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**Supervisor**

**Professor (Dr.) R.K. Saket**

**Department of Electrical Engineering,**

**IIT(BHU), Varanasi,**

**Uttar Pradesh, INDIA.**



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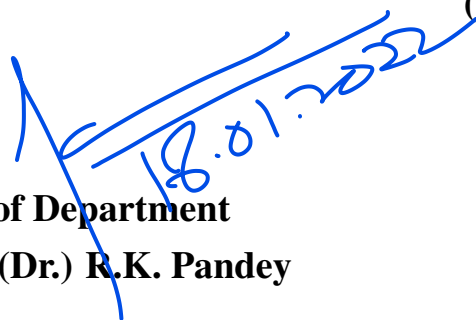
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**To**

**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)**





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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.

# Contents

	<b>Page</b>
<b>Abstract</b>	<b>vii</b>
<b>Contents</b>	<b>ix</b>
<b>List of Tables</b>	<b>xiii</b>
<b>List of Figures</b>	<b>xv</b>
<b>List of Abbreviations</b>	<b>xx</b>
<b>1 Introduction</b>	<b>1</b>
1.1 Historical Background . . . . .	1
1.2 Inverters in Electrical Power System . . . . .	2
1.3 Three-phase Inverter Modelling . . . . .	4
1.3.1 Failures in inverters and its causes . . . . .	6
1.4 Reliability, Availability, and Condition Monitoring (RACM) . . . . .	8
1.5 Need of RACM of Inverters . . . . .	9
1.5.1 Inverters in PV Systems . . . . .	10
1.5.2 Inverters in Wind Energy Systems . . . . .	12
1.5.3 Inverters in EVs and other drives systems . . . . .	12
1.6 Role of Signal Processing Techniques in RACM . . . . .	13
1.7 Role of Machine Learning Techniques in RACM . . . . .	13
1.8 Thesis Motivation . . . . .	16
1.9 Objectives of the Thesis . . . . .	18
1.10 Contributions of the Thesis . . . . .	18
1.11 Outlines of the Thesis . . . . .	19



<b>2</b>	<b>Literature Survey</b>	<b>23</b>
2.1	Introduction . . . . .	23
2.2	Layouts of Solar-PV Systems . . . . .	25
2.3	Reliability and Availability Analysis . . . . .	27
2.3.1	System Decomposition . . . . .	28
2.3.2	Reliability Evaluation of Inverter System . . . . .	29
2.3.3	Reliability Modeling . . . . .	30
2.3.4	Data Collection . . . . .	31
2.4	Availability Estimation . . . . .	32
2.5	RACM of Inverters of PV Systems . . . . .	35
2.6	OC Fault Diagnosis of Inverters . . . . .	38
2.7	Summary . . . . .	42
<b>3</b>	<b>RACM of Inverters: 2 Samples Approach</b>	<b>43</b>
3.1	Introduction . . . . .	43
3.1.1	Proposed Fault Diagnosis System . . . . .	47
3.2	Two Samples-based Method for RACM . . . . .	49
3.2.1	Two-Samples based Fault Detection Technique . . . . .	49
3.2.2	Features Extraction Technique . . . . .	52
3.3	Simulation Studies . . . . .	57
3.4	Results and Discussion . . . . .	59
3.4.1	Fault Diagnosis using EWP-SVM Technique . . . . .	60
3.4.2	Comparison between Proposed Technique and Existing Techniques . . . . .	65
3.5	Summary . . . . .	68
<b>4</b>	<b>RACM of Inverter: Wavelet Entropy Based PCA-SVM Technique</b>	<b>69</b>
4.1	Introduction . . . . .	69
4.2	EWP-PCA-SVM Method for RACM . . . . .	72
4.2.1	OC Fault Detection using PCA . . . . .	74
4.2.2	WPD . . . . .	77
4.2.3	Wavelet Entropy . . . . .	79
4.3	Results and Discussion . . . . .	80
4.4	Summary . . . . .	88

<b>5</b>	<b>RACM of Inverters: Walsh Function based KNN Approach</b>	<b>91</b>
5.1	Introduction . . . . .	91
5.2	WFC-KNN Approach for RACM . . . . .	94
5.2.1	Walsh-Function Coefficients (WFC) . . . . .	95
5.2.2	OC Fault Detection using WFC . . . . .	96
5.2.3	WFC-SVM and WFC-KNN Techniques for Fault Diagnosis . . . . .	103
5.3	Results and Discussion . . . . .	106
5.4	Summary . . . . .	120
<b>6</b>	<b>Conclusions and Scopes for the Future Work</b>	<b>121</b>
6.1	Conclusions . . . . .	121
6.2	Benefits of the Proposed Work . . . . .	123
6.3	Scopes for the Future Work . . . . .	123
	<b>Appendix A Data Collection</b>	<b>125</b>
	<b>References</b>	<b>129</b>
	<b>List of Publications</b>	<b>143</b>



# List of Tables

## Chapter 2

2.1	Comparison of the proposed method with existing methods . . . . .	25
2.2	Details of sub-assemblies of each component of PV system. . . . .	33
2.3	Subsystem failure rate ( $YR^{-1}$ ) estimated from Tables A.1 and A.2. . . . .	33
2.4	Subsystem repair rate ( $YR^{-1}$ ) estimated from Table 2.2 . . . . .	33
2.5	Comparison of fault detection time of proposed methods with existing techniques	41

## Chapter 3

3.1	Features extracted from three-phase currents under different conditions . . . . .	56
3.2	Fault diagnosis results using Simple Entropy-SVM technique . . . . .	67
3.3	Comparison of fault detection time of different techniques . . . . .	67

## Chapter 4

4.1	Features extraction under different conditions . . . . .	81
4.2	Different OC faults used to train and validate the classifier . . . . .	84
4.3	Comparison of the accuracy of different fault diagnosis techniques . . . . .	86
5.1	Training time for KNN and SVM classification techniques . . . . .	110

## Chapter 5

5.2	Subsystem reliability of PV system for one year of operation (in %) (using eq 2.19) . . . . .	112
5.3	Subsystem reliability of PV system for 20 years of operations (in %) (using eq 2.20) . . . . .	112

- 5.4 Subsystem availability (in %) . . . . . 114
- 5.5 Availability importance measures . . . . . 114
- 5.6 Importance measures based on failure rates . . . . . 115
- 5.7 Importance measures based on repair rates . . . . . 115
- 5.8 Ranking of components affecting the availability of PV system . . . . . 118
- 5.9 Comparison of the reliability values of PV system found from proposed method  
and existing methods after one year of operation. . . . . 119
- 5.10 Comparison of the reliability values of PV system found from proposed method  
and existing methods after twenty years of operation. . . . . 119

**Appendix A**

- A.1 Gathered data of failure rate and repair rate from literature . . . . . 126
- A.2 Gathered data of failure rate and repair rate from literature . . . . . 127

# List of Figures

## Chapter 1

1.1	Inverters used in electrical power system including wind generation, solar PV panel, EVs, and ESS connected to the grid. . . . .	3
1.2	Block diagram of three-phase inverter. . . . .	7
1.3	Benefits of condition monitoring of system . . . . .	10
1.4	Division of PV system into its components and sub-components and reliability block diagram. . . . .	12
1.5	Features extraction from three-phase currents using signal processing technique	14
1.6	Features extraction from three-phase voltages using signal processing technique	14
1.7	Fault diagnosis using machine learning technique. . . . .	16

## Chapter 2

2.1	Arrangement of components in PV system connected with grid. . . . .	26
2.2	Division of PV system into its components and sub-components and reliability block diagram. . . . .	31
2.3	The proposed methodology for RACM in PV systems. . . . .	37
2.4	Flow chart of PCA-based condition monitoring algorithm. . . . .	38
2.5	Condition monitoring output showing the data points lying in normal, warning, and alarm range. . . . .	39

## Chapter 3

3.1	RACM using two samples and EWP-SVM based techniques . . . . .	44
3.2	Flow chart of the proposed system . . . . .	46
3.3	Schematic diagram for two-samples based fault detection algorithm . . . . .	48

3.4	WPD of a signal into Approximate (A) and detail (D) coefficients up to 3 levels	49
3.5	Flow chart of two-samples based OC fault detection algorithm . . . . .	50
3.6	Estimated current of phase-a of the inverter under multi-IGBTs OC faults at S1 and S5 . . . . .	51
3.7	Original current of phase-a of the inverter under multi-IGBTs OC faults at S1 and S5 . . . . .	52
3.8	OC fault detection by comparing estimated and original current signals . . . . .	53
3.9	The difference of actual and estimated current signal, fault occurring and alarm generation . . . . .	53
3.10	Simulink model of the fault diagnosis system . . . . .	58
3.11	Three-phase output currents of the 3-phase, 3-level inverter under normal condition . . . . .	59
3.12	Three-phase currents for single IGBT (S1) fault . . . . .	60
3.13	OC fault detection for single IGBT (S1) fault . . . . .	61
3.14	Three-phase currents for multiple IGBTs (S1, S2, S5) faults . . . . .	61
3.15	OC fault detection for multiple IGBTs (S1, S2, S5) faults . . . . .	62
3.16	OC fault detection output with current of phase-b under OC fault in S1 . . . . .	62
3.17	OC fault detection output with current of phase-b under OC faults in S1, S2, and S5 . . . . .	63
3.18	OC fault detection output with current of phase-c under OC fault in S1 . . . . .	63
3.19	OC fault detection output with current of phase-c under OC faults in S1, S2, and S5 . . . . .	64
3.20	Classification results using proposed EWP-SVM technique . . . . .	64
3.21	Classification results using simple entropy as feature extraction . . . . .	65

## Chapter 4

4.1	RACM using PCA-EWP-SVM technique. . . . .	70
4.2	Process flow of the proposed algorithm. . . . .	73
4.3	Data variance covered by the principal components individually and cumulatively. . . . .	74
4.4	Schematic diagram of PCA-based fault detection technique. . . . .	75
4.5	OC fault detection output pattern under normal condition. . . . .	76

4.6	PCA-based OC fault detector output pattern for single IGBT. . . . .	76
4.7	PCA-based OC fault detector output pattern for multiple IGBTs. . . . .	77
4.8	Decomposition of wavelet packets into Approximate and detail coefficients. . .	78
4.9	Process flow of fault localization using WE feature. . . . .	80
4.10	Three-phase currents of the inverter under normal condition. . . . .	82
4.11	Three-phase currents of the inverter under OC fault in single IGBT (S1). . . .	82
4.12	Three-phase currents of the inverter under OC faults in multiple IGBTs (S1, S5).	83
4.13	PCA-based OC fault detector output under S1 fault. . . . .	83
4.14	Classification results using simple entropy. . . . .	85
4.15	Classification results using WE of the current signal as feature. . . . .	85
4.16	Accuracy of fault classification algorithm during training. . . . .	87
4.17	Accuracy of fault classification algorithm during testing. . . . .	88
4.18	Prototype for the proposed algorithm of fault detection and localization. . . . .	89
4.19	Outputs of fault detection and localization algorithms under normal condition.	89
4.20	Outputs of fault detection and localization algorithms under fault condition in switch S1. . . . .	90

## Chapter 5

5.1	RACM using PCA-EWP-KNN technique. . . . .	92
5.2	Process flow of the proposed algorithm . . . . .	94
5.3	Line voltage $V_{ab}$ under normal condition . . . . .	97
5.4	Line voltage $V_{ab}$ under fault condition at $S_1$ . . . . .	97
5.5	WFCs of voltage signal under normal condition . . . . .	98
5.6	Reconstruction of voltage signal using WFCs . . . . .	98
5.7	WFCs of voltage signal under fault condition in $S_1$ . . . . .	99
5.8	WFCs of voltage signal under normal condition with second next sample coming in. . . . .	100
5.9	WFCs of voltage signal under normal condition with third next sample coming in. . . . .	100
5.10	WFCs of voltage signal under normal condition with forth next sample coming in. . . . .	101



5.11	WFCs of voltage signal under $S_1$ fault condition with second next sample coming in. . . . .	101
5.12	WFCs of voltage signal under $S_1$ fault condition with third next sample coming in. . . . .	102
5.13	WFCs of voltage signal under $S_1$ fault condition with forth next sample coming in. . . . .	102
5.14	Magnitude of WFCs of window of 11 samples of voltage signal under normal condition. . . . .	103
5.15	Phase of WFCs of window of 11 samples of voltage signal under normal condition. . . . .	104
5.16	Magnitude of WFCs of window of 11 samples of voltage signal under fault condition at $S_1$ . . . . .	104
5.17	Phase of WFCs of window of 11 samples of voltage signal under fault condition at $S_1$ . . . . .	105
5.18	Fault detection and generation of alarm under fault condition at $S_1$ . . . . .	105
5.19	Zoomed view of occurrence of fault, detection and generation of alarm under fault condition at $S_1$ . . . . .	106
5.20	Fault classification result using SVM-algorithm . . . . .	107
5.21	Fault classification result using fine KNN-algorithm . . . . .	107
5.22	Fault classification result using weighted KNN-algorithm . . . . .	108
5.23	Accuracy of SVM-based fault classification technique . . . . .	108
5.24	Accuracy of KNN-based fault classification technique . . . . .	109
5.25	Accuracy of MLP-based fault classification technique . . . . .	109
5.26	Prototype for the proposed algorithm of fault detection and localization. . . . .	110
5.27	Outputs of fault detection and localization algorithms under normal condition. . . . .	111
5.28	Outputs of fault detection and localization algorithms under fault condition in switch $S_1$ . . . . .	111
5.29	Percentage reliability of PV systems for one year of operation. . . . .	113
5.30	Percentage reliability of PV systems for 20 years of operation. . . . .	113
5.31	Sub-systems availability for the studied systems. . . . .	115
5.32	Importance measures for PV module, converter and inverter. . . . .	116
5.33	Sub-system availability for inverter. . . . .	116

5.34	Overall system availability before inverter redundancy . . . . .	117
5.35	Overall system availability after inverter redundancy . . . . .	118



# List of Abbreviations

<b>ANN</b>	Artificial Neural Network
<b>ASTS</b>	Automatic Static Transfer Switch
<b>AC</b>	Alternating Current
<b>AI</b>	Artificial Intelligence
<b>BOS</b>	Balance of System
<b>CNN</b>	Convolution Neural Network
<b>CB</b>	Circuit Breaker
<b>DC</b>	Direct Current
<b>DA</b>	Discriminant Analysis
<b>DT</b>	Decision Tree
<b>DWT</b>	Discrete Wavelet Transform
<b>ESS</b>	Energy Storage System
<b>ESO</b>	Extended State Observer
<b>EWP</b>	Entropy of Wavelet Packet
<b>ELM</b>	Extreme Learning Machine
<b>EVs</b>	Electric Vehicles
<b>FACTS</b>	Flexible AC Transmission System

<b>FTA</b>	Fault Tree Analysis
<b>FNN</b>	Fuzzy Neural Network
<b>FFT</b>	Fast Fourier Transform
<b>HHT</b>	Hilbert-Huang transform
<b>IGBT</b>	Insulated Gate Bipolar Transistor
<b>IGBTs</b>	Insulated Gate Bipolar Transistors
<b>IoT</b>	Internet of Things
<b>KNN</b>	k-Nearest Neighbor
<b>LE</b>	Log Energy
<b>MPPT</b>	Maximum power point tracking
<b>MKSTM</b>	Mixed Kernel Support Tensor Machine
<b>MLC</b>	Multilevel Converters
<b>MLI</b>	Multilevel Inverter
<b>MMI</b>	Modular Multilevel Inverter
<b>MLP</b>	Multilayer Perceptron
<b>MRVM</b>	Multiclass Relevance Vector Machine
<b>NA</b>	Not Available
<b>NB</b>	Naive Bayes
<b>OC</b>	Open Circuit
<b>OF</b>	Oversampling Factor
<b>PCA</b>	Principal Component Analysis
<b>PCs</b>	Principal Components

<b>PV</b>	Photo-Voltaic
<b>PCB</b>	Printed Circuit Board
<b>PWM</b>	Pulse Width Modulation
<b>RE</b>	Renewable Energy
<b>RF</b>	Random Forest
<b>RMS</b>	Root Mean Square
<b>RAM</b>	Reliability, Availability, and Maintainability
<b>RACM</b>	Reliability, Availability, and Condition Monitoring
<b>RA</b>	Reliability and Availability
<b>RBD</b>	Reliability Block Diagram
<b>RBFNN</b>	Radial Basis Function Neural Network
<b>SVM</b>	Support Vector Machine
<b>SPWM</b>	Sinusoidal Pulse Width Modulation
<b>SOM</b>	Self-Organizing map
<b>SMO</b>	Sliding Mode Observer
<b>STM</b>	Support Tensor Machine
<b>SE</b>	Shannon Entropy
<b>SC</b>	Short-Circuit
<b>SM</b>	Sub-Module
<b>TE</b>	Threshold-based Entropy
<b>VPMAM</b>	Variable Parameter Moving Average Method
<b>WE</b>	Wavelet Entropy

<b>WP</b>	Wavelet Packet
<b>WT</b>	Wavelet Transform
<b>WPD</b>	Wavelet Packet Decomposition
<b>WF</b>	Walsh Function
<b>WFC</b>	Walsh Function Coefficients