ADAPTIVE PROTECTION SCHEMES FOR MICROGRID: A REVIEW

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Abstract: Microgrids have gathered a significant amount of attention within the past decade and becoming an essential asset in the energy industry. The ability to integrate sustainable energy generation methods into the distribution network is one of the main reasons for microgrids popularity. A wide variety of Distributed Generation (DG) including wind and other micro-turbine generation, photovoltaic generation along with energy storage, makes the microgrid viable in both grid-connected and islanded modes while reducing the power losses. There are various technical challenges to be tackled in order to harvest the full potential of microgrids, and protection is one of them. Various solutions were introduced, driven by the development of protection techniques. One of the most promising approaches for microgrid protection is adaptive protection. This paper contains a systematic review on adaptive protection of microgrids, including a wide range of applicability variants, their strengths, and drawbacks. A method is proposed to overcome the drawbacks using intelligent relay model in MATLAB.

Keywords: Microgrid Protection, Adaptive Protection, Protection Schemes, Distributed Generation, Power System Protection.

1. Introduction

Microgrids are small-scale power grids, deployed to supply power to localized load pockets. Microgrids usually employ locally available renewable and low carbon resources and contribute considerably towards reduction of greenhouse gas emissions and global warming. Other reported benefits of microgrids include supplying emergency and premium power to critical and power quality sensitive loads and peak-shaving during peak load hours. Microgrids work in two operating modes, viz., stand-alone (autonomous operation) and grid-connected. In grid-connected operation, the microgrid is connected to the main utility grid at a Point of Common Coupling (PCC) through some isolating device [1][2].

The main objectives of a microgrid protection scheme are firstly to detect any fault within the microgrid in both operating modes; secondly, to detect any fault in the grid and isolate the microgrid from the utility in such events by opening the PCC breaker or switch and thirdly, to synchronize the microgrid generators with the main grid while connecting the microgrid back to the utility after the utility fault is cleared [1-2].

Mode of operation of the microgrid affects the sensitivity and performance of its overcurrent protection. This is because the generation capacity of stand-alone microgrids is much less compared to utility generation and fault current magnitude in a network is dictated by the available generation. Therefore, fault current levels in a microgrid in grid-connected mode drastically reduce after its transition to stand-alone mode. This poses a problem for the overcurrent relays to sense the magnitude of fault current in stand-alone mode with their settings suitable for grid-connected mode leading to possible maloperation and loss of coordination between consecutive relays. One means of tacking this problem is to use adaptive overcurrent relaying where the relay settings would always automatically change to suit the operating mode of the microgrid in order to ensure correct fault-sensing and coordination.

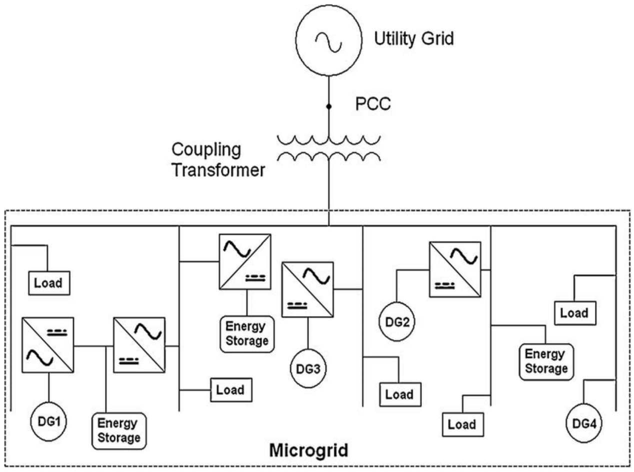

Fig 1. Microgrid Architecture Diagram

With the technology of new emerging energy scenario, the use of environment-friendly and of distributed generation units like gas, solar, wind energy, etc. are being used widely. Microgrid integrates control and load devices, storage devices, generators to a controllable unit. There is a point of common coupling (PCC) as shown in Fig 1 between Microgrid and public grid that avoids the connection problem and satisfies user end's power quality. Above Fig 1 represents the Microgrid architecture diagram. It consists of basic radial feeders that are, when source is present only at one end of the transmission line, which could be a part of distribution system. There is a single point of connection to the useful (utility) grid called the point of common coupling (PCC). Some feeders as in Fig 1 from 1 to 4 have sensitive loads, which require local generation whereas non-sensitive loads do not have local generation. Feeders 1 to 4 have the capability to island from the grid with the help of static switch that can separate all the 4 DG's control the operation using only local voltages and currents measurements. When there is a fault in the system while supplying power, the switch will be opened isolating the sensitive loads from the power grid. Non sensitive loads ride through the event. Generation of electricity is sufficient to meet the load's demand. When Microgrid in grid connected mode, power that comes from the local generation can be supervised to the non-sensitive loads.

This paper presents a problems faced during DG penetration in microgrids with their solutions and comprehensive review of microgrid adaptive protection researches.

2. Problems Due To DG Penetration In Microgrids

2.1 Voltage, Frequency And Power Flow Control

Voltage and frequency control are a common problem occurring due to the imbalance of electricity generation and consumption. Voltage and frequency variation problem arises due to the mismatch between generation and consumption of both active and reactive power values. Especially in the islanded mode, DGs must participate in active frequency controlling. Inverter interfaced micro sources do not occupy the frequency controlling ability where they are designed to output a constant power when the energy source is available [3]. This lack of inertia can cause fast frequency variations, and even small frequency change can snowball into a more significant problem. Droop control is a popular solution for frequency and voltage control (see Figure 2) but may not be the ideal solution in islanded microgrids, which will require further modifications [4]. Sophisticated power flow analysis methods like Newton trust region method [5] or communication-based approaches such as Multi-Agent Systems (MAS) [6] can be used to overcome power flow problems in islanded mode.

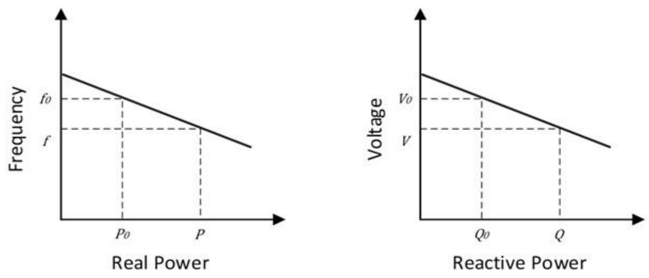

Fig 2. Droop Characteristics Of DGs

2.2 Islanding And Topology Changes

Two main sets of control methods can be identified as for grid-connected and islanded modes in microgrid operation. In fact, two types of set values and algorithms are vital for all microgrid control and protection tasks, while the detection of islanding should also be integrated into the microgrid control system. However, topological changes such as connection/disconnection of DG or loads, have made microgrid operation more complicated. These topological changes can also be the result of energy storage status and network reconfiguration due to faults or maintenance. Extensive communication infrastructure combined with mathematical algorithms is usually required to cope with these reconfigurations [7].

2.3 Stability

Power system stability, as identified by CIGRE and IEEE Task Forces, can be categorized into three areas [8]. Rotor angle stability, voltage stability, and frequency stability are these significant classes of system stability. But unlike traditional power systems, microgrids have less synchronous generation, and more Inverter interfaced Generation. The existence of different operating modes also contributes to the stability issues that arise in microgrids. Therefore, microgrid stability problems are mainly classified as Grid-connected issues and Islanded issues. In each of these modes, the stability issues are further segmented into two areas, namely small disturbance stability and transient stability [9]. Microgrid small-signal modeling and comprehensive control methods are required to overcome small disturbance stability issues. Unlike the traditional power systems, microgrids have less inertia prominently due to the lack of rotating mass where the majority of microgrid DGs are PE (POWER ELECTRONICS) interfaced. Existence of PE interfaced DG mainly creates problems in maintaining system frequency during transient periods. Since most of the DGs in microgrids are renewable, power oscillations could occur frequently and should be balanced out to create stability. Intermittency of these Renewable DGs and the variations in loads can create significant power imbalances and therefore energy storage methods are vital in islanded microgrid operation.

2.4 Harmonics

Excessive use of power electronic inverters and converters, which is common in modern microgrids, can contribute to the increase of harmonic currents. The concepts of DC microgrids and AC/DC hybrid networks further increases the harmonic losses. As per the IEC 61000-3 standards, each source should contribute below the permissible limit of the Voltage Total Harmonic Distortion [10]. Otherwise harmonic compensation methods such as filters should be used. To further mitigate the harmonic current injection by microgrid inverters, harmonic compensation algorithms can be implemented [11].

2.5 Communication

Modern microgrids can have centralized, decentralized, or hierarchical network topologies where all three requires a robust communication network. Different types of microgrid messages occupy this communication channel, including protection information, control information, and monitoring information. The communication architecture should allow Real-time operation with minimum latency and enough bandwidth, reliability with the capability to handle many nodes or agents and have higher security with less vulnerability to cyber-attacks [12].

2.6 Protection

Unlike the conventional power systems which have a unidirectional power flow, DG integrated microgrids have bi-directional power flow characteristics. Power flow variation creates a whole new problem series in relation to the fault current path concerning the location of the fault. Reconfiguration of the network topology and the states of islanded and grid-connected, further increases the complexity of the protection problem [13]. Fault protection methods must incorporate more than one approach to coping with the issues arising in microgrid networks protection problems are more systematically discussed in the next section.

2.7 Economic And Environmental Aspects

Microgrids were initially popularized mainly due to their environmental and economic benefits with the addition of renewables. Thus, there is a pressure to live up to its reputation of being economical while creating them technologically feasible. Therefore, when presenting solutions to technical problems, they should also be acceptable in an environmental and commercial aspect [14].

3. Problems Regarding Protection

3.1 Blinding Of Protection

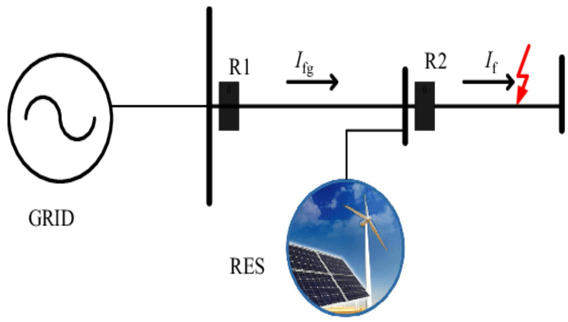

Fig 3. Blinding Of Protection

In case of a large penetration of the RES, because of their intermittent nature, fault levels on the network will change with respect to the level of RES penetration.

As shown in Fig 3, the fault is supplied from the grid as well as from the RES. For the fault near relay R2, the fault current seen by relay R2 will increase and it will decrease for relay R1 depending on the RES rating and RES impedance. The change in fault level seen by the relays will result in the under-reach operation of the relays. the fault current sensed by relay R1 will be lesser than without a RES connection. This reduction in fault current will result in no operation by relay R1 and is known as a blinding operation of the relay [15].

3.2 False Tripping And Sympathetic Tripping

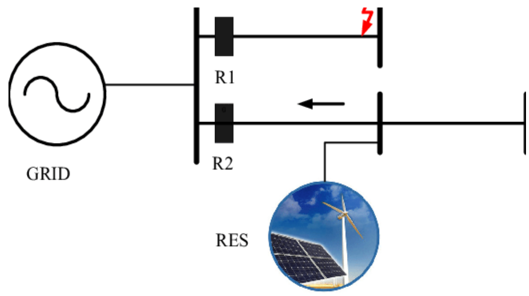

Fig 4. False Tripping

Integration of large scale RESs in distribution systems results in the bidirectional flow of the fault current on most of the feeders/lines. A non-directional over current relay may fail to provide the desired protection for these networks during infeed from the RES. As shown in Fig 4, for a fault, the relay R2 may trip in a reverse direction because of the forward operation of relay R1. These types of trippings are known as false trippings. In big interconnected distribution systems, a few relays may experience fault levels greater than their pickup value and may trip before the desired primary/backup relays which results in isolation of a larger portion of the network. These types of false trippings are known as sympathetic trippings [15].

3.3 Bidirectional Power Flows

Conventional distribution systems are radial with unidirectional power flow. Flow direction is from single or multiple sources at one end to the load at the opposite end. With the DG penetration of microgrids, this one-directional flow could change its direction according to the status of local generation and local consumption [16]. The reverse power flow in the system may cause change in the magnitude and direction of fault current. This makes conventional protection coordination invalid, and the necessity for a directional protection element arises.

3.4 Loss Of Coordination

The false/sympathetic/blinding operation of the relays from downstream to upstream feeders leads to the sequentially false operation of the relays. This type of false tripping of the relay in a cascade manner is known as loss of coordination [15].

3.5 Under-Reach And Over-Reach

Under-Reach, also known as blinding of protection, occurs from the grid fault current reduction due to the addition of DGs. As the fault current contribution decreases with the addition of DGs according to Figure 5[a], the grid fault current may not be enough to trip the breaker associated with relay R3.

Overreach occurs with a fault occurring downstream of the DG connected bus, during the grid-connected operation. As per the scenario in Figure 5[b], Relay R2 will operate for the fault beyond its zone due to the increased fault current when compared with a non-DG scenario.

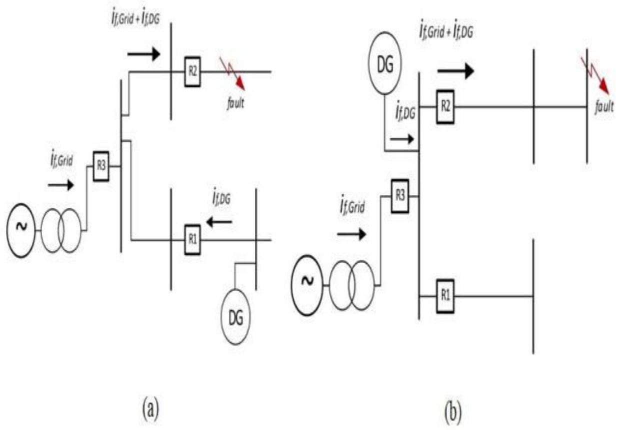

Fig 5. (a) The underreach of relay R3, (b) The overreach of relay R2

4. Existing Techniques

4.1 Differential Protection

Differential protection is mainly used in the islanded mode, where the fault current is lower and difficult to detect using conventional methods. The differential method cannot be used as a complete protection solution. It is more suited to detect downstream earth faults while some other techniques should be adopted to identify further faults like upstream ground faults, Line-to-Line (L-L) faults, and symmetrical faults [17]. This method also employs communication links for the differential operation.

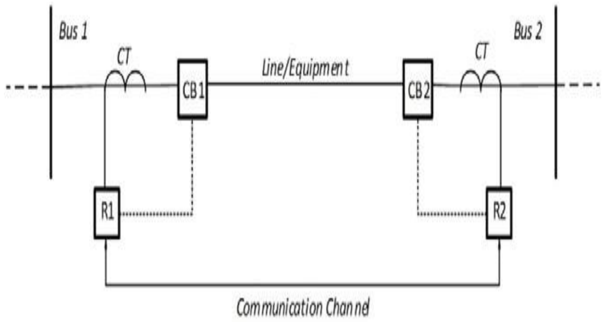

Fig 1: Differential Protection Scheme

4.2 Distance Protection

Distance protection is usually applied for the protection of transmission lines and it measures the voltage and current at the relay point to calculate the impedance and utilizes to detect faults in its defined protection zone. Communication between relays is not required in the distance protection which is a main advantage of the method. This method may have some inaccuracies when considering the current harmonics and transients. The resistance of the fault and shorter distribution lines could create errors in the measured admittance.

4.3 Use Of External Devices For Protection Improvement

In situations when fault current levels are drastically different between the grid-connected and the islanded operation (typically with inverter-interfaced DG), the design of an adequate protection system, which performs properly in both situations, can be a real challenge. In this regard, there is a possibility of applying a different approach which actively modifies the fault current level when the microgrid changes from grid-connected to islanded operation and vice versa, by means of certain externally installed devices. These devices can either increase or decrease the fault level. The main options are as follows:

1. To reduce the aggregated contribution of many DG sources, which can alter the fault current level enough to exceed the design limit of various equipment components, as well as to guarantee an adequate coordination despite the feeding effect of DG to fault current, fault current limiters (FCL) can be used. This effect is particularly evident with synchronous machine-based DG.
2. To equalize the fault current level in both grids connected and islanded operation, due to the reduced fault contribution by inverter-interfaced DG sources. This can be achieved in two different ways:
3. By incorporating energy storage devices (flywheels, batteries, etc.) into the microgrid in order to increase the fault current to a desired level, allowing overcurrent protection to operate in a traditional way.
4. By installing certain devices between the main grid and the microgrid, to alleviate the contribution of fault current from the utility grid.

4.4 Adaptive Protection

Adaptive protection, as it says in the name, is an online protection system that changes the fault response according to the system's state. There are numerous techniques of applying the adaptive protection to a microgrid system, but the simplest and the classic approach is to have two sets of relay-set-values each for islanded and grid-connected modes. Relay settings would be updated with the change of microgrid status and usually includes the shifting of relay characteristic curve to cope with the change of fault current [18].

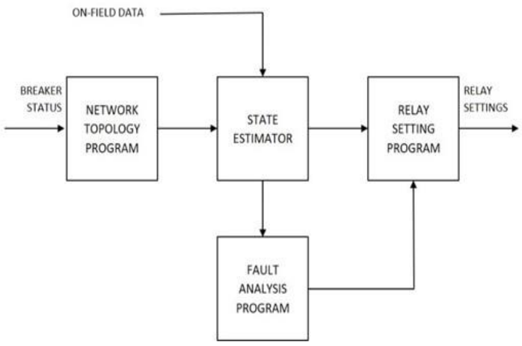

Fig 6: Simple Adaptive Protection Scheme.

Protection infrastructures such as microprocessor-based relays, communication channels and software programs for appropriate control.

5. Discussion

The primary purpose of this study was to examine various protection schemes available for the microgrid protection. Several protection schemes discussed above need further development to make the system more reliable. Microgrids operate in two modes – stand-alone and grid-connected. This poses a problem in microgrid protection settings in a sense that the fault current magnitude in a microgrid reduces drastically during its transition from grid-connected to stand-alone mode of operation. Sometimes several important characteristics of relays are not fulfilled during drastic conditions in conventional protection system. It is seen that Apart from adaptive relaying scheme there is no such system or technique to know the mode of operation for microgrid. To overcome these limitations adaptive relaying scheme can be developed using microprocessor based digital relays.

6. Conclusion

Most recent developments have been focused on relay function and their capability of directly controlling the circuit breakers for accurate fault clearance.

There are several existing techniques suggested in previous work each having its own merits and demerits. Due to the dynamic and uncertain nature of microgrid network, an adaptive solution is an ideal scheme. Adaptive protection is more favored to be combined with, in order to create a complete protection solution.

This paper has reviewed the development of adaptive protection schemes throughout the earlier decade, followed by introduction of microgrid protection faults or problems and their various solutions.

7. Proposed Work

Adaptive relaying scheme for the protection of microgrid using intelligent relay model is proposed. The main objective of these scheme is to detect the mode of operation of the microgrid and operate according to the prevailing condition of the power system.

In the scheme, it is considered that the protection elements required are the same as the ones used in a conventional grid, viz., transducer, circuit breaker and relays. The only specificity is that the relays must be microprocessor based digital relays with adaptive capabilities. The protection method used is overcurrent relaying. This method uses the overall impedance of the system to calculate the current through it, if the impedance is too low and the current too high, in other words a fault is present, it will trigger the circuit breaker to open and isolate the fault. In the two modes of operation the overall impedance of the power system consisting of the microgrid and utility grid will vary.

Therefore, it is important that the relays are communicated with and informed of what mode of operation the microgrid is in, otherwise it may trip unnecessarily. The relays generate a time delay and trip the circuit breaker according to the current input, a fixed Time Multiplier setting, Pick-up current setting, IEC Normal Inverse IDMT characteristic and the Microgrid mode of operation. The relays in the power network will be coordinated in such a manner that the breaker closest to the fault will open first. The circuit breakers further away from the fault will open later and only if necessary.By using this method, design of a test model and the simulation of the same will be done using MATLAB.

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