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# An analytical literature review of the available techniques for the protection of micro-grids

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ABSTRACT

During the last decade, besides the rapid increase in the penetration level of Distributed Generation (DG) units of micro-grids, the connection of micro-grids as a developed technology to the existing distribution networks has also attracted much attention. One of the major challenges associated with the protection of micro-grids is to devise a proper protection strategy that is effective in the grid-connected as well as the islanded mode of operation. In order to deal with the challenge, many researchers have recently proposed various techniques. The purpose of the current study is to provide a comprehensive review of the available protection techniques that are applied to address micro-grid protection issues in both grid-connected and islanded mode. The most up to date relevant options are described and categorized into specific clusters. A comparative analysis is carried out in which the advantages and disadvantages to each technique are assessed. Lastly, after the appraisement of the existing protection techniques, some conclusions and suggestions are put forward for the protection of micro-grids in the future.



## 1. Introduction

Increasing concerns regarding global warming caused by greenhouse gases, which are substantially generated by conventional energy resources, e.g., fossil fuels have created significant interest in the research and development in the field of renewable energies [1,2]. Such interests are also intensified by the finitude availability of conventional energy resources. To take full benefit of renewable-energy resources, e.g., wind and solar energy, interfacing power electronics devices are essential, which together with the energy resources form DG units [3–6]. The increasing proliferation of DG units, such as wind turbines, micro-gas turbines, photovoltaic generators and fuel cells is anticipated, and this inevitably challenges the traditional operating principles of the power networks [7–11]. An emerging philosophy of operation to alleviate the technical issues with regard to high penetration of DG units, and to offer additional values is to designate relatively small areas of a distribution network that embed DG units and loads, and to operate them in a deliberate and controlled way. Such sub-networks, referred to as micro-grids [12]. The structure of a typical micro-grid is depicted in Fig. 1.

The most important benefit of micro-grids is to provide high-reliability and high-quality power for the consumers who require uninterruptible power supplies [13,14]. Furthermore, micro-grids bring significantly economic benefits with the utilization of combined heat and power technology. In fact, micro-grids have the potential to generate the electrical and useful thermal energy simultaneously (hot, cold, or both) to optimize the consumed energy efficiency by applying cogeneration or tri-generation systems [15].

Micro-grids have the ability to operate independently or in conjunction with the rest of the distribution network. The philosophy of the micro-grid's operation is that under normal conditions the micro-grid operates in the grid-connected mode but when the utility damages or has a power failure; it expeditiously disconnects from the utility by the static switch at the Point of Common Coupling (PCC) and then operates in isolation from the rest of the network [16–22].

In spite of numerous advantages provided by micro-grids, there are some technical challenges, which require to be met for the engineers and one of them such as micro-grid protection and its entities. Since the protection devices of the existing distribution systems are designed according to the large fault currents, they do not have the ability to protect micro-grids. This is because when a fault takes place in the micro-grid with the widespread proliferation of electronically-coupled DG units, operating in autonomous mode, the DGs are not able to contribute adequate currents towards the total fault current. It is due to the inverters have a low thermal overload capability, limiting their maximum output

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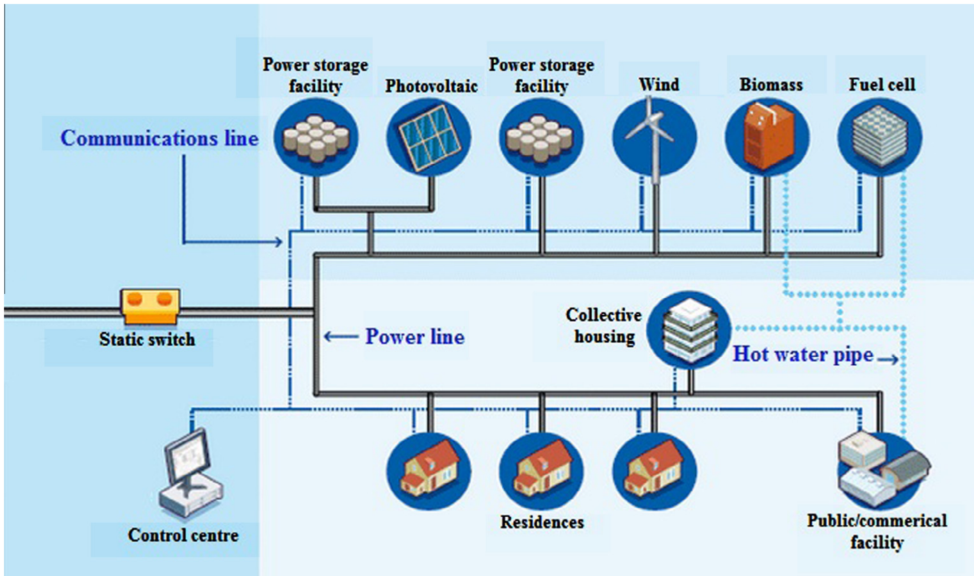


**Fig. 1.** The structure of a typical micro-grid.

current to about 2–3 times the rated current [23]. On the other hand, despite the traditional distribution networks, power flow within micro-grids can be bidirectional owing to DG connections at the different locations. Accordingly, in order to protect micro-grids in both grid-connected and islanded mode of operation, novel protection schemes should be employed [24,25].

This paper aims to present a brief analysis of various protection schemes based on the published papers in attempting to provide an appropriate protection strategy which is capable of protecting micro-grids in both grid-connected and autonomous mode of operation. The organization of this paper is as follows: Section 2 discusses the available techniques for the protection of micro-grids, and Section 3 analyzes the proposed techniques as well as putting forward some suggestions for the protection of micro-grids in the future and finally; Section 4 concludes the paper.

## 2. Available techniques for the protection of micro-grids

An appropriate technique for the protection of micro-grid should have the ability to respond to both utility grid and micro-grid fault incidents. In other words, if a fault occurs on the utility grid, the desired response is to isolate the micro-grid from the rest of the network. This leads to an autonomous operation of micro-grid, and if a fault takes place within the micro-grid, the protection system should remove the smallest possible faulted area of micro-grid to clear the fault. In recent years, various techniques have been proposed to present an adequate protection strategy for micro-grids. These techniques are precisely illustrated in the following subsections.

### *2.1. Adaptive protection: available techniques and their challenges*

Adaptive protection schemes have the ability to solve the problems associated with the protection of micro-grids in both grid-connected and islanded mode of operation. In such protection schemes, there is an automatic readjustment of relay settings when the micro-grid alters from grid-connected mode to islanded mode and vice versa. In fact, adaptive protection is an online system that modifies the preferred protective response to change in system circumstances or requirements in a timely manner through external generated signals or control actions. Numerical directional over-current relays, which have the potential of using several settings groups, are employed in the practical implementation of adaptive protection systems. In order to provide more effective protection, a communication system can be applied such that individual relays can communicate and exchange information with a central computer or between different individual relays.

The work by Tumilty et al. [26], suggested an adaptive protection strategy without the need of the communication system. The authors simulated the voltage response for both short-circuit and overload events. The results of simulations indicated that the voltage magnitude has a reduction in both events. Nevertheless, the magnitude of this reduction was such that these two events could be differentiated. In fact, the voltage drop resulting from short-circuits were significantly greater than that of overloads. Accordingly, they employed a voltage based fault detection method to discriminate the voltage drop in short-circuit and over-load incidents.

Based on centralized architecture, Oudalov and Fidigatti [27] presented a novel adaptive protection scheme using digital relaying and advanced communication technique. In the scheme, the protection settings were updated periodically by the micro-grid central controller with regards to the micro-grid operating states. The scheme was realized using numerical directional relay with the directional interlock capability to act selectively to protect the micro-grid.

In the following year, Han et al. [28] analyzed the fault behavior of an inverter-based micro-grid, and proposed an adaptive fault current protection algorithm. They deployed the voltage and current fault components at the installation of protection to determine the system impedance. Afterwards, the current instantaneous protection adjusted the settings automatically by comparing with the utility grid and micro-grid impedances.

In another study conducted by Dang et al. [29], they proposed an adaptive strategy using Energy Storage (ES) and isolation transformers to protect low-voltage micro-grids in the islanded mode as well as the grid-connected mode of operation. Firstly, in order to recognize the micro-grid's mode of operation, the over-current protection and dq0 voltage detection were utilized for the grid-connected mode and islanded mode, respectively. Then, the different protection zones could be discriminated by comparing the zero sequence current and a threshold value.