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A Protection Scheme for Microgrids Using Intelligent Relays

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Abstract: **Microgrids are emerging as an important part in modern power distribution systems due to significant development in distributed generation technologies. Microgrids operate with a high level of inverter interfaced distributed generation (IIDG) penetration such as fuel cells, solar cell, and battery storage etc. The problem of microgrid protection becomes challenging as the fault current varies widely depending upon the operating conditions such as grid-connected and islanded mode in presence of IIDG. Fast and accurate fault detection coupled with a clearing mechanism is required for a safe and secured micro-grid operation. The relay detects and classifies faults using local measurements irrespective of the operating mode of the micro grid. The process starts by measuring and pre-processing the current signal at the relaying point using the Wavelet Transform. Time-frequency features such as change in energy, entropy and standard deviations are calculated using the wavelet coefficients. Cases representing various faulted and normal conditions are simulated to generate the complete data set containing the above mentioned features.**

Index Terms - **Consortium for Electric Reliability Solutions, Combined Heat and Power, Distributed Energy Resource, Distributed Generation, High Impedance Faults, Inverter Interfaced Distributed Generation, Point of Common Coupling, Phasor Measurement Unit, Random Forest and Voltage Source Inverter.**

I. INTRODUCTION

Looking Microgrids are of distributed energy emerging as an important part of the modern power distribution infrastructure. Microgrids have high penetration resources (DERs) along with communication, control and protection devices. Microgrids operate in semiautonomous manner and cover a small geographical area within a power distribution system. Distributed energy resources or DERs, also known as distributed generation (DG), are small scale energy resources such as a fuel cell, gas turbine, micro turbine, diesel generator, photovoltaic cell, wind turbine, battery storage etc. These DGs are embedded within the distribution network forming the microgrid. Other than electrical power needs, DERs producing waste heat such as micro turbines, gas engines, and small scale combined heat and power (CHP) units can be placed closed to the heat loads in order to fulfil the thermal need of customers. Thus, the presence of DERs in proximity to the loads makes the power delivery more reliable as it reduces power transmission loss and increases the energy efficiency of the power system by waste heat utilization. Efficient use of energy from DERs with a higher proliferation of renewable energy resources within a microgrid also helps to reduce the carbon footprint of the utility company and of the nation. Thus, the microgrid enhances the reliability of the power network with both economic and environmental benefits.

Motivation:
Motivation Various linear programming problem techniques have been used for OCR coordination. A sequential quadratic programming method has been used for optimizing all the settings of OCRs. In a distributed system where fault current has a tendency to in the forward or reverse direction, it is necessary to incorporate relays that respond differently for each direction. Due to this requirement dual setting OCRs have been proposed. In the directional relays were associated with different settings for forward and reverse directions of fault current for radial and meshed distribution systems, respectively. However, the impact of DG control modes on the coordination of conventional and dual setting OCRs has not been addressed. Therefore, a comprehensive analysis of the fault current contribution of DGs operating in VCM and CCM and its impact on protection coordination of conventional and dual setting OCRs.

Objective:
Objectives In order to design an intelligent relay for a low voltage microgrid which can identify all kinds of balanced and unbalanced shunt faults with the help of local measurements, an analysis will be performed using the following roadmap.

- A low voltage distribution microgrid will be developed and simulated using IIDGs only.
- An extensive fault study will be carried out for balanced and unbalanced faults with varying fault impedances for different operating conditions within the microgrid.
- Setting suitable features which are most affected during the fault conditions.
- Building data-mining based model using Decision Trees considering the most affected features derived at the local end to detect and classify faults in microgrids. The advantages of using an intelligent relay with local measurements are as follows:

- The protection strategy using intelligent relays with local measurements can result in accurate fault detection in grid-connected mode and islanded mode as compared instantaneous over current relays.
- The protection strategy needs to be effective when the microgrid topology changes from radial to mesh and vice versa.
- The protection strategy does not need any communication infrastructure; hence it increases the reliability of microgrid operation and reduces the operation cost.

II. RELATED WORK

Protection schemes for microgrids must address the problems related to bidirectional power flow and different levels of fault current in islanded and grid-connected modes. The protection strategy should be fast and accurate in order to maintain the stability with the microgrid operating in islanded mode and to protect sensitive loads [2, 16]. Several methods have been proposed to protect microgrids [8-13] [15-16]. Protection strategies using zero sequence components for single-line-to ground faults and negative sequence components of the line current for line-to-line faults in a microgrid was proposed by Nikkhajoei and Lasseter [9]. The high impedance fault detection issue was highlighted as an unresolved protection issue for the microgrid. A differential relaying based protection strategy was proposed for a microgrid with IIDGs [10].

A protection scheme based on dq-components of voltage was proposed for a microgrid [3]. The dq-components of voltage were compared with the voltage reference dq-component. It is not clear how the protection scheme will perform in case there is an unbalanced load in the system or for a high impedance fault. Several protection schemes for a microgrid using communication have been proposed. A differential relaying technique has been proposed for a medium voltage microgrid containing synchronous generators and IIDGs. This method has been tested for balanced and unbalanced faults including high impedance faults. A communication assisted adaptive protection method with a high penetration of DGs. However, it does not take into account the islanded mode operation and the proposed method has not been tested on IIDGs. A communication (wireless local area network protocol) assisted relaying technique has been proposed using microprocessor based relays for a medium voltage grid with IIDGs [4-6]. Most of the concepts used with this relay was originally proposed in which uses the over current method and negative sequence current component for the relaying system inside a low voltage microgrid. An additional technique to identify high impedance faults using the third harmonic component of current has been added to the enhanced relay and the communication method helps to reduce the operation time of the relay. It also advocates for a back-up protection strategy without using communication [7].

In a relaying strategy using communication for a medium voltage looped network has been proposed which uses a similar protection strategy as proposed in are independent of the location of DERs, microgrid operational mode, microgrid size and fault current level. However, the protection strategy needs communication. A centralized communication assisted over current based relaying technique, using IEC-61850 protocol, has been proposed for the microgrid [11]. It contains synchronous DGs and IIDGs in the test network. The centralized controller is connected to all DERs and relays in the network. The current value used in each relay is calculated dynamically using microgrid operational parameters and updated repeatedly. There is no information regarding the performance of the protection scheme for different types of balanced and unbalanced faults. This scheme will not be effective for high impedance faults. The protection technique as described in has been improved to include back up relays. The current value used in each relay is calculated dynamically using microgrid operational parameters and the relay will operate as an instantaneous time grading relay with latest setting in case of communication failure. This paper has considered balanced three phases to ground faults only and there is no information related to the performance of the protection technique on different types of faults within the microgrid [6].

III. BLOCK DIAGRAM

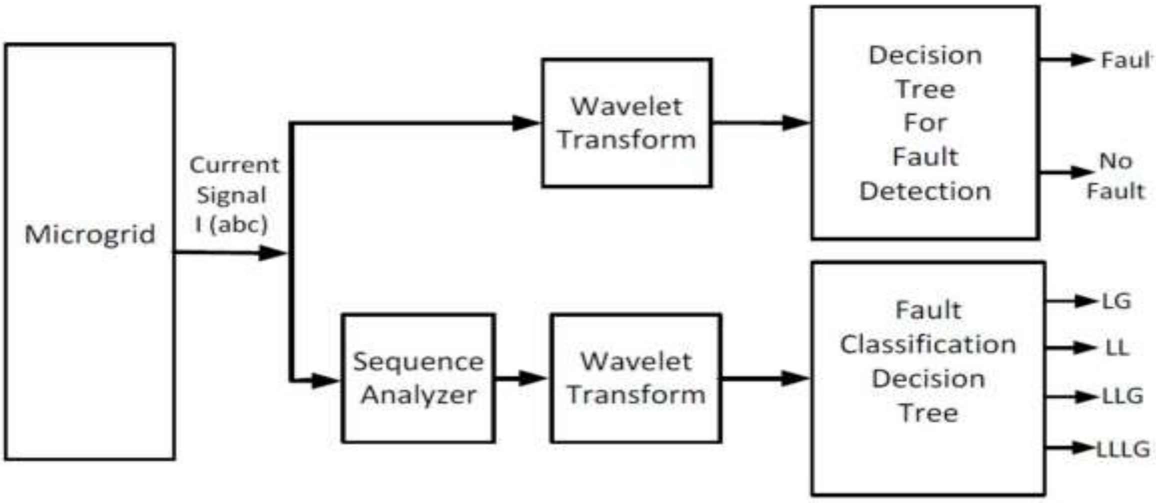

Figure 3.1 Block Diagram Of Protection Scheme For CERTS Microgrid

A new protection scheme has been proposed for the CERTS microgrid as shown in Figure 4.1. The objective of this protection scheme is to provide primary protection using intelligent relays. The intelligent relay uses local measurements to make decision regarding fault detection and classification. The sequence analyzer produces sequence components by analyzing input current. This scheme includes signal pre-processing using wavelet transform. The line current signal was measured for 3904 conditions i.e. different faulted and healthy conditions within the microgrid. The current signal is the input signal to the intelligent relay. This current signal is processed by the sequence analyzer to produce negative and zero sequence components. Wavelet coefficients for the measured current signal and for the sequence components were extracted. Features using the wavelet coefficients were calculated. These features will be used by the decision tree for detection and classification of faults. This scheme uses 15 different features based on wavelet coefficients. These features are the inputs for data mining models used for fault detection and classification. Nine out of fifteen features were used to train the decision tree for fault detection and the decision tree used for fault classification was trained using uses all the features. The output of the intelligent relay will identify and classify different types of faults. For the transformer and generator, a differential protection scheme with dual slope characteristics is to be utilized. In this case, the major concern is the operation of differential relays. However, in this paper OCRs in the distributed system are addressed. To address the protection scheme of the generator and transformer a coordination of overcurrent, differential, and distance relay has to be accomplished. In the case that any line contains the series capacitor, then the equivalent impedance of that particular line will be reduced, which will in turn increase the level of current. Apart from the benefits of the series capacitor, their presence in the fault loop affects the voltage and current signals at the relay location. In this condition the relays connected to the line may maloperate for the initial settings. Therefore, the setting of the OCRs should be fixed in such a manner that for normal line current the relay does not operate.

Overview of Wavelet Transform

The Wavelet transform helps to analyses a signal in time-frequency domain and gives time localized frequency information. The Wavelet transform is a powerful tool for the analysis of non-stationary signals as the frequency content of a non-stationary (transient) signal changes with time. The Wavelet transform is a better tool than the Fourier transform as the latter is used for analyzing a signal in frequency domain only. The Fourier transform does not give any information related to time frequency domain. The short time Fourier transform (STFT) has limitations in resolution due to window size. The Wavelet transform is a better tool as compared to the Fourier transform or STFT, providing both time and frequency information which is required for the analysis non-stationary fault transient signals.

IV. DATA MINING TECHNIQUES USED FOR THE PROTECTION SCHEME

Decision Trees:

The Decision Tree (DT) is a highly popular and efficient way to build classifiers. The decision tree algorithms are based upon supervised learning algorithms. It resembles an inverted tree structure and works on a series of conditional (if-then) logic.

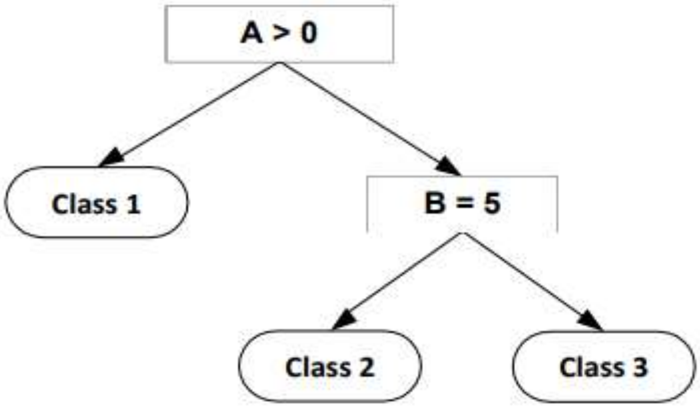

Figure 4.2 Decision Tree for classification

So the decision rules from this decision tree can be listed as follows.

- When A is greater than zero the output is 'Class 1'.
- When A is less than or equal to zero and B is equal to five then the output is 'Class 2'.
- When A is less than zero or equal to zero and B is not equal to five the output is 'Class 3'.

Random Forest:

Random forest (RF) is an ensemble learning method to increase the classification accuracy. It is created by combining many classifiers. It uses a collection of trees acting on same set of input attributes. The DTs used for the random forest method are independent of each other. Random forests or random decision forests are an ensemble learning method for classification, regression and other tasks that operates by constructing a multitude of decision trees at training time and outputting the class that is the mode of the classes (classification) or mean/average prediction (regression) of the individual trees.

V. METHODOLOGY FOR FAULT DATA GENERATION

In the grid-connected mode, the DG penetration was set to three different values 100%, 40%, and 10% of the total DG capacity. The load was equally distributed among the 3 generators. In the grid-connected mode, when the generation capacity of the DG within the microgrid decreases, then additional power flows from the grid. For the islanded mode, the 3 DG operate at a 100% of capacity. The DG penetration remains at 100 %, in islanded mode, in order to have maximum grid current.

Table 5.1 Number of Cases Simulated Different Types of Faults in the Network

Mode of Operation	Topology	Type of Fault	Types of Fault Resistance	No. of Fault Location	No. of Fault Inception Angle	Total no. of Cases
Grid Connected	2	AG, BG, CG, AB, BC, CA, ABG, BCG, CAG, and ABCG	3	4	4	2880
Islanded	2	AG, BG, CG, AB, BC, CA, ABG, BCG, CAG, and ABCG	3	4	4	960

The values used for simulating different types of faults are as follows:

- Different balanced and unbalanced faults were simulated. They can be referred as AG, BG, CG, AB, BC, CA, ABG, BCG, CAG, and ABCG (10 types).
- Different types of fault resistance 0.01 Ω, 0.5 Ω and 2 Ω were used for all the faults simulated.
- Faults were simulated in the network at location F1, F2, F3 and F4 as shown in Figure. These faults are simulated at the mid-point on the distribution line between two adjacent buses.
- Three different DG penetration levels were used for the simulation were 100%, 40%, 10% for simulating every fault with microgrid operating in grid-connected mode. It applies to to frequency controlled VSI generation capacity. In islanded mode, the IIDGs operating with grid-frequency imposed current control mode operate at 100% of its capacity.
- Different fault inception angles used in the simulation such as: 0 degree, 45 degree, 90degree, 180 degree.
- The microgrid was operated in loop and radial configurations.

VI. METHODOLOGY FOR NO FAULT DATA GENERATION

The line current measurements for no fault conditions were made under heavy load and light loading conditions within the microgrid. Three loads within the microgrid were changed for adjusting the total microgrid load. Those three loads were load bank 3, load bank 4 and load bank.The measurements were taken at each bus. During the heavy load condition within the microgrid, the microgrid load is: 2 x [90kw, 45Kvar (inductive load)] + [90 Kw, 40Kvar (capacitive load)]. The description for lighting loading condition is: 2 x [20kw, 5Kvar (inductive load)] + [20 Kw, 5 KVAR (capacitive load)].

Table 6.1 Parameters for Simulating Different Condition for No Fault Cases in Microgrid

Mode of Operation	Topology	Types of Load	DG Penetration Levels	Relay Points	Total no. of cases
Grid Connected	2	capacitive load & inductive load	3	4	48
Islanded	2	capacitive load & inductive load	1	4	16

VII. CONCLUSION

In this project, a microgrid protection scheme has been proposed using intelligent relays. This scheme addresses the possible problems of fault detection arising due to the wide variation in fault current magnitude in grid connected and islanded mode of a microgrid having a high penetration of inverter interfaced distributed generation (IIDG).A good protection should be capable of fulfilling the requirements of reliability, selectivity, speed and cost. The accuracy problem has been addressed by using intelligent relays which are modelled by two types of data mining methods such as DT and RF. The accuracy of fault detection improves to 97% for DT based relay and 99% for the RF based relay as compared to 56% accuracy of the instantaneous over current relay. The improvement in accuracy of the intelligent relay is due to the use of time-frequency information of the current signal used to build the data mining models.

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