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New transient fault location method in non-solidly earthed system for distribution network

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Abstract: The technology of faulted line detection for non-solidly earthed distribution network has a wide range of applications in China and it has made significant achievements. However, the accuracy of the faulted section location (FSL) technique is not very high, which affects its large-scale application. Therefore, the focus of this study is to analyse the limitations of the existing techniques and to give some practical improvements. This study establishes a trial network in Xiamen, Fujian Province, China to comprehensively demonstrate the practicality of the new technique. The results show that the system can achieve accurate FSL and will be promoted for large-scale application.

1 Introduction

Compared with the transmission network, there is a high occurrence of earth faults in the medium-voltage distribution network, bringing undesired troubles to many power supply utilities. To improve power supply reliability and customers' satisfaction, China has recently expanded the investment in distribution network transformation. However, single-phase earth fault (SPEF) detection technology is still limited by the measuring principle, device design, network structure etc. Its function in the existing distribution automation system is relatively weak. Moreover, the accuracy of faulted section location (FSL) system implemented by the feeder terminal units (FTUs) and the fault passage indicators etc. is generally low.

In recent years, the application of waveform correlation analysis for FSL method becomes very popular. The application often ignores the effective trade-offs between polarity, amplitude, noise and other factors, resulting in low accuracy in the field. The location method has to be supplemented by the traditional manual technique, which consumes a large amount of manpower and material resources. Improving the computational techniques of FSL so as to provide a comprehensive overall SPEF location scheme through supervisory control and data acquisition or distribution automation (DA) system has become an urgent task [1–3].

2 Traditional FSL method of waveform comparison

2.1 FSL principle

The transient current characteristics on both sides of the faulted section are determined by the different parameters of their equivalent zero mode networks, and they have opposite polarities. Therefore, the characteristics of the zero mode currents can be effectively applied in FSL technique. The transient zero mode current upstream from the fault is the sum of the distributed capacitive currents for all the non-faulted lines and all the sections upstream from the measuring point. Its characteristics are high amplitude, low frequency, and the direction of current is from the fault point to the bus. The transient zero mode current downstream from the fault is the sum of the distributed capacitive current for all the rest of the downstream sections. Its characteristics are low amplitude, high frequency, and the direction of current is from fault point to the end of the line. As shown in Fig. 1, the characteristics of the transient current waveforms on both sides of the faulted section can be applied to perform FSL. These characteristics include frequency, amplitude, and polarity relationship [4].

2.2 FSL scheme

The correlation coefficient reflecting the relationship between different amplitudes and phases is widely used in feature extraction for the digit signal processing. Therefore, the correlation coefficient can be used by the correlation analysis of zero-module transient current at each measuring point on the feeder. This method is called 'included angle cosine' method as follows [5]:

$$\rho_{m,n} = \frac{\sum_{m=1}^{N} i_{0,m}(m) \sum_{n=1}^{N} i_{0,n}(n)}{\sqrt{\sum_{m=1}^{N} i_{0,m}^2(m) \sum_{n=1}^{N} i_{0,n}^2(n)}} \tag{1}$$

where i_0, $_m(k)$, $i_{0,n}(k)$ is related with the different period of zero-module current on their corresponding terminal (Table 1).

Therefore, this method sets a threshold δ. When the correlation coefficients of the zero mode transient current in #*m* FTU and #*n* FTU meet the following formula, the fault is judged to occur between these two FTUs. Otherwise, the fault is outside this section. Experience suggests that δ ranges from 0.5 to 0.7

$$|p_{m,n}| < \delta \tag{2}$$

2.3 Localisation limitation

The FSL criterion based on (2) does not require voltage signals. It only requires zero mode currents. Therefore, it is simple to implement. It also has big margin and good flexibility. However, there are some limitations.

2.3.1 Strongly coupled zero mode currents on either side of the faulted section cannot be discriminated: Under some

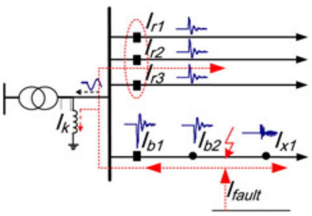

Fig. 1 *Waveform of zero-mode current*

special circumstances, the line to ground capacitive currents upstream and downstream of the faulted section cannot be distinguished. These situations occur when there are large cable sections in the downstream route. In this case, strong coupling will appear and the following may occur:

$$-1 \leq p_{m,n} \leq -\delta \tag{3}$$

This corresponds to $|\rho_{m,\,n}| > \delta$ for the faulted section. Therefore, the system fails to locate the faulted section and may even misjudge the fault to occur at the end of the line.

Thus, if the method does not consider the influence of polarity, it can have blind areas and can misjudge the faulted section.

2.3.2 Accurate location is affected by zero drift value and noise jamming: Due to electromagnetic interference, the aging of equipment etc, the waveforms acquired by the CT may be contaminated by noise and zero drift. Equation (1) fails to consider the above factors, and may lead to failures when interference occurs [6].

2.3.3 It ignores the influence of amplitude on the correlation coefficient: Equation (1) only reflects the extent of the relationship between signals; it does not quantify the difference of the signal amplitudes. However, the difference in amplitudes on the both sides of fault location is obvious. Thus, the influence of current amplitude needs to be considered. For instance, two signals may have the same frequency and phase signal but with different varying amplitudes, the correlation coefficients are all equal to one. This is demonstrated with $y = A\cos(2\pi 50t + 30)$, changing the value of A does not change the correlation coefficient.

3 Optimisation and improvement of location method

3.1 Principle of location method

Through the localisation limitation analysis from the previous section, this paper provides comprehensive consideration from three dimensions, as shown in Fig. 2.

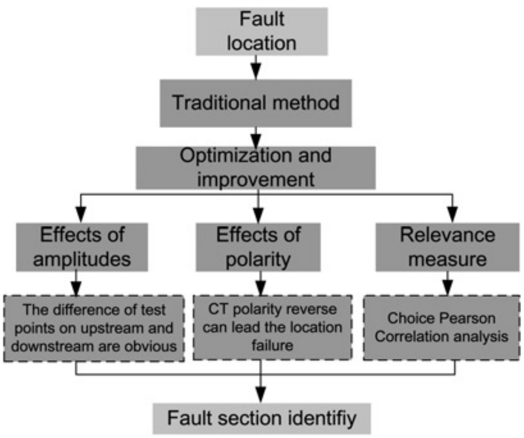

Fig. 2 *Fault location structure*

3.2 Similarity measurement base on Pearson product moment correlation coefficient (PPMCC)

In the practical applications, signals acquired from CTs are often subjected to a variety of electromagnetic interference, with a certain amount of noise and zero drift. This is equivalent to adding white noise and zero drift value to the original pure fault signal. Therefore, the actual signal can be expressed as follows:

$$\boldsymbol{X} = x + \boldsymbol{n}(t) + \zeta \tag{4}$$

where $\boldsymbol{X}$ is the original pure fault signal vector; $\boldsymbol{n}(t)$ stands for the addictive white noise vector; ξ means zero drift.

In statistics, in addition to the 'included angle cosine' method, (PPMCC/pearson correlation coefficient (PCCs)) is applied to measure the statistical indicators of the close correlation between the two sets of data:

$$p_{m,n} = \frac{\Sigma_{k=1}^{N}\left(x_k - \bar{X}\right)\left(y_k - \bar{Y}\right)}{\left[\Sigma_{k=1}^{N}\left(x_k - \bar{X}\right)^2 \Sigma_{k=1}^{N}\left(y_k - \bar{Y}\right)^2\right]^{(1/2)}} \tag{5}$$

where N represents the length of the signal, x_k, y_k stand for the kth sampling dot of the corresponding sampling signal $\bar{X}$, $\bar{Y}$, and show the average value of two signals.

PPMCC index is to comply with calculation principle of product difference method on the basis of the deviation of two different signals and their average values. The correlative degree between the two signals can be indirectly measured through two differential multiplications. When the zero drift and noise appear in the signal samples, the deviation effect causes the calculation of each sampling point to subtract the mean value and also the noise. As a result, the electromagnetic interference can be effectively suppressed, and the recognition rate of the signals can be improved.

Therefore, this paper uses PPMCC method. x_k, y_k are equivalent to $i_{0,m}(k)$, $i_{0,n}(k)$, the current sampling signals of two adjacent transient zero mode currents.

3.3 Influence of signal amplitude on correlation

According to Section 2.1, under normal circumstances, the amplitude of the upstream zero mode current from the fault point is significantly larger than the amplitude downstream. Therefore, it is effective to use amplitude differences for measuring the correlation, which is specifically demonstrated as follows.

(i) Obtain the maximum amplitude of the transient zero mode current of each terminal device on the fault line:

$$D_{\max} = \max\left(\sum_{k=1}^{N} i_{0,j}^2(k)\right) \tag{6}$$

where $i_{0,j}(k)$ represent the zero mode current for fault line detection, j stands for the terminal number.

ii. Take into account the influence of amplitude correction

$$\gamma_{m,n} = \rho_{m,n} \times \mathrm{e}^{-1 \times \frac{\left|\Sigma_{k=1}^{N} i_{0,m}^2(k) - \Sigma_{k=1}^{N} i_{0,n}^2(k)\right|}{D_{\max}}} \tag{7}$$