Adaptive Protection Schemes for the Microgrid in a Smart Grid Scenario: Technical Challenges

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***Abstract* — Microgrids are gaining attention as an important part of the smart grid, due to their numerous benefits and their ability to operate both in the island mode as well as in the grid connected mode. However, a protection scheme which suits to a microgrid both in the island mode and the grid connected mode of operation is a challenge. The conventional overcurrent protection scheme faces selectivity and sensitivity issues during the grid faults and the microgrid faults, since the fault current level is different in both the cases for the same relay. Various approaches have been implemented in the past to deal with this problem yet the most promising ones are the adaptive protection techniques. The feasibility, reliability and cost benefit issues are some major concerns which are associated with the implementation of the adaptive microgrid protection schemes. This paper presents a critical review of the existing adaptive protection schemes, the technical challenges, if any, and the recent advancement concerning to their suitability to operate in a smart grid scenario.**

***Index Terms*—Adaptive protection techniques; distribution network protection; distributed generation (DG); microgrid protection; smart grid.**

I. Introduction

Renewable energy sources (RES) based microgrid and its integration into the existing grid is the demand of today's electric power system (EPS) [1]. This helps in reducing the dependability on conventional generation, thus reducing the emission of greenhouse gases. Local energy availability, economic electricity, good service quality and increased reliability are certain benefits to the society which imposes the integration of the microgrid to the existing distribution networks [2, 3]. The major technical issue associated with the integration of microgrid is the suitable design of protection system for the microgrid. A conventional protection system which is designed for passive distribution networks is no more suitable for the microgrid embedded active distribution networks [4]. The power flow is now bidirectional and the conventional fault current grading for the overcurrent (OC) relays do not suits to the present scenario. The protection must respond to the grid faults and the microgrid faults both; however the fault current level is different in both the cases for the same relay [5]. During grid faults the protection system should island the microgrid quickly to protect the microgrid loads. However during micro grid faults the protection system is needed to isolate the smallest faulted section of the microgrid. The fault current for the operation of any particular relay depends on the number of DG present in the microgrid, mode of operation and the fault type. The fault current grading for an OC relay in different topological scenarios may be different and relay must adapt and update its settings according to the particular configuration of the network [6]. This needs a fast and a reliable communication scheme, which tells about the actual topological situation of the network so that the online selection of the pick current of an OC relay can be done.

The paper is organized in six sections. Section II addresses the protection issues in a microgrid. Section III reviews the existing adaptive protection techniques and the technical challenges associated with them, if any. Section IV discusses the recent advancement concerning to the microgrid protection for their suitability to operate in a smart grid scenario. Section V concludes the paper.

II. Protection Issues In A MicroGrid

The microgrid integration to existing grid raises major protection issues for the classical protection techniques and demands an adaptive, smart and an upgraded protection system [3-5]. The major technical challenges to overcome while designing the protection system for a microgrid to be successfully operated in a smart grid scenario are as follows:

A. *Bidirectional Power Flow*

Integration of microgrid to the distribution network makes the distribution network active. Besides feeding the local load, the microgrid is also expected to export power to the main grid in case of excess generation thus making the power flow in the reverse direction. The bi-directional power flow affects the amplitude and direction of the fault current, thereby affecting the protection coordination of the protective relays [4].

B. *Frequent Change in Microgrid Configuration*

The short circuit fault current capacity of the system may get affected by any change in the microgrid configuration either due to the integration or the disconnection of DGs in the existing grid. The frequent change in the short circuit fault current level makes the OC relay grading more complicated. The relay upgraded with an adaptive feature may solve this problem. Such relay modifies its tripping characteristics online, immediately a change in the network configuration is reported by the data acquisition system (DAS) [6].

C. *Reduction in Short Circuit Fault Current Level*

Sharing of the fault current by the main grid and the microgrid reduces the fault current for any particular OC relay. Moreover, the power electronic converter based DG limits the short circuit fault current level especially in the island mode of operation, as they are equipped with current limiting devices that prevents the high overload current [4, 7]. Installation of a flywheel or a super capacitor with the PE converter based sources in the LV Busbar increases the short circuit fault current and can address this issue to some extent [5]. This requires a heavy investment on installation, maintenance and operation of such huge capacity energy storage systems.

D. *Selectivity and Sensitivity of an Overcurrent Relay*

The protection system must be able to distinguish between the main grid and the microgrid faults [8, 9]. During the main grid faults, the microgrid is needed to be islanded to protect the microgrid, whereas during the microgrid faults the protection system should isolate only the smallest faulted section. Thus the protection system should be able to operate selectively during various faults to disconnect the faulted section. The sensitivity of the relays is required to be adjusted such that the high redundancy can be achieved without affecting the selectivity of the protection system [5, 10, 11].

E. *Fast and Reliable Communication in case of Adaptive Protection System*

This is the major issue related to the microgrid protection system design in a smart grid scenario. The prior knowledge of every state of the grid, the online monitoring and calculation of the short circuit fault current level for every small change in grid configuration is needed for the smooth operation of any adaptive protection system. This requires application of a fast, reliable and a robust communication system with a backup, so that the online relay setting can be done automatically. The addition of this adaptive feature in the protection system is a complex and an expensive issue [5, 12].

III. Existing Adaptive Protection Schemes and The Associated Technical Challenges

Initially the penetration of DGs in the distribution network was low and the operation of a DG was ceased during the faults [7]. But this solution is not advisable during the high penetration of DGs because the interruption of a significant amount of power is not suitable from the utility owner and the consumer point of view [3, 5]. Also the microgrid is required to follow the grid codes strictly, which demand the operation of the microgrid to be continued even during the faults. Since most of the faults in the EPS are temporary and lasts only for few minute, the microgrid is expected to be equipped with fault ride through capability. To overcome these issues the modern power electronic converter controls are designed to provide the reactive power support during the faults, which can reduce the severity of faults. The protection system is required to be upgraded with adaptive features and newer multifunctional relay design. The multifunctional adaptive relay has the ability to change its settings online, whenever a change in the network configuration is noticed and can operate quickly to protect the system against the faults [13]. This requires the support of a reliable communication and fast data acquisition system between the generators, the protective devices and loads etc [5]. The data processing unit calculates the new value of the settings and sends a control signal immediately to modify the relay settings. Many adaptive protection schemes were suggested in the literature to overcome the microgrid protection issues in a smart grid scenario. But the existing adaptive protection schemes are condition specific and innovated as per the developments happened in the grid configuration from time to time [9]. But none of the protection scheme provides a complete solution to the coordination problems of the relays. A survey of existing key adaptive protection schemes and their associated technical challenges is presented in this section.

In [5], an adaptive protection scheme is suggested which modifies and updates its relay settings by observing the change in the microgrid configuration. The proposed adaptive microgrid protection system uses digital relaying along with the latest communication infrastructure. The technique is further extended by a directional interlock scheme for fast fault detection and selective isolation of PE interface based microgrid. The technical challenges are as follows:

- The practical implementation of this scheme insists on replacing all the electromechanical and the solid state relays or fuses by the directional numerical overcurrent relays. These relays have the flexibility and capability of changing the relay tripping characteristic settings.
- Require an advanced communication system to work efficiently with the fast instructions and settings dictated by the central computer unit.
- The cost-benefits analysis is essential before implementing and investing a substantial cost on this scheme.

In [6], an adaptive protection is implemented with the help of an extensive communication system which keeps on updating the data and supervises the present configuration of microgrid by means of a central protection unit (CPU). The new tripping characteristics of relays are calculated for every interruption call for connection/disconnection of DG is reported by the controller. The relays and DGs in the microgrid are required to be connected to CPU through a communication system. For every interruption call received, the CPU updates the relay tripping characteristics.

- Every DG and relay needs to be connected to the CPU through a communication system thus requiring installation of an extensive communication infrastructure.
- The CPU must be equipped with a quick data acquisition system and fast processor to calculate the new tripping characteristics every time an interruption call is received.

An automatic instantaneous overcurrent protection algorithm is suggested in [10] which calculates the system's and the microgrid's impedance by utilizing the voltage and current fault component in a real time manner. Thus by observing and comparing the impedances of the grid and the microgrid, the relay operating characteristics are updated. The technical challenges are:

- The method is valid within 2 cycles of the fault occurrence.
- The method is suitable for inverter interfaced distributed generator (IIDG) based microgrid only.

User defined characteristic based microprocessor reclosers are implemented in [12], which minimizes the coordination problems between the reclosers and the fuse. A recloser in a smart grid is expected to be adaptive in nature which suggest a variety of operating curve-choices, provide liberty to the user to define its own operating curve and allows user to use various operating curves as per the need. The implemented microprocessor based relays are multifunctional, flexible and adaptive in nature. The technical challenges are:

- Flexibility to the users to select and develop their own curves increases the complexity of the system.
- The automation and optimization of relays enable a single protective device to perform multiple functions thus protection is sensitive to common mode failures.

In [14], an adaptive protection scheme, which is independent of system parameters, is developed for the network with high penetration of DG. The high penetration of DG affects the coordination of the fuses, reclosers and the relays since the distribution system loses its radial nature. A centralized computer system stores the grid data from DAS, processes it, generates a command signal and communicate with the respective device in the system. The modern circuit breakers and reclosers are equipped with the communication features and online monitoring is done with the help of a central computer control system. The fault detection is done by calculating the Thevenin's equivalent impedance. The network can be simply considered as Thevenin's network where each source can be represented by a voltage source in series with a Thevenin's impedance. The fault contribution from all sources is known online and for a particular type of fault on the adjoining bus of any source, the change in the Thevenin's impedance of that source is utilized. Thus the relay detects a fault, its type, along with the faulted section and trips the appropriate circuit breakers. The technical issue is:

- The short circuit analysis is done by considering zero fault resistance value, which can lead to a false result during a fault with resistance.

In [15], an approach to protect an inverter dominated microgrid is implemented which changes its time current characteristics for short-circuits and overloads by observing the difference in voltage drops during these two events respectively. A combination of voltage based fault detection method and an adaptive protection scheme is suggested to sense the lower current threshold setting by voltage controlled overcurrent devices. The technical issue is:

- The design of protection device and defining its rating with respect to the inverter's power electronics device current limitation and system earthing is a major concern in context of the suggested scheme.

An adaptive network overcurrent protection system is implemented in [16]. The system consists of a real time conventional protection block and a non-real time adaptive protection block. The real-time block monitors the actual grid data and trips the respective circuit breaker, in case if required. The job of adaptive non-real-time block is to use prediction data to decide the selectivity of tripping characteristics of the relays. For each new grid configuration, the decentralized energy management system (DEMS) predicts the relay's new tripping characteristics and the relay updates its new tripping characteristics on successful adaptation. If the adaptation is not possible within the set up boundary conditions, the operation predicted by the DEMS is denied. The technical challenges are as follows:

- Fuses are required to be replaced by the multifunctional microprocessor-based relays which must have the directional sensitivity.
- A communication system which has the capability of transferring the high speed data to long distances.
- Implementation of DEMS for calculating short circuit fault current for all the grid configurations and developing the tripping characteristics for the adaptive relays.
- Cost-benefits analysis.

In [17], an adaptive protection scheme based on zero-sequence component of the current is proposed for LV microgrid which suits to both in the grid connected and the island mode of operation. The scheme is divided into three steps; microgrid operation mode detection, fault detection and protection coordination. The method distinguishes the microgrid operation mode by comparing the angle of zero sequence impedance. The fault detection during grid connected mode is done by overcurrent protection whereas during island mode of operation, dq0 voltage detection method [18] is employed. Since the zero sequence network remains same irrespective of the mode of operation, the discrimination of protection zone is done by utilizing the zero sequence component of the current. The advantage of this scheme is that it does not require communication system. The technical challenges are as follows:

- Relay sensitivity issues i.e. defining the correct threshold for zero sequence current based relay.
- The operational speed issues i.e. speed may be slow as compared to communication based schemes.
- The method is yet to be validated by software/hardware implementation, which is not carried out in the paper.

However, in [19], the overcurrent relay tripping characteristic settings for the grid connected and the island mode of operation is calculated offline and saved in the relays. Whenever the islanding of microgrid happens, the relay settings are automatically shifted to that group of relay settings which is suitable for standalone mode of operation of the microgrid. This approach helps in detecting the fault with much small short circuit fault current levels by the overcurrent relays in a microgrid without involving much complexity. The technical challenges are:

- Requires a fast detection of the islanding of a microgrid. There are many fast islanding detection methods, yet when it comes to perfectly matched load condition the options are very limited.
- Communication between the numerical relays and circuit breakers, to update its setting according to the status of various circuit breakers in the system.

IV. Recent Advancement In the Microgrid Protection Schmes

Smart grid is generally referred to an electric power system equipped with smart technologies such as smart energy management system, smart metering, smart protection and smart communication system. Integration of LV microgrid into the smart grid and its protection are certain issues without solving which the realization of the future smart grid can't be expected [20]. Integration of local generation at the distribution level, enhances the grid efficiency thus improves the availability of energy to the consumers. As far as protection is concerned the smart grid protection system architecture must embed smart schemes into the modern digital substations along with de-risking and self contained modules [21]. The smart systems in a smart grid help in achieving the automation and optimization of various tasks and operations.

Many authors recommended the implementation of the multifunctional microprocessor relay that can adapt to the new tripping characteristics, whenever necessary. Smart grid communication technologies make this task possible for the microprocessor based relays. This involves investment of huge revenue on the installation of an advance communication infrastructure, which is complex and not a cost effective method. Although some of the authors recommend WSN based communication schemes, which is cost effective being a wireless technology [22]. The WSN communication system enables the fast transfer of data from the various machines and the devices to the computer control. The computer control intelligently interacts with the entire protective devices and protects the system against the faults. The recent advancement in the field of adaptive protection system for the microgrid and the smart grid can be categorized into two fields as follows:

A. Relay Technology

The conventional electromechanical and solid state relays do not support the adaptive protection scheme since they do not have multiple settings features nor they are able to provide protection intelligently in the real time scenario [5-6] [12]. On the other hand, the recent microprocessor/numerical relays are multifunctional [12] i.e. they have various features like multiple setting options, algorithm processing unit, ability to interact with other devices, flexible logic schemes and ability to adapt to the real time situations [23]. These relays are based on artificial intelligence techniques that make use of neural, fuzzy techniques for optimization and making the relay adaptive in nature. The adaptive protection system consists of a smart computer control unit that monitors the grid parameter, a smart fault diagnostic system to detect the fault, fault type, the faulted zone and a smart relaying system which protect the system against the fault [24]. The protection system adapts to the changing conditions in the grid making it to be self-monitoring and self-healing system.

B. Communication Infrastructure

The communication in the traditional power system automation is done through wired system. Since the installation of wired communication system is an expensive issue, it is not widely implemented looking the huge size of power system [22]. A wireless monitoring system is cost effective and is a suitable choice for the modern smart grid operation and management system [26], [28]. The recent advancement in the field of wireless sensor networks (WSN) suggests it to be a suitable choice for EPS/smart grid [22] [25 - 29]. The sensor nodes are developed at the important places of the smart grid, which transport the data to the computer control. Thus any change in the grid configuration is immediately reported to the computer control which initiates a fast action to take care of the event in a timely manner.

V. Conclusions

This paper reviewed many key papers in the field of adaptive protection techniques for the microgrid. It was observed that the adaptive protection schemes for the microgrid have not been thoroughly researched and many authors either presented the idea only or in some cases, only the specific implementation is done. A complete solution is yet to be developed and this is the reason the schemes are not widely accepted in the power sector industry. The main observations and technical challenges are as follows:

- The adaptive protection system for a microgrid in a smart grid scenario is expected to be a smart self-monitoring and smart self-healing system. Thus, suggests a complex design for the adaptive protection system and involves the use of various intelligent technologies.
- The modern smart relays must be equipped with software and hardware units in order to enable the use of various intelligent techniques that makes the relays multifunctional.
- These adaptive relays have short life cycles because of fast changing software technology and the market will be flooded with newer relay designs. Thus, always there will be a demand for capital investments on the installation of the newer relays.
- The implementation of intelligent technologies in adaptive protection schemes makes the complex power system sophisticated and more complex.
- The feasibility and realization of recently designed adaptive protection schemes depends upon the effective

and efficient implementation of the smart relaying system along with fast and reliable communication links.

- Due to huge investment in implementing the wired communication system, wireless sensor networks are recommended. But the implementation of a cost effective, reliable, noiseless and robust WSN based communication system in a complex smart grid is a great challenge.

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