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AC Micro Grid Protection –A Review

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Abstract *– Micro grid is a convenient, reliable, and eco-friendly approach for the integration of Distributed Generation (DG) sources into the utility power systems. To date, AC micro grids have been the most common architecture). In this paper, main challenges and available approaches for the protection of AC micro grids are discussed. After description, analysis and classification of the existing schemes, some research directions including coordination between AC and DC protective devices as well as development of combined control and protection schemes for the realization of future hybrid AC/DC micro grids are also discussed.*

Keywords*: AC micro grids, DC micro grids, Hybrid AC/DC micro grids, Protection challenges,*

1. Introduction

Most recently, there have been growing concerns associated with gradual depletion of fossil fuel resources, environmental pollution and global warming. These challenges have led to a new type of generation at users' site by applying small DG sources [1, 2]. The DG sources which enhance the reliability and power quality of the network can either be non-renewable (such as fuel cells,gas turbines, micro turbines, reciprocating engines, etc.) or renewable sources (such as wind turbines, photovoltaic systems, small hydro power, etc.) [3].

The integration of distributed generators has created the concept of micro grid which is defined as a collection ofDG sources, loads and ESSs that cooperate with each other to act as a single-controllable entity with respect to the grid[4]. The total generation capacity of DG sources installedin a micro grid can be a few hundred kilowatts to a few megawatts. Under normal conditions, micro grid is connectedto the main grid (grid-connected mode) and imports orexports power from or to the main grid. Once a fault occurred at the main grid, it is disconnected via a Static Switch (SS) at the Point of Common Coupling (PCC) and is transferred to the islanded mode. After the fault clearance, the micro grid is reconnected to the main grid[5, 6].

Micro grids should have two significant features: peer-to-peer and plug-and-play. The former means that the operationof micro grid is not influenced by the availability of a specific component such as a master controller or a central storage system. The latter enables DG sources to be installedat any location in the micro grid without restructuring of protection scheme. This capability reduces the possible engineering errors and facilitates the installation of newDG sources in the micro grid [7].

Notwithstanding many benefits provided by micro grids, there are some technical challenges which need to be resolved by power system researchers and engineers. One field which requires more attention is the protection. The significant challenge associated with the protection of micro grid is that the magnitude of short circuit currents in islanded mode of operation is too low [8]. The reason is that the power electronic interfaces required for the connection of DG sources to the micro grid are designed to limit their output current to protect their semiconductor switches [9]. Hence, fault detection strategies for the islanded operating mode should be based on low shortcircuit currents. In fact, a desirable micro grid protection scheme should not only possess the general features suchas sensitivity, selectivity, speed of response and security level, but also ponder the number of installed DG sources and the fault current contribution of each of them in the islanded operating mode [10, 11].

In recent years, many studies have been conducted to design and model effective protection strategies for different structures of micro grids. In this paper, the pivotal challenges in protection of AC and DC micro grids are discussed, and the existing methodologies against thesechallenges are introduced and classified.

The remainder of this paper is as follows: Sections II and III discuss the main protection challenges and approaches in AC and DC micro grids, respectively. In Section IV, the conclusion is reported and some research directions for protection of future hybrid AC/DC micro- grids are suggested.

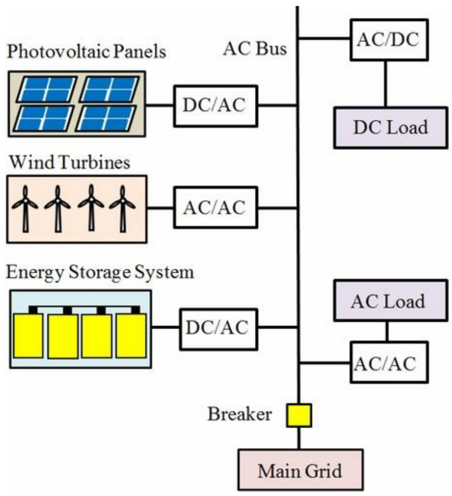

Fig. 1. Structure of a typical AC micro grid

2. Protection Challenges and Approaches in AC Microgrids

To date, AC system has been the most popular architecture which is used for the majority of micro grid research projects. Since the design and modeling of AC systems are much simpler than DC ones, a large number of micro grids around the world have been developed based onthis technology [12]. The structure of a typical AC micro gridis shown in Fig. 1. As can be seen from the figure, differenttypes of DG sources, ESSs and loads can be connected to the micro grid AC bus, either directly or indirectly by means of converters [13].

2.1 Protection challenges in AC micro grids

Most conventional distribution systems operate radially, where power flows unidirectional from large power plants to the customers. In such systems, since the magnitude of short circuit current is proportional to thefault location, the protection is done by overcurrent-based protective devices [14]. Also, the time-graded coordination between them enables upstream devices to operate as backup for downstream ones [15]. In recent years, the emergence of micro grids has changed the structure of distribution systems from passive networks into active ones.This change disturbs the operation of the overcurrent-based strategies such that they would no longer have the ability to protect new structures [16, 17].

As mentioned earlier, the fault current contribution of inverter-based DG sources in a micro grid is limited (only2 to 3 times the maximum load current) due to the low thermal capability of their power electronic devices. Therefore, the protective devices of a micro grid containing inverter-based DG sources would operate very slowly or may not be triggered at all in case of a fault event during islanded mode. In addition, the considerable difference between the magnitudes of short circuit current in grid-connected and islanded modes makes single-setting traditional overcurrent relays unable to protect dual-mode operating micro grids [18, 19]. Therefore, the protection of AC micro grids including inverter-based DG sources is not possible using traditional overcurrent protective devices and some new techniques should be devised.

2.2 Protection approaches for AC micro grids

As discussed earlier, the traditional overcurrent-based strategies have not the ability to protect AC micro grids and sub grids due to the drastic difference between magnitude of fault currents in grid-connected and islanded modes. In order to overcome the challenge, a number of strategies have recently been proposed in the scientific literature. In the following subsections, apart from introducing and categorizing the most relevant approaches proposed to date,the merits and demerits of each category are discussed.

2.2.1 Adaptive protection

According to [20], Adaptive protection is defined as an online system which modifies the preferred protective response to a change in system conditions through an externally generated signal. Adaptive protection schemes can be classified into three main categories including overcurrent, differential and symmetrical components.

a)Adaptive overcurrent schemes

In adaptive overcurrent schemes [21-24], a central protection unit is used to periodically store and updatethree distinct tables namely event, fault current and action tables. Event table lists all possible configurations of the micro grid along with the respective status of DG sources. Subsequently, in accordance with each configuration, the fault current measured by each relay for all possible fault locations is stored in the fault current table. Also, for each set of configurations, action table lists the relay settings for each type of fault along with its time delays. Finally, the central protection unit is able to issue the proper tripping signals to the respective relays based on the status of these three tables in each period. Moreover, in case a relay failsto trip, its upstream or downstream relay (based on action table) operates after a predetermined period of time and provides the secondary protection. Likewise, if a fault takes place in the main grid, the closest micro grid relayto the main grid interrupts the fault current provided by micro grid DG sources, and then the micro grid is transferred to the islanded mode [25]. However, adaptive overcurrent protection strategies suffer from some challenges including: (a) necessity to consider all possible configurations of a micro grid with regard to different locations and types of faults. (b) Complicated analysis of short circuit currents in a large microgrid with many radial and looped feeders. (c) costs associated with installation of

a communication infrastructure.

b)Adaptive differential schemes

Differential protection schemes operate based on comparison between the measured currents by relays installed at both ends of a protected element (such as bus bar, line and transformer). In case a fault occurs in the protected element, the difference between these measured currents exceeds a threshold value and the relays trip to isolate the faulted element from the rest of network. In addition, backup protection can be provided by setting the adjacent upstream and downstream relays of the protected element [22, 26].

In [27], a differential strategy using traditional overcurrentrelays as well as communication links is proposed whichis able to protect medium voltage microgrids includingboth inverter- and synchronous-based DG sources. Even though the economic issues are considered in the scheme,it is unable to provide protection during unbalanced loads.

Sortomme et al. designed another differential-based protection scheme applying digital relays and Phasor Measurement Units (PMUs) along with communication channels [28]. The scheme provides three levels ofprotection including instantaneous and comparative voltagerelays. Additionally, the protection against High- ImpedanceFaults (HIFs) is presented in the scheme. Nevertheless, the suggested method is not economical, since PMUs are quite expensive.

In [29], a different protection scheme is introduced for micro grids including both radial and looped feeders. In the scheme, lines and bus bars are protected by means of only differential currents, whereas the protection of DG sources is provided by over- and under-voltage, reverse power flow,and synchronism check relays. Although the developed methodology can provide a robust protection for both grid-connected and islanded modes, it still suffers from problems related to the unbalanced loads and switching transients.

Generally, the main drawbacks of differential protection approaches are: (a) need for communication system as a keyelement, while its failure endangers protection of micro grid.
(b) Deployment of costly synchronized measurement devices. (c) Difficulties resulting from unbalanced loadsand transients during connection or disconnection of DG sources.

c)Adaptive protection schemes based on symmetricalcomponents

The offered protection schemes in the category substantially apply principles of symmetrical components and enable overcurrent-based strategies to protect micro- grids in both grid-connected and islanded modes. The mainproposal in the area is put forward by Nikkhajoei and Lasseter in 2006 [30]. In their proposal, they make use of zero- and negative- sequence currents to detect and isolate, respectively, single-line-to-ground and line-to-line faults in islanded mode of operation. However, their devised solution has not the ability to protect micro grids during HIFs. Furthermore, the operation of their

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protection schemerequires communication links.

In [31], a microprocessor-based relay along with a protection strategy is designed. The strategy which is able to protect low voltage micro grids against both solid and high-impedance faults, operates by applying zero- and negative- sequence components. The main feature of the strategy is that it does not require communication links. However, the proposed method is not capable of protecting microgrids including mesh feeders.

The authors of [32] developed another protection scheme based on only positive-sequence components. In their proposed scheme, they use a designed Microprocessor- Based Relay (MBR) along with PMUs and a digital communication system to protect micro grids including both radial and looped feeders against different types of faults. The designed MBRs have the ability to update their pickup values after any change in the structure of micro grid,thereby protecting micro grids against subsequent faults. Even though the offered protection scheme remedies the drawbacks of the previous works, it is not economical due to the high price of PMUs.

The main issues related with the implementation of the above-mentioned schemes are: (a) necessity to extensive communication infrastructure in some proposals that may fail at some point, jeopardizing the whole micro grid protection. (b) Inability to provide protection for looped micro grids (c) high costs associated with deployment of PMUs.

2.2.2Distance protection

Distance protection scheme which offers a high selectivity is another way to protect AC microgrids. The installed distance relays in the scheme are responsible for calculation of impedance using the measured voltage and current at their location, by which they are able to detectthe fault occurrences. Prior to fault occurrence, themeasured impedance value is high because it includes the load impedance, while in case of a fault event on the network lines, the value becomes equivalent to only line impedance and decreases. As a result, the fault in each zonecan be detected and located by comparison between the measured impedance values before and after the fault [33].

The typical time settings for a three-zone distanceprotection scheme are depicted in Fig. 2. According tothe figure, Zone 1 protects 80% of the line length of ABwithout any tripping time delay. Zone 2 is set to not onlyprotect whole Line AB, but also provide protection for20% of its adjacent line (Line BC) with tripping time delayt_1. Also, 100% of both Lines AB and BC plus 25% of LineCD are protected with tripping time t_2 through Zone 3 [34].The main study in this category is accomplished by Dewadasa and his research group in references [35, 36]. In

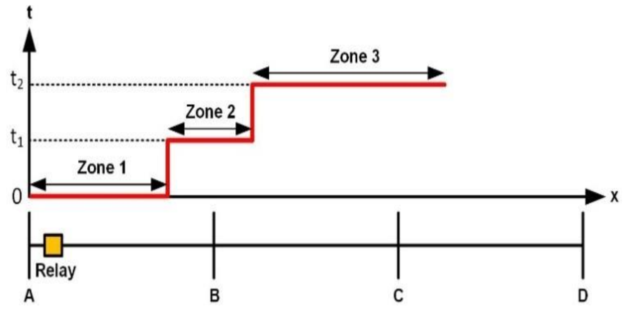

Fig. 2. Time settings for a three-zone distance protectionscheme

their offered protection scheme, new admittance relays are developed based on characteristics of inverse time tripping. The developed relays have the ability to provide protection in their forward and inverse directions against different kinds of faults. However, some shortcomings of this methodology include: (a) errors resulting from fault resistance in measured impedances by relays (b) com- plications associated with impedance measurements in short lines.

2.2.3 Pattern recognition schemes

In reference [36], a new micro grid protection scheme is developed by applying a time-frequency transform which has the ability to protect radial and looped micro grids against different types of faults in both grid-connected and islanded mode. In the developed scheme, first, S-transform is used to extract the spectral energy contents of the fault current signals, measured at both ends of each line. Subsequently, fault patterns are registered by differential energy computations. Based on the predetermined threshold values (in accordance with each type of fault) on differential energy, the protection scheme is able to detect and isolate the faulted line. With regard to the indicated simulation results, the differential energy can be a suitable criterion, since it remarkably varies for a faulty phase in comparison with healthy ones. Moreover, the developed strategy is immune to the noise and less sensitive to synchronization errors.

3. Conclusion and Future Directions

Penetration of micro grids is currently growing aroundthe world, since they offer less environmental impact, low running cost as well as high reliability and power quality. Hybrid AC/DC micro grids are composed of independent AC and DC sub grids, in which all AC- and DC-basedDG sources and loads are connected to the buses directlyor indirectly through power electronic interfaces. The aim of this paper was to provide a review on key issuesand existing approaches for the protection of AC and DCmicrogrids

.With regard to the analysis of the wide range of technical publications presented in the previous sections, protection of future hybrid AC/DC micro grids necessitates simultaneous development of several fields. Coordination between AC and DC protective devices in hybrid AC/DC micro grids including Line-Commutated Converters (LCCs)is one of these fields. It is important, because a fault incident on the inverter AC system side in the case of LCC will cause commutation failure with temporary interruptionsin the power transfer and stress in the converter equipment. Furthermore, it can result in significant DC current increase,and thus leads to additional heating of the converter valves and shortening their lifespan. Development of Combined control and protection schemes is another field which can be effective in resolving the following challenges: (a) self- healing which is an ability to provide fast recovery and resilience of the power system in response to the short circuit conditions. (b) Low-Voltage Ride Through (LVRT) which is defined as the capability of generators to stay connected in short periods of lower electric network voltage. (c) Driving current to zero prior to its interruption by circuit breaker. However, development of combined control and protection schemes necessitates coordination with communication and information infrastructure

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