Differential Protection for Microgrids with Embedded Generations

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***Abstract*— The permeation of distributed generation (DG) resources (wind turbines, photovoltaic, fuel cells, biomass, small hydroelectric power, etc. ranging from below kW to multi MW sizes) in distribution grids is growing worldwide. The improved permeation of distributed generation in microgrid method introduces quite a lot of technical complications in the setup of the grid such as steady state and transient over and under voltages at point of connection (PCC), protection failures, upsurge in short circuit levels and power quality difficulties. The key encounter in microgrid is the protection coordination. Microgrid is too subjected to the equal safety and stability requirements as every other utility electric power system.**

***Index Terms*— Distributed generation, differential protection, integration of DG.**

I. Introduction

An emerging form of power distribution system which is embedded with a combination of different kinds of power generation sources, like renewable energy sources, combined heat and power (CHP), and distributed energy resources (DER). The advantages of microgrid configuration are low transmission and distribution cost and potentially high efficiency and low environmental impact. Microgrids are designed to operate in one of the two modes which is grid connected or islanded mode. Shorts circuits levels in islanded mode are small compared to those in grid connected mode. Moreover, power flows in microgids are not always unidirectional for these reasons it is difficult to protect microgrids using relaying strategies traditionally used in distribution systems. Most of the existing systems are radial where power flows from substation to the customers in a unidirectional manner. Overcurrent protection is used for such systems because of its simplicity and low cost [1, 4].

One of the main benefits of microgrids is the possibility of improving the reliability and continuity of energy supply by making possible that a part of the network operates autonomously, in an islanded or standalone mode, during a power outage of the main grid [5], [6]. Moreover, microgrids can provide benefits for both utilities and consumers since they can reduce power loss, improve voltage profile and reduce transmission and distribution costs due to their location close to customers [2, 3].

Main challenge for protecting the microgrid arises because power can flow in both directions in each feeder of microgrid. Sources are located in both sides of load due to which power flows in opposite direction from two sources towards the load. Power flow also changes its direction in case of distribution network with embedded generation when local generation exceeds local consumption. The reverse power flow can also cause power quality problems resulting in variation of voltage. The other problem is the reach of impedance relay depends upon the distance between the relay location and fault point, maximum distance means minimum fault current that is detected. When DG is according to defined zone settings and faults occur downstream of the bus DG connected to utility network, impedance measured by relay located in upstream is higher than real fault impedance. This affects grading of relays and causes delayed operation or sometimes relay does not operate at all.

II. DIFFERENTIAL PROTECTION OF MICROGRIDS

Protection is one of the most important challenges for the deployment of microgrids. Microgrids compromise of low voltage distribution systems with small DG sources and controllable loads and are capable of operating either in the grid connected mode or islanded mode. The concept of the microgrid is becoming popular as microgrids are expected to provide environmental and economic benefits to end customers, utilities and society. However, for their effective operation, potential technical challenges related to protection and control need to be addressed. This chapter discusses protection issues and challenges arising when a microgrid is operating in both grid connected and islanded mode operation. The protection functions are considered adequate when the protection relays perform correctly in terms of dependability, security, speed of operation, selectivity and the single failure criterion.

In order to comprehend the theory of differential protection for microgrids with various embedded generations, one must first have a firm understanding of diverse protection schemes for microgrids

A. Adoptive Protection Scheme

The adaptive protection technique was suggested on behalf of the distribution structure with high dissemination when the variations of voltage drip response that would appear in short circuits and overloads, with respect to its scale.

At the beginning load flow and short circuit examination aimed at all kinds of faults must be approved upon. Subsequently the alterations of scheme arrangement owing to the loads or DGs, the load flow and short circuit study once more have to be repeated. This adaptive method is complex as it is not easy to define zones with the fluctuation of loads and DG generation. However protection is independent of DG size and location.

- The power of DG capability on relay setup and synchronisation in a radial distribution system has been studied in [13]. It has been presented that for a downstream fault from the connection point of DG, the relay selectivity remains unaffected and sensitivity rises in line to the rise in fault current. However, there is a concentrated capability for the DG to retain the relay coordination all the time. Alternative method was suggested in [14] in order to discover out the maximum value for the DG capacity. The main problems with regard to a possible implementation of an adaptive protection system may be:
  - The need for previous knowledge of all possible microgrid configurations;
  - The prerequisite of running extensive power flows or short circuit calculations when a topology change is detected;
  - The necessity of communication infrastructure may be high;
  - The need to update or upgrade many protection devices (fuses, etc.) that are currently used in the present power system

B. Voltage Based Protection Scheme

Voltage built protection procedures extensively makes use of voltage measurements to protect microgrids against different kinds of faults. The key approach in this field was the one suggested in [10]. The structure, in which output voltages of DG sources were monitored and then transformed into dc quantities using the d-q reference frame, had the capability to protect microgrids against in-zone and out-of-zone faults. The main challenges in regard to probable employment of voltage built protection strategies are:

- Every voltage drop inside the microgrid might lead to misoperation of protection devices.
- HIFs cannot be acknowledged using above stated approaches.
- Most of these methods are aimed and tested for particular microgrids. In reality, they are strongly reliant on the microgrid structure and on the description of protection zone. Consequently, they may not be appropriate for microgrids with different structures.
- A smaller amount of sensitivity in the grid-connected mode of operation.

C. Over current Protection Scheme

Distributed generators have influences on the protective relays with their contribution currents in the event of faults [17]. Overcurrent relay is the universally used protective relay in distribution systems. For high DG infiltration, it is difficult to synchronize Overcurrent relays without losing the selectivity of the protection system. The following examples are evaluating the problem wisely. Figure 1 shows four bus method with three end generators and directional overcurrent relays. There should be directional overcurrent relays in the opposed ends of R1, R2, and R3.

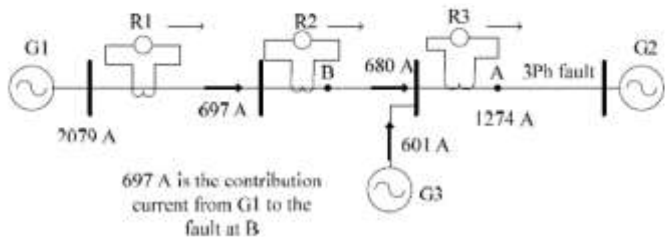

Figure 1: Three DG's system with directional Overcurrent relays.

Additional illustration could be considered by addition of another DG to the last configuration of Figure 1, the short circuit level would change. For that reason a new setting ought to be applied to the protective relays. Figure 2 illustrates the new formation with a new short circuit level

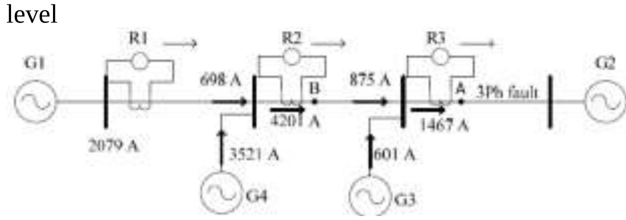

Figure 2: Four DG's system with directional Overcurrent relays.

Check selectivity: For a fault on A, R3 trips on for 0.2 seconds, R2 trips on for 0.6 seconds, and R1 trips on for 0.685. As a result, one can conclude that there is no synchronisation between R2 and R1 and they trip instantaneously in case of a fault at A. It can be concluded that coordinating directional Overcurrent relays on high DG permeation networks may not be usable for many network formations.

D. Distance Protection Scheme

The basic principle of distance protection is based on the continuous measurement of distribution line impedance, whereby the relay responds to the impedance between the relay measuring point and fault location [18]. The advantage of distance relay is that it can operate without the use of communication device.

Distance protection uses zone of operation to discriminate between normal and fault condition. During normal operation the apparent impedance seen by the distance relay is outside the zones of operations, but in case when there is fault on the network the apparent impedance falls within the zone of operation.

Figure 7 illustrates mode of operation of distance relay. The distribution line is protected by two relays that are relay A and relay B on both ends of the line. The distance protection uses zones of operation to protect the line [19]. Each section of the line will protect by a certain percentage of the zone.

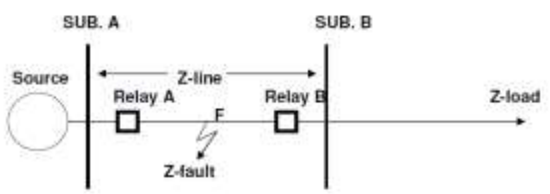

Figure 7: A single line diagram of distance relay

III. PROPOSED PRACTICAL DESIGN OR STRATEGIES

Differential protection, as its name indicates, compares the currents incoming and leaving the protected zone and functions when the difference between these currents surpasses a predetermined magnitude [21].

One of the most extensively used techniques for power system protection is differential protection. It is established on the fact that under all circumstances the sum of all the currents in the protected zone will add up to zero apart from internal faults [22]. Since it only uses electrical current value from the power system, it does not need voltage measurements and, therefore, is less sensitive to power swings, sudden load fluctuations and voltage variations. Differential protection is particularly attractive if both ends of the apparatus are close to each other. Subsequently, it is regularly used to protect transformers, generators, bus bars and motors [23].

Differential protection is said to be the best appropriate system to be used in this project because it takes into consideration all protection encounters, such as bidirectional power flow and reduction of fault current level in islanded operation mode, and it is be able to protect microgrids in both grid-connected and islanded kinds of operation.

Feeder Protection

Differential protection in a line operates by having two sets of current transformer and two differential relay at both ends of the line. The basic principle of differential is that the current into the line must be equal to the outgoing current [25]. However due to the faults that occur on the distribution network the circumstance is not always achieved. During the internal fault condition current from both ends of the line flow towards the fault with different fault current magnitude. Once a differential relay detects the difference in magnitude of the fault current the relay sends a tripping signal to the circuit breaker to protect the line from the fault and both circuit breakers connected at both ends of the line will open. During the condition of external fault the current flowing through the relay is zero that is the fault current flow towards the fault which is outside the protected zone. The current flowing into the line is equal to the current leaving the line, in that condition the relay does not issue a tripping signal to the circuit breaker.

A. Product Development Strategy

The elementary idea of differential relay rest on the two ends dimensions and relates the difference to the threshold value. Differential relays are direct time relays. In instance of a circuit breaker failure tripping, a time delayed signal is send toward the nearby relays on the same bus to force it to trip. If the relay or the communication means malfunctions, all other relays are notified that the differential structures are lost. Relays are using the proportional voltage protection which matches the relative rms voltage at every relay with the rest of the relays.

Many of the differential relay applications are of the current-differential type. This system may possibly be a length of circuit, a winding of a generator, a portion of a bus, etc. A current transformer (CT) is presented in every one connection to the system component. The secondary sides of the CTs are intersected, and the coil of a differential relay is connected through the CT secondary circuit.

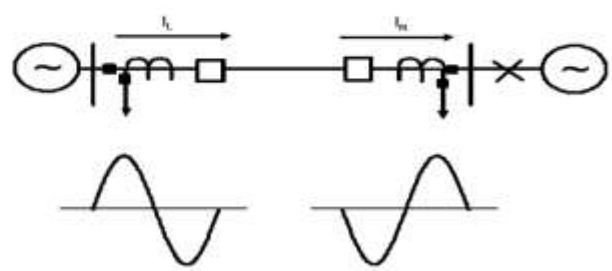

Figure 9: Condition for an external load or fault

For external fault, the current will flow into the line in one terminal and out of the other as shown in figure 12. The currents will be 180 degrees out of phase that is the remote current and the local current with equal magnitude. For external fault the following equation is used

$$\left|\overline{I}_L + \overline{I}_R\right| = 0 \tag{1}$$

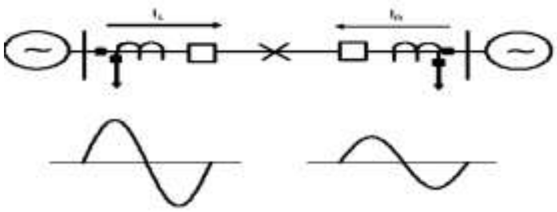

Figure 10: Condition for an internal fault

For internal fault, fault current will flow into the line from both ends, with the polarity of the current transformer as shown in figure 13. Both the remote and local currents will be in phase but due to different source angles from both the local and remote the currents will have different magnitude. To determine the internal fault the following equation is utilized

$$\left|\overline{I}_L + \overline{I}_R\right| \neq 0 \tag{2}$$

B. *Implementation of product/strategy*

Required equipment will be listed in this chapter and also test to be done on the apparatus to check whether they comply with the specification. The testing procedure will also be discussed.

1. Matlab Simulink software
2. Distributed generators x 3
3. 22kv Circuit breaker
4. Current transformer
5. Voltage transformer
6. Lap top or desk computer
7. Relay

Relay burden test: Relay burden test is performed in order check whether the current transformer and voltage transformer comply with the specification.

Relay Inputs: Relay inputs are tested over the specified ranges. Inputs include those for auxiliary voltage, VT, CT, frequency, optically isolated digital inputs and communication circuits.

Rating Tests: The rating tests are performed in order to check whether apparatus are used within their specified ratings and to verify that there are no electrical short circuit that can endanger human life under normal load or fault conditions and also to check if the component complies with the technical specifications.

IV. TESTING PROCEDURE

Model simulation which is differential protection for microgrids will be presented in Matlab Simulink. The model consists of three phase, three sources, 50 HZ, 22kv distribution line with impedance of 0.05+j2.1677. Characteristics of the relay must be considered in order to have correct settings. Different types of fault current will be simulated on different location of the network. Firstly the single phase to ground fault would be simulated on the external zone of the network and the results will be measured on the scope. Secondly the same fault type of fault would be simulated but this time on the internal zone of the network. The simulations will start by connecting two distributed generators and observe the behavior of the network, then connect the third distributed generator and also observe the results. The simulations are done in order to prove that differential protection is not affected by number of distributed generators connected to the network and also to prove that differential protection can protect microgrids from bidirectional flow of currents due to increase penetration of distributed generators.

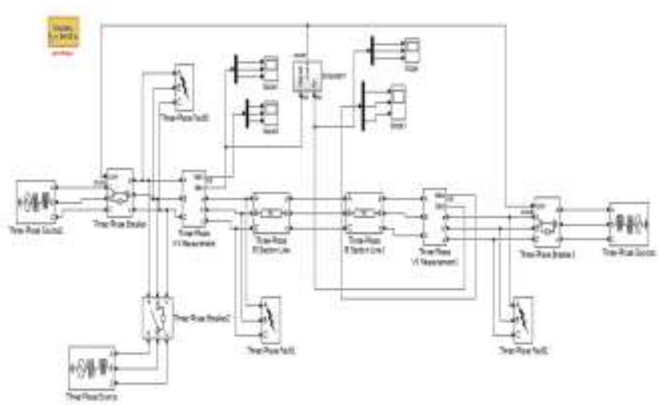

Figure 1**:** Line Differential Protection diagram on Matlab Simulink for Microgrid

In this part, different types of fault condition would be simulated on different locations of the network that is the external faults and internal faults.

Fundamental principle of the differential relay is to compare currents from both ends of the protected object. To simulate this model with different fault types on different location will be measuring the fault currents from the two ends of the network and the results will be shown on different scopes. The results for all the fault type are shown from figure 15 to 30. There are two diagrams for each case that is for current and voltage scenarios.

The faults are simulated on different location of the network that is the external fault and internal fault, also different types of faults are simulated whereby the relay sends the tripping signal to the circuit breaker for internal faults and for external faults relay doesn't send the tripping signal. The relay uses the binary of 1 to trip and 0 not to trip.The Figures 15 to 20 show simulation of external fault on the network whereby fault current and voltage are measured. Three distributed generators will be used to supply electrical energy to the network and different fault type will be simulated on different locations. The simulation proves that differential protection can protect microgrids from bidirectional currents by not tripping for external faults.

A. *Results of Tested Product/Procedure*

Figure 13-14 show results of an external single phase to ground fault on the network, and the results show that the circuit breaker does not trip because the fault is not within the protected zone. Different types of faults were also simulated on different location of the network.

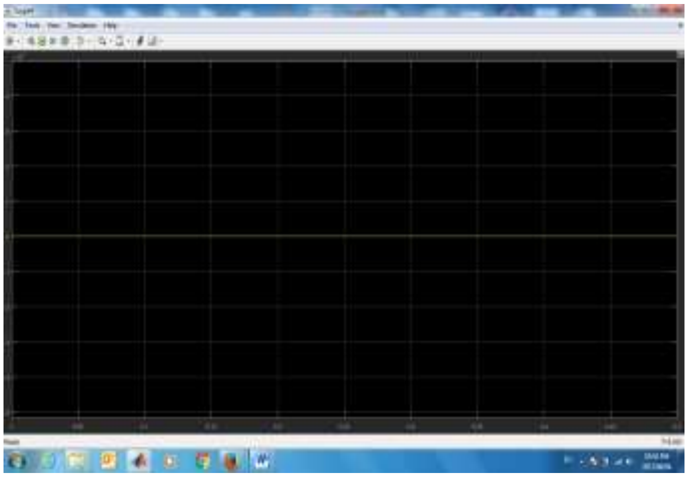

Figure 2**:** Single phase fault: Current diagram

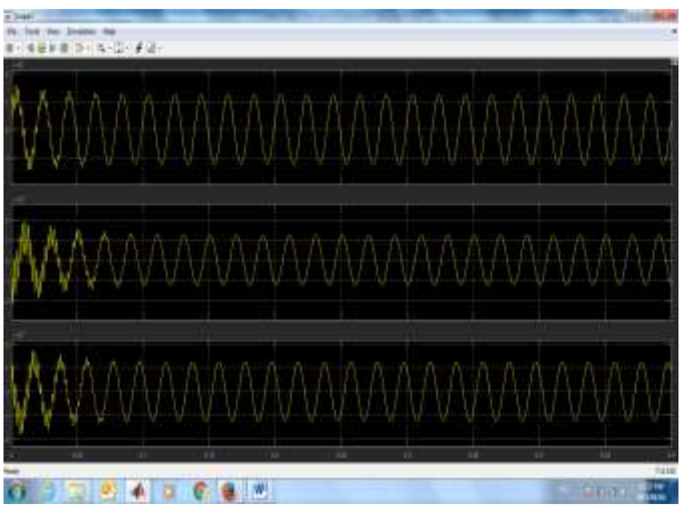

Figure 3: Single phase fault: Voltage diagram

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