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A THESIS

Submitted in partial fulfillment of the requirements for the award of the degree

of

DOCTOR OF PHILOSOPHY

in

ELECTRICAL ENGINEERING

by

YOUR NAME

DEPARTMENT OF ELECTRICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE - 247667 (INDIA)

JANUARY, 2026

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

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ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my supervisor, for their guidance, support, and encouragement throughout the course of this research. Their valuable insights and constructive feedback were essential to the completion of this thesis.

I am thankful to the [Department Name] at [University Name] for providing a supportive academic environment and the necessary facilities to carry out this work.

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Finally, I am deeply grateful to my family for their constant love, patience, and unwavering support throughout my academic journey. Their belief in me has been a continual source of strength and motivation.

(Your Name)

ABSTRACT

Replace with your abstract that defines the issue, the brief solution proposed, and its effect on the system.

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संक्षेप

यह एक उदाहरणात्मक (Example) पाठ है जिसका उपयोग केवल सामग्री की संरचना दिखाने के लिए किया जाता है। इसका किसी वास्तविक अर्थ से कोई संबंध नहीं होता, लेकिन यह पढ़ने में स्वाभाविक लगता है। इस प्रकार के पाठ का प्रयोग आमतौर पर वेबसाइट डिज़ाइन, प्रिंट लेआउट, पोस्टर, ब्रोशर और अन्य दृश्य प्रस्तुतियों में किया जाता है ताकि वास्तविक सामग्री आने से पहले स्थान और प्रवाह को समझा जा सके

इस डमी पाठ का उद्देश्य यह दिखाना है कि अंतिम सामग्री कैसी दिखाई देगी। इसमें शब्दों की लंबाई, वाक्यों की संरचना और पैराग्राफ का संतुलन शामिल होता है। डिजाइनर और डेवलपर इसका उपयोग यह जांचने के लिए करते हैं कि टेक्स्ट फ़ॉन्ट, साइज और स्पेसिंग के साथ कैसा दिखेगा। इससे यह सुनिश्चित होता है कि वास्तविक सामग्री जोड़ने पर कोई दृश्य समस्या न हो।

हिंदी लिप्सम विशेष रूप से तब उपयोगी होता है जब प्रोजेक्ट हिंदी या देवनागरी लिपि में हो। इससे यह समझना आसान हो जाता है कि भाषा के अनुसार डिज़ाइन कितना प्रभावी है। इस तरह का पाठ न तो पाठक को विचलित करता है और न ही ध्यान वास्तविक संदेश से हटाता है, क्योंकि इसका कोई वास्तविक संदेश होता ही नहीं।

संक्षेप में, यह केवल एक भराव सामग्री है जो डिज़ाइन प्रक्रिया को आसान और अधिक प्रभावी बनाती है।

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

SPV Solar Photovoltaic

MPPT Maximum Power Point Tracking

GMPP Global Maximum Power Point

P&O Perturb and Observe

DEPSO Differential Evolutionary with Particle Swarm Optimization

HPO Human Psychology Optimization

STC Standard Test Conditions

ISDM Ideal Single-Diode Model

SDM Single-Diode Model

SSDM Simplified Single Diode Model

qZSI Quasi-Z-Source Inverter

PR Proportional–Resonant

VSI Voltage Source Inverters

CSI Current Source Inverters

ZSI Z-Source Inverter

LIST OF SYMBOLS

Parameters

L^{con}	Converter Inductance
C_o	Output Capacitance
R_o	Output Resistance
C_{in}	Input Capacitance
K_{pi}^{con}	P Gain of Converter Current PI
K_{ii}^{con}	I Gain of Converter Current PI
K_{pv}^{con}	P Gain of Converter Voltage PI
K_{iv}^{con}	I Gain of Converter Voltage PI
L_f	Filter Inductance

Variable

V_{in}	Input Voltage
I_{in}	Input Current
I_L^{con}	Converter Inductor Current
V^{dc}	DC Bus Voltage
I^{dc}	Output DC Voltage
D^{con}	Converter Duty Cycle
i_i, v_i	Grid Forming/Feeding/qZSI Input Current and Voltage
i_o, v_o	Grid Forming/Feeding/qZSI Output Current and Voltage

Additional Subscripts on Variables

0	Nominal Value of the Variable
d, q	Variable in dq Reference Frame
i	i^{th} Element
D, Q	Variable in DQ Reference Frame

Additional Superscripts on Variables

$*$	Vector Conjugate
ref	Reference of variable

Operators

Δ	Variable Small Signal Variation
$(\cdot)^T$	Matrix Transpose
$diag\{\cdot\}$	Diagonal Matrix
$(\cdot)^{-1}$	Matrix Inverse

Chapter 1

OVERVIEW

1.1 Background and Motivation

This first paragraph extensively reviews the existing literature, examines the selected research problem, establishes its theoretical foundations, and highlights its relevance across various contexts. Prior studies have contributed valuable insights through diverse approaches and methodologies, thereby advancing understanding within the field. However, a critical review of this literature reveals several limitations, including fragmented findings, methodological inconsistencies, limited contextual focus, and insufficient empirical validation. These gaps indicate the need for further systematic investigation to integrate existing knowledge, address unresolved issues, and provide a more comprehensive and context-specific understanding of the problem.

1.2 Objectives

By identifying the literature gaps the objectives are defined as follows:

1. *Research Gap 1*: Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

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1.3 Thesis Organization

To fulfill the objectives defined in Section 1.2, the following thesis chapters have been covered as follows:

1. *Chapter One Name*: Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

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1.4 Thesis Contribution

The major contributions of this research work can be summarized as follows:

- Define your contribution 1.
- Define your contribution 2.
- Define your contribution 3.
- Define your contribution 4.
- Define your contribution 5.
- Define your contribution 6.

Chapter 2

NAME OF CHAPTER-2

2.1 Introduction

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2.2 Literature Review

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2.3 Content Heading

To regulate the DC bus voltage at the terminals of DC-DERs, an appropriate converter model is required for controller design. In this thesis, a boost converter is employed to interface the DC DERs with the DC bus. The basic block diagram of the DC DER integrated through a boost converter is shown in Fig. 2.1.

The modeling of the converter is performed by taking the average of the system during turn-on and turn-off cases of the SW as follows

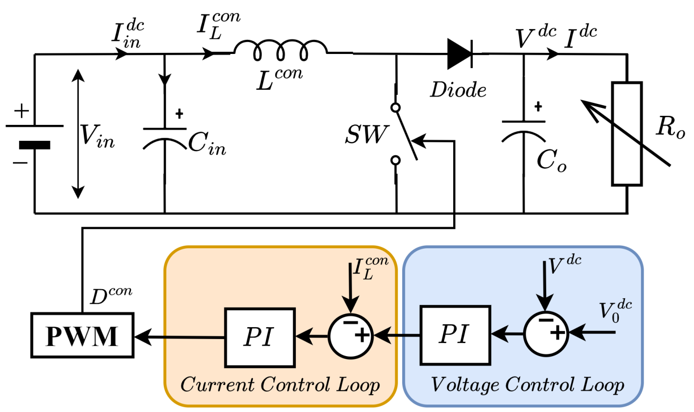

Figure 2.1: Basic block diagram for boost converter based DC-DERs

During SW is turn-on

$$V_{in} = L^{con} \cdot \frac{dI_L^{con}}{dt} \tag{2.1}$$

$$C_o \cdot \frac{dV^{dc}}{dt} = -\frac{V^{dc}}{R_o} \tag{2.2}$$

During SW is turn-off

$$V_{in} - V^{dc} = L^{con} \cdot \frac{dI_L^{con}}{dt} \tag{2.3}$$

$$C_o \cdot \frac{dV^{dc}}{dt} = I_L^{con} - \frac{V^{dc}}{R_o} \tag{2.4}$$

Now using (2.1), (2.2), (2.3), and (2.4), the average model is developed as follows:

$$V_{in} - V^{dc}(1 - D^{con}) = L^{con} \frac{dI_L^{con}}{dt} \tag{2.5}$$

$$C_o \cdot \frac{dV^{dc}}{dt} = I_L^{con} \cdot (1 - D^{con}) - \frac{V^{dc}}{R_o} \tag{2.6}$$

Taking the small perturbation, the state space model is developed as follows:

$$\begin{bmatrix} \Delta \dot{I}_L^{con} \\ \Delta \dot{V}^{dc} \end{bmatrix} = \begin{bmatrix} 0 & \frac{-(1-D^{con})}{L^{con}} \\ \frac{1-D^{con}}{C_o} & \frac{-1}{C_o R_o} \end{bmatrix} \begin{bmatrix} \Delta I_L^{con} \\ \Delta V^{dc} \end{bmatrix} + \begin{bmatrix} \frac{1}{L^{con}} & \frac{V^{dc}}{L^{con}} \\ 0 & \frac{-I_L^{con}}{C_o} \end{bmatrix} \begin{bmatrix} \Delta V_{in} \\ \Delta D^{con} \end{bmatrix} \tag{2.7}$$

$$\Delta V^{dc} = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} \Delta I_L^{con} \\ \Delta V^{dc} \end{bmatrix} \tag{2.8}$$

Table 2.1: DC-DC Boost Converter Details

Parameter	**Value**	**Parameter**	**Value**
$Rating$	$10kW$	L	$9mH$
V_{in}	$600V$	C_{in}	$100\mu F$
V^{dc}	$900V$	$K_{pi}^{con}, K_{ii}^{con}$	0.0539, 175
$Switching\ Frequency\ (F_{sw})$	$10kHz$	$K_{pv}^{con}, K_{iv}^{con}$	0.0243, 30.5
C_o	$41\mu F$		

2.4 Conclusion

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Chapter 3

NAME OF CHAPTER-3

3.1 Introduction

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3.2 Literature Review

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3.3 Contribution

The contributions of this chapter are as follows:

- Contribution 1.
- Contribution 2.
- Contribution 3.
- Contribution 4.

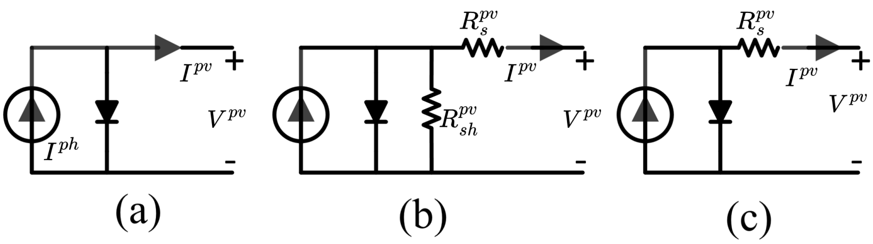

Figure 3.1: Equivalent circuits for SPV: (a) ISDM, (b) SDM, (c) SSDM.

3.4 Content Heading

The SPV module operates in a wide range of atmospheric conditions, but the manufacturers provide electrical parameters at only STC in their datasheet [1]. The SPV models are classified into three main types. The first is the ISDM as shown in Fig. 3.1(a), the second one is the SDM as shown in Fig. 3.1(b), and the third is an SSDM as shown in Fig. 3.1(c) [1]. The basic IV characteristic for SPV module, which has series-connected cells, is expressed as (3.1) [1, 2, 3].

$$I^{pv} = I^{ph} - I_{ds}^{pv}\left[\exp\left(\frac{V^{pv} + R_s^{pv} \cdot I^{pv}}{V_T \cdot A_d^{pv}}\right) - 1\right] - \frac{V^{pv} + R_s^{pv} \cdot I^{pv}}{R_{sh}^{pv}} \tag{3.1}$$

Where $V_T = N_s^{pv} KT/q$. The parameter A_d^{pv} usually ranges in between $1 \leq A_d^{pv} \leq 1.5$ [2]. In this thesis, the ISDM is used. ISDM includes simplicity, ease of modeling, and accuracy [1]. The model relies on the ISDM is expressed as (3.2).

$$I^{pv} = I^{ph} - I_{ds}^{pv}\left[\exp\left(\frac{q \cdot V^{pv}}{N_s^{pv} \cdot K \cdot A_d^{pv} \cdot T^{pv}}\right) - 1\right] \tag{3.2}$$

where I^{ph} depends on solar irradiance and temperature as (3.3) [1, 3].

$$I^{ph} = G^{pv} \cdot (I_{sc}^{pv} + \alpha^{pv} \cdot \Delta T_{STC}^{pv}) \tag{3.3}$$

The open circuit voltage of the SPV depends on the temperature as (3.4) [1, 3].

$$V_{oc}^{pv}(T) = V_{oc}^{pv}(T_0) - |\beta^{pv} \cdot| \, \Delta T_{STC}^{pv} \tag{3.4}$$

The diode saturation current is expressed as (3.5) [1].

$$I_{ds}^{pv} = \frac{\exp\left(\frac{|\beta^{pv}| \cdot \Delta T_{STC}^{pv} \cdot q}{N_s^{pv} \cdot K \cdot T \cdot A_d^{pv}}\right) \cdot G^{pv} \cdot [I_{sc}^{pv} + \alpha^{pv} \cdot \Delta T_{STC}^{pv}]}{(G^{pv} \cdot I_{sc}^{pv}/I_{rs}^{pv} + 1)^{\frac{T_0}{T}} - \exp\left(\frac{|\beta^{pv}| \cdot \Delta T_{STC}^{pv} \cdot q}{N_s^{pv} \cdot K \cdot T \cdot A_d^{pv}}\right)} \tag{3.5}$$

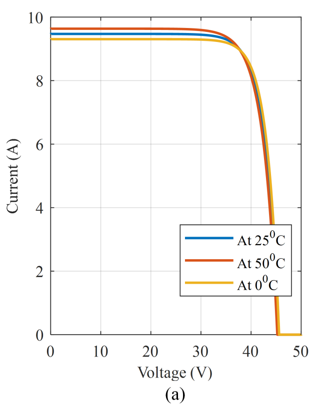

Figure 3.2: SPV module I-V characteristics

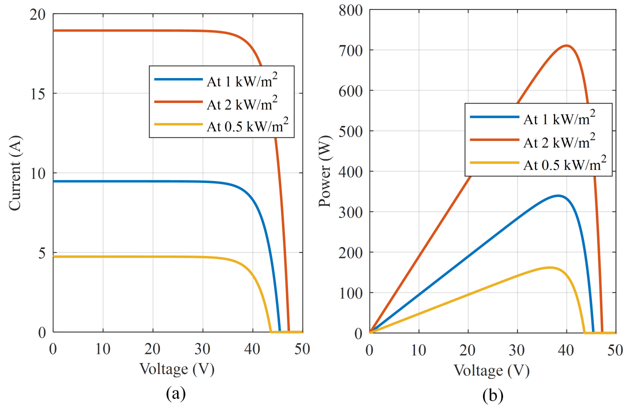

Figure 3.3: SPV module P-V characteristics

Table 3.1: SPV Module Parameter

Parameter	**Value**	**Parameter**	**Value**	**Parameter**	**Value**
V_{oc}^{pv}	$46.22V$	V_{mp}^{pv}	$39.09V$	P_{mp}^{pv}	$345W$
I_{sc}^{pv}	$9.47A$	I_{mp}^{pv}	$8.8A$	α^{pv}	$+0.66\%/K$
β^{pv}	$-0.36\%/K$	N_s^{pv}	$72Nos.\ Cells$		

where I_{pvm}^{rs} is the saturation current at STC and defined as (3.6) [1, 2, 3, 4].

$$I_{rs}^{pv} = \frac{I_{sc}^{pv}}{\exp\left(\frac{q \cdot V_{oc}^{pv}(T_0)}{N_s^{pv} \cdot K \cdot A_d^{pv} \cdot T_0}\right) - 1} \tag{3.6}$$

The I-V and P-V characteristics of the SPV module can be plotted as Fig. 3.2 and Fig. 3.3 using the manufacturer's datasheet as given in the Table 3.1.

3.5 Conclusion

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Chapter 4

SYNTHESIS AND PERSPECTIVES

4.1 Concluding Insights

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4.2 Future Scope

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1. S. Agrawal, B. Tyagi, V. Kumar and P. Sharma, ”Enhancing Transient Response of Grid Connected DFIG-WT through Adaptive Inertia and Damping Control with Virtual Synchronous,” in IEEE Transactions on Industry Applications, doi: 10.1109/TIA.2025.3584037. (Impact Factor = 4.5) - **Published**
2. S. Agrawal, B. Tyagi, V. Kumar and P. Sharma, ”Operation and Control of Parallel-Operated Interlinking Converter in Hybrid Microgrid,” in IEEE Transactions on Industry Applications, vol. 61, no. 4, pp. 5660-5669, July-Aug. 2025, doi: 10.1109/TIA.2025.3546205. (Impact Factor = 4.5) - **Published**
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