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Detection of faulted phase type in distribution systems based on one end voltage measurement

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ABSTRACT

Distribution power systems exposed to various unexpected failures due to many random causes. These failures are mostly happened as a result of phase faults in power system and will affect negatively the availability and reliability of the power system. Accurate detection of these faults will help in restoration of power in a timely manner and not to cause any severe damage to the power system equipment. This paper investigates the problem of accurate detection of faulted phase types occurred in the distribution system. The features of the voltage waveforms recorded from one end measurement of the distribution system during the fault occurrence are used in the proposed technique. Clarke's transformation criterion used to identify if the fault is line-to-ground (grounded fault) or phase-to-phase (ungrounded fault). Then the fault types are classified by the high performance comparison method of the voltage signals using phase angle shift prior and during the fault occurrence. Different types of faults namely, single-phase to ground, double-phase to ground, phase–phase and balanced three-phase faults that are occurred at different locations with different fault resistances and inception angles are tested and analyzed. Results from simulation of faults on a model of 33 kV distribution system typical networks presented.

1. Introduction

Power distribution lines, among all other electrical components of the network, are exposed to different types of unexpected failures due to various random causes. The availability and reliability of the network is negatively impacted due to phase faults that lead to these failures. Accurate classification and detection of these faults will assist in the restoration of power in a timely manner and not to cause any severe damage to the power system equipment. There are several methods, in the last three decades, used for classification and detection of faults in the radial overhead distribution systems. Many researchers performed studies on fault classification and detection in distribution systems based mainly on wavelet transform, artificial neural networks and support vector machines. Wavelet multi-resolution approach is used with current measurement at the main substation to estimate the fault type of radial distribution system [1]. This method uses a set of rule base to identify ten different types of faults. In [2], fault type and fault location were determined by using artificial neural network (ANN). In this approach, three phase currents of main source feeder were normalized and used as an input array to the ANN. Use of Clark transformation with ANN was reported, to determine the fault location and fault type in power distribution systems [3,4]. In another work, authors used Traveling Wave (TW) and Clark Transformation (CT) based on voltage signals to estimate fault location and various types of faults in a distribution system [5]. In Clark transformation, voltage signals are transformed from phase domain into modal domain. Few works based on phase angle shift for estimation of fault type classification were also reported. In [6], phase angle shift method was used for fault type classification based on voltage captured by distribution PQ monitor.

This paper investigates the problem of accurate classification of faulted-phase type occurred in the distribution system. The proposed algorithm utilizes only the extracted features of the voltage waveforms recorded from one end of the radial distribution system during fault occurrence to find the accurate fault type. The faulted-phase type is determined into two parallel schemes. In the first scheme, distinctive features of voltage signals due to fault are extracted by the application of Clarke Modal Transformation (CMT) to verify between grounded and ungrounded faults. In the second scheme, Voltage phase angle shift of pre and during fault occurrence period is calculated to differentiate between faulty and un-faulty phases by certain criteria. Different types of faults (single-phase-ground, double-phase-ground, phase–phase and balanced three-phase) that are occurred at different locations are analyzed. Results from simulation of faults on a model of 33 KV distribution power system are presented. Validation of classification of faulted phase type is performed using ATP/EMTP for

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transient simulations and MATLAB for software applications. Fault location distance is not considered in this paper.

2. Classification of Fault Type Techniques

Clarke Modal Transformation (CMT) and voltage phase angle shift (PAS) criteria are tools used in the faulted phase type detection in distribution systems technique. These tools performance is dependent on the features of only voltage waveforms recorded during the event of a fault from one end of the radial distribution system.

2.1. Clarke Modal Transformation (CMT)

To determine whether the fault is grounded or ungrounded, in the proposed approach, by the modal transformation matrix, from the phase domain signals the modal components are extracted, it is assumed in this study that all overhead distribution line models are fully transposed, the well known real transformation matrix and Clarke's constant will be used for this purpose. As stated below, the matrix is given by [7]:

$$T = \begin{bmatrix} 2/\sqrt{6} & -1/\sqrt{6} & -1/\sqrt{6} \\ 0 & 1/\sqrt{2} & -1/\sqrt{2} \\ 1/\sqrt{3} & 1/\sqrt{3} & 1/\sqrt{3} \end{bmatrix} \tag{1}$$

By implementation of this transformation matrix in (1) the phase signals are transformed into their modal components, as shown in the following equation,

$$\begin{bmatrix} V\alpha \\ V\beta \\ V0 \end{bmatrix} = \begin{bmatrix} 2/\sqrt{6} & -1/\sqrt{6} & -1/\sqrt{6} \\ 0 & 1/\sqrt{2} & -1/\sqrt{2} \\ 1/\sqrt{3} & 1/\sqrt{3} & 1/\sqrt{3} \end{bmatrix} * \begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} \tag{2}$$

where

$$S_{\mathrm{mode}} = \begin{bmatrix} V\alpha \\ V\beta \\ V0 \end{bmatrix} \text{ and } S_{\mathrm{phase}} = \begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} \tag{3}$$

The modal and phase signals (voltages or currents) vectors are the Smode and Sphase respectively. With any transposed line, the real Clarke's transformation can be used. An eigenvector based transformation matrix, which is frequency dependent have to be used, for the study of untransposed lines. The frequency for computation of this matrix should be equal or close to the frequency of the initial fault transients. At first the recorded three phase signals are changed into their modal components. To obtain the aerial and ground mode signals from the three-phase transients Clarke's transformation matrix can be used. The first two modes (mode α and mode β), are usually referred to as the areal modes, and the third (mode 0) is referred to ground mode, and only during faults having a path to ground its magnitude is significant. For the purpose of distinguishing between grounded and ungrounded fault situations, the faulted phase essentially based on the ground mode (mode 0) making use of the ground mode, the faulted phase type problem is formulated. Therefore, Eq. (2) can be rewritten as

$$V_0 = \begin{bmatrix} 1/\sqrt{3} & 1/\sqrt{3} & 1/\sqrt{3} \end{bmatrix} * \begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} \tag{4}$$

Based on the V_0 value in (3), the fault situation can be decided either the fault scheme is ungrounded or grounded. Faulted phases of single-line-to-ground, double-line-ground and three-line-ground will be distinguished, in the grounded fault situation. Similarly, for ungrounded fault situation, line-to-line fault and three lines fault will be determined.

2.2. Phase angle shift (PAS) criterion

Phase angle shift (PAS) is a change in voltage phase angle associated with fault occurrence. Due to the type of fault, in addition to other factors, the characteristics of faults at certain locations are determined. PAS is related to X/R line impedance ratio of the source and the faulted feeder [8]. By calculating the difference between the during-fault voltage waveform angle and the pre-fault voltage waveform angle, which is related, the phase angle shift due to the fault occurrence can be obtained. PAS may have a negative or a positive value and can be in the form of angle (in radians or degrees), or of time (in milliseconds). The sampling of the voltage waveform that occurred due to fault in the system and used in the calculation of PAS is formed over the period of one cycle with ½ cycle to cover pre-fault and ½ cycle to cover during-fault data. There are several methods for the calculation of PAS. In this paper, calculation of PAS uses Fast Fourier Transform (FFT) method. This method is uncomplicated and suitable to the sampling data of the voltage waveform. In nominal case, PAS equals to zero since there is no phase shift between the pre-fault angle and during-fault angle.

3. Faulted Phase Type Classification Algorithm

The classification algorithm of faulted phase type is divided into two parts as shown in Fig. 1. One part is to determine if the fault is grounded or ungrounded by using the Clarke Modal Transformations (CMT). In the other part, faulted phase type is determined. This is accomplished by the comparison of calculated phase angle shift values of the voltage waveform due to a fault occurrence. The values of the three calculated PAS indicate which phase is in fault. In Fig. 1, the phase angle shift values are given the weight of large (*L*) or small (*S*) for comparison between the resulted phase angle shifts for each phase to indicate the fault type. The steps of flow chart in Fig. 1 are explained in the following procedure:

A. Faulted phase polarity determination:
   - Read, sampling and normalizing of *Va*, *Vb* and *Vc*.
   - Apply Clarke Modal Transform (CMT) for ground mode, V_0.
   - Compare the resulted V_0 value for grounded or ungrounded signal using certain threshold value.

B. Classification of faulted phase type:
   - Read, sampling and normalizing of *Va*, *Vb* and *Vc*. (As in part A above)
   - Calculate PAS for each phase (*Va*, *Vb*, *Vc*).
   - Compare the calculated values of PASa = PASb = PASc = 0.
   - If result is true then system is healthy (no-fault).
   - If result is false, then compare the values of all phases for *L* and *S* as in the tabulation of Fig. 1 to detect the type of faulty phases.

For faulted phase polarity, the threshold value of ε is to be determined by trial and error based on data collected.

4. Distribution system model

From a power system model simulated in Fig. 2, determination and classification of faults is performed. Using ATP/EMTP simulation program [9], in the overhead distribution system, the simulation of transient signals is performed. The power system consisting