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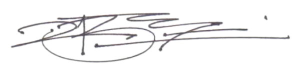

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I, **Kumari Sarita**, certify that the work embodied in this thesis is my own bona fide work and has been carried out by us under the supervision of **Professor (Dr.) R.K. Saket** from **July-2019** to **December-2021**, at the Department of **Electrical Engineering**, **Indian Institute of Technology (Banaras Hindu University)**, **Varanasi, Uttar Pradesh, INDIA**. The matter embodied in this thesis has not been submitted for the award of any other degree/diploma. I declare that I have faithfully acknowledged and given credits to the research workers wherever their works have been cited in my work in this thesis. I further declare that I have not wilfully copied any other's work, paragraphs, text, data, results, etc., reported in journals, books, magazines, reports dissertations, theses, etc., or available at websites and have not included them in this thesis and have not cited as my own work.

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18.01.2022

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To

Savitribai Phule

(3 January 1831 – 10 March 1897)

(An Indian social reformer, educationalist, and poet)

My Parents

(Mr. Dhananjay Kumhar & Mrs. Yashoda Devi)

and

My Elder Brother

(Mr. Hare Shankar Kumhar)

Acknowledgements

No doubt that the thesis is mine, but I owe my gratitude to all those people who have made this thesis work possible and because of whom my experience as a research scholar has been one that I will cherish forever.

I whole heartily express my regards and gratitude to my esteemed supervisor Dr. R.K. Saket, Professor, Department of Electrical Engineering, IIT (BHU), Varanasi, Uttar Pradesh, INDIA, for his moral guidance, mentoring, and constant encouragement during my Ph.D. work. Though he is the thesis supervisor, he has treated me just like his daughter and provided all kind of support whenever required. In addition, I would like to express profound gratitude towards my head of the department Professor (Dr.) R.K. Pandey and former head of the department Professor (Dr.) Devender Singh for their invaluable time, support, and suggestions, which made my research work easy and proficient.

I have no words to express gratitude to my faculty members. Still, I would like to mention special thanks to my subject teachers Prof. Shyam Krishna Nagar (Retd.), Prof. Ranjit Mahanty, Dr. Soumya Ranjan Mohanty, Ms. Sobhita Mehar, and Dr. N. Krishna Swami Naidu for implementing their subject concepts in my research work.

I am lucky to have Prof. R.K. Srivastava (Department of Electrical Engineering) and Prof. Suprakash Gupta (Department of Mining Engineering) as my Research Performance Evaluation Committee (RPEC) members from IIT (BHU), Uttar Pradesh, INDIA. It wasn't easy to achieve continuous progress in my research work without their suggestions and support. I would also like to thank Dr. Kalpana Choudhary (Convener, DPGC, Department of Electrical Engineering, IIT (BHU), Uttar Pradesh, INDIA) for his positiveness towards any Post Graduate student.

I am obliged to the staff members of Department of Electrical Engineering, IIT (BHU), Varanasi, Uttar Pradesh, INDIA, with special mention to Mr. Sanjeev Kumar Maurya, Mrs. Ranjana Singh, Mr. Santosh Kumar Vishwakarma, Mr. Sirish Anand, Mr. Sunil Kumar Sonkar, Mr. Satish Singh, and Mr. A.N. Singh, who have been patient to deal with my Ph.D. related work throughout.

Besides, I want to express my deepest gratitude to my seniors Dr. Abhishek Kumar, Mr. Amit Singh, Mr. Basant Sethi, and Mr. Debottam Mukherjee who supported me throughout my experimental work in the System laboratory. I am grateful to Dr. Dharmendra Kumar Dheer (National Institute of Technology, Patna, Bihar, INDIA), Prof. L.D. Arya (Department of Electrical Engineering, Medi-Caps University, Indore (MP) INDIA), Prof. D.P. Kothari (Head (Retd.) in the Centre of Energy Studies at Indian Institute of Technology, Delhi, INDIA), Prof. Ramesh C. Bansal (University of Sharjah, United Arab Emirates), Prof. Almoataz Youssef Abdelaziz (Ain Shams University & Future University, Egypt), Prof. Narottam K. Das (Central Queensland University, Melbourne, Australia), Mr. Rajvikram Madurai Elavarasan (Clean and Resilient Energy Systems (CARES) Laboratory, Texas A&M University, Galveston, United States of America), who have provided me with technical, moral, and emotional support during my research program. My gratitude would not be valid till I would not mention special thanks to my Ph.D. senior Dr. Sachin Kumar (Department of Electrical Engineering, G B Pant Institute of Engineering & Technology, Pauri-Garhwal, Uttarakhand. INDIA), my colleagues, Mr. Uday B. Rao, Mrs. Saumya Singh, Mrs. Haritha, Mr. Parijat, Ms. Sweta Sharad, Mrs. Rangoli, Mr. Siva, Mr. Hari Shankar, Mr. Ashish, Mr. Rajat, Ms. Kala, and my juniors Mr. Harsh Srivastava, Ms. Eram Taslima, Mr. Suchetan, Ms. Ruchi, Ms. Laxmi, Ms. Sanno, Ms. Purnima, Ms. Srishti, Ms. Monika, Ms. Kalpana, Mr. Kameshwar, Ms. Kiwi, Ms. Maanshi, Ms. Monika, Ms. Vaagisha, Ms. Vaibhavi, and Ms. Aanchal Verma for their continuous technical and moral support till date, without them, there was no fun and encouragement in these years at IIT(BHU) campus. In addition, I can not forget the priceless support of my research team members, Professor Saket Research Team (PSRT) group, Dr. K.S. Anand, Dr. Lokesh, Dr. Vipin, Dr. Sachin Kumar Gupta, Dr. Sanjay Kumar, Dr. Sunil Kumar Singh, and Dr. Om Prakash Bharti, Dr. Sharat, and other team members for their support in Ph.D. research work.

I am thankful to Prof. Pankaj Rai (Department of Electrical Engineering, Birsa Institute of Technology, Sindri, Dhanbad, Jharkhand, INDIA) and other faculties from my M.Tech. college for their continuous motivation regarding the completion of my Ph.D. work at the earliest. I am very much thankful to my faculties of B.Tech. college (Guru Gobind Singh Educational Society's Technical Campus, Bokaro, Jharkhand, INDIA) for their continuous support and motivation regarding the completion of my Ph.D. work at the earliest.

Special gratitude goes out to my friends with special mention to Ms. Prerana Raj, Ms. Rajni Kumari, Mr. Mukesh, Mr. Manish, Ms. Kusum Kumari Oraon, Ms. Manisha Oraon, Mr. Gopal, Mr. Krishna Marandi, Mr. Karamat, Mr. Rohit, Mr. Sailesh, Mr. J. Prakash, Mr. Om, Mr. Shahid, Mr. Samim, Mrs. Nirupa Rani, Mrs. Jayanti, Ms. Babita, Ms. Juhi, Ms. Sweta Mishra, Ms. Jyoti, Ms. Bidisha Shahoo, Mrs. Surabhi Sivendra, Ms. Neelam Kumari, Mrs. Pallavi, Ms. Purnima, Ms. Rekha, Ms. Anamika, Mr. Kanchan, Mr. Suraj, Mr. Surjendu Dey, Mr. Shammi, Ms. Anupama Rani, Ms. Bhuneshwari, Ms. Pooja, Mrs. Suman, Mrs. Richa, Mrs. Nandini, Ms. Kanchan, Ms. Sunaina, Mrs. Priyanka, Mr. Jitendra, Mr. Ajit, Ms. Aakanksha Singh. S. Vardhan, and Ms. Aanchal Singh S. Vardhan, for their physical, emotional, and intellectual support, especially precious suggestions in need.

I am very much thankful to my villagers (Telotand, Dumra, Dhanbad, Jharkhand, India) for their continuous support and blessings. In family, I thank especially my grand mother, Mrs. Sarubala Devi, maternal grand mothers, Mrs. Chandmani Devi, Mrs. Pamila Devi, Mrs. Pasholya Devi, my maternal grand fathers, Mr. Shashi Bhushan Kumar, Mr. Amulya Kumar, my parents, Mr. Dhananjay Kumhar and Mrs. Yashoda Devi, my elder brother Mr. Hare Shankar Kumhar, my younger brothers Mr. Tankeshwar Kumhar, Mr. Deepak Kumar, and Mr. Madhav Kumar, my uncles Mr. Niranjan Kumhar, Mr. Dheeran Kumhar, aunties Mrs. Kalavati Devi and Mrs. Shulochana Devi, my maternal uncles Mr. Devashish Kumar, Mr. Achintya Kumar, Mr. Sanjeev Kumar, Mr. Rajeev Kumar, Mr. Bankim, and Mr. Bishwajit, maternal aunties, Mrs. Ruma Devi, Mrs. Pushpa Devi, Mrs. Geeta Devi, and Mrs. Mamta Devi for their constant emotional support and encouragement, without which this Ph.D. work would have not been completed at all. I am grateful to my other family members who have supported me along the way.

Last but not the least, I would like to present special gratitude to my would be family especially my would be husband Mr. Vishnu Kumar Paul, would be mother-in-law, Mrs. Bimla Devi, would be father-in-law, Mr. Narayan Kumhar, would be brothers-in-law, Mr. Laxman, Mr. Santosh Kumhar, Mr. Rajiv Kumbhakar, and would be sisters-in-law, Mrs. Pushpa Kumbhakar and Mrs. Seema Devi. They motivated and supported me to complete this thesis work at the earliest.

Kumari Sarita

Date: 17.01.2022 Kumari Sarita

Abstract

This thesis presents a comprehensive analysis of the reliability evaluation and fault diagnosis of inverter. The converter and inverter form important part of electrical power system. Fault detection can increase the reliability and efficiency of power electronic converters employed in the power systems. The inverters are also used to drive electric motors and Electric Vehicles (EVs). Due to high pressure and complex work in this environment, the inverters are prone to breakdowns and faults. That is why providing a way to recognize faults in the inverters is very important. The Open Circuit (OC) faults may occur because of a short circuit between two legs, OC fault in triggering pulse, and OC fault in supply connection. This thesis studies the OC fault of IGBTs of three-phase inverters. The three-phase currents are used to identify the state of the system and extracting the features using different feature extracting algorithms for fault localization. This thesis first focuses on the literature survey made for understanding the importance of inverter and its applications in Electrical power system and EVs. The Reliability and Availability (RA) evaluation have become the critical area of interest for researchers. In this thesis, the Reliability Block Diagram (RBD) with exponential probability distribution function is used for the RA analysis of seven practical grid connected solar Photo-Voltaic (PV) systems. It aims to identify the weakest subsystem of a system in order to enhance system reliability. Elaborate analysis is presented for these systems beginning from the sub-assemblies to the subsystems and then to the overall system. In addition, the subsystems are ranked based on their impact on the overall system availability using availability importance measures. It is observed that inverter forms the weakest subsystem in the solar system. Types of faults that occur in the inverter are divided into two categories: OC fault and Short-Circuit (SC) fault. In case of occurring SC fault, system current increases up to 4 or 5 times its nominal amount which makes the detection easy but the OC fault is not like SC fault and current changes are very low. That is why identifying the OC fault is very important. After coming to these conclusions, the further study and analysis have been carried out taking the OC fault diagnosis and condition monitoring of

inverter as main focus. Therefore, the overall work done in this thesis is Reliability, Availability, and Condition Monitoring (RACM) of inverters. Along with the RBD method, the Principal Component Analysis (PCA) technique is used to monitor the health status of the inverter. The technique used for condition monitoring in second chapter is an unsupervised type machine learning technique which is also a well know dimensional reduction technique. This method is also used for features extraction from data set. There are various supervised type machine learning techniques also available in the literature such as Support Vector Machine (SVM), k-Nearest Neighbor (KNN), and Artificial Neural Network (ANN) based deep learning techniques which claim better results than unsupervised machine learning techniques. These supervised machine learning techniques need strong features which can be good predictors for monitoring. The features can be obtained either from time-domain or frequency-domain analysis of the signals of the equipment to be monitored. The signal processing techniques have been observed to be good for extracting the features from the signal. Therefore, the third chapter of this thesis is focused on the role of signal processing and machine learning based algorithms for the proper condition monitoring and fault diagnosis system of inverters. The two samples based signal processing technique for fault detection is proposed and validated. For fault localization, SVM method is used which uses the Entropy of Wavelet Packet (EWP) and mean of current signals as features. The results were found satisfactory and EWP is found to be better feature than mean as the prediction results using mean as feature show misclassification of faults. For further increasing the accuracy and decreasing the time of OC fault detection, the PCA-based machine learning technique is proposed in chapter four for fault detection and Wavelet Entropy (WE) feature based SVM technique is used for the localization of fault, which gives results better than the two-samples based technique. The research is further carried out to find a best feature extraction technique which involves simple addition and subtraction operations rather than involving complicated mathematical calculus. A KNN technique involving Walsh Function (WF) based feature has been proposed in chapter five, which is found faster than the previous two techniques and giving better results (accuracy of 98-100% and detection time of lesser than 10% cycle) because the feature includes simple mathematical addition and subtraction operations. The motive of this thesis is accomplished by proposing the various techniques, which can help to increase the accuracy and enhance the RACM of inverters.

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List of Abbreviations

ANN Artificial Neural Network

ASTS Automatic Static Transfer Switch

AC Alternating Current

AI Artificial Intelligence

BOS Balance of System

CNN Convolution Neural Network

CB Circuit Breaker

DC Direct Current

DA Discriminant Analysis

DT Decision Tree

DWT Discrete Wavelet Transform

ESS Energy Storage System

ESO Extended State Observer

EWP Entropy of Wavelet Packet

ELM Extreme Learning Machine

EVs Electric Vehicles

FACTS Flexible AC Transmission System

FTA Fault Tree Analysis

FNN Fuzzy Neural Network

FFT Fast Fourier Transform

HHT Hilbert-Huang transform

IGBT Insulated Gate Bipolar Transistor

IGBTs Insulated Gate Bipolar Transistors

IoT Internet of Things

KNN k-Nearest Neighbor

LE Log Energy

MPPT Maximum power point tracking

MKSTM Mixed Kernel Support Tensor Machine

MLC Multilevel Converters

MLI Multilevel Inverter

MMI Modular Multilevel Inverter

MLP Multilayer Perceptron

MRVM Multiclass Relevance Vector Machine

NA Not Available

NB Naive Bayes

OC Open Circuit

OF Oversampling Factor

PCA Principal Component Analysis

PCs Principal Components

PV Photo-Voltaic

PCB Printed Circuit Board

PWM Pulse Width Modulation

RE Renewable Energy

RF Random Forest

RMS Root Mean Square

RAM Reliability, Availability, and Maintainability

RACM Reliability, Availability, and Condition Monitoring

RA Reliability and Availability

RBD Reliability Block Diagram

RBFNN Radial Basis Function Neural Network

SVM Support Vector Machine

SPWM Sinusoidal Pulse Width Modulation

SOM Self-Organizing map

SMO Sliding Mode Observer

STM Support Tensor Machine

SE Shannon Entropy

SC Short-Circuit

SM Sub-Module

TE Threshold-based Entropy

VPMAM Variable Parameter Moving Average Method

WE Wavelet Entropy

WP Wavelet Packet

WT Wavelet Transform

WPD Wavelet Packet Decomposition

WF Walsh Function

WFC Walsh Function Coefficients