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A protection scheme for microgrid with multiple distributed generations using superimposed reactive energy

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ABSTRACT

With the growing integration of distributed generation, distribution networks have evolved toward the concept of microgrids. Microgrids can be operated in either the grid-connected mode to achieve peak shaving and power loss reduction or the islanded mode to increase the reliability and continuity of supply. These two modes of operation cause a challenge in microgrid protection, because the magnitude of fault current decreases significantly during the transition of a microgrid from the grid-connected mode to the islanded mode. This paper proposes a protection scheme for the microgrid based on superimposed reactive energy. The proposed scheme uses the Hilbert transform to calculate the superimposed reactive energy (SRE). The sequence components of superimposed current are adopted to detect fault incidents in the microgrid. The faulty phase and section are recognised by using the directional characteristics of SRE along with a threshold value. Moreover, a relay structure, which enables the proposed protection scheme, is designed. The significant feature of the proposed protection scheme is that it has the ability to protect the looped and radial microgrids against solid and high-impedance faults. To verify the efficacy of the proposed approach, extensive simulations have been carried out using the MATLAB/SIMULINK software package. The results show that the proposed scheme successfully identifies and isolates various types of fault in a microgrid and performs well with different fault resistances and fault locations.

1. Introduction

In conventional power systems, power is generated centrally and then transmitted to the customer end by using long transmission and distribution networks. In this case, power flows are unidirectional in the distribution networks. Nowadays, mounting load demand, developments in renewable energy technology and increasing concerns on global warming have led to a new trend of electricity production at the distribution level. These technologies are usually called distributed generation (DG) [1,2]. The introduction of DGs at the distribution level decreases the power transfer burden on the transmission and distribution networks [3]. These new technologies have enabled the smaller distribution networks called microgrids [4,5].

A microgrid is a small part of a power system which consists of parallel DGs, energy storage devices and electrical/heat loads. It can work in the grid-connected as well as the islanded mode, for providing uninterrupted service to customers, and for improving the reliability, operational optimality and power quality of the system [6,7]. Microgrids offer various benefits, but present some technical obstacles, which need to be explored. Microgrid protection and its entities is a major obstacle [8].

The main problem related to microgrid protection is the protection during the islanded mode, when the microgrid works independently of the main grid. In this case, the fault currents are small due to the limited current-carrying capacity of power electronics devices. The fault current is merely 2–3 p.u. of rated current in case of inverter based DGs [9]. Thus, the traditional overcurrent protection, which relies on the assumption of high fault current, is insufficient for the protection of islanded microgrids. However, in the grid-connected mode, the main grid also contributes to fault current therefore, the magnitude of the fault current is significantly larger. Although it is possible to use overcurrent relays for the protection of grid-connected microgrid, the existence of DGs alters the direction and magnitude of fault current and hence compromise the relay coordination.

A protection scheme for microgrid must ensure safe operation of microgrid in both modes of operation and should take into account (1) two-way power flow in distribution networks (2) presence of looped feeders and (3) reduced fault current magnitude in the islanded mode. As, traditional protection schemes mainly based on overcurrent relays are ineffective in protecting microgrids. Hence, there is a need for alternate schemes of microgrid protection.

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Various schemes for microgrid protection have been developed and reported in the literature [10,11]. In [12], the authors used a central controller along with a digital relay to update the precalculated relay settings according to the operating mode of the microgrid. This scheme was upgraded by Coffele [13] who suggested an online method to calculate the settings of adaptive overcurrent relays. The developed scheme had the capability to automatically adjust the settings of all overcurrent relays in response to the status of DGs, operational mode of the microgrid and active networks management. However, relatively sophisticated fault calculations were required for microgrids operating in different modes. Moreover, the scheme was not suitable for high-impedance faults (HIF). In a research by Mirsaeidi et al. [14], a central processing unit-based protection scheme for microgrids was proposed. Prefault and post fault positive sequence impedances of distribution lines at both ends were calculated and compared to locate the faulty section. However, the suggested scheme required complete upgrading of the protection devices currently used in the distribution networks; moreover, the presented scheme was not able to protect the microgrid against HIFs. In [15], Oureilidi and Konstantinos suggested the switching of converter control from droop control to current control during faults in microgrid. The faulty section was identified by measuring the fault current provided by each converter. The scheme was only applicable to inverter-dominated microgrid; moreover, it required some external energy source in case of HIF. A travelling wave scheme based on mathematical morphology filter was presented in [16]. Two different logics were developed for microgrids with different configuration and topologies. The developed method was independent of fault resistance. The scheme required accurate signal synchronisation and very high sampling frequency, which is impractical due to lack of cost effective DSP hardware. In [17], the wavelet packet transform (WPT) was suggested to detect and clear the faults in microgrids. The scheme used a half-band digital high-pass filter to realize the WPT. The authors did not consider HIFs and looped structure of microgrids. A voltage-based protection strategy for microgrids was proposed in [18,19]. The abc-dq0 transformation of voltage was used to detect the fault incidents in microgrids. The scheme was limited to islanded microgrids and solid faults. Moreover, the scheme did not consider the microgrid with looped configuration. The authors in [20] suggested the deployment of energy storage devices in the islanded mode of microgrids to equalise the fault current magnitude in islanded and grid-connected modes. However, the installation of such devices with high short-circuit capacity was not economical. Zamani et al. [21] developed a protection strategy by using negative and zero-sequence components to protect the microgrid against various types of faults. The scheme also had a backup protection in case of communication failure. As the scheme used zero sequence current as a directional element, it required a grounding transformer inside the microgrid. In [22], a differential protection scheme based on a statistical classifier has been developed for microgrids. Various features from voltage and current signals were obtained at both ends of a line in microgrids. A learning-from-data feature selection approach was used to select most useful subset of features among the ones obtained initially at each relay point. Finally, a differential operation is applied to selected features to detect and locate the faults in microgrids. The scheme was implemented on islanded microgrids against solid faults only. A protection scheme based on wavelet and data mining-based approach was suggested by Mishra et al. [23]. The statistical features of current waveform extracted by a wavelet transform were used to develop the data-mining models. The fault classification was conceded based on these models. The scheme was applicable to inverter-interfaced DGs only.

The main limitations of above-mentioned schemes are that they either protect the microgrids in one mode (islanded or grid-connected mode) or consider radial configuration of microgrids only. Some schemes, which protect the microgrids in both modes of operation, are not suitable for HIFs. The schemes developed for HIFs, require additional devices in microgrids; therefore, they involve very high cost.

This paper proposes a novel scheme for the protection of microgrids based on superimposed reactive energy (SRE). In this paper, SRE is defined as the integral of superimposed reactive power during a specified period of time. A new fault detection ratio based on sequence components of superimposed current is developed for detection of fault incidents in microgrids. The proposed scheme uses the Hilbert transform to calculate the SRE. The directions of SRE flow at both ends of each feeder are employed to identify the faulty line in a microgrid. This paper uses a threshold on SRE of each phase to classify the faults. To validate the effectiveness of the proposed scheme, extensive simulations are carried out using MATLAB/SIMULINK software. The main contributions of this paper are as follows:

- The proposed scheme has the ability to protect the looped and radial microgrid against solid and HIFs.
- The scheme is valid for both islanded and grid-connected microgrid and there is no need to modify the setting of relays when the microgrid changes its mode.
- The proposed protection scheme also offers backup protection against faults in case of failure of main protection.

The rest of the paper is structured as follows. Section 2 illustrates the basic principle of the superimposed components, Hilbert transform and SRE characteristics, which are the basis of the suggested protection scheme. Section 3 explains the proposed scheme in details. Exhaustive simulations are performed to test the efficiency of the proposed protection in Section 4. Finally, the paper is concluded in Section 5.

2. Basic principle

2.1. Superimposed components

Subsequent to short-circuit fault on any point in a microgrid, the variables like current, voltage, power etc. may face significant changes with respect to their corresponding prefault values. The change in the variables due to a fault is known as the superimposed component/fault-imposed component. The superimposed components appear due to the fault in the network. They keep fault signature and are independent of the values under normal-running conditions. Hence, any electrical variable during a fault comprises two components: (1) a normal operating component and (2) a superimposed component. Thus, any arbitrary variable $x(t)$ during a fault can be expressed as

$$x_f(t) = x_{f_i}(t) + x_{pre}(t) \tag{1}$$

where $x_f(t)$, $x_{pre}(t)$ and $x_{fi}(t)$ are the fault, prefault and superimposed components of variable $x(t)$ respectively.

$$x_{f_i}(t) = x_f(t) - x_{pre}(t) \tag{2}$$

Eq. (2) shows that the superimposed component can be computed by subtracting the normal or prefault component from the fault component. Therefore, the superimposed component does not appear under normal operation but exists if a fault occurs within the microgrid. Superimposed components can be calculated by using delta filters [24]. The simplest delta filter subtracts the integral multiple delayed version of the input signal from the input signal itself.

$$x_{f_i}(t) = x(t) - x(t - nT) \tag{3}$$