Review

Sohrab Mirsaeidi, Dalila Mat Said*, Mohd. Wazir Mustafa, Mohd. Hafiz Habibuddin, and Mohammad Reza Miveh

A Comprehensive Overview of Different Protection Schemes in Micro-Grids

Abstract: In recent years, there has been an increasing interest in applying micro-grid systems not only to improve reliability but also to enhance power quality. One of the major challenges associated with the implementation of micro-grids is to design an appropriate protection scheme which has the ability to protect micro-grids in both grid-connected and islanded mode. In order to overcome this challenge, different approaches have recently appeared in the literatures. This paper aims to provide an introspective review of the available protection schemes used for addressing micro-grid protection issues in both grid-connected and islanded mode. In addition to description of existing protection schemes to date and categorizing them into specific clusters, a comparative analysis is done in which the merits and demerits of each methodology are evaluated.

Keywords: micro-grid, protection schemes, grid-connected, islanded, distributed generation (DG)

***Corresponding author: Dalila Mat Said**, Centre of Electrical Energy Systems (CEES), Faculty of Electrical Engineering (FKE), Universiti Teknologi Malaysia (UTM), 81310 Skudai, Johor, Malaysia, E-mail: dalilamatsaid@yahoo.com
Sohrab Mirsaeidi: E-mail: msohrab2@live.utm.my, **Mohd. Wazir Mustafa**: E-mail: wazir@fke.utm.my, **Mohd. Hafiz Habibuddin**: E-mail: mhafiz@fke.utm.my, **Mohammad Reza Miveh**, Centre of Electrical Energy Systems (CEES), Faculty of Electrical Engineering (FKE), Universiti Teknologi Malaysia (UTM), 81310 Skudai, Johor, Malaysia: E-mail: mivem@yahoo.com

1 Introduction

The recent technological developments and the increasing concerns for global warming motivated engineers to search for cleaner and more efficient systems. One of the most efficient ways for the reduction of impacts of fossil fuels on the environment is to generate energy from the cleaner energy sources which are located close to the consumers [1]. These sources which are termed as distributed generation (DG) units may be in different forms such as wind turbines, wave generators, photovoltaic generators, small hydro, fuel cells and combined heat and power plants [2].

One of the emerging network concepts in the field of distribution generation is the micro-grid. Micro-grid is an aggregation of electrical/heat loads, paralleled DG sources and storage devices which operates as a single-controllable unit at the distribution voltage level [3]. The structure of a typical micro-grid is shown in Figure 1.

Micro-grids have the ability of operating in both grid-connected mode and islanded mode [4–8]. The philosophy of the micro-grid's operation is that under normal circumstances the micro-grid operates in the grid-connected mode but when the utility damages or has a power failure, it immediately disconnects from the utility by the static switch at the point of common coupling and then operates in the islanded mode [9].

Although micro-grids have provided numerous advantages for the costumers, there are some technical challenges which need to be met for the engineers. Micro-grid protection and its entity is one of them. The protection of the traditional distribution systems is designed based on the large short-circuit currents and the unidirectional power flow, whereas such protection strategy cannot be considered for protecting active distribution networks such as micro-grids. Because when a short-circuit occurs in the micro-grid with high penetration of inverter-based DG sources, operating in islanded mode, the DGs are not able to contribute sufficient currents to the total short-circuit current. It is due to the fact that inverters have a low thermal overload capability, limiting their maximum output current to about 2–3 times the rated current [10]. Therefore, in order to protect micro-grids in both grid-connected and islanded mode, innovative protection schemes should be explored [11].

The purpose of this paper is to present a brief analysis of the different protection schemes based on the published papers in trying to provide an appropriate

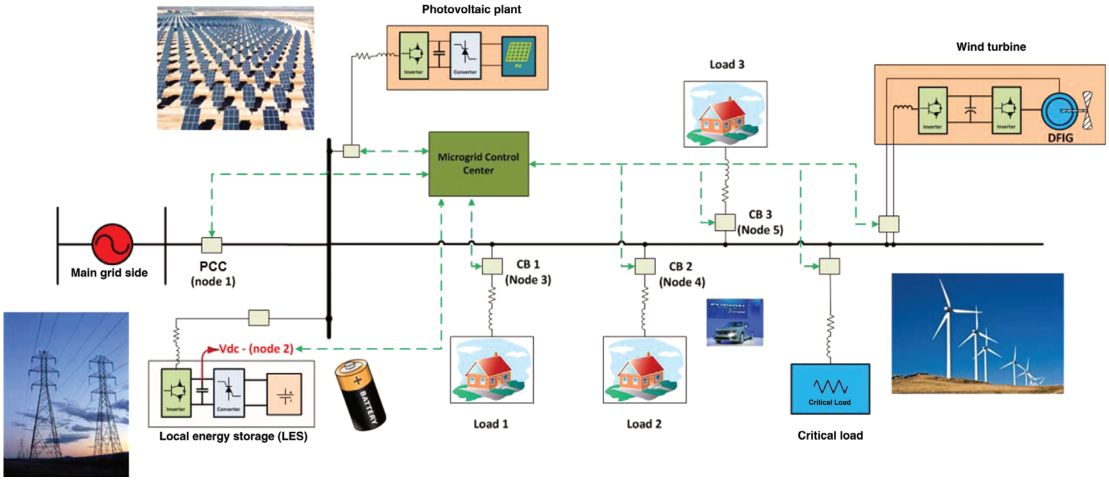

Figure 1 The structure of a typical micro-grid.

protection strategy which is able to protect micro-grids in both grid-connected and islanded mode.

2 Available protection schemes

2.1 Adaptive protection schemes and their problems

These protection schemes are substantially based on applying adaptive relays that can possess their settings characteristics or logic functions altered online in a timely behavior through externally produced signals.

In reference [12], Tumilty, Brucoli, Burt and Green presented an adaptive protection scheme without the need of communication system. In the scheme, they used a voltage-based fault detection method to differentiate the voltage drop in short-circuit events and over-load events.

Then, Oudalov and Fidigatti in [13] proposed another protection scheme that was aimed at adjusting the setting of the relays according to micro-grid's current state based on offline analysis and online operation.

One year later, Han, Hu, and Zhang in [14] made use of the voltage and current fault components at the installation of protection to determine the system impedance. Afterwards, current instantaneous protection could adjust the settings automatically by comparing with the utility grid and micro-grid impedances.

In reference [15], Dang, He, Bi, and Feng used energy storage (ES) and isolation transformers to determine micro-grid's operation mode. Then, the fault could be recognized through comparing between the zero sequence current and a threshold value.

Then, Ustun, Ozansoy and Zayegh in [1] proposed another adaptive protection scheme that made use of extensive communication for monitoring and updating settings of relays based on different micro-grid's operation mode. In the proposed scheme, micro-grid was equipped with a central protection unit (CPU) which communicated with the relays to update their operating currents and with DGs to store their status as ON/OFF.

Finally, M. Khederzadeh in [16] introduced a methodology to coordinate the over-current relays within a specific micro-grid. In the methodology, the settings of the relays were adapted to the status of micro-grid based on their different operating modes.

The main problems associated with the implementation of the above-mentioned adaptive protection schemes are as follows:

- The need for updating or upgrading the protection devices which are currently utilized in the power networks.
- The necessity to know all possible configurations of micro-grid before implementing these schemes.
- Establishment of a communication infrastructure can be costly.
- Short-circuit calculations will be complicated for a micro-grid with different operating modes.

2.2 Differential protection schemes and their problems

Differential protection schemes outlined below are mainly based on the fact that in normal operating circumstances, current entering to a specific feeder should be equal to the current leaving from that feeder.

Nikkhajoei and Lasseter in [17] presented a combined method to protect micro-grids by differential protection and symmetrical components calculations. Using the method, they were capable of detecting single line-to-ground faults within the micro-grid.

In reference [18], Zeineldin and his research group discussed the future of micro-grids and considered two major challenges including voltage/frequency control and protection. In the proposed scheme, they made use of differential relays in both ends of each line. These relays which were designed to operate in 50 ms were able to protect micro-grid in both grid-connected and islanded operation modes.

Afterwards, Conti, Raffa, and Vagliasindi in [19] proposed three protection schemes to detect phase-to-ground faults in isolated neutral micro-grids. Moreover, three more protection schemes were presented for three-phase faults in micro-grids with synchronous-based generators.

One year later, Sortomme, Venkata, and Joydeep in [20] presented a novel protection scheme based on some of the principles of synchronized phasor measurements and microprocessor relays to recognize all kinds of faults including high impedance faults (HIFs). By installing the relays on the end of each line of micro-grid, a robust protection could be developed.

In reference [21], Parsai, Du, Paquette, Back, Harley, and Divan presented a power line carrier communication-based method with multiple levels of protection to provide the most effective form of network protection for meshed micro-grids.

Finally, a novel methodology based on differential protection was presented by Dewadasa, Ghosh and Ledwich [22] in 2011. This methodology in which all the protection challenges such as bidirectional power flow and reduction of fault current level in islanded operation mode were considered was capable of protecting micro-grids in both grid-connected and islanded modes. One of the salient features of this method was that the authors not only focused on feeder protection but they also proposed some solutions to protect buses and DG sources within the micro-grid.

One of the most important advantages of implementing the differential protection approaches is that they are not sensitive to bidirectional power flow and reduction of fault current level in autonomous micro-grids. However, their problems can be summarized as follows:

- Since the communication system may fail, providing a backup protection scheme is necessary.
- Establishing a communication infrastructure is relatively expensive.
- Unbalanced systems or loads may cause some problems in the above-mentioned protection schemes.
- Transients during connecting and disconnecting DGs may bring in some problems.

2.3 Distance protection schemes and their problems

Distance protection schemes mainly make use of admittance or impedance measurements to recognize and isolate the faulted zones in the micro-grids.

The main method in this group was put forward by Manjula Dewadasa [23, 24]. It was based on an admittance relay with inverse time tripping characteristics. The relay had the ability to recognize and isolate the faults in both grid-connected and autonomous micro-grids.

Some problems associated with the use of these types of relays are as follows:

- Harmonics and transient behavior of current may cause some problems in the accuracy of extracting fundamentals.
- Fault resistance may make some errors in the measured admittance.
- The measurement of the impedance/admittance for short lines (which is usually the case in distribution networks) is challenging.

2.4 Voltage-based protection schemes and their problems

Voltage-based protection proposals substantially make use of voltage measurements to protect micro-grids against different kinds of faults.

The main scheme in this field was the one proposed by Al-Nasseri and Redfern [25] in 2006. The scheme, in which output voltages of DG sources were monitored and then transformed into dc quantities using the d–q reference frame, had the ability to protect micro-grids against in-zone and out-of-zone faults. Moreover, a communication link was utilized in the scheme to differentiate in-zone and out-of-zone faults. Since the distances within a micro-grid are usually short, the communications could make use of pilot wires, optical fibers or the Ethernet.

Subsequently, Hou and Hu [26] proposed another method based on only positive sequence of voltage in 2009.

In the same year, Loix, Wijnhoven and Deconinck [10] presented a new protection strategy. This strategy which was based on the impact of different fault types on Park components of the voltage had the ability to protect micro-grids against three-phase, two-phase and one phase-to-earth faults. The protection scheme did not rely on communication for its operation, but it could be optimized by means of communication links between different detection modules. The salient feature of this scheme in comparison with the one in [25] was that the proposed strategy was not only designed for a specific micro-grid and could be used for protecting different micro-grids with various configurations.

Finally, Wong, Li and Yu [27] proposed another protection scheme based on busbar voltage analysis and the fault direction to protect micro-grids in both grid-connected and autonomous operation modes. Additionally, the authors designed the relay protection hardware and software using industrial personal computers.

The main problems associated with possible implementation of voltage-based protection schemes are:

- Any voltage drop within the micro-grid may lead to mis-operation of protection devices.
- HIFs cannot be recognized using the above-mentioned methodologies.
- The majority of these methodologies are designed and evaluated for specific micro-grids. In fact, they are strongly dependent on the micro-grid configuration and on the definition of protection zone. So, they may not be appropriate for micro-grids with different configurations.
- Less sensitivity in the grid-connected mode of operation.

2.5 Protection schemes with the use of external devices and their problems

As mentioned in the introduction, the micro-grid protection challenge is related to the dramatic difference between the short-circuit current level in the grid-connected mode and autonomous mode [28]. Therefore, the implementation of an adequate protection scheme which is able to operate properly in both grid-connected and autonomous modes can be an effective solution.

These protection schemes which make use of external devices are based on modifying the short-circuit level when the operation mode of micro-grid alters from grid-connected to autonomous, or vice versa. These devices can be categorized into two groups as follows:

2.5.1 Fault current limiters (FCLs)

FCLs which can be used to decrease the aggregated contribution of many DG units, are able to change the short-circuit current level enough to exceed the design limit of different equipment components.

The main protection scheme in this field was the one developed by Ustun, Ozansoy, and Zayegh [1] in 2011. The scheme made use of a CPU along with a communication system to monitor the status of micro-grid and update relay short-circuit current based on the changes in the system.

The major problem of applying FCL-based protection schemes is that the determination of the FCL impedance value is difficult for the micro-grids containing a large number of DGs, owing to the mutual influence of DGs. Moreover, the transient response of the FCL is one concern that should be taken into account.

2.5.2 Energy storage devices

Since the short-circuit current level in the micro-grid is limited to approximately 2–3 times the rated current due to the presence of inverter-based DGs, energy storage devices such as flywheels and batteries can be used to provide additional short-circuit level to the network [1, 29].

The problems associated with the use of the methodologies based on additional current source are as follows:

- Storage devices need significant investments.
- These methodologies depend on the islanding detection's technology and the proper performance of storage devices.

2.5.3 Protection schemes based on over-current and symmetrical components and their problems

These protection schemes which are mainly based on the analysis of current symmetrical components, try to improve the operation of traditional over-current protection and provide an adequate protection system for micro-grids.

The main methodology in this field was developed by Nikkhajoei and Lasseter [17] in 2006. They proposed a new protection scheme based on the measurements of the zero sequence current and negative sequence current to detect single line-to-ground and line-to-line faults, respectively.

Two years later, Best, Morrow, and Crossley [30] presented a three-stage communication assisted selectivity scheme. In the scheme, stage-one detected the fault event according to the local measurements; stage-two employed inter-breaker communications; and stage- three adapted the settings of the relays by means of a supervisory controller.

Subsequently, Zamani, Sidhu, and Yazdani [31] proposed a new protection scheme with the use of micro-processor-based relays to protect low-voltage micro-grids against different kinds of faults in both grid-connected and islanded operation modes. The salient characteristic of the proposed scheme was that all relays within the micro-grid were coordinated based on a definite-time grading method, So It had no need of communication links between the relays.

Finally, Mirsaeidi, Gandomkar, and Miveh [32] designed a directional digital over-current relay sensitive to symmetrical components. Subsequently, they proposed a protection scheme based on the designed relay, communication system, and micro-grid central controller (MGCC). The most important feature of the presented scheme was that it did not require a wide bandwidth communication system.

The main problem of the majority of the above-mentioned protection schemes is related to the necessity of communication systems. In such schemes, the protection coordination may be endangered in case of communication system failure.

3 Conclusion

Micro-grids have been designed to fulfill the requirements of reliability and power quality of costumers. However, the emergence of micro-grids has been accompanied with significant challenges. Protection of micro-gird is one of them. In recent years, various proposals have been put forward to present a reliable protection scheme for micro-grids. An appropriate protection scheme should be able to protect the micro-grid against different types of faults and assure its safe and secure operation in both grid-connected and islanded modes. The purpose of the current study was to present a comprehensive review on the existing proposals for tackling the micro-grid protection issues. Moreover, an attempt was made to classify these proposals in specific groups, and finally, the advantages and disadvantages of each group were discussed.

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