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PROJECT STAGE-1 REPORT

ON

Pattern Recognition based Approach for Open Switch Fault Diagnosis in 3 Phase VSI

(SDG 09- Industry, Innovation and Infrastructure)

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF

BACHELOR OF ENGINEERING IN

ARTIFICIAL INTELLIGENCE AND DATA SCICENCE ENGINEERING

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CERTIFICATE

This is to certify that the Project Stage-1 Report entitled

Pattern Recognition based Approach for Open Switch Fault Diagnosis in 3 Phase VSI

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is a bonafide work carried out by them under the supervision by **Dr. R.B. Dhumale** and it is approved for the partial fulfilment of the requirement of **Savitribai Phule Pune University** for the Project Stage-1 in the Final Year of Artificial Intelligence and Data Science Engineering.

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ABSTRACT

This project presents a novel approach for the diagnosis of open switch faults in Three-Phase Voltage Source Inverters (3-φ VSI) used in various industrial applications. Open switch faults can severely impact the performance and reliability of power electronic converters, leading to costly downtimes and potential safety hazards. Proposed method leverages the power of pattern recognition techniques to detect and diagnose these faults swiftly and accurately. The project involves the development of a real-time monitoring system that captures voltage and current waveforms from the VSI and employs advanced signal processing and machine learning algorithms for fault identification. The system offers an intuitive graphical interface for easy fault visualization and diagnosis. Through extensive simulations and experimental validation, our approach demonstrates its effectiveness in detecting open switch faults, enabling timely maintenance and ensuring the uninterrupted operation of critical systems. This project contributes to enhancing the reliability and performance of power electronic converters, ultimately benefiting a wide range of industries.

Keywords:

- **3 Phase Voltage Source Inverters**
- **Open-switch faults**
- **Pattern Recognition**
- **Intuitive graphical interface**

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CHAPTER 1
INTRODUCTION

INTRODUCTION

1.1 Introduction

The society needs affordable device maintenance and clean energy. An inverter is an electronic device which converts Direct Current (DC) to Alternating Current (AC). It is used where AC power is needed, such as electric grid, industrial machinery, and Renewable energy systems like solar plants. 3Φ VSI produces sinusoidal waveform signals for current in three different phases that can be controlled in terms of both amplitude and frequency. It is necessary to maintain 3Φ VSI to provide healthy current output to the load. Noisy output signals may lead to damage load. There are two methods of maintenance namely scheduled based maintenance and condition-based maintenance. In Industry 4.0, the schedule-based maintenance was done based on the historical data at fixed time intervals. Where as in industry 5.0, the condition-based maintenance is performed where switches are continuously monitor to detect impending failure so that maintenance can be proactively scheduled.

An inverter is an electronic device which converts Direct Current (DC) to Alternating Current. It is used where AC power is needed, such as electric grid, industrial machinery, and Renewable energy systems like solar plants. inverters are classified into two types, voltage source inverters, and Current source inverters. In a voltage source inverter, the voltage is the Same and the current is variable. VSIs Produce AC voltage output that can be controlled in terms of both amplitude and frequency.

Single-phase inverters are used for low-range power applications, while three-phase inverters are used for medium to high-power applications VSIs are used in industrial applications and renewable energy systems such as Variable Frequency Drives to control the speed and torque of AC motors, in wind turbine Converter to convert the variable-speed AC generated by wind turbines into a stable and grid-synchronized AC output.

Condition-based Maintainance:

Condition-based maintenance (CBM) is a pivotal concept in modern industrial maintenance practices, particularly within the context of Industry 5.0. Unlike traditional scheduled maintenance, which relies on historical data and fixed time intervals, CBM leverages real-time data and continuous monitoring to make maintenance more efficient and effective. It involves the systematic monitoring and assessment of the actual condition of critical equipment, such as 3Φ VSI inverters, to detect deviations from normal operation and impending failures. By using sensors, data analysis, and predefined thresholds, CBM allows for the proactive scheduling of maintenance when it is genuinely needed. This approach not only optimizes maintenance efforts but also significantly reduces the risk of noisy or faulty output signals, which can potentially damage sensitive loads, making it an essential strategy for ensuring the reliability and longevity of equipment in an era where clean energy and affordable device maintenance are of paramount importance.

1.2 Motivation

- In the industrial landscape, 3 Phase Voltage Source Inverters (3 Phase VSI) stand as indispensable contributors to precise motor control, grid stability, and sustainable power generation. However, their reliability is consistently jeopardized by potential faults, notably multiple open-switch faults. Addressing this challenge head-on, our presentation proposes an innovative solution leveraging advanced pattern recognition techniques for proactive fault diagnosis. Our objectives encompass the creation of a comprehensive dataset and the development of an advanced deep learning model. Anticipated outcomes include heightened fault diagnosis effectiveness, minimized implementation effort, enhanced capability to diagnose multiple switch faults, reduced detection time, and a profound understanding of 3 Phase VSI behavior and fault patterns. Join us on this journey towards resilient and intelligent industrial power systems.

1.3 Problem Statement

- To develop a Pattern Recognition based Diagnostic system for detecting Open Switch Faults in 3 Phase VSI, by accurately classifying pattern generated from 3 phase VSI

1.4 Objectives

a) To collect current samples for various faulty conditions.
b) To generate patterns for different faulty using Direct Quadrant Transformation.
c) To collect features for fault conditions diagnosis.
d) To evaluate performance of different classification techniques of Pattern Recognition.

CHAPTER 2
LITERATURE REVIEW

LITERATURE REVIEW

2.1 Literature Review

Every electronic power Machines is affected by faults. Different types of faults can occur in VSI, which may affect the Industrial machinery and system operations. The maintenance cost of these systems and machinery is very expensive and requires a lot of time to repair a system or machinery fault. To improve performance and avoid this maintenance cost and loss of time, it is necessary to detect the fault in 3-PHASE VSI.

- **[1] Chen et. Al. (2021)**
- Chen et. Al. proposed a method for multiple Open Circuit Fault (OCF) diagnosis for Voltage Source Inverter (VSI) based Permanent Magnet Synchronous Motor (PMSM) drive system. Current Vector Phase (CVP) and Fault Diagnostic Variables (FDVs) are calculated using Clarke Transform (CT). An efficient and robust OCF diagnosis method with low implementation effort and high effectiveness can diagnose a total of 18 combinations of OCF with average Fault Isolation Time (FIT) 1.7 ms which is 11.3% of the fundamental current cycle.

- **[2] Achintya et. Al. (2020)**
- The authors suggested method for Threshold Independent Single Switch OCF Diagnosis in Multilevel Inverters to improve performance under variable load conditions. The features are extracted using Discrete Wavelet Transform (DWT) with effort relatively higher than traditional methods, and different Machine Learning Algorithms (MLA) are evaluated using performance evaluation parameters. Results show that FIT for the combination of DWT with MLA like ANN, SVM, KNN and DT is 0.502 sec, 0.471 sec, 0.448 sec and 0.433 sec respectively.

- **[3] Gong et. Al. (2020)**
- The authors processed an approach for IGBT open-circuit fault diagnosis for electrical power DC-DC inverters. This method uses Convolutional Neural Network with Global Average Pooling (CNN-GAP). It can detect a total of 12 types of multiple open switch faults. The accuracy of the proposed method is 99.95% with training and testing time 824.89 sec and 2.488 sec respectively making the method intelligent and fast with low threshold dependencies.

- **[4] Chen et. Al. (2021)**
- One of the diagnostic methods for same phased Open Switch Faults in inverters is detected by using Extended State Observer (ESO). A voltage ESO is designed for mixed logic dynamic model and eliminate unknown disturbances by estimating the output of 3 phase voltage in real time. The diagnosis time for this method is about 1/3 cycle with low cost and high robustness.

- **[5] Mehta et. Al. (2022)**
- Mehta et. Al. (2022) proposed a technique for OCF diagnosis in Multilevel Inverters using Fuzzy Logic Controller with Total Harmonic Distortion (THD) feature. There is a total of 9 rules associated per phase in the fuzzy interface. To avoid false faults this method requires authenticating threshold value. the diagnostic time is about two fundamental cycles of 60 Hz (up to 32 ms). Effectiveness of proposed method is moderate with low implementation effort.

- **[6] Bolbolnia et. Al. (2021)**
- A method for open-switch fault diagnosis is proposed in this paper for the six phase AC-DC wind turbine . The proposed method is associated with hysteresis controller so, it doesn't require ant additional equipment for fault detection. This technique is based on difference between the phase current and the adaptive threshold. This method is robust against load changes. In both single and multiple open-switch faults, the maximum value of DC-link voltage ripple is 5 volts, which is smaller than 1% of the reference value. The detection time for the proposed method is about 0.14 sec with lowest implementation effort but, high dependency over adaptive threshold. It is effective against both single and multiple open-switch faults.

- **[7] Bengharbi et. Al. (2023)**
- This paper deals with methods for single open-switch and double open-switch fault detection in photovoltaic solar pumping system. The proposed method for three phase inverters is based on Artificial Neural Network and Adaptive Neuro Fuzzy Interface System. It involves sampling of three phase inverter currents (I_{abc}) in heathy and all faulty cases. Proposed neural network and neuro fuzzy network involves 193 node, 129 parameters and 81 fuzzy rules. With less than 5% of error for neuron-fuzzy and less than 7% for ANN and response times of less than 0.1 sec both the techniques show good performance and high accuracy.

- **[8] Halabi et. Al. (2023)**
- This paper proposed a method for open circuit faults for HANPC inverter. The proposed method is based on Artificial Neural Network (ANN) for fault detection. This involves the operation at two different switching frequencies; fundamental frequency (f_{fund}) of 50 Hz and hybrid frequency (f_{hyb}) of 30 kHz. This method show creative and effective fault detection technique. It has low dependency on threshold values and robust on multiple open-switch faults. Results show that detection time is around 0.11 sec. It has high implementation effort.

- **[9] Ibem et. Al. (2023)**
- This paper discussed unique method for open-switch fault detection in three phase voltage source inverters. The proposed method uses ensemble bagged decision tree machine learning technique for fault detection and compared it with traditional machine learning techniques like SVM, KNN and DT. The proposed method uses current RMS and average ratio as decision parameters. Diagnosis time is about 2.5 ms with 100%

accuracy. Ensemble bagged decision tree involves multiple DT classifiers in series or parallel architecture provided with inputs and using combination algorithm ensemble model is generated with maximum accuracy. The proposed method is effective under low current conditions but, requires high implementation effort.

- **[10] Jian-Jian et. Al. (2019)**
- Real time open-switch fault diagnosis method for three phase voltage source inverters is proposed under this paper. This method involves calculated sum of absolute value of the normalized phase currents and current zero-cross detection method. The proposed method detects total 12 distinct types of single and simultaneous open circuit faults. Results show that detection time for this method is about 4 ms. This method is effective against load variation and current frequency variations but highly dependent on threshold values.

2.2 Literature Summary Table

Research Paper Title	Year of Publication & Authors	Methodology Adapted	Major Findings
[1] Fault diagnosis scheme for single and simultaneous open-circuit faults of voltage-source inverters on the basis of fault online simulation	2021 Chen, Tao, Yuedou Pan, and Zhanbo Xiong.	Fault Online Simulation	Single and simultenous open-circuit faults(18 types)
[2] Open circuit switch fault detection in multilevel inverter topology using machine learning techniques	2020 Achintya, Pratibha, and Lalit Kumar Sahu.		Single-switch faults
[3] A data-driven-based fault diagnosis approach for electrical power DC-DC inverter by using modified	2020 Gong, Wenfeng, et al.	CNN-GAP and 2-D feature image	Single and simultenous open-circuit faults(12 types)

convolutional neural network with global average pooling and 2-D feature image.			
[4] The Diagnostic Method for Open-Circuit Faults in Inverters Based on Extended State Observer	2021 Chen, Chaobo, et al.	Voltage Expansion Observer	Multiple open-switch faults
[5] Open Circuit Fault Diagnosis in Five-Level Cascaded H-Bridge Inverter	2022 Mehta, Pavan, Subhanarayan Sahoo, and Harsh Dhiman	Fuzzy Logic Controller	Multiple open-switch faults
[6] Diagnosis and Fault-Tolerant Control of Six-Phase Wind Turbine under Multiple Open-Switch Faults.	2021 Bolbolnia, Rouhollah, Karim Abbaszadeh, and Mojtaba Nasiri	Hysteresis Controller	Multiple open-switch faults
[7] Open-Circuit Fault Diagnosis for Three-Phase Inverter in Photovoltaic Solar Pumping System Using Neural Network and Neuro-Fuzzy Techniques	2023 Bengharbi, Abdelkader Azzeddine, et al.	ANN and ANFIS	Multiple open-switch faults
[8] Efficient Fault Detection for Open Circuit Faults in HANPC Inverters Using Artificial Neural Network for Motor Drive Applications	2023 Halabi, Laith M., Hasan Ali Gamal Al-Kaf, and Kyo-Beum Lee	ANN	Multiple open-switch faults
[9] Multiple open switch fault diagnosis of three phase voltage source inverter using ensemble bagged	2023 Ibem, Chukwuemeka N., et al.	Ensemble-Bagged Machine Learning	Multiple open-switch faults

tree machine learning technique			
[10] Open-switch fault diagnosis method in voltage-source inverters based on phase currents	2019 Jian-Jian, Zhang, et al.	Current Zero-Cross Detection	Single and simultenous open-circuit faults(12 types)

CHAPTER 3
REQUIRMENT & ANALYSIS

3.1 Requirement Analysis

Data Acquisition: Implement a system capable of acquiring voltage and current data from 3 Phase Voltage Source Inverters (3 Phase VSI).

Pattern Recognition Algorithm: Develop and employ advanced pattern recognition algorithms for the detection of open switch faults in the 3 Phase VSI.

Fault Localization: Ensure the system can pinpoint the exact location of the open switch fault within the VSI.

Accuracy and Reliability: The system must achieve high accuracy in fault diagnosis and provide reliable results in real-time or near-real-time.

3.2 Problem Analysis

Insulated Gate Bipolar Transistors (IGBTs) are used as switching devices in many VSIs. IGBT has the features like high voltage and high current ratings. Due to excess electrical and thermal stress, IGBT causes failures like DC-short circuit faults, AC-short circuit fault, intermittent gate-misfiring faults, overtemperature faults and open circuit faults. short circuit faults are difficult to deal with because time between fault beginning and malfunction is very small and can lead to a sudden increase in temperature potentially damages the IGBT semiconductor in VSI, open circuit faults can disrupt the generation of the desired AC output waveform leading to voltage or current distortion,

3.3 Software Requirement

1. Python
2. Integrated Development Environment (IDE):
   - MATLAB
   - Jupyter Notebook

3. Python Libraries
   - NumPy, Pandas, Scikit-Learn, Matplotlib

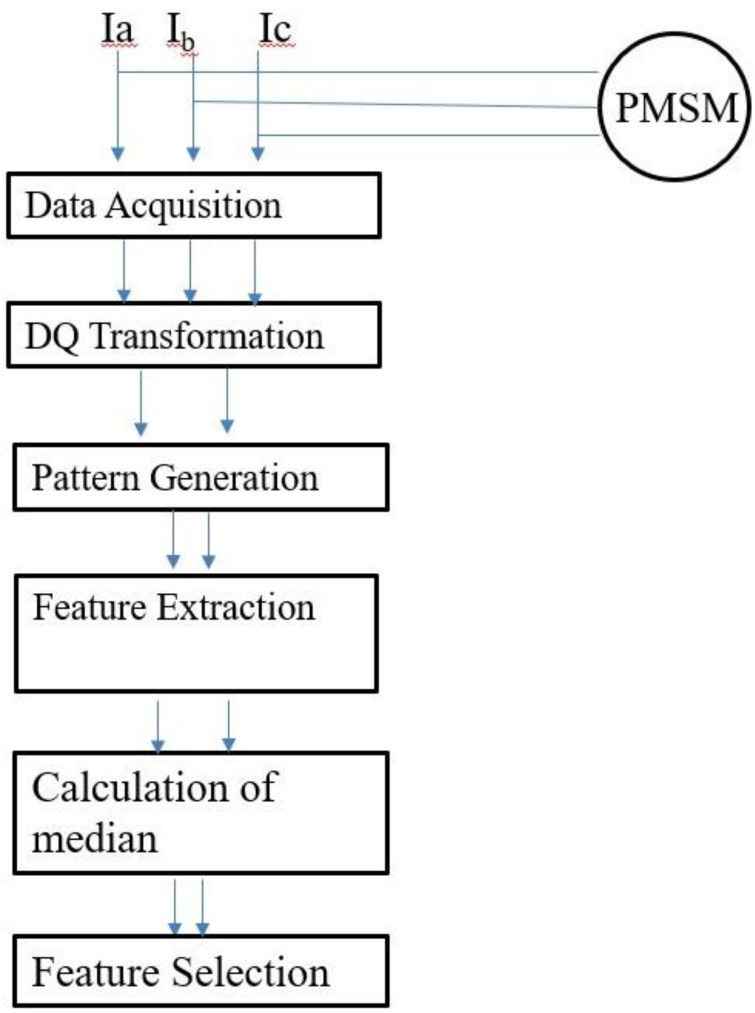
4. Algorithms Required:
   - Support vector Machine, (or any other for checking accuracy)

.

CHAPTER 4

DESIGN

4.1 Architecture



4.2 Project Modules

The switches are operated in a way that allows the voltage across the load to alternate between positive and negative half-cycles to produce an AC waveform. The specific switching patterns and timing are determined by the control circuitry and the desired output pulse-width modulated (PWM) sinusoidal wave. The method mainly contributes to diagnosis and detection of Open Switch Faults (OSFs). Single and Simultaneous/Multiple OSF combinations in 3Φ VSI was considered to propose a robust pattern recognition technique.

A 3Φ VSI model is built with 6 switches. The first step is to collect data using this model by running it on various operating states. Initial condition of switches would be 'healthy', where all the switches will be working in healthy condition, giving pure output in 3Φ current. Next, the faults are detected using different combinations of faulty switches. Since the basic switches conditions are first observed by opening the switches one by one, followed by combinations for faulty switches. In total, there will be 1 healthy condition, 6 single OSF conditions and followed by simultaneous/multiple OSF conditions with combination of first open switch and remaining others. Approximately 8000 samples for each open switch fault condition were collected.

The data collected for each switch namely I_a, I_b, and I_c, corresponding to the three phases of the AC output. Certain data cleaning methods are then used to clean this data to remove the data anomalies and null values.

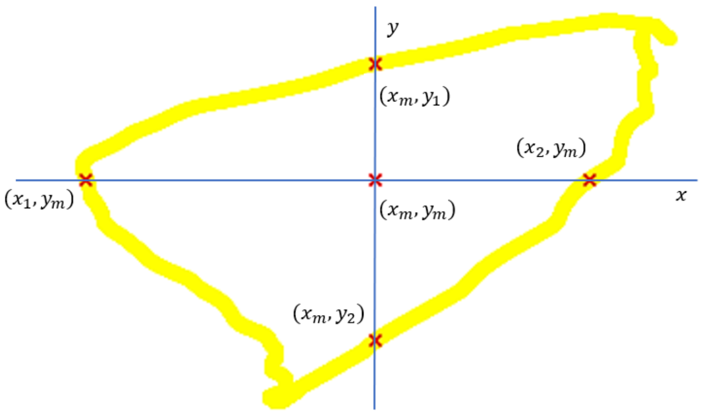
Data transformation is the next step in the data preprocessing pipeline, as it can impact the results of the model. The collected 3Φ current is converted in 2 attributes using Direct Quadrant Transformation (DQ Transformation). Quadrant transformation is a mathematical technique used to convert a set of data points from Cartesian coordinates (X, Y) into a new coordinate system based on polar or quadrant coordinates (R, Θ or ρ, φ). This transformation ensured decrease in the numbers of features selected for pattern recognition and helped in easier implementation. The I_a, I_b, and I_c condition was reduced to I_q and I_d currents.

$$I_d = \sqrt{\frac{2}{3}} I_a - \frac{1}{\sqrt{6}} I_b - \frac{1}{\sqrt{6}} I_c$$

$$I_q = \frac{1}{\sqrt{2}} I_b - \frac{1}{\sqrt{2}} I_c$$

The 2 attributes, I_q and I_d is now used for data visualization. Patterns are generated for every switch condition by plotting I_q and I_d on the x-axis and y-axis respectively. In total get 1 healthy condition pattern and 10 faulty condition patterns. When these patterns are analyzed, it can be clearly seen that the patterns are uniquely different from each other. The end point of the model will be to observe if can use these conditions directly for further analysis or it needs different feature selection process for a more efficient model.

4.4 Mathematical Model



$$G \equiv (x_m, y_m) \qquad \ldots Centroid$$

$$P_{(1)} \equiv (x_m, y_2) \qquad P_{(3)} \equiv (x_1, y_m)$$
$$P_{(2)} \equiv (x_m, y_1) \qquad P_{(4)} \equiv (x_2, y_m)$$

$$x_m = Med(X) = \begin{cases} X\left[\frac{n+1}{2}\right] & if\ n\ is\ odd \\ \frac{X\left[\frac{n}{2}\right] + X\left[\frac{n}{2}+1\right]}{2} & if\ n\ is\ even \end{cases}$$

$$X = ordered\ list\ of\ values\ in\ dataset\ (I_q)$$
$$n = number\ of\ values\ in\ dataset\ (I_q)$$

$$y_m = Med(Y) = \begin{cases} Y\left[\frac{k+1}{2}\right] & if\ k\ is\ odd \\ \frac{Y\left[\frac{k}{2}\right] + Y\left[\frac{k}{2}+1\right]}{2} & if\ k\ is\ even \end{cases}$$

$$X = ordered\ list\ of\ values\ in\ dataset\ (I_d)$$
$$k = number\ of\ values\ in\ dataset\ (I_d)$$

$$If\ locus\ of\ given\ plot\ curve\ follows\ \ y = f(x),$$
$$then\ \ldots \quad y_1\ \&\ y_2 = f(x_m) \quad and \quad x_1\ \&\ x_2 = f(y_m)$$

Feature selection process involves calculations for 5 data samples from every generated pattern after DQ transformation. First, the co-ordinates of the Centroid (G) of pattern have been calculated using median formula over all the data samples in x and y axes. Then, shifted the co-ordinate axes to the centroid and calculated the intersection of co-ordinate axes to the locus of the generated pattern with points $P_{(1)}$, $P_{(2)}$, $P_{(3)}$, $P_{(4)}$. All the co-ordinates of given 5 points have been updated to the tuples of data frame called features.

CHAPTER 5

CONCLUSION

5.1 Conclusion

The experiments over data was performed in Jupyter Notebook 7.0.3 using Python programming language. this methodology outlines the process of collecting, preprocessing, transforming, and visualizing data from a VSI hybrid model, and then using pattern recognition techniques to select features for further analysis. The resulting 'features' data frame serves as the foundation for subsequent fault detection and analysis in voltage source inverters. After performing given steps in the methodology, the dataset of 12 files in which 3 attributes with approx. 8000 datapoints is converted into the single 11x10 data frame represented in the fig.

median_x	median_y	points_x1	points_y1	points_x2	points_y2	points_x3	points_y3	points_x4	points_y4
-0.010053	-0.027711	-0.013265	-4.155529e+00	-0.010053	4.214940	3.994504	-0.028060	-4.234925	-0.027711
-0.114004	-1.679206	-0.116014	-4.148596e+00	-0.114004	-0.660057	2.740320	-1.679216	-3.211027	-1.679206
-1.853260	1.278385	-1.853623	-2.241037e+00	-1.853260	3.794933	-0.429503	1.277781	-3.770979	1.278385
1.793486	0.545962	1.793486	5.281698e-01	1.792536	0.567068	2.569807	-0.449480	2.399141	-0.524882
1.989217	1.255643	1.989217	-1.079898e+00	1.986517	2.976616	4.318647	1.255643	-0.096537	1.254023
-1.965891	-1.167720	-1.966609	-2.969280e+00	-1.965891	1.165875	-0.071717	-1.167720	-4.050314	-1.169151
-0.093985	0.000013	-0.095471	8.371049e-07	-0.093985	0.000045	2.026739	0.000013	-0.977127	0.000013
-1.700281	-1.253082	-1.701346	-3.022104e+00	-1.700281	-0.804152	-0.678145	-1.255196	-2.624940	-1.253082
0.557851	-2.537266	0.557365	-4.560043e+00	0.557851	-1.497422	2.471099	-2.537326	0.092445	-2.537266
1.927068	-0.244184	1.924618	-1.329009e+00	1.927068	0.073300	5.127691	-0.244491	0.384684	-0.244184
-1.856178	-2.202212	-1.891577	-1.687574e+00	-1.856178	-1.282467	-0.091146	-2.202993	-3.967985	-2.202212

Fig. : 11x10 data frame(features)

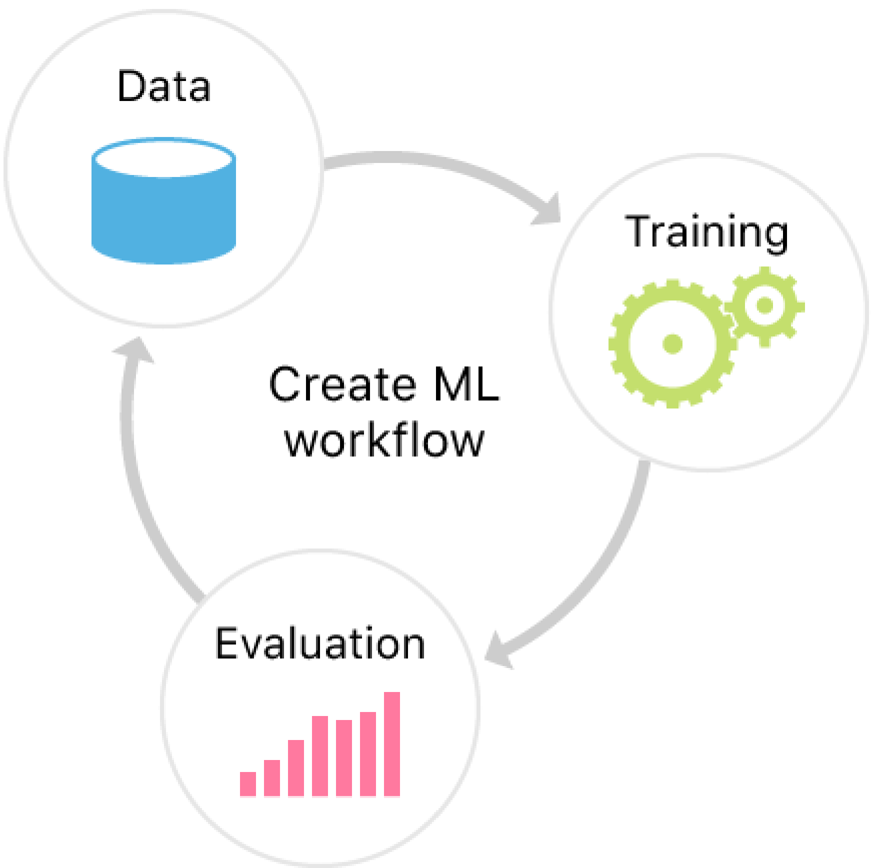
By using pattern recognition techniques propose a robust & effective method for multiple open-switch fault diagnosis in 3 phase voltage source inverters with minimum implementation efforts, Low threshold dependencies and high resistivity to load variations. *Applications* of this project further extends to uninterrupted power supplies, Industrial Induction motors as well as power generation methods like solar energy systems and wind energy turbines.

CHAPTER 6
PROJECT STAGE-2 PLAN

6.1 Project Stage II Plan

In stage I we have collected a data from virtual circuit which is created on MATLAB software, perform a DQ Transformation and visualise generated patterns by using matplotlib library extension like. pyplot. After generation of this patterns feature selection was the crucial procedure to reduce data samples and simplify the complexity of model that we are going to build. We used technique mentioned in 4.4.

For Stage II of the project we are planning to build a machine learning model for pattern recognition of open swich fault diagnosis in 3φ VSI. Selection of model is important step to achieve maximum accuracy. Then training model with the features that have been collected from feature selection technique. Performance evaluation of model helps to tune the parameter and helps to identify the fitness of the model for new samples. Outcome of stage II involves a robust and effective ML model which can classify faulty conditions from a healthy condition with minimum detection time and threshold dependency. In conclusion, Stage II involves building ML model to successfully classify faulty conditions for condition-based maintenance.



CHAPTER 7
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APPENDIX

1. Project Title Mapping with PO's and PSO's (With Justification)

Gr. No	Project Title	Project Guide	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2
	Pattern Recognition based Approach for Open Switch Fault Diagnosis in 3 Phase VSI		3	3	3	3	2	1	1	1	1	1	2	1	2	3

1. Poster Presentation Participation Certificate

SAVITRIBAI PHULE PUNE UNIVERSITY

Internal Quality Assurance Cell (IQAC)

AAVISHKAR - 2023

ZONAL LEVEL RESEARCH PROJECT COMPETITION

Certificate of Participation

This is to certify that ~~Mr.~~/Miss. ANSHIKA PRAVEEN SINGH of AISSMS, IOIT, PUNE College/Institute has participated in Zonal Level Research for UG / PG / Post PG (M.Phil. / Ph.D.) at "AAVISHKAR 2023" Research Festival, Under ENGINEERING & TECH. category, held at AISSMS, COE, PUNE during 27 - 10 - 2023.

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