Microgrids protection schemes, challenges and strategies

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***Abstract* - A Microgrid (MG) embraces a Low Voltage (LV) Distribution Network (DN) with Distributed Energy Resources (DER) and controllable loads. A MG can operate connected to the upstream Medium Voltage (MV) grid—utility grid—or islanded (disconnected from the MV grid) in a controlled and coordinated way. One of the major technical challenges associated with a wide deployment of MGs is the design of its protection system. Protection must respond both to the utility grid system and to MG faults. The presence of several DERs in MGs that dominated by power electronics interfaced might lead to protection failures. As more MGs have power electronics interfaces (inverters), fault detection and selective isolation become very challenging tasks. Thus, the traditional protection devices (fuses and electromechanical switches) and standard solid-state relays are design for selectivity purposes, making them inapt to ensure the protection of MGs. In addition to, the scope of this paper is to explored different protection issues caused by integration of DERs into DNs. In addition, this paper presents a review of various protection schemes and solutions for MGs both in grid-connected and islanded mode of operation. Other solutions based on adaptive MG protection concepts using advanced communication system, real-time measurements, and data from offline short-circuit analysis are also addressed. Finally, the possible use of fault current limitation in a MG is discussed.**

***Keywords* - Distributed Energy Resources, Faults, Microgrids, Operation Modes, Protections.**

I. INTRODUCTION AND MICROGRIDS (MG)

In the last two decades, the augmented penetration and integration of different technologies of Distributed Generation (DG) units mainly in Distribution Network (DN) has created many challenges for all stakeholders (Operators, Producers, Consumers, and Prosumers etc.). Some of the most known DG units with the highest potential are Photovoltaics (PV), Wind Turbines (WT), Fuel Cells (FC), Microturbines (MT), Small Cogeneration of Heat and Power (CHP), Small Hydroelectric Plants (mHydro), Geothermal Power Plants etc. [1]. The presence of DGs units close to demand can offer several economic benefits, including participation in ancillary services, [2], [3]. In addition, if DGs units coordinated in an efficient way, they can form a sizeable quantity and form part of an Energy Service provider portfolio. The coordinated control of DG units in a Smart Microgrid (S-MG) structure allows the full exploitation of them.

As we see in Fig.1 microgrids are Low Voltage (LV) or Medium Voltage (MV) networks with DG sources, storage devices and controllable loads with a total installed capacity in the range of few KWs to couple of MWs. The unique feature of Microgrids is that, all the above Distributed Energy Resources (DERs) appear to the upstream network as a single, controlled entity. Moreover, although they operate mostly interconnected to the DN, they can automatically transfer to islanded mode, in case of faults in the upstream network. Microgrids operation provides distinct advantages to the end customer and the Utility, such as improved quality of service, loss reduction, deferral of investments, and improved environmental behavior, [2]-[8].

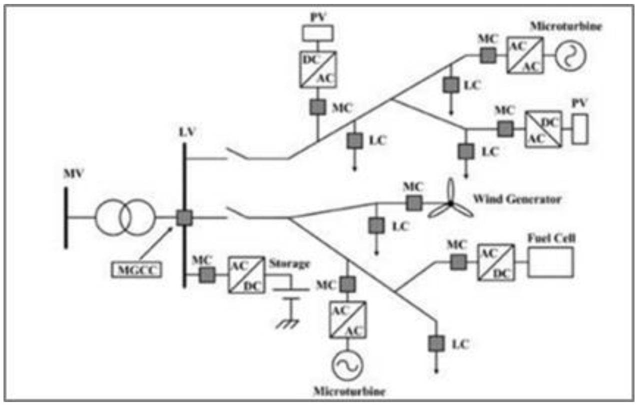

Figure 1. Structure of the Microgrid [9]

Carefully observing a distribution network, we will see that Power flow is unidirectional. However, with the integration of DERs the power flow in the distribution systems can be bi-directional. Faults current path may change depending upon the location of the fault. Constant relay settings may be invalid in case of microgrids (especially for the microgrids with an inverter based DGs). Hence, the conventional protection schemes are not valid in the case of microgrids. Microgrids with the ability to operate both in grid connected and islanded mode impose more challenges, and hence, more sophisticated protection schemes are needed for the successful operation of a microgrid. Protection issues (e.g. bidirectional flow, fault current path, relay settings, short circuit capacity) of microgrids have been discussed in literature where several protection schemes have been proposed. In the case of an inverter, based DG fault current is limited (maximum 2 p.u.). Conventional relay systems are not suitable in case of inverter based DGs. Protection strategies could have been base on communication, time grading, and other techniques. Time grading technique is used to when the primary relay fails to operate during the occurrence of a fault. In such cases, backup relays operate after a specific time delay defined in the settings of the relay. Usually, the network is dividing into zones, with each zone having its own protection relay system. Fig. 2 shows a microgrid with several protection zones and relay modules. Protection scheme for radial distribution systems was present [10].

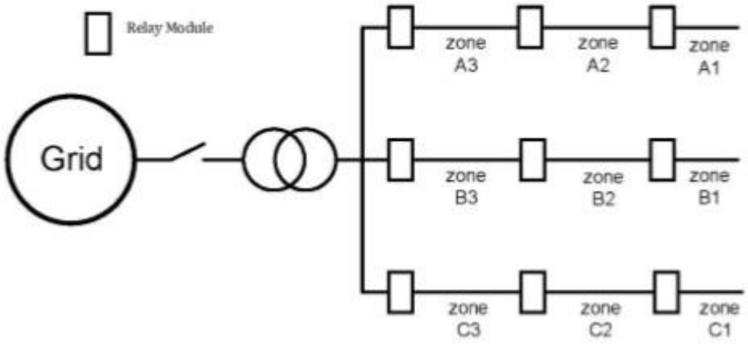

Figure 2. Microgrid with protection zones and relay module [11]

A protection scheme that uses microprocessors for the protection of microgrids operating in either grid connected or islanded mode was also presented [12]. Adding communication can help improve the level of protection of microgrids but at the expense of additional cost. In this type of protections system, the circuit breakers and protection relays are connect with a central control unit via a communication network. Optical ethernet communication network, which connects the relay devices with the protection and control unit, was proposing [13]. Flywheel inverter system was proposed to increase the fault current so that the relays can detect and can clear the fault. Use of fault current limiters is propose in [14], where these limiters are used to in combination with over-current relays to solve the protection issue [15]. A protection scheme was propose for inverter based DGs in which differential relay measures the difference in the current between two points [16]. Differential protection is one of the most reliable protection schemes for the protection of microgrids (in both grid-connected and islanded mode). Different protection scheme incorporated with digital communication relays was propose [17]. Another protection scheme based on communication is the wide area protection (WAP). Protection strategy based on WAP was proposing [18]. Most of the faults in the system are temporary and are automatically remove. Auto reclosing relays give the best protection against such faults. At the time the relay senses the fault, it sends the signal to the circuit breaker to trip. After few milliseconds (or nanoseconds), the relay closes the circuit automatically to check whether it was a temporary fault or not. If yes, the network continues to operate in normal mode. If no, the reclosure relay trips, senses it as the permanent fault and opens the circuit permanently. Adaptive differential overcurrent protection was proposed in which the numerical directional overcurrent relays with directional interlocking capability was used to the protection of radial networks [19]. Its implementation cost is high because of the requirement of a communication network. A multi-agent protection scheme was propose, where the network was, divide into zones and wavelet coefficients of transient current was use to fault location [20]. The proposed scheme did not require any central data processor or voltage transformer. In addition, the computational time was lower making it more efficient but this requires high-speed communication. Many papers present methodologies for Microgrids protection schemes, challenges and strategies**.**

In this paper we will investigate in an episcopal way the issues regarding to the protection of microgrids. This paper divided into four (4) main sections. In the first section we make a small reference to the microgrids. In the second and third section we focus on challenges of dc and ac MG’s protection and current approaches for protection of ac and dc MG’s respectively. Finally, this paper completed with the new trends, various issues and conclusions.

CHALLENGES OF DC AND AC MG'S PROTECTION

Transition from the conventional grid to the future electric grid arises a set of numerous and new challenges. One of the prominent challenges, which hinder wide adaptation of the microgrid technology, is AC and DC microgrids protection. To meet the basic requirements of the smart grid, i.e. plug and play, and self-healing, a set of new approaches has to be design to address the smart protection in the microgrids.

A. Technical Challenges in AC Microgrid

1) Microgrid operation modes: Microgrid operation modes effect on fault currents in term of magnitude and direction. In grid-connected mode, utility and DGs contribute to fault current, while in islanded-mode, fault currents only are fed by DGs.

2) DERs impacts on PDs: DERs could effect on PDs coordination in at least two ways [21]:

1. Mis operation of PD at point of common coupling (PCC), due to high current contribution of DER.

2. Sympathetic tripping of PD of DER, when DER is at the adjacent feeder.

3) Microgrid topology effects on PDs coordination: Microgrids have dynamic topologies. The reasons for those dynamic structures are as follows [22]:

- New DG or load deployments.
- Islanding of the system.
- Fault conditions.
- Reconfiguration of the structure for reasons such as maintenance.

4) Grid code compliance: High penetration levels of renewable energy sources in power system have led to elaboration of specific technical requirements in the grid codes. The goal of modification in the existing grid codes is to improve stability of the grid [23].

5) Standardization and communication: The power distribution grid consists of a considerable number of Intelligent Electronic Devices (IEDs) to cope with a high degree complexity of the future grid.

B. Technical Challenges in DC Microgrid

1) Grounding: The main purpose of grounding is to detect the ground fault. In order to design the grounding system, two contradictory requirements must be took into account [24]:

1. Minimize DC stray current.

2. Maximize personnel safety by minimizing the common mode voltage. Consequently, designing an optimum grounding system is a tough challenge.

2) No zero-crossing current: In ac system, mechanical circuit breakers disconnect circuit when currents cross zero at every half-period; however, in dc system CBs there are no zero crossings.

CURRENT APPROACHES FOR PROTECTION OF AC AND DC MG'S

There are some approaches for improving the protection performance. These approached categorized intro three main general groups: adaptive protection, current limiting, and standardization of protection.

A. Solutions for AC Microgrid Protection

Adaptive protection: After advent of microgrids, conventional overcurrent protection relays encounter selectivity and sensitivity issues due to different levels of fault during islanded and grid-connected modes. One of the promising solutions is adaptive protection technique. In [25], a simple adaptive protection using local information is proposed to overcome the challenges of overcurrent protection. The detection algorithm was utilized to change the trip characteristics. A typical AC microgrid systems interconnected with MV system at the PCC is shown in Fig.3

Current limiting: One of the effective approaches to confine fault current is current limiting. This goal can be achieve through various ways.

• Virtual impedance: In this case, virtual impedance reduces the voltage reference to confine the current.

• Fault current limiter: According to the LVRT capability, DGs must have to connect to grid during the faulty condition. [26] - [27].

Fault current limiter: According to the LVRT capability, DGs must have to connect to grid during the faulty condition.

Fault detection: Fault or islanding detection could have a numerous contributions (i.e. facilitate applying adaptive protection and active management) to the grid [28]-[29].

Standardization: To achieve the highly cooperative relationship of different components of the grid, standardizations for implementation of smart grids as well as a high reliable and cost-effective communication are required [30]-[31].

Self-healing actions: Self-healing is an ability to allow resilience and fast recovery of the power system in response to the fault conditions has been envision. Self-healing usually refers to reconfiguration, load shedding, or controlling the dispatch able generators' output powers.

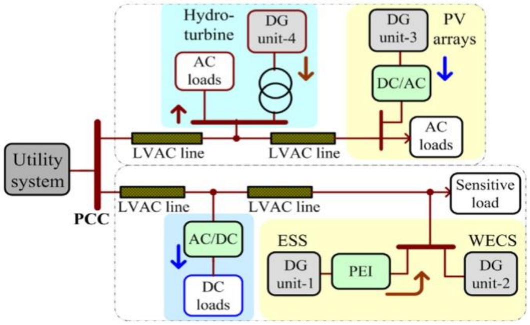

Figure 3. AC microgrid structure with the DG units and mixed types of loads [32]

B. Solutions for DC Microgrid Protection

Some of the solutions are common in AC and DC microgrids i.e. adaptive protection, standardization, and reconfiguration. However, other solutions such as DC fault detection methods, optimal grounding systems, and current limiting approaches in DC microgrids. Fig. 4 shows the typical DC MG systems interconnected with the main systems at PCC which can be medium voltage AC (MVAC) network from the conventional power plants or an HVDC transmission line connecting an offshore wind farm

Grounding systems and fault detection: DC microgrid needs to be floating system. There are some reasons for high impedances grounding follows:

- Navy army is floating to guarantee continuity of energy to essential loads.
- Some industrial system refuse to grounding system for not let an extra increase in common mode voltage.

Current limiting methods: Due to no zero-crossing current in DC microgrid, new approaches or physical circuit are necessary for DC microgrids. Some of the promising solutions are as follows:

- Z-source circuit breakers: To avoid arc on the solid-state DC breaker (SSDCB), and axillary circuit switch as well as precharged commutation capacitor are employed to force commutate by reverse biasing.

Virtual impedance: Although there exists a few papers on limiting the current through virtual impedance [33]-[34], to the authors' knowledge virtual impedance approaches for limiting the current is at its infancy stage in DC microgrids

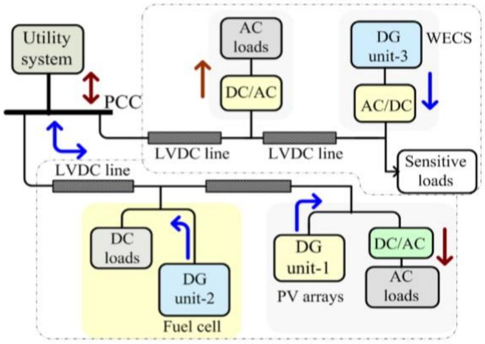

Figure 4. Concept of a DC microgrid system with the DG units and mixed types of loads [35]

NEW TRENDS AND ISSUES

According to the previous parts, AC and DC microgrids are confronting the minor or major protection challenges. Regarding the smart grid structure, an intelligent coordination of communication systems, control systems, and protection systems leads to a resilient and robust microgrids' structure. Consequently, from authors' viewpoint, different layers in the smart grid must be developed and reinforced fundamentally address the current and upcoming challenges of microgrids protection. These three main parts are as follows:

A. Communication and information infrastructures: The smart grid could roughly be divide into three domains in terms of communication coverage and functionality: home area network (WAN), neighbourhood area network (NAN), and home area network (HAN). According to the each domain's characteristics, dedicated communication technology might be different for the each domain. For example, third generation (3G) and fourth generation (4G) cellular networks, worldwide interoperability for microwave access (WIMAX), cognitive radio technology, and optical networks are employed for WAN; whereas, power line communication (PLC), energy efficient Ethernet (EEE), visible light technology, Wi-Fi, and Zigbee are appropriate candidates for HAN.[36]

B. Control and protection systems: In AC and DC microgrids, protection scheme must corporate with control system, because of some issues such as LVRT capability, reconfiguration and self-healing, and approaching current to zero before CBs operations in DC microgrid.[37]

C. Smart protective and control devices: Recently, the solid-state transformer (SST) has been regarded as one of the 10 most emerging technologies by Massachusetts Institute of Technology (MIT) Technology Review in 2010, has gained increasing importance in the future power distribution system. The SST designed for the purposes of power flow control, voltage sag compensation, fault current limitation, seamless transition between the microgrids' two operation modes, isolation, active power management of the DC microgrids, and providing dc and ac interface.[38]

CONCLUSIONS

In this paper, we investigated the following issues: a) AC (on-grid) and DC (off-grid) protection methods, b) new trends on MG's protection. Microgrid is consider as a main part of smart grid. Protection is the one of the toughest challenges in microgrids. Nevertheless, few papers have been concentrated on the protection of microgrids. On the other hand, to the authors' knowledge, no comprehensive papers has been publish on the protection challenges and the possible solutions to address them in AC and DC microgrids. As a result, this paper try to fill this gap by presenting various challenges in AC and DC microgrids and addressing these challenges by several approaches. Finally, this paper investigates the future trends and their related open issues in order to pave the way of implementation of protection in microgrids.

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