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Fault diagnosis in distribution networks with distributed generation

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ABSTRACT

The penetration of distributed generation (DG) in distribution power system would affect the traditional fault current level and characteristics. Consequently, the traditional protection arrangements developed in distribution utilities are difficult in coordination. Also, the reclosing scheme would be affected. With the rapid developments in distribution system automation and communication technology, the protection coordination and reclosing scheme based on information exchange for distribution power system can be realized flexibly. This paper proposes a multi-agent based scheme for fault diagnosis in power distribution networks with distributed generators. The relay agents are located such that the distribution network is divided into several sections. The relay agents measure the bus currents at which they are located such that it can detect and classify the fault, and determine the fault location. The proposed technique uses the entropy of wavelet coefficients of the measured bus currents. The performance of the proposed protection scheme is tested through simulation of two systems. The first system is a benchmark medium voltage (MV) distribution system and the second system is practical 66 kV system of the city of Alexandria.

1. Introduction

The traditional power systems, which are based on large fossil fuel fired power generation plants, long distance transmission lines and hierarchical control centers, are changing. A large number of distributed generation units including renewable energy sources such as wind turbines, PV generators, fuel cells together with Combined Heat and Power (CHP) plants, are being integrated into power systems at distribution level. The penetration of DGs changes the traditional distribution power system short circuit power, fault current level and the characteristics of the fault current, such as amplitude, direction and distribution [1].

Most distribution network protection schemes are initially designed without DGs. The nature of distribution network can be radial or meshed. Traditionally, radial networks are protected using coordinated overcurrent relays whereas meshed networks are protected using directional overcurrent relays [2].

To deal with the problem of protection of distributed networks with the penetration of DGs, distribution utilities impose interconnected regulations. These regulations are often based on IEEE Std. 1547, 2003 [3] and recommend the tripping of DGs even for remote faults in order to maintain the protection coordination during fault. According to [3], immediate tripping of DGs is recommended also if a power island is created. That is why protection schemes, which are capable of immediate identifying and isolating faults after their occurrence, are required. These schemes can ease the requirement for the disconnection of DGs to ensure protection coordination and enable intentional power islands.

Several protection schemes have been proposed in literature [1–9] in order to address the shortcomings in current DG interconnection practices and protection problems associated with DGs.

This paper proposes a multi-agent based protection scheme to classify and locate the fault in a distribution network with DG. The proposed technique aims to locate and isolate a faulty section in a distribution system with DGs. It is based on entropy calculation of wavelet coefficients of the three phase current signals. This method uses only current signals measured by relay agents at the boundaries of the network sections to identify the type of fault if it is a three line to ground (3LG), single line to ground (LG), double line to ground (DLG) or a line to line (LL) fault. It also determines the phases included in fault and the bus or line at which the fault occurred. The performance of the proposed algorithm is investigated through the simulation of a benchmark MV distribution system and part of the 66 kV network if Alexandria. The results proved the effectiveness of the proposed protection scheme under different conditions of fault type, fault location and fault resistance.

2. Analysis of three phase power system transients

2.1. Modal transformation

In three-phase systems, many different fault types depending on the phase involved or the involvement of ground can occur. In order to diagnose such types of faults, currents and/or voltages of all

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three-phase quantities must be analyzed. However, the amount of processing can be reduced by transforming three-phase quantities into modal components.

The modal transformation resolves three-phase signals in a coupled network into three uncoupled modal components, namely, (1) the ground mode; (2) aerial mode-1; and (3) aerial mode-2 components. For nontransposed multiphase systems, an eigenvector-based frequency-dependent transformation matrix is required to convert the quantities from phase domain to modal domain. For balanced and ideally transposed lines, a frequency-independent, real transformation matrix, such as Clarke transformation, can be used. Although practical distribution systems do not satisfy the aforementioned conditions, a frequency-independent real transformation matrix can be used to obtain somewhat decoupled signals that can be advantageous in transient-based fault location.

The relationship between the Clarke components and the phase components is given by

$$\begin{pmatrix} I_0 \\ I_\alpha \\ I_\beta \end{pmatrix} = \frac{1}{3}\begin{pmatrix} 1 & 1 & 1 \\ 2 & -1 & -1 \\ 0 & \sqrt{3} & -\sqrt{3} \end{pmatrix}\begin{pmatrix} I_a \\ I_b \\ I_c \end{pmatrix} \quad (1)$$

where, I_a, I_b and I_c are the phase currents and I_0, I_α and I_β are the respective Clarke components. Transients in the phase currents are well reflected in the Clarke components.

2.2. Wavelet transformation and entropy calculation

Lots of fault information is included in the transient components. So it can be used to identify the fault or abnormity of equipments or power system. It can also be used to deal with the fault and analyze its reason. This way the reliability of the power system will be considerably improved.

Transient signals have some characteristics such as high frequency and instant break. Wavelet transform is capable of revealing aspects of data that other signal analysis techniques miss and it satisfies the analysis need of electric transient signals. Usually, wavelet transform of transient signal is expressed by multi-revolution decomposition fast algorithm which utilizes the orthogonal wavelet bases to decompose the signal to components under different scales. It is equal to recursively filtering the signal with a high-pass and low-pass filter pair. The approximations are the high-scale, low-frequency components of the signal produced by filtering the signal by a low-pass filter. The details are the low-scale, high-frequency components of the signal produced by filtering the signal by a high-pass filter. The band width of these two filters is equal. After each level of decomposition, the sampling frequency is reduced by half. Then recursively decompose the low-pass filter outputs (approximations) to produce the components of the next stage [10,11].

Given a discrete signal $x(n)$, being fast transformed at instant k and scale j, it has a high-frequency component coefficient $D_j(k)$ and a low-frequency component coefficient $A_j(k)$. The frequency band of the information contained in signal components $D_j(k)$ and $A_j(k)$, obtained by reconstruction are as follows [12].

$$\begin{cases} D_j(k): & [2^{-(j+1)}f_s, 2^{-j}f_s] \\ A_j(k): & [0, 2^{-(j+1)}f_s] \end{cases} \qquad (j = 1, 2, \ldots, m) \quad (2)$$

where f_s is the sampling frequency.

The original signal sequence $x(n)$ can be represented by the sum of all components as follows [12].

$$x(n) = D_1(n) + A_1(n) = D_1(n) + D_2(n) + A_2(n) = \sum_{j=1}^{J} D_j(n) + A_J(n) \quad (3)$$

Various wavelet entropy measures were defined in [10]. In this paper, the nonnormalized Shannon entropy will be used. The definition of nonnormalized Shannon entropy is as follows [12].

$$E_j = -\sum_k E_{jk}\ \log E_{jk} \quad (4)$$

where E_{jk} is the wavelet energy spectrum at scale j and instant k and it is defined as follows.

$$E_{jk} = |D_j(k)|^2 \quad (5)$$

3. Proposed agent-based fault diagnosis

3.1. Protection arrangement based on relay agents

Protective relays detect fault occurrence in a power system and isolate that part of the power system to prevent fault from affecting the whole power system. Traditional protective schemes generally used dual systems of primary and backup protection relays for high sensitive and reliable protection of the system. The primary protection relays are usually current differential relaying that has a high accuracy of fault detection. The backup protection relays are usually distance relaying that work with local power system information only [13].

With the introduction of distributed generation and deregulation, the power system impedance and fault currents through protective devices would change. The protective devices are therefore difficult to be coordinated [14].

The distribution power system automation techniques have been widely adopted and the infrastructure of communication has been developed. The protection schemes based on microprocessors with communication capabilities are utilized, so that the status of the relays and breakers can be obtained from the distribution power system supervisory control and data acquisition system, which can serve as an information exchange platform. Based on the platform, the protection coordination and adaptation can be dealt with flexibly [1].

The concept of a cooperative protection system with an agent model (relay agent) was first proposed by Tomita et al. back in 1998 [13]. The application of this concept has been proposed in [14,15] to build an intelligent, adaptive protection system.

In this paper, the distribution network is divided into a number of network segments as shown in Fig. 1 for fault isolation purpose. Each network segment can be isolated from the rest of the system for a fault inside it by opening the circuit breakers (CBs) at its interconnection points to the system. The three phase bus currents are measured and fed to the relay agents which are placed at the interconnection points of different network segments. The relay agents exchange data between each other through a telecommunication network. A simple algorithm based on the information collected by different relay agents is proposed to classify and then locate the fault such that the faulted area can be correctly isolated.

3.2. Fault classification using current transients

An analysis of all possible types of fault in three-phase system (AG, BG, CG, AB, BC, CA, ABG, BCG, CAG and ABCG) is carried out. In this paper, the proposed algorithm determines the type of fault first, then the phases included in fault and finally it determines the fault location.

The sum of absolute entropies of wavelet coefficients of the Clarke components is used to determine the type of fault if it is 3LG, LG, DLG, or LL fault. Next, the sum of absolute entropies of wavelet coefficients of the three phase currents (I_a, I_b, and I_c) are used to determine the phases included in fault. Finally, the values of the sum of absolute entropies of wavelet coefficients of Clarke