FFT Based Fault Detection and KNN Based Fault Classification in Grid Tied Wind Farm Microgrid

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Abstract

Detection and classification of fault in grid connected microgrid is very important part of the power system engineering. Accurate detection and proper classification of faults are utmost required to improve the reliability and stability of the microgrid. In this article, authors proposed Fast Fourier Transform (FFT) based approach to detect different types of electrical fault and machine learning based method to classify the different faults. At the Point of Common Coupling (PCC), current signature is captured continuously for analysis. Normalized current data has been analyzed by FFT and K-Nearest Neighbor (KNN) based approach to identify and classify different faults respectively. Here the normalized data has been used to make the algorithm universal. Using FFT and KNN, upbeat results have come out of fault assessments in grid connected microgrid.

Keywords: *FFT; THD; KNN; microgrid*

1. Introduction

Day by day the demand of electrical power is increasing. It's not necessary to mention that the electricity is the power of world and every portion of industrial application is dependent on electrical energy [1]. Besides this household application, streetlight, medical sector, small scale industries are depending on electricity. There are various sources of electrical energy. Basic classifications of this are renewable and non-renewable. Non-renewable sources of electrical energy are most popular throughout the world. But there are some drawbacks of non-renewable source of electrical energy. First of all the sources of this type of energy is very much limited. Secondly the carbon emission in in the atmosphere is very much higher in case of non-renewable energy. This also creates various hazardous situations which is not desirable. So the sector of power generation is taking a turn to the renewable source of energy [2].And they also merged up the renewable source of energy with non-renewable source of energy called microgrid system. Which is most efficient than a typical conventional source of energy. One of them famous renewable source of energy is wind energy. In the region of coastal area or various places where winds flow is very high in every time, electricity can be produced from there. Government of India has been taken varies steps to promote this type of idea. One of them is Vayumitra Skill Development Programme (VSDP). So now a day wind power based microgrid is very much popular. But the main problem is fault analysis of the grid tide wind based microgrid system. Now a day lots of research work on this topic are going on to properly detect the fault to enhance the reliability and stability of the system [3] [16]-[23]. Zadeh et al. worked on the detection of wind system failure in a microgrid [4]. Kariya M Gamage Yashodha Swwandi et al. worked on to develop and simulate the operation of wind turbines connected to a micro grid in a controlled laboratory environment [5]. Protection is very important part of microgrid specially wind based microgrid because its bidirectional power flow [6][7] and lack of advance forecast of wind flow. For this reason, this paper focus on the fault analysis of wind farm based microgrid using Fast Fourier Transform (FFT) [1][9] and classify the fault using machine learning methods. Fault analysis is very important subject of recent power system scenario. Classification of the type of the faults using machine learning is very unique feature of this paper.

2. Proposed Model

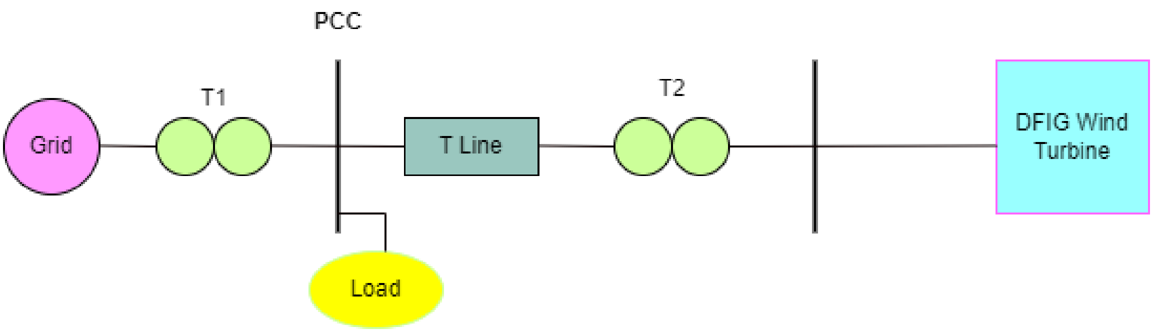

Fig 1. Block Diagram of the proposed model

In this proposed system a 9 MW wind farm consisting of six 1.5 MW wind turbines connected to a 25 kV distribution system is consider. Here the power exports to a 120 kV grid through a 30 km, 25 kV feeder. Doubly-fed induction generator(DFIG) based wind turbines consist of a wound rotor induction generator and an AC/DC/AC IGBT-based PWM converter consider as a renewable energy source. The stator winding is connected directly to the 50 Hz grid while the rotor is fed at variable frequency through the AC/DC/AC converter.

3. Method and Technique

In this work, current signal is continuously monitored and captured at the point of common coupling (PCC) and then it is normalized for fault analysis. Total Harmonic Distortion (THD) has been calculated from the normalized data by FFT analysis. Fault is detected if any abnormality is observed in FFT based THD values. After detection the fault, normalized data has been processed again using machine learning methods to classify the faults.

3.1 Fast Fourier transform

Fast Fourier transform (FFT), is a fast version of the discrete Fourier transform (DFT). It is one of the popular tools and is widely used in the signal processing. FFT is a one type of discrete Fourier transform algorithm which decreases the amount of computations required for P points from $2P^2$ to $2P \log P$, where log is the base-2 logarithm. In the formula of FFT, equation of the DFT $P(k) = \sum P(n) W^{nk}$ is broken down into a series of small transforms, which are then rejoined in the FFT calculation. FFT formula is defined as radix-2or radix-4 although other radix-p forms can be found for $p = 2^k$, where $p > 4$ [7]. Algorithms of FFT are generally describes into two classes: based on decimation in time and based on decimation in frequency. The main idea is to break the function of length X into two function of length X/2 using the algorithm [6].

$$\sum_{n=0}^{X-1} a_n e^{-2\pi i n k}/_X = \sum_{n=0}^{\frac{X}{2}-1} a_{2n} e^{-2\pi(2n)k/X} + \sum_{n=0}^{X/2-1} a_{2n+1}\, e^{-2\pi i(2n+1)k/X} \quad \text{(i)}$$

If M = FFT(L) and L = IFFT(M) represents the Fourier transform and inverse Fourier transform respectively. For M and L of length n, these transforms are defined as follows[7]:

$$L(K) = \sum_{j=1}^{n} X(j) W_n^{(j-1)(k-1)} \quad \text{(ii)}$$

$$M(j) = \frac{1}{n}\sum_{k=1}^{n} L(k) W_n^{-(j-1)(k-1)} \quad \text{(iii)}$$

Where, $W_n = e^{-2\pi i/n}$ (iv)

Flow chart for detection and classification of faults is depicted in Fig. 2.

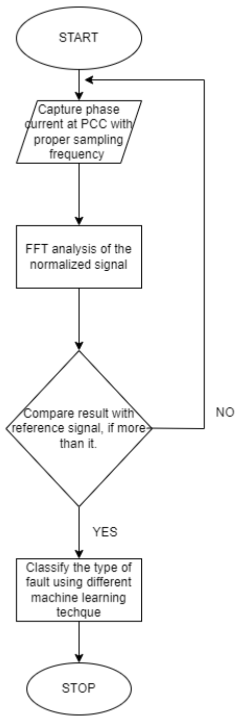

Fig 2. Flow chart of the proposed method

3.2 K-Nearest Neighbor (KNN)

KNN stands for the k-nearest neighbor algorithm in machine learning. It is a supervised, non-parametric classifier that generates a forecast or potential outcome regarding the grouping of a single data point. It has too many benefits since it provides precise forecasts for a certain collection of data. KNN would be correctly defined by two key characteristics [10][11]. Lazy learning algorithms and non-parametric learning algorithms have these characteristics [12]-[15].

3.3 Confusion matrix

A matrix known as the confusion matrix is used to assess the effectiveness of the classification models for a particular set of test data. It cannot be determined until the true values of the test data are known. Since it depicts the errors in the model performance as a matrix, it is also known as an error matrix. The confusion matrix features listed below include:

a. The matrix is divided into two dimensions , which are predicted values and actual values along with the total number of predictions.
b. The matrix is 2*2 for the 2 prediction classes of classifiers, 3*3 for the 3 classes, and soon.
c. The matrix is divided into two dimensions, which are the total number of forecasts, actual values, and forecasted values.
d. Actual values are the true values for the provided data, where as projected values are those values that the model predicts.

3.4 Parallel coordinates of KNN

Plotting individual data pieces across several performance criteria is done using a visualization approach called parallel coordinates. Each measure is displayed as a set of connected points along the measure/axes, and each data piece is displayed as a vertical axis.

3.5 Classification accuracy

It is one of the crucial factors in figuring out how accurate a classification problem is. It specifies how frequently the model predicts the right result. The number of accurate predictions made by the classifier divided by the total number of predictions made by the classifiers can be used to compute it. The following is the formula:

Accuracy= $\frac{TP+TN}{TP+FP+FN+TN}$ where, TN = True Negative , TP = True Positive, FN = False Negative , FP= False Positive.

4. Result and Discussion

4.1 At normal condition (without fault condition)

Initially voltage, current and frequency are monitored on the grid at normal condition at PCC and calculate the THD. Fig 3a shows the voltage and current injected at the grid at normal healthy condition. Fig 3b shows the current harmonic (THD). THD of the system at healthy condition is 2.20%.

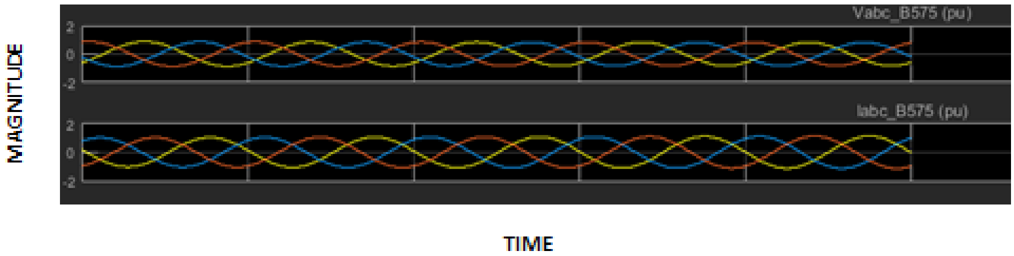

Fig.3a. Current and Voltage of grid at healthy condition

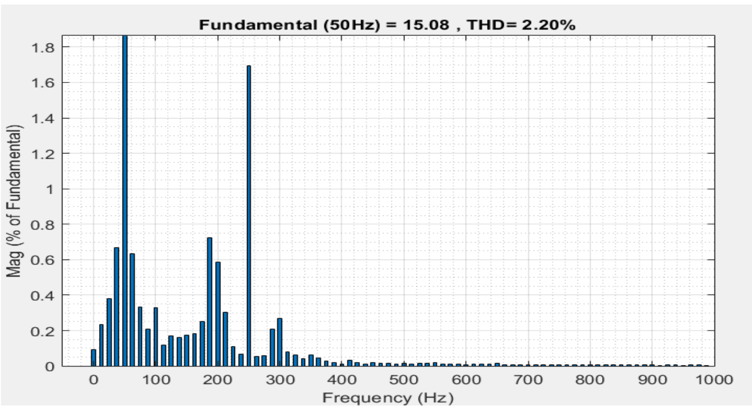

Fig.3b. THD of the system of healthy condition

4.2 At faulty condition (L-G fault)

A single line to ground fault on a transmission line occurs when any conductor drops to the ground, touches to the ground or come contact with neutral conductor. Such type of failures may occur in power system due to much natural reason like high speed wind blowing, falling of a tree and lighting etc. Fig.4 shows the result of FFT analysis of the system where THD of the system at L-G fault condition is 11.06 % which is much higher than the standard value.

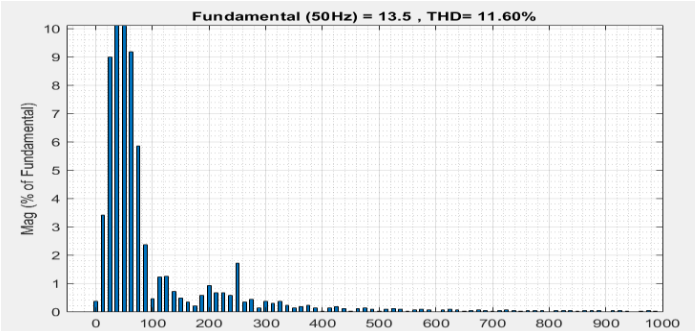

Fig4. THD of the system at L-G fault

4.3 At faulty condition (L-L fault)

Whentwoconductorsareshortcircuitedalinetolinefaultorunsymmetricalfaultoccurs.Fig.5 showstheresultofFFTanalysisof the system at line to line fault where THD of the system at L-L fault condition is 23.18 % which is very high as compared to normal value.

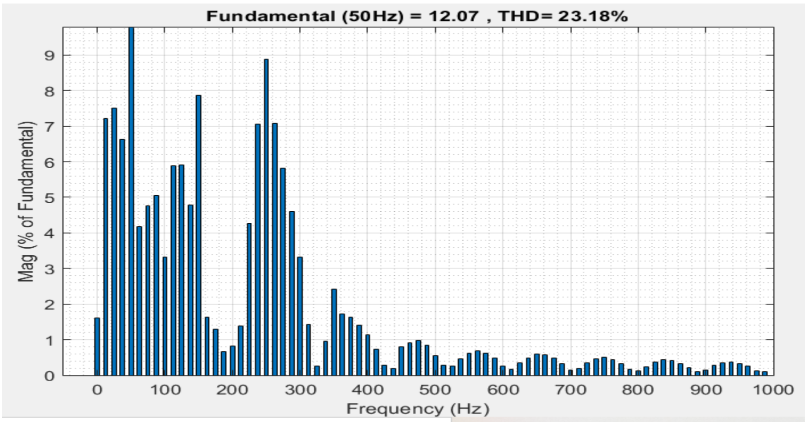

Fig5. THD of the system at L-L fault

4.4 At symmetrical fault condition

Symmetrical fault is one of the most dangerous faults in transmission and distribution system. This fault can be classified into two parts such as i) LLL fault ii) LLLG fault. In case LLL fault, 3 phase are shorted each other. Fig. 6 shows the result of FFT analysis of the system current at line to line-to-line fault where THD of the system at L-L-L fault condition is 29.64 % which is much higher than the ideal value.

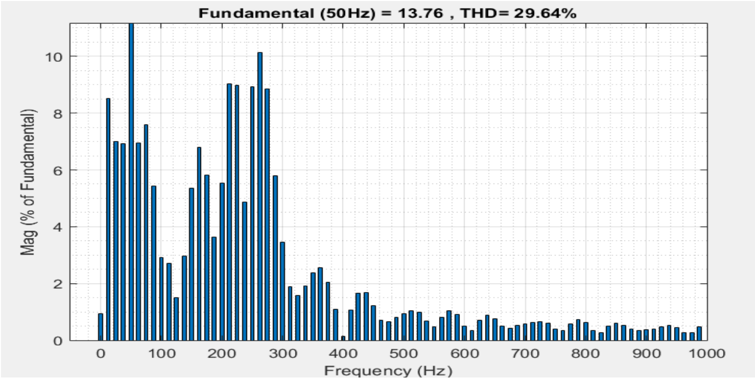

Fig6. THD of the system at L-L-L fault

Line to Line to Line to Ground Fault is one of the severe faults of the system. Fig.7 depicts that THD of the system current at symmetrical fault condition. At this condition THD has come out is30.38%whichis higher than LLL fault.

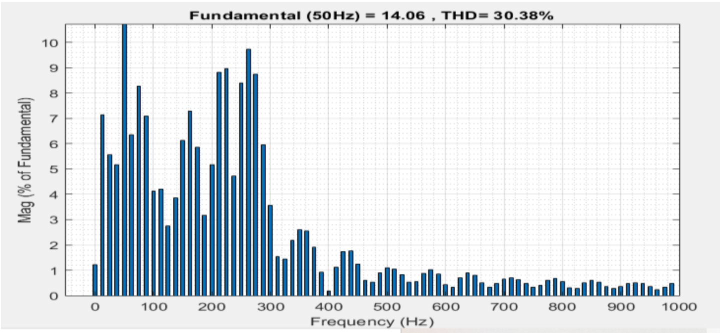

Fig 7. THDat L-L-L-G fault

Table 1 shows the THD level at different conditions. From this table it is clearly observed that, THD is maximum at LLLG condition and minimum at normal condition. From this FFT based THD analysis, fault conditions are easily detected based on the THD value. After detection, the classification of the fault is another important objective of this work.

Table1:ComparativestudyoftheTHD Analysis

Condition	*THD(%)*
Normal	*2.2*
LG	*11.6*
LL	*23.18*
LLL	*29.64*
LLLG	*30.38*

Classification or identification of fault is also very important issue of power system network as well as microgrid. In this analysis, different type of K-Nearest Neighbor (KNN) is used to identify the type of faults. Table 2 shows the accuracy and specificity of different KNN methods where 100% accuracy was achieved in Fine KNN method.

Table2:Comparative study of different KNN methods

PARAMETER	KNN *(Fine)*	KNN *(Medium)*	KNN *(Cubic)*
Accuracy(%)	*100*	*67.9*	*60.1*
Specificity	*98.46*	*65.77*	*62.87*

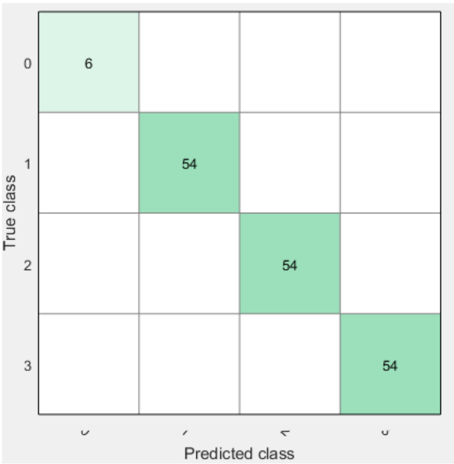

Fig 8. Confusion Matrix of KNN(Fine)

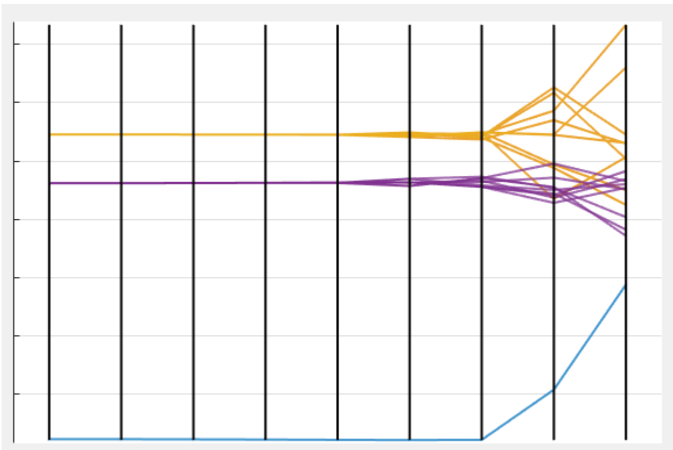

Fig 9. Parallel coordinate of KNN(Fine)

Fig.8 describes the confusion matrix and Fig.9 shows the parallel coordinates of fine KNN. In confusion matrix 0,1,2,3 describe the no fault, LG fault, LL fault and symmetrical fault respectively.

5. Conclusions

In this paper FFT-based THD and DC component analysis have been used for quick detection of faults and K-Nearest Neighbor (KNN) based machine learning method has also been used to classify the type of electrical faults on grid connected Wind Farm. In this study almost 100% accuracy was achieved using KNN analysis, where for other machine learning techniques 85%accuracy has been achieved for fault classifications. The KNN method is a fairly common machine learning technique although it is rarely utilized to classify electrical faults. But in this work KNN is used to classify electrical faults and which produced very satisfactory result. Accurate fault detection and classification enhances the stability and reliability of this type of wind farms based microgrid.

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