CHAPTER 1:

Introduction

Fig. 1.1 3D view of Solar PV array

Solar Photo-voltaic (PV) source is extensively used worldwide, compared to other sources of Renewable energy. Fig 1.1 shows the 3D view of solar PV array. Due to recent developments, reduced module cost, ease of installation and increased life of Solar PV module, there is an increased attention towards use of solar PV system. Such solar PV systems suffer from low System Conversion Efficiency (SCE). At present, many investigations are under progress to improve SCE. Generated output power mainly depends on 'Temperature' and 'Solar irradiation'. These two factors (Temperature and Irradiation) respectively have inverse and direct relationship with generated output power. Therefore, Temperature and Irradiation factors play significant role during power generation process from solar PV system. Different irradiation levels across solar PV structure is termed as 'Partial Shading Conditions (PSC) or Non-homogenous irradiation'. In the present project work, variation of solar PV array output power with respect to irradiation level (at fixed temperature) is assessed. The PSC arises because of 'Neighboring buildings', 'Tall chimneys', 'Electric or Telephone poles' in the closed vicinity of solar PV plant. PSC may also arise due to 'Self-shading' of solar PV plant. The output power generated in solar PV array under uniform irradiation conditions involves a peak point corresponding to maximum power. Due to non-homogenous irradiation, generation of output power and efficiency of solar PV plant decreases.

This results in delay of the capital returns for investors. Therefore, enhancing the solar PV array power output, while array is subjected to PSC or non homogeneous effect is the most important challenge that has to be addressed to meet effective end-applications. To enhance power output of solar PV array under PCS, hybrid PV array interconnection schemes are recommended. Many authors have proposed various conventional interconnections for increasing total output generated power, specifically while nonhomogenous effects are prevailing. Each of the interconnection topologies has its particular advantages and disadvantages.

1.1 History:

The study of solar PV systems began in the mid-20th century when researchers focused on the fundamental operation of solar cells under uniform sunlight. With the increasing adoption of PV systems, it became evident that partial shading significantly impacted energy generation, as it caused mismatch losses and reduced overall system efficiency. In the late 20th century, efforts were directed toward understanding these shading effects, primarily through experimental approaches. However, as computational tools advanced, simulation methods became a key focus for assessing the performance of PV systems under real-world shading conditions.

By the early 2000s, tools like MATLAB/Simulink and PVSystem enabled researchers to simulate PV array performance under various shading scenarios. This period saw the exploration of basic topologies, such as series-parallel (SP) and total cross-tied (TCT) configurations, under partial shading conditions. Studies highlighted the limitations of traditional topologies, such as significant power losses and hot-spot risks, spurring interest in advanced configurations and shading mitigation techniques. Bypass diodes, dynamic reconfiguration, and improved maximum power point tracking (MPPT) algorithms became key areas of investigation during this time.

In recent years, simulation studies have evolved with the integration of artificial intelligence (AI) and machine learning (ML) to optimize PV array configurations and predict shading patterns. Hybrid simulation approaches, combining electrical and thermal modelling, have provided deeper insights into shading effects on power output and long-term module degradation. Researchers have also developed adaptive systems that reconfigure PV arrays in real time to mitigate shading losses. These advancements, supported by sophisticated simulation tools and real-world case studies, have cemented the role of simulation studies in designing efficient and reliable solar PV systems, even in complex shading environments.

1.2 Scope of work:

1. Simulation Framework:

The study will employ advanced simulation tools such as MATLAB/Simulink, PVSyst, or equivalent software to model and analyze the performance of different PV array topologies. The topologies under consideration will include series-parallel (SP), total cross-tied (TCT) configurations. Simulations will incorporate realistic shading scenarios, such as those caused by nearby structures, vegetation, or moving objects. A detailed analysis of electrical parameters, such as current-voltage (I-V) and power-voltage (P-V) characteristics, will be conducted to quantify the impact of shading.

2. Performance Metrics and Analysis:

Key performance indicators, including power output, fill factor, and efficiency, will be evaluated for each topology. The study will also compare the effectiveness of bypass diodes and maximum power point tracking (MPPT) techniques in mitigating shading effects. Sensitivity analysis will be performed to examine the impact of shading intensity, angle, and distribution on array performance. The findings will help establish correlations between shading patterns and performance variations across different array configurations.

3. Deliverables and Recommendations:

The outcomes of the simulation study will include comprehensive performance assessments and visual representations of results, such as I-V and P-V curves. The study will provide actionable recommendations for selecting optimal PV array topologies and shading mitigation strategies. These insights will be valuable for PV system designers, installers, and stakeholders aiming to maximize the efficiency and reliability of solar installations in diverse environmental settings.

1.3 Importance of the study:

The findings of this study are particularly important in light of the global transition toward renewable energy sources and the increasing deployment of solar PV systems in urban and rural environments. By identifying topologies that minimize power losses and improve shading resilience, the study contributes to the development of cost-effective and efficient PV systems. This research also supports policymakers, engineers, and system designers in making informed decisions about array configurations, shading mitigation technologies, and layout planning, ensuring long-term sustainability and performance of solar energy installations.

This research holds significant value for urban areas and regions where shading from trees, buildings, or other structures is unavoidable. By analyzing various array topologies and identifying those that perform best under shading, this study provides practical solutions to enhance the reliability and resilience of solar PV systems. Furthermore, it supports the development of innovative design strategies, aiding engineers and stakeholders in maximizing energy efficiency and reducing the environmental footprint of solar installations. The outcomes will directly contribute to advancing renewable energy technology and supporting global sustainability goals

1.4 Present Scenario:

In recent years, significant advancements have been made in simulation studies to understand and improve the performance of solar PV arrays under partial shading conditions. Researchers have developed detailed computational models using advanced software tools like MATLAB/Simulink, PVSyst, and PVlib. These tools enable precise simulation of real-world shading scenarios, including static shading caused by buildings and dynamic shading from moving objects. They also allow for the modeling of various array topologies, such as seriesparallel (SP), total cross-tied (TCT) configurations, under diverse environmental and operating conditions.

A key area of focus in these studies is the integration of shading mitigation technologies, such as bypass diodes, reconfigurable PV modules, and smart maximum power point tracking (MPPT) algorithms. Recent developments have also included the use of artificial intelligence (AI) and machine learning to predict shading patterns and optimize array performance in real time. Additionally, hybrid simulation approaches combining electrical and thermal modeling have emerged, providing deeper insights into the effects of partial shading on overall system performance, including temperature-related losses and degradation.

With the increasing deployment of solar PV systems in urban areas, there is growing interest in evaluating performance under complex and irregular shading patterns. Current studies are focusing on dynamic and adaptive topologies, where PV arrays can reconfigure themselves in response to shading. Such innovations represent a promising direction for improving energy efficiency, system reliability, and the economic feasibility of solar PV systems in challenging environments.

CHAPTER 2:

Literature Review

H.oufettoul 2023: In this paper, The research was inspired by observations at Morocco's Green Energy Park, where certain sections of PV panels consistently accumulated higher levels of soil and experienced more shading. This led the authors to investigate how different module orientations—specifically portrait versus landscape—affect the performance of PV systems under partial shading conditions. Utilizing simulations through PSIM and MATLAB, alongside practical tests, the study assessed the energy output of PV modules in both orientations. The findings revealed that modules arranged in a landscape orientation produced more power compared to those in a portrait configuration. For a modest PV system

N. Lamdihine: In this Paper, The authors focus on different PV array topologies, such as series-parallel (SP), total-cross-tied (TCT), bridge-linked (BL) configurations. They analyze how shading patterns, such as tree shadows, passing clouds, and nearby structures, influence power output and electrical performance. By comparing these configurations, the study aims to determine the optimal module arrangement that minimizes power losses and enhances energy yield under non-uniform irradiance conditions. A key aspect of the research is the use of simulation models and experimental validation to evaluate power generation efficiency. The authors employ MATLAB/Simulink to simulate PV array behavior under different shading conditions. The study also includes real-time experimental verification to support the theoretical findings. By combining numerical simulations with practical tests, the researchers ensure the reliability and accuracy of their results.

K.Abdulmawjood: In this paper, The study focuses on how shading conditions affect power output, efficiency, and the overall electrical characteristics of PV systems. Given that partial shading is one of the main challenges in solar energy systems, the authors analyze various shading scenarios and their influence on current-voltage (I-V) and power-voltage (P-V) curves, highlighting power losses. The research employs simulations and experimental validations to assess the shading impact on different PV configurations. The authors explore various bypass diode arrangements and reconfiguration techniques to mitigate shading effects and enhance energy yield. Their findings emphasize the importance of proper PV array design and management strategies to optimize performance under non-uniform solar irradiation conditions. The study provides valuable insights for improving the efficiency and reliability of solar power generation, making it useful for researchers, engineers, and industry professionals working on solar energy systems.

S.Kumaravel: In this paper, The authors emphasize that conventional PV array configurations suffer from power loss due to mismatched currents among the modules. This mismatch results in multiple peaks in the power-voltage (P-V) curve, making it difficult for maximum power point tracking (MPPT) algorithms to locate the global peak efficiently. To address this issue, the paper evaluates and compares several reconfiguration techniques and interconnection topologies that redistribute the shaded and unshaded modules in a way that minimizes the impact of partial shading. Among the different topologies analyze , the researchers focus on series-parallel (SP), total-cross-tied (TCT) configurations. Each topology is examined under different shading scenarios to determine its effectiveness in power enhancement. The results show that reconfigured topologies, particularly TCT and HC, perform significantly better in mitigating the power losses caused by shading. The TCT configuration, in particular, ensures a more even distribution of shading effects, leading to improved performance compared to traditional SP connections.

D. Prince Winston: In this paper, The research extensively compares conventional PV array topologies such as Series-Parallel (SP), Total Cross-Tied (TCT), Bridge-Linked (BL), and Honeycomb (HC) configurations. By conducting simulations and experimental validations, the study demonstrates that optimized interconnections can significantly improve power output and reduce shading-induced mismatches. The findings highlight that certain topologies, such as TCT and HC, offer better performance under complex shading scenarios by redistributing the mismatch losses effectively. This work is particularly relevant for large-scale solar installations where shading from trees, buildings, or clouds is unavoidable. The study contributes to the ongoing development of more efficient PV systems, making solar energy more viable and reliable in real-world applications.

B. Praveen Kumar: In this paper, The study by B. Praveen Kumar examines the impact of partial shading conditions (PSC) on solar photovoltaic (PV) arrays and proposes methods to enhance their performance. Partial shading leads to power loss and uneven energy distribution, reducing the overall efficiency of PV systems. The researchers analyze various PV array topologies to determine their effectiveness in mitigating shading effects. Their findings highlight the advantages of specific configurations in maintaining higher power output and improving reliability. This research is crucial for optimizing PV system design, ensuring better energy generation even under non-uniform shading conditions.

CHAPTER 3:

Objectives and Methodology

3.1 Objective:

In the proposed project work, the focus is to develop a Solar PV array topologies under Partial Shading Condition to reduce the Maximum Power Loss.

- Simulate model for Solar PV array topologies under normal and partial shading condition..
- Proposing interconnections schemes to reduce the MPL of SPV array, under PS condition.
- Compare the performance of each proposed hybrid interconnected configurations with that of various conventional configurations of SPV array.

3.2 Methodology:

3.2.1. Selection of Solar PV Array Topologies:

The first step in the methodology is to select various solar PV array topologies for evaluation. These topologies include traditional configurations like series-parallel (SP), as well as more advanced designs such as total cross-tied (TCT) configurations. Each topology is chosen for its potential to minimize the impact of partial shading on power output. The selection of these topologies is based on their ability to handle mismatch losses, reduce voltage drops, and improve energy generation efficiency under non-uniform irradiance conditions.

3.2.2. Shading Simulation and Modeling:

The next step involves simulating partial shading scenarios that may occur in realworld environments. Using simulation tools like MATLAB/Simulink or PVSyst, shading patterns are modeled based on factors like the position of obstacles (trees, buildings) and seasonal variations in sunlight. These models account for both static and dynamic shading conditions, where the shade moves or changes throughout the day.

3.2.3. Performance Analysis and Data Collection:

Once the shading scenarios are modeled, the performance of each solar PV array topology is analyzed. Key parameters, such as current-voltage (I-V) and power-voltage (P-V) characteristics, are obtained for each configuration under shaded conditions. The efficiency, energy yield, and mismatch losses are then evaluated, By using below formulas;

1. **Power Loss, ΔPl %** $= \frac{Pmpp - Ppsc}{Pmpp} \text{ x } 100$
2. **Fill Factor, FF %** $= \frac{Vmpp \text{ x Impp}}{Voc \text{ x Isc}} \text{ x } 100$
3. **Efficiency,** η **%** $= \frac{Vmpp \text{ x Impp}}{I \text{ x A}} \text{ x } 100$

3.2.4. Optimization and Recommendations:

Based on the performance analysis, optimization strategies are developed to enhance the efficiency of the solar PV systems. This can involve the implementation of techniques such as dynamic reconfiguration, advanced maximum power point tracking (MPPT) algorithms, or the integration of bypass diodes to mitigate shading effects. Recommendations are made regarding the most suitable array topologies for specific environmental conditions, helping system designers make informed decisions. The results of this simulation study serve as a guide for future PV system designs, ensuring optimal energy harvest and system reliability under partial shading conditions.

CHAPTER 4:

Implementation Methodology

4.1 Block Diagram:

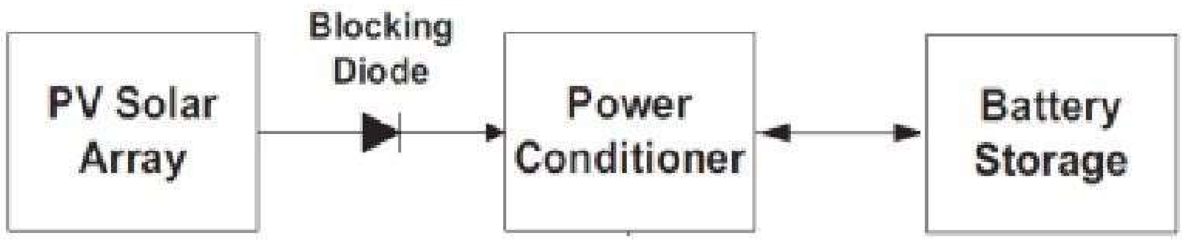

Fig 4.1 Block Diagram

Fig. 4.1 shows the basic block diagram of solar PV system. The various blocks of solar PV system are explained as follows,

1. PV Solar Array: A PV (Photovoltaic) array is a system of interconnected solar panels that convert sunlight into electricity.

2. Blocking Diode: A blocking diode is a unidirectional device that allows current to flow in one direction while preventing reverse current, commonly used for protection in circuits.

3. Power Conditioner: A power conditioner is a device that improves the quality of electrical power by regulating voltage, filtering noise, and protecting connected equipment from power surges and fluctuations.

4. Battery Storage: Battery storage refers to the technology that stores electrical energy in batteries for later use, enabling grid stability, renewable energy integration, and backup power.

4.2 Block Diagram Components Details:

4.2.1 PV Solar Array:

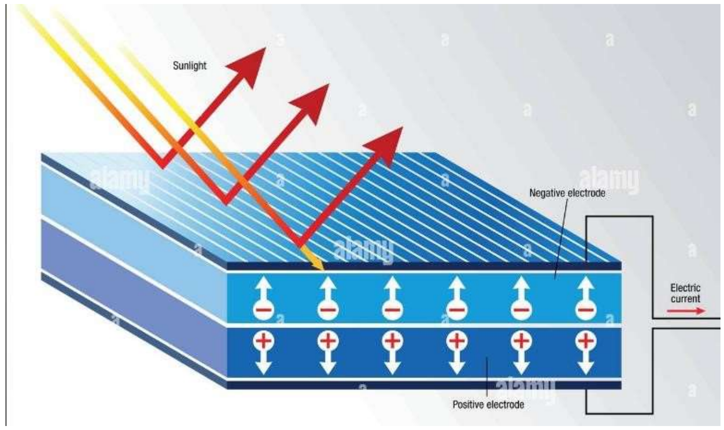

Fig. 4.2.1 – Solar array

Fig 4.2.1 shows a Solar array. A solar array is a collection of multiple solar panels connected together to increase the total power output. The panels can be connected in series, parallel, or a combination, depending on the desired voltage and current for the system.

Solar arrays convert sunlight into electricity through photovoltaic cells. The size of the array directly affects the energy production, with larger arrays generating more power to meet higher energy demands.

Solar arrays are scalable, meaning additional panels can be added to increase capacity, allowing the system to grow in size as energy needs increase or as new panels become available.

Working of Solar array

- The solar array is mainly responsible for passing the electric current to the solar inverter.
- When the sun rays fall on the surface of the solar panels, the silicon cells take the energy. Through their conductive properties, these silicon cells transform the sun rays into electricity.
- When this conversion happens, the electrons within the cells charge up and start moving restlessly. This motion forms the electric current which passes from the wires to the solar cell arrays.
- Through the cables, the arrays deliver direct current to the solar inverter. The solar inverter then converts the direct current to alternating current.

4.2.2 Blocking Diode:

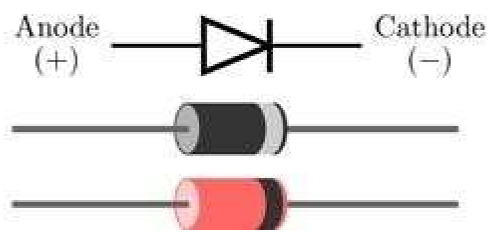

Fig. 4.2.2 – Blocking Diode

Fig 4.2.2 shows a Blocking Diode .A blocking diode stops electricity from flowing back into the solar panels when they are not generating power, such as at night. It protects the solar panels and other components from damage caused by reverse current. Blocking diodes cause a small voltage drop, slightly reducing the overall system efficiency.

4.2.3Power Conditioner:

Fig. 4.2.3 – Power Conditioner

Fig 4.2.3 shows a Power Conditioner. A power conditioner is used in solar energy systems to regulate the voltage and current, ensuring that the power output from the solar panels is stable and suitable for use by the connected appliances or grid.

It filters and smooths the electrical signals, removing noise, harmonics, or spikes, and ensuring that the power is clean and reliable, which enhances the performance and lifespan of the system.

4.2.4 Battery Storage:

Fig. 4.2.4 – Battery Storage

Fig 4.2.4 shows a Battery Storage. Battery storage systems store excess energy generated by solar panels during the day for use at night or during periods of low sunlight, helping ensure a consistent power supply.

Common types of batteries used in solar systems include lithium-ion (which are more efficient and have a longer lifespan) and lead-acid (which are more cost-effective but have a shorter lifespan and lower efficiency).

Lithium-ion batteries represent a more recent advancement in energy storage technology. These batteries utilize lithium ions as charge carriers between cathodes and anodes within their cells. For solar applications, Lithium Iron Phosphate (LiFePO4 or LFP) is the most commonly utilized type due to its stability and safety profile.

4.3 MATLAB:

The proposed project is simulated using MATLAB R2024a software.

Fig. 4.3.1 MATLAB LOGO

The name MATLAB stands for **MAT**rix **Lab**oratory. MATLAB was written originally to provide easy access to matrix software developed by the LINPACK (linear system package) and EISPACK (Eigen system package) projects.

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and a programming environment. Furthermore, MATLAB is a modern programming language environment: it has sophisticated data structures, contains built-in editing and debugging tools, and supports object-oriented programming. These factors make MATLAB an excellent tool for teaching and research.

MATLAB has many advantages compared to conventional computer languages (e.g., C, FORTRAN) for solving technical problems. MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. The software package has been commercially available since 1984 and is now considered a standard tool at most universities and industries worldwide

It has powerful built-in routines that enable a very wide variety of computations. It also has easy-to-use graphics commands that make the visualization of results immediately available.

Specific applications are collected in packages referred to as toolboxes. There are toolboxes for signal processing, symbolic computation, control theory, simulation, optimization, and several other fields of applied science and engineering.

MATLAB Simulink

For the mentioned project, MATLAB version R2024a is used to simulate.

Simulink is a simulation and model-based design environment for dynamic and embedded systems, which are integrated with MATLAB. Simulink was developed by a computer software company, MathWorks.

It is a data flow graphical programming language tool for modelling, simulating, and analysing multi-domain dynamic systems. It is basically a graphical block diagramming tool with a customizable set of block libraries.

Furthermore, it allows you to incorporate MATLAB algorithms into models as well as export the simulation results into MATLAB for further analysis.

Simulink supports the following functionalities:

- System-level design.
- Simulation.
- Automatic code generation.
- Testing and verification of embedded systems

To get started with Simulink, type **Simulink** in the command window.

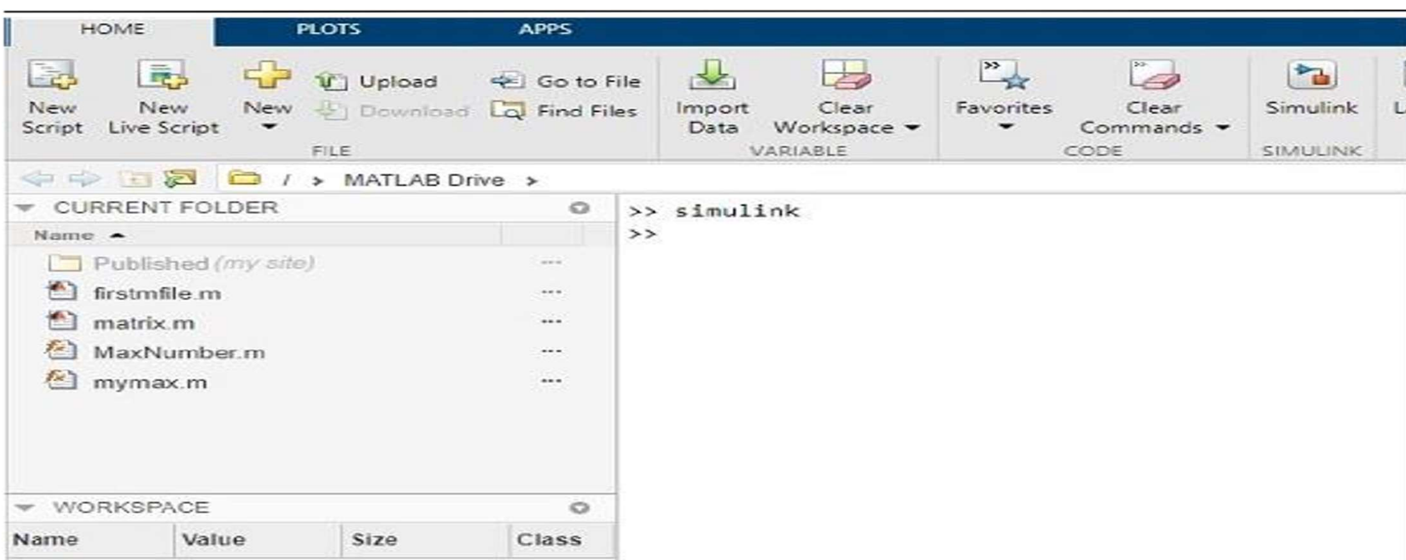

Fig 4.3.2 To Open Simulink

It will open the Simulink page as shown below –

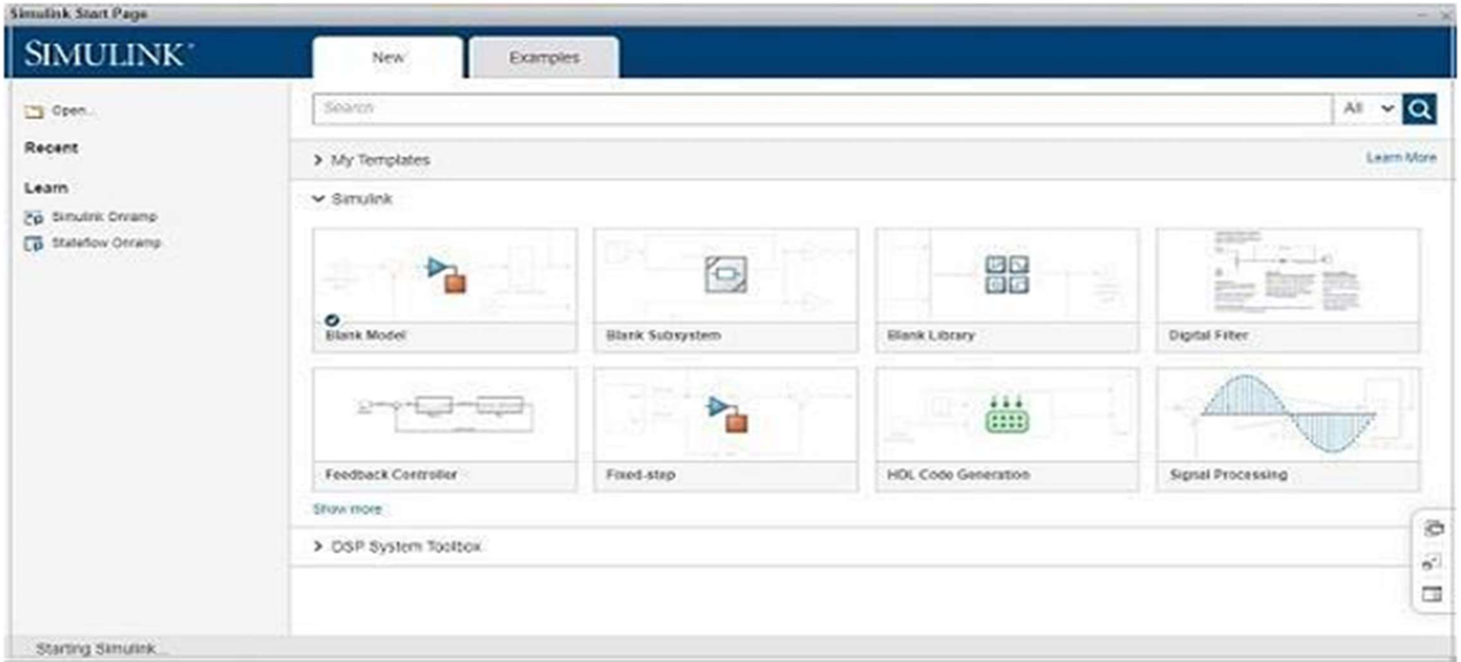

Fig 4.3.3 Simulink Start Page

You can also make use of Simulink icon present in MATLAB to get started with Simulink

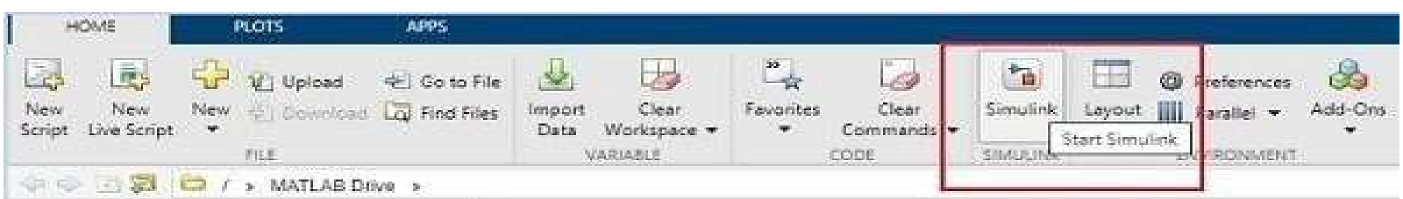

Fig.4.3.4 Simulink Icon

Here you can create your own model, and also make use of the existing templates. Click on the Blank Model and you will get a Simulink library browser that can be used to create your own model.

4.4 Simulink model of Solar PV Topology:

PV configurations/topologies are simulated in Matlab / Simulink for one uniform and 6 different shading cases.

The Simulink model for each type of topology connections are grouped into sub-system named as SPV topology and the sub-system model of SP, TCT connections as shown in Fig 4.4.1

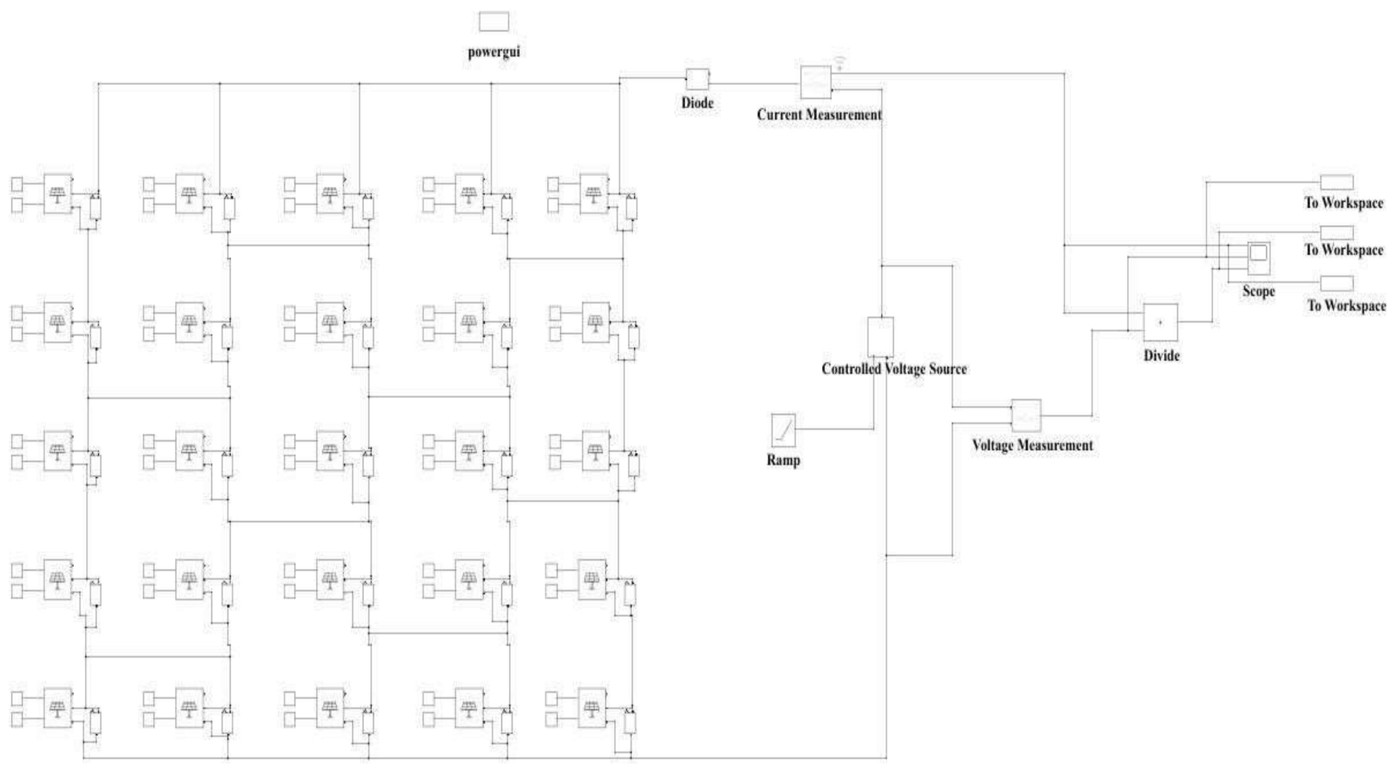

Fig.4.4.1 Simulink model of different PV topologies

4.5 Simulink Blocks Used in the Project Implementation :

4.5.1 Power Gui Block :

Fig.4.5.1 Discrete Gui Block

The power Gui block allows you to choose one of these methods to solve your circuit: Discrete, which uses a fixed step solver from Simulink ®.

- Ideal switching continuous.
- Discretization of the electrical system for a solution at fixed time steps.
- Phasor solution.

The power Gui block also opens tools for steady-state and simulation results analysis and for advanced parameter design.

You need the Power Gui block to simulate any Simulink model containing Supersystems™ Specialized Technology blocks. It stores the equivalent Simulink circuit that represents the statespace equations of the model.

4.5.2 PV array:

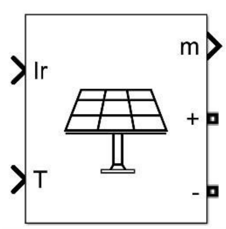

Fig.4.5.2 PV array

The PV Array block represents a photovoltaic array, which consists of multiple PV modules connected in series and parallel to form an array. The block models the electrical behavior of the array based on parameters such as irradiance, temperature, and module characteristics.

4.5.3 Constant Block:

Fig.4.5.3 Irradiance and Temperature constant block

The Constant block in MATLAB Simulink provides a fixed value output throughout a simulation, making it ideal for modeling steady conditions like irradiance, temperature, or shading coefficients in solar PV studies.

It supports various data types (e.g., scalar, vector) and integrates with other blocks like PV modules or MPPT controllers. In partial shading simulations, it can assign specific shading or irradiance values to modules in the array.

Users can configure the block's value, data type, and sample time for specific needs. This block ensures consistent, repeatable inputs for analyzing the performance of PV array topologies.

4.5.4 Ramp Generator:

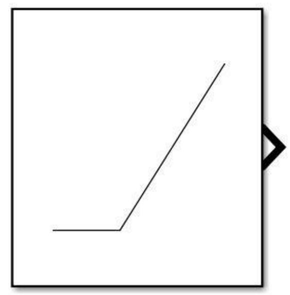

Fig.4.5.4 Ramp Generator

The Ramp block in MATLAB Simulink generates a signal that increases or decreases linearly over time. It is commonly used to simulate gradually changing conditions, such as increasing solar irradiance, temperature, or load in solar PV studies. The ramp's slope, start time, and initial value can be configured for specific scenarios. This makes it useful for analyzing the dynamic performance of PV systems under varying environmental conditions.

4.5.5 Diode:

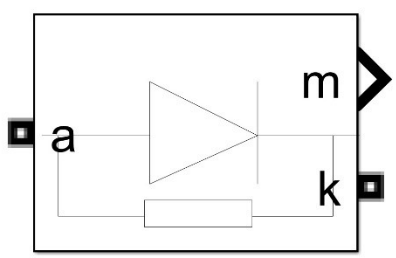

Fig.4.5.5 Diode

A diode is a semiconductor device that allows current to flow in only one direction while blocking it in the opposite direction. It consists of a p-n junction, where the p-side (anode) is connected to a positive voltage and the n-side (cathode) to a negative voltage for conduction. When forward-biased, it permits current flow, but in reverse bias, it blocks current, except for a small leakage current. Diodes are widely used in rectifiers, voltage regulators, signal modulation, and protection circuits. Special types of diodes include Zener diodes, LED (Light Emitting Diodes), and Schottky diodes.

4.5.6 Current Measurement Block:

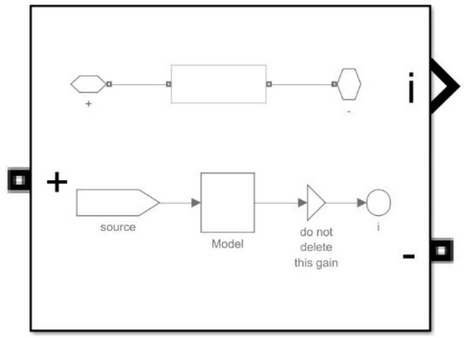

Fig.4.5.6 Current Measurement Block

The current measurement block is used measures the electrical current in a circuit or component, providing the value as an output for monitoring or control purposes. Commonly used in simulations and real systems to observe current behavior.

4.5.7 Voltage Measurement Block:

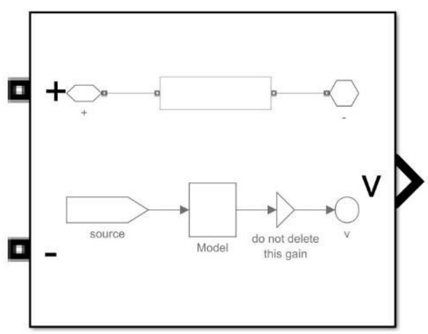

Fig.4.5.7 Voltage Measurement Block

A Voltage Measurement Block is used to measure the electrical potential difference between two points in a circuit. It is commonly found in circuit simulation tools like MATLAB/Simulink and real-world measuring instruments such as voltmeters and oscilloscopes. The block is connected in parallel with the component or section where voltage needs to be measured. It typically has high input impedance to avoid interfering with the circuit operation. Voltage measurement can be AC or DC, depending on the application. In simulations, it helps analyze circuit behavior in real-time. Such blocks are essential in power systems, control circuits, and electronic testing setups.

4.5.8 Controlled Voltage Source:

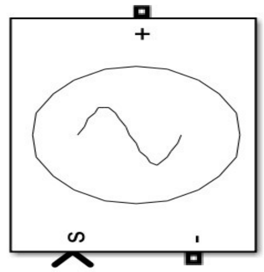

Fig.4.5.8 Controlled Voltage Source

The Controlled Voltage Source block in MATLAB Simulink generates a voltage output based on an external input signal, allowing dynamic control of the voltage. It is useful for simulating power systems, such as emulating the output of solar PV modules under varying shading or irradiance conditions. The block provides flexibility for modeling time-dependent or feedback-controlled voltage behavior in solar PV studies.

4.5.9 Divide Block:

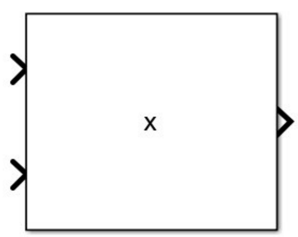

Fig.4.5.9 Divide Block

The Divide block in MATLAB Simulink performs element-wise division of two input signals, outputting the result as a quotient. It is often used to compute ratios, such as power per unit irradiance or efficiency in solar PV studies. The block supports scalar, vector, or matrix inputs, allowing flexibility in system modeling. It ensures smooth simulation by handling division operations dynamically. Proper input configuration is essential to avoid division by zero errors during simulations.

4.5.10 Scope:

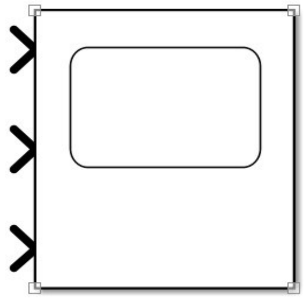

Fig.4.5.10 Scope

The Scope block in MATLAB Simulink is used to visualize signals during simulations, displaying waveforms in real time. It is essential for analyzing system behavior, such as voltage, current, or power outputs in solar PV studies. The block supports multiple input signals, enabling users to compare performance metrics like shading effects across different PV topologies. It offers features like zoom, scaling, and cursors for detailed waveform analysis. The Scope block is a critical tool for debugging and validating simulation results.

4.5.11 To Work Space Block:

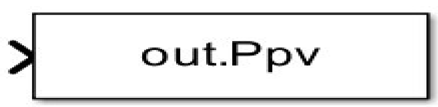

Fig.4.5.11 To Work Space Block

The To Workspace block in MATLAB Simulink saves simulation data to the MATLAB workspace for post-processing and analysis. It allows users to store signal data, such as voltage, current, or power, for detailed evaluation after the simulation ends. The block supports different data formats, including arrays, structures, or time series, making it versatile for various analysis needs. It is commonly used in solar PV studies to analyze results like shading effects or performance metrics over time. Proper configuration of variable names and data types ensures seamless integration with MATLAB scripts and functions.

CHAPTER 5:

Result and Discussion

5.1 Modeling and Simulation Of PV Array Configruation:

5.1.1 Series:

5.1.1.1 For 1000 W/m^2

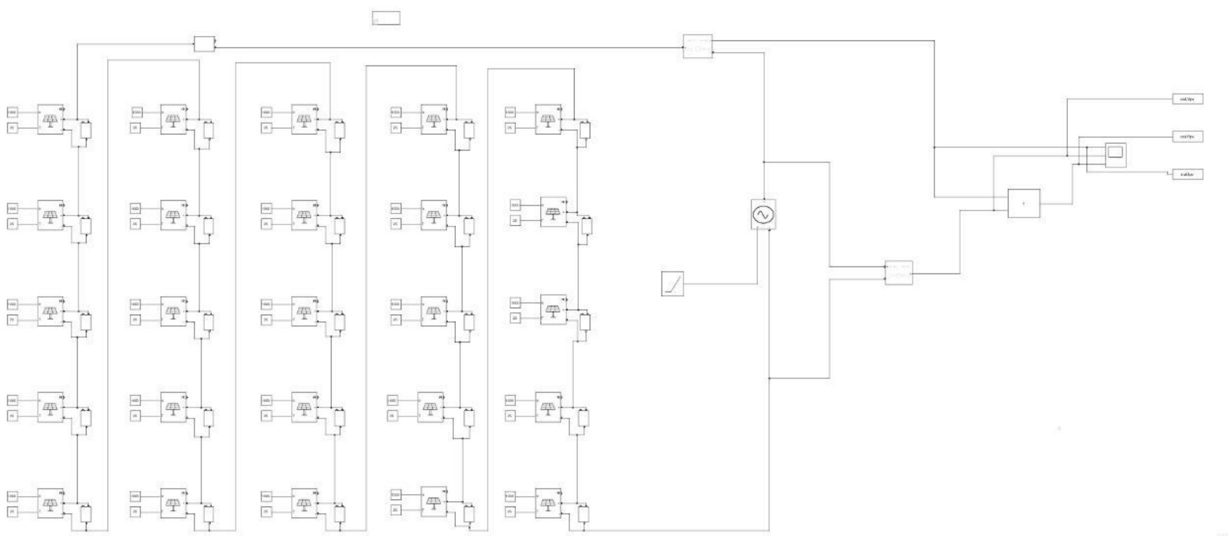

Fig.5.1.1 MATLAB/Simulink model of 5 × 5 Series (S) PV array configuration.

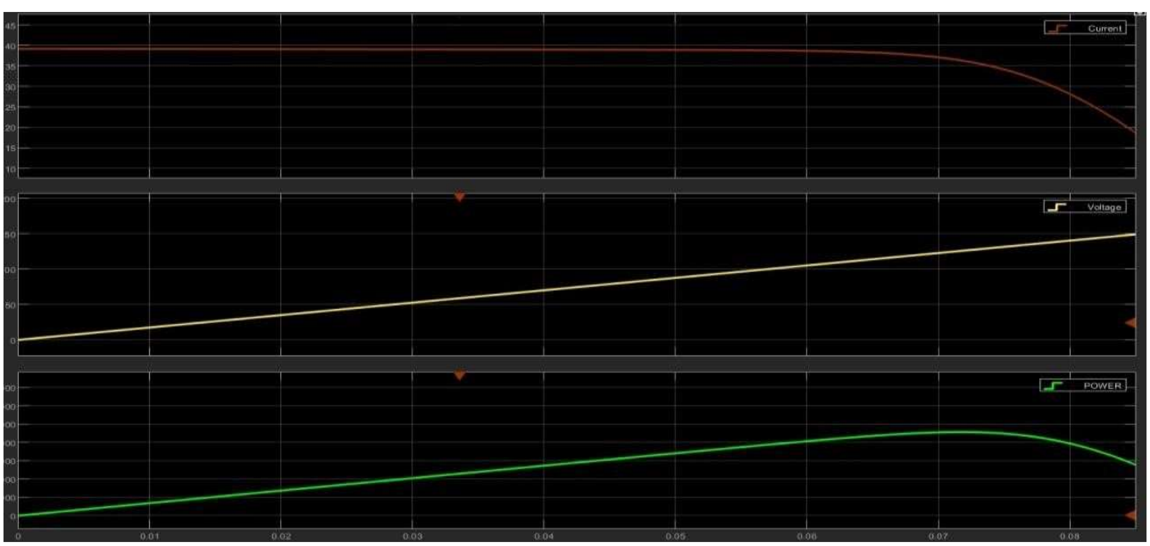

Fig.5.1.2 Simulated output of Series (S) PV array configuration.

5.1.1.2 For 800 W/m^2

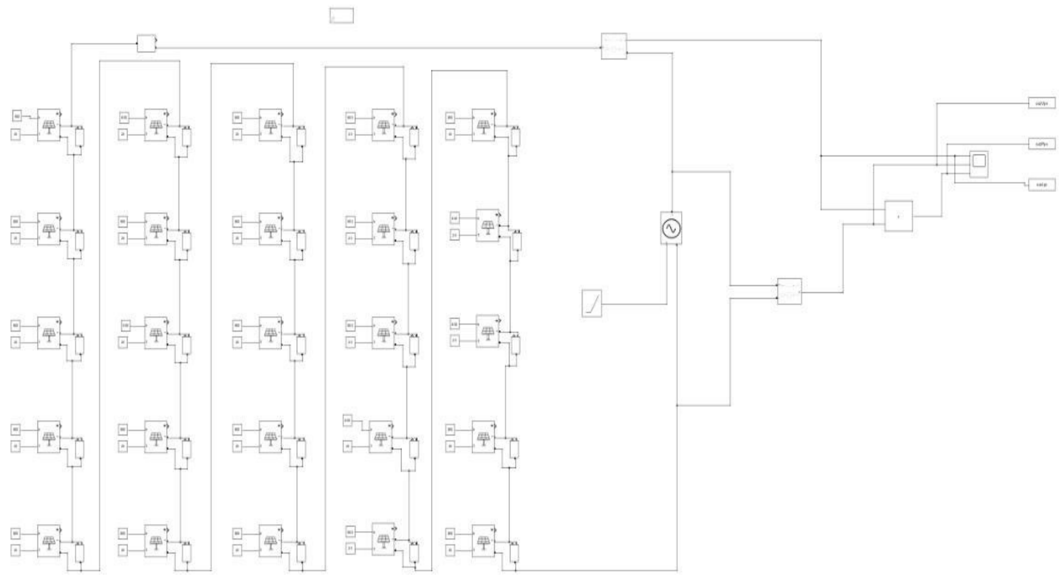

Fig.5.1.3 MATLAB/Simulink model of 5 × 5 Series (S) PV array configuration.

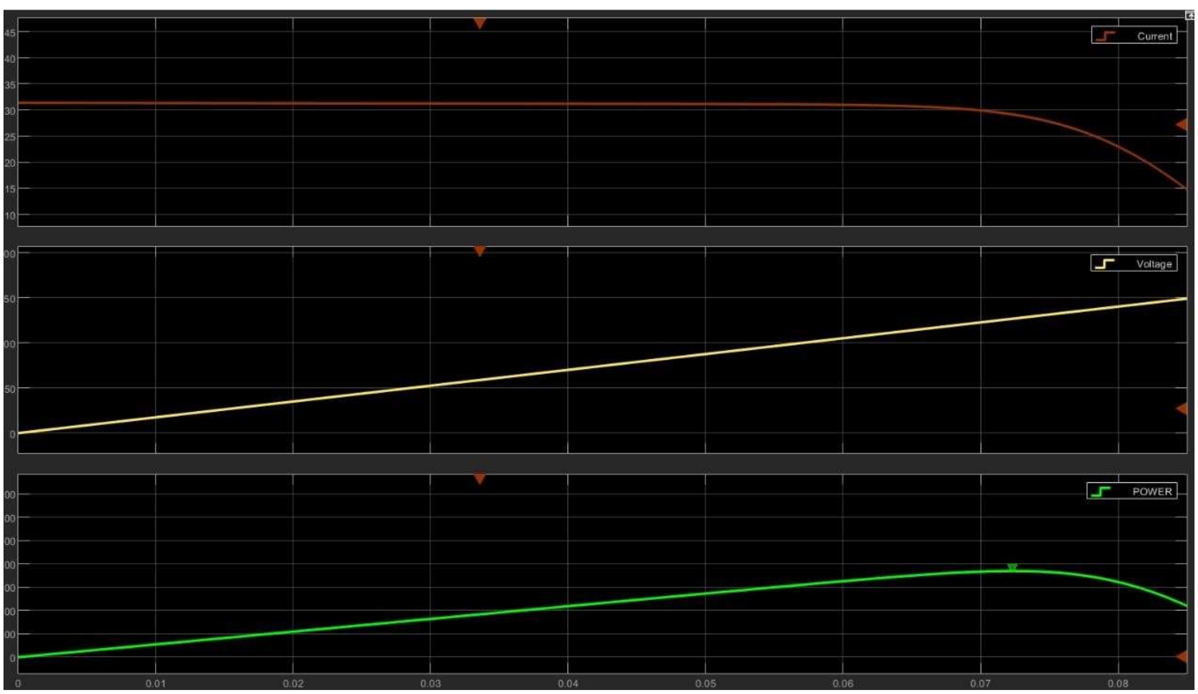

Fig.5.1.4 Simulated output of Series (S) PV array configuration.

5.1.1.3 For 600 W/m^2

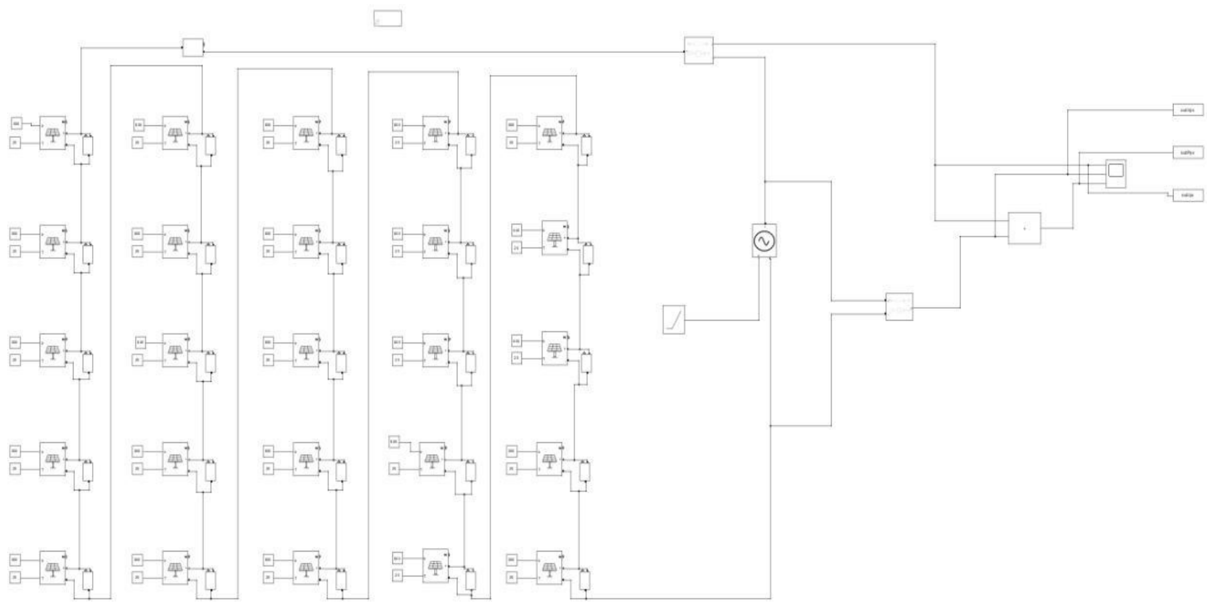

Fig.5.1.5 MATLAB/Simulink model of 5 × 5 Series (S) PV array configuration.

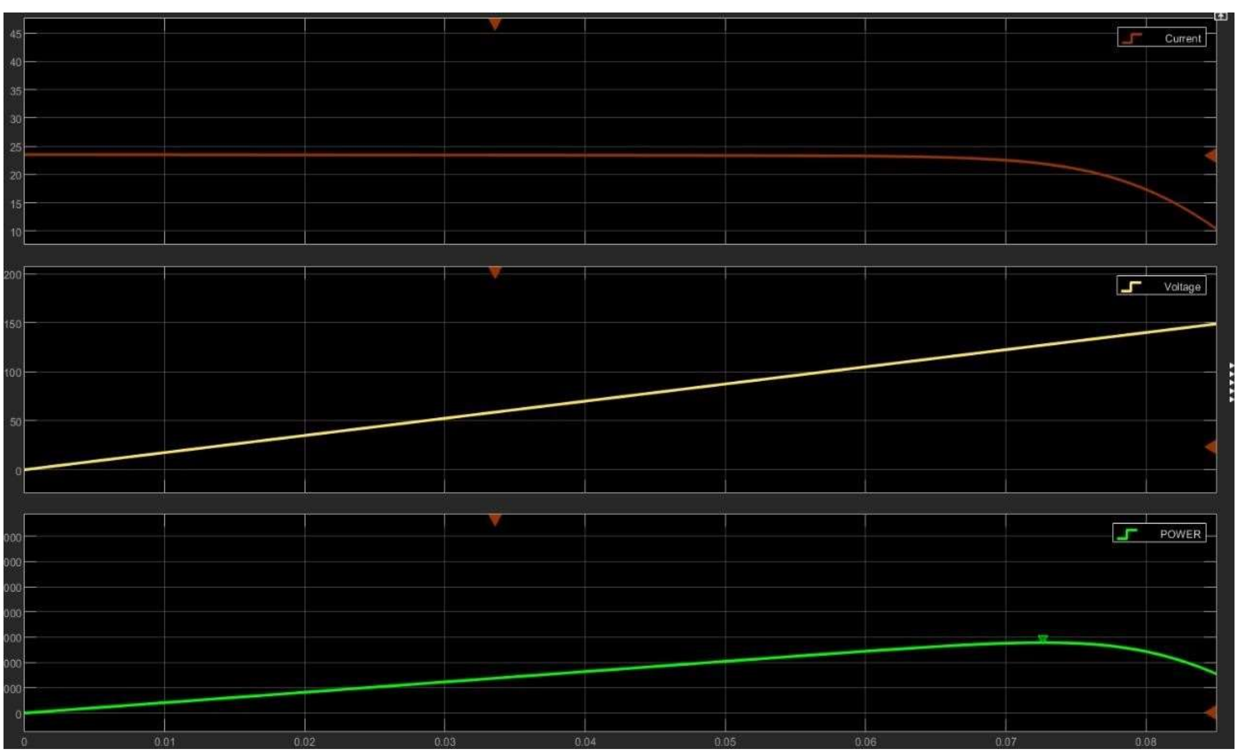

Fig.5.1.6 Simulated output of Series (S) PV array configuration.

5.1.1.4 For 400 W/m^2

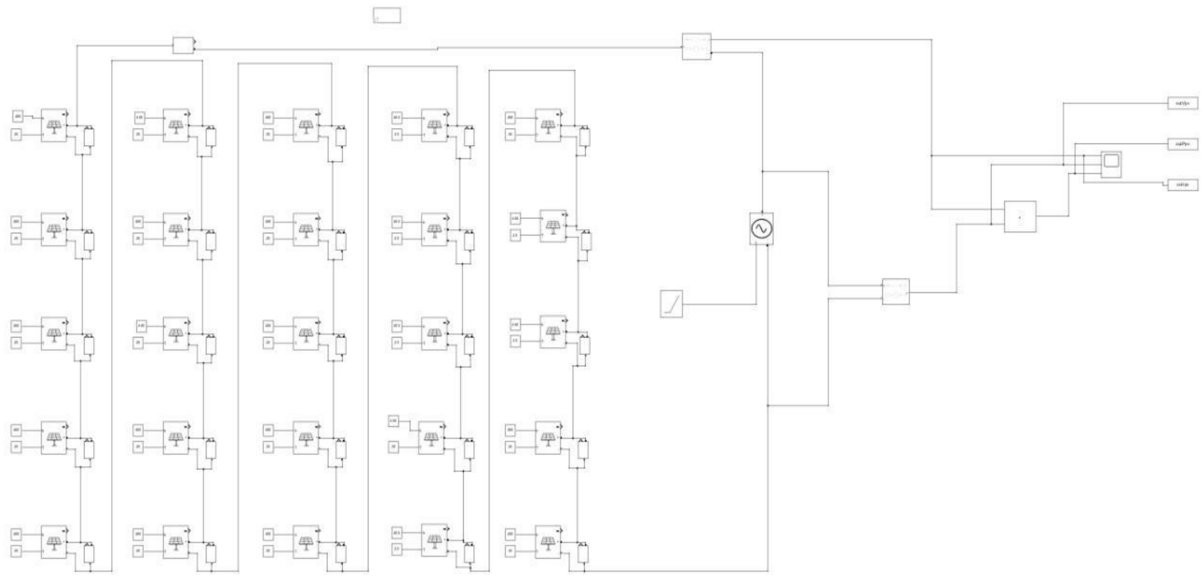

Fig.5.1.7 MATLAB/Simulink model of 5 × 5 Series (S) PV array configuration.

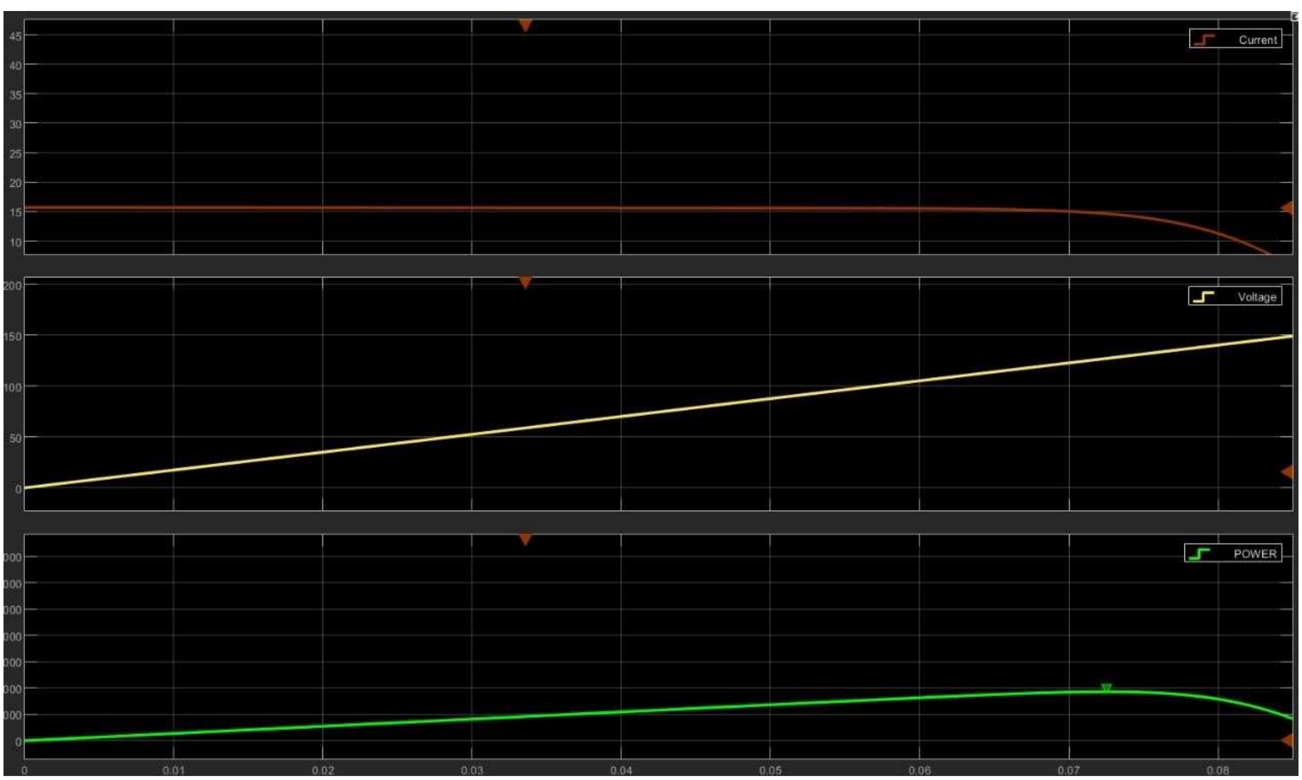

Fig.5.1.8 Simulated output of Series (S) PV array configuration.

5.1.1.5 For 200 W/m^2

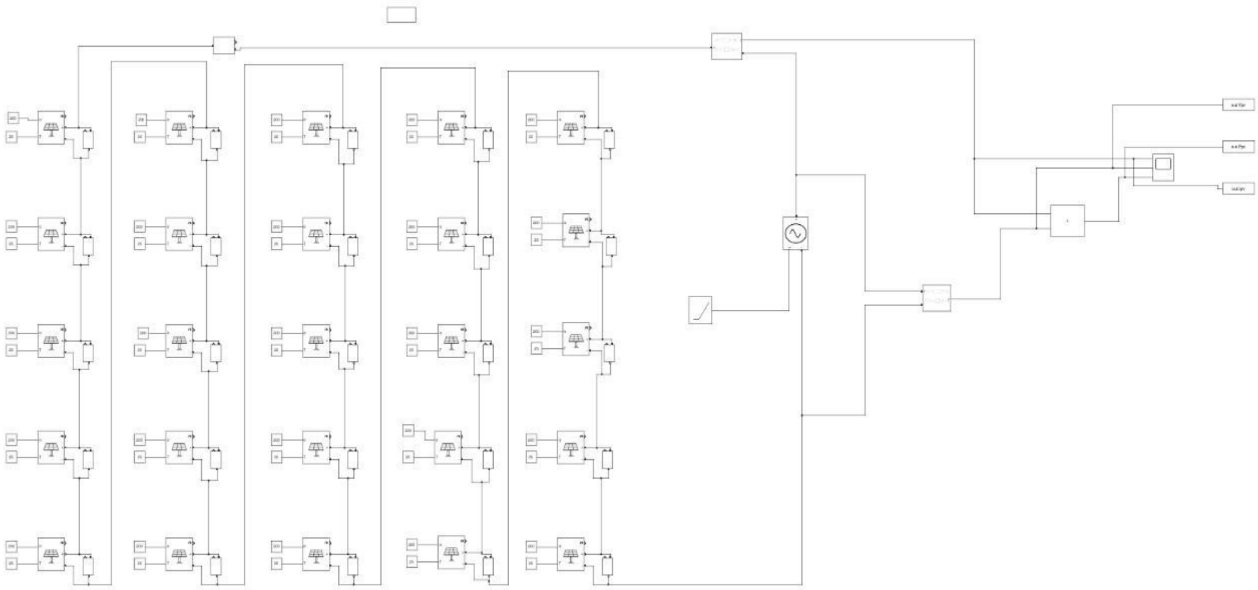

Fig.5.1.9 MATLAB/Simulink model of 5 × 5 Series (S) PV array configuration.

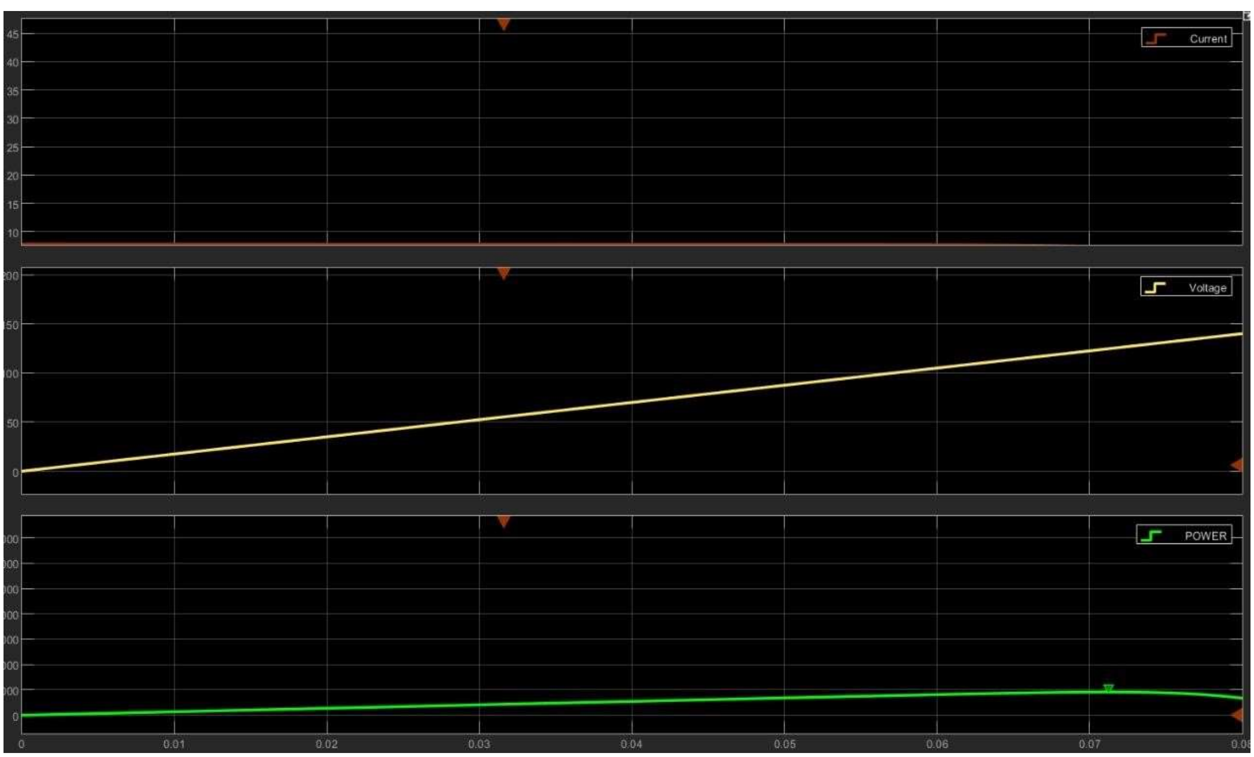

Fig.5.1.10 Simulated output of Series (S) PV array configuration

5.1.1.6 For Centre Shading Pattern

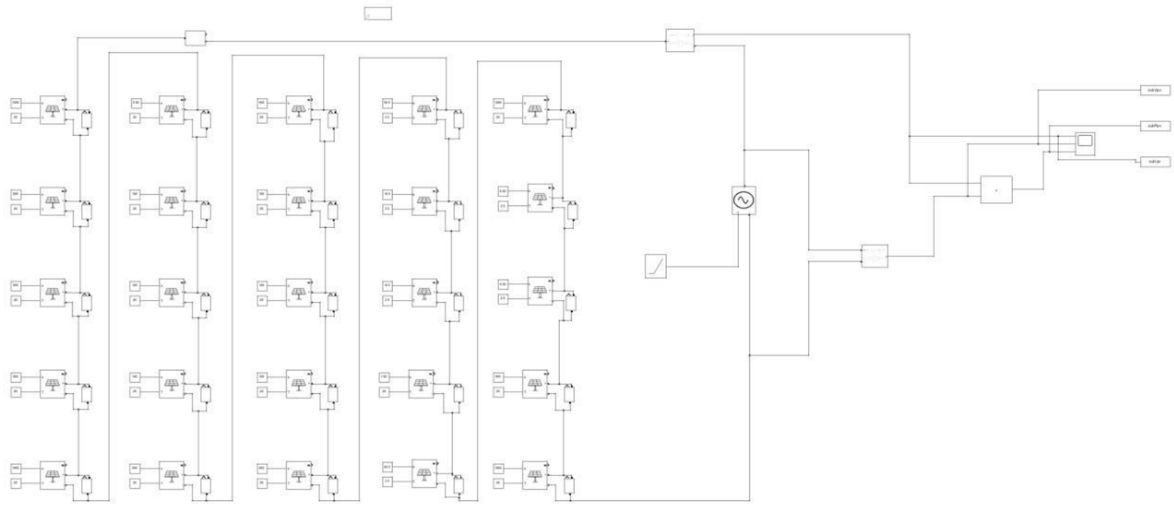

Fig.5.1.11 MATLAB/Simulink model of 5 × 5 Series (S) PV array configuration.

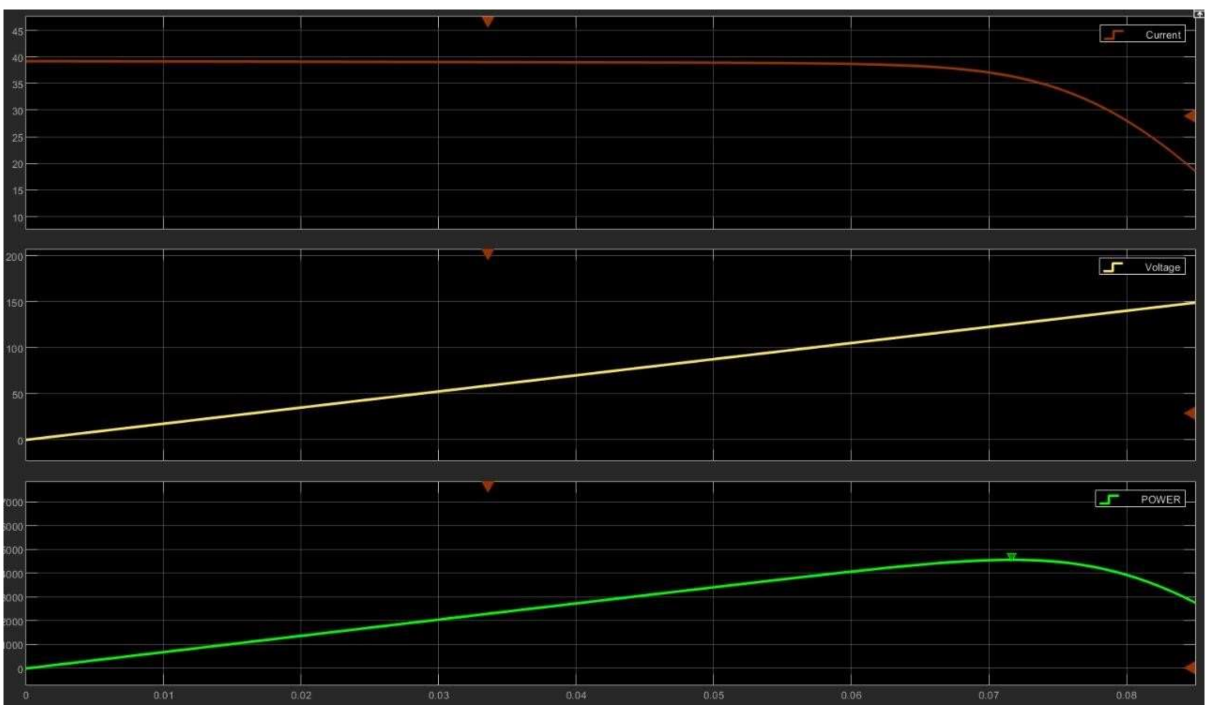

Fig.5.1.12 Simulated output of Series (S) PV array configuration.

5.1.1.7 For Middle Shading Pattern

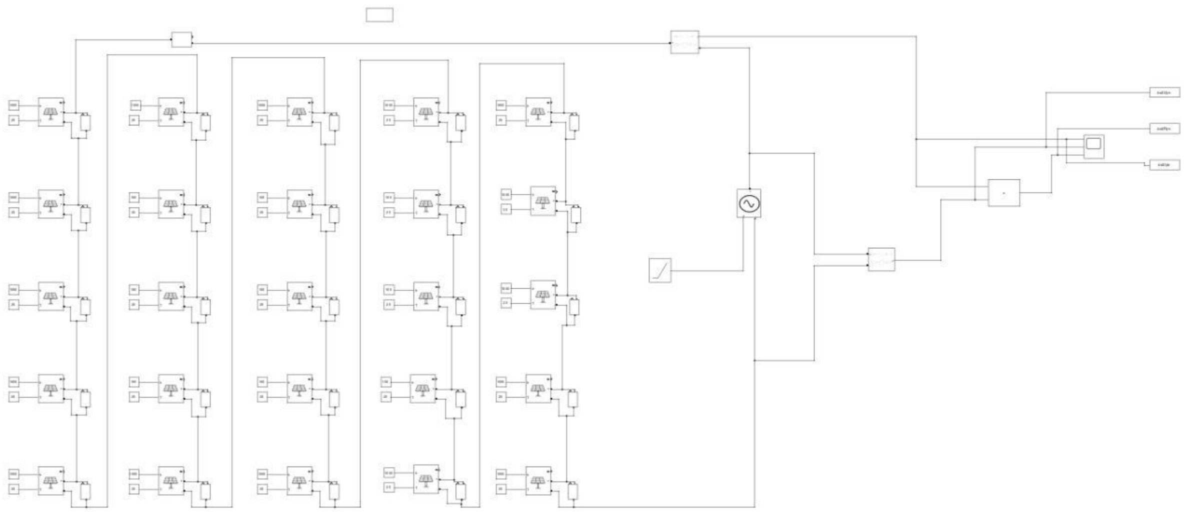

Fig.5.1.13 MATLAB/Simulink model of 5 × 5 Series (S) PV array configuration.

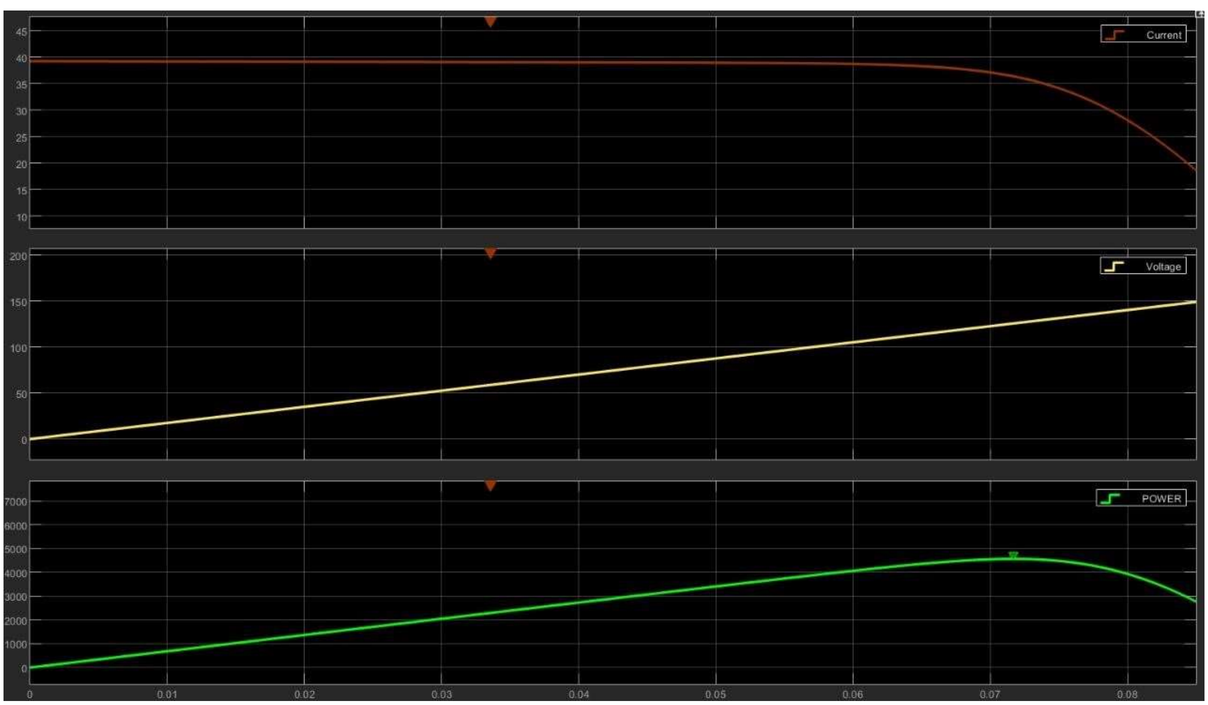

Fig.5.1.14 Simulated output of Series (S) PV array configuration.

5.1.1.8 For Narrow Shading Pattern

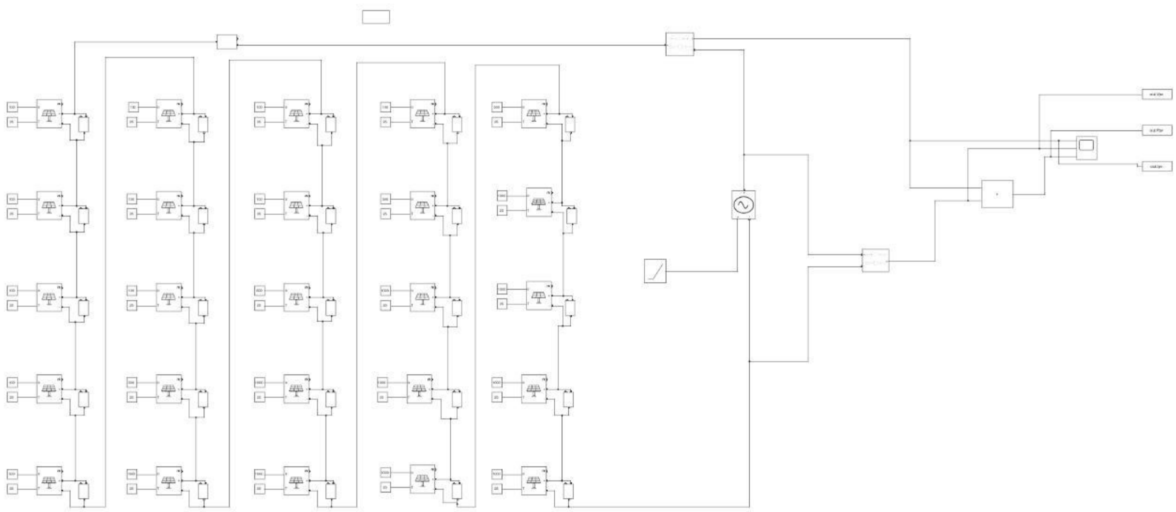

Fig.5.1.15 MATLAB/Simulink model of 5 × 5 Series (S) PV array configuration.

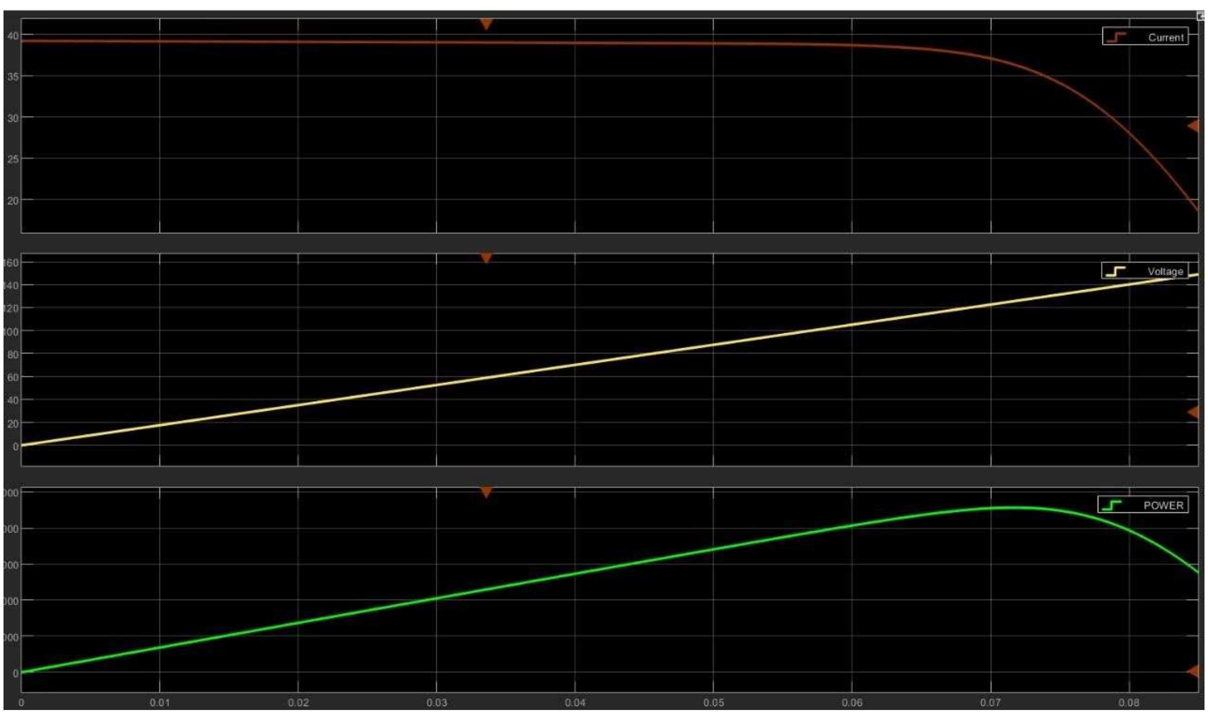

Fig.5.1.16 Simulated output of Series (S) PV array configuration.

5.1.1.9 For Row Shading Pattern

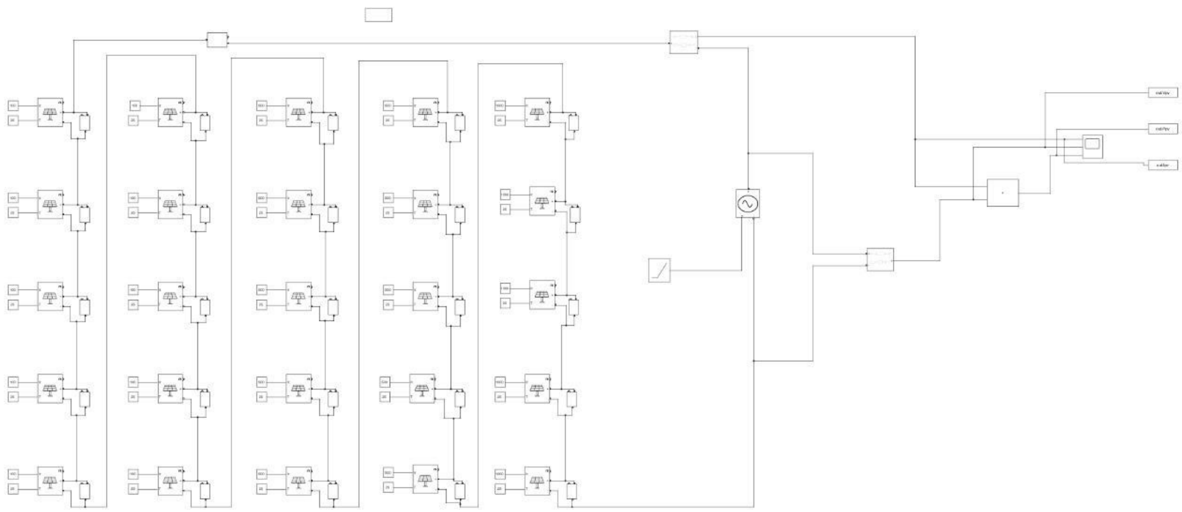

Fig.5.1.17 MATLAB/Simulink model of 5 × 5 Series (S) PV array configuration.

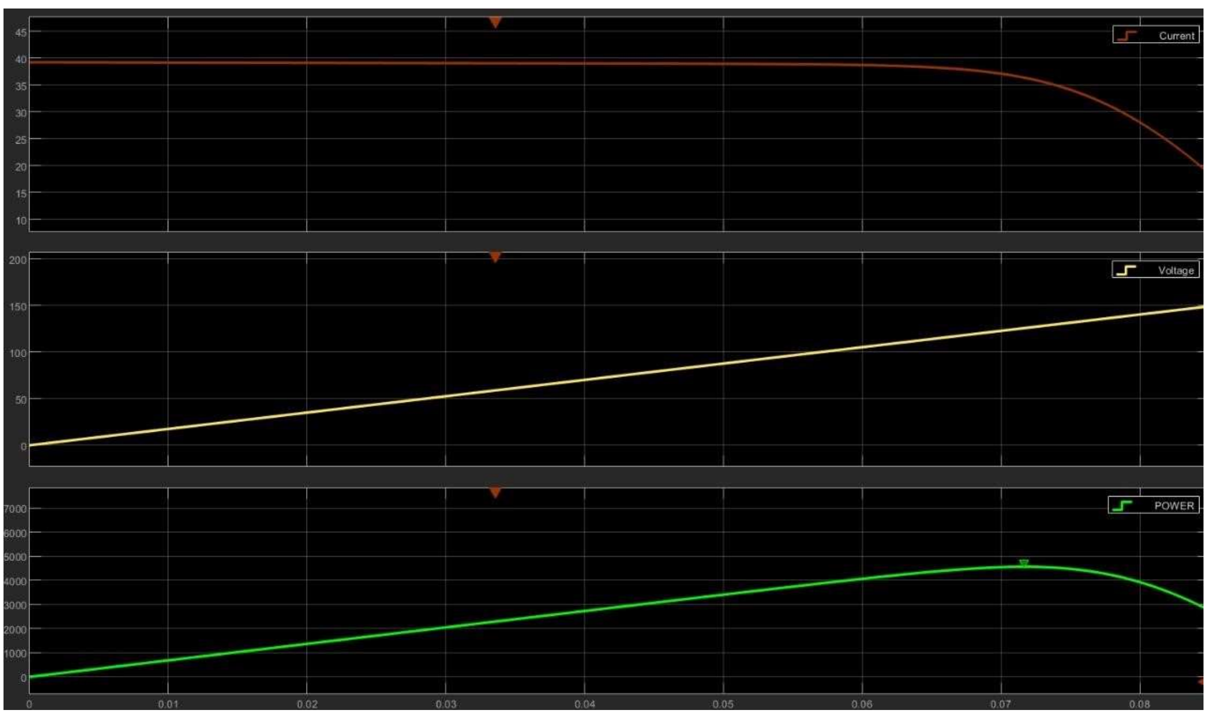

Fig.5.1.18 Simulated output of Series (S) PV array configuration.

5.1.1.10 For Wide Shading Pattern

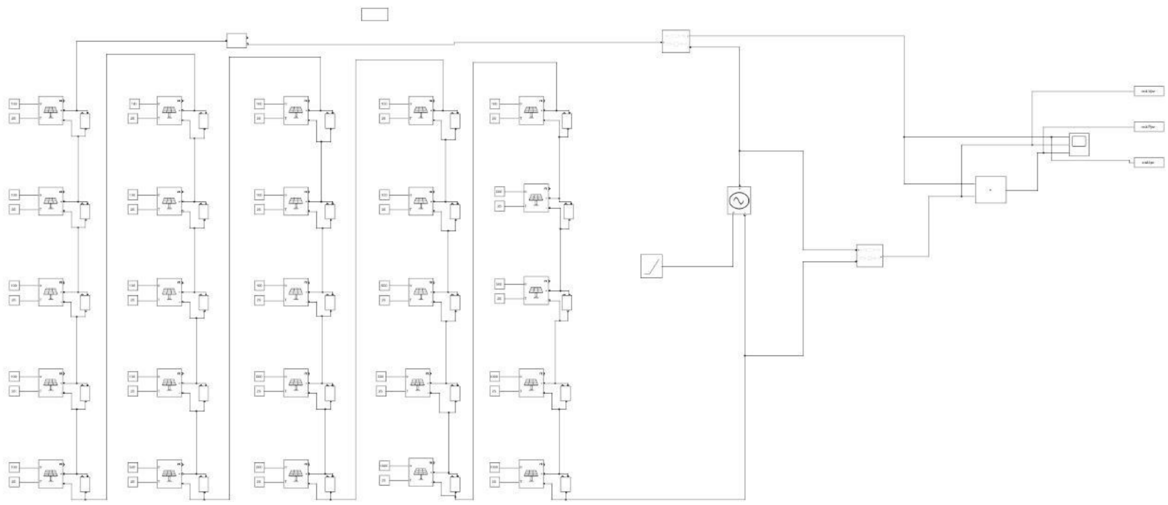

Fig.5.1.19 MATLAB/Simulink model of 5 × 5 Series (S) PV array configuration.

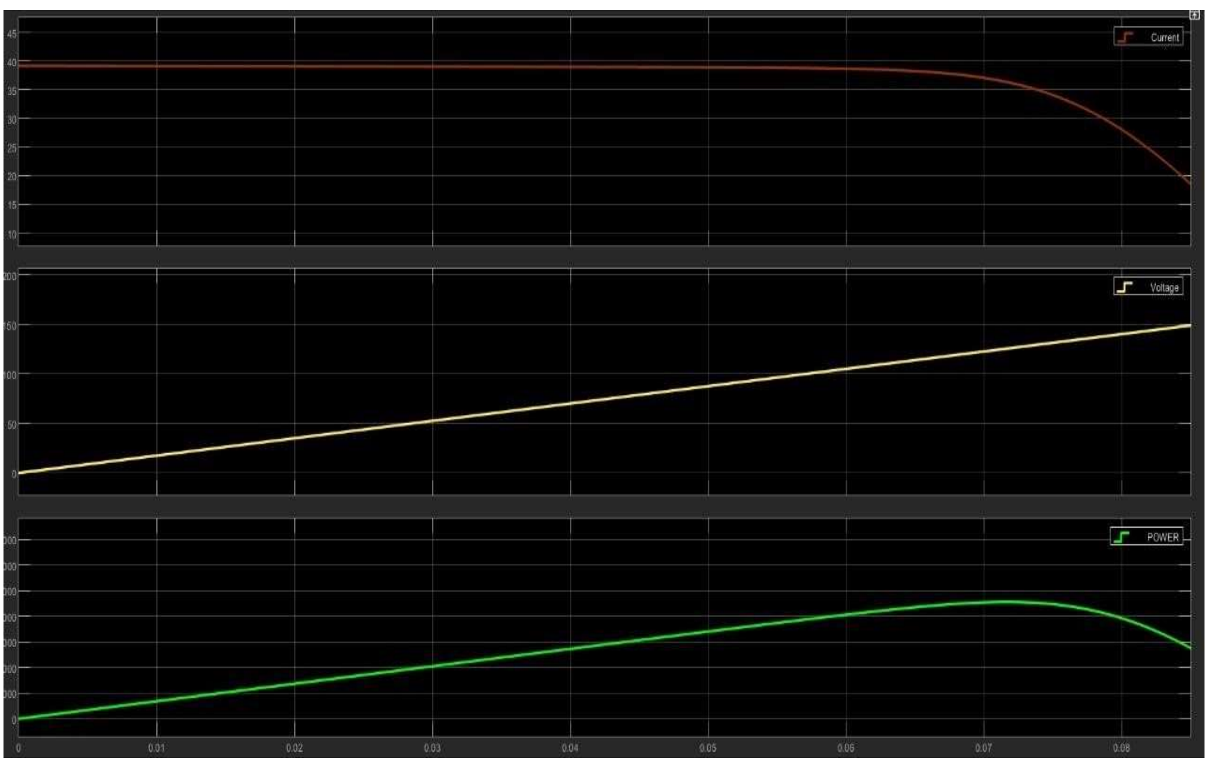

Fig.5.1.20 Simulated output of Series (S) PV array configuration.

5.1.1.11 For Random Shading Pattern

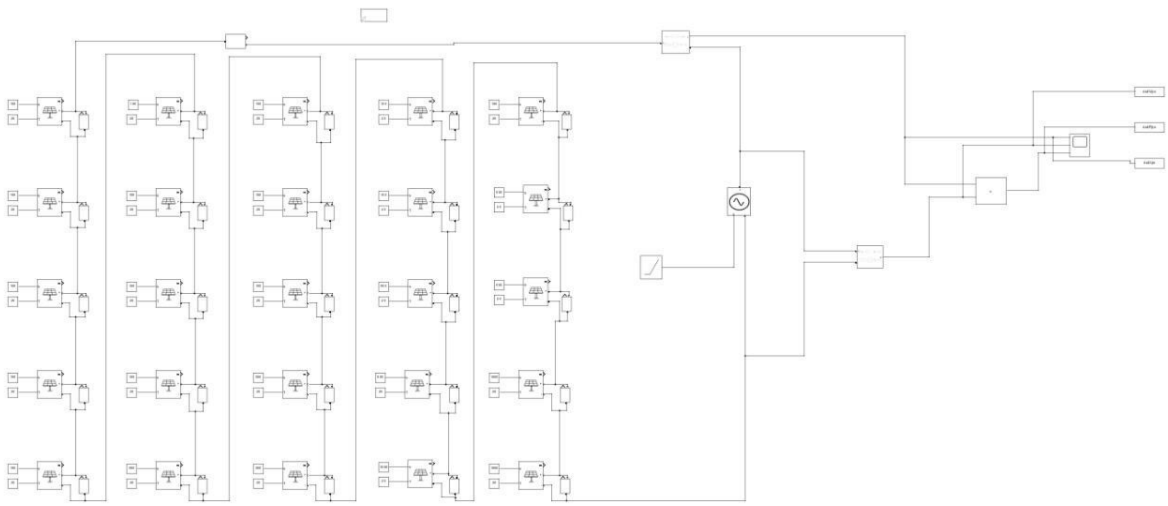

Fig.5.1.21 MATLAB/Simulink model of 5 × 5 Series (S) PV array configuration.

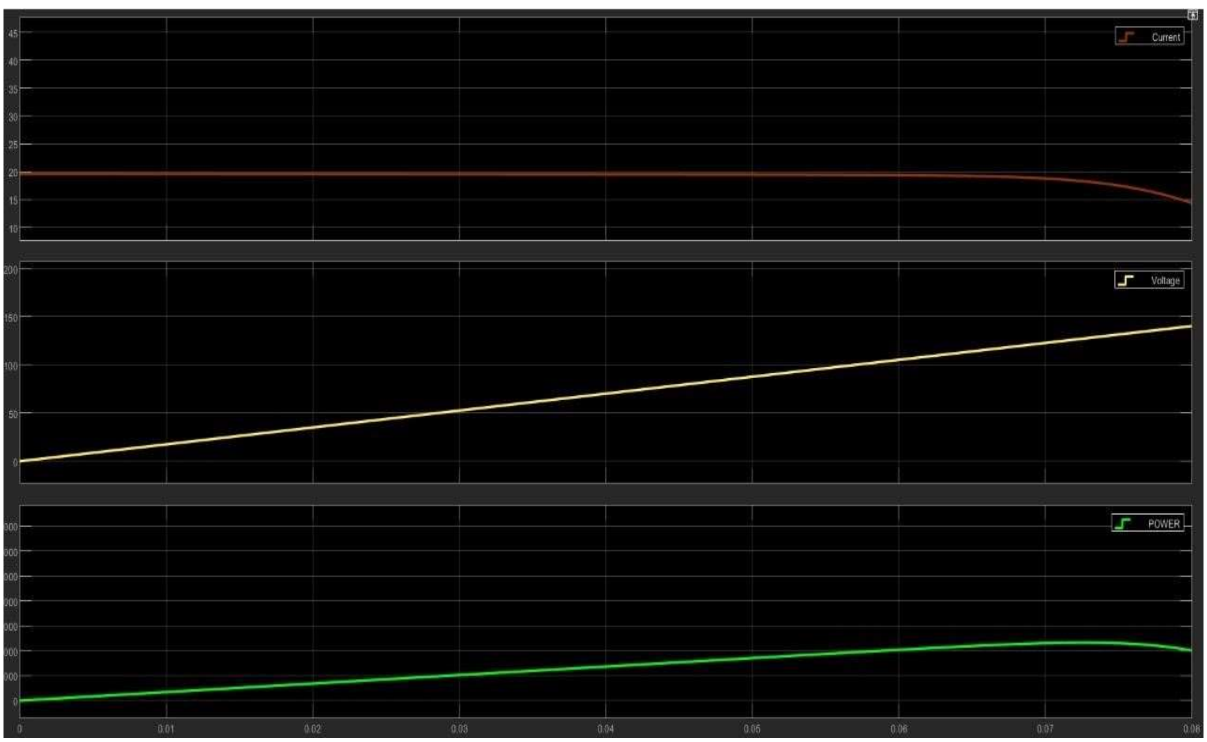

Fig.5.1.22 Simulated output of Series (S) PV array configuration.

5.1.2 Series-Parallel:

5.1.2.1 For 1000 W/m^2

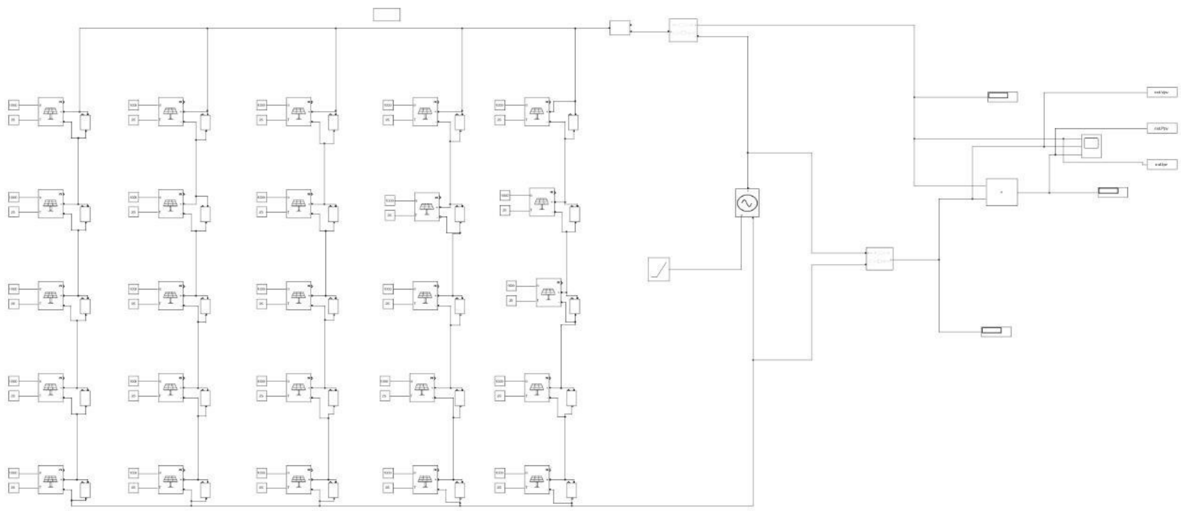

Fig.5.2.1 MATLAB/Simulink model of 5 × 5 Series-parallel PV array configuration.

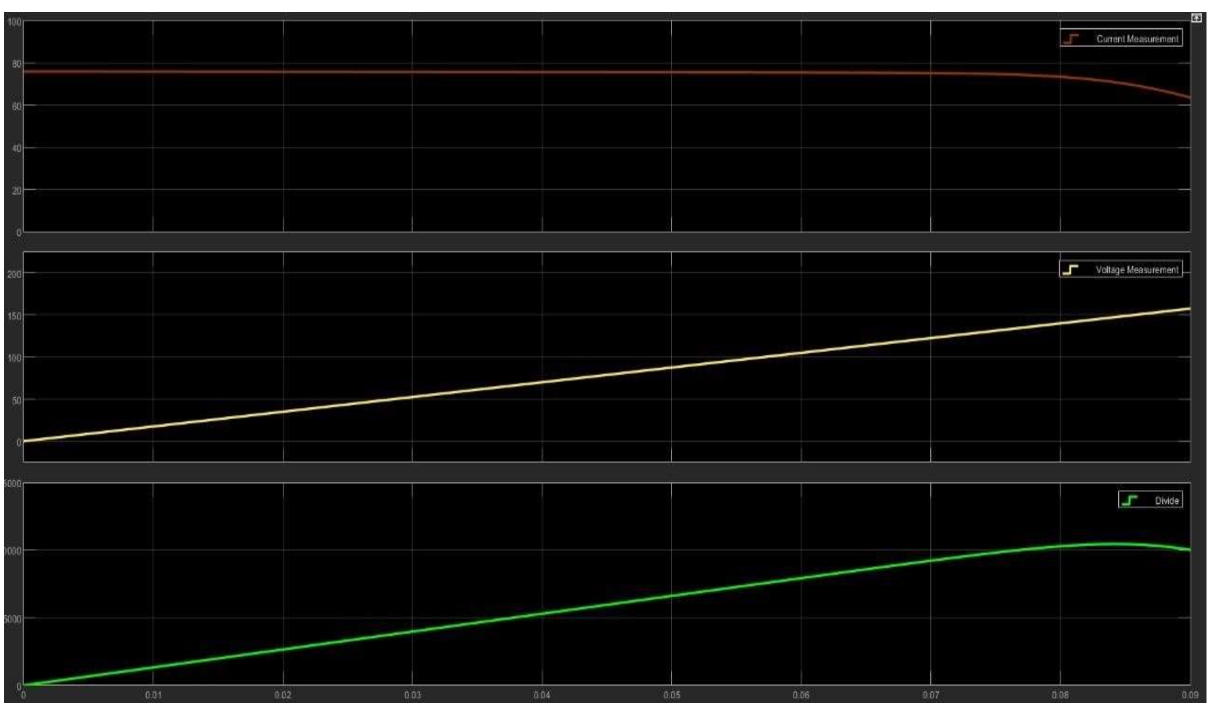

Fig.5.2.2 Simulated output of Series-Parallel (SP) PV array configuration.

5.1.2.2 For 800 W/m^2

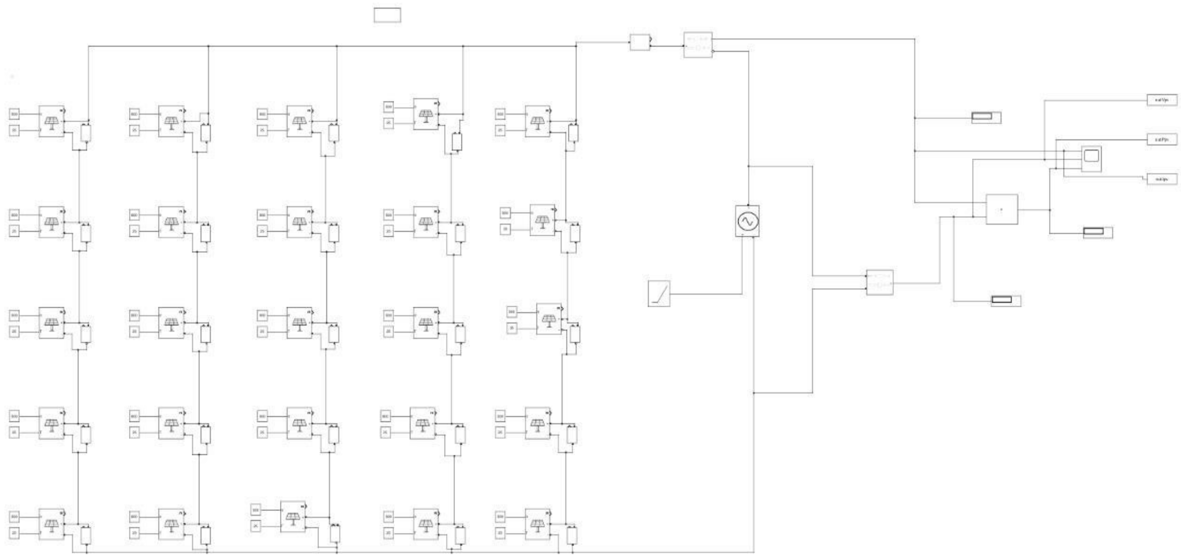

Fig.5.2.3 MATLAB/Simulink model of 5 × 5 Series-parallel PV array configuration.

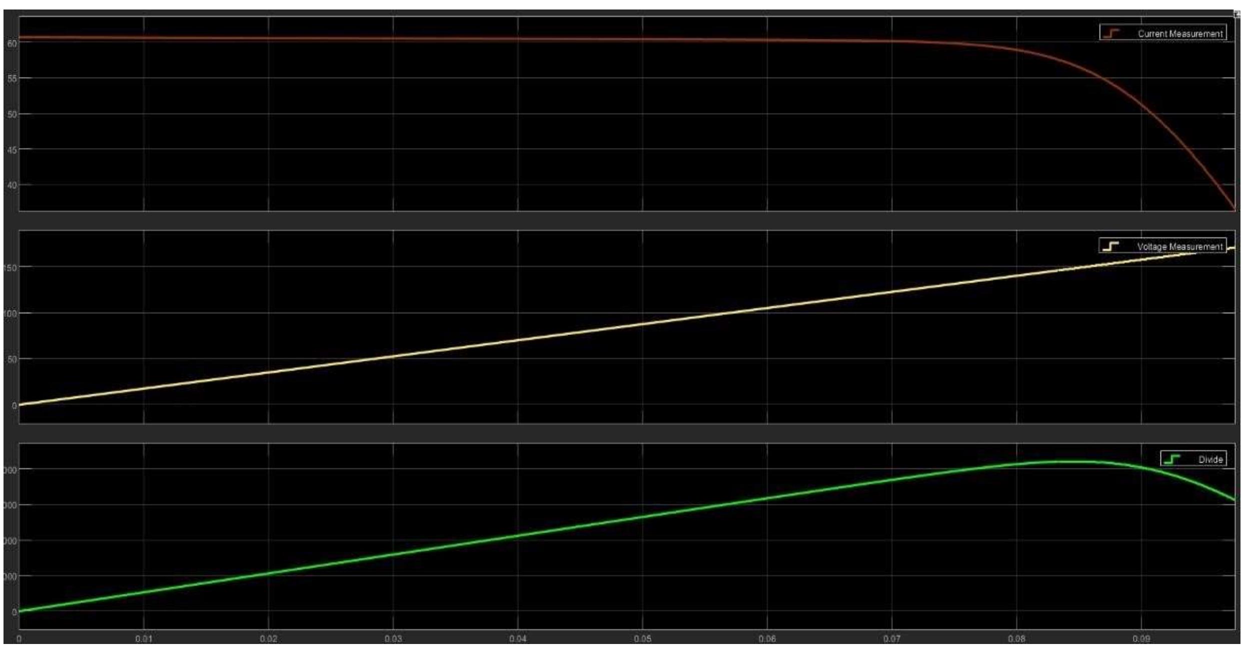

Fig.5.2.4 Simulated output of Series-parallel (SP) PV array configuration.

5.1.2.3 For 600 W/m^2

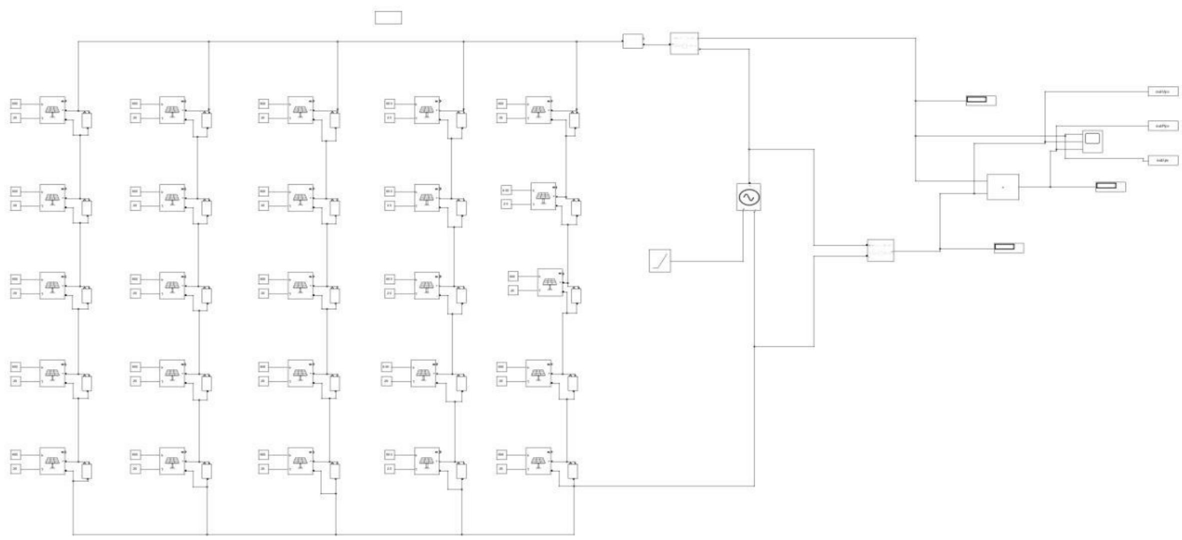

Fig.5.2.5 MATLAB/Simulink model of 5 × 5 Series-parallel PV array configuration.

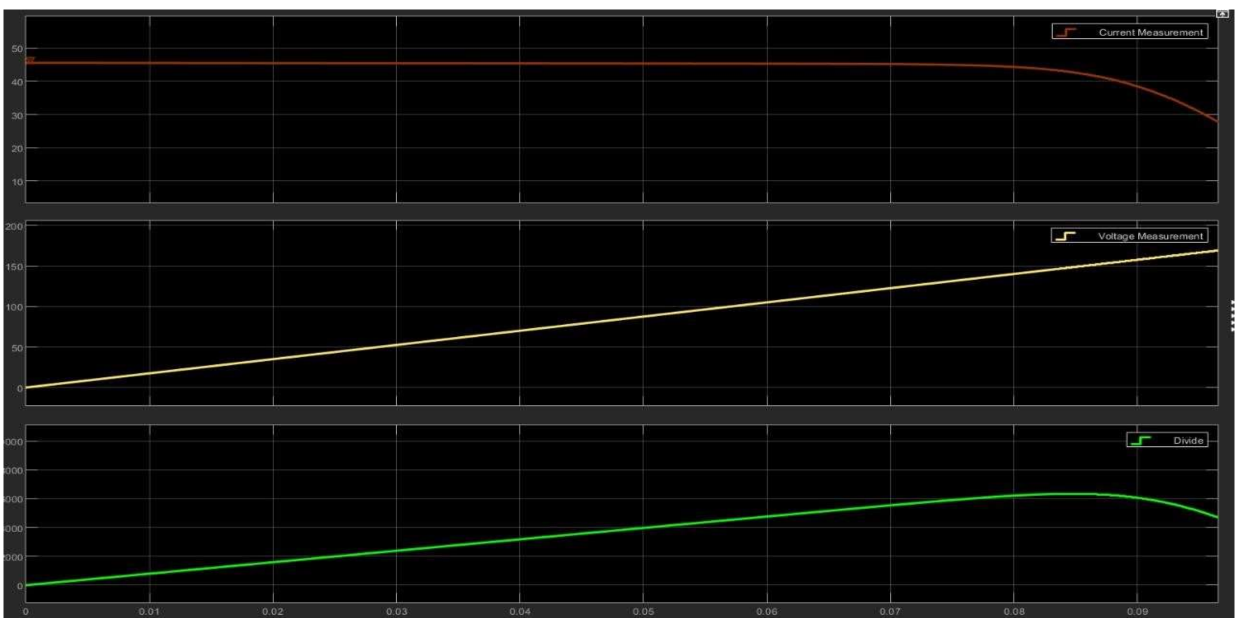

Fig.5.2.6 Simulated output of Series-parallel (SP) PV array configuration.

5.1.2.4 For 400 W/m^2

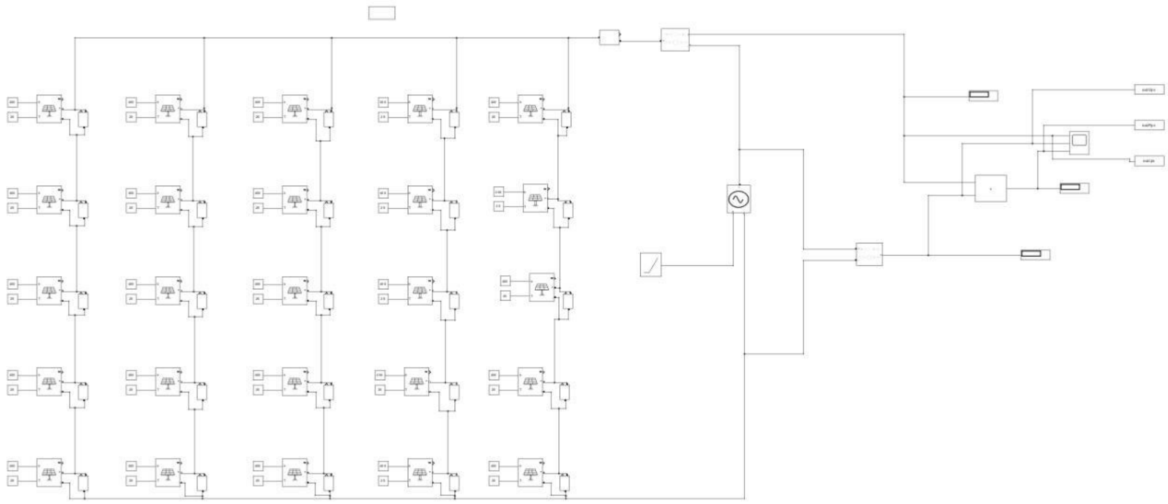

Fig.5.2.7 MATLAB/Simulink model of 5 × 5 Series-parallel PV array configuration.

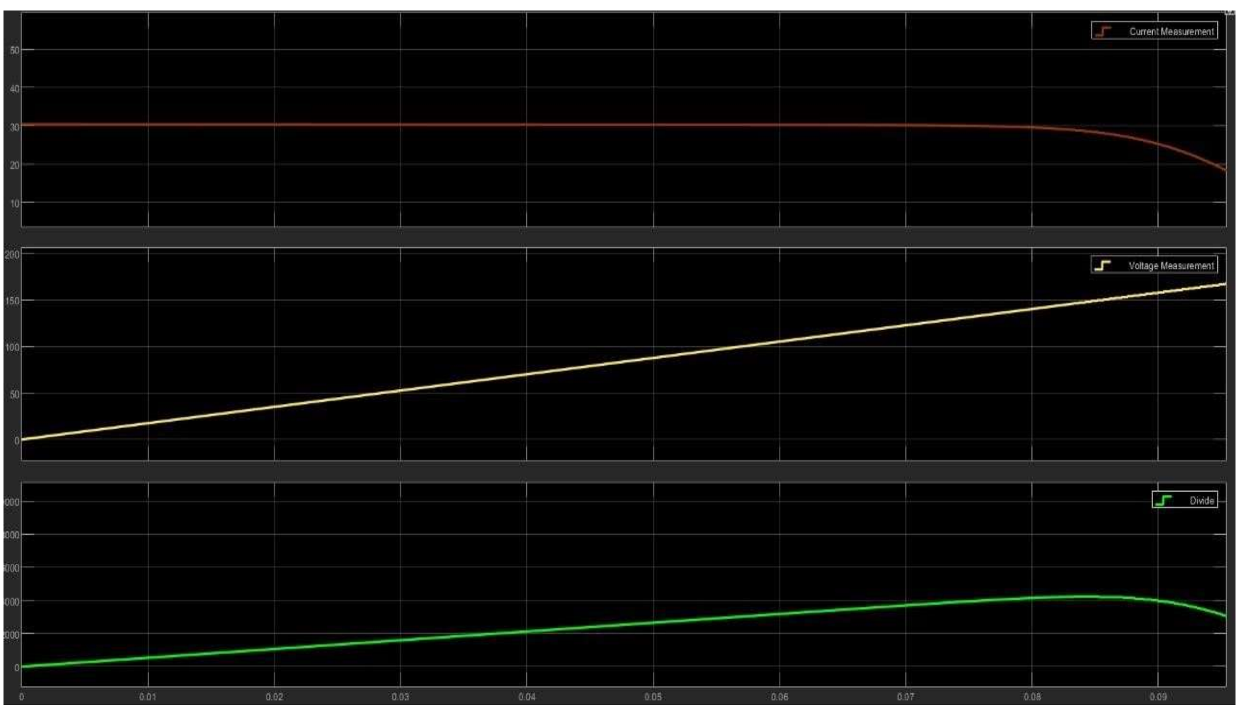

Fig.5.2.8 Simulated output of Series-parallel (SP) PV array configuration.

5.1.2.5 For 200 W/m^2

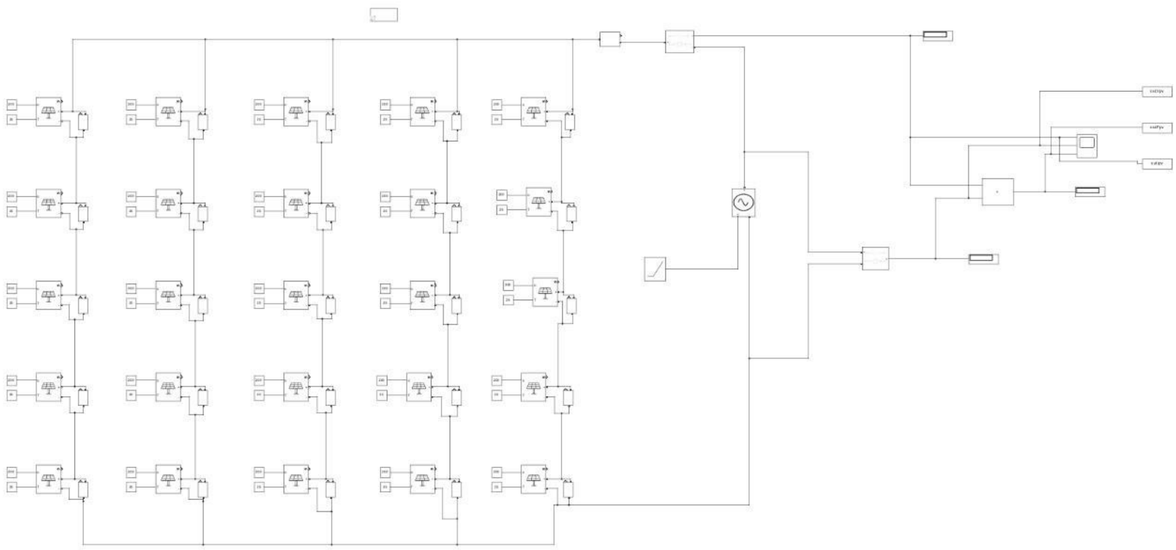

Fig.5.2.9 MATLAB/Simulink model of 5 × 5 Series-parallel PV array configuration.

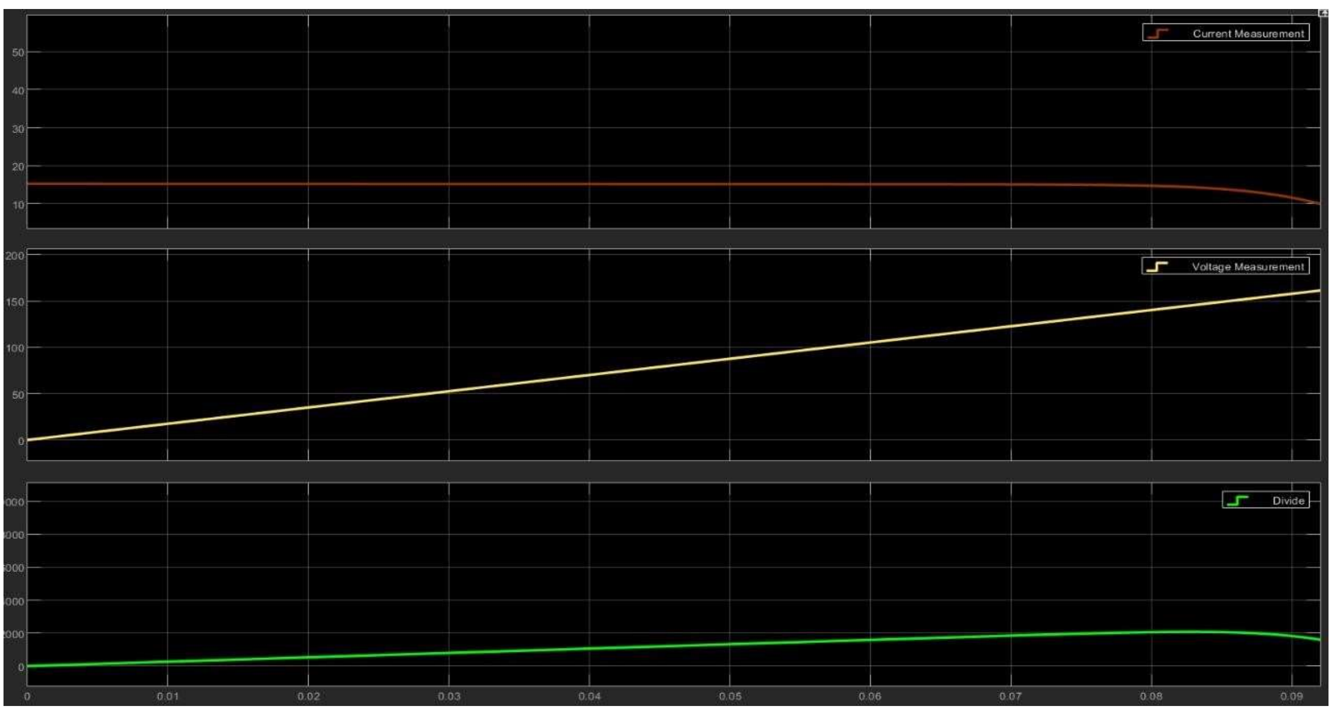

Fig.5.2.10 Simulated output of Series-parallel (SP) PV array configuration.

5.1.2.6 For Centre Shading Pattern

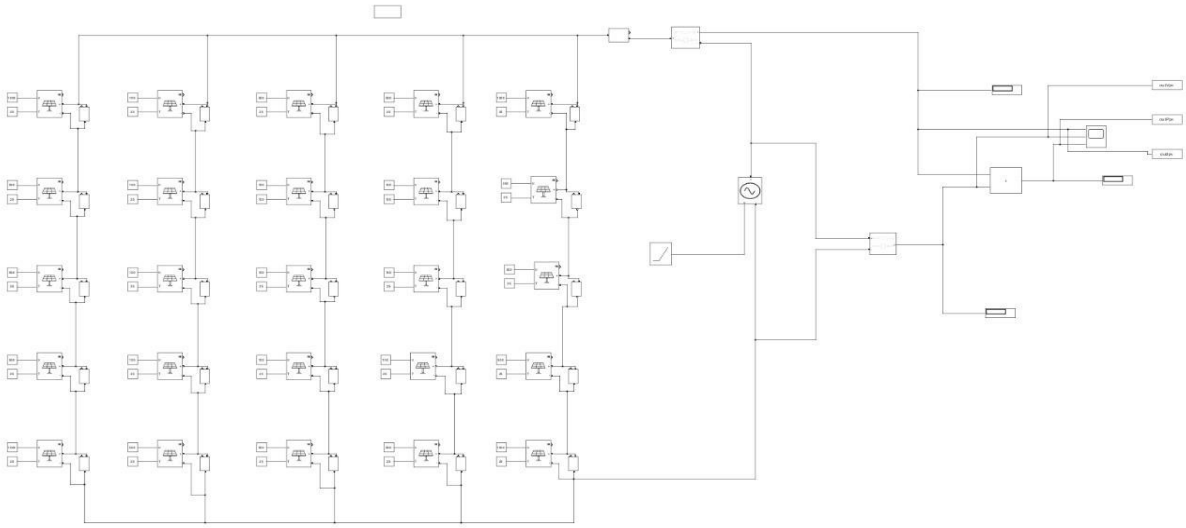

Fig.5.2.11 MATLAB/Simulink model of 5 × 5 Series-parallel PV array configuration.

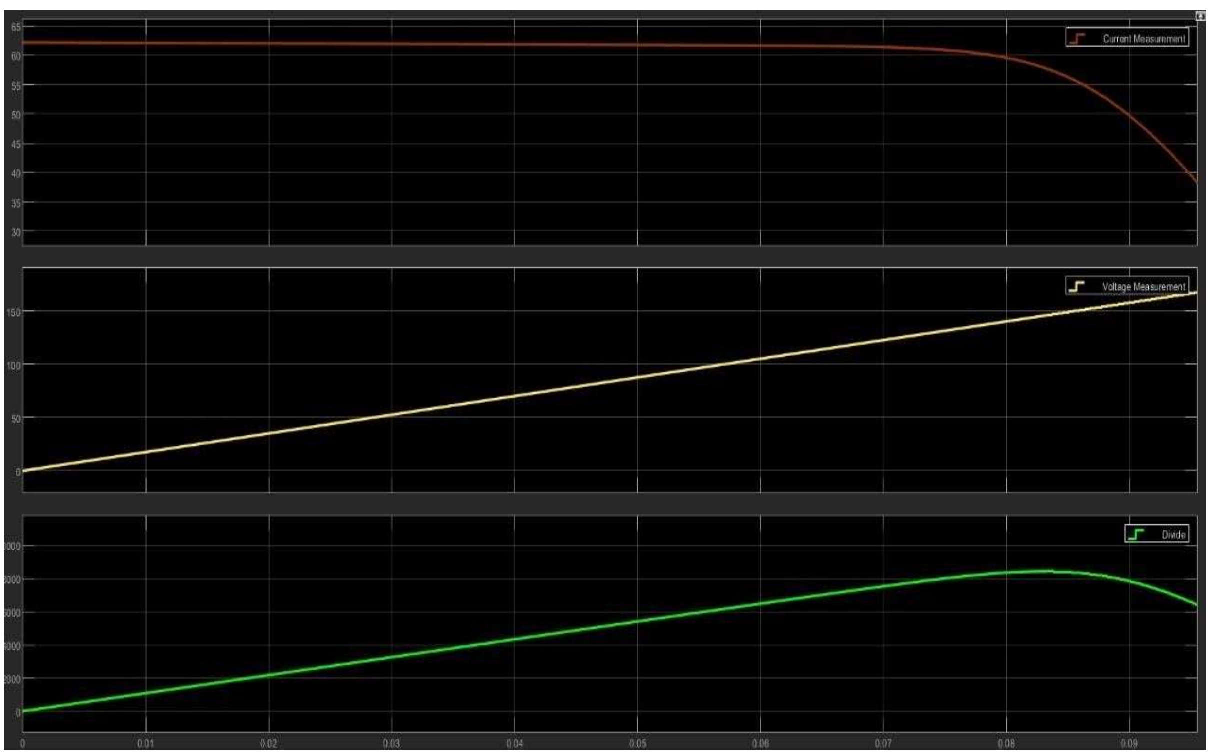

Fig.5.2.12 Simulated output of Series-parallel (SP) PV array configuration.

5.1.2.7 For Middle Shading Pattern

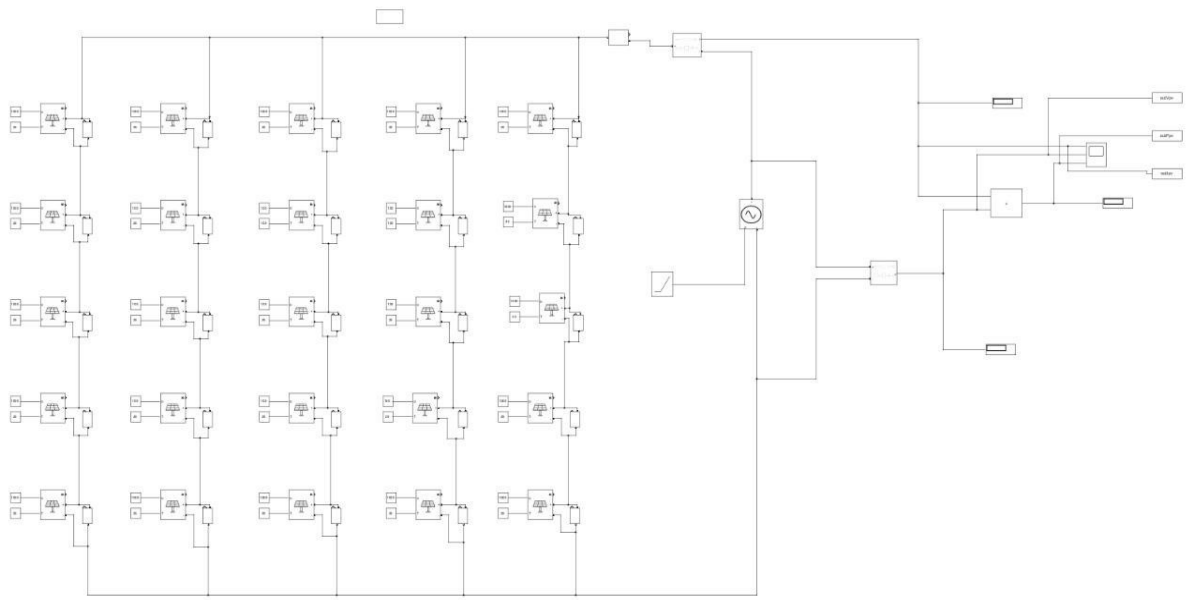

Fig.5.2.13 MATLAB/Simulink model of 5 × 5 Series-parallel PV array configuration.

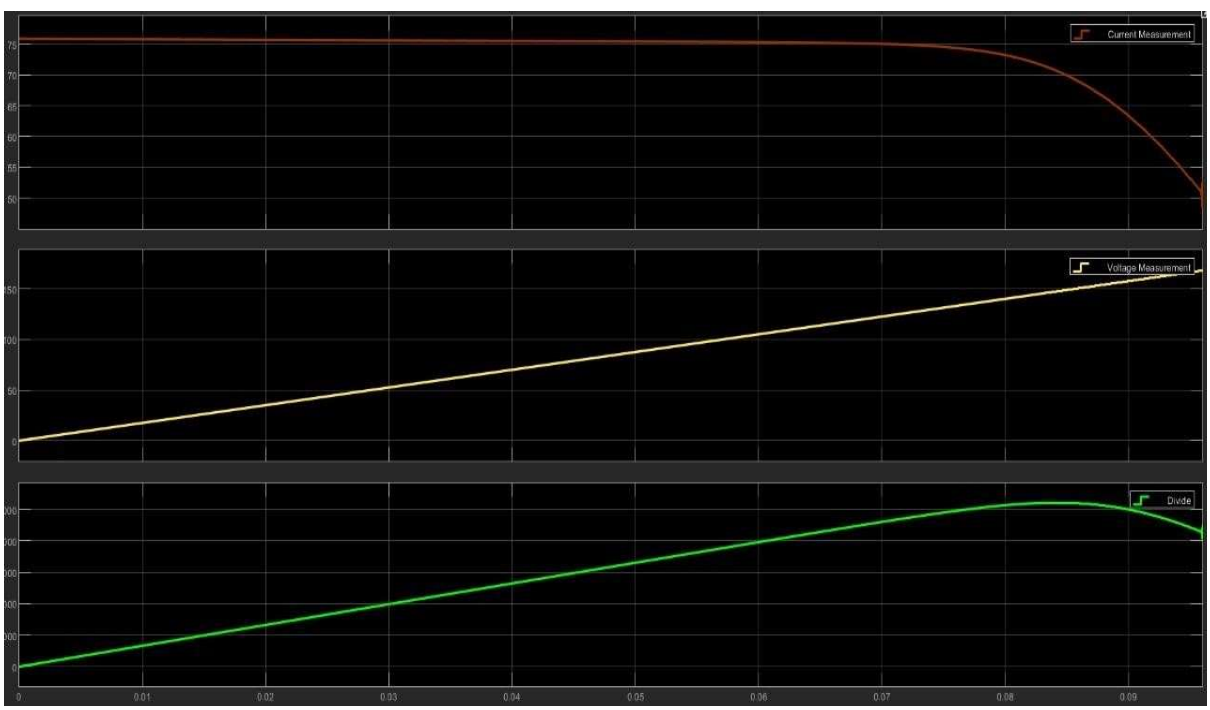

Fig.5.2.14 Simulated output of Series-parallel (SP) PV array configuration.

5.1.2.8 For Narrow Shading Pattern

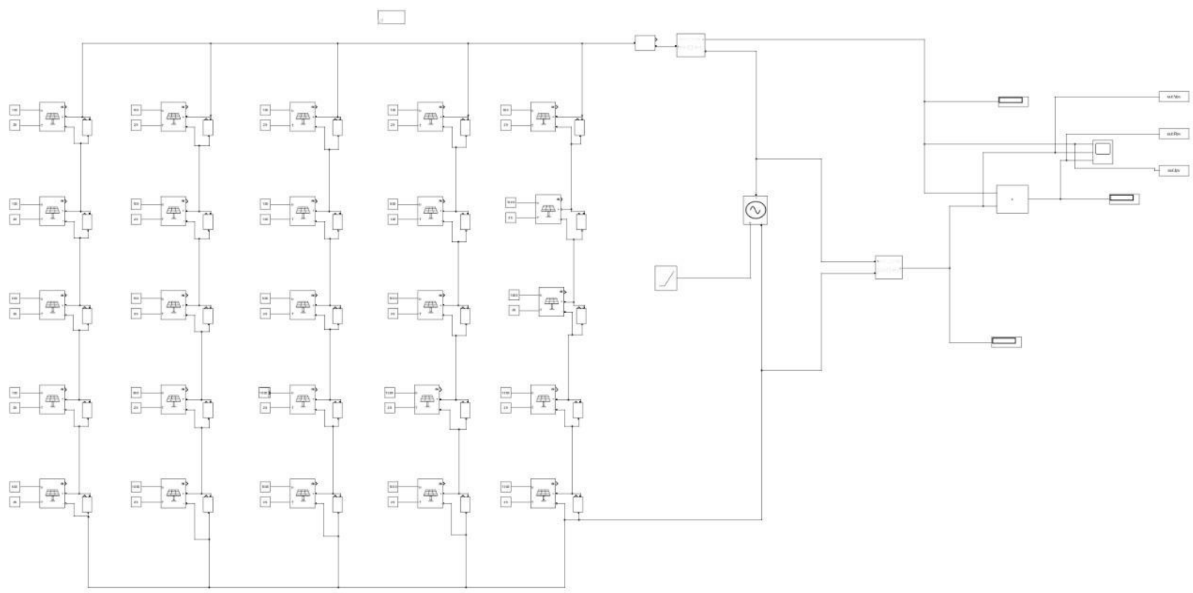

Fig.5.2.15 MATLAB/Simulink model of 5 × 5 Series-parallel PV array configuration.

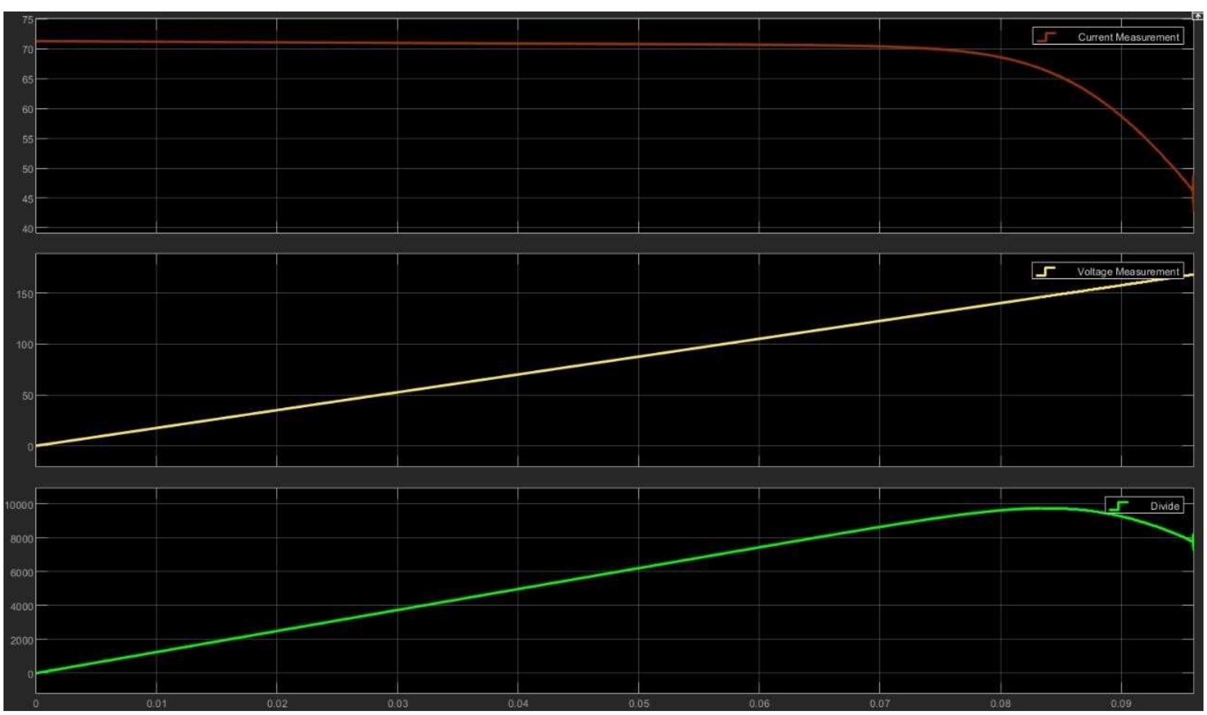

Fig.5.2.16 Simulated output of Series-parallel (SP) PV array configuration.

5.1.2.9 For Row Shading Pattern

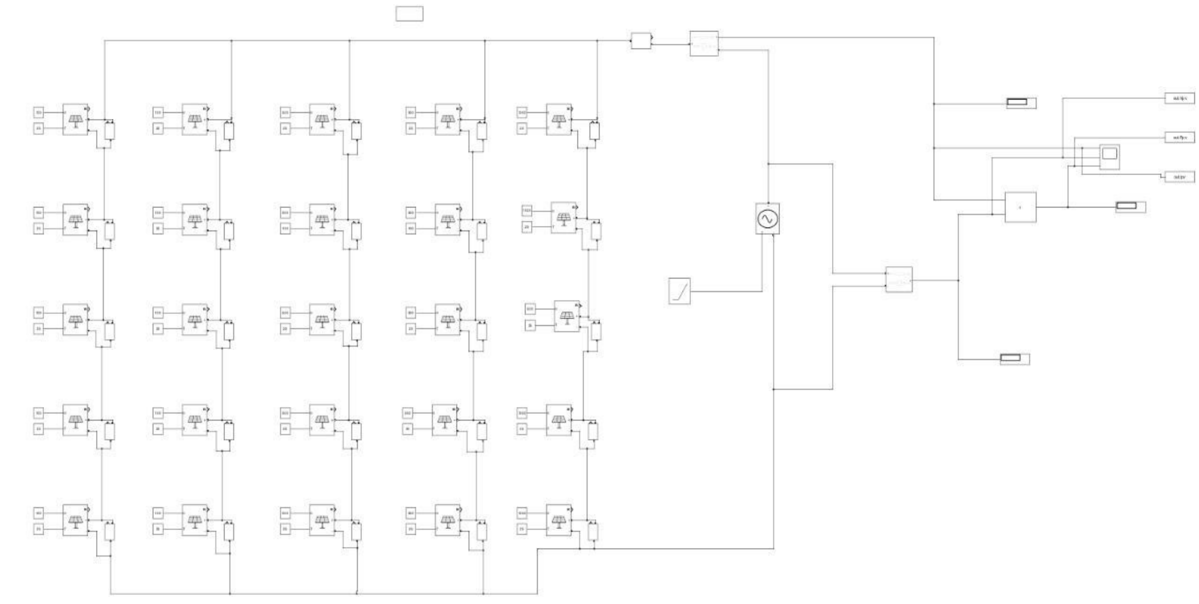

Fig.5.2.17 MATLAB/Simulink model of 5 × 5 Series-parallel PV array configuration.

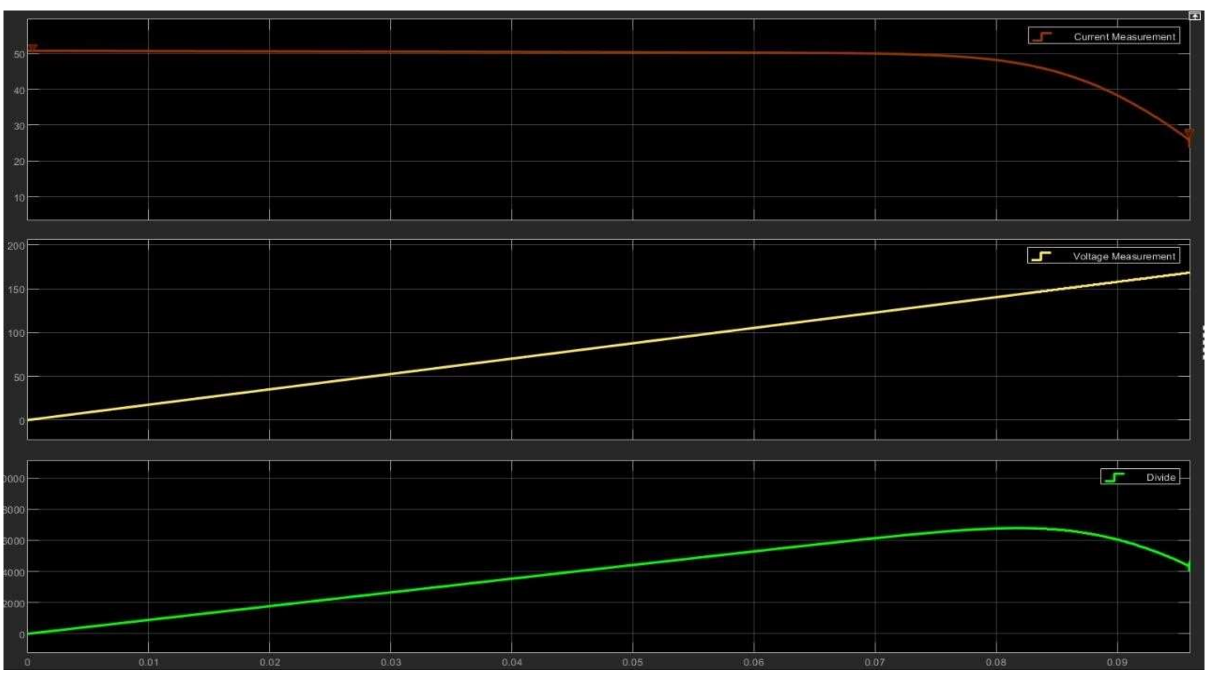

Fig.5.2.18 Simulated output of Series-parallel (SP) PV array configuration.

5.1.2.10 For Wide Shading Pattern

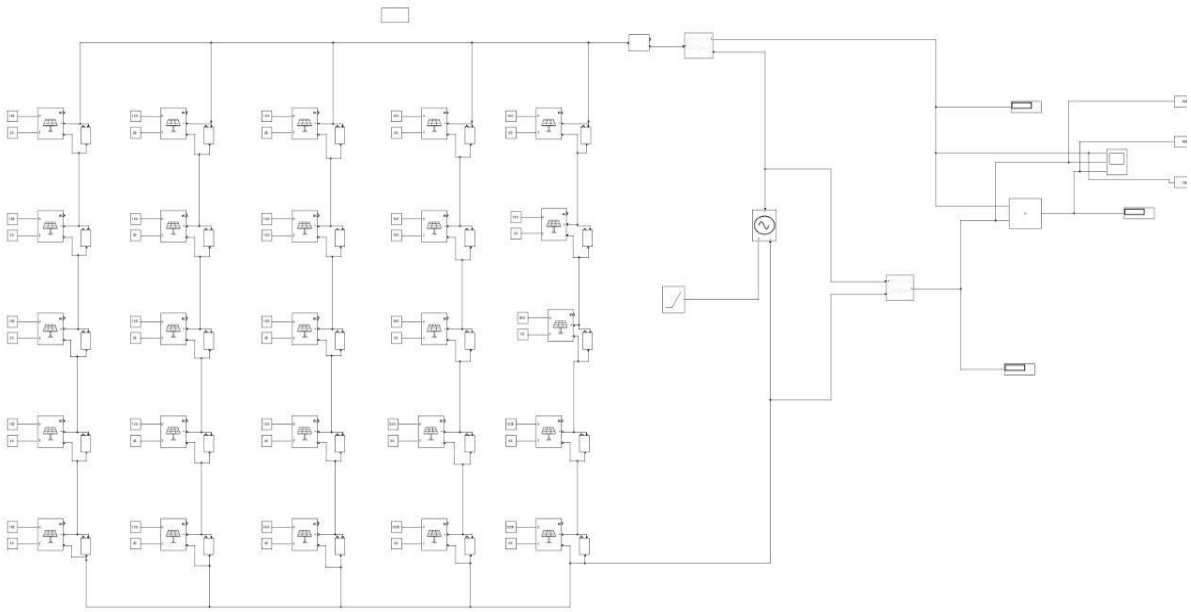

Fig.5.2.19 MATLAB/Simulink model of 5 × 5 Series-parallel PV array configuration.

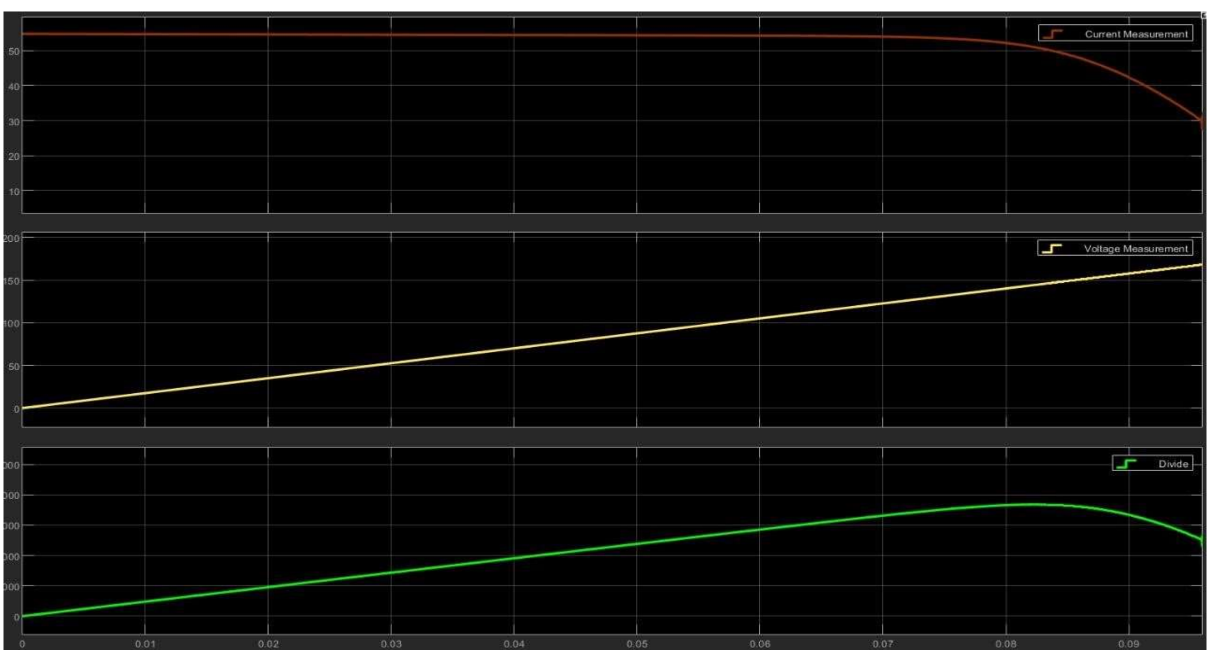

Fig.5.2.20 Simulated output of Series-parallel (SP) PV array configuration.

5.1.2.11 For Random Shading Pattern

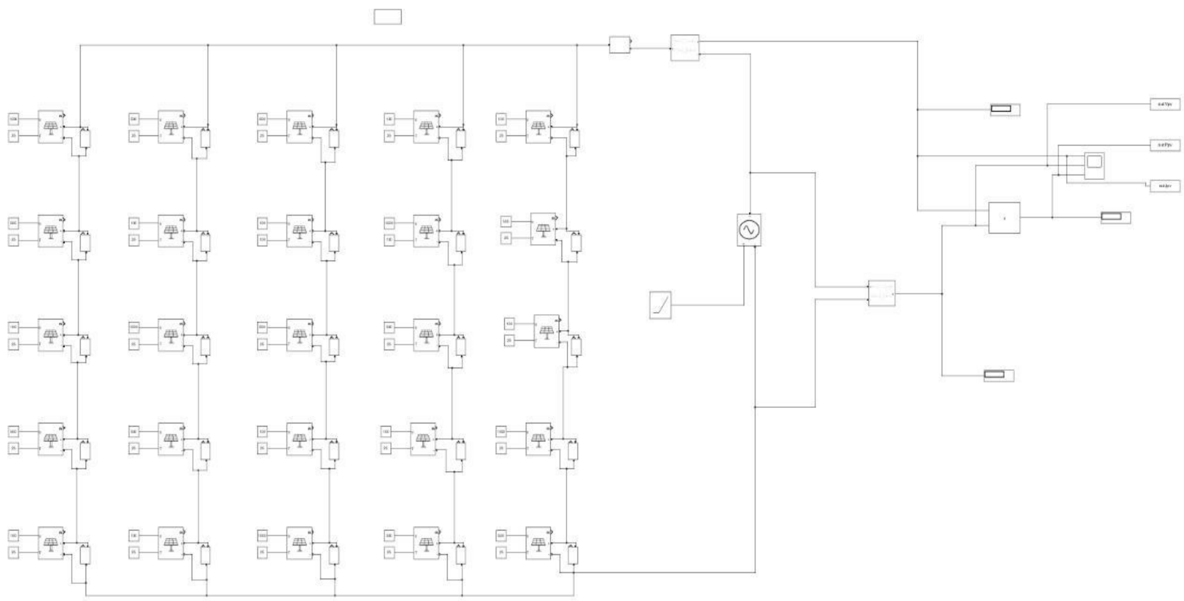

Fig.5.2.21 MATLAB/Simulink model of 5 × 5 Series-parallel PV array configuration.

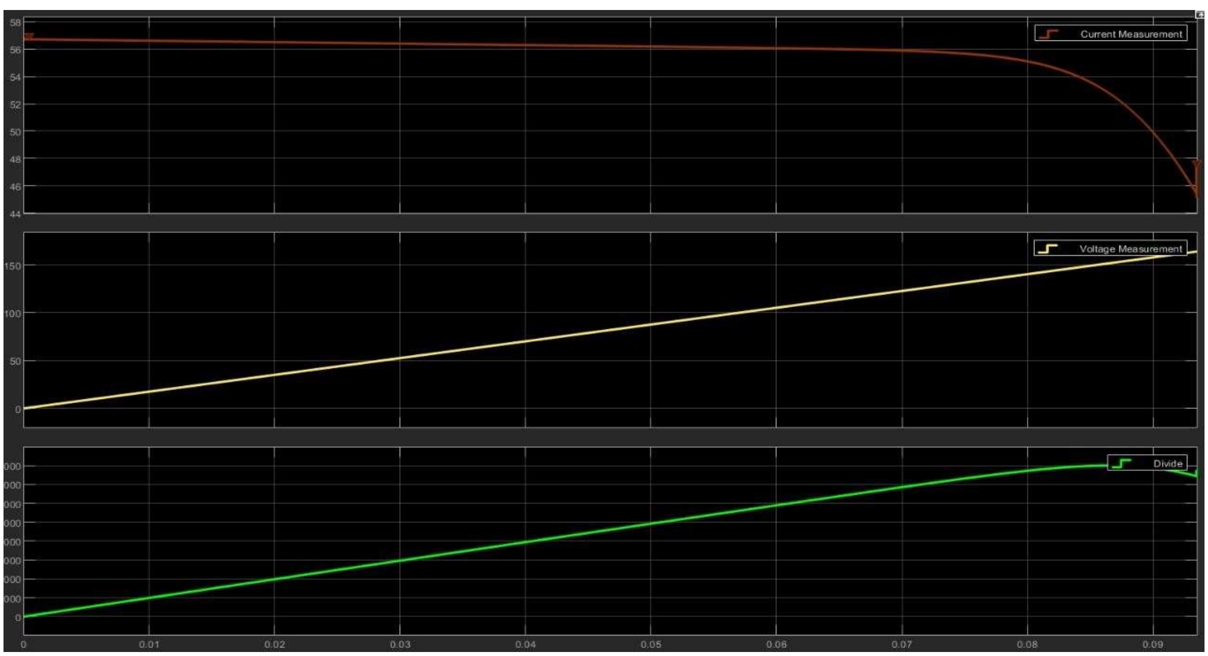

Fig.5.2.22 Simulated output of Series-parallel (SP) PV array configuration.

5.1.3 Total Cross Tide:

5.1.3.1 For 1000 W/m^2

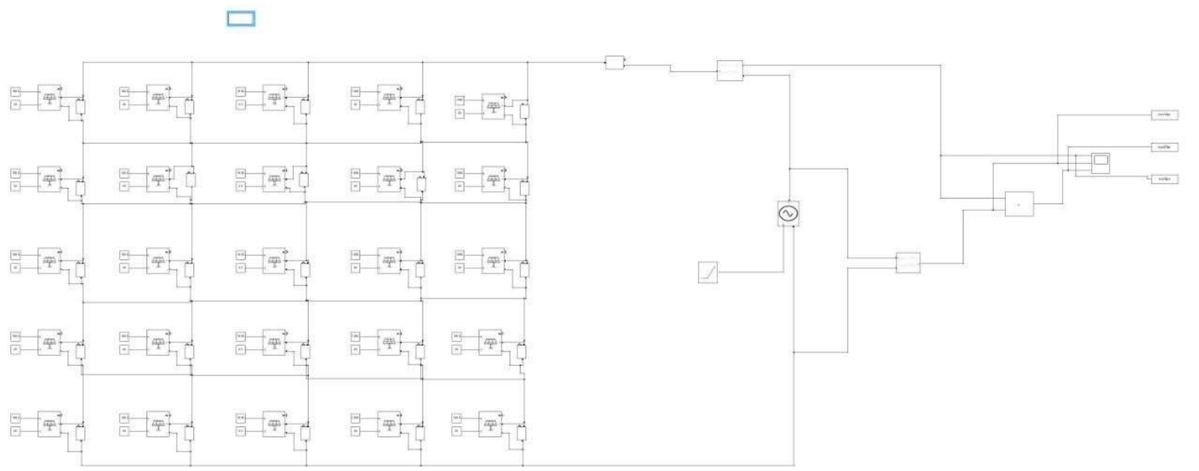

Fig.5.3.1 MATLAB/Simulink model of 5 × 5 Total Cross Tide PV array configuration.

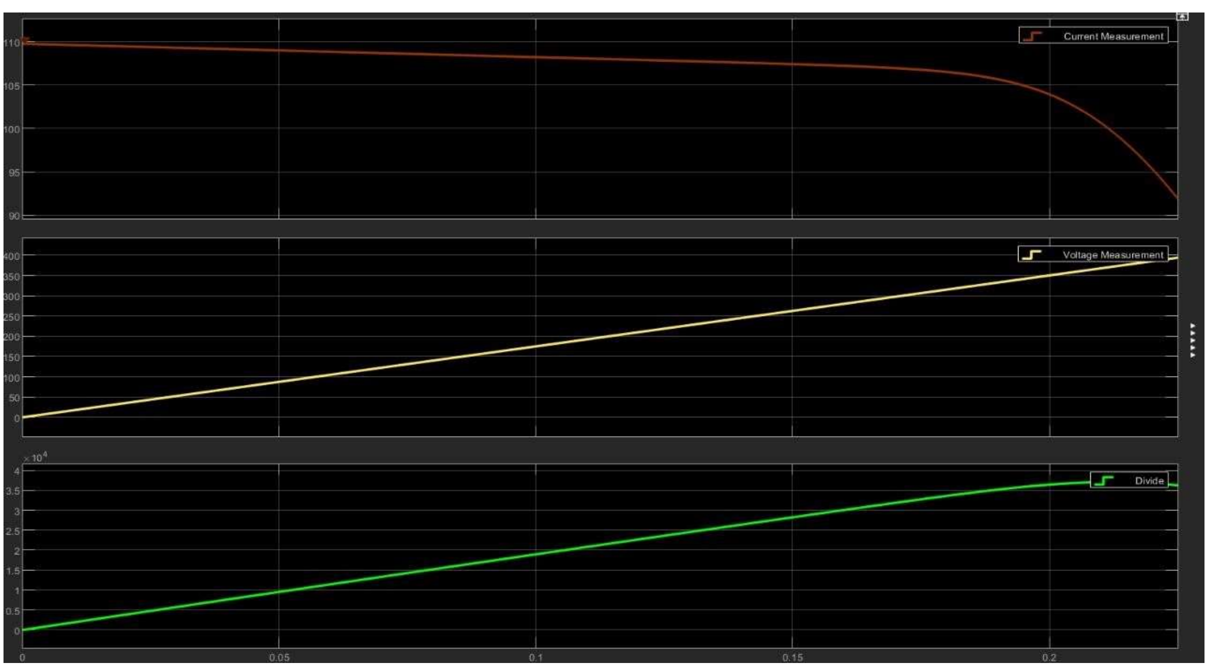

Fig.5.3.2 Simulated output of Total Cross Tide(TCT) PV array configuration.

5.1.3.2 For 800 W/m^2

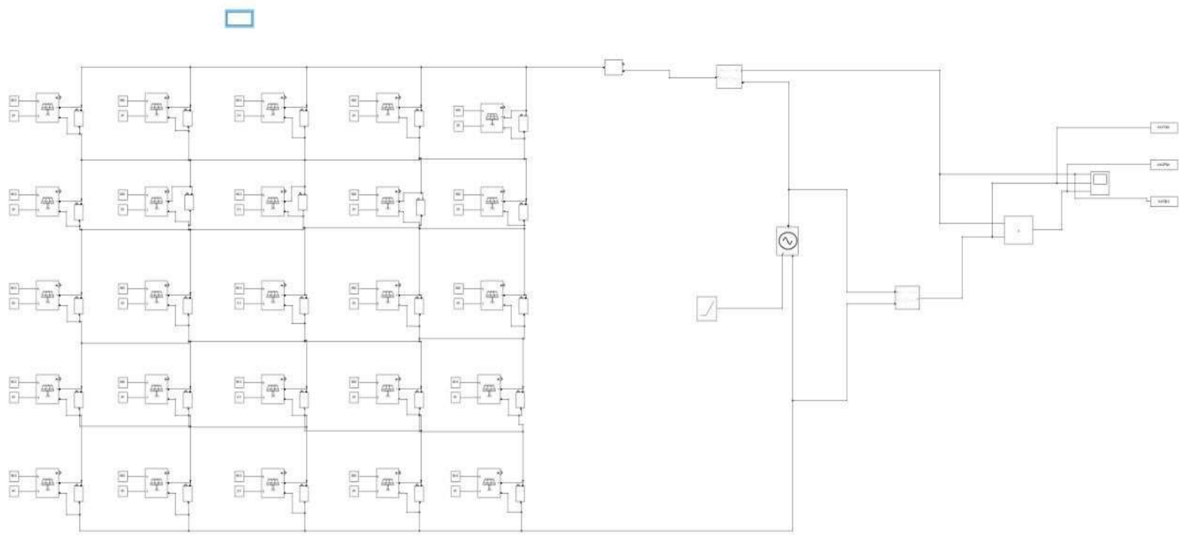

Fig.5.3.3 MATLAB/Simulink model of 5 × 5 Total Cross Tide PV array configuration.

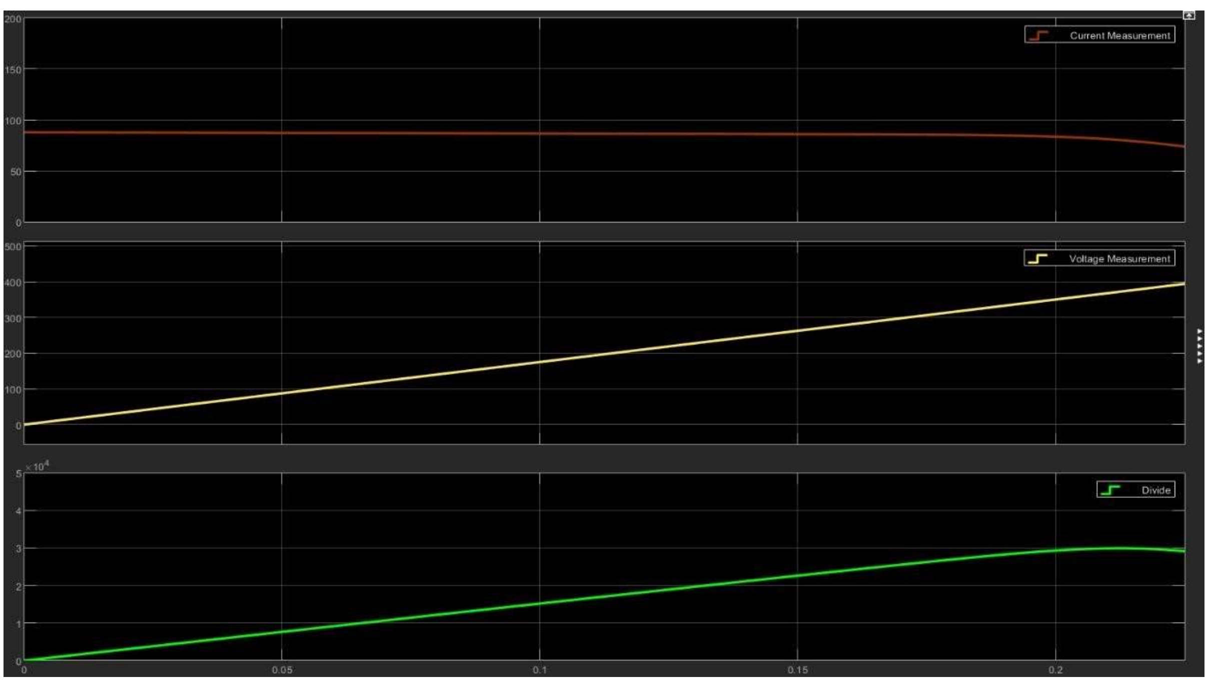

Fig.5.3.4 Simulated output of Total Cross Tide(TCT) PV array configuration.

5.1.3.3 For 600 W/m^2

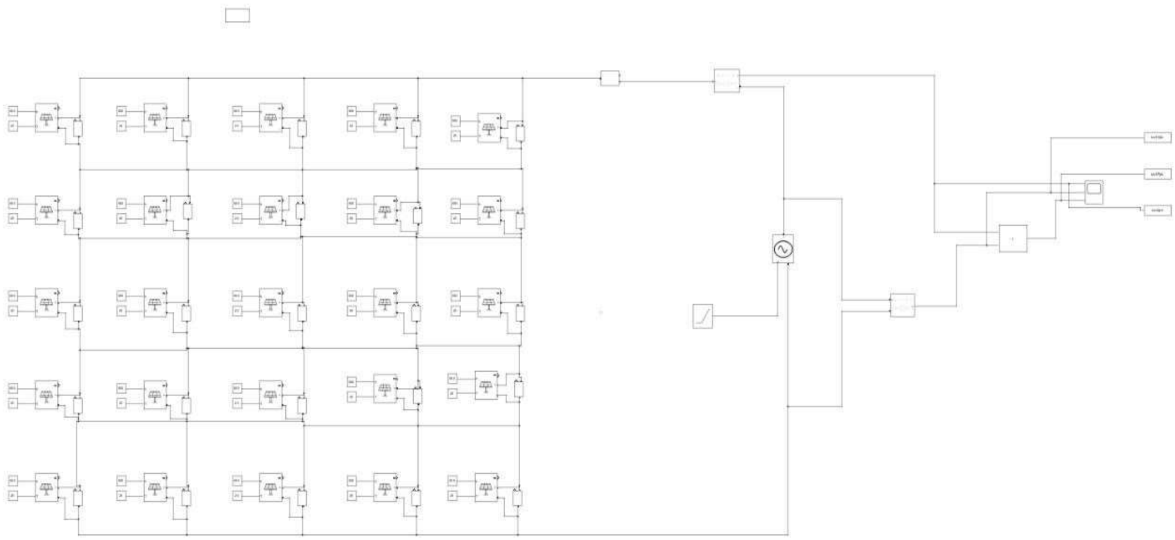

Fig.5.3.5 MATLAB/Simulink model of 5 × 5 Total Cross Tide PV array configuration.

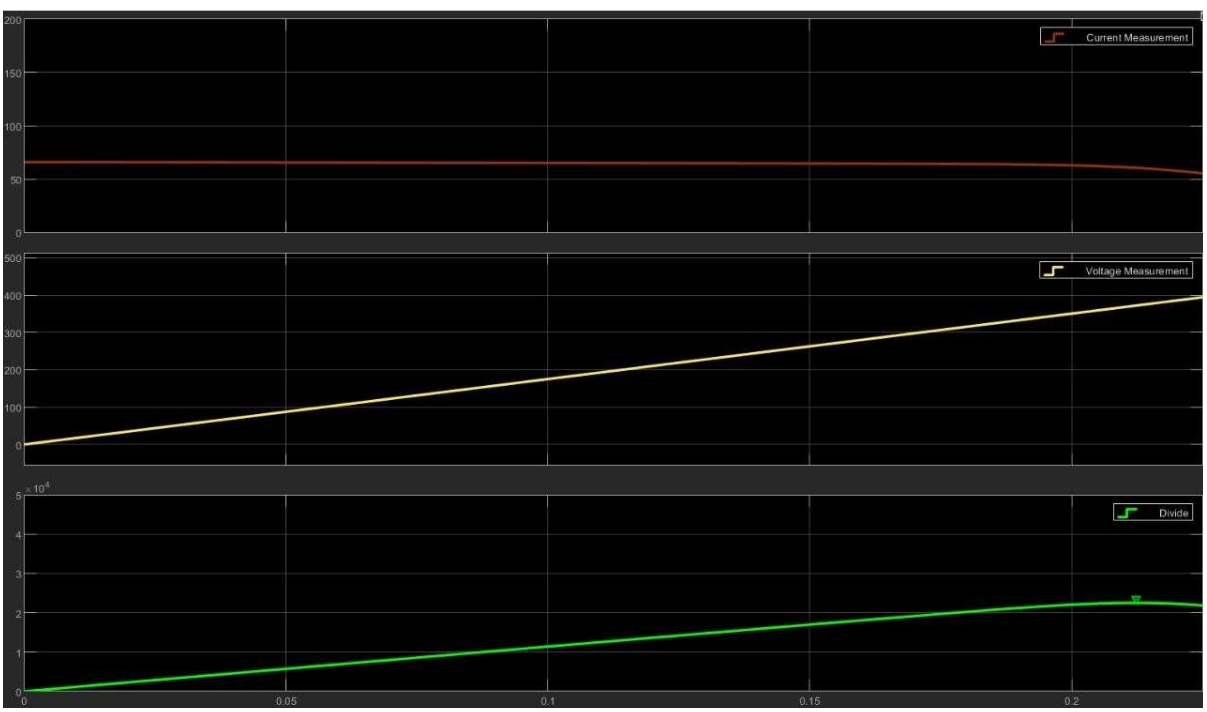

Fig.5.3.6 Simulated output of Total Cross Tide(TCT) PV array configuration.

5.1.3.4 For 400 W/m

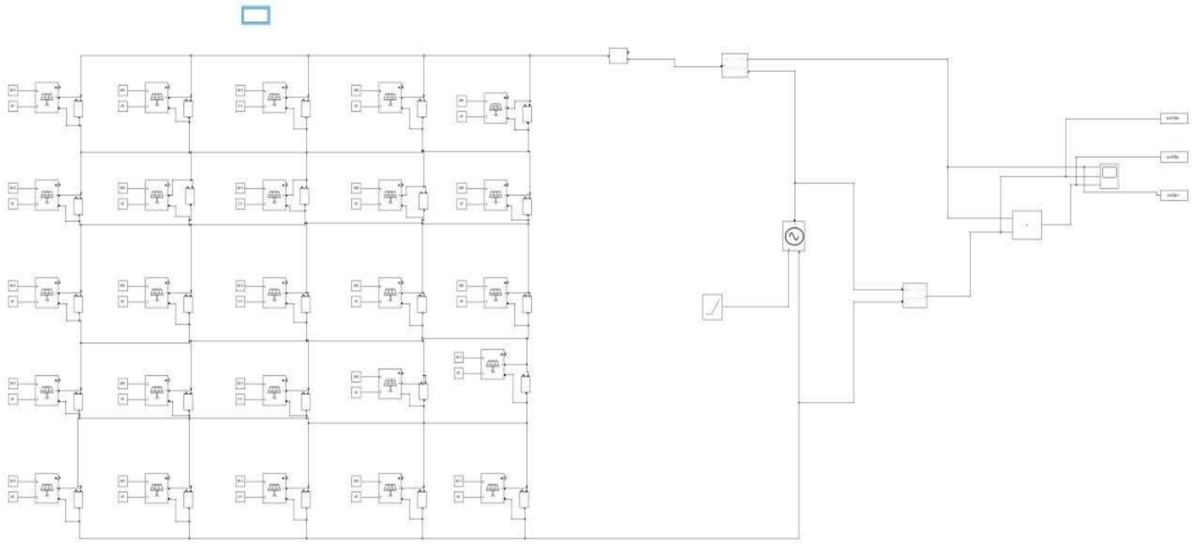

Fig.5.3.7 MATLAB/Simulink model of 5 × 5 Total Cross Tide PV array configuration.

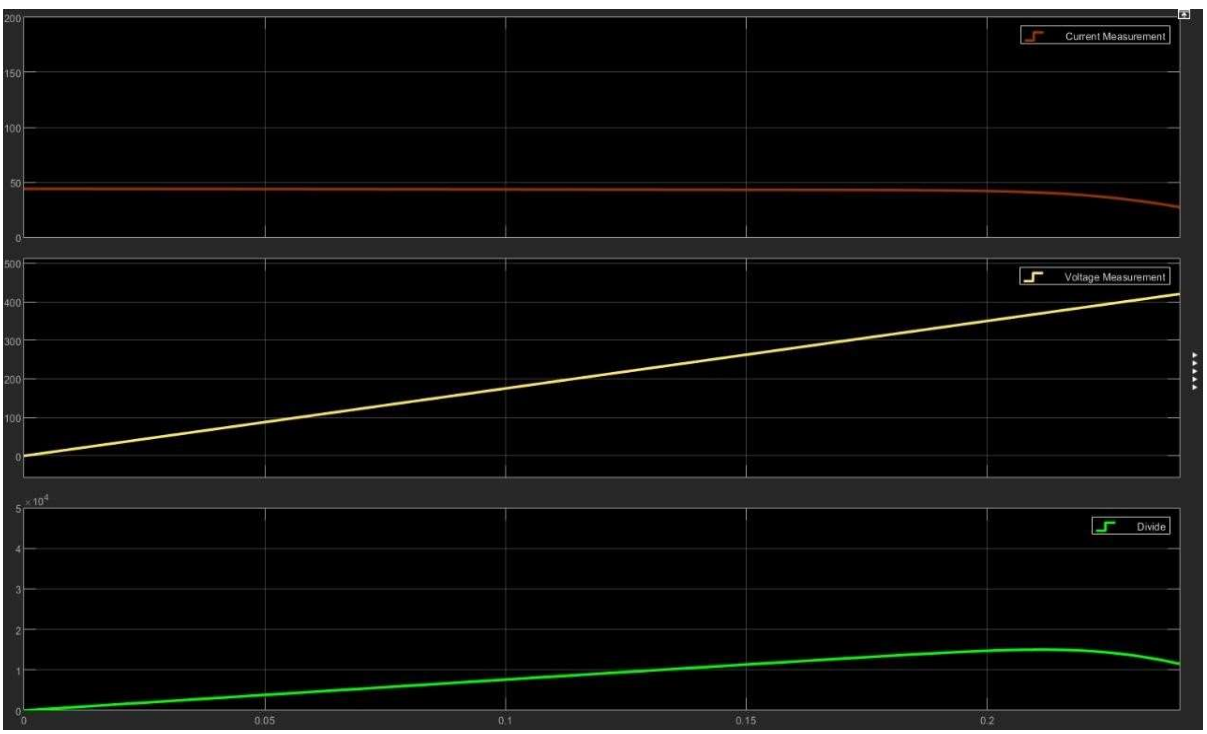

Fig.5.3.8 Simulated output of Total Cross Tide(TCT) PV array configuration.

5.1.3.5 For 200 W/m^2

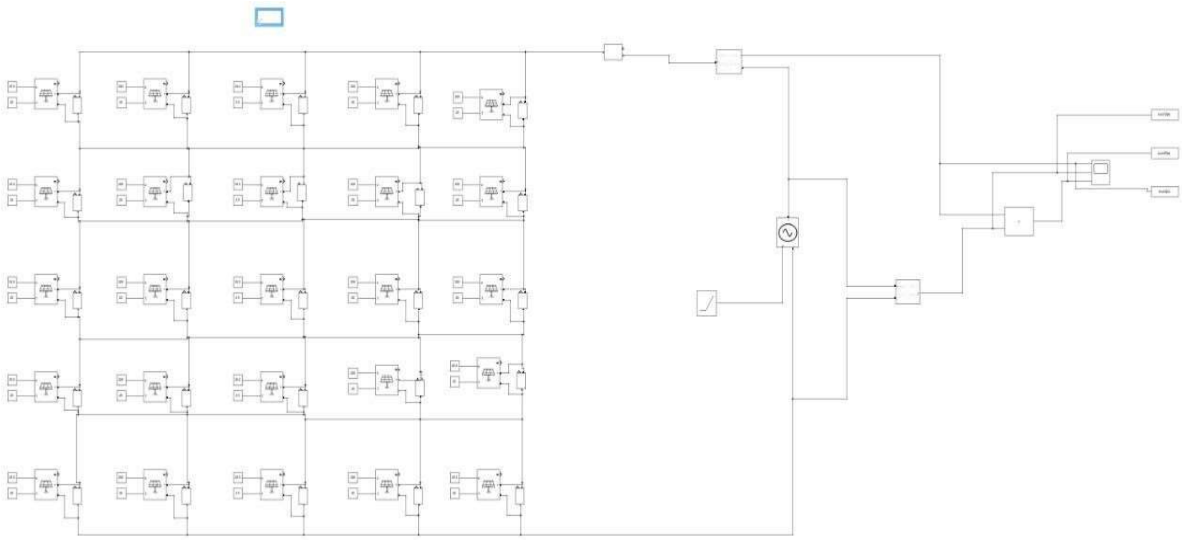

Fig.5.3.9 MATLAB/Simulink model of 5 × 5 Total Cross Tide PV array configuration.

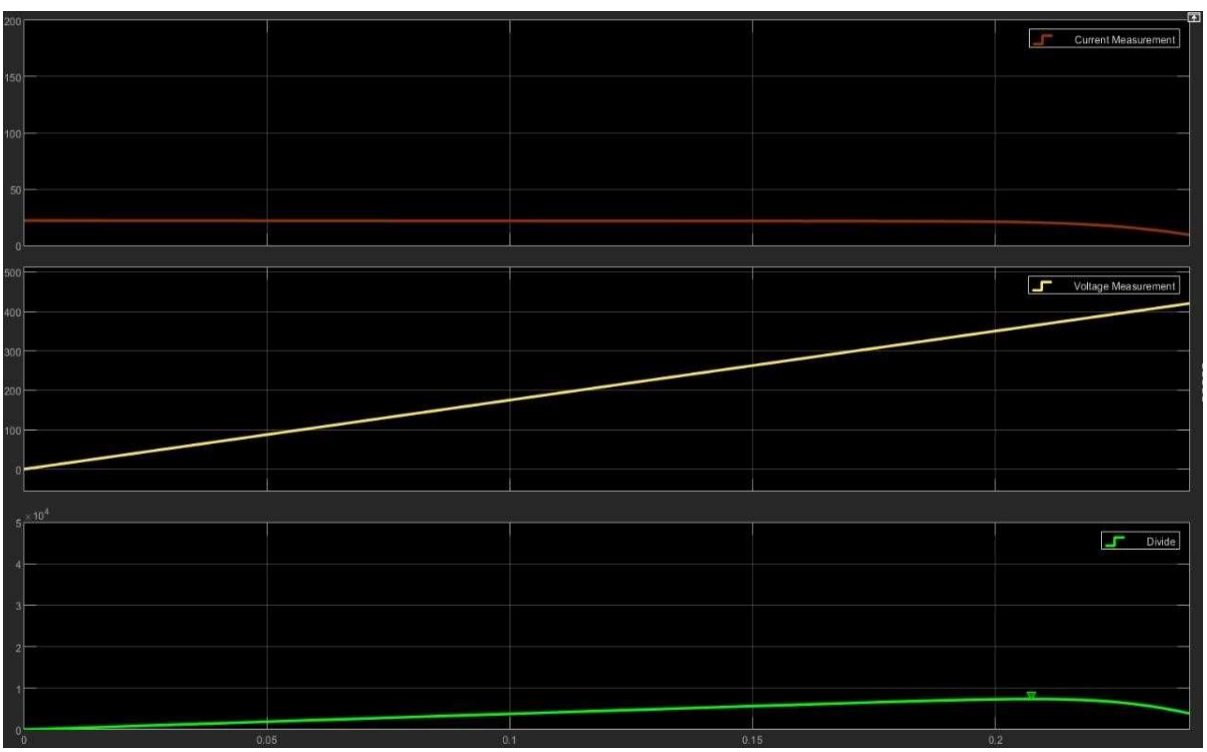

Fig.5.3.10 Simulated output of Total Cross Tide(TCT) PV array configuration.

5.1.3.6 For Centre Shading Pattern

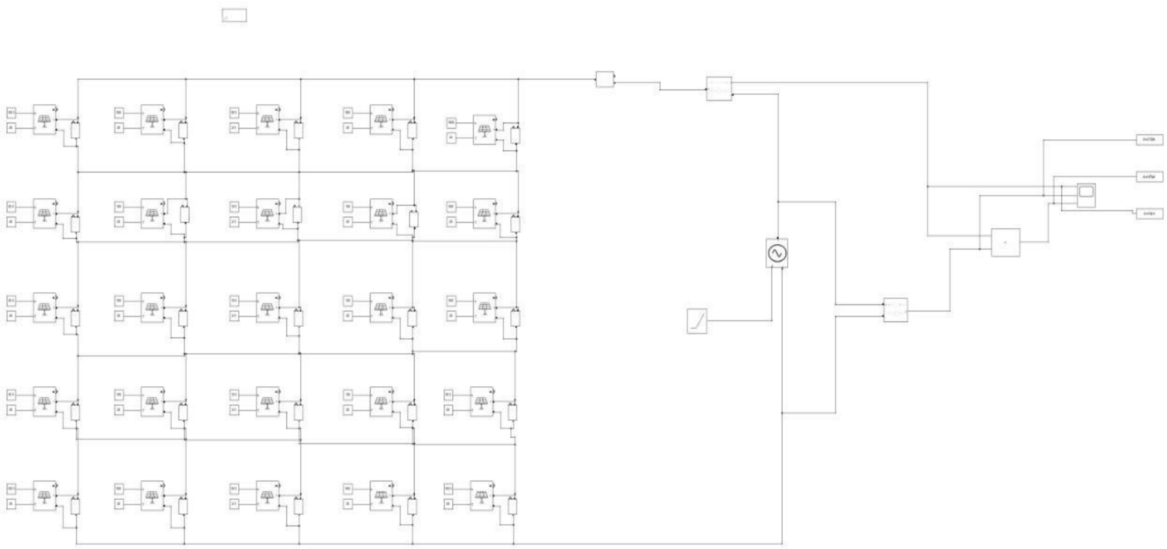

Fig.5.3.11 MATLAB/Simulink model of 5 × 5 Total Cross Tide PV array configuration.

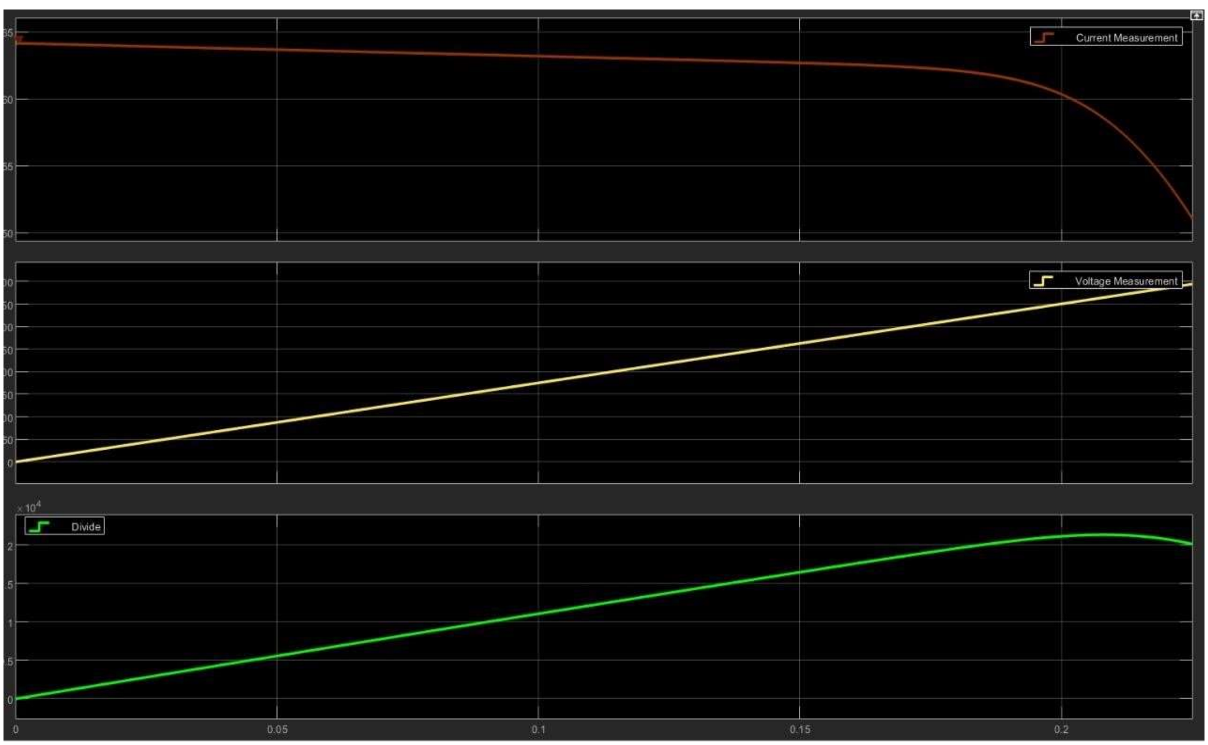

Fig.5.3.12 Simulated output of Total Cross Tide(TCT) PV array configuration.

5.1.3.7 For Middle Shading Pattern

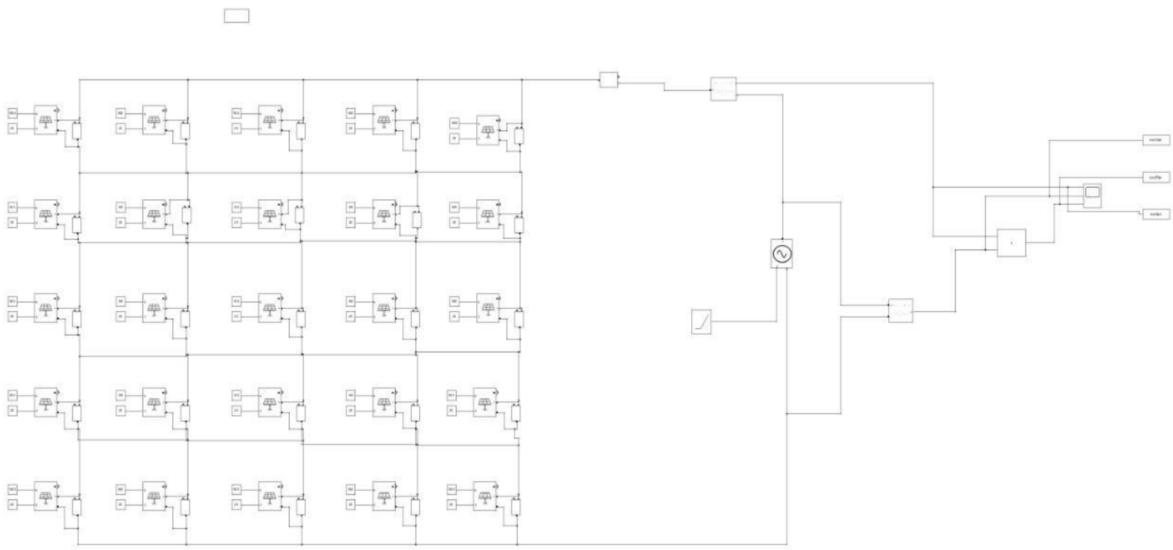

Fig.5.3.13 MATLAB/Simulink model of 5 × 5 Total Cross Tide PV array configuration.

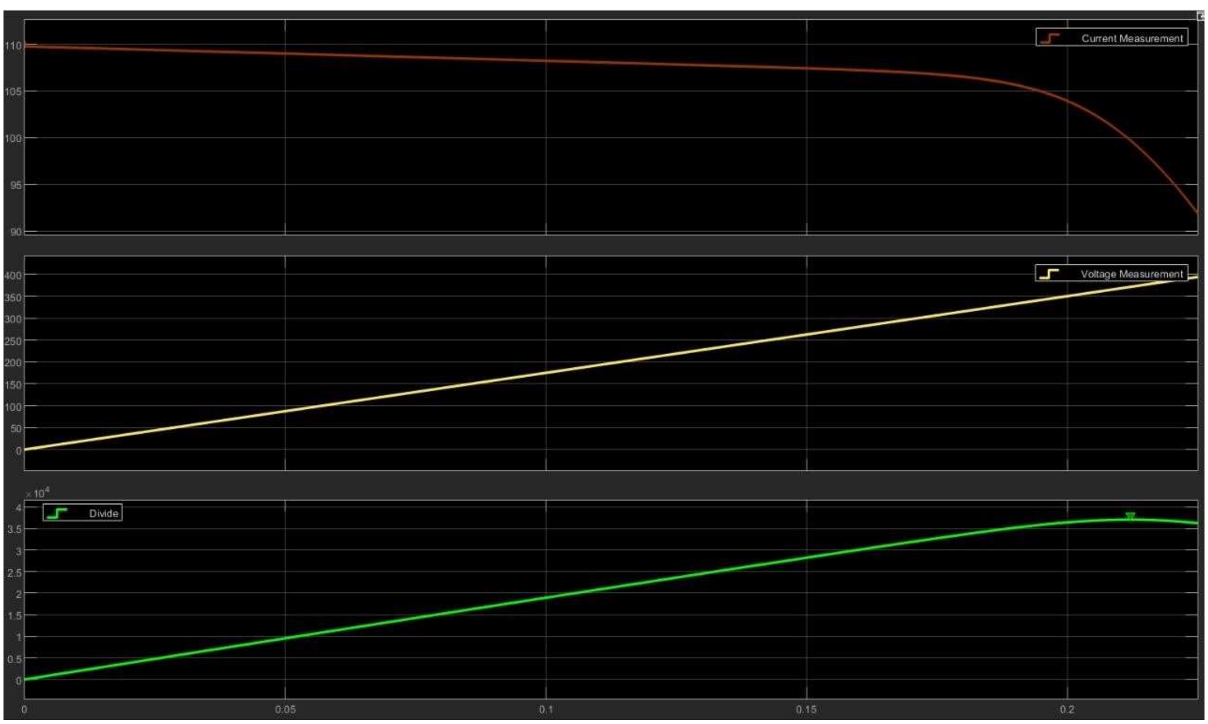

Fig.5.3.14 Simulated output of Total Cross Tide(TCT) PV array configuration.

5.1.3.8 For Narrow Shading Pattern

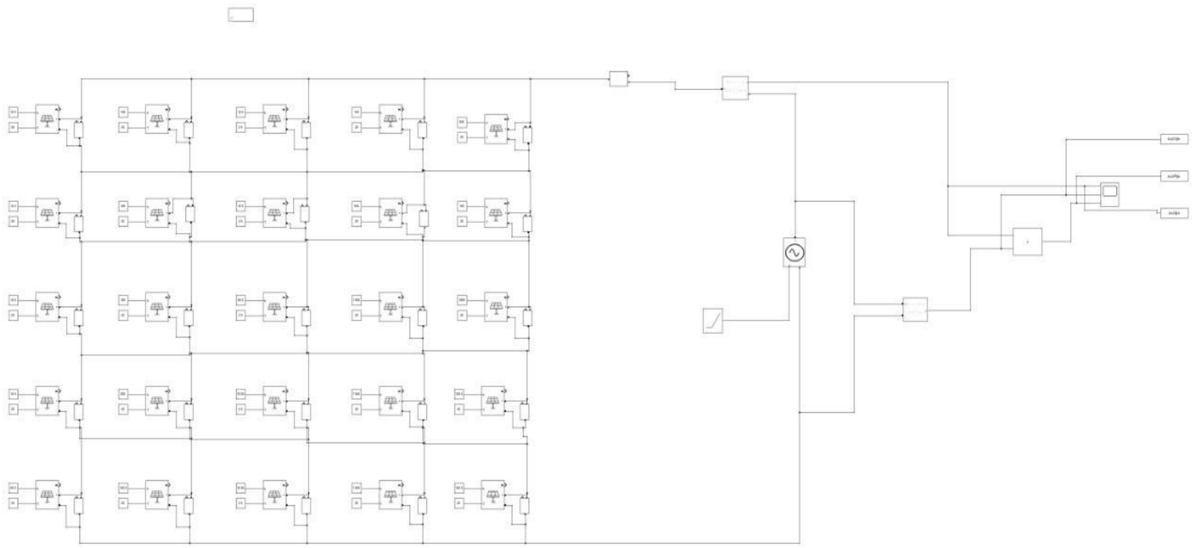

Fig.5.3.15 MATLAB/Simulink model of 5 × 5 Total Cross Tide PV array configuration.

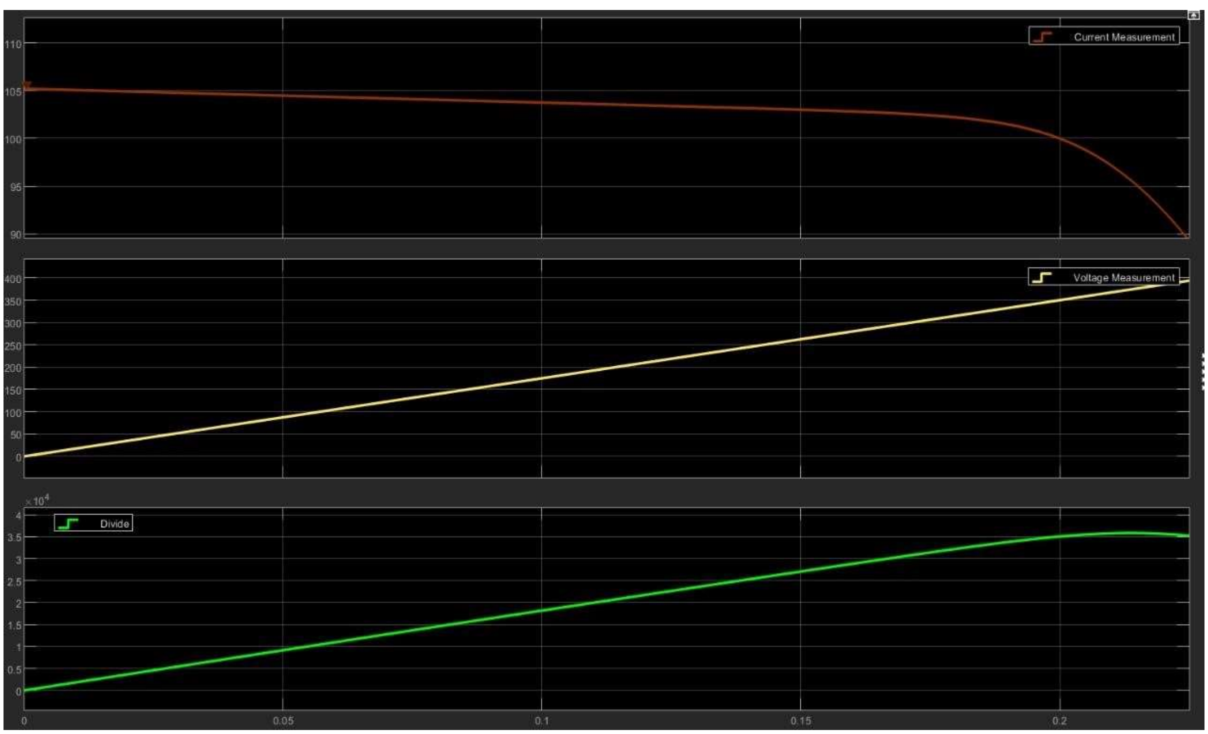

Fig.5.3.16 Simulated output of Total Cross Tide(TCT) PV array configuration.

5.1.3.9 For Row Shading Pattern

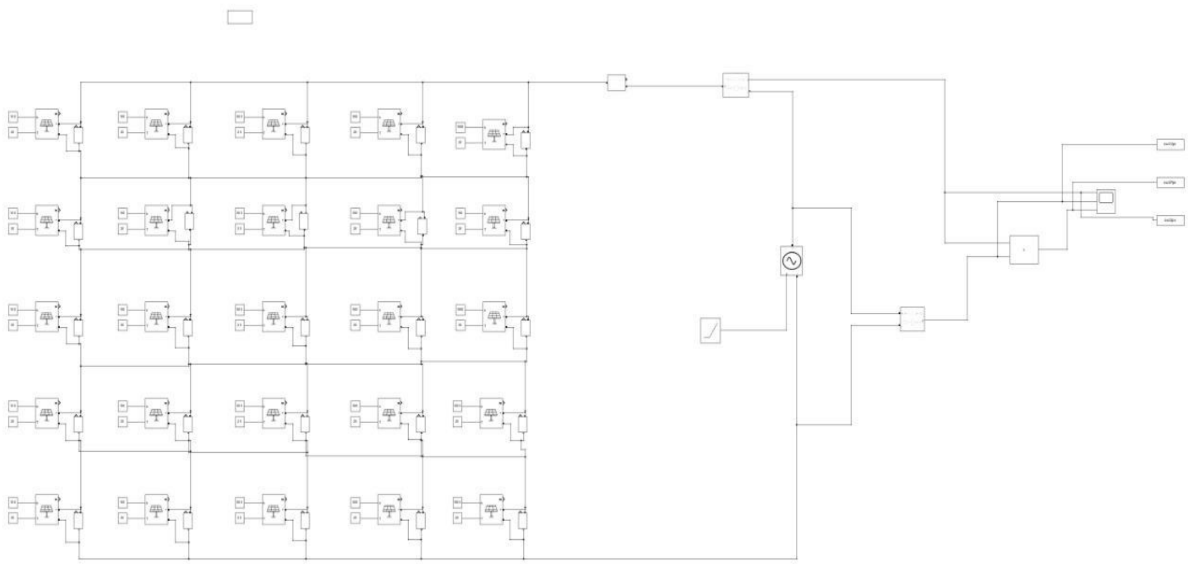

Fig.5.3.17 MATLAB/Simulink model of 5 × 5 Total Cross Tide PV array configuration.

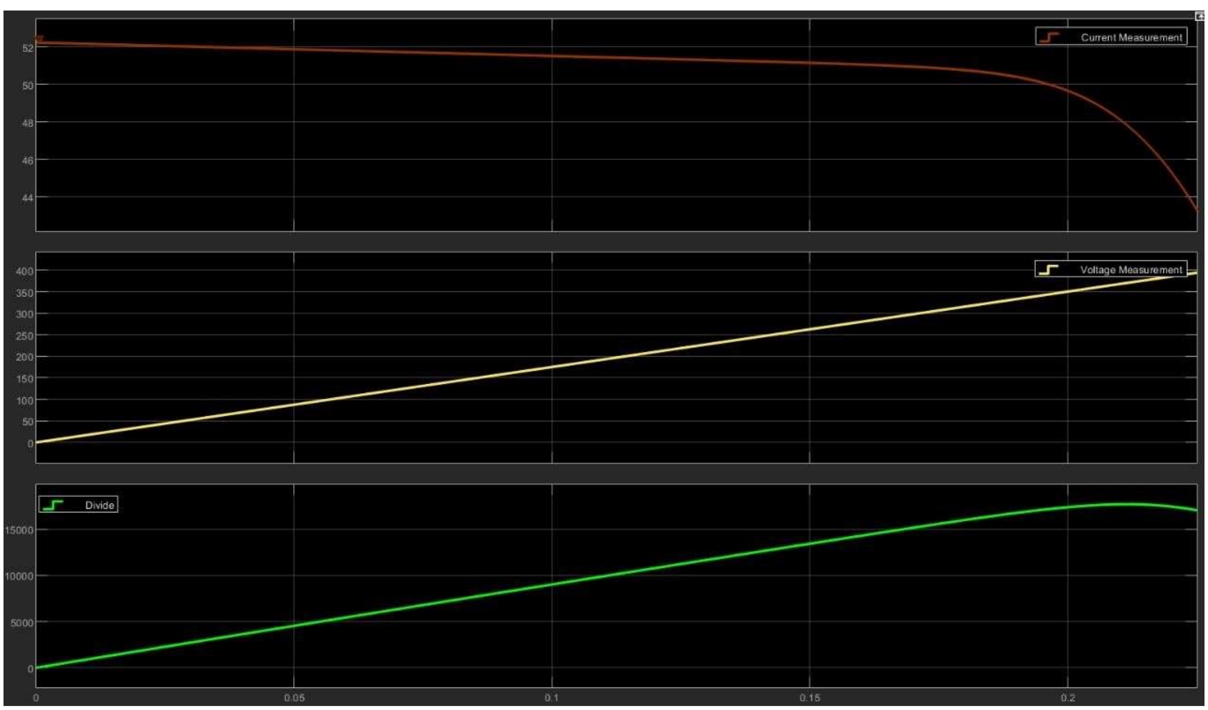

Fig.5.3.18 Simulated output of Total Cross Tide(TCT) PV array configuration.

5.1.3.10 For Wide Shading Pattern

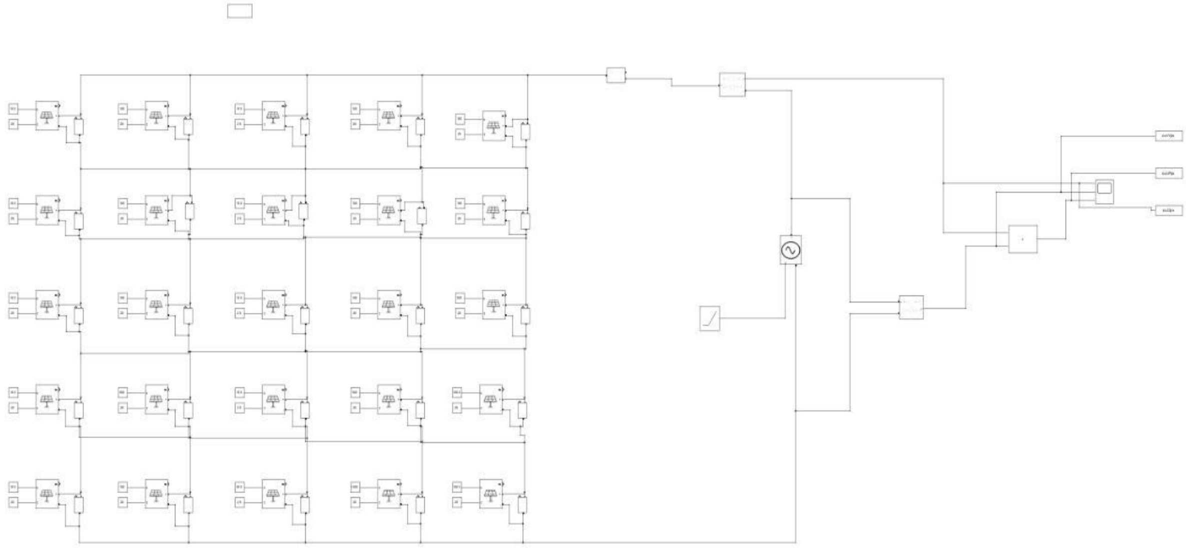

Fig.5.3.19 MATLAB/Simulink model of 5 × 5 Total Cross Tide PV array configuration.

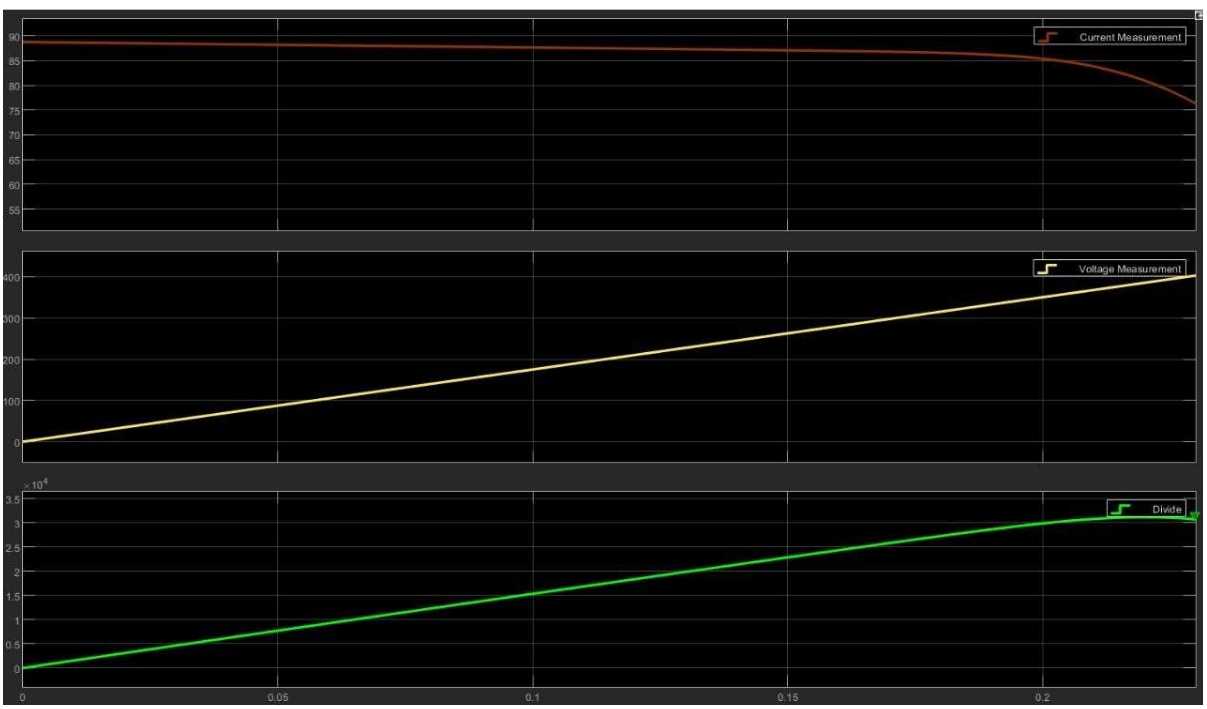

Fig.5.3.20 Simulated output of Total Cross Tide(TCT) PV array configuration.

5.1.3.11 For Random Shading Pattern

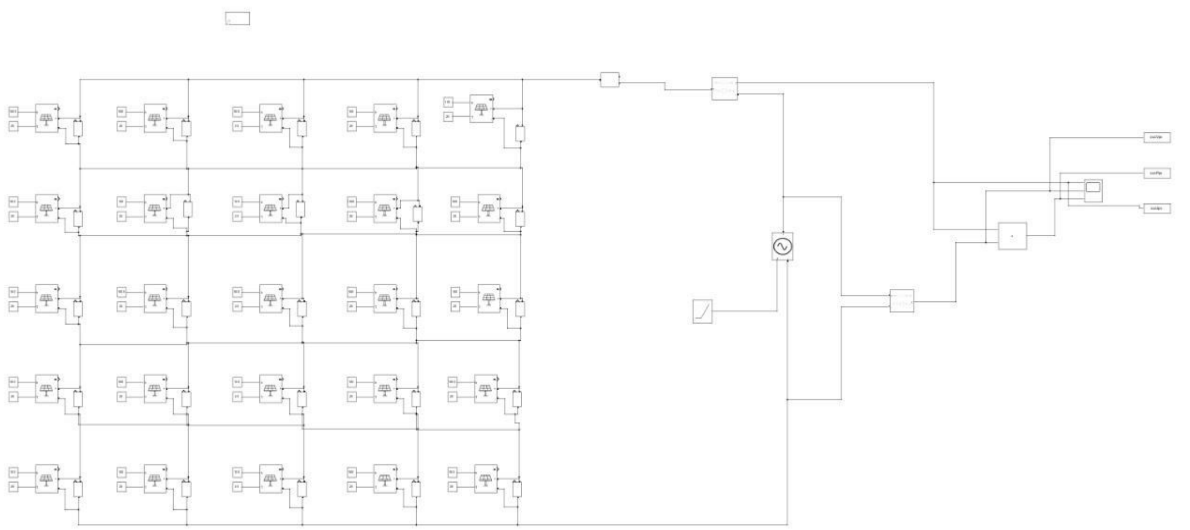

Fig.5.3.21 MATLAB/Simulink model of 5 × 5 Total Cross Tide PV array configuration.

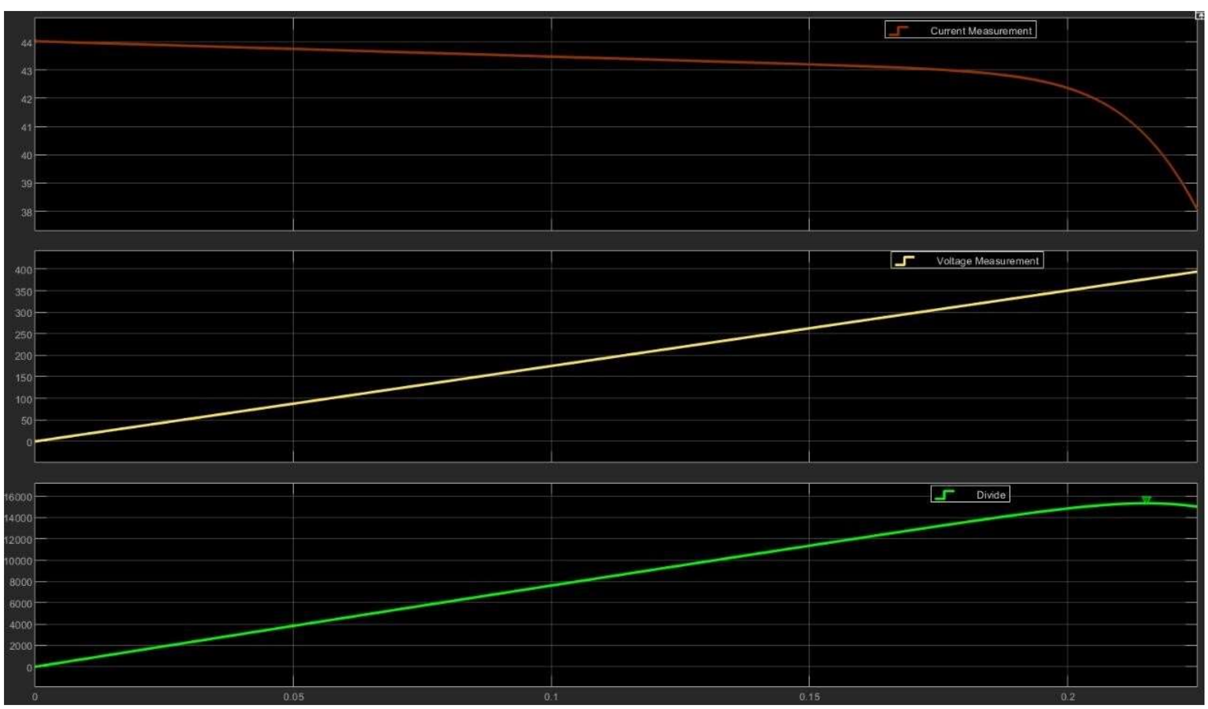

Fig.5.3.22 Simulated output of Total Cross Tide(TCT) PV array configuration.

5.2 Summary of the Proposed and Conventional Interconnection Topologies under 5x5 Test Solar PV Array:

Tabel 1: Simulation results under uniform radiation without shading

Topology	Voc(V)	Isc(I)	Pmax(W)	Vmpp(V)	Impp(A)	DeltaPI%	FF%	n%
Series	148.92	39.21	4568	125.8	36.32	0	78.24	6.34
Se-Pa	157.68	75.86	10440	147.64	70.82	0	87.411	14.5
TCT	1005	18.3	15790	900.5	17.53	0	95.7	21.93

Tabel 2: Simulation results under uniform radiation with 20% shading

Topology	Voc(V)	Isc(I)	Pmax(W)	Vmpp(V)	Impp(A)	DeltaPI%	FF%	n%
Series	148.8	7.8	913.6	124.9	7.315	80	78.718	6.34
Se-Pa	160.48	15.21	2078	145.2	14.31	80.095	85.123	14.4
TCT	941.2	5.51	3488	941.2	3.676	77.9	85.85	24.2

Tabel 3: Simulation results under uniform radiation with 40% shading

Topology	Voc(V)	Isc(I)	Pmax(W)	Vmpp(V)	Impp(A)	DeltaPI%	FF%	n%
Series	148.83	15.69	1859	127.2	14.62	59.303	79.637	6.45
Se-Pa	167.05	30.43	4223	147.7	28.59	59.549	83.07	14.6
TCT	988.8	7.34	6861.4	988.8	6.98	56.5	94.53	23.82

Tabel 4: Simulation results under uniform radiation with 60% shading

Topology	Voc(V)	Isc(I)	Pmax(W)	Vmpp(V)	Impp(A)	DeltaPI%	FF%	n%
Series	148.83	23.5	2789	127.4	21.9	38.943	79.771	6.45
Se-Pa	169.6	45.65	6343	148.4	45.36	39.243	86.944	14.68
TCT	957.8	11.0	10050	957.8	10.48	36.352	95.12	23.26

Tabel 5: Simulation results under uniform radiation with 80% shading								
Topology	**Voc(V)**	**Isc(I)**	**Pmax(W)**	**Vmpp(V)**	**Impp(A)**	**DeltaPI%**	**FF%**	**n%**
Series	148.83	23.5	2789	127.4	21.9	38.943	79.771	4.84
Se-Pa	169.6	45.65	6343	148.4	45.36	39.243	86.944	11.01
TCT	929	14.6	13020	929	14.02	17.542	95.66	22.60

Tabel 6: Simulation results under row partial shading pattern								
Topology	**Voc(V)**	**Isc(I)**	**Pmax(W)**	**Vmpp(V)**	**Impp(A)**	**DeltaPI%**	**FF%**	**n%**
Series	148.67	39.28	4563	124.707	36.59	0.1	78.134	14.4
Se-Pa	168.92	50.83	6781	143.5	50.43	35.047	84.282	21.4
TCT	770.3	7.97	5876	770.3	7.649	62.786	95.831	18.54

Tabel 7: Simulation results under center partial shading pattern								
Topology	**Voc(V)**	**Isc(I)**	**Pmax(W)**	**Vmpp(V)**	**Impp(A)**	**DeltaPI%**	**FF%**	**n%**
Series	148.83	38.97	4540	122.13	37.175	0.61	78.279	14.46
Se-Pa	166.1	62.16	8419	145.5	57.89	19.358	81.58	17.23
TCT	374	12.86	4571	374	12.23	71.05	95.038	16.88

Tabel 8: Simulation results under narrow partial shading pattern								
Topology	**Voc(V)**	**Isc(I)**	**Pmax(W)**	**Vmpp(V)**	**Impp(A)**	**DeltaPI%**	**FF%**	**n%**
Series	148.8	38.97	4561	126.3	36.12	0.153	78.671	11.73
Se-Pa	168.19	71.48	9738	146.8	66.35	6.724	81.018	25.04
TCT	219.2	16.43	3037	204.3	14.94	80.76	63.144	7.811

Tabel 9: Simulation results under wide partial shading pattern								
Topology	**Voc(V)**	**Isc(I)**	**Pmax(W)**	**Vmpp(V)**	**Impp(A)**	**DeltaPI%**	**FF%**	**n%**
Series	148.83	39.97	4562	125.7	36.3	0.131	76.702	24.75
Se-Pa	167.64	54.83	7357	144.2	51.03	29.53	80.056	39.91
TCT	216.4	9.86	1831	204	8.97	88.404	85.778	9.933

Tabel 10: Simulation results under middle partial shading pattern								
Topology	**Voc(V)**	**Isc(I)**	**Pmax(W)**	**Vmpp(V)**	**Impp(A)**	**DeltaPI%**	**FF%**	**n%**
Series	148.8	38.97	4542	124.1	36.6	0.589	78.328	9.33
Se-Pa	167	76.08	10420	147.4	70.6	0.19	81.905	21.40
TCT	359.2	18.29	6300	359.2	17.54	60.101	95.893	12.94

Tabel 11: Simulation results under random partial shading pattern								
Topology	**Voc(V)**	**Isc(I)**	**Pmax(W)**	**Vmpp(V)**	**Impp(A)**	**DeltaPI%**	**FF%**	**n%**
Series	148.8	19.62	2315	127.4	18.27	49.321	79.727	7.30
Se-Pa	163.8	56.71	8000	151.4	52.83	23.371	86.105	25.2
TCT	753.1	8.61	5790	753.1	7.689	63.331	87.90	18.27

CHAPTER 6:

Future Work

Simulation studies on the performance assessment of solar PV array topologies under partial shading conditions is vast and promising. As the adoption of solar energy continues to grow, optimizing PV systems to handle varying shading scenarios effectively becomes crucial. Advanced simulation tools and machine learning algorithms can be employed to develop intelligent shading prediction models and adaptive configurations. Further research can focus on integrating dynamic reconfiguration techniques and maximum power point tracking (MPPT) algorithms to enhance energy yield. Studies can also explore hybrid solutions combining simulation with real-time monitoring for improved accuracy and system resilience. Additionally, there is potential for evaluating novel PV materials and innovative topologies, such as bifacial or multi-junction arrays, under diverse shading environments. These advancements can significantly contribute to reducing power losses, improving efficiency, and accelerating the transition to a more sustainable energy future.

CHAPTER 7:

Conclusion

The study on Simulation Studies on Performance Assessment of Solar PV Array Topologies under Partial Shading Conditions investigates how various solar photovoltaic (PV) array configurations perform under partial shading, a common issue that leads to significant energy losses. In typical PV arrays, partial shading causes mismatched currents between the modules, resulting in multiple peaks in the power-voltage (P-V) curve, which complicates the operation of maximum power point tracking (MPPT) algorithms. This paper presents simulation-based analyses of different PV array topologies, including Series-Parallel (SP) and Total-Cross-Tied (TCT) configurations, aiming to reduce the power losses during shading conditions. Simulation results indicate that traditional SP arrays are more susceptible to power loss when subjected to shading, due to the inability to bypass shaded modules effectively. In contrast, TCT and HC topologies distribute the shading effects more evenly across the array, ensuring better energy capture and reducing mismatched currents. These reconfigured arrays not only mitigate the impact of shading but also improve overall performance and efficiency compared to conventional topologies. Additionally, the study evaluates the integration of bypass diodes and the role of MPPT algorithms in enhancing the system's performance. The findings suggest that optimized PV array configurations combined with intelligent MPPT strategies can significantly improve the energy yield and stability of PV systems, particularly in real-world environments where shading is inevitable.

CHAPTER 8:

References

[1] H. Oufettoul, N. Lamdihine, S. Motahhir, N. Lamrini, I. A. Abdelmoula and G. Aniba, "Comparative Performance Analysis of PV Module Positions in a Solar PV Array Under Partial Shading Conditions," in IEEE Access, vol. 11, pp. 12176-12194, 2023, doi: 10.1109/ACCESS.2023.3237250.

[2] K. Abdulmawjood, S. Alsadi, S. S. Refaat and W. G. Morsi, "Characteristic Study of Solar Photovoltaic Array Under Different Partial Shading Conditions," in IEEE Access, vol. 10, pp. 6856-6866, 2022, doi: 10.1109/ACCESS.2022.3142168.

[3] D. Prince Winston, S. Kumaravel, B. Praveen Kumar, S. Devakirubakaran,Performance improvement of solar PV array topologies during various partial shading conditions,Solar Energy,Volume 196, 2020.

[4] Mohamed, A. M., El-Sayed, A. M., Mohamed, Y. S., & Ramadan, H. A. (2021). ENHANCEMENT OF PHOTOVOLTAIC SYSTEM PERFORMANCE BASED ON DIFFERENT ARRAY TOPOLOGIES UNDER PARTIAL SHADING CONDITIONS. *Journal of Advanced Engineering Trends*, *40*(1), 49-62. doi: 10.21608/jaet.2021.82192.