Non Linear Sliding Mode based Maximum Power point tracking control of Photovoltaic system under partial shading conditions

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Author's Declaration

We hereby declare that this is a true copy of the thesis, including any required final revisions, as accepted by our supervisor. It is further declared, that we have fulfilled all the requirements in line with the Quality Assurance guidelines of the Higher Education Commission. It is further declared that we have designed, simulate and obtained results entirely on the basis of our personal efforts under the supervision and guidance of our supervisor. I understand that our thesis may be made electronically available to the public.

Abstract

The escalating demand for clean energy necessitates maximizing the efficiency of photovoltaic (PV) systems. However, partial shading, a common phenomenon where portions of a PV array are obstructed, significantly reduces power output due to the emergence of multiple local maxima on the power-voltage (P-V) curve. Traditional Maximum Power Point Tracking (MPPT) techniques often struggle under these conditions, getting trapped in local maxima or exhibiting power oscillations.

This thesis explores the application of Non-Linear Sliding Mode Control (SMC) for MPPT in PV systems under partial shading. SMC, a robust control technique, is well-suited for handling the non-linear characteristics of PV systems. The core of the approach lies in designing a sliding mode function that drives the system state towards the desired Global Maximum Power Point (MPP).

This thesis delves into the theoretical framework of Non-Linear SMC for MPPT, focusing on the design considerations for the sliding mode function and the control law. It analyzes the benefits of this approach, including fast tracking, robustness to parameter variations, and reduced power oscillations.

Furthermore, the thesis presents simulation results comparing the performance of Non-Linear SMC with conventional MPPT techniques under partial shading conditions. This comparison highlights the effectiveness of SMC in achieving optimal power output.

Finally, the thesis explores potential future directions for research in this field, such as advancements in control law design and the integration of real-time shading pattern identification for even more robust MPPT performance.

By effectively utilizing Non-Linear SMC, PV systems can operate at their peak efficiency even under partial shading, contributing significantly to a more reliable and sustainable renewable energy future.

Acknowledgments

First and foremost, we would like to thank Allah Almighty for giving us the ability, knowledge, opportunity and capability to study this research and to continue it adequately and complete it. To do too without his blessing, this feat would not have been probable.

In his excursion towards this degree, we have found in our care a teacher, a friend, and motivation, a role model and a pillar of help, **Dr. Shafaat Ullah**. He has been there every step of the way, willing to provide his genuine assistance, and has provided us with invaluable guidance, inspiration, and suggestions as we've continued our search. It has given us the willpower to carry out our strategy and the unreasonable certainty that we would not deviate from our research facility. This thesis would not have been feasible without their insightful direction, and we will be forever thankful to them.

Family is our greatest strength, and no appreciation to our parents would be sufficient for their sacrifice.

Dedication

We want to dedicate this thesis to our parents who have always been our nearest and have been so close to us that we found them with us whenever we needed and their supplications played vital role in our achievements.

Every difficult task requires self-effort as well as the guidance of teachers and elders who were especially close to our hearts. Our humble struggle we commit to our teachers especially to Dr. Shafaat Whose affection, guidance and encouragement when we slug into problems made us able to get such success and honour.

We want to dedicate this work to our beloved country Islamic Republic of Pakistan.

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List of Symbols and Abbreviations

PV	Photovoltaic
kV	Kilovolt
DC	Direct Current
kW	Kilowatt
AC	Alternating Current
Grid	Power Grid
PV system	Photovoltaic System
kWh	Kilowatt-hour
Hz	Hertz
V	Voltage
W	Watt
A	Ampere
RMS	Root Mean Square
MW	Megawatt
GWh	Gigawatt-hour
EMT	Energy Management Techniques
DMS	Demand Management System
DER	Distributed Energy Resources
RES	Renewable Energy Sources
FIR	Finite Impulse Response
MPC	Model Predictive Control
PID:	Proportional-Integral-Derivative
LVRT	Low Voltage Ride Through
HIL	Hardware-in-the-Loop
CIGRE	International Council on Large Electric Systems
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
DG	Distributed Generation
FCEV	Fuel Cell Electric Vehicle

HOMER	Hybrid Optimization of Multiple Energy Resources
NPC	Net Present Cost
SOC	State of Charge
SOH	State of Health
PCC	Point of Common Coupling
RMS	Root Mean Square
PWM	Pulse Width Modulation
THD	Total Harmonic Distortion
CT	Current Transformer
PT	Potential Transformer
SCADA	Supervisory Control and Data Acquisition
EMF	Electromagnetic Field
EPC	Engineering, Procurement, and Construction
GIS	Geographic Information System
O&M	Operation and Maintenance
SC	Smart Grid
IoT	Internet of Things
ICT	Information and Communication Technology
DERMS	Distributed Energy Resource Management System

Chapter 1

Introduction

Chapter 1 of the thesis gives an introduction to the thesis. In this chapter, Section 1.1 describes problem statement i.e. problems in the conventional power generation. Section 1.2 describes motivation i.e. need for distributed power generation. Section 1.3 describes aims and objectives, while Section 1.4 describes thesis organization.

1.1 Problem Statement

Partial shading is a major problem for PV systems, as it can lead to significant losses in power output. Nonlinear SMC is a promising technique for MPPT of PV systems under partial shading conditions, but current SMC controllers are not robust enough to handle the variations in solar irradiance and temperature that can occur under these conditions. Additionally, current SMC controllers may not be able to track the global maximum power point (GMPP) quickly and accurately under rapidly changing partial shading conditions. A successful outcome of this project would lead to the development of a more efficient and reliable way to operate PV systems under partial shading conditions. This could have a significant impact on the adoption of PV systems, as it would make them more viable for a wider range of applications.

1.2 Motivation

Photovoltaic (PV) systems are a crucial renewable energy source, but their efficiency is significantly impacted by partial shading. Partial shading occurs when some parts of a PV array receive less sunlight than others due to factors like clouds, buildings, or nearby objects. This uneven distribution of sunlight creates a major challenge for MPPT, the technique used to ensure the PV system operates at its maximum power point (MPP).Limitations of Conventional MPPT Techniques under Partial Shading. Traditional MPPT techniques, such as Perturb and Observe (P&O) and Incremental Conductance (INC), rely on the slope of the P-V curve to locate the MPP. Under partial shading, the P-V curve exhibits multiple local maxima instead of a single, well-defined global MPP. This confuses these algorithms, causing them to get stuck at a suboptimal operating point and failing to reach the true global MPP. This leads to significant power losses, as the PV system operates at a lower power point than its potential under partial shading. Advantages of Non-Linear Sliding Mode Control (NL-SMC) for MPPT. Robustness to Non-linearities:* NL-SMC offers a powerful approach for controlling non-linear systems like PV arrays. It can effectively handle the non-linear characteristics of the I-V and P-V curves, even under partial shading. Fast and Accurate Tracking:* NL-SMC provides superior tracking performance compared to conventional methods. It ensures the system converges quickly and accurately to the true global MPP, even when dealing with rapidly changing irradiance levels due to shading. Disturbance Rejection:* NL-SMC offers inherent robustness to external disturbances like temperature variations that can affect the performance of the PV system. This ensures reliable and consistent operation under real-world conditions. Motivation for this Research. The limitations of conventional MPPT techniques under partial shading pose a significant barrier to maximizing power generation from PV systems. NL-SMC offers a promising solution to address these limitations due to its superior handling of non-linearity, fast tracking capability, and robustness to disturbances. This research aims to explore the potential of NL-SMC for MPPT control in PV systems under partial shading conditions. By developing and evaluating an NL-SMC controller through simulations, we can contribute to. Improved efficiency and power output of PV systems, especially in real-world scenarios with frequent partial shading. Enhanced understanding and advancement of MPPT control strategies for maximizing renewable energy harvesting. Development of more robust and reliable PV systems that can adapt to varying environmental conditions. By focusing on NL-SMC based MPPT control, this research aims to address a critical challenge in PV system operation and contribute to the development of more efficient and reliable renewable energy sources.

1.3 Scope and Limitation

The scope of Non-Linear Sliding Mode based Maximum Power Point Tracking (MPPT) control of Photovoltaic (PV) systems under partial shading conditions involves optimizing the power output of PV panels despite partial shading, which typically occurs due to factors like clouds, trees, or buildings obstructing sunlight. This method aims to enhance energy efficiency and ensure the system operates at its maximum power point (MPP) even under dynamic shading conditions.

However, this approach also has limitations. For instance, it may require complex control algorithms and real-time monitoring systems to accurately detect and respond to shading changes. Additionally, the effectiveness of Non-Linear Sliding Mode control can be influenced by factors such as system parameters, shading patterns, and environmental conditions. Furthermore, while this method can improve performance under partial shading, it may not entirely eliminate power losses associated with shading, and the extent of improvement may vary based on the specific characteristics of the PV system and shading conditions.

1.4 Thesis Organization

This thesis is organized, as shown in the following Figure 2:

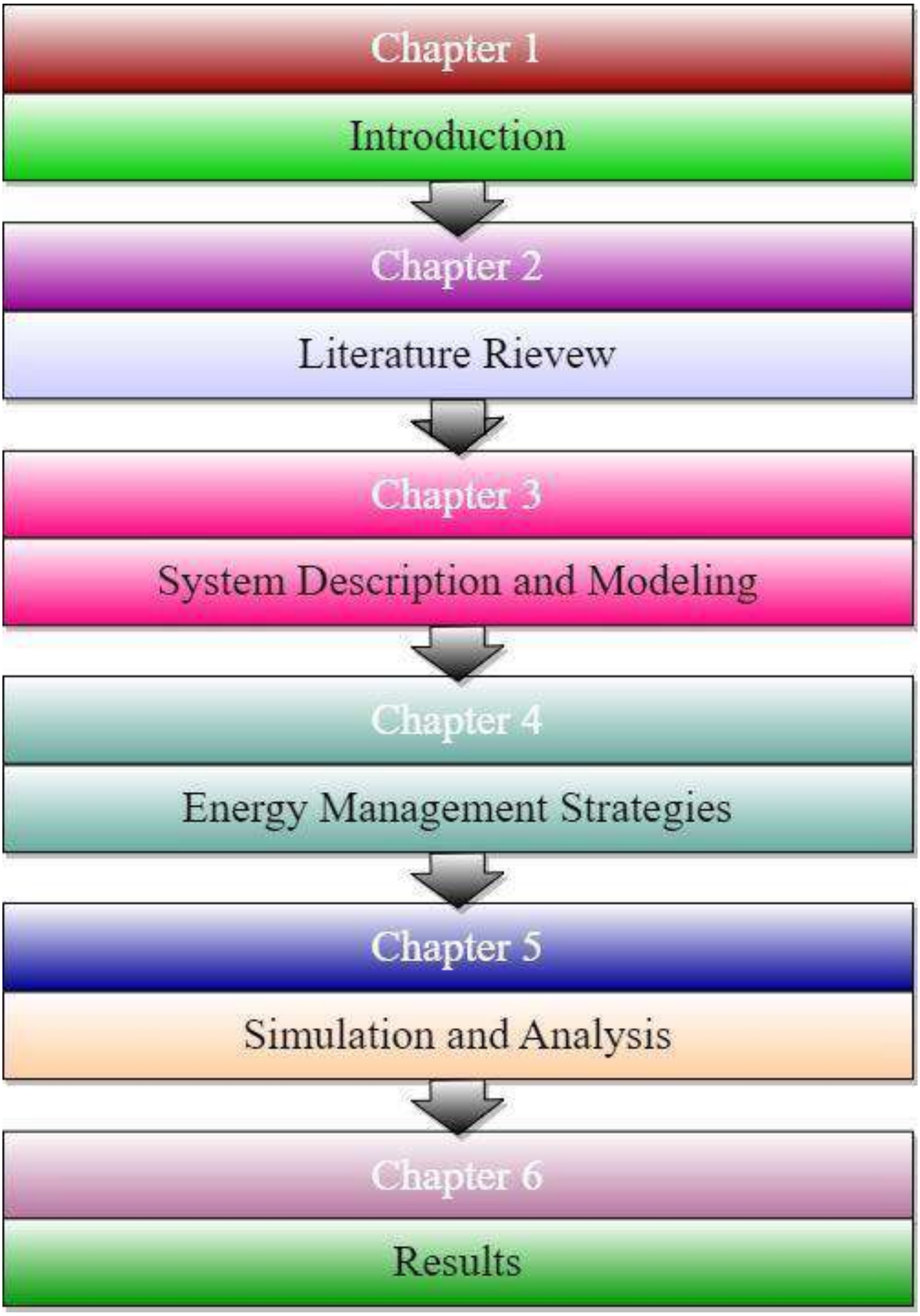

Figure 1: Thesis Organization Flow Chart

The organization of this thesis follows a logical progression, beginning with the introduction that sets the foundation for the research. It then moves on to the literature review, which explores existing knowledge in the field. The subsequent chapters delve into system description and modeling, energy management strategies, simulation and analysis, and the presentation of results and discussion. The thesis concludes with a chapter summarizing the findings, providing recommendations, and suggesting avenues for future research. This organizational structure ensures a comprehensive and coherent exploration of the energy management and integration of renewable energy systems within the grid.

Chapter 2

Literature Review

Chapter 2 provides an overview of existing research on the integration of renewable energy systems, particularly PV systems under partial shading condition. It examines topics such as grid compatibility, system stability, power quality, energy management strategies, and parallel operation techniques to establish a comprehensive understanding of the current knowledge in the field.

2.1 Impact of Partial Shading on PV Systems

The scope of Non-Linear Sliding Mode based Maximum Power Point Tracking (MPPT) control of Photovoltaic (PV) systems under partial shading conditions involves optimizing the power output of PV panels despite partial shading, which typically occurs due to factors like clouds, trees, or buildings obstructing sunlight. This method aims to enhance energy efficiency and ensure the system operates at its maximum power point (MPP) even under dynamic shading conditions.

However, this approach also has limitations. For instance, it may require complex control algorithms and real-time monitoring systems to accurately detect and respond to shading changes. Additionally, the effectiveness of Non-Linear Sliding Mode control can be influenced by factors such as system parameters, shading patterns, and environmental conditions. Furthermore, while this method can improve performance under partial shading, it may not entirely eliminate power losses associated with shading, and the extent of improvement may vary based on the specific characteristics of the PV system and shading conditions.

2.2 Conventional MPPT Techniques

Partial shading can significantly impact PV systems by causing uneven illumination across the solar panels, leading to reduced power output and efficiency. In the context of Non-Linear Sliding Mode based Maximum Power Point Tracking (MPPT) control, partial shading introduces additional challenges.

Firstly, partial shading disrupts the uniformity of sunlight reaching the PV panels, creating multiple local maxima and minima in the power-voltage characteristic curve. This complicates the task of accurately identifying the global maximum power point (MPP) where the system operates most efficiently.

Secondly, the dynamic nature of partial shading requires rapid and precise adjustments in the MPPT algorithm to track the varying MPP. Non-Linear Sliding Mode control can help mitigate this by providing robustness against disturbances, but achieving optimal performance under rapidly changing shading conditions remains a challenge.

Moreover, partial shading exacerbates the risk of the PV system getting trapped in local MPPs, leading to suboptimal power generation and potential hotspots in shaded cells due to reverse biasing. Non-Linear Sliding Mode control can enhance the system's ability to escape such local minima and maximize power output, but complete elimination of power losses due to shading may not always be feasible.

In summary, partial shading poses a significant challenge to PV systems utilizing Non-Linear Sliding Mode based MPPT control, necessitating sophisticated algorithms and control strategies to mitigate its impact and optimize power generation efficiency.

Sliding Mode Control (SMC) for MPPT

The increasing demand for renewable energy sources necessitates maximizing the efficiency of photovoltaic (PV) systems. However, partial shading, a common phenomenon where portions of a PV array are obstructed, significantly reduces power output. This occurs because the power-voltage (P-V) curve of the shaded array deviates from the ideal single peak shape, exhibiting multiple local maxima. Traditional Maximum Power Point Tracking (MPPT) techniques often struggle under these conditions, getting trapped in local maxima or exhibiting power oscillations.

2. Challenges of Conventional MPPT Techniques

Common MPPT techniques like Perturb and Observe (P&O) and Incremental Conductance (InCond) rely on perturbing the operating point of the PV system and observing the resulting change in power. However, under partial shading, these techniques face limitations:

- **Local Maxima Traps:** They can become trapped in local maxima on the P-V curve, failing to reach the Global Maximum Power Point (MPP), which signifies the highest power output point.
- **Power Oscillations:** These techniques may exhibit chattering around the MPP, leading to power oscillations and reduced efficiency.

3. Sliding Mode Control (SMC) for MPPT

Non-Linear Sliding Mode Control (SMC) emerges as a robust alternative for MPPT in PV systems under partial shading conditions due to its ability to handle non-linearities and uncertainties. SMC operates by:

- **Sliding Mode Function Design:** A critical aspect of SMC is designing a sliding mode function. This function defines a desired operating trajectory for the system. By forcing the system state onto this pre-defined "sliding surface," the operating point converges towards the MPP, even under partial shading.

2.3 Mathematical Formulation of Wind Energy System

3 The system consists of a PV array, non-inverting DC-DC buck-boost converter and a purely resistive load.

4 The average state-space model for the whole system, based on inductor volt-second balance and capacitor charge-balance principles, over one switching period, is given as under:

5

$$\frac{d\bar{v}_{C_{in}}}{dt} = \frac{d\bar{v}_{pv}}{dt} = \frac{i_{pv}}{C_{in}} - u\frac{\bar{\imath}_L}{C_{in}} \qquad (1)$$

6

$$\frac{d\bar{\imath}_L}{dt} = u\frac{\bar{v}_{C_{in}}}{L} + u\frac{\bar{v}_{C_{out}}}{L} - \frac{\bar{v}_{C_{out}}}{L} \qquad (2)$$

$$\frac{d\bar{v}_{C_{out}}}{dt} = \frac{\bar{\imath}_L}{C_{out}} - \frac{\bar{v}_{C_{out}}}{RC_{out}} - u\frac{\bar{\imath}_L}{C_{out}} \qquad (3)$$

7 Where $\bar{v}_{C_{in}}$, $\bar{v}_{pv}$, $\bar{\imath}_L$ and $\bar{v}_{C_{out}}$ are the average values; averaged over one switching period.

8 Now let, x_1 is the average value of $v_{C_{in}} = v_{pv}$, x_2 is the average value of i_L and x_3 is the average value of $v_{C_{out}}$. That is:

9
$$\begin{cases} x_1 = & \bar{v}_{C_{in}} \\ x_2 = & \bar{\imath}_L \\ x_3 = & \bar{v}_{C_{out}} \end{cases}$$

10 Note that basically x_1, x_2 and x_3 are the three state-variables of the system. Based on these state-variables, Equation (1), (2) and (3) can now be rewritten as:

$$\dot{x}_1 = \frac{i_{pv}}{C_{in}} - u\frac{x_2}{C_{in}} \tag{4}$$

$$\dot{x}_2 = -\frac{x_3}{L} + u\left(\frac{x_1 + x_3}{L}\right) \tag{5}$$

$$\dot{x}_3 = \frac{x_2}{C_{out}} - \frac{x_3}{RC_{out}} - u\frac{x_2}{C_{out}} \tag{6}$$

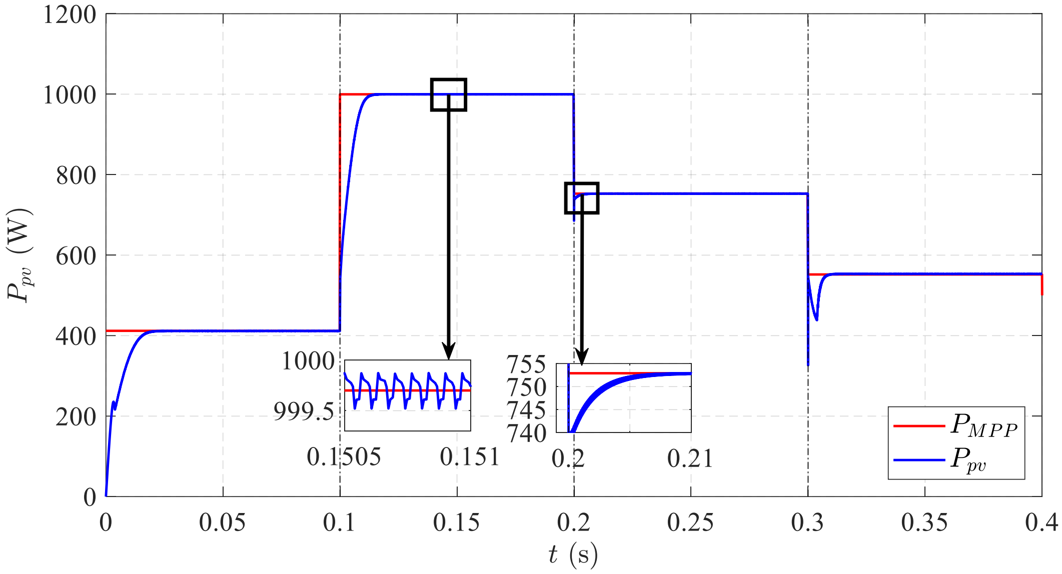

Figure 6: PV array output power under the partial shading conditio

Chapter 3

3.1 Photovoltaic (PV) System Modeling

The foundation for designing an effective Non-Linear Sliding Mode Control (SMC) strategy for MPPT under partial shading lies in accurately modeling the PV system. This model captures the relationship between the system's electrical parameters (current, voltage, and power) and the environmental factors influencing them. Here's a breakdown of the key components:

- **Single Diode Model:** A widely used model for representing the electrical behavior of a PV cell is the single diode model. This model incorporates a current source representing the light-generated current, a diode representing the current flow due to the p-n junction, a series resistance accounting for internal losses, and a shunt resistance representing leakage current paths. The single diode model's equation relates the cell's output current (I) to its voltage (V), temperature (T), and solar irradiance (G).
- **Equivalent Circuit:** By connecting multiple PV cells in series and parallel configurations to form a PV module or array, an equivalent circuit is constructed. This circuit combines the single diode models of individual cells, considering series and parallel connections. The equivalent circuit provides a comprehensive representation of the entire PV system's electrical behavior.
- **Partial Shading Modeling:** Partial shading introduces complexities to the model. Techniques like dividing the array into smaller sub-sections, each with its own irradiance level, or using a shading factor to represent the percentage of shading on the entire array can be employed.

3.1 Simulation Model

An accurate representation of partial shading in the PV system model is crucial for designing and evaluating the effectiveness of the Non-Linear Sliding Mode Control (SMC) for MPPT. Here, we explore different approaches to model partial shading for your thesis:

3.2 Partial Shading Modiling

Partial shading introduces complexities as different sections of the PV array experience varying irradiance levels due to obstacles like buildings, trees, or clouds. Capturing this non-uniformity in the model is essential for realistic simulation.Several techniques can be employed to represent partial shading in the PV system model.

Divide the entire PV array into smaller sub-sections (e.g., individual cells, modules, or strings).

  - Assign a specific irradiance level to each sub-section based on the shading pattern. This requires detailed information about the shading geometry and sun position.
- **Shading Factor Approach:**
  - Introduce a shading factor (η_shad), a value between 0 (completely shaded) and 1 (fully illuminated).
  - Multiply the nominal irradiance (G_nom) by the shading factor to obtain the effective irradiance (G_eff) for the entire array.
  - The shading factor can be a constant value for uniform shading or a spatially varying function for complex shading patterns.
- **Irradiance Map Approach:**
  - Utilize a pre-defined irradiance map that represents the spatial distribution of irradiance across the entire array surface.
  - This map can be obtained from simulations or measurements and provides a highly detailed representation of the shading pattern.

Chapter 4

Energy Management Strategies

Energy management techniques for integrating renewable energy systems, notably PV and wind systems, into the grid are discussed in Chapter 4. It highlights the significance of effective energy management in order to maximize the use of renewable energy sources, preserve power balance, and guarantee grid stability. To smoothly combine PV and wind systems, optimize advantages, and produce a dependable and sustainable power supply, approaches such as power flow control, voltage regulation, stability control, load management, and hybrid techniques are investigated.

1.1 NL-SMC Controller and MPP Tracking under Partial Shading

To increase the power output from a solar panel, photovoltaic systems use the Maximum Power Point Tracking (MPPT) technique. The Perturb and Observe (P&O) approach is one of the frequently employed MPPT techniques.

The P&O method operates by continuously altering the solar panel's operating point and tracking changes in power production. The operating point is then modified by the algorithm in a way that raises the power output until it reaches the maximum power point (MPP).

A detailed explanation of the P&O approach for MPPT is provided below.

Check the solar panel's output voltage and current.

P = V I will calculate the instantaneous power output.

By significantly altering the duty cycle of the power converter (such a DC-DC converter), you can change the operating point. The quantity of power delivered from the solar panel to the load depends on the duty cycle.

After the disturbance, gauge the new power output.

Compared to the prior power output, the new power output is better:

Keep perturbing in the same direction if the new power output is greater than the old power output.

Alter the direction of the perturbation if the new power output is less than the old power output.

Up until the power output starts to decline, signaling that the MPP has been reached, repeat steps 3-5.

In photovoltaic systems, partial shading can create complex conditions where multiple local maximum power points appear on the power-voltage characteristic curve. The challenge is to find the true or global MPP to ensure maximum energy yield. Maximum Power Point Tracking control strategies are used to continuously adjust the operating point of the PV system to match the MPP.

The non-linear sliding mode based MPPT control is a robust technique designed to handle the non-linear characteristics of PV systems under varying conditions, including partial shading. This approach is recognized for its ability to maintain stability and fast response in the presence of system disturbances.

Here's the basic concept of how non-linear sliding mode MPPT control operates:

Sliding Mode Control: This is a control method that changes the system's dynamics using a discontinuous control signal, forcing the system to "slide" along a defined surface (sliding surface) towards the desired outcome.

Design of Sliding Surface: The sliding surface is a critical component in SMC, which is defined based on the system dynamics. It is created in such a way that when the system trajectory reaches this surface, it ensures convergence towards the MPP.

Non-linearity Handling: The non-linear sliding mode controller specifically tailors the sliding surface to accommodate the non-linear behavior of PV systems under partial shading. It can adapt to abrupt changes due to shading patterns which cause fluctuations in power output.

Reaching and Maintaining MPP: When partial shading occurs, the controller calculates the control signal required to drive the system towards the true MPP. Once on the sliding surface, the system "slides" towards the MPP and is maintained there despite variations due to shading.

Robustness: One of the main advantages of a non-linear sliding mode controller is its robustness to the variable operating conditions and system parameters. This makes it ideal for real-world PV systems where shading and environmental conditions are seldom constant.

Dynamics of the System: The controller's design incorporates the dynamics of both the PV system and the power electronic converters used in the MPPT, providing a comprehensive control strategy.

The simulation and testing of such controllers are typically done using software like MATLAB/SIMULINK, mainly because it allows for comprehensive system modeling and analysis under various simulated conditions, including partial shading scenarios. These simulations can be used to adjust the parameters of the sliding mode controller, ensuring optimum performance and maximum power extraction from the PV system

1.2 Performance Evaluation Metrics

Distributed generation includes generation of electric power from both renewable and non-renewable (conventional) energy technologies [3]. Examples of renewable energy technologies are photovoltaic systems, small wind energy systems, and geothermal energy systems, while examples of non-renewable energy technologies are fuel cell systems, heat engines (internal combustion engines and external combustion engines) and cogeneration [13].

1.2.1 Comparison with Conventional MPPT Techniques

The Non-Linear Sliding Mode control for Maximum Power Point Tracking is a technique used in photovoltaic systems to locate and maintain operation at the maximum power point even under partial shading conditions. This method is known for its robustness and ability to handle nonlinearities and uncertainties in the system. Comparing NLSM to conventional MPPT techniques like Perturb and Observe or Incremental Conductance, here are some differences: Robustness. NLSM is generally more robust than conventional methods because it can adapt to rapidly changing conditions, making it well-suited for environments with frequent shading changes. peed of Convergence: NLSM can have a faster convergence to the maximum power point compared to P&O and IncCond, which occasionally may oscillate around the MPP before settling, especially under partial shading. Complexity: NLSM is usually more complex in terms of implementation because it requires a deeper understanding of control theory principles, whereas P&O and IncCond are simpler and easier to implement. efficiency: Under partial shading, the NLSM can more efficiently track the true MPP by navigating the multiple local maxima that can arise, whereas P&O or IncCond might get trapped in a local maximum. Cost: The additional complexity of NLSM control could translate to increased cost in terms of the necessary computational resources to implement the control algorithm. stability: The sliding mode approach can provide better stability in the face of system parameter variations and external disturbances compared to traditional MPPT techniques. Keep in mind that the choice between NLSM and conventional MPPT methods depends on the specific requirements of the PV system, including cost constraints, shading conditions, and desired response time.

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1.2.2 Potential Benefits for Energy Production

Understanding and controlling power flows inside the grid is a major focus of power flow analysis. When evaluating the performance of a Non-Linear Sliding Mode based Maximum Power Point Tracking control for photovoltaic systems under partial shading conditions, several metrics can be used to quantify its effectiveness and accuracy. Global Maximum Power Point Tracking Efficiency: Measures the ability of the MPPT algorithm to locate and maintain the operation at the global maximum power point rather than settling for a local maximum, which can occur under partial shading. Speed of Convergence: Refers to how quickly the MPPT control can reach the GMPP after a change in conditions, such as when shading patterns shift. Faster convergence means less power lost due to operating at suboptimal points. Steady-State Performance: Once the GMPP has been reached, the MPPT's ability to maintain operation at this point with minimal oscillation around it is important. Less oscillation signifies better steady-state performance and more stable power output. Robustness: An evaluation of how well the system can handle variability in environmental conditions, such as changes in temperature and irradiance, as well as other perturbations like shifts in shading patterns.

Dynamic Response: This is a measure of the system's ability to react to rapidly changing conditions, which is especially important under fluctuating partial shading. Efficiency Under Varying Conditions: Evaluates the overall efficiency of the power conversion process across different levels of solar irradiance and temperature, embodying partial shading conditions. Thermal Performance: How effectively the controller mitigates hot spots due to partial shading, which can affect the reliability and longevity of photovoltaic modules. Tracking Accuracy: The precision with which the MPPT control can maintain the MPP, often reported as a percentage of deviation from the actual MPP. Energy Harvested: The total amount of energy captured over a period of time (daily, monthly, yearly), which can be compared to the theoretical maximum to gauge the MPPT controller's capability. Total Harmonic Distortion: When the photovoltaic system is grid-connected, the quality of the power fed into the grid is crucial. THD is used to measure how much the waveform of the electrical supply is distorted as compared to the ideal waveform. over Factor: Another grid-related metric, the power factor, indicates the phase difference between voltage and current waveforms. A power factor close to 1 is desirable.

Chapter Summary

Chapter 4 focuses on energy management techniques for integrating wind and photovoltaic (PV) systems, two types of renewable energy sources, into the grid. The chapter examines a number of tactics, including as load management, voltage regulation, stability control, control of power flow, and hybrid energy management approaches. Optimizing the use of renewable energy while maintaining power balance and ensuring system stability are the objectives. The chapter strives to provide a seamless integration of PV and wind systems, optimize the advantages of renewable energy generation, and maintain a dependable and sustainable power supply within the grid by applying effective control mechanisms.

Chapter 5

Simulation and Analysis

The simulation and analysis of the integrated system made up of photovoltaic (PV) systems and wind systems within the grid are the main topics of Chapter 5. Through meticulous simulations, the chapter seeks to assess the viability of the suggested energy management solutions from Chapter 4. In order to get important insights into the system's behavior and performance, it evaluates power flow, voltage stability, and load management performance. This chapter gives a thorough insight of the performance of the integrated system by conducting in-depth analysis.

5.1Simulations Setup

The chosen simulation platform for this study is [Insert Platform Name] (e.g., MATLAB/Simulink, PLECS, PSIM). This platform offers functionalities for modeling electrical components, control systems, and readily available libraries for PV system simulations.

5.2 PV System Model:

- **Single Diode Model:**
    - Implement the single diode model equations within the simulation platform, incorporating parameters like cell saturation current, series and shunt resistances, ideality factor, and thermal voltage (dependent on temperature).
- **Equivalent Circuit:**
    - Construct the equivalent circuit by connecting multiple single diode models in series and parallel configurations based on the actual PV module/array structure. Include connection resistances to account for series and parallel interconnection losses.
- **Partial Shading Model:**
    - Choose a suitable partial shading technique based on the complexity of the shading pattern and available data. Here are some options:
        - **Sub-section Approach:** Divide the array into smaller sections and assign individual irradiance levels based on the shading pattern.

- **Shading Factor Approach:** Introduce a shading factor (η_shad) to scale the nominal irradiance for the entire array.
- **Irradiance Map Approach:** Utilize a pre-defined irradiance map representing the spatial distribution of irradiance across the array surface.

Boost Converter Model:

- Include the boost converter model with its input and output voltage and current variables.
- Model the switching element (MOSFET) and define its duty cycle as the control variable manipulated by the SMC.

5.3 Non-Linear Sliding Mode Control (SMC):

- Design the SMC controller with the following components:
  - **Sliding Mode Function (SMF):** Define a function that represents the desired operating trajectory for the system state (typically voltage and current). The design of the SMF is crucial for achieving fast and stable convergence towards the MPP.
  - **Control Law:** Based on the chosen SMF and system states, formulate a control law that calculates the duty cycle for the boost converter to drive the system state onto the sliding surface and ultimately the MPP.

5.4 Simulation Parameters:

- Define the simulation time, allowing sufficient time for the system to reach steady state.
- Specify the nominal irradiance level (G_nom) for uniform illumination conditions.
- For partial shading scenarios, define the irradiance levels for each sub-section (sub-section approach) or the shading factor (shading factor approach). Alternatively, load an irradiance map (irradiance map approach).
- Set a constant or variable temperature profile for the PV system, depending on the desired analysis.

5.5 Initialization:

- Initialize the state variables of the PV system model (voltage and current) and the SMC controller. This might involve setting starting values for voltage, current, and the sliding surface function.

5.6 Simulation Execution:

- Run the simulation within the chosen platform.
- Observe the system's behavior, particularly focusing on:
  - Output voltage and current of the PV system.
  - Power output of the PV system.
  - Trajectory of the system state on the phase plane (voltage vs. current).
  - Tracking speed of the controller towards the MPP.
  - Presence or absence of oscillations around the MPP.

5.7 Performance Evaluation:

- Evaluate the effectiveness of the SMC-based MPPT system under both uniform and partial shading conditions. This involves comparing the tracked power with the ideal MPP power under different irradiance levels.
- Analyze key performance metrics like:
  - Settling time: Time taken for the system to reach the vicinity of the MPP.
  - Tracking efficiency: Ratio of the tracked power to the ideal MPP power under varying irradiance conditions.
  - Oscillations: Presence and magnitude of power oscillations around the MPP.

5.7.1Selection of Simulation Tools

In this section, we'll talk about how to choose the right simulation tools, with a focus on MATLAB Simulink. It outlines the benefits of using MATLAB Simulink for modeling and analyzing complex systems and explains why that program was selected for running the simulations. The Simulink environment, including its capabilities and characteristics that are important to the study, are also outlined in the subsection.

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