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Intelligent Fault Detection Scheme for Microgrids using Wavelet-based Neural Network: A review

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Abstract - *The protection of microgrids (MGs) is one of the most important and dangerous operational challenges with the gradual implementation of renewable energy sources in recent power systems. MGs are generally combined with photovoltaic (PV) arrays, wind turbines, fuel cells. Fault detection in MG is very much difficult due to complex structures and so many bus bars available in MG, so fault detection is necessary for MG operation and control, as it allows the system to perform rapid fault isolation and recovery. Otherwise, MG component like transformer, loads and insulator may get damage due to long-duration faults presents in the system. The different fault detection schemes are discussed in this paper. This paper provides brief information related to various fault detection techniques which will be helpful. The technique discussed in this paper used wavelet transform (WT) and neural network (NN) which provide significantly better fault detection and classification accuracy and also detect the locations of faults. In this technique, branch current measurements sampled by protective relays are pre-processed by WT to extract statistical features. Then all available data is input into NN to develop fault information.*

Key Words: **Microgrid protection, fault detection, fault location, wavelet transform, neural network.**

INTRODUCTION

MG is defined as a network that includes distributed energy resources (DERs) such as distributed generators (DGs), storage devices, and small load clusters. MG can operate in a grid connected mode or it can run in an islanded (non-grid connected) mode as a standalone System [1].The main aim of the MG is to increase system efficiency, power quality, and reliability [2]. The use of various types of distributed generation (DG) for power generation presents challenges for operating, controlling, and protecting the MG [3]. The fig.1. Shows the simple example of low voltage DC MG. The MG consist of photovoltaic (PV) arrays, wind turbine, AC loads, DC loads, battery and circuit breaker [4]. With the slow implementation of renewable energy sources in recent power systems, MG are normally combined with inverter interfaced DGs (IIDG), such as photovoltaic DGs (PVDG) and battery energy storage systems (BESS). Old protective relays that are used for distribution system fault detection depend on huge fault currents. But, IIDGs can only give unimportant fault currents such that the protection schemes are not initiated. So these relays fail to protect MG [5].

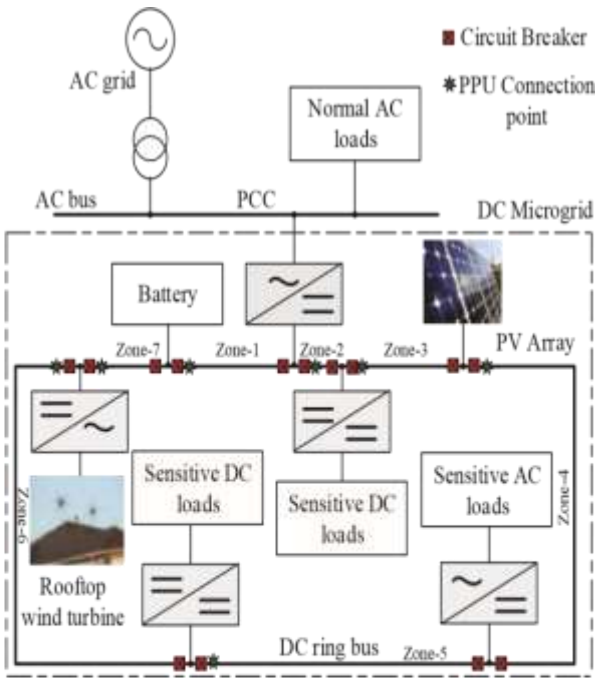

Fig-1: A theoretical schematic diagram of low voltage DC MG.

Overcurrent or directional relays that are used previously in traditional protection systems may be useless when applied to MG since they cause malfunctions and incorrect tripping. Various factors responsible for this are:

1. due to the bidirectinality of fault current when DGs are fixed into a grid.
2. due to IIDGs which limits the level of fault current.

The extreme fault current created by IIDGs is restricted to 2 times the inverter-rated current. Synchronous machines produce fault currents that are four to ten times greater than IIDGs [1]. So fuses and overcurrent relays frequently fail to trip when used with IIDGs. So a new class of devices required to protect the MG against various types of faults [6]. These faults classified as an unsymmetrical and symmetrical type of fault as shown in fig.2.such as a line to ground fault (LG), a line to line fault (LL), double line to ground fault (LLG), three-phase to ground fault (LLLG), three-phase fault (LLL) [7].

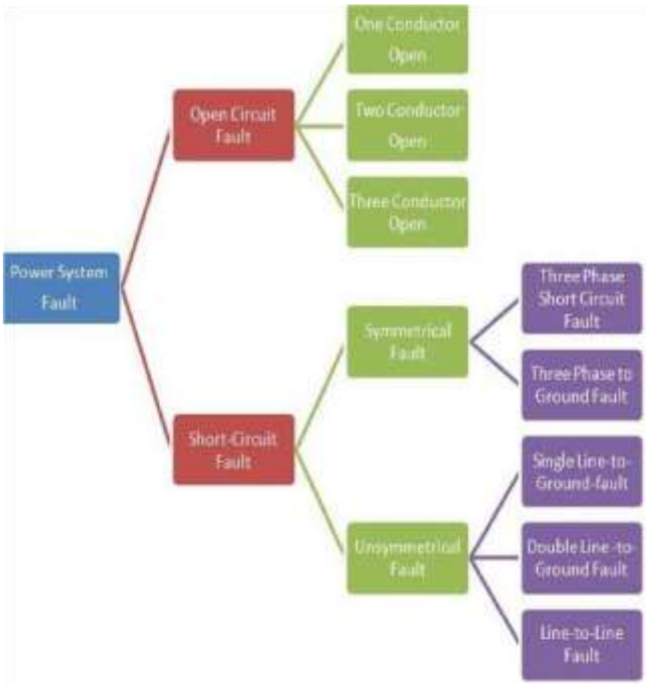

Fig-2: Power system faults.

So different methods for protecting MGs were proposed [1]. Fault detection in MG has three main objectives or aims. First is fault detection technique should detects the fault if there is fault in the power system (e.g. LG, LLL, LLG, LLLG, LL). Second is determination of fault location and the third objective is fault phase detection in unbalanced conditions [5].

2. DIFFERENT TECHNIQUES FOR MG FAULT DETECTION AND CLASSIFICATION

2.1 Differential Relay technique

This is a traditional method used for detecting a fault in a power transformer (internal and external faults). This method suffers from vigorous difficulties. The relay can also operate when there is an inrush current due to the energization of the transformer [8]. Thus it is very important to identify the internal faults and inrush current conditions separately otherwise relay may trip. This type of relay tripping is called false tripping. The current transformer (CT) is used for measuring those inrush currents [9]. Fig. 3. Shows a simple differential relay connection diagram. In which two CTs i.e. CT1 and CT2 are used. CT1 and CT2 are used for measurement of current at two ends.

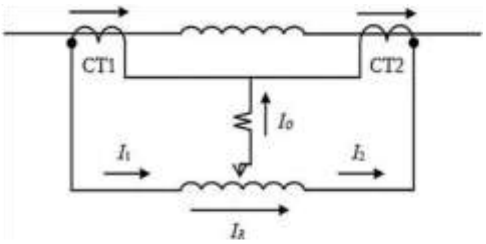

Fig-3: Differential relay connection diagram [10]

The main function of relay in this scheme is to compares an operating current (differential current) with restraining current.

I_0 is operating current and I_R restraining current as shown in fig.

3. The I_0 and I_R are calculated using following equation as [10].

$$I_0 = | I_1 + I_2 | \quad (1)$$

$$I_R = K | I_1 - I_2 | \quad (2)$$

When I_0 greater than I_R then relay generates tripping signals according to

$$I0 = KIR + IP \quad (3)$$

Where I_P is pick up current and K is relay operating characteristic with slop equal to k [11].

In this way, the differential relays are used to detect the faults in the power transformer. The proposed procedure is independent of the frequency deviation in the power system. The proposed method made correct identification of internal faults and inrush currents. Thus, the proposed algorithm can be considered for new differential protection schemes.

2.2 Random forest technique

Islanding (non-grid connected) is a mode in which the external grid no longer supply electrical power to the MG. thus efficient islanding detection method is needed. Random forest (RF) classification technique in [12] is used to detect and classify the islanding and non-islanding condition in MG. this classification technique has great accuracy and fast response. RF can combine the number of Decision Tree (DT) outputs and thus giving higher and extra robust results than one DT. In this case, RF is trained to discriminate between an islanding condition and normal condition. Fig. 4. Shows the entire process of islanding detection.

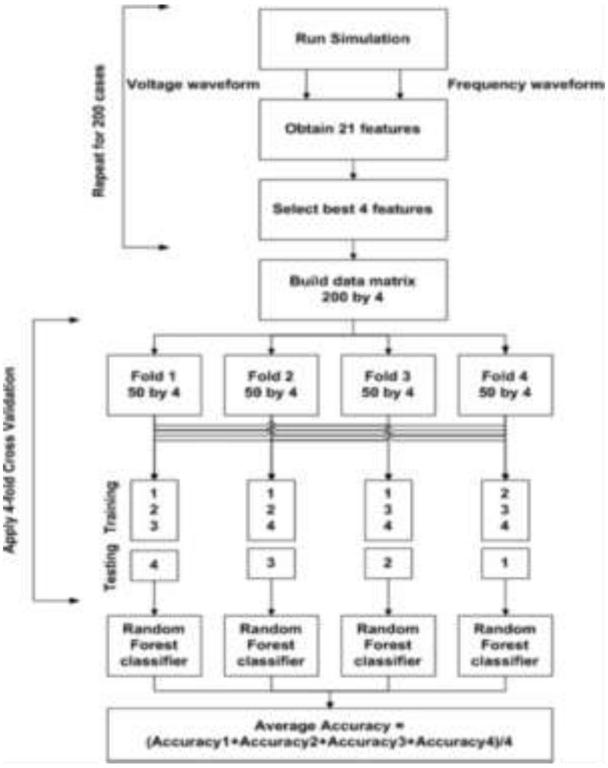

Fig-4: Proposed method for islanding detection [12]

1. Feature selection: The forward sequential feature selection (FSFS) and the backward sequential feature selection (BSFS) were applied for feature selection.
2. Data preparation: 200 cases are generated to simulate all possible islanding and non-islanding conditions. K-fold cross validation method is used in order to prepare the data for the classifier.
3. Training RF: RF classifier is trained to distinguish between an islanding condition and normal condition.

The process repeats four times to find the average accuracy for more robust island detection. The proposed technique as shown in above fig.4. RF is form by combining C4.5 DTs. This method is based on a voting criterion. The final decision made by RF technique is based on majority vote of these trees. This voting criterion decides whether an islanding or a non-islanding condition has occurred. RF method is extremely very fast in detecting islanding with average accuracy of 99% [12].

2.3 Decision tree technique

Decision tree (DT) classifiers are used in several areas like radar signal classification, remote sensing, medical analysis, speech recognition, modern power system, and many other areas. DT break down a complicated decision-making procedure into a group of the simpler decision [13]. Procedures established for building decision trees are computationally reasonable, forming it possible to quickly construct models even when the training data set size is very huge. Once a DT is built, classifying a test record is extremely fast [14]. DT approach in [15] used to detect islanding. Islanding is defined as when a part of the distribution network is separated from the rest of the system but continues to be energized by a distribution resource (DR). Unable to trip the islanded DR can lead to severe problems for DR and the other linked loads. Fig.5. shows the approach used to detect islanding. Using this technique satisfactory results are obtained.

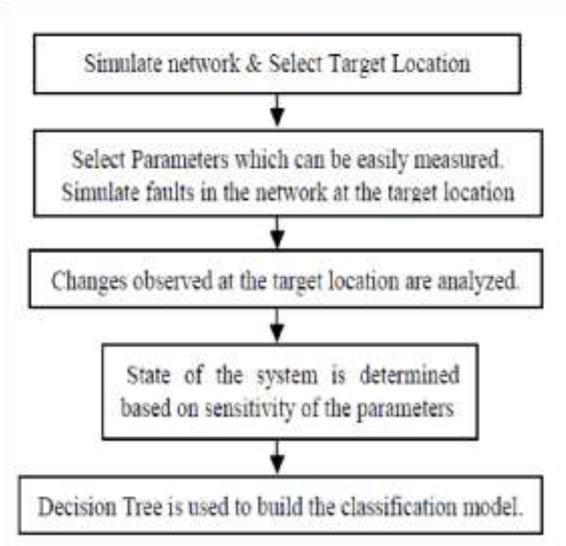

Fig-5: Flowchart for islanding detection [15]

DT approach in [12] is used to detect islanding for DG using pattern recognition. Islanding detection is done by using the following steps:

1. Feature selection: FSFS and the BSFS were applied for feature selection.
2. Data preparation: 200 cases are generated to simulate all possible islanding and non-islanding conditions. K-fold cross validation method is used in order to prepare the data for the classifier.
3. Training DT: DT classifier is trained to distinguish between islanding a non-islanding.

The accuracy of islanding detection is 97% when all features of DT are used. The accuracy reduced by 1% when only 4 features of DT are used. DT act as an ideal classifier for islanding detection. The combination of WT and DT used in [16] to discover and classify faults in MG. Fig.6 presents a block diagram of the proposed protection technique using current measurements to detect and classify faults by applying the WT and the DT model.

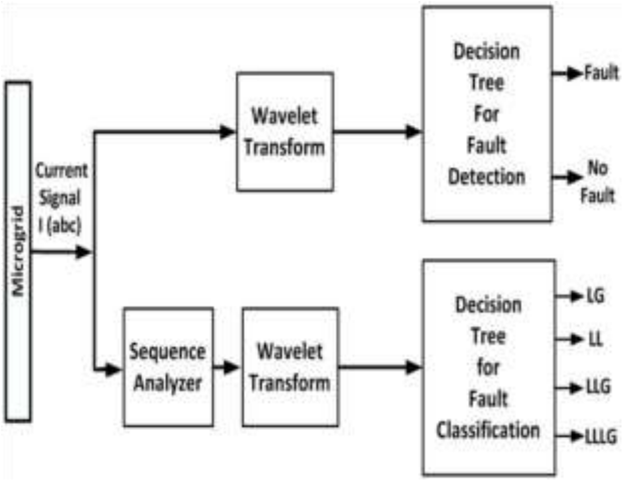

Fig-6: Methodology for fault detection [16]

The protection scheme preprocesses the current data for one cycle using the WT and arithmetical features are calculated. These features are used to form the DT models for fault detection and classification. The tripping signal is given in case of a faulted situation to clear the fault. The proposed DT model offers considerably upgraded performance over existing overcurrent relays. As the WT is very fast, thus the reply time for fault detection is 1.5 cycles and classification time is 2.5 cycles. DT method is extremely fast in detecting islanding with an accuracy of 97%.

2.4 Support vector machine technique

Support vector machine (SVM) technique in [17] is used for fault classification in an advance series compensated transmission line. The FACTS (flexible ac transmission system) devices such as thyristor-controlled series compensator (TCSC) used to improve the system performance. When the fault contains TCSC, the 3rd and 5th harmonic components are highly prominent compared to the fault which does not include the TCSC. This issue is taken care of by SVMs. In this technique, Half-cycle current samples and firing angles are used as input to the SVMs (SVM-1, SVM2, and SVM-3) as shown in fig.7. SVM-1 is used for fault classification, SVM-2 is used for ground detection, and SVM-3 is used for section identification. The error found in this SVM method is 5%. SVMs required less number of training samples as compared to the neural network. For the protection of the transmission line, this method is very correct and robust.

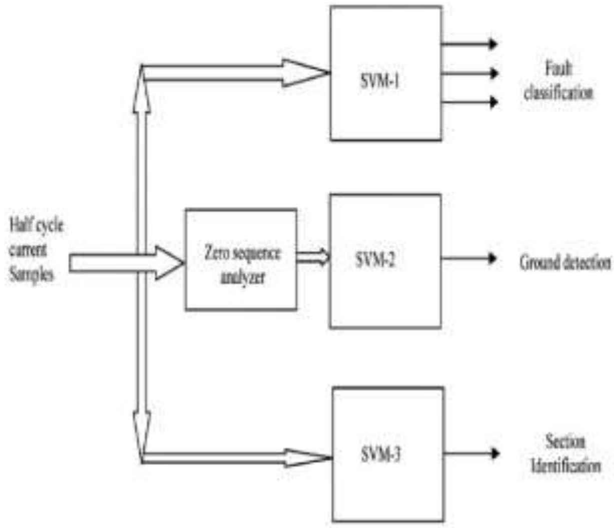

Fig-7: Proposed scheme for protection [17]

SVM algorithm used in [18] detects the transient stability status after a fault. The tests are carried out on a New England 39 bus system. The accuracy of the proposed algorithm is about 97% under all types of faults. The time required in the proposed technique is 0.067 msec (four cycles). A simulation model with the fault is developed using PSCAD/EMTDC software and then required data generated. The SVM classifier is trained using voltage magnitudes. Three classifiers are used for three-phase voltages (phase A, phase B, and phase C). So, the outputs of the three classifiers were joined using an OR logic. A per-phase classification unit and the procedure of developing the SVM-based transient stability Calculation scheme is given in Fig. 8

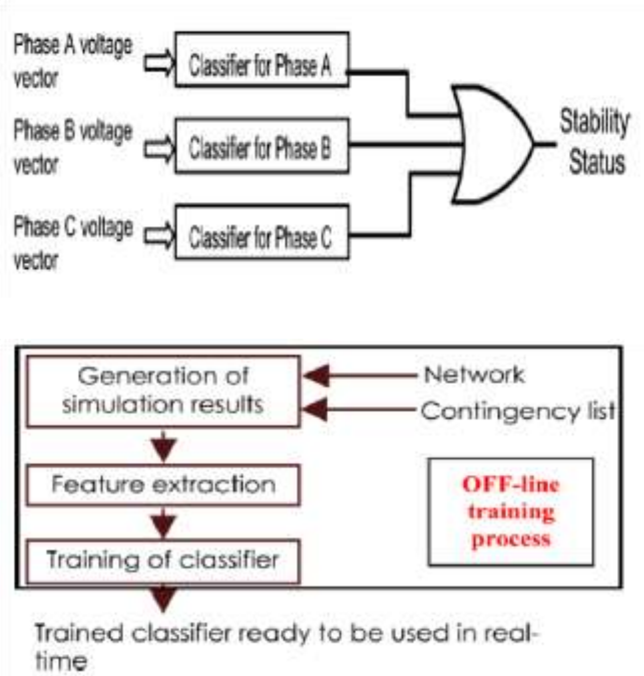

Fig.-8: SVM classifier implementation for transient stability analysis [18]

2.5 Neural network technique

A neural network (NN) is a combination of artificial neurons. The nervous system is formed by joining a large number of neurons. The main function of the nervous system is information processing. The information given to the neurons is in the form of signals that are passed between neurons through the connection links. Each connection link has a proper weight that multiplies with the signal transmitted. Each neuron has a separate activation function which is applied to the weighted sum of input signals to generate an output signal. Fig.9. shows the model for NN. Where x1, x2 up to xn are the input signal and w1, w2 up to wn are the weights of associated links. If the firing threshold is b and the activation function is f, then the output (y) of that neuron is

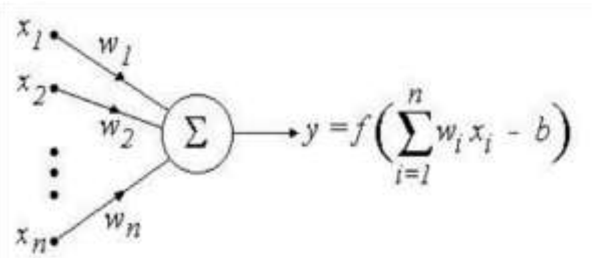

Fig-9: Model of NN [19]

A typical model of multilayer neural network consist of an input layer, an output layer, and one hidden layer is shown in [14], [20], [21] Fig.10.

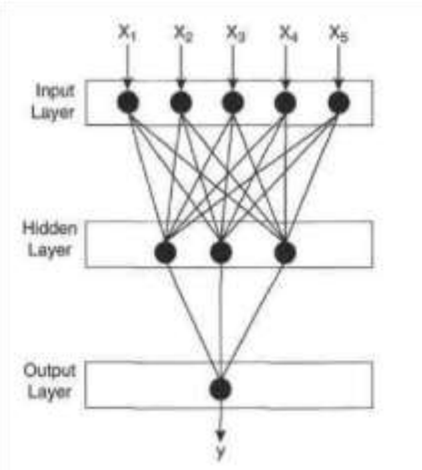

Fig-10: a one layer NN [14]

A deep neural network (DNN) is a type of artificial neural network (ANN) with several hidden layers of neurons between the input and output [5]. The example of DNN having one input layer, one output layer, and three hidden layers as shown in fig.11.

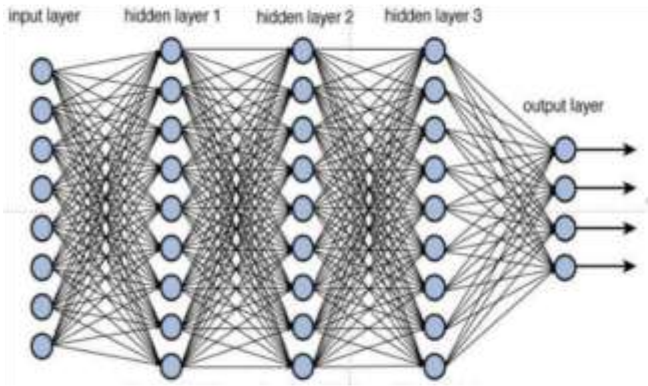

Fig-11: DNN with multiple layers [5]

NN used in [22] used to detect the incipient faults present in the power distribution feeder. The traditional overcurrent protective devices were used to detect the fault in power system but these devices unable to detect the high impedance faults (HIFs) in power distribution feeders. HIFs can result in fires and electric shock. The main aim of HIFs detection is to increase the public safety rather than system protection. Fig.12. shows a block diagram of the NN technique.

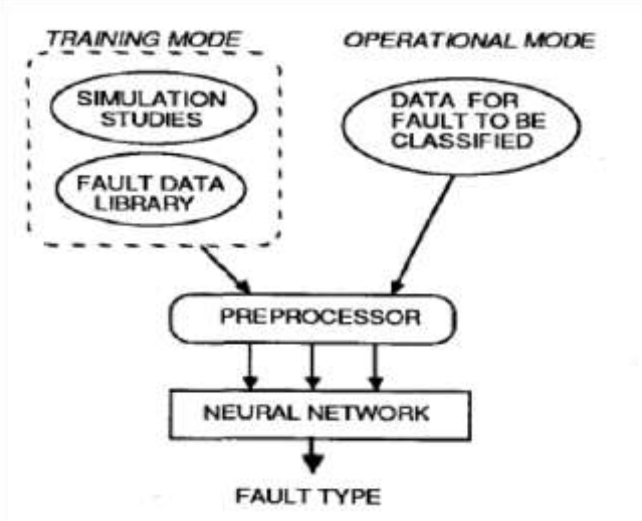

Fig-12: Incipient fault detection using neural network [22]

To implement the NN technique, the simulation model of the feeder is simulated using a computer. Which provides data samples of substation current after that analysis of fault current is achieved. Preprocessor preprocesses the current signal using Fourier transform or measuring other parameters. NN is trained and configured with these parameters. After that network is then capable of processing feeder current data in real-time and depending on the earlier examples given to it, determine whether a HIF is present or not. The average accuracy of the NN technique is about 98% [12].

4. CONCLUSION

In this paper, an outline of different fault detection and classification techniques of MG are reviewed. The various techniques available to detect and classify faults are a differential relay, DT, SVM, RF, and ANN. Differential relay is a traditional technique that only detects the faults present in the system. RF can detect faults and classify fault type (LG, LL, LLL, LLG, and LLLG). SVM and DT detect faults and classify fault types and fault phase also. The average accuracy of NN (98%) is very close to the average accuracy of RF (99%). The accuracy of SVM is about 97%. So the RF technique is more accurate as compared to other techniques. The technique discussed in this paper used the combination of ANN and DWT for detection and classification of faults. The wavelet-based neural network can detect faults and classify fault phase, fault type. One advantage of this scheme is we can also find the location of fault. In this technique, the various tests are carried out on IEEE 34 standard bus system.

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