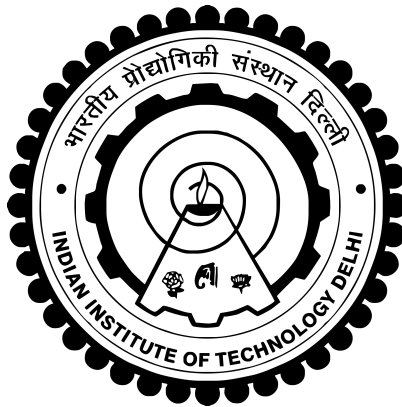


**AN INTELLIGENT APPROACH FOR FAULT
DETECTION AND MPPT CONTROL OF
PHOTOVOLTAIC-BASED SYSTEM**

PUSHPA KUMARI



**DEPARTMENT OF ELECTRICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DELHI**

FEBRUARY, 2025

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DETECTION AND MPPT CONTROL OF
PHOTOVOLTAIC-BASED SYSTEM**

by

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DEPARTMENT OF ELECTRICAL ENGINEERING

Submitted

in fulfillment of requirements of degree of Doctor of Philosophy

to the



INDIAN INSTITUTE OF TECHNOLOGY DELHI

FEBRUARY, 2025

Dedicated to my Parents

CERTIFICATE

This is to certify that the thesis entitled ‘**AN INTELLIGENT APPROACH FOR FAULT DETECTION AND MPPT CONTROL OF PHOTOVOLTAIC-BASED SYSTEM**’, being submitted by **Pushpa Kumari** to **Indian Institute of Technology Delhi** is a record of bonafide research work carried out under my supervision and I consider it worthy for consideration of the award of the degree **Doctor of Philosophy** in Electrical Engineering. The results obtained here have not been submitted to any other University or Institute for the award of any degree or diploma.

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— Pushpa Kumari

Abstract

Photovoltaic (PV) systems have emerged as a prominent source of renewable energy owing to their ease of availability, contributing significantly to the global shift towards sustainability and reduced carbon emissions. Despite these encouraging aspects, PV arrays are susceptible to various faults. The conventional protection schemes fail to detect array faults in the presence of a blocking diode and other typical operating conditions, which causes additional losses and may lead to fire hazards. Therefore, to enhance the PV-based system's efficiency, safety, and reliability, there is a vital need to design new techniques to identify and classify PV array faults with high efficacy. This work first presents the identification and classification of LL and LG faults, which incorporates the challenges associated with the existing fault detection scheme. It is also competent in distinguishing array faults from partial shading conditions (PSCs), as both have similar characteristics. The developed scheme is based on machine-learning techniques, which mitigate the shortcomings of existing ML-based methods. Following this, the integration of the ML-based method for large PV-based systems with limited data sets has been investigated by leveraging the concept of transfer learning. In addition, another major challenge of PV-based systems is the low conversion efficiency and non-linear characteristics of PV panels. This necessitates the incorporation of the Maximum PowerPoint Technique (MPPT) with PV-based system. Therefore, an easy-to-implement and efficient parabolic curve fitting-based MPPT technique is presented to mitigate the downside of the conventional method under uniform shading conditions. Following this, challenges associated with meta-heuristic techniques for partial shading conditions have been studied, and a particle swarm optimization-based MPPT method has been introduced, which is competent in distinguishing different dynamics.

Key Words: PV array, MPPT, Fault identification and classification, Optimisation, Machine learning.

सारांश

"फोटोवोल्टेक (पीवी) प्रणालियाँ एक प्रमुख नवीनीकरणीय ऊर्जा स्रोत के रूप में सामने आई हैं जिसकी मुख्यता से उपलब्धता की सरलता के कारण, वे वैश्विक धारिता और कम कार्बन उत्सर्जन के प्रति महत्वपूर्ण योगदान देते हैं। इन प्रेरक पहलुओं के बावजूद, पीवी अर्रेज़ कई प्रकार की खराबियों के लिए संवेदनशील हैं। पारंपरिक सुरक्षा योजनाएँ ब्लॉकिंग डायोड और अन्य सामान्य ऑपरेटिंग शर्तों की उपस्थिति में अर्रेज़ की खराबियों को पता नहीं लगा पाती हैं, जिससे अतिरिक्त हानियाँ होती हैं और आग के जोखिम को बढ़ा सकती हैं। इसलिए, पीवी आधारित प्रणाली की कुशलता, सुरक्षा, और विश्वसनीयता को बढ़ाने के लिए, पीवी अर्रेज़ की खराबियों को पहचानने और श्रेणीबद्ध करने के लिए नई तकनीकों का डिज़ाइन करने की एक महत्वपूर्ण आवश्यकता है। यह काम पहले एलएल और एलजी खराबियों की पहचान और श्रेणीबद्धी को प्रस्तुत करता है, जिसमें मौजूदा खराबी पहचान योजना के साथ जुड़े चुनौतियों को शामिल किया गया है। यह भी अर्रेज़ की खराबियों को आंशिक छाया की स्थितियों (पीएससी) से भिन्न करने में प्रतिष्ठित है, क्योंकि दोनों के समान विशेषताएँ होती हैं। विकसित योजना में मशीन सीखने की तकनीकों पर आधारित है, जो मौजूदा एमएल आधारित विधियों की दोषों को कम करती हैं। इसके बाद, मशीन सीखने की आधारित विधि को सीमित डेटा सेट के साथ बड़ी पीवी आधारित प्रणालियों के लिए एमएल आधारित विधि का सम्मिलन करने का अध्ययन किया गया है। इसके अलावा, पीवी आधारित प्रणालियों का एक अन्य मुख्य चुनौती एपीएससी और पीवी पैनेलों की अल्पिकरण क्षमता और गैर-रैखिक विशेषताओं से है। इसलिए, एक सरल और प्रभावी पैराबोलिक कर्व फिटिंग आधारित मैक्सिमम पॉवर प्वाइंट तकनीक प्रस्तुत की गई है जो विपरीत छाया की स्थितियों के तहत पारंपरिक विधि की कमियों को कम करने में सहायक है। इसके बाद, पीएससी के लिए मेटा-वैज्ञानिक तकनीकों के साथ जुड़ी चुनौतियों का अध्ययन किया गया है, और एक पार्टिकल स्वार्म अपटिमाइज़ेशन आधारित एमपीपीटी विधि प्रस्तुत की गई है, जो विभिन्न गतिकी को भिन्न करने में सक्षम है।

मुख्य शब्द: पीवी अर्रे, एमपीपीटी, खराबियों की पहचान और श्रेणीबद्धी, अनुकूलन, मशीन सीखना।

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Nomenclature

Acronyms/Abbreviations

BN Batch Normalisation

CLs Convolutional Layers

CNN Convolutional Neural Network

GFPD Ground Fault Protection Device

GMPP Global Maximum Power Point

HC Hill Climbing

I-V Current-Voltage

LL Line to Ground

LL Line to Line

LSM Least square Method

MBGA Modified Binary Genetic Algorithm

ML MACHine Learning

MPPT Maximum Power Point Tracking

NREL National Renewable Energy Laboratory

OCPD Over Current Protection Relay

P-V Power-Voltage

P&O Perturb & Observe

PCF Parabolic Curve Fitting

PCHC Parabolic Curve-fitting-based Hill Climbing

PSCs Partial Shading Conditions

PSO Particle Swarm Optimization

PV Photovoltaic

RD Rayleigh Distribution

TL Transfer Learning

WKNN Weighted k nearest neighbour