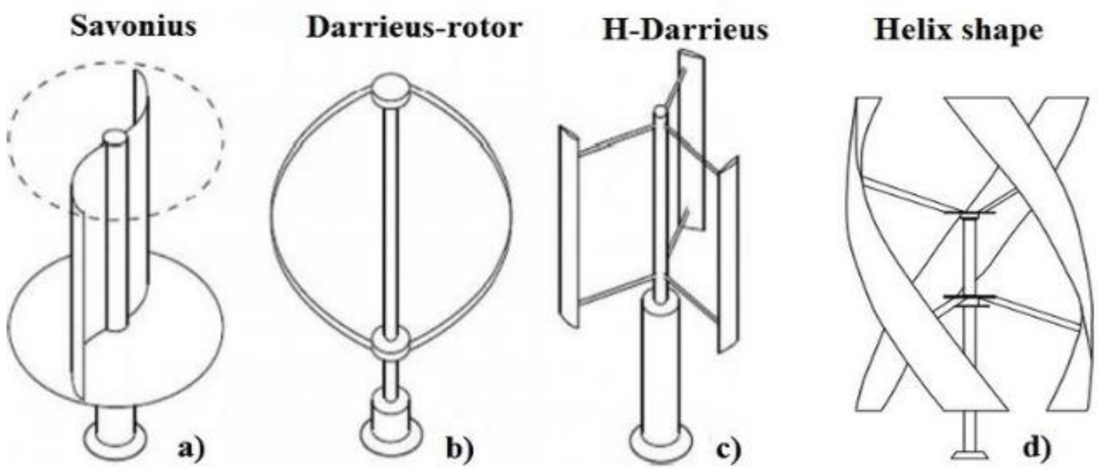


Figure I.8: Different kinds of vertical axis wind turbines (VAWT): (a) Savonius; (b) Darrieus with egg beater" design rotor; (c) H-shape blades; (d) helix shape blades.[12]

A horizontal-axis wind turbine consists of a shaft, propellers, and a nacelle that contains a generator and power lines that transmit electricity (see Figure I.9). The figure below shows the main components of a horizontal axis wind turbine.

The generator converts the mechanical energy from the wind into electrical energy. The turbine tower contains wiring so the generator can send electricity into a transformer or a battery which will eventually distribute usable electric power. A brake is installed to prevent mechanical failure from high wind [14].

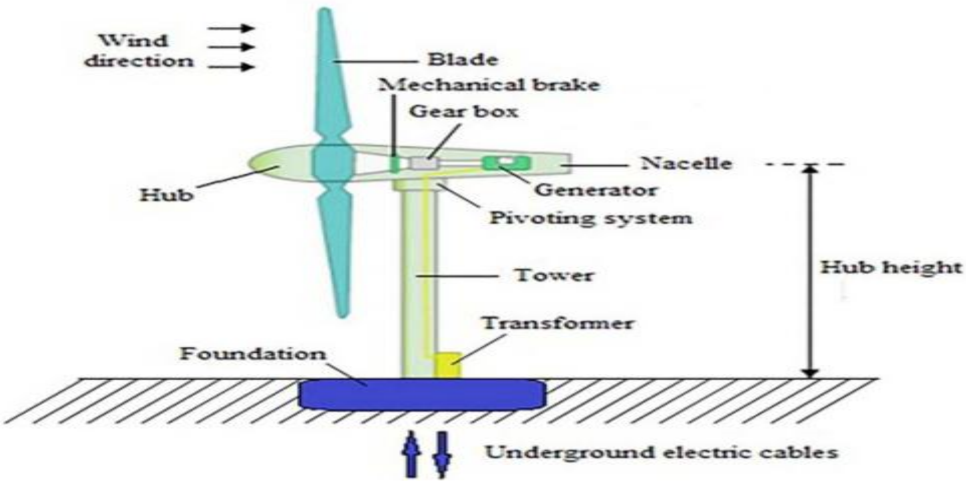


Figure I.9: Overview of main components for a wind turbine.[13]

I.2.4. Biomass Energy:

Refers to any organic matter of plant, animal or fungal origin that, after methanation (new chemical transformations), can become an energy source through combustion [15].

Biomass has been used by man (masters of fire) for centuries. It remains the main renewable energy used for heating and cooking around the world, but especially in less industrialized countries. Benefits of Biomass Energy is produced directly by incineration or processing, which can later be used as a fuel. An example of a biomass processing cycle is shown in Figure I.10.

Figure I.10: Example of biomass transformation cycle.[16]

There are three main categories of energy from biomass:

- **Biogas:**

Biogas is a gas produced by the fermentation of organic substances of animal or vegetable origin in the absence of oxygen. This fermentation, also called anaerobic digestion, occurs naturally (in swamps) or spontaneously in organic waste landfills, but it can also be induced artificially in digesters (to treat sewage sludge, industrial or agricultural organic waste, etc.). Raw biogas can be used in boilers, generators and ovens.

- **Wood:**

As always been used as a power source. Wood energy is solution for collective and residential heating, as well as the production of fossil energy (diesel, gas, etc.) and electricity.

- **Biofuel:**

Another advantage of biomass is its ability to produce biofuels. There are two types: ethanol and biodiesel. [17] The working principle of biomass is on the plan of the biomass plant as shown in the figure below:

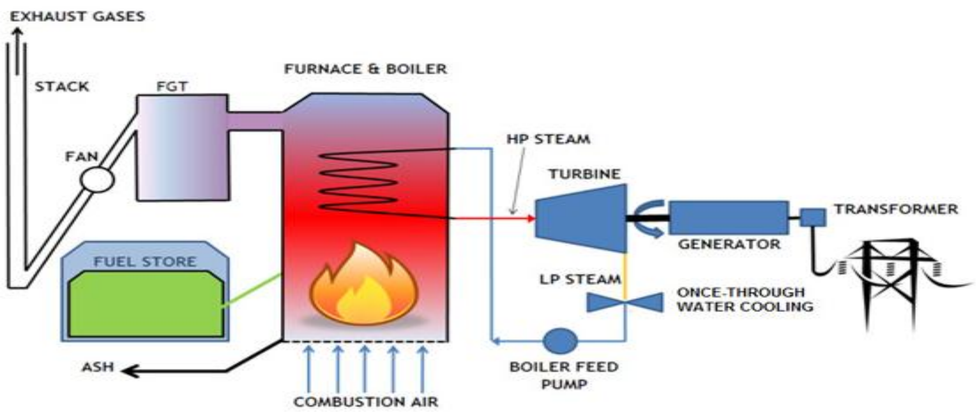


Figure I.11: the operation of a biomass power plant[18]

First the biomass is burned, this process generates high temperatures which transform the water into steam, then electricity is produced thanks to the turbines which feed the generator.

I.2.5. Hydraulic energy:

Hydropower (hydroelectric power), is a renewable energy source derived from the conversion of hydroelectric power. The kinetic energy of the water flow is converted into mechanical energy by a water turbine and then into electrical energy by an alternator.

The principle of operation of a gravitational power plant is shown in Figure I.12.

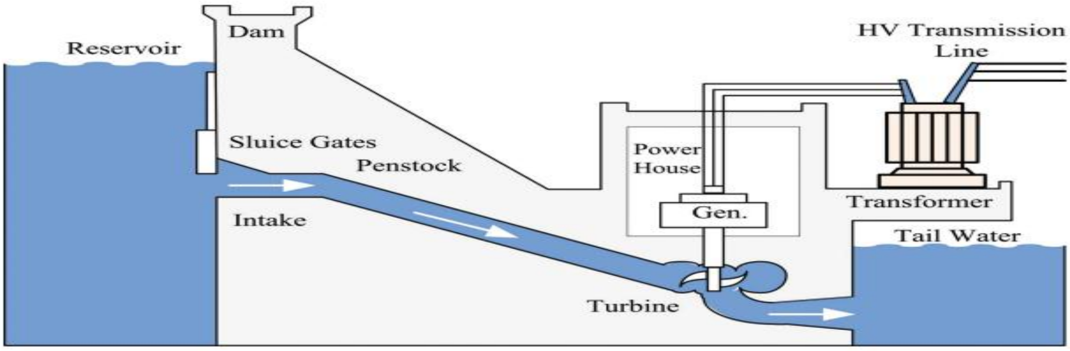


Figure I.12: Le principe de fonctionnement du centre de gravité[19]

Depending on the head, there are different types of hydroelectric power plants:

I.2.5.1. High-pressure systems:

Have heads greater than 300 m, use Pelton turbines. These plants are found in the Alps and other very mountainous regions. tank capacity is relatively small.

I.2.5.2. Medium plants:

Have a height of 30 to 300 m; They use Francis turbines. These plants are fed by water collected behind a dam built in a riverbed in a mountainous region. You have a large capacity tank.

I.2.5.3. Low-pressure systems:

fall from a height of less than 30 m uses Kaplan or Francis turbines. These plants are found near streams or rivers with high flow rates [20].

I.2.5.4. Operation of a hydroelectric power station

Hydroelectric power plants convert the energy of water movement into electricity. The energy of the falling mass of water is first converted into mechanical energy in a water turbine. This turbine drives an alternator in which mechanical energy is transformed into electrical energy.

I.2.6. Geothermal energy:

Geothermal energy is natural thermal energy that relies on absorbing heat from the earth's crust to produce electricity (temperature between 90° and 150°) or heat (temperature below 90°), composed of two Greek words ("Gê" means earth and "thermia" means heat) [21].

Compared to other renewable energy sources, geothermal energy has the advantage of being independent of climatic conditions (rain, sun, wind, etc.).

Figure I.13: Geothermal energy

The principle of geothermal energy is based on thermal power plants, which are a source of electricity generation through:

1- Subsidization of heat (from the ground) into water, which is turned into steam.
2- A turbine converts part of the steam into mechanical energy.
3- Generate electricity with a generator attached to a turbine.

The contained geothermal fluid is used to obtain geothermal heat deep tanks to drive a turbine, which in turn drives a generator to produce electricity.

Types of geothermal power plants:

There are three main types of power plants:

a) Conventional plant:

- ✓ **Dry steam plant (dry stem plants):**

This type of power plant was the first to be built, and this type depends on direct gasification technology, which involves sending steam (often at temperatures in excess of 150°C) directly from dry steam wells to reservoirs, where it is then drilled into the ground by simple Release dry steam into the turbine.

This type of geothermal power plant is the most common in the world. Flash evaporation involves pumping hot water at a temperature of about 180 °C or higher from deep to the surface at high pressure. On the surface, hot water is sent to a separator at high pressure, and some of the water is quickly turned into steam, which is then used to drive turbines that power generators.[22]

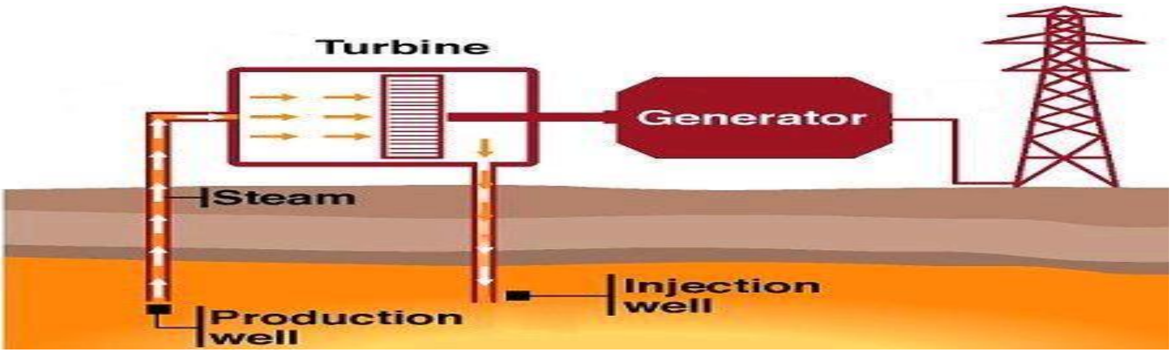


Figure I.14: Descriptive diagram of a direct vaporization geothermal power plant.[22]

Flash stem plant:

This type of geothermal power plant is the most common in the world.

Flash evaporation involves pumping hot water at a temperature of about 180 °C or higher from deep to the surface at high pressure. On the surface, hot water is sent to a separator at high pressure, and some of the water is quickly turned into steam, which is then used to drive turbines that power generators.

After use, the vapor is sent to the condenser where vacuum conditions prevail. Cooled water supplied by cooling towers condenses it back into water, which is then sent to geothermal banks for reheating and reuse (these units have a production capacity of 20 to 110 MW).[22]

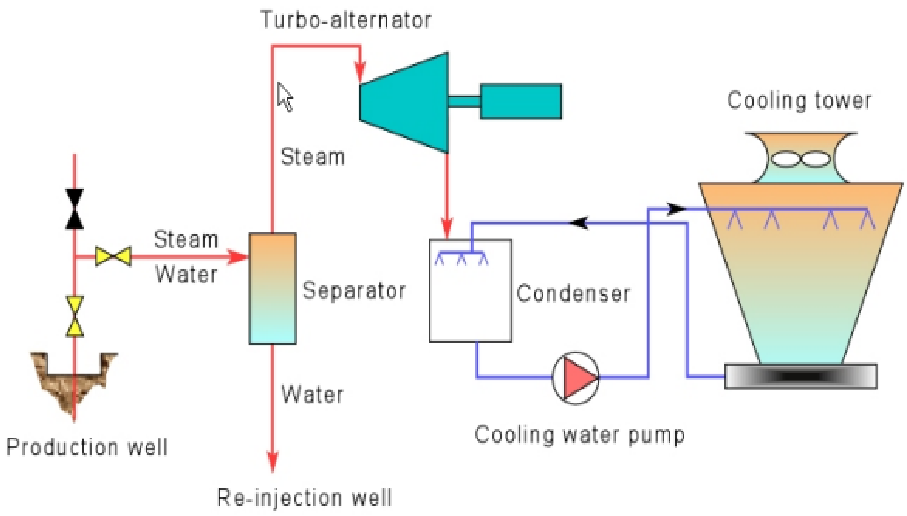


Figure I.15: Descriptive diagram of a flash vaporization geothermal power plant.[22]

b) Binary cycle geothermal power plants:

These power plants have a different binary cycle than other power plants. In this case, a deep geothermal source for the reservoir is developed using a mesophilic (85-170°C) geothermal fluid and a secondary fluid with a lower boiling point than water, called a working fluid. The hot geothermal fluid flows through a heat exchanger to heat the working fluid in the tubes, which is then evaporated and passed through a turbine to generate electricity.[22].

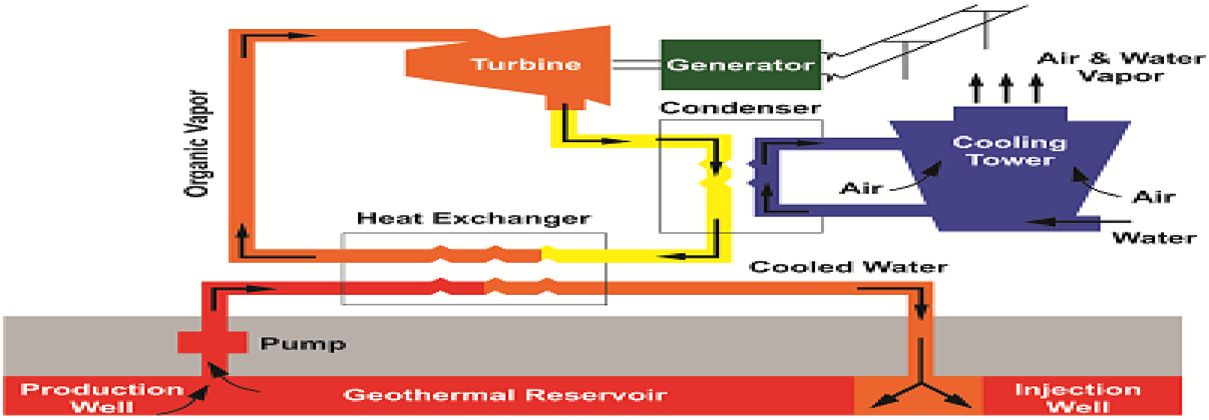


Figure I.16: Descriptive diagram of a cycle power plant.[22]

I.3. Electrical Quality and Conformity of Solar Panels:

We know that efficiency is the most important parameter to assert photovoltaic technology on the market. Ensuring the electrical quality and compatibility of solar panels is critical to maximizing their performance and efficiency in renewable energy systems. Electrical quality refers to the ability of the solar panels to maintain their electrical properties, while compliance refers to the ability of the solar panels to meet certain standards factors are affecting the PV efficiency [23]. These include:

I.3.1. Temperature effect:

That the efficiency of photovoltaic solar cells. Decreases with increasing temperature, cooling is required under intense light conditions such as concentrated sunlight. Temperature plays a crucial role in causing a drop in photovoltaic efficiency and its output power. This is due to the narrowing of the bandgap with increasing temperature, resulting in a decrease in the open circuit voltage. During this time, energy carriers increase from the valence band to the conduction band as more incident light is absorbed. [24]

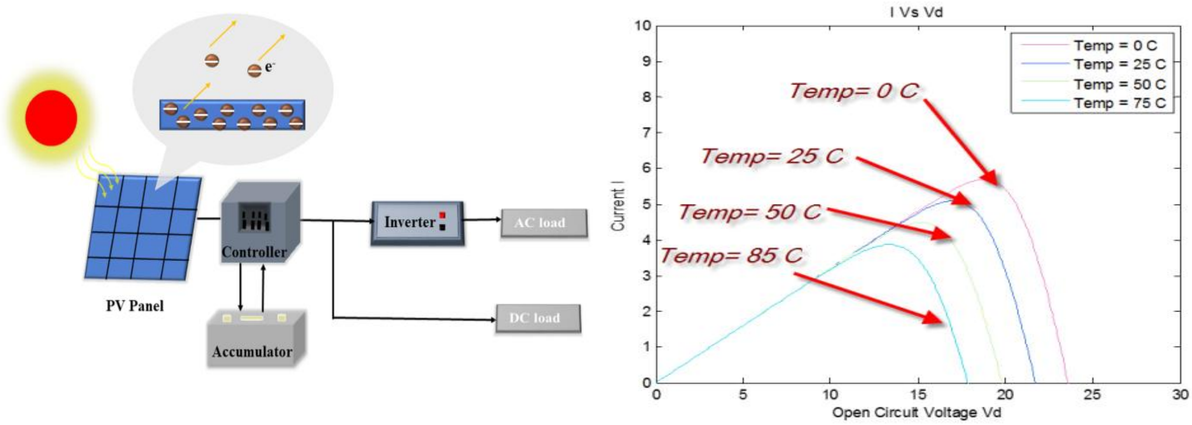


Figure I.17: Simulated effect of temperature to output voltage P-V curves for various temperatures. [25]

I.3.2. Manufacturing Quality:

To improve quality, detailed testing shall be carried out to validate the design and qualification under realistic operating and environmental conditions including pilot testing under end use conditions. In addition, electrical interfaces or other interfacial signals must be of a quality that can improve manufacturing processes, use tolerances, and testing. Testing should be carried out on products in a statistical network on transformers that are difficult to predict, using. Analyze feedback when preventing problems.[26]

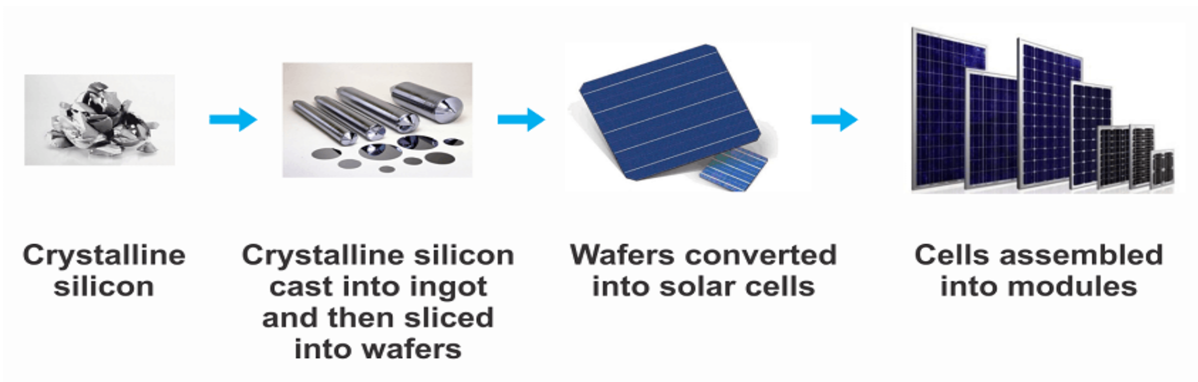


Figure I.18: Stages of manufacturing solar panels

I.3.3. Efficiency:

Is another measurement of photovoltaic cells that is sometimes reported. Efficiency is calculated by dividing the largest electrical output by the light incident power. Efficiency is frequently cited for incoming light with a spectrum similar to noontime sunlight, a photovoltaic cell temperature of 25°C, and an irradiance of 1000 W/m^2. Cost reduction in solar energy systems is directly related to an increase in cell efficiency. Each stage of the photovoltaic process has gone through a number of research and development initiatives. The efficiency of a single crystalline silicon solar cell has increased through technical progress to 14-15%, while the efficiency of polycrystalline silicon solar cells in large production lines has reached 12-13%.[27].

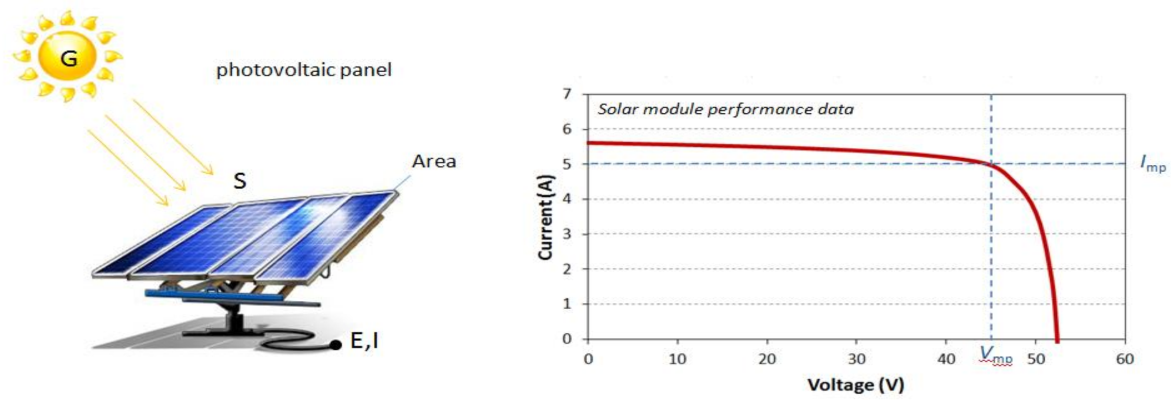


Figure I.19: The connection of efficiency with performance. A solar module of total cell area 2 m2 produces a voltage of 45V and a current of 5A at the peak power.[28]

I.3.4. Safety

Incompatibilities between solar panels and other system components can lead to safety concerns such as electric shock. Ensuring solar panels comply with relevant standards and guidelines can help mitigate these risks.

Photovoltaic module safety qualification requirements for testing, which contains many environmental stress tests to the extent that some consider it to be a de facto standard for photovoltaic module complementary design qualification.[29]

Figure I.20: Safety rehabilitation

I.3.5. Environmental Impact:

Environmental impact of solar photovoltaic technology. In order to generate electricity by PV module, some manufacturing processes are needed generate electricity by PV module, some manufacturing processes are PV module has different environmental sensitivity and pollution prevention key points, effect analysis and life cycle crystalline PV system by Zhang et al. The solution is PV in the end is beneficial to reduce the environmental mitigation of PV raw materials to some extent, and to avoid resources. The EIA for this should focus on technology.[30]

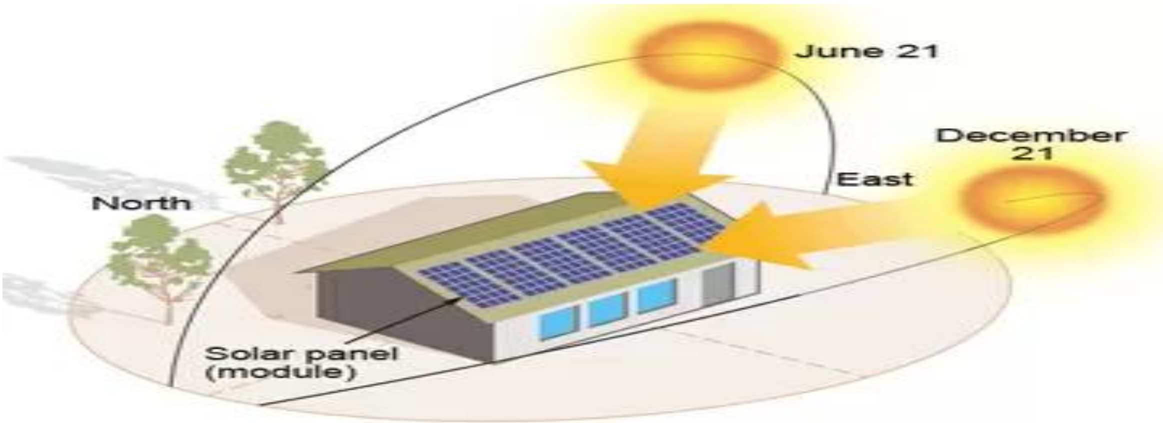


Figure I.21: The path of the sun on a solar panel

Maintaining the electrical quality and conformity of solar panels is crucial for the efficiency, safety, durability, and environmental impact of renewable energy systems.

Adhering to relevant standards and guidelines, conducting regular testing and maintenance, and investing in quality solar panels can all help ensure that solar panels are performing optimally in the renewable energy system.

I.4. Electronic Converters and Their Role in Solar Panel Efficiency:

I.4.1. Electronic Converters in Solar Panel:

Electronic converters play a crucial role in the efficiency of solar panel systems. This is because solar panels generate DC (direct current) power, while most electrical appliances and power grids use AC (alternating current) power. Electronic converters are responsible for converting DC power generated by solar panels into AC power that can be used by homes, buildings, and other electrical loads.

During the conversion process, some power can be lost, which reduces the overall efficiency of the solar panel system. Therefore, it is important to use electronic converters that are highly efficient to minimize power loss during conversion. [31]

There are different types of electronic converters used in solar panel systems, including:

I.4.1.1. DC-AC Inverter:

These inverters are used to convert the DC power generated from the solar panels into AC power. Alternating current is the type of electricity used in most homes and buildings. DC-AC inverters are important in solar panel systems because they allow the power generated by the solar panels to be used in a wide variety of applications. Solar inverters are very efficient, usually 93-96% depending on the make and model, never 100%, as they consume some DC input power, usually around 10-25W. Their efficiency can be controlled through an electronic technology called Maximum Power Point Tracking (MPPT). Inverters used in grid systems fall into three categories: micro, series, and central. Microinverters are the smallest string and mainline inverters connected to multiple modules connected in series to form a series of modules, which can be connected in parallel to increase the input power and current of the inverter.[32]

Although all inverters serve the same basic function. Among them we mention the following:

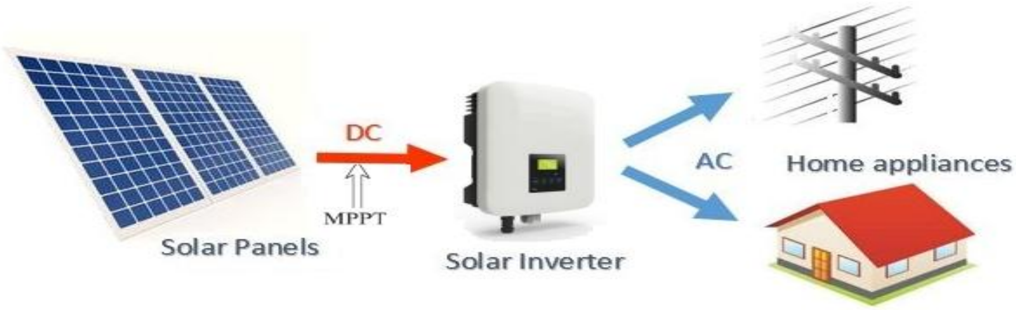


Figure I.22: the renewable energyt inverter DC to AC

I.4.1.2. String inverters:

Are a common architecture for connecting to the power grid. Multiple modules are connected in series to increase string tension.

The high DC power is converted to alternating current (AC) in a highly efficient string inverter.

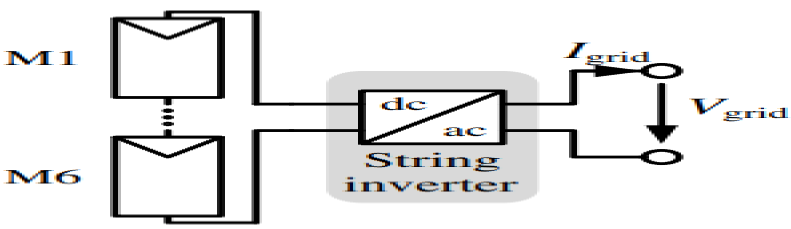


Figure I.23: Schematic of string inverter

I.4.1.3. Central inverters with power optimiser:

String inverters only track the MPP of the entire string, which means that individual modules work outside of their MPP in the event of partial shading.

To solve this problem, power optimizers were developed. Instead of connecting all modules directly to the string, each module is connected to a power optimizer. The power optimizer outputs are connected in series to increase the string voltage. The string inverter converts the DC string output into AC voltage and current needed to feed into the grid.

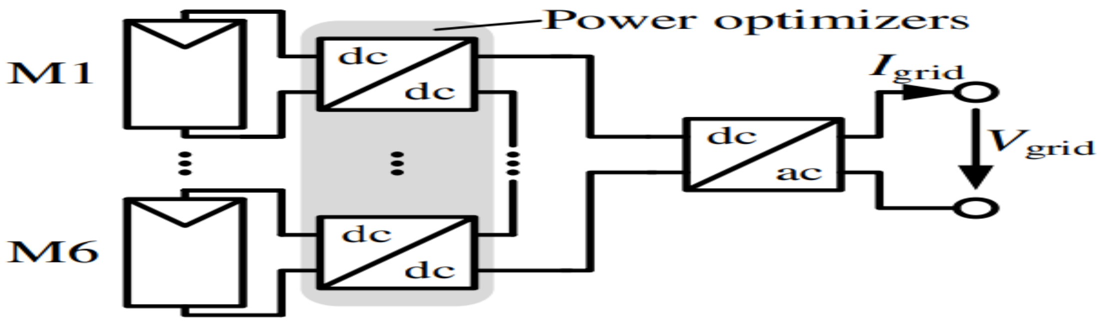


Figure I.24: Schematic of Power optimizer

I.4.1.4. Micro Inverter:

Micro-inverters are advantageous over traditional string inverters as they perform DC to AC conversion at the module level, enabling independent operation of each module. This approach avoids shading issues that can affect performance in string inverter systems. Micro-inverters also allow for computer-based monitoring of individual modules, facilitating troubleshooting and energy production verification and improving overall system efficiency DC-DC converters.

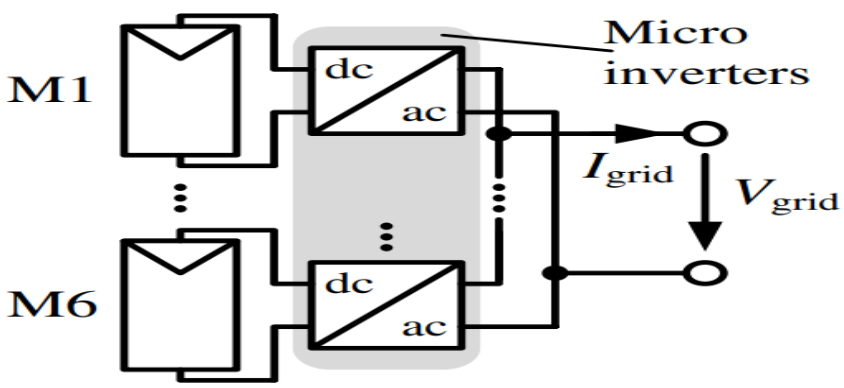


Figure I.25: Schematic of Micro Inverter

I.4.2.DC-DC converters:

Because the voltage generated by photovoltaic (PV) itself varies with the intensity of sunlight received by the surface of the solar panel, a circuit such as an inverter is required. These inverters are used to regulate the output voltage of solar panels. They work by increasing or decreasing voltage to meet load requirements.[33]

It has several types, the most important of which are as follows:

I.4.2.1. DC-DC Boost Converter:

Figure 1 shows the basic schematic of a DC-DC boost converter circuit consisting of a power switch (M), diode (D), inductor (L), capacitor (C), switch and load control unit (R). This structure can be used as an interface between the low PV array voltage and the high input voltage of a battery pack or any DC load. A DC-DC boost converter boosts the output voltage to be greater than the input voltage.[34]

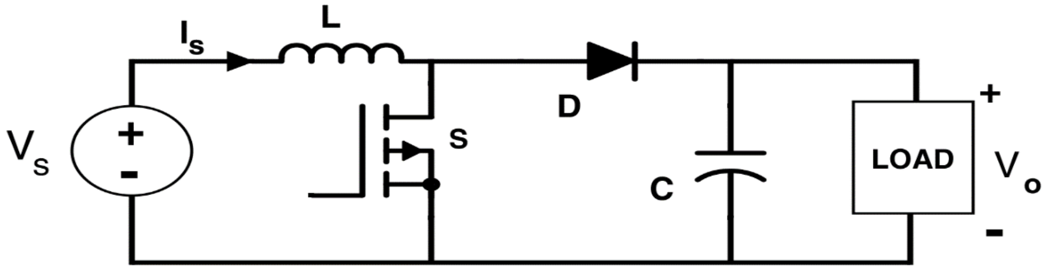


Figure I.26: Boost converter circuit diagram.[34]

I.4.2.2. DC-DC Buck Converters:

A buck converter, also called a step-down converter, is a type of DC-to-DC power converter. It reduces the input voltage while increasing the current before delivering power to the load. This converter falls under the category of switched-mode power supply (SMPS), specifically class 81. Typically, it contains at least two semiconductors and one energy storage element, which could be a capacitor, an inductor, or a combination of both.

Filters are commonly integrated into the output (load-side filter) and input (supply-side filter) of converters, typically utilizing capacitors in conjunction with inductors, to minimize voltage ripple. [34]

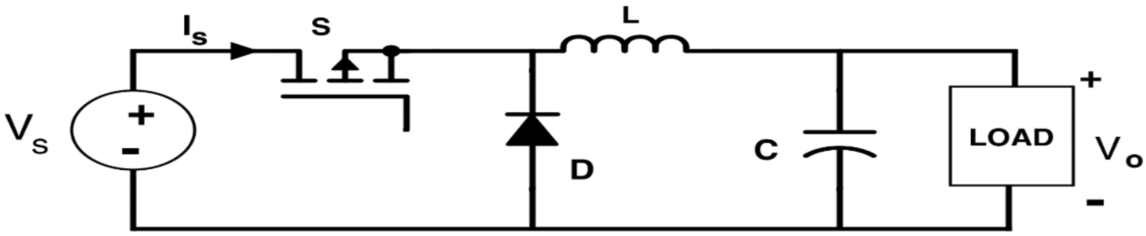


Figure I.27: Buck converter circuit diagram.[34]

I.4.2.3. DC-DC Buck-Boost Converters:

A Buck-Boost converter is an innovative switched mode power supply that merges the Buck Converter and the Boost converter in one circuit. It has the capability to produce regulated DC output voltage from AC or DC input sources, akin to other SMPS designs.[34]

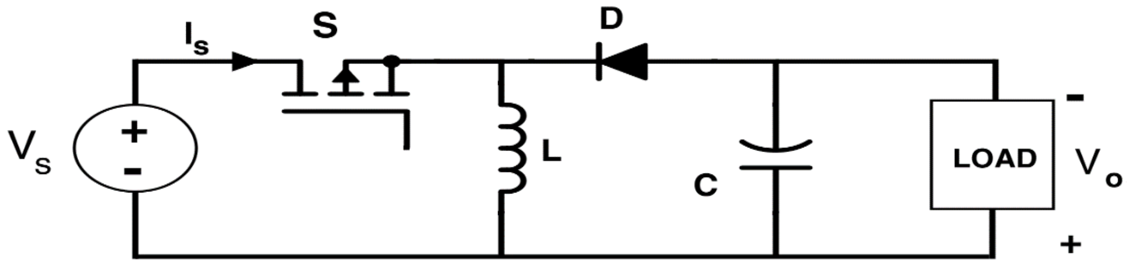


Figure I.28: Buck-Boost converter circuit diagram.[34]

I.4.3. Their Role in Solar Panel:

I.4.3.1. DC-DC Boost Converter:

The primary role behind a boost transformer is that the inductor resists current fluctuations by creating and dissipating a magnetic field. This results in the output voltage being consistently higher than the input voltage. The inductor stores energy by generating a magnetic field as current flows through it in a clockwise direction when the switch is closed, the left side of the inductor carrying a positive charge. When the switch is opened, the flow of current is obstructed, which reduces the impedance. To maintain current towards the load, the inductor destroys the previously created magnetic field.

The polarity reversal - denoted by the negative charge - will occur on the left side of the inductor. This will create a series connection between two sources, which will increase the voltage charging the capacitor across diode D. [34]

I.4.3.2. DC-DC Buck-Boost Converters:

The DC-DC Buck-Boost Converter is a cascade combination of two base converters that are buck and boost DC-DC converters. The output of this converter can be controlled by changing its duty cycle D. When the duty cycle is less than 50%, the converter works in buck mode and the output voltage is lower than the input voltage. When the duty cycle is more than 50%, the inverter runs in boost mode and the output voltage is higher than the input voltage.

The design parameters to consider when designing this converter are the operating frequency of the inductor, the maximum current and voltage that the inductor can withstand,

and the gate drive circuitry to generate signals PWM switch to enable the control switch diet.[34]

a. Modes of Buck Boost Converters:

There are two different modes of operation of the buck-boost converter. Here are two different types of buck-boost converters.

- Continuos conduction mode.
- Discontinuons conduction mode.

❖ **continuous conduction mode:**

In continuous conduction mode, the end-to-end inductor current never falls to zero. Therefore, the inductor partially discharges before the commutation cycle.

❖ **Discontinuous conduction mode.**

In this mode, the current through the inductor drops to zero. Therefore, the inductor fully discharges at the end of the switching cycles.

b. Applications of Buck boost Converter:

Used in self-regulating power supplies.

- It has consumer electronics.
- Used in battery powered systems.
- Power amplifier applications.

I.4.3.3. DC-DC Buck Converters:

The essential part is the inductor, which alternates between load (reducing the voltage, supplied by the generator, available for the downstream circuit) and source (supplying a voltage when the generator is switched off). Operation can be divided into two phases depending on the state of switch S. [34]

- The switch S is closed. The current supplied by the generator, initially zero, increases linearly and crosses the inductance. The inductance opposes this increase in current, producing an opposite voltage, and it stores the energy received in magnetic form. the voltage across the inductance terminals is $V=Vi-Vo$. Since the diode is reverse-biased with the voltage Vi of generator, no current passes through it. (The voltage across the inductance is $V_L= Vo$)
- The switch is open. The generator is switched off, no more current flows through it. The diode becomes conducting in order to ensure the continuity of the current in the inductor. The current through the inductor decreases. The

inductor opposes this reduction in current, producing a voltage which puts it in a situation of source for the downstream circuit, by using the magnetic energy stored in the phase.

I.4.3.4. DC-AC inverters:

The DC/AC inverter plays a crucial role in a solar panel system by converting the direct current (DC) electrical energy produced by the solar panel into alternating current (AC) electrical energy that can be used to power electrical devices. While solar panels generate DC power, most household and industrial appliances require AC power. Overall, the DC/AC inverter is a critical component of a solar panel system, enabling the use of solar energy to power a broad range of electrical devices.

I.5 Transistor Driving Techniques in Electronic Converters:

Transistor driving techniques are crucial in electronic converters, particularly in DC-DC and DC-AC inverters used in solar panel systems. Transistors, such as MOSFETs and IGBTs, are the fundamental building blocks of power electronics, and their switching behavior directly affects the efficiency and performance of the electronic converter.

The main function of transistors in electronic converters is to switch the DC power from the solar panels on and off rapidly, which allows the conversion of the DC power to the required voltage and frequency for AC power. The switching frequency of the transistors plays a critical role in the efficiency of the electronic converter. Higher switching frequency reduces the size of the components required for the electronic converter, but it also increases switching losses and reduces the overall efficiency of the system. Lower switching frequency reduces switching losses but requires larger and more expensive components.[35]

To optimize the efficiency of electronic converters, different transistor driving techniques can be employed. These techniques include:

I.5.1.Ground Referenced Drive :

I.5.1.1. PWM Direct Drive

In power applications, the easiest way to control the gate of the master switching transistor is to use the PWM output to drive the gate as shown in Figure 8.

This distance introduces parasitic inductance due to the loop created by the gate drive paths and ground, which can slow the switching speed and cause oscillations in the gate drive waveform. To reduce the inductance associated with the gate drive connection, a wider PCB path is desirable.[36]

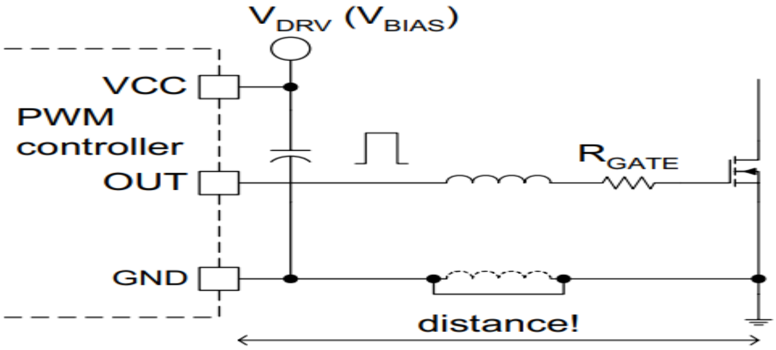


Figure I.29:Direct Gate-Drive Circuit.[36]

I.5.1.2.Bipolar Totem-Pole Drive:

One of the most popular and inexpensive driver circuits for driving MOSFETs is the bipolar motor, which is a motorless drive as shown in Figure 9. Like all outboard motors, this circuit handles current spikes and power losses, making the PWM controller more conducive. It can be placed right next to the MOSFET with the LED. In this way, the high current transients of the gate motor are localized in a very small loop area, reducing the value of the parasitic inductances. [36]

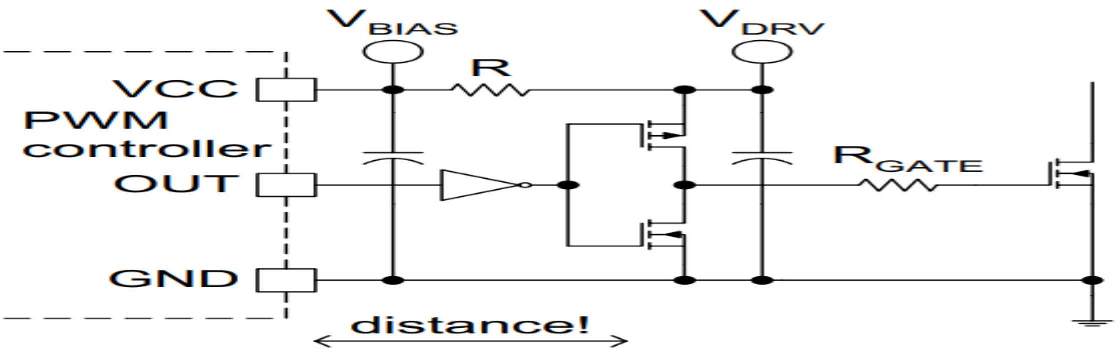


Figure I.30:Bipolar Totem-Pole MOSFET Driver.[36]

I.5.2 Synchronous Rectifier Drive:

The MOSFET synchronous rectifier is a special case of single-ended switches. These devices are the same N-channel MOSFETs used in traditional applications, but are used in low-voltage power outputs instead of rectifier diodes. Ideally, both switches turn on and off at the same time to prevent the QSR body diode MOSFET from turning on. Therefore, in most cases, a short period - 20 ns to 80 ns - of body Diode conduction precedes turn-on and follows turn-off of the synchronous MOSFET switch as shown in Figure I.31.[36]

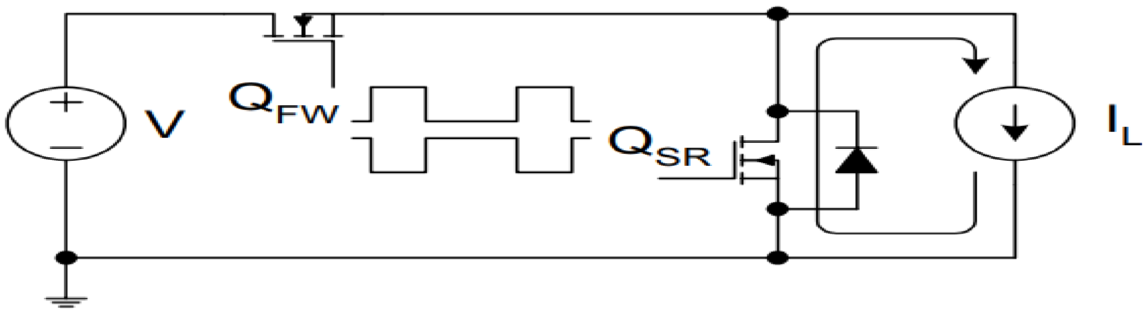


Figure I.31: Synchronous Rectification MOSFET Driver.[36]

I.5.3 High-Side Non-Isolated:

High-side non-isolated gate drive circuits can be classified by the device type they are driving or by the type of drive circuit involved. [36] Accordingly, they are differentiated whether P-channel or N-channel devices are used or whether they implement direct drive, level shifted drive, or bootstrap technique:

- Efficiency.
- Speed limitations.
- Maximum duty-cycle limit.
- dv/dt implications.

I.5.3.1 High-Side Drivers for P-Channel Devices:

In this circuit set, the source of the P-channel MOSFET switch is connected to the positive input rail. High-side P-channel drivers do not need to oscillate between large potential differences based on switching frequency, but they do need to operate over the entire input voltage range. In addition, the driver is referenced to AC ground potential due to the low AC impedance of the input voltage source.[36]

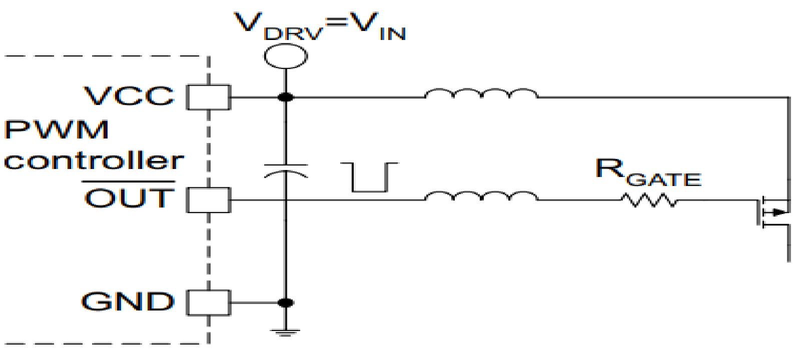


Figure I.32: Direct Drive for P-Channel MOSFET.[36]

I.5.4 Bootstrap Gate Drive Technique:

This method uses a gate driver and an associated bias circuit, both of which are referenced to the main MOSFET transistor source, however, the driver and its float bias can be implemented by the LV circuit elements since the input voltage is never applied across their components. The driver and bias circuit oscillate between the input voltage rails with a source. Which must tolerate high voltage difference and large capacitive shunt currents between the floating high side and the grounded low side circuits.[36]

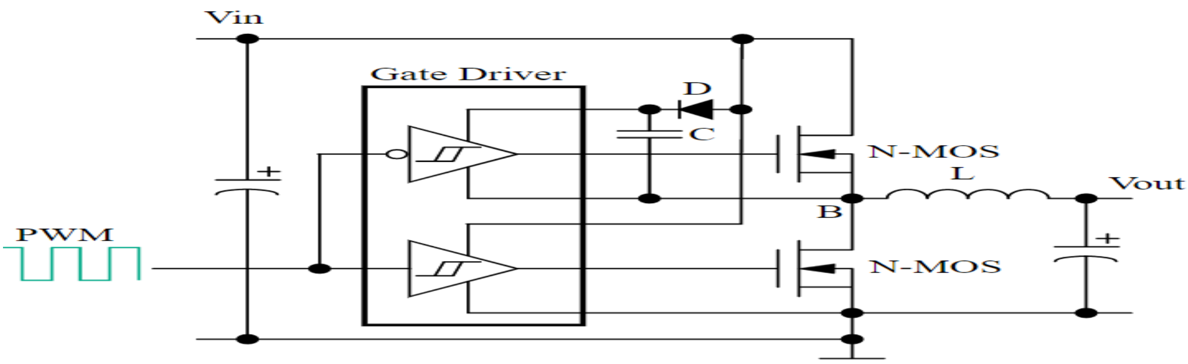


Figure I.33: bootstrap circuit for the upper switching MOSFET of a switch mode half bridge.[36]

I.5.5 Transformer-Coupled Gate Drives:

The integrated high side drivers are convenient, use smaller circuit board area but have significant turn-on and turn-off delays. The properly designed transformer coupled solution has negligible delays and it can operate across higher potential differences. Usually, it takes more components and requires the design of a transformer or at least the understanding of its operation and specification.

Before concentrating on the gate drive circuits, some common issues pertinent to all transformer designs and their correlation to gate drive transformers will be reviewed.[36]

- A significant portion of the switching period might be reserved to reset the core of the main power transformer in single ended applications, (working only in the first quadrant of the B-H plane) such as the forward converter.
- The transformer design must provide a secondary overvoltage product under all operating conditions, which must take into account the worst-case transients at maximum duty cycle while at maximum input voltage.

- Faraday's law requires that the average voltage across the transformer winding is zero for some time. Even a small DC component can cause the flux to "wander" and eventually saturate the core. This principle will have significant implications for the design of transformer-coupled gate drivers driven by single-ended PWM circuits.

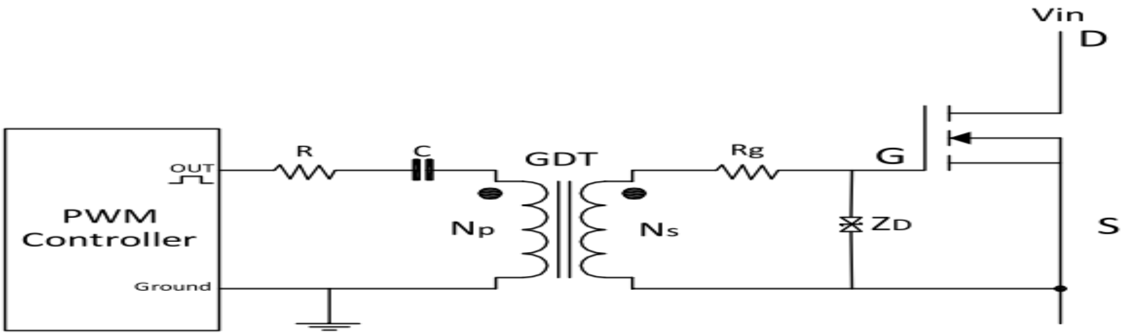


Figure I.34: Transformer insulated gate drive circuit diagram.[36]

The choice of transistor driving technique depends on the specific requirements of the solar panel system, such as the power rating, voltage and frequency requirements, and cost constraints. By optimizing the transistor driving technique, the efficiency and performance of the electronic inverter can be improved, leading to a more efficient and reliable solar panel system.

I.6.General Measurement of PV Solar:

Measurement is a process that provides quantitative information about the relationship between a measurable quantity and a unit of the same nature. Measuring devices, such as voltmeters, ohmmeters, are used to measure voltage, current, and resistance in circuits. Solar panel measuring instruments, including solar radiation detectors and thermal cameras, are essential to accurately measure the efficiency of solar panels in converting solar energy into electricity.[16] These tools help determine optimal operating temperatures, radiation levels, and absorption efficiencies. With these tools, it is possible to improve the performance of solar panels and increase their efficiency in converting solar energy into electricity. Among the most important measuring devices, we mention the following:

I.6.1.Multi-meter:

A multimeter is an electronic measuring tool that can be used to measure various electrical properties in measuring solar panels, including voltage, current, and resistance. There are two types of multimeters: analog and digital, with digital multimeters being used more commonly due to their improved accuracy and ease of use. By using a multimeter to measure these electrical characteristics, engineers and technicians can troubleshoot problems with a solar panel system and identify areas that require maintenance or repairs to improve its performance and efficiency.[38]

Figure I.35: Features of Analogue and Digital Multimeters

I.6.2.Voltmeter:

he voltmeter is an essential tool for measurement, control and troubleshooting. The voltmeter is placed in parallel (or in shunt) across the terminals of a source, a receiver or the part of the circuit to be studied, used for measuring the voltage or potential difference between two points in an electrical circuit. It works by connecting the two probes of the voltmeter to the points being measured. The potential difference between these points is then measured and displayed on the voltmeter's screen. Voltmeters can be either analog or digital, with digital voltmeters being more accurate and precise. [39]

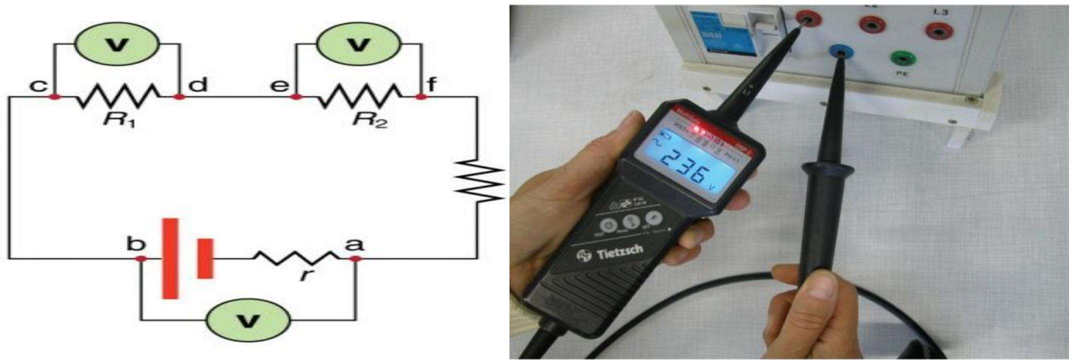


Figure I.36: Measure potential differences in this series circuit and digital voltmeter in use

I.6.3. Watt-meter:

A wattmeter is a device used to measure the electrical power output of a circuit. It works by measuring both the voltage and current of the circuit and calculating the power by multiplying the two values together. In a solar panel system, a wattmeter can be used to measure the power output of the solar panels and determine the maximum power point of the system. This information can be used to optimize the design and performance of the solar panel system for maximum efficiency in converting solar energy into electricity.[39]

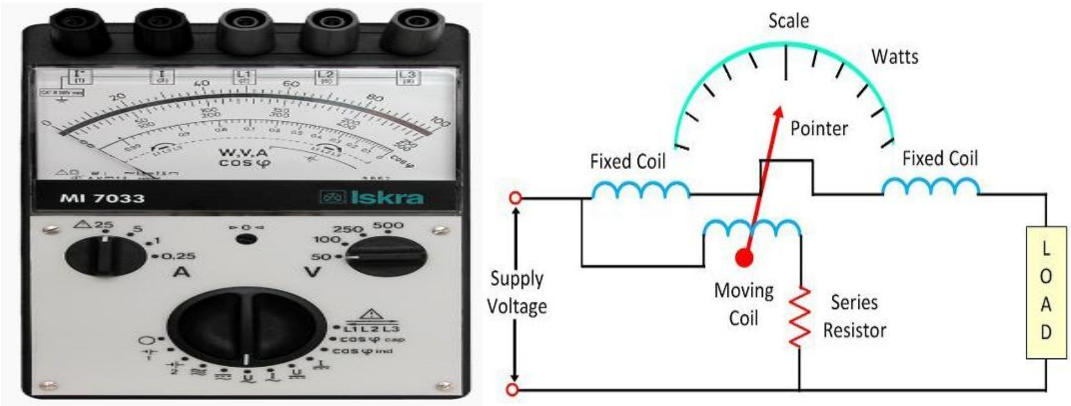


Figure I.37: Dynamometer type Wattmeter

I.6.4. Current test SET:

A current test set is a device that is used to test and measure the performance of protective relays and current transformers in power systems. It does this by generating a controlled and precise current in the circuit, simulating the actual operating conditions of the protective relays and current transformers. The current test set consists of a high-precision current source, a digital meter for measuring the generated current, and a control panel for adjusting the current output. The accuracy and proper functioning of protective relays and current transformers are critical for maintaining the reliability and safety of the power system, and the current test set is an important tool for testing and maintaining their performance.[39]

Figure I.38: Current Injection Test

I.6.5. Radio-meter:

A radiometer is a device that measures solar radiation by absorbing it at its sensor and converting it into heat. The amount of heat generated is measured to determine the level of solar radiation. Different methods may be used to measure the heat, including temperature change or thermoelectric measurements. The most commonly used radiometers are pyrheliometers and pyranometers, which measure direct and global solar radiation, respectively. Other types of radiometers are also available for measuring diffuse sky radiation and net radiation. Radiometers are essential tools used in various fields, including meteorology, agriculture, and solar energy.[40]

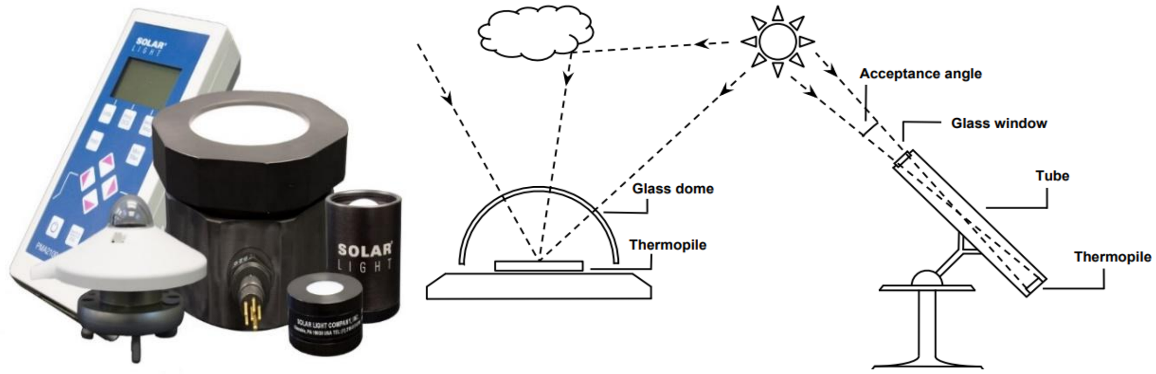


Figure I.39: A schematic illustration of a pyranometer and a pyrheliometer.[41]

I.6.6. Thermal camera:

A thermal camera is a device that captures infrared radiation and converts it into visible images, allowing it to measure temperature variations across a surface. In solar energy systems, thermal cameras can be used to monitor and inspect solar panels by detecting hotspots caused by defects or malfunctions in individual cells or groups of cells. By detecting and addressing hotspots early, thermal cameras can help improve the overall efficiency and lifespan of the solar panel.[42]

Figure I.40:Experimental setup at rooftop.[43]

I.7 Conclusion:

In conclusion, this chapter provides a brief overview of the importance of renewable energy in the modern world, with a focus on solar energy and the critical role of solar panels in harnessing this energy. By examining the importance of maintaining electrical quality and conformity, understanding the different types of electronic converters, exploring transistor driving techniques, and discussing the specialized tools used to measure solar panel efficiency, we gain a deeper understanding of how to optimize solar energy systems. The references cited in this chapter offer readers a wealth of additional information on this important topic.

Chapter II

The Role of Converters in Extracting Data from Solar Panels

II.1. Introduction

The utilization of solar energy has gained significant attention in recent years due to its abundant availability and environmental benefits. Solar photovoltaic (PV) systems play a crucial role in harnessing solar energy for various applications. Understanding the characteristics of solar panels and employing efficient DC/DC converters are vital for optimizing the performance and power extraction from PV systems. This chapter provides an overview of solar panel characteristics and discusses different types of DC/DC converters used in PV systems. Furthermore, it explores maximum power point tracking (MPPT) techniques for solar PV and presents a proposed technique for extracting data from PV solar using a DC/DC converter. Additionally, solar PV modeling and simulation techniques are introduced to facilitate accurate data extraction.

II.2. Overview of Solar Panel Characteristics:

The electrical characteristics of a photovoltaic array are summarised in the relationship between the output current and voltage. The amount and intensity of solar insolation (solar irradiance) controls the amount of output current (I), and the operating temperature of the solar cells affects the output voltage (V) of the PV array. Solar cell I-V characteristic curves that summarise the relationship between the current and voltage are generally provided by the panels manufacturer and are given as: [44]

II.2.1.Characteristics of solar panels:

- **V_{OC} (open-circuit voltage):** The open-circuit voltage (V_{OC}) is the maximum voltage that can be obtained from a photovoltaic (PV) module or array when there is no load connected to it. This value is typically higher than the maximum power point voltage (V_{mp}) of the array, which is the voltage at which the array operates most efficiently. The VOC depends on the number of PV panels connected together in series and should not exceed the maximum voltage rating of the inverter or charge controller to prevent damage to the system [44].
- **I_{SC} (short-circuit current):** The short-circuit current (I_{SC}) is the highest current that can be obtained from a photovoltaic (PV) array when the output connectors are directly shorted together. This value is generally higher than the current at which the array operates at its maximum power output (I_{mp}) under normal operating conditions. ISC is an important parameter for sizing electrical components but short-circuiting a PV array can be dangerous and should only be attempted by qualified personnel using appropriate safety measures [44].

- **MPP (maximum power point)** : The maximum power point (MPP) is the point where a photovoltaic (PV) array supplies the maximum power to the connected load, determined by the product of Imp and Vmp. It is typically measured in Watts or peak Watts and is important for optimizing the performance of a PV system. The MPP can vary depending on the amount of sunlight and temperature, and can be affected by shading or soiling of the PV array [44].
- **FF (fill factor):** The fill factor (FF) of a photovoltaic (PV) array is the ratio of the maximum power output under normal operating conditions to the product of VOC and ISC. FF is an important indicator of the efficiency of a PV array, with values closer to 1 indicating higher efficiency. Typical values range from 0.7 to 0.8 and can be affected by factors such as temperature, shading, and soiling. Proper system design and maintenance can optimize FF [44].
- **Percent efficiency:** The percent efficiency (%eff) of a photovoltaic (PV) array is the ratio between the maximum electrical power output of the array and the amount of solar irradiance it receives. The efficiency of a typical solar array is usually low, around 10-12%, and varies depending on the type of photovoltaic cell used, such as monocrystalline, polycrystalline, amorphous, or thin film [44].

II.2.2 The effect of temperature on the characteristics of solar panels:

The effect of temperature on solar panel characteristics is significant, as higher temperatures can reduce their efficiency and output. The electrical properties of solar panels, such as open-circuit voltage and short-circuit current, are negatively affected by temperature increases. Reference [45] highlights the inverse relationship between temperature and solar panel efficiency. Efficient cooling systems and proper heat sink properties are essential to manage panel temperature and prevent performance degradation. Temperature variations also impact the output performance of solar panels, as examined in reference [46, 47], which investigates the electrical characteristics under different temperature conditions. Understanding the effects of temperature on solar panels helps optimize their efficiency and power generation capabilities.

II.2.3 The effect of radiation on the characteristics of solar panels:

The effect of radiation on the characteristics of solar panels is an important consideration for analyzing their performance and efficiency. Solar panels convert sunlight, a form of radiation, into usable electrical energy through photovoltaic processes. Factors such as radiation intensity, spectrum, and angle of incidence directly impact the performance and output of solar panels. Understanding these effects is crucial for optimizing the design and operation of solar panels. References [48], [49], and [50] provide valuable insights into the influence of radiation on different parameters of solar cells and offer information on factors affecting their performance. By studying the impact of radiation, researchers and engineers can enhance the efficiency and functionality of solar panels, leading to improved energy generation.

II.3. Types of DC/DC Converters used for PV system:

Power converters are essential for maximizing the power output of solar panels because they allow for the efficient transfer of energy from the panels to the load. Solar panels generate direct current (DC) electricity, which is not suitable for most commercial and residential applications that require alternating current (AC) power.

Power converters, such as boost converters, are used to transform the DC output from the solar panels into AC power that can be used by the load. Boost converters step up the voltage of the DC output to match the voltage of the load, and they can also regulate the current to ensure that the load receives a steady stream of power.

In addition to transforming the DC output into AC power, power converters also help to maximize the power output of the solar panels by adapting the output to meet the requirements of the load. This can include adjusting the voltage and current levels of the output to match the needs of the load, as well as optimizing the overall efficiency of the system to ensure that the maximum amount of power is being generated.

Overall, power converters play a crucial role in maximizing the power output of solar panels and ensuring that the generated energy is efficiently transferred to the load [51,52,53,54].

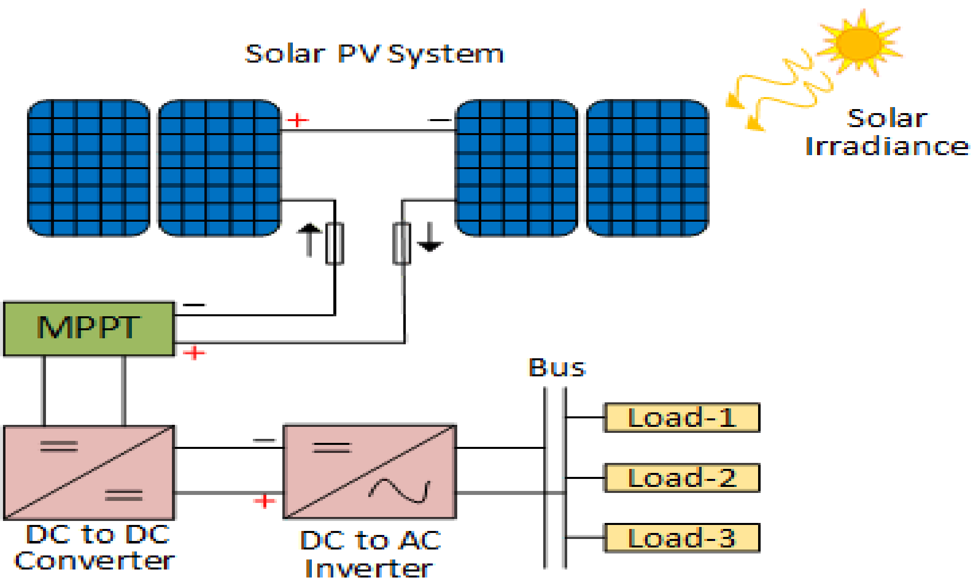


Figure II.1 Solar PV System with MPPT [55]

II.3.1. Boost Converter:

High step up DC converters, such as the boost converter, are commonly used in applications where a fixed DC voltage needs to be generated from a variable DC voltage source. The main advantage of high step up converters is their ability to generate a much higher output voltage than the input voltage, using a single power semiconductor switch. However, during high step up operation, the current ripple in the power devices can be larger, causing conduction loss and turning off the current. This can reduce the efficiency of the converter. To address this issue, researchers have proposed using a coupled inductor and switched capacitor in the boost converter. This can help to reduce the current ripple, improve efficiency and provide a more stable output voltage. Overall, the choice of DC converter depends on the specific application requirements, such as input and output voltage ranges, load current, and efficiency [56].

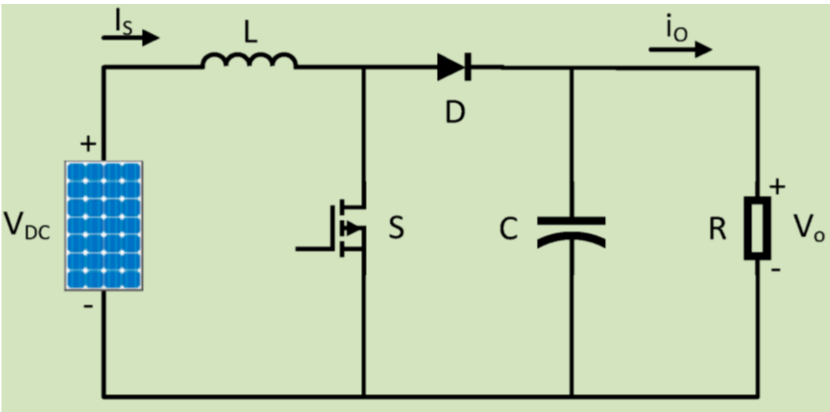


Figure II.2: Boost Converter for PV Application. [57]

II.3.2. Buck Converter:

The DC-DC buck converter is a popular converter topology used in various solar PV applications such as standalone solar PV pumping systems, solar battery chargers, grid-connected MPPT tracking, and off-grid PV systems. The converter steps down the output voltage level to a level that is lower than the input voltage level, making it suitable for integrating higher module voltages to lower loads or batteries. The converter is especially useful in rural areas where water supply is limited, making it a crucial component in standalone solar PV pumping systems [57].

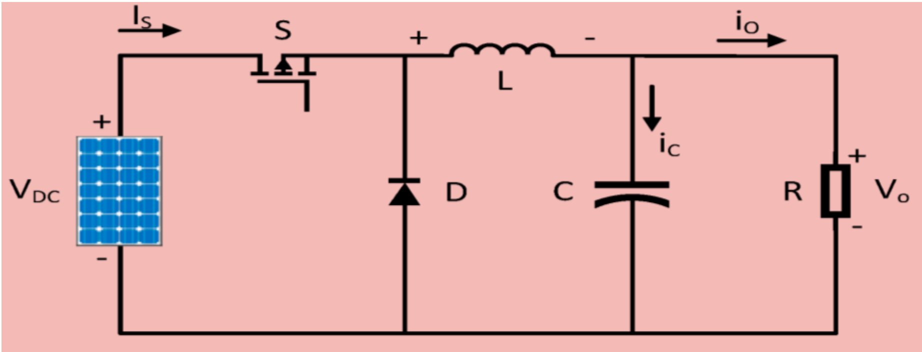


Figure II.3: Buck converter for the PV application [57].

II.3.3 Buck–Boost Converter:

The buck-boost converter combines the basic buck and boost converter topology and is used in various applications such as standalone/grid-connected PV systems and motor drives. Researchers are developing non-isolated DC-DC converter topologies like Cuk, SEPIC, and Luo converters to enhance voltage gain. Two-switch buck-boost converters are preferred as they have minimal voltage and current stress on operating components.

The converter can operate in two modes, PWM-controlled mode buck or boost, based on the instantaneous input voltage corresponding to the output voltage. The Perturb and Observe MPPT algorithm-based technique is used for optimal MPPT operation, and the proposed converter has high efficiency when operated with heavy load applications [57].

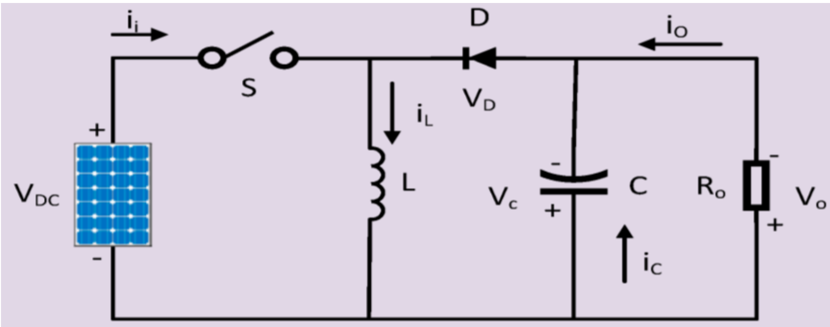


Figure II.4: Buck–Boost converter for PV application [57].

II.4. MPPT Techniques for PV solar:

II.4.1. Perturb and Observe (P&O) MPPT Techniques

In the P&O method, the controller periodically perturbs the operating point of the solar panel by incrementally increasing or decreasing the duty cycle of the converter. This causes a change in the power output of the panel, which is measured by the controller.

The controller then checks the sign of the voltage change (dV) resulting from the perturbation to determine whether the operating point has moved closer or farther away from the MPP. If the voltage change is positive, it means the operating point is on the left side of the MPP, so the controller adjusts the duty cycle in the opposite direction to move the operating point closer to the MPP. If the voltage change is negative, it means the operating point is on the right side of the MPP, so the controller adjusts the duty cycle in the same direction to move the operating point closer to the MPP.

The process is repeated several times until the controller detects that the power change (dP) resulting from the perturbations is zero, indicating that the operating point has reached the MPP. The frequency of perturbations made in one second is often referred to as the perturbation frequency or the MPPT frequency [58].

II.4.2. Hill Climbing (HC) Method:

HC also involves perturbing the converter's duty cycle to track the MPP of the solar panel. However, unlike P&O, HC perturbs the duty cycle directly rather than perturbing the terminal voltage.

In the HC method, the controller measures the power output of the solar panel and compares it to the previous power output. If the power output has increased, the controller adjusts the duty cycle in the same direction as the previous adjustment, since this indicates that the operating point is moving closer to the MPP. If the power output has decreased, the controller adjusts the duty cycle in the opposite direction, since this indicates that the operating point is moving away from the MPP.

The HC method can be seen as a more advanced version of the P&O method, as it has the ability to adjust the direction of duty cycle perturbations based on the previous power output. This can help to reduce oscillations around the MPP and improve the overall efficiency of the MPPT system. However, it can also be more complex to implement compared to the P&O method [58].

II.4.3. Constant Voltage (CV):

One advantage of the CV method is its simplicity, as it requires only the measurement of the array voltage and can be implemented using both analog and digital circuitry. However, it can be less effective than other MPPT methods, as it assumes a fixed voltage value for the MPP and does not take into account variations in temperature and irradiance that can affect the MPP voltage.

The relationship between the voltage at MPP (V_{mpp}) and V_{oc} can be expressed by the equation $V_{mpp}=k\times V_{oc}$, where k is a constant In the CV method, a fixed voltage value for the MPP is assumed based on the manufacturer's Standard Test Conditions (STCs), which is usually between 72% and 80% of the open-circuit voltage (V_{oc}) of the solar panel. This fixed voltage value is then used as a reference voltage to adjust the duty cycle of the MPPT converter via a feedback control loop. The controller measures the array voltage and compares it to the reference voltage, adjusting the duty cycle to maintain the voltage at the reference level.

Between 0.72 and 0.8. This equation is used to determine the reference voltage for the CV method [58].

II.4.4. Ripple Correlation Control (RCC):

To implement RCC, the derivatives of the varying PV power are correlated to those of the variable PV voltage or current. If the current or voltage increases while the power increases, the operating point is below the MPP. On the other hand, if the power falls and the current or voltage rises, the operating point rises above the MPP. The controller adjusts the duty cycle of the power converter to drive the power gradient to zero and reach the MPP.

One advantage of RCC is that it utilizes the existing current and voltage ripples in the system, rather than introducing any additional interference. This makes it a relatively simple and cost-effective MPPT technique to implement. However, it may not be as effective as other MPPT methods in certain operating conditions or with certain types of PV arrays [58].

II.4.5. Open Circuit Voltage (OCV) :

The Open Circuit Voltage (OCV) method assumes that the voltage at MPP is equal to the product of the Voc of the PV module and a constant coefficient, typically ranging from 0.7 to 0.8. This method is easy to implement because it has a simple procedure, but it has some drawbacks.

One major disadvantage of the OCV method is that it requires disconnecting the load each time Voc is measured. This can result in power supply interruptions and reduced system efficiency, making it unsuitable for applications where continuity of supply to the load is critical.

Additionally, the OCV method does not consider changes in environmental conditions, such as temperature and irradiance, which can cause the PV module's V_{oc} to vary. As a result, this method may not be accurate in all operating conditions and may not always track the true MPP. For these reasons, the OCV method is not commonly used in modern MPPT controllers [58].

II.4.6. Short Circuit Current (SCC):

This tracking method, similar to the OCV tracking method, is based on the observed linear relationship between the PV current at MPP and the short-circuit current. It makes use of a proportional constant K1 as shown in Equation (7), which is primarily determined by PV cell technology, meteorological circumstances, and the fill factor. For polycrystalline PV modules, the constant can be estimated to be approximately 0.85. In many cases, the constant is established by running a PV scan every few minutes. After obtaining it, the system uses the updated estimate until the next calculation is performed. The control flowchart is then

comparable to that of the OCV approach. As a result, this strategy has the same benefits and drawbacks as the OCV control method [58].

II.4.7. Adaptive Reference Voltage (ARV) :

The Adaptive Reference Control (ARC) method is similar to the Constant Voltage (CV) approach but takes into account the environmental conditions, such as temperature and solar radiation, to improve the accuracy of MPPT. ARC uses additional sensors to measure the temperature and solar radiation in addition to the PV voltage.

To implement ARC, the solar radiation is divided into several partitions based on a particular temperature, and the corresponding reference voltage is stored in an offline table. The proportional integral controller generates a duty cycle to control the converters by comparing the PV voltage and the reference voltage and using the error obtained. By using this approach, ARC can maintain its efficiency even under varying solar radiation conditions.

One advantage of ARC over the CV method is that it can provide more accurate tracking of the MPP by considering changes in the environmental conditions. However, ARC requires additional sensors and offline table storage, which can increase the system's complexity and cost [58].

II.4.8. Incremental Conductance (InC) :

Incremental Conductance (InC) is another conventional method used for tracking the maximum power from PV systems. The technique uses the current and voltage of the PV modules to find the MPP and can track the MPP with varying weather conditions. The equations governing this technique are detailed in Subudhi et al. Although more complicated compared to P&O, the implementation of InC is easier thanks to the advancement of DSPs (Digital Signal Processors) [58].

II.4.9. Look-Up Table Based (LTB) Method:

The LTB approach, or Look-Up Table approach, involves comparing current and voltage values of a PV array to pre-stored values in a database to find the MPP. The database contains information about different system conditions, such as temperature and insolation, and their corresponding MPPs for individual PV arrays. However, the approach requires a large amount of memory to store all the operational situations and is difficult to implement since it is array-specific. As tracking accuracy improves, additional data storage is needed, which can be inconvenient to save and archive [58].

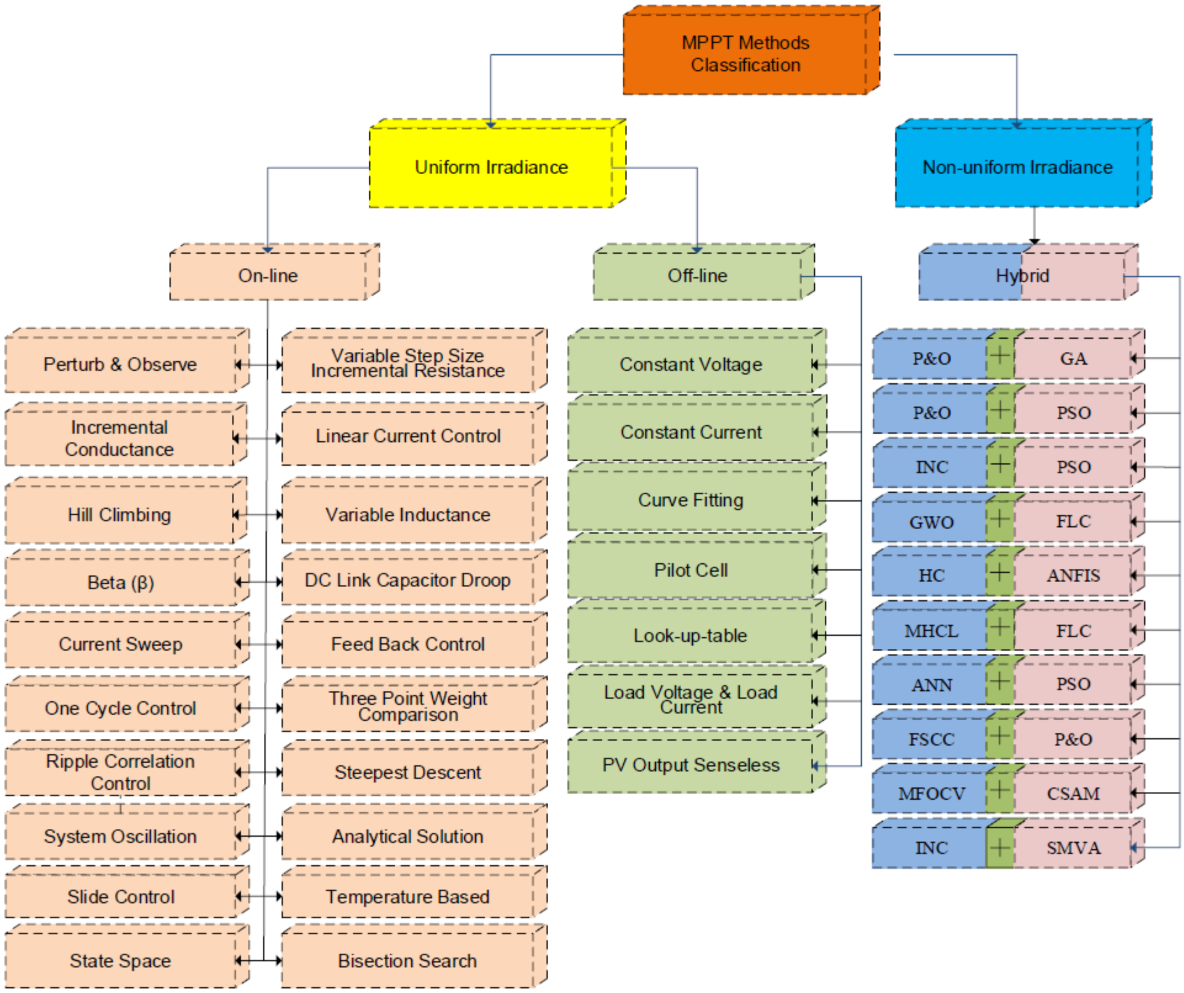


Figure II.5: MPPT Techniques Classification [59].

II.5. Proposed technique for extracting data of PV solar by DC/DC converter:

II.5.1. The importance of using converter for MPPT:

The use of a converter for MPPT in photovoltaic (PV) systems offers several advantages. First, it optimizes system efficiency by continuously adjusting the operating point to track the maximum power point (MPP) of the PV panel, maximizing energy extraction and minimizing losses. Second, the converter enables adaptation to varying load conditions by matching voltage and current between the PV panel and the load or storage system, ensuring efficient power transfer. Third, it overcomes voltage mismatch by stepping up or stepping down the voltage to match the required level, allowing for optimal power transfer. Fourth, the converter provides safety and protection features, such as over-voltage, over-current, and short-circuit protection. Finally, in grid- connected systems, the converter facilitates grid integration and energy management by converting DC power to AC and providing grid synchronization and power factor correction [60,61,62,63].

II.5.2. How the converter can used for photovoltaic:

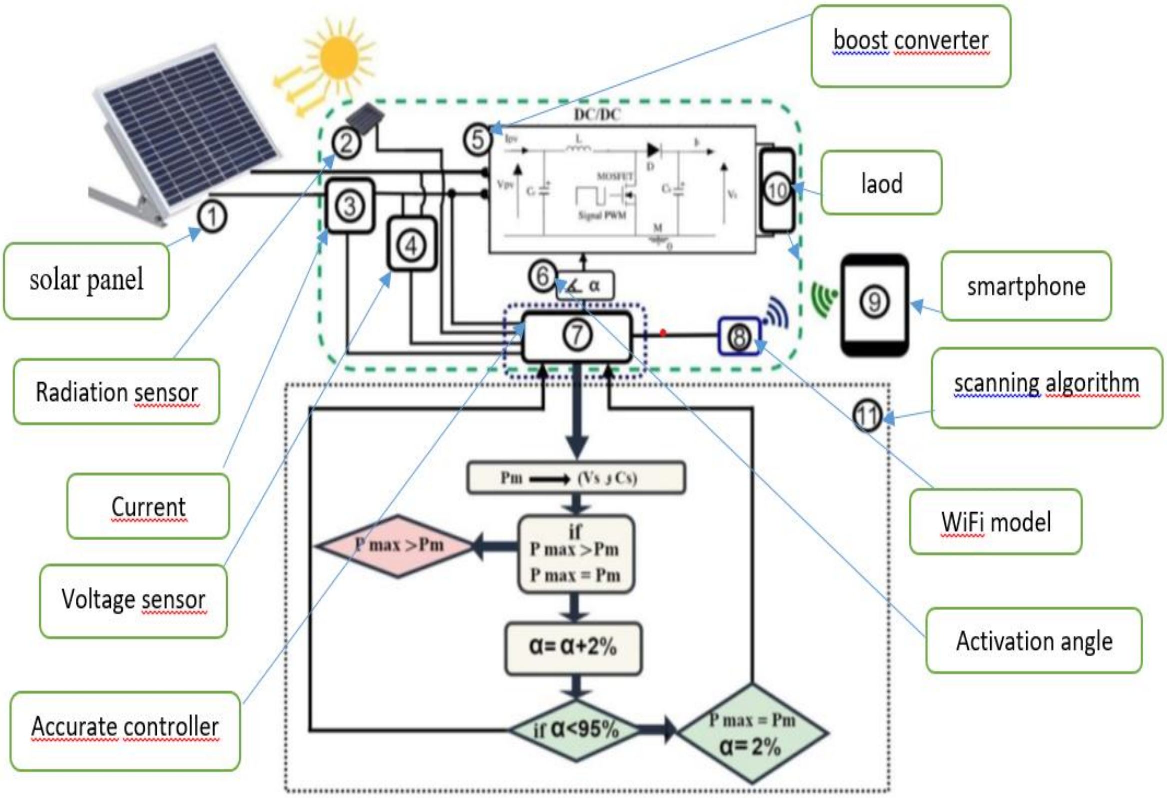


Figure II.6: proposed algorithm for extracting data

This invention depends on measuring the intensity of the current, the tension, and the brightness of the solar radiation, in order to obtain a set of conditions for changing the electrical load to cover all points related to the characteristics of the solar panel and this is done by relying on an electronic power transformer that converts the direct current into a variable continuous current, and also by changing the activation angle α using the microcontroller, this is done by an algorithm that depends on changing the angle α in a sequential manner to ensure that all points are cleared as shown in the figure (II.6).

Each transistor gate activation angle applied to the electronic transformer is received. Its own data is the current, tension, and intensity of solar radiation (by means of current, tension, and intensity of solar radiation sensors), after that the voltage for the open circuit and the current for the short circuit and the yield are calculated, then the results are displayed through an application installed in the smartphone that communicates with the device wirelessly.

In the proposed technique, the DC-DC converter plays a crucial role in extracting data from the solar panel. The duty cycle is the ratio of the ON time of the converter to the total period. By varying the duty cycle from 0 to 1, the converter can adjust the output voltage or current accordingly.

To collect data points covering the full range of solar panel characteristics, the duty cycle is systematically changed. The converter is controlled by the microcontroller, which implements an algorithm to sequentially adjust the activation angle α. This angle determines the duty cycle of the DC-DC converter.

By changing the duty cycle, the converter can sample different operating points of the solar panel. This allows for data collection across various conditions, such as different levels of solar radiation and varying electrical loads. The collected data, including the current, voltage, and intensity of solar radiation, is then used for calculations and analysis.

By covering the full range of duty cycles from 0 to 1, the proposed technique ensures that data points are obtained across the entire spectrum of the solar panel's characteristics. This comprehensive data collection enables a more accurate understanding of the solar panel's performance and allows for optimal adjustments to maximize its efficiency.

Overall, the use of a DC-DC converter with a varying duty cycle provides a flexible and effective method for data extraction in order to capture the full range of solar panel characteristics.

II.6. Modelling system PV solar for extracting Data:

II.6.1. PV Model and simulation:

The passage explains the basic functionality of a solar cell and the formation of a photovoltaic (PV) module by connecting solar cells in series and parallel configurations. The single diode solar cell model, which includes a diode, photocurrent generator, and two resistors, is used to represent a solar cell's behavior. The simplified circuit model of a solar panel is shown in Figure II.6 and includes a diode, photocurrent generator, series resistor, and parallel resistor. Multiple PV modules can be connected in series and parallel to create a solar PV array that generates clean and sustainable electricity. The simplified circuit model of a solar PV module is useful for understanding solar panel behavior and optimizing its performance.

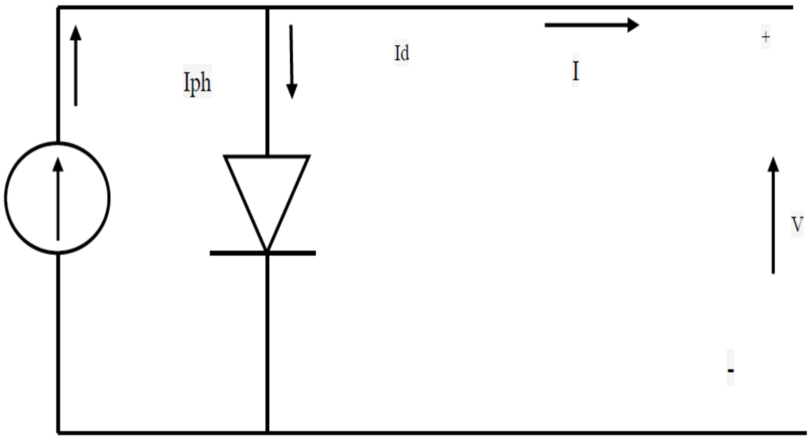


Figure II.7: Simplified equivalent circuit of PV panel.

An ideal solar cell generates current proportional to light intensity and irradiance, but this model does not consider some parameters that affect the PV device's output in practical situations. To address this, a more realistic model with series resistance (Rs) and parallel resistance (Rp) is used to create a circuit model for a solar PV cell. The modified single diode model in Figure II.9 shows the effect of Rs and Rp on the PV cell's efficiency. While the ideal model ignores Rs and Rp, it is not possible to do so in reality. Thus, the model in Figure II.7 is appropriate for practical situations.

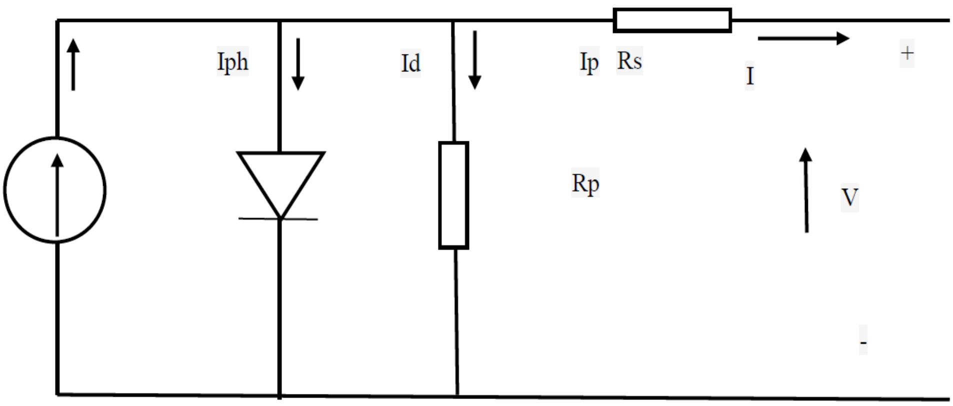


Figure II.8: Equivalent circuit of real model for PV panel

The solar PV device can be depicted as an ideal solar cell that has a current source (Iph) running in parallel to the diode. Equation (II-1) defines the output current of an ideal solar cell

$$I = Iph - I_d \qquad (II.1)$$

The fundamental mathematical equation that describes the I-V (current-voltage) characteristics of a PV solar cell is known as Shockley's diode current equation. This equation is derived from the principles of semiconductor physics and can be represented by Eq. (II.2).

$$I_d = I_s\left[\exp\left(\frac{qV_{oc}}{N_sKAT_o}\right) - 1\right] \quad (II.2)$$

To obtain the output current I of an ideal solar cell, one can substitute the value of Id (diode current) into equations (II-1) and (II-3).

$$I = Iph - I_s\left[\exp\left(\frac{qV_{oc}}{N_sKAT_o}\right) - 1\right] \quad (II.3)$$

In a solar photovoltaic system that employs a large number of PV modules, the impact of Rp (parallel resistance) becomes noticeable. Therefore, Rs (series resistance) is considered, and Rp is assumed to be infinite. Equation (2) for the diode current is then modified to become Equation (3) or (4), depending on the context.

$$I_d = I_s\left[\exp\left(\frac{q(V + IRs)}{N_sKAT_o}\right) - 1\right] \quad (II.4)$$

$$I = Iph - I_s\left[\exp\left(\frac{q(V + IRs)}{N_sKAT_o}\right) - 1\right] \quad (II.5)$$

If PV cells are connected in a series-parallel configuration, Equation (II-5) can be modified when calculating the output current I. The modified equation is represented by Equation (II-6).

$$I = Np * Iph - Np * Is\left[\exp\left(\frac{q(V + IRs)}{N_sKAT_o}\right) - 1\right] \quad (II.6)$$

$$Iph = [Isc + Ki(To - Tr)] * \frac{G}{Gref} \quad (II.7)$$

To model PV cells using the equations mentioned above, several parameters must be determined, depending on the type of PV module model employed. Bellini and colleagues (Bellini et al., 2009) proposed a model that requires the following parameters, as shown in Equations (II-8) and (II-9).

$$Irs = Isc/\left[\exp\left(\frac{qV_{oc}}{N_sKAT_o}\right) - 1\right] \quad (II.8)$$

$$Is = Irs[To/Tr]3exp\left[\left(\frac{qEg}{AK}\right)\left(\frac{1}{Tr} - \frac{1}{To}\right)\right] \quad (II.9)$$

Figure II.8 involves developing a temperature conversion model that can be utilized in the field. In solar PV systems, temperature is an input parameter measured in degrees Celsius.

However, for accurate mathematical modeling of PV systems, temperature data must be in Kelvin. Figure II.10 displays the steps involved in converting temperature data from Celsius to Kelvin. This converted temperature is then used in the mathematical modeling of PV systems, specifically as a subsystem in the PV model.

The figure labeled II.9 describes the creation of a product model for a PV module, which involves utilizing the NsKATo equations detailed in the previous section. Since the operating temperature is measured in Kelvin, a product model is necessary. The software tool Simulink is employed to compute and apply the NsKATo value, which is incorporated as a subsystem into the ultimate PV model. Figure II.11 displays the resulting product model, specifically the PV photocurrent model.

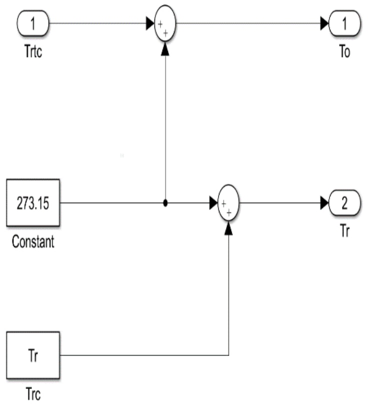


Figure II.9: Operating Temperature conversion

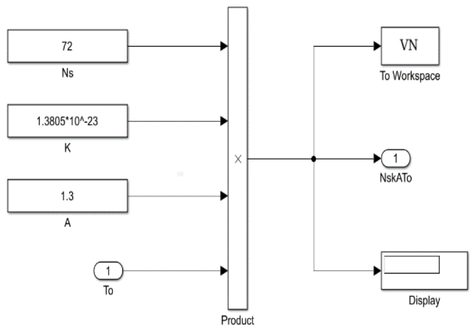


Figure II.10: Product model of NsKATo

The modeling of PV photocurrent is performed by building a subsystem using Eq. (II-7) in Simulink as part of the solar PV model. The photocurrent is affected by solar irradiation and temperature, with a linear relationship. The implementation of Iph in Simulink includes subsystems and environmental effects and takes solar irradiance (G) and temperature (To) as input parameters, as demonstrated in Figure II.10.

For the PV reverse saturation current model, Eq. (II-8) is utilized within Simulink to create the model, as shown in Figure II.11. Additionally, information regarding the manufacturing process is used to generate the model using sheet parameters.

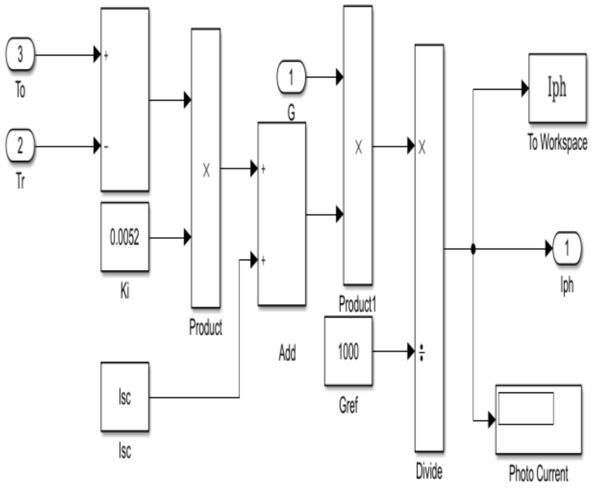


Figure II.11: Photo-current model

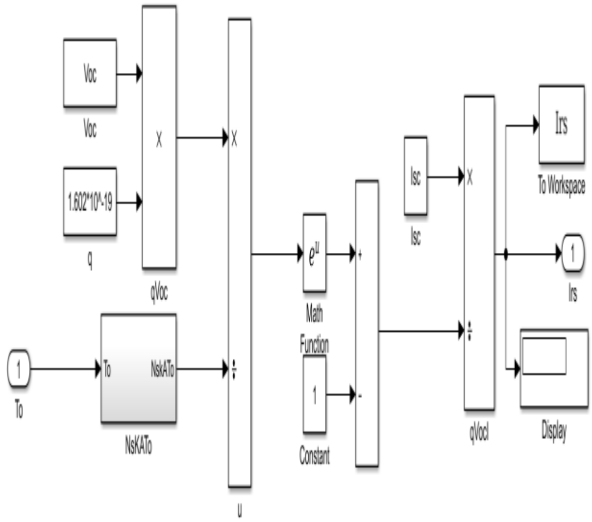


Figure II.12: Reverse saturation current model

Figure II.12 depicts the PV saturation current model using Eq. (II-9), which varies with the temperature of the solar cell. A Simulink model is created for the saturation current, using the energy bandgap, electron charge, reference temperature, and operating temperature of the module as input parameters, along with the reverse saturation current subsystem model depicted in Figure II.11. The simulation model shown in Figure II.14 is used to calculate the saturation current.

Figure II.13 shows the current PV output model, which is created in Simulink using Eq. (II-6), This Simulink model enables exploration of the relationship between the output current and voltage, which is influenced by irradiance and temperature.

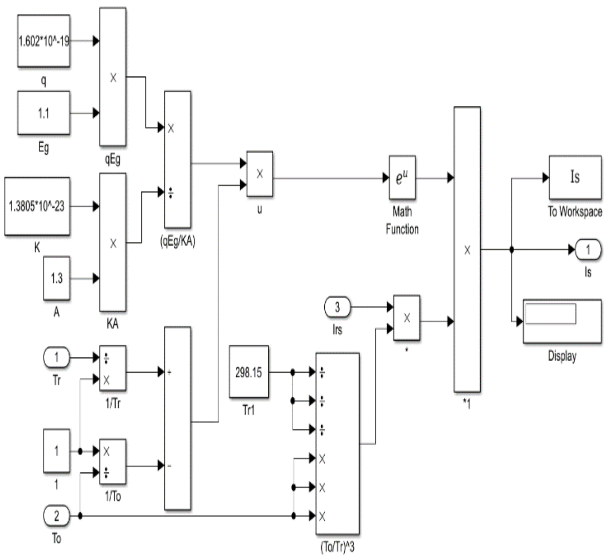


Figure II.13: saturation curent model

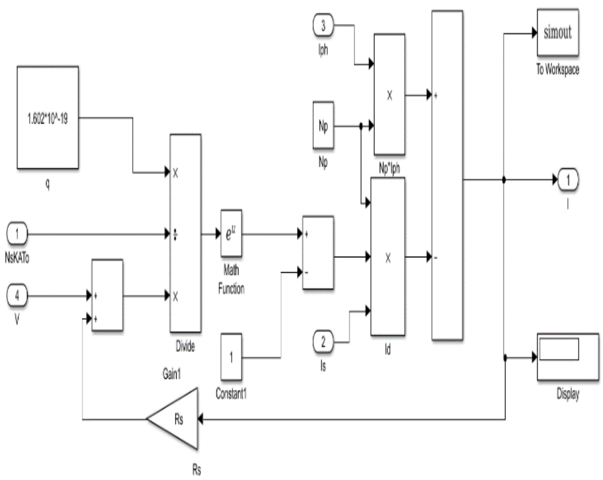


Figure II.14: PV output current model

Figure II.14 illustrates the complete subsystem model generated in Simulink, which involves linking together the steps 1 through 6 to establish a complete, connected model.

Figure II.15 displays the final PV module model, which is constructed using Simulink and takes irradiance (G) and temperature (T) as input parameters, while current (I) and voltage (V) are the output values.

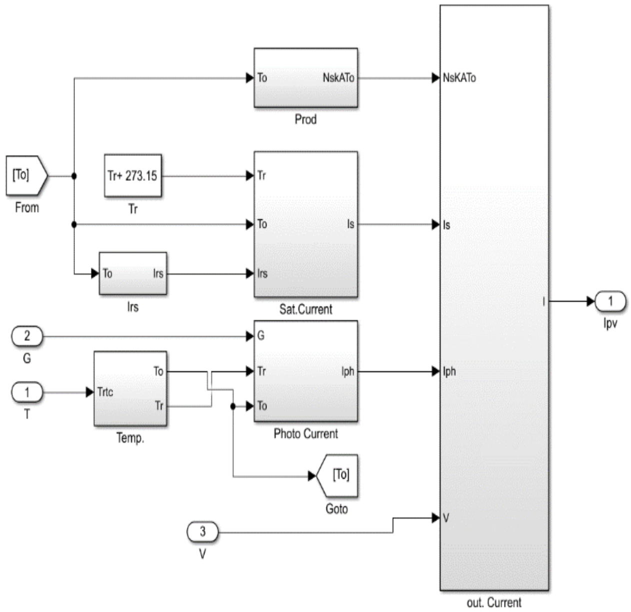


Figure II.15: Linkd model of subsystems

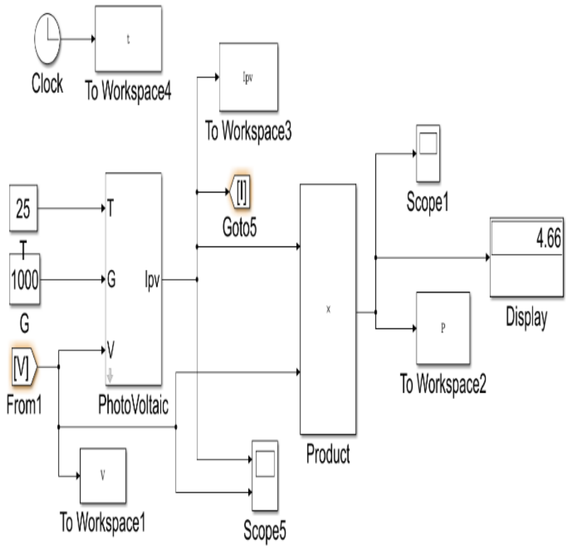


Figure II.16 PV module modelling in MATLAB/Simulink

II.6.2.Converter Model and Simualtion:

II.6.2.1. Boost converter:

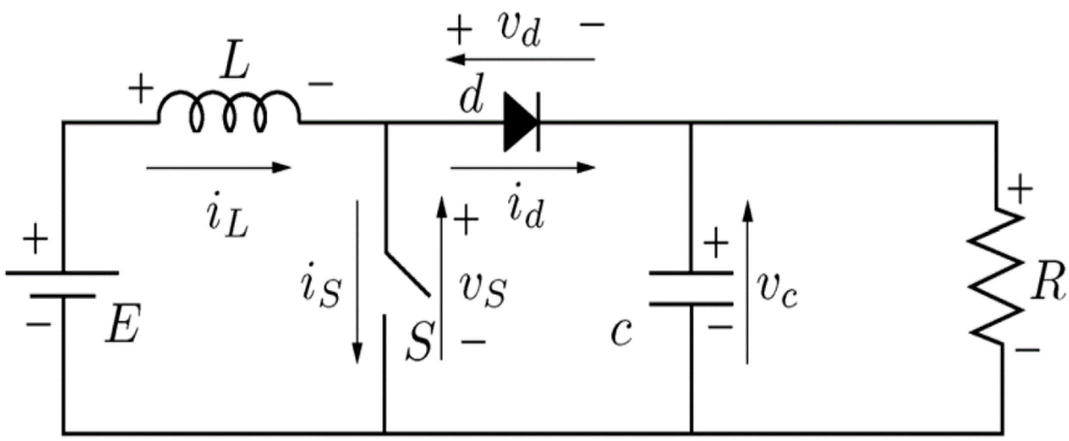


Figure II.17: Schematic representation of the DC-DC Boost converter [64].

$$\begin{cases} S=0 \\ d=1 \\ \frac{d}{dt}v_C=-\frac{1}{Rc}v_C+\frac{1}{c}i_L \\ \frac{d}{dt}i_L=-\frac{1}{L}v_C+\frac{E}{L} \end{cases} \qquad \begin{cases} S=1 \\ d=0 \\ \frac{d}{dt}v_C=-\frac{1}{Rc}v_C \\ \frac{d}{dt}i_L=+\frac{E}{L} \end{cases} \qquad (II.10,11)$$

$$\begin{cases} S=0 \\ d=0 \\ \frac{d}{dt}v_C=-\frac{1}{Rc}v_C \\ \frac{d}{dt}i_L=0 \end{cases} \qquad \begin{cases} S=1 \\ d=1 \\ \frac{d}{dt}v_C=0 \\ \frac{d}{dt}i_L=\frac{E}{L} \end{cases} \qquad (II.12,13)$$

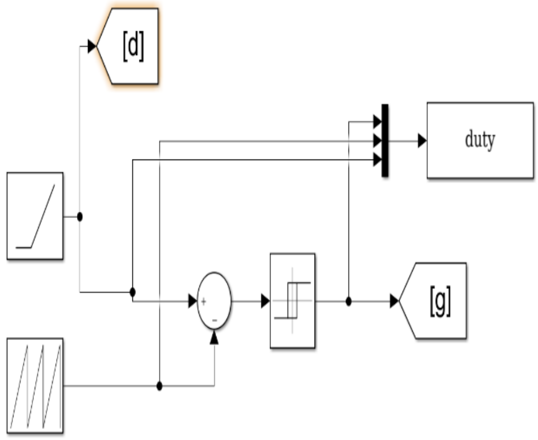


Figure II.18: Simulation of proposed methode for extacting PV data

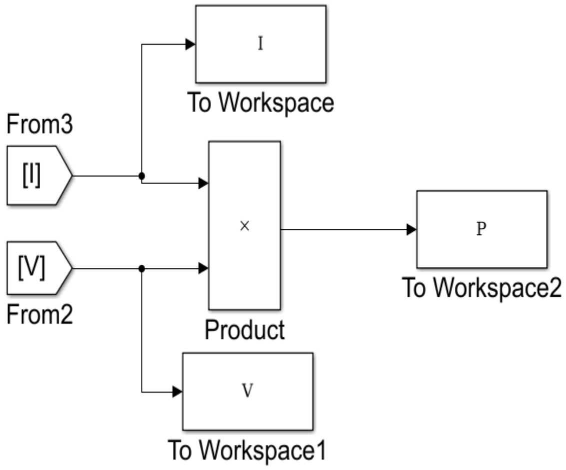


Figure II.19 Mesuring of power

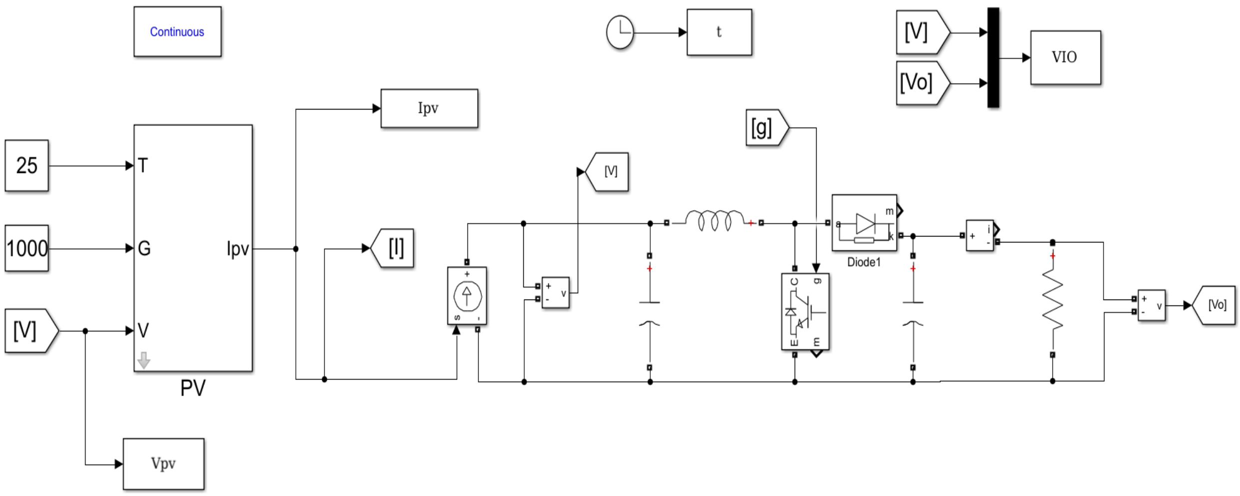


Figure II.20: Association of PV pannel with converter DC/DC boost

II.6.2.2. Buck-boost converter :

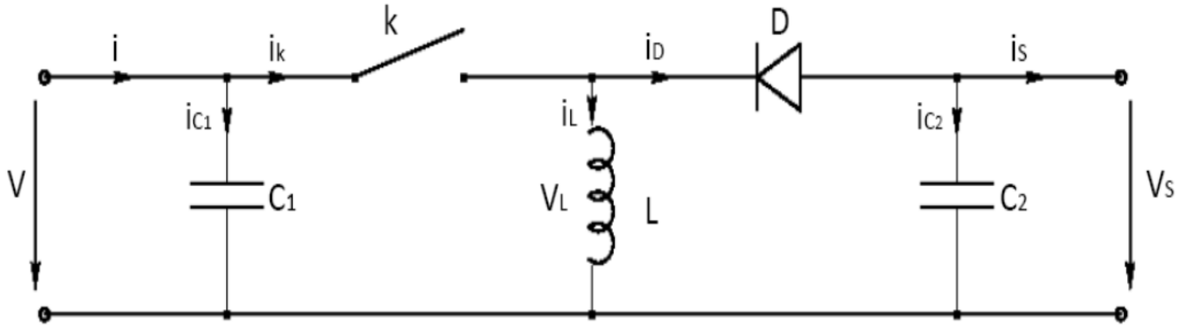


Figure II.21: Electrical circuit of a Buck-Boost converter [65].

$$i_L = \frac{1}{D}\left(i - c_1 \frac{dV}{dt}\right) \quad \text{(II. 14)}$$

Equation II. (14) is the “inductor current balance equation” or “inductor current equation” in the context of power electronics and transformer systems. It is commonly used in the analysis and design of switching transformers, such as buck transformers, boost transformers and other types of switching power supplies.

$$i_s = -(1 - D)i_L - c_2 \frac{dV_s}{dt} \quad \text{(II. 15)}$$

The equation II.(15) describes the relationship between the switch current and the inductor current, duty cycle, and the rate of change of switch voltage in a converter system operating in continuous conduction mode. It helps to characterize the behavior of the switch current and provides insights into the power dissipation, losses, and overall performance of the converter.

$$V = \frac{1}{D}\left(L \frac{di_L}{dt} - (1 - D)V_s\right) \quad \text{(II. 16)}$$

The equation II.(16) describes the relationship between the voltage across an inductor and a switch in a converter system operating in continuous conduction mode. It takes into account the inductance value, the rate of change of the inductor current, the duty cycle, and the voltage across the switch.

The equation II.(16) is commonly used in the analysis and design of switching converters to understand and control the voltage across the inductor during operation. By solving or analyzing this equation along with other relevant equations, it is possible to optimize the converter design, evaluate voltage stresses on the components, and determine suitable control parameters for efficient converter operation

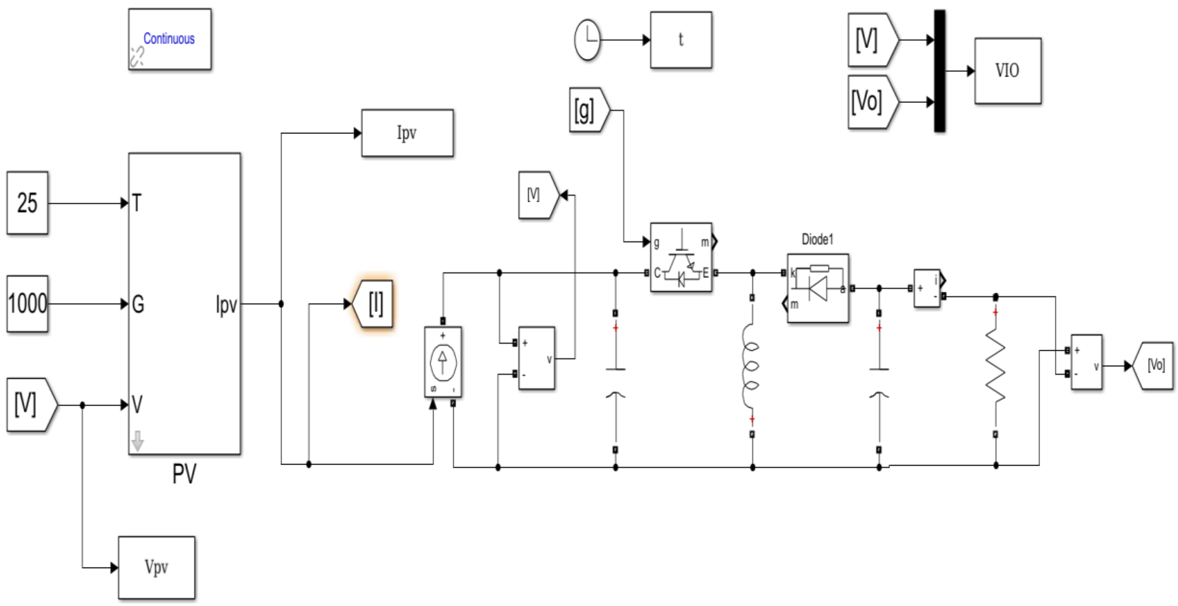


Figure II.22: Association of proposed methode for extracting PV pannel with converter DC/DC buck-boost

II.7.Photovoltaic system properties results using:

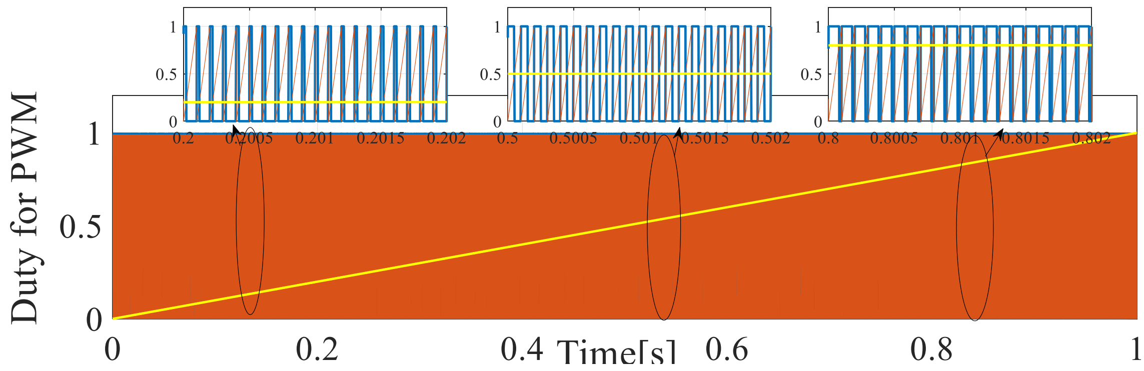


Figure II.23 Duty for PWM

II.7.1. Temperature effect:

Temperature is a very important parameter in the behavior of solar cells. Its increase leads to an increase in the photonic current and in order to be able to study the influence of temperature on the output parameters of a photovoltaic panel, we have fixed the illumination at (G=1000 W/m²) and we draw the curves for different temperatures.

II.7.1.1. Boost converter:

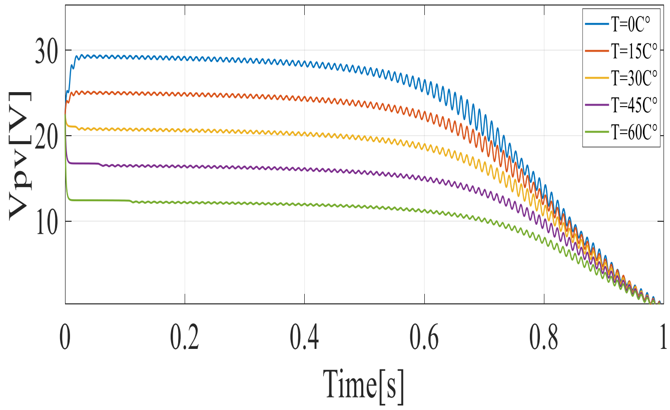


Figure II.24:Characteristics (Vpv) for different temperature values at G=1000W/m²

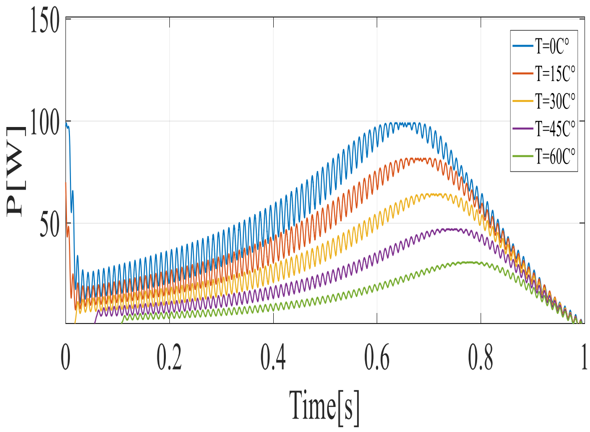


Figure II.25: Characteristics (P) for different temperature values at G=1000W/m²

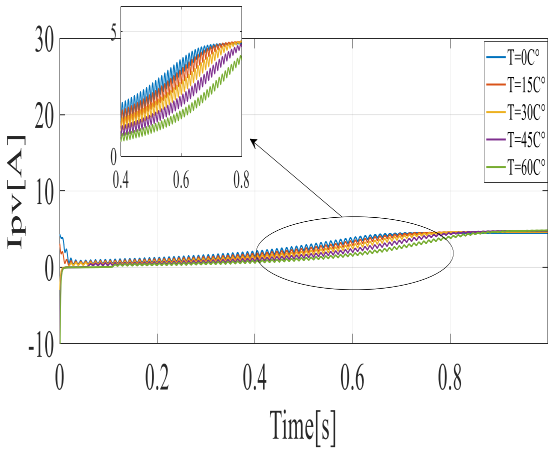


Figure II.26: Characteristics (Ipv) for different temperature values at G=1000W/m²

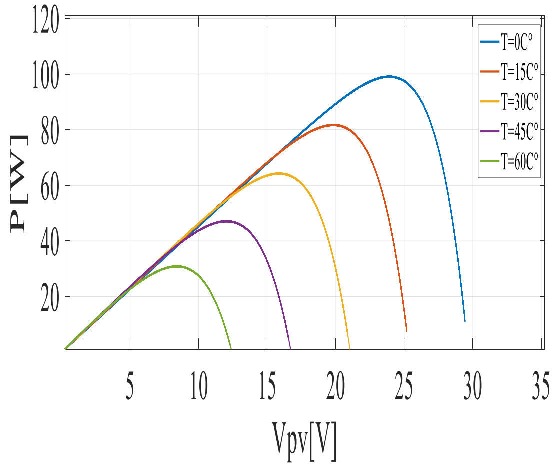


Figure II.27: Characteristics (P-V) for different temperateur values at G= 1000w/m²

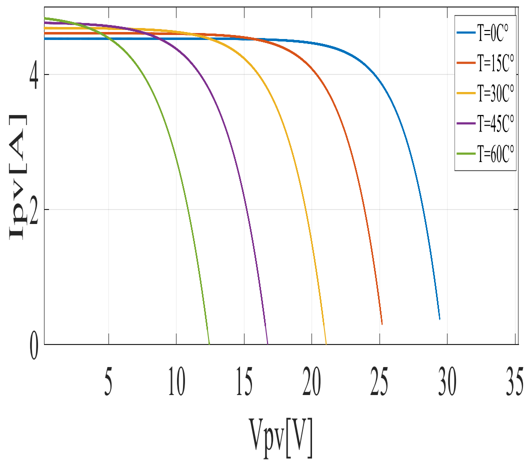


Figure II.28:Characteristics (I-V) for different temperature values at G=1000W/m²

II.7.1.2. Buck-boost converter:

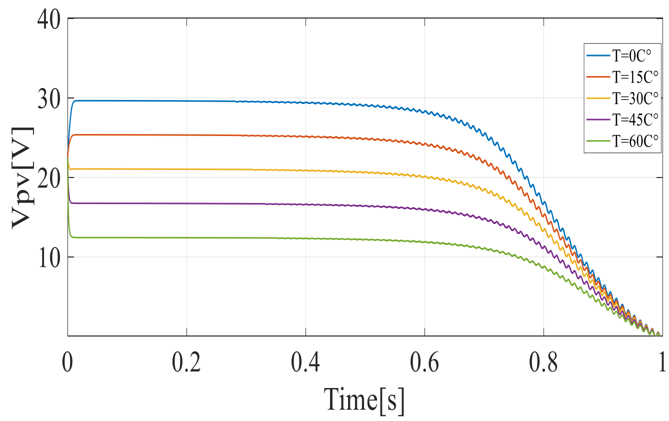


Figure II.29: Characteristics (Vpv) for different temperature values at G=1000W/m²

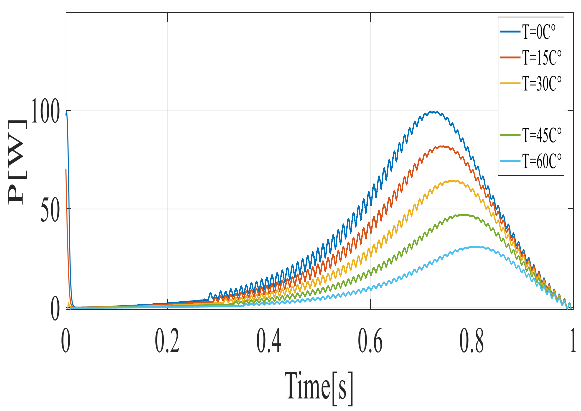


Figure II.30 Characteristics (P) for different temperature values at G=1000W/m²

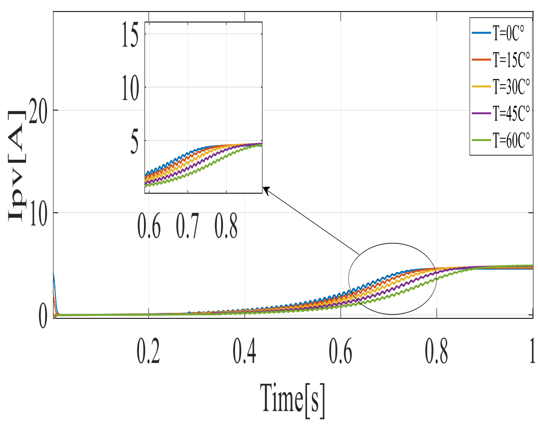


Figure II.31 Characteristics (Ipv) for different temperature values at G=1000W/m²

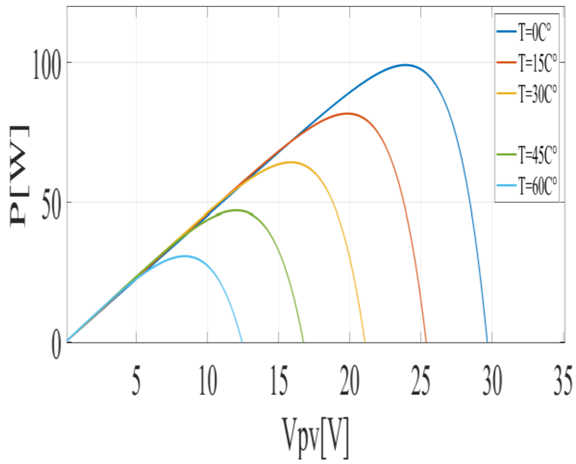


Figure II.32: Characteristics (P-V) for different temperature values at G= 1000w/m²

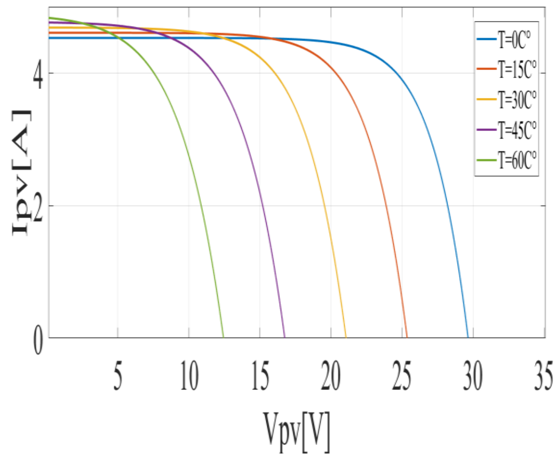


Figure II.33: Characteristics (I-V) for different temperature values at G=1000W/m²

Results discussion:

An important note is that as the temperature increases, the maximum power output of the PV panel decreases. Moreover, a small positive relationship is seen between current and temperature, indicating that with increasing temperature, the current also experiences a slight increase. On the contrary, voltage is negatively affected by temperature.

II.7.2.Radiation effect:

This time we set the temperature to (25 °C) and plotted curves for different values of radiation

II.7.2.1. Boost converter:

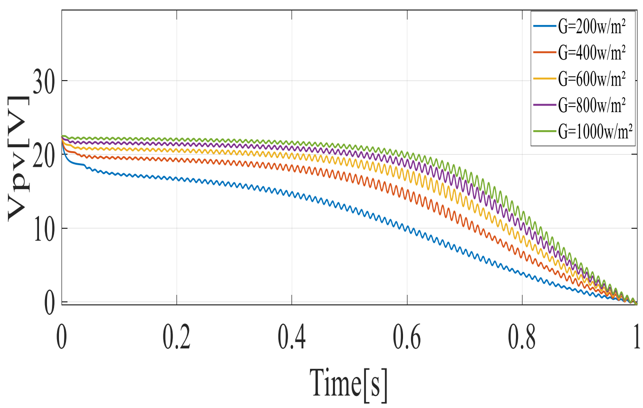


Figure II.34: Characteristics (Vpv) for different radiation values at T=25C°

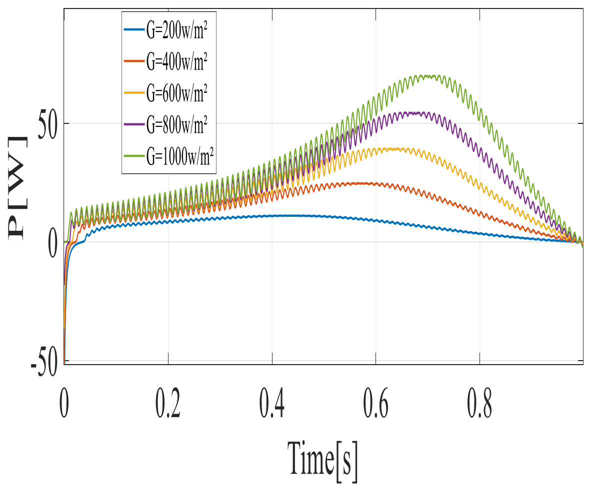


Figure II.35: Characteristics (P) for different radiation values at T=25C°

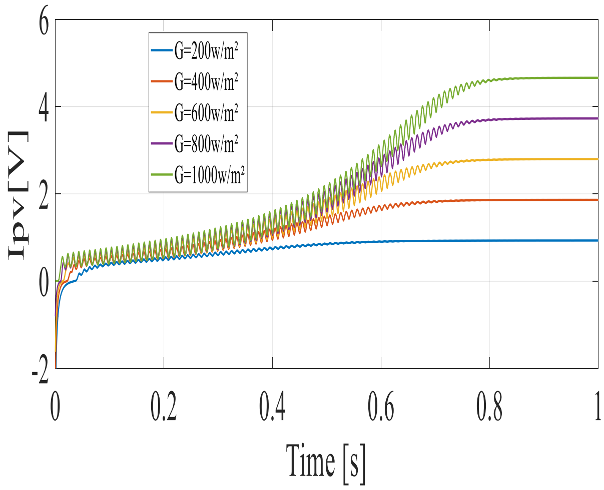


Figure II.36: Characteristics (Ipv) for different radiation values at T=25C°

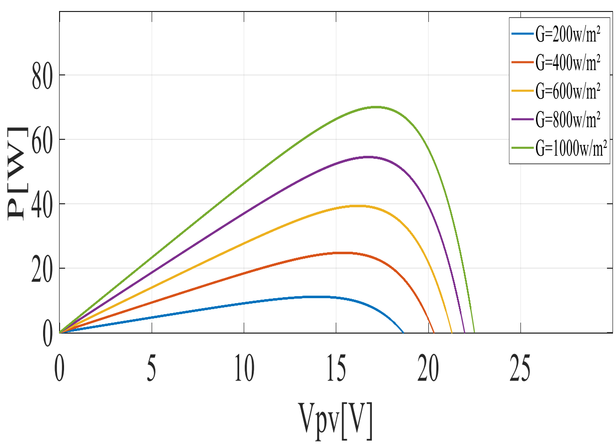


Figure II.37: Characteristics (P-V) for different radiation values at T= 25°C

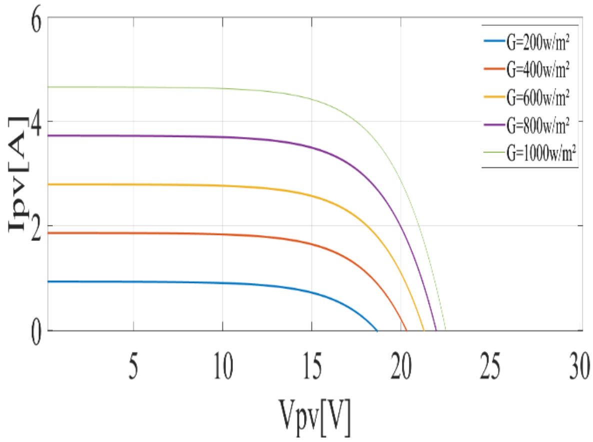


Figure II.38: Characteristics (I-V) for different radiation values at T= 25°C

II.7.2.2. Buck-boost converter:

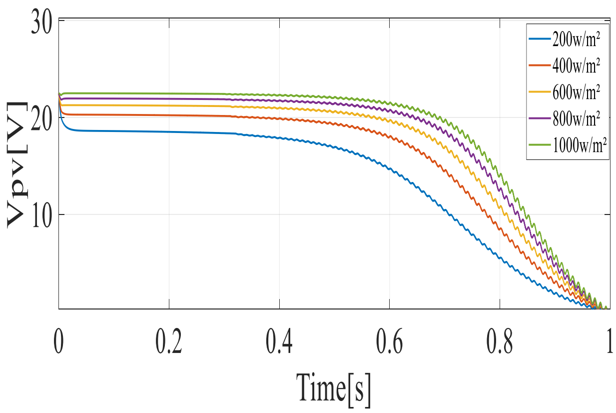


Figure II.39: Characteristics (Vpv) for different radiation values at T=25C°

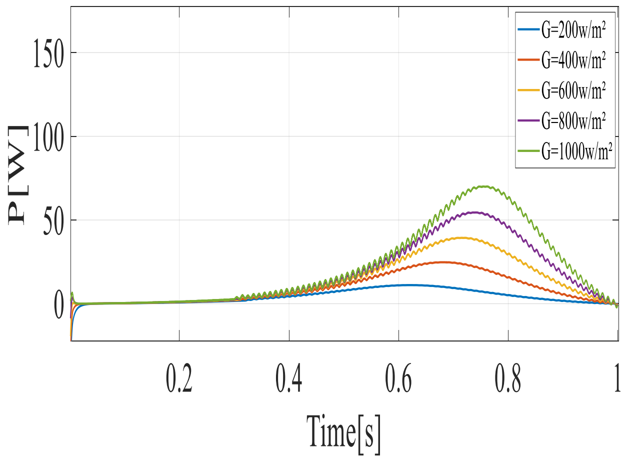


Figure II.40: Characteristics (P) for different radiation values at T=25C°

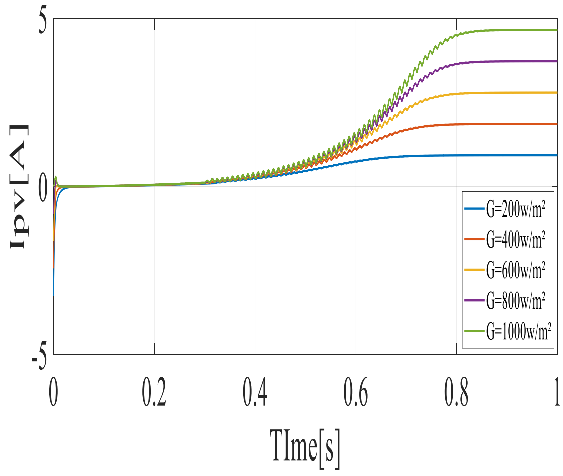


Figure II.41: Characteristics (Ipv) for different radiation values at T=25C°

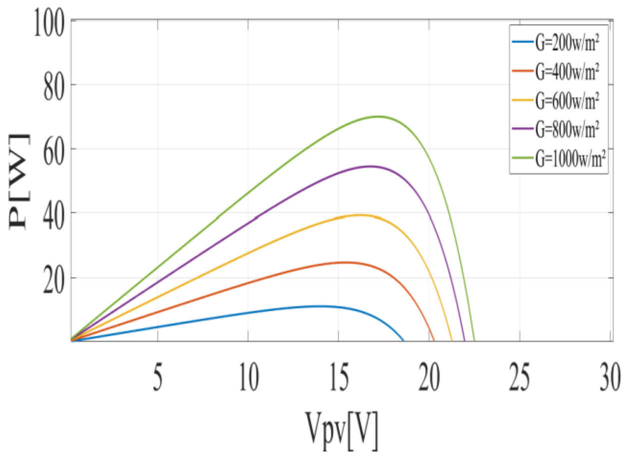


Figure II.42:Characteristics (P-V) for different radiation values at T= 25°C

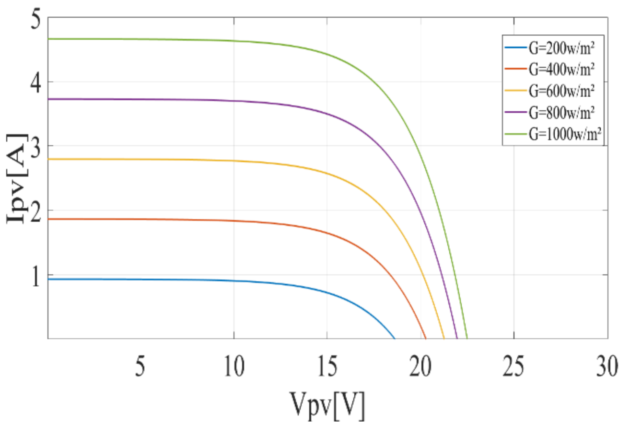


Figure II.43:Characteristics (I-V) for different radiation values at T= 25°C

Results discussion:

It is noted that with a decrease in radiation, a significant decrease in current occurs. This decrease in current directly affects the power output, which deteriorates accordingly. However, there is only a slight difference in voltage. This indicates that voltage is affected by changes in radiation to a lesser extent than by current. It is important to realize that different electrical systems may exhibit varying responses to changes in radiation based on their specific components and designs.

II.8. Conclusion:

This chapter has provided an overview of solar panel characteristics and the different types of DC/DC converters used in PV systems. We have explored the key characteristics of solar panels, including their voltage-current (I-V) and power-voltage (P-V) curves, as well as the impact of temperature and radiation on their performance. The understanding of these characteristics is essential for optimizing the power generation and efficiency of solar PV systems.

Furthermore, we have discussed various types of DC/DC converters, including the boost converter, buck converter, and buck-boost converter. These converters play a vital role in regulating the voltage and optimizing the power extraction from PV systems. Each converter has its advantages and applications, and the selection depends on specific system requirements.

The chapter has also delved into maximum power point tracking (MPPT) techniques for solar PV systems. MPPT techniques ensure that PV systems operate at their maximum power output, regardless of changing environmental conditions. The exploration of different MPPT techniques has provided insights into their classification and performance under various irradiation conditions.

Moreover, a proposed technique for extracting data of PV solar using a DC/DC converter has been presented. This technique aims to enhance the accuracy and efficiency of data acquisition from PV systems, enabling better monitoring and analysis of system performance.

Lastly, the chapter has emphasized the importance of solar PV modeling and simulation for data extraction. Accurate modeling and simulation of both PV panels and DC/DC converters are crucial for understanding system behavior, optimizing performance, and predicting power generation under different conditions.

Chapter III

Implementation of Solar Panel Measurement System

III.1.Introduction

This chapter focuses on the components and design aspects of a solar panel metering system. The class covers several major elements, including the gate drive of a DC/DC boost converter, measurement sensors, design process, PCB design and fabrication, circuit board fabrication, Arduino programming algorithm, and interface of an Android application with the system. Measurement sensors are essential for capturing accurate data, while the gate drive of the DC/DC boost converter ensures efficient operation. The chapter provides a detailed discussion of these components, their functions, and their importance within a system. In addition, the PCB design and fabrication process, circuit board fabrication, Arduino programming algorithm, and integration with an Android application are explored. The objective of this chapter is to provide a comprehensive understanding of the proposed solar panel metering system and its design considerations.

III.2 Gate Drive for DC/DC Boost Converter: [66]

III.2.1. Function Diagram:

The device being described is an optocoupler that consists of a GaAsP LED and an integrated circuit with a power stage. Optocouplers are components that use light to transmit signals between two isolated circuits, without any electrical connection between them. The GaAsP LED emits light that is then detected by the integrated circuit, which controls the power stage.

These optocouplers are particularly well-suited for applications that require high frequency driving of power IGBT (Insulated Gate Bipolar Transistor) and MOSFETs (Metal-Oxide-Semiconductor Field-Effect Transistor). These components are commonly used in Plasma Display Panels, which require precise and high-speed control of the individual pixels, as well as in high-performance DC/DC converters and motor control inverters.

Overall, the optocoupler described here provides a reliable and efficient way to transmit signals and control power in a variety of electronic applications.

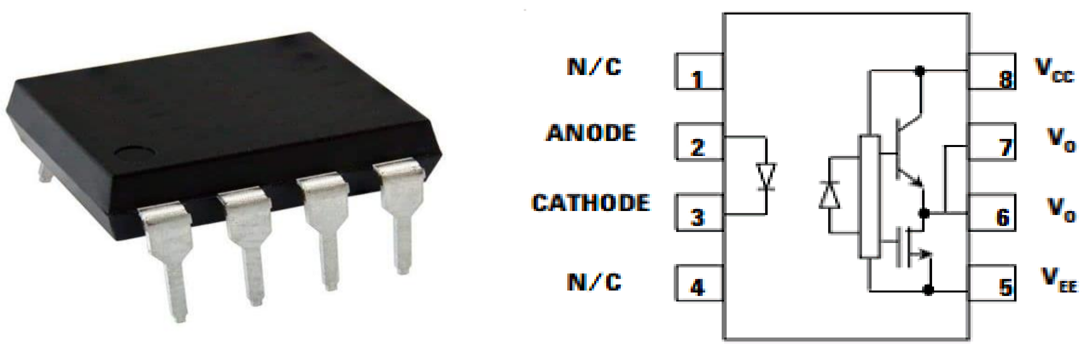


Figure.III.1 :Functional diagram.

III.2.2. Test Circuit and Waveform:

The test circuit for measuring these parameters typically consists of a pulse generator, a device under test (DUT), and an oscilloscope. The pulse generator generates a square wave input signal, which is applied to the DUT input. The output of the DUT is connected to the input of the oscilloscope, which displays the output waveform.

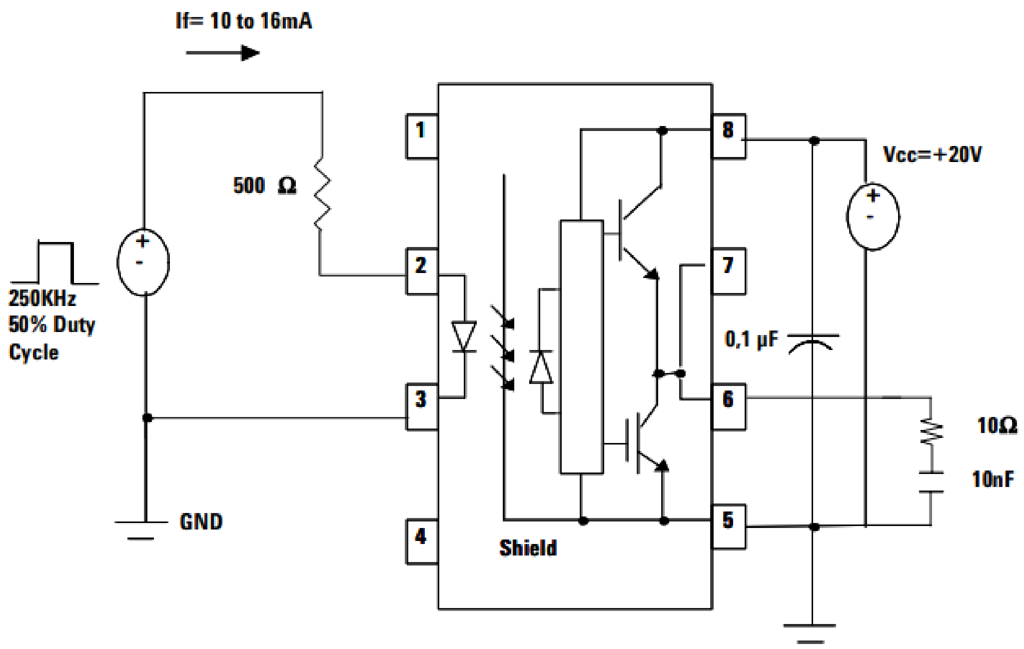


Figure III.2 : TPLH, TPHL, Tr and Tf Test Circuit and Waveform.

III.2.3. Applications Information Eliminating Negative IGBT Gate Drive:

To keep the IGBT firmly off, the HCPL-3180 has a very low maximum VOL specification of 0.4 V. The HCPL-3180 realizes the very low VOL by using a DMOS transistor with 1 W (typical) on resistance in its pull down circuit. When the HCPL3180 is in the low state, the IGBT gate is shorted to the emitter by Rg + 1 W. Minimizing Rg and the lead inductance from the HCPL-3180 to the IGBT gate and emitter (possibly by mounting HCPL-3180 on a small PC board directly above the IGBT) can eliminate the need for negative IGBT gate drive in many applications as shown in Figure III.3.

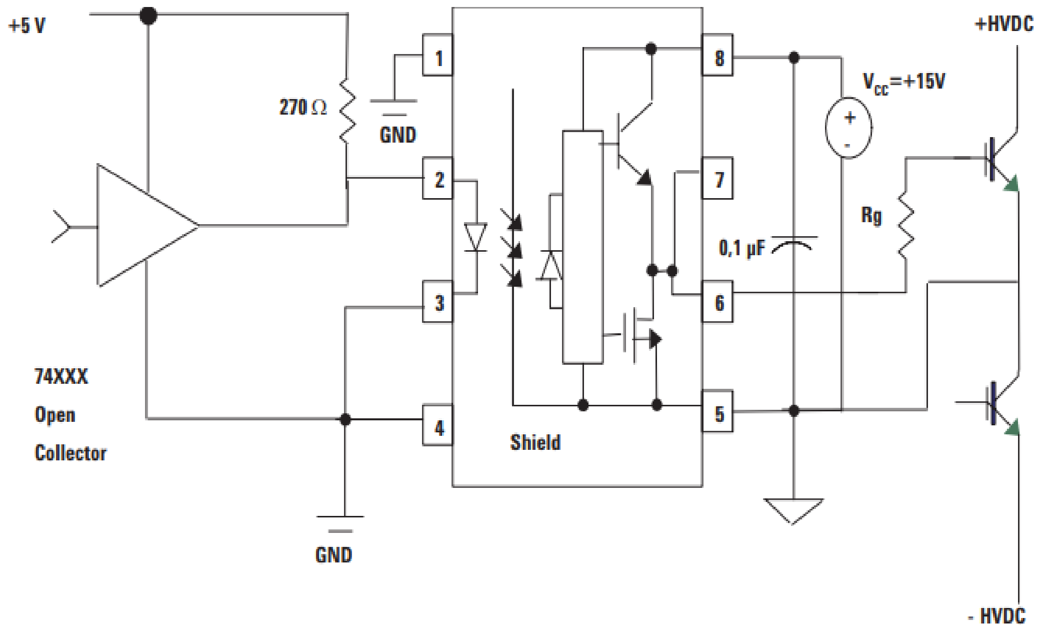


Figure.III.3: Recommended LED Drive and Application Circuit for HCPL-3180.

III.2.4. Isolated DC Power Module B0515 : [67]

The process of using a step up converter to increase the voltage from 5V to 12V involves using electronic components and transferring them from the input voltage to the output voltage. During the set time of the switching element, the energy is stored in the inductor, and during the off time, the energy is transferred to the output through the diode and capacitor. This results in a higher output voltage than the input voltage. The output voltage is regulated by a feedback control circuit to ensure it remains at the required level. In general, a boost converter is an effective way to step up voltage from 5V to 12V and can be used in a wide variety of electronic applications.

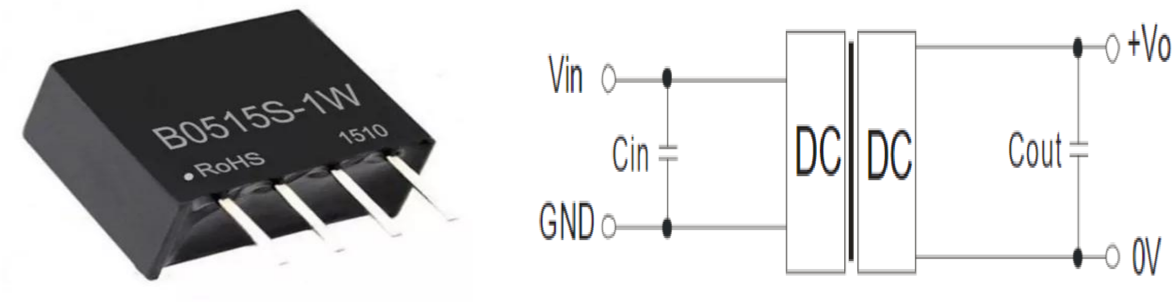


Figure.III.4: Output voltage regulation and over-voltage protection circuit

III.3 The components of the proposed device:

III.3.1. The SWITCHMODE Power Rectifier (DIODE):[68]

The rectifier's forward voltage drop can result inmatched dual die construction and high junction temperature capability help ensure reliable operation under a range.

In addition, the rectifier has excellent ability to withstand reverse avalanche energy transients, which can help protect against damage from voltage spikes or other electrical disturbances. The guard ring provides further stress protection, and the rectifier is electrically isolated, eliminating the need for additional isolation hardware.

Overall, the SWITCHMODE Power Rectifier is a high-quality component that offers a range of features and benefits for power supply and protection applications. Its Schottky Barrier technology, oxide passivation, and other advanced features make it a reliable and efficient choice for low-voltage, high-frequency systems.

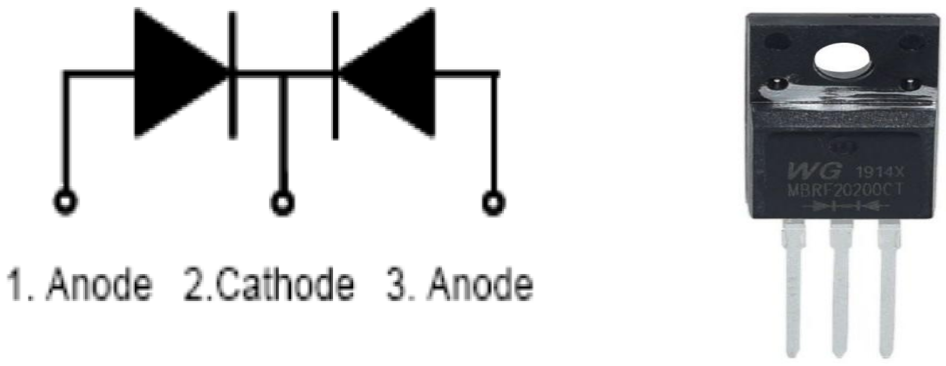


Figure.III.5: The SWITCHMODE Power Rectifier

III.3.2. MOSFET:[69]

It is a high performance mosfet that provides a range of features and benefits to power electronics designers. Its positive temperature coefficient, high current capacity, and fast conversion speed make it a reliable and efficient choice for a wide variety of applications, including solar power inverters, UPS, welders, and communications equipment. Its low conduction and switching losses make it suitable for applications where high efficiency is required.

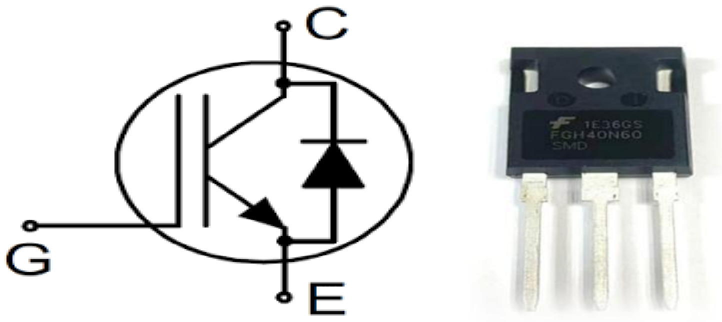


Figure.III.6: High-Performance MOSFET for Power Electronics Applications.

III.3.3. Inductor: [70]

Triad high current rod core inductors are a cost-effective solution for energy storage in power electronics applications. These inductors are designed to smooth out the current waveform by conditioning the output signal, resulting in a more stable current. Additionally, these inductors are low cost and compatible with automated P.C.B. installation, making them a convenient choice for a variety of applications.

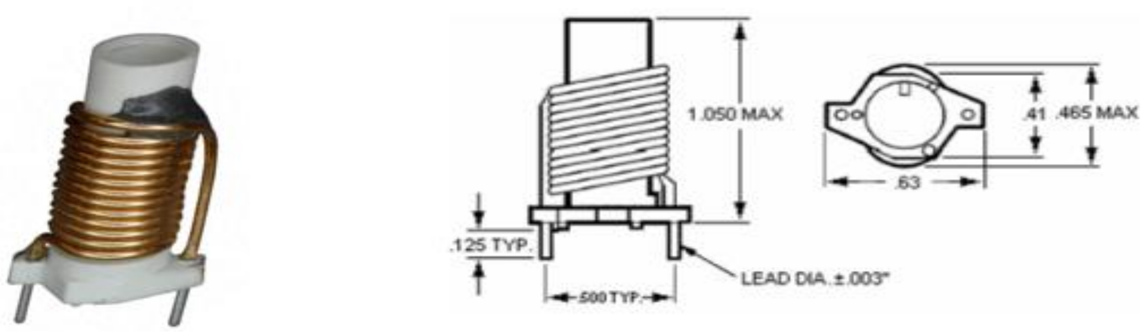


Figure.III.7: Triad High Current Rod Core Inductors

III.3.4. Capacitor: [6]

A capacitor is a fundamental component in electronic and electrical circuits, consisting of two metal plates facing each other and separated by an insulator. The operation of a capacitor is based on the electrostatic effect between the two metal plates, and it is used to store, convert, and distribute electrical energy efficiently in electronic circuits.

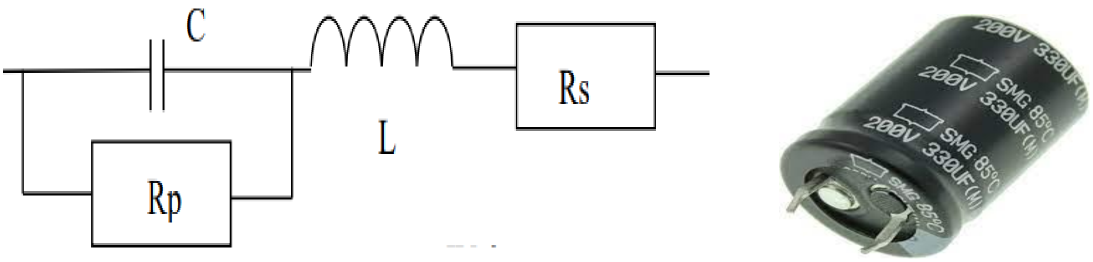


Figure.III.8: External structure and internal design of the electronic capacitor

III.3.5. ARDUINO microcontroller: [71]

Arduino is open source hardware/software programming Microcontroller based platform. He has devices on a single chip. All components are connected to Arduino.

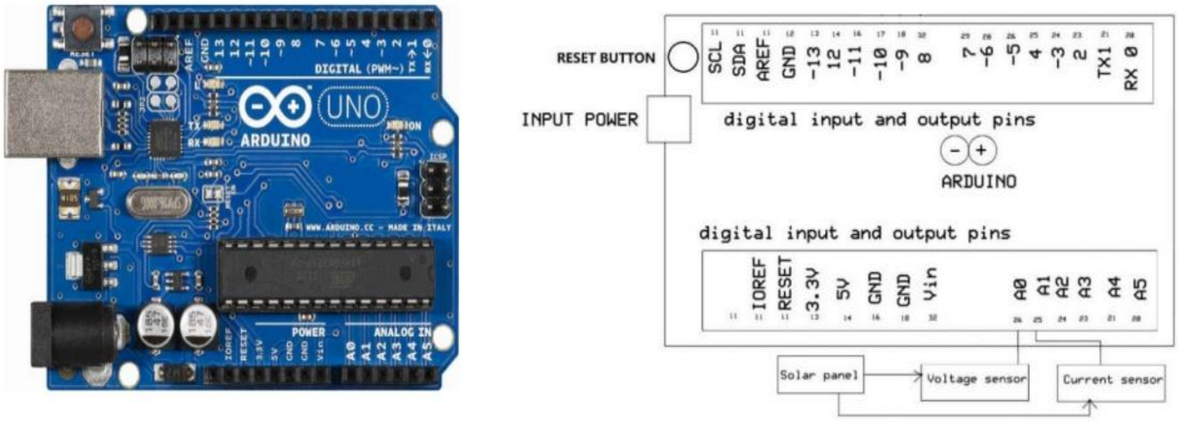


Figure.III.9: The Arduino Board and Circuits.

III.4. Measurement sensors used for proposed system: [71]

Solar panels need accurate measurement devices to achieve the best performance in generating electrical energy. PV and electrical efficiency are measured using voltage and current sensors and specialized devices. Other factors such as conversion efficiency, heat coefficient and tolerance to environmental conditions are also measured. These measurements are necessary to determine the efficiency of solar panels and improve the quality of electricity generation. Measurement of voltage, current, and insulation is also required to determine the electrical properties of solar panels, improve their quality, and fix faults and problems. Accurate measurement sensors in the optical and electrical aspects are vital to ensuring the highest levels of quality and efficiency in generating electrical energy from solar panels. We mention the most important of them as follows:

III.4.1. Voltage Sensor:

A voltage sensor is a device used to measure the voltage of a circuit. When the voltage range is between 0-5V, an analog pin can be used directly. However, if the voltage range is above 5V, a voltage divider circuit is needed to reduce the voltage to a level that can be read by the analog pin, which has a maximum input voltage of 5V. The voltage sensor module works by reducing the input voltage by a factor of 5, allowing the sensor to read a maximum voltage of 25V when the desired analog input voltage is 5V.

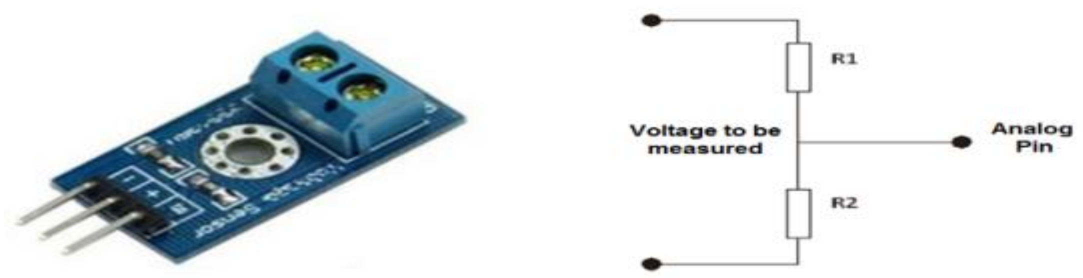


Figure.III.10: Voltage sensor Board module, Circuits.

III.4.2. Current sensor ACS712:

Current Sensor is the sensor that is used to measure and calculate the amount of current applied to the conductor. It is a fully integrated, Hall-effect based linear sensor IC.

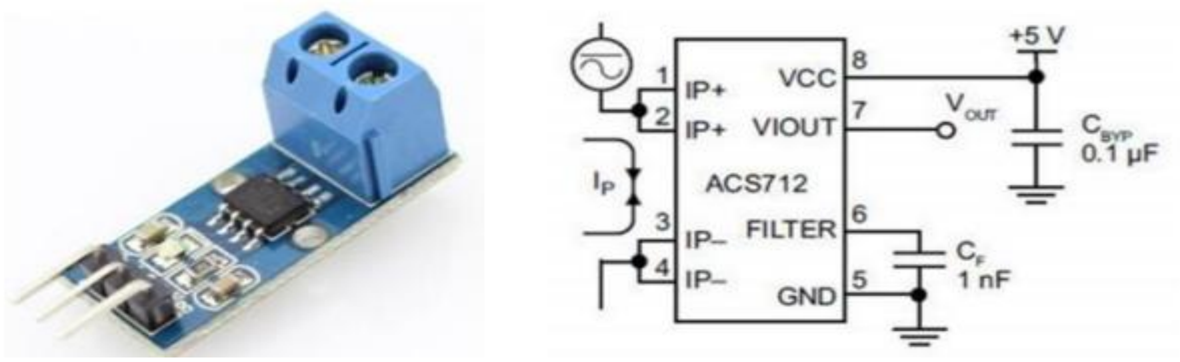


Figure.III.11: Current sensor Board module, Circuits.

III.5. Printed Circuit Board (PCB) Design: [72-73-74-75-76-77-78-79]

Printed Circuit Board (PCB) design is a critical process in the development of electronic systems, including solar panel measurement systems. The design process involves creating a layout of the circuit board that connects the various electronic components and enables them to function together. The PCB design process for a solar panel measurement system typically involves the following steps:

III.5.1. Determine the requirements:

The requirements for the printed circuit and the elements it must contain must be determined, including the number and type of components, board size, voltage requirements and others.

III.5.2. Electrical schematic design:

The electrical schematic diagram is generated using ALTUM software, and the electronic components and connections between them are shown. This step involves using standard component codes and ensuring that they comply with specified requirements.

III.5.3. Determine the dimensions:

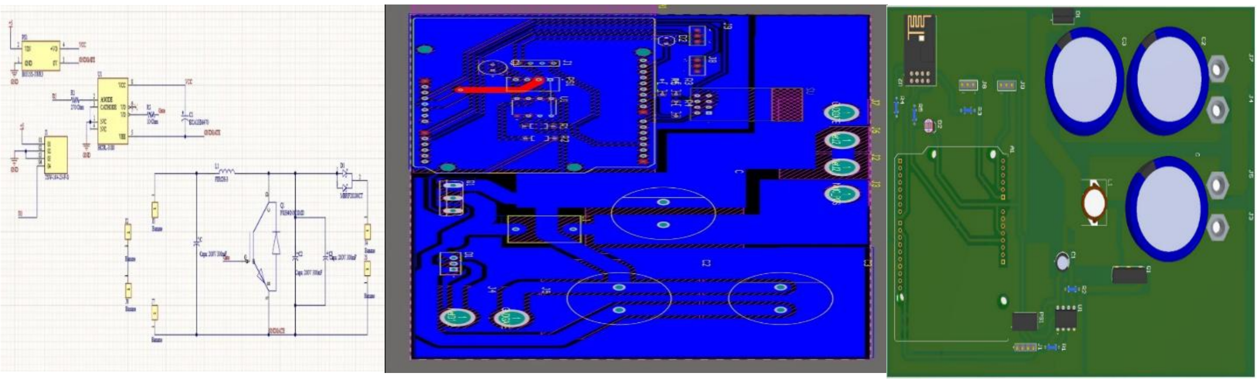
The dimensions of the board and the locations of components, tracks, holes, connectors, etc. must be determined. This is done using ALTUM software which helps to determine the exact dimensions and ensure that they comply with the specified requirements.

III.5.4. Connecting components:

Components are connected on the board using spaces, connectors, holes, etc. This is done using ALTUM software and ensuring that the spacing and connections between components are consistent and avoiding connection errors.

III.5.5. Connecting the tracks:

After the components are placed on the board, they need to be connected using the copper tracks. This is done using ALTUM software and make sure that the tracks meet the specified requirements and avoid overlapping the tracks.



(A) (B) (C)

Figure.III.12: Stages of designing a printed circuit board (PCB).

(A): Circuit diagram in Altium software, (B): 2D drawing of a circuit, (C): 3D drawing of a circuit.

III.6. Manufacturing Electronic Circuit Board: [-80-81-82-83]

When the design phase is complete, we move on to the manufacturing phase which involves manufacturing the electronic circuit board. It has several steps, each of which is critical to ensuring that the final product functions correctly and meets the required specifications. which comes after the stage of connecting the paths. Here are the steps involved in manufacturing a circuit board:

III.6.1. Drilling:

The board is drilled at the positions where the components will be installed or the different layers will be connected. This is done using a drill bit that is chosen to be the appropriate size for the required drilling.

III.6.2. Trellis layer:

A trellis layer has been added on the board which includes ingredient labels, logos and guide signs. This is done using ALTUM software and make sure the marks are aligned with the marked positions.

III.6.3. solder layer:

Solder layer is added on the board to protect the copper tracks and avoid the formation of solder bridges between adjacent tracks. This is done using ALTUM software and make sure that the layer matches the specified requirements.

III.6.4. Inspection and testing:

The board is checked for faults in connections, dimensions, etc. This is done using various testing devices and simulation software. Gerber Files Created: Gerber files are created, which are industry standard files containing all the information required for panel manufacturing. These files are uploaded to the factory that will manufacture the board.

III.6.5. Plate manufacturing:

The plate is made in the factory with special equipment, brazing, welding, engraving, etc., based on the provided Gerber files.

III.6.6. Assembly and Testing:

After the board is manufactured, the components are assembled on it and tested to ensure that they function properly according to the specified requirements.

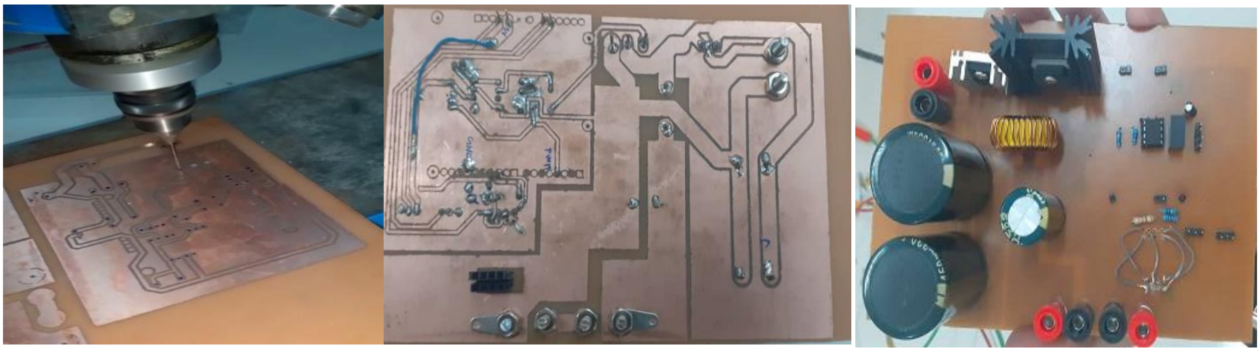
After the board is manufactured, the components are assembled on it and tested to ensure that they.

Figure.III.13: Stages of developing a printed circuit board (PCB).

(A): Printed circuit board (PCB) before acidification.

(B): Printed circuit board (PCB) during development.

(C): Printed circuit board (PCB) after acidification.



(A) (B) (C)

Figure.III.14: Stages of manufacturing a printed circuit board (PCB).

(A): Printed circuit board (PCB) in the hole stage.

(B): The printed circuit board (PCB) is in the soldering stage.

(C): Printed circuit board (PCB) end of manufacture.

III.7. Arduino Programming Algorithm:

- ✓ **Include necessary libraries:**

```
#include <TimerOne.h>
#include <SoftwareSerial.h>
```

The program begins by including the required libraries: TimerOne for timer functions and SoftwareSerial for communication with the Bluetooth module.

- ✓ **Define Bluetooth module pins :**

```
const int bluetoothRx = 10;
const int bluetoothTx = 11;
SoftwareSerial bluetooth(bluetoothRx, bluetoothTx);
```

Here, the RX and TX pins for the Bluetooth module are defined, and a SoftwareSerial object named bluetooth is created to handle communication.

- ✓ **Declare variables:**

```
int incomingByte = 0; // for incoming serial data
int duty = 500; // for incoming serial data
float VOC;
float Pmax=0;
float Isc;
float anaVol;
float voltage ;
float current ;
int Period=50;// for ms
```

```
int TPeriod=0;
int NmbIt=0;
float RMSCurrent;
String Test="GND00.000.0000.00";
int IntTime;
```

These variables are used throughout the program for different purposes, such as storing voltage and current values, calculating measurements, and managing test results.

- ✓ **Setup function:**

```
void setup() {
  Serial.begin(9600); // opens serial port, sets data rate to 9600 bps
  bluetooth.begin(9600);
  Timer1.initialize(50);
  Timer1.pwm(9,0);
```

The setup function is called once when the program starts. It initializes the serial communication for debugging purposes and sets up the Timer1 with a period of 50 milliseconds. It also sets the PWM pin 9 to 0, indicating no output initially.

- ✓ **Main loop function:**

```
void loop() {
  // check if data is available
CallBlue();
  anaVol=analogRead(A0);
  voltage=((anaVol*25)/1024.0);
   Test = "VO"+String(voltage);
   bluetooth.println(Test);
   delay(500);
   }
```

The loop function is the main part of the program that runs repeatedly. In this case, it first calls the CallBlue function to check for any incoming Bluetooth commands. Then, it reads the analog voltage from pin A0, converts it to a voltage value, and stores it in the voltage variable. The voltage value is then added to a string with a prefix "VO" and sent over Bluetooth using the bluetooth.println function. Finally, it delays for 500 milliseconds before repeating the loop.

- ✓ **calltest function:**

```
void calltest() {
Serial.println("Start Test... ");
delay(100);
Timer1.pwm(9,0);
RMS();
VOC=voltage;

for (int it=1; it<20; it++){
      Timer1.pwm(9,it*50);
      RMS();
```

```
    if (voltage*RMSCurrent>Pmax){
     Pmax=voltage*RMSCurrent;
     }

     Serial.println(it*10);

     }
           Isc=RMSCurrent;
     Serial.print("VOC= ");
     Serial.println(VOC);
     Serial.print("Pmax= ");
     Serial.println(Pmax);
     Serial.print("Isc= ");
     Serial.println(Isc);
        Timer1.pwm(9,0);
     Test = "GND"+String(VOC)+String(Isc)+String(Pmax);//+String(70);
     bluetooth.println(Test);
     Serial.println(Test);
     Pmax=0;
    }
```

The calltest function performs the test by iterating through a loop and gradually increasing the PWM value on pin 9. It first prints a message and initializes the PWM to 0. Then it calculates the RMS current using the RMS function. It stores the current voltage value as the open circuit voltage (VOC).

Next, it enters a loop that iterates from 1 to 19 (incrementing by 1). In each iteration, it sets the PWM value to a specific level and calculates the RMS current. If the product of voltage and RMS current is greater than the previous maximum power (Pmax), it updates Pmax.

During each iteration, it prints the iteration value. After the loop, it stores the final RMS current value as the short circuit current (Isc). It prints VOC, Pmax, and Isc values to the serial monitor.

Then, it sets the PWM value to 0, prepares a string with VOC, Isc, and Pmax values, and sends it over Bluetooth. Finally, it resets Pmax to 0 for the next test.

✓ **RMS function:**

```
void RMS() {

anaVol=analogRead(A0);
voltage=((anaVol*25)/1024.0);
IntTime=millis();
NmbIt=0;
RMSCurrent=0;
TPeriod=0;
  while (TPeriod < Period){
    NmbIt=NmbIt+1;
```

```
      TPeriod=millis()-IntTime;
      RMSCurrent=RMSCurrent+analogRead(A1);
      delay(1);

    }
    RMSCurrent=RMSCurrent/NmbIt;//abs(520-RMSCurrent/NmbIt)/40;
    RMSCurrent=(1.167/10000000)*RMSCurrent*RMSCurrent*RMSCurrent+(-
1.605/10000)*RMSCurrent*RMSCurrent+(4.76/100)*RMSCurrent+2.01;
    }
```

The RMS function calculates the RMS (root mean square) current. It first reads the analog voltage from pin A0, converts it to a voltage value, and stores it in the voltage variable.

Then, it records the initial time value using millis() function, initializes iteration count, RMS current value, and current time period.

The function enters a while loop that runs until the current time period exceeds the specified period. In each iteration, it increments the iteration count, calculates the current time period, accumulates the analog current values from pin A1, and adds a small delay for stability.

After the loop, it calculates the average of the accumulated current values. Then, it applies a mathematical function to convert the analog current value to RMS current based on a specific equation.

- ✓ **CallBlue function:**

```
void CallBlue() {
     if (bluetooth.available() > 0) {
    // Read the incoming data and store it in a variable
    char data = bluetooth.read();
    //Serial.println("bluetooth.available");
    //Serial.println(data);


    // If the incoming data is '1', turn on the LED
  if (data == '1') {

      calltest();
       }

      delay(1000);
      data = '0';
   }

   }
```

The CallBlue function is responsible for checking incoming Bluetooth commands. It first checks if there is any data available using bluetooth.available() function. If data is available, it reads the incoming data and stores it in the data variable.

If the incoming data is '1', it calls the calltest function to initiate the test. Afterward, it introduces a delay for stability, and then resets the data variable to '0.'

III.8. Association android application with the system:

Based on the provided code, it appears that the software communicates with a mobile app via a Bluetooth module. The app is responsible for displaying the Voc, Isc, and Pmax values obtained from the Arduino hardware.

Here's an overview of how the software interacts with the app:

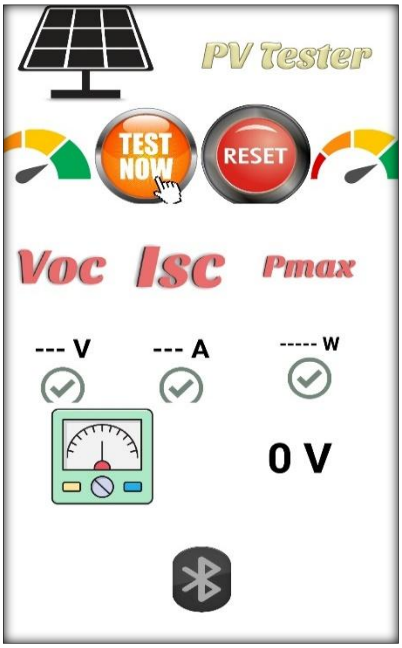


Figure.III.15: application interface

- ✓ **Initialization:**

The Arduino board is connected to a Bluetooth module, which is configured with RX (receive) and TX (transmit) pins using the Software Serial library.

Serial communication is established at a baud rate of 9600 for both the Arduino and Bluetooth module.

Timer1 is initialized with a period of 50 milliseconds.

- ✓ **Main Loop:**

The loop function runs continuously.

The CallBlue function is called to check for any incoming Bluetooth commands from the mobile app.

The analog voltage from pin A0 is read using analogRead and converted to a voltage value.

The voltage value is sent to the mobile app via Bluetooth by creating a string with the prefix "VO" and using bluetooth.println.

The loop then waits for 500 milliseconds before repeating the process.

- **Test Execution:**

If the mobile app sends the command '1' via Bluetooth, the calltest function is executed.

The function begins by printing a message indicating the start of the test.

The PWM pin 9 is set to 0, turning off the output initially.

The RMS function is called to calculate the RMS current.

The current voltage value is stored as the open circuit voltage (VOC).

A loop runs from 1 to 19 (incrementing by 1) to gradually increase the PWM value on pin 9.

In each iteration, the RMS function is called again to calculate the RMS current.

If the product of voltage and RMS current is greater than the previously recorded maximum power (Pmax), Pmax is updated.

The iteration value is printed to the serial monitor.

After the loop, the final RMS current value is stored as the short circuit current (Isc).

The VOC, Pmax, and Isc values are printed to the serial monitor.

The PWM pin 9 is set to 0 to turn off the output.

A string is created with the test results (VOC, Isc, and Pmax) and sent to the mobile app via Bluetooth.

The Pmax value is reset to 0 for the next test.

- **RMS Calculation:**

The RMS function is responsible for calculating the RMS current value.

The analog voltage from pin A0 is read and converted to a voltage value.

The initial time value is recorded using millis.

Variables for iteration count, RMS current, and current time period are initialized.

A while loop runs until the current time period exceeds the specified period (50 milliseconds).

In each iteration, the iteration count is incremented, the current time period is calculated, and the analog current values from pin A1 are accumulated.

A small delay of 1 millisecond is introduced for stability.

After the loop, the average of the accumulated current values is calculated.

A mathematical function is applied to convert the analog current value to RMS current using a specific equation.

- **Bluetooth Communication:**

The CallBlue function checks if there is any data available from the Bluetooth module.

If data is available, it is read and stored in the data variable.

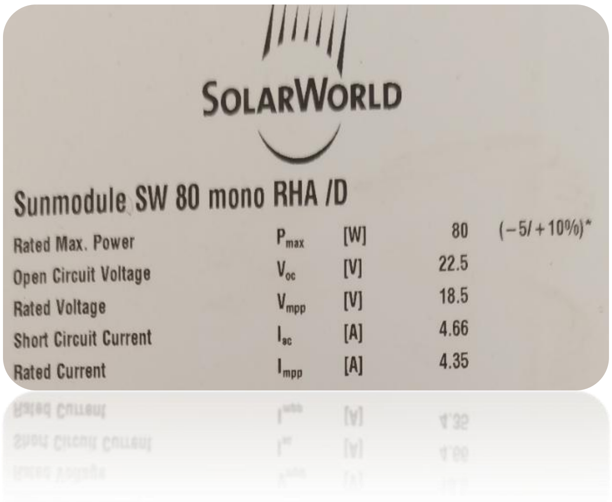
If the received data is '1', indicating a command from the mobile app, the calltest.

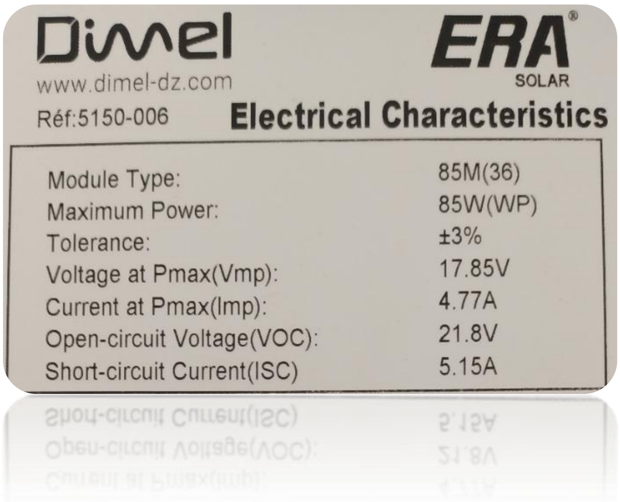
III.9. Testing of Solar Panel Measurement System:

The solar panel metering system plays a crucial role in determining the efficiency and performance of solar panels. This system involves experimenting with several solar panels and analyzing the characteristics of each panel separately and individually, including capacity, voltage, efficiency and reliability. The efficiency of solar panels is measured based on its ability to convert solar energy into electrical energy, which can vary based on the type of solar panel and its characteristics. Data related to the performance of solar panels is analyzed and evaluated using the smart phone application, which provides customized data through which it is evaluated. The reliability and efficiency of solar panels characteristics.

III.9.1. Characteristics of each slab before measurement:

Each of the solar panels has characteristics that distinguish it from others in terms of capacity, efficiency, voltage and current, and from it in our experience we have taken two panels in order to conduct an experiment on them, each of which carries certain characteristics that we mention as follows:





solar panel (A) **solar panel (B)**

Figure.III.16: General structure of solar panels.

III.9.2. General structure of the measurement system:

The structure of solar panels is complex and exquisite, requiring technical expertise and attention to detail. Installing a metering system on different types of solar panels is critical to achieving accurate and reliable data that can improve solar energy efficiency. Installation requires precision to avoid errors that may lead to inaccurate data.

The process of conducting and installing the measurement system on the various types of solar panels chosen in order to obtain the experience shown in the figure shows the method of explaining the process to connect the device with the various and correct solar panels.

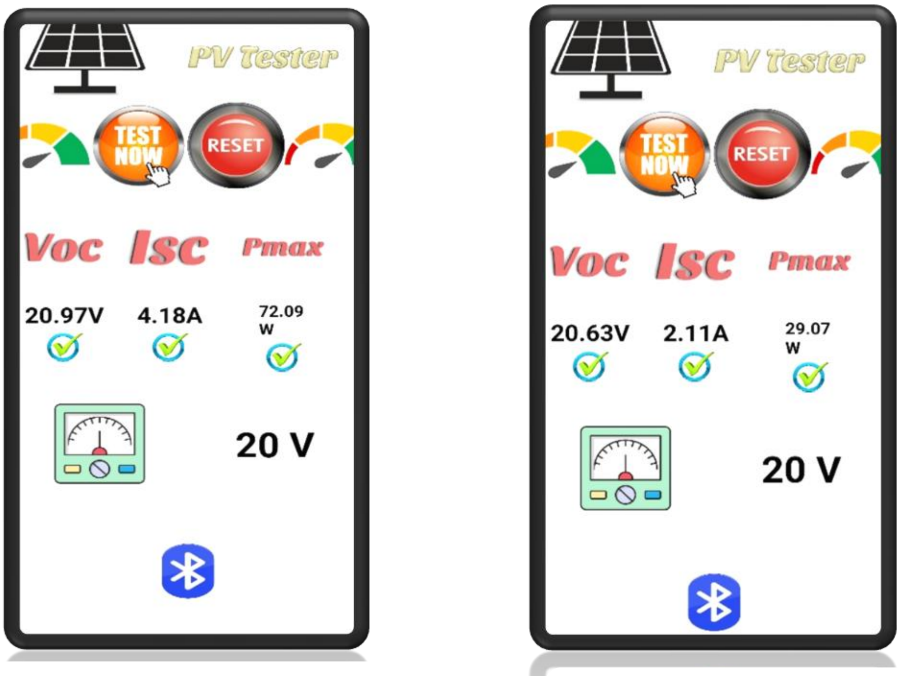
General structure of solar panel (A) General structure of solar panel (B)

Figure.III.17: General structure of solar panels.

III.9.3. Results of experimentation

Results of experimentation on the boards with the “Smart-phone” measuring system device:

Experiments on solar panels using a smart phone metering system device resulted in an application displaying data and values related to the solar panel. The experiment was conducted on two different types of solar panels, and the results are presented in Fig. By analyzing this data, we can obtain valuable reviews about the performance and efficiency of solar panels, which helps to improve their contribution to sustainable energy production. In general, the use of smart phone metering systems holds great potential for advancing the field of solar energy and improving the efficiency and effectiveness of solar panels.



(A) : A healthy solar panel

(B): Broken solar panel

Figure.III.18: Show results in the interface of the smart application.

III.9.4. Interpretation of the results:

In the first partexperiment (B), the solar panel produced a power output of 29.07 watts, with a current of 2.11 amps and a voltage of 20.63 volts. The power output of a solar panel is a function of the current and voltage generated, and is affected by factors such as temperature, solar radiation, and shading. The relatively low power output and current of this solar panel indicates that it may be less efficient or less suitable for certain applications than a second solar panel.

n the second part experiment (A), the second solar panel produced a power output of 72.09 watts, with a current of 4.18 amps and a voltage of 20.97 volts. The higher power output and current of this solar panel indicates that it is more efficient or more suitable for certain applications than the first solar panels. This may be due to a variety of factors, such as the materials used, the plate design, or environmental conditions during the experiment.

The data obtained through experiments on two different types of solar panels using a smartphone measurement system provides valuable insights into their performance and efficiency. These findings can be used to improve the design and performance of solar panels, and to increase their contribution to sustainable energy production.

III.10.Conclusion :

Chapter has provided a comprehensive overview of the components and design aspects of the solar panel measurement system. The chapter focused on important elements such as the gate drive for the DC/DC boost converter, measurement sensors, design process, PCB design and fabrication, manufacturing of the electronic circuit board, Arduino programming algorithm, and integration with an Android application. The gate drive for the DC/DC boost converter was discussed in detail, highlighting its significance in ensuring efficient system performance. The measurement sensors were examined, emphasizing their role in capturing accurate data related to solar panel performance.

The design process for the solar panel measurement system was explained, covering considerations and steps to create a reliable system. The PCB design and fabrication process were explored, emphasizing industry standards and best practices. The manufacturing of the electronic circuit board was addressed to ensure functionality and durability.

The overview of the Arduino programming algorithm provided insights into data collection, processing, and transmission. The integration of an Android application with the system was also discussed, enhancing accessibility and usability.

General Conclusion

General Conclusion

In conclusion, this thesis has provided a comprehensive exploration of solar energy and the critical role of solar panels in harnessing this renewable resource. By examining various aspects such as electrical quality and conformity, DC/DC converters, transistor driving techniques, solar panel efficiency measurement, and solar PV modeling, we have gained a deep understanding of optimizing solar energy systems.

The first chapter emphasized the importance of renewable energy, particularly solar energy, in the modern world. We discussed the significance of maintaining electrical quality and conformity, and how it affects the overall performance and reliability of solar energy systems. The chapter also provided an overview of the different types of electronic converters and specialized tools used for measuring solar panel efficiency.

In the second chapter, we explored the characteristics of solar panels and their impact on power generation. We discussed the voltage-current (I-V) and power-voltage (P-V) curves, as well as the influence of temperature and radiation. Additionally, we delved into various types of DC/DC converters and their role in regulating voltage and optimizing power extraction. The chapter also covered maximum power point tracking (MPPT) techniques, which ensure maximum power output under changing environmental conditions.

Moving on to the third chapter, we focused on the components and design aspects of the solar panel measurement system. We discussed the gate drive for the DC/DC boost converter, measurement sensors, design process, PCB design and fabrication, manufacturing of the electronic circuit board, Arduino programming algorithm, and integration with an Android application. Each component and step in the design process were explored to ensure a reliable and accurate measurement system.

By combining the knowledge and insights gained from these chapters, we can enhance the efficiency and performance of solar energy systems. The optimization of solar panel characteristics, proper selection and implementation of DC/DC converters, utilization of MPPT techniques, and the design of a robust measurement system all contribute to maximizing the potential of solar energy.

In conclusion, this thesis serves as a valuable resource for researchers, engineers, and professionals in the field of renewable energy. By understanding the intricacies of solar panel performance and measurement, we can advance the adoption of solar energy and contribute to a more sustainable future. With continued research, innovation, and collaboration, we can further optimize solar energy systems and make significant strides towards a greener and cleaner world.

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