Electrical Power and Energy Systems 49 (2013) 243–252

Contents lists available at SciVerse ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

An ANFIS-based fault classification approach in power distribution system

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ARTICLE INFO

Article history:
Received 5 August 2010
Received in revised form 11 December 2012
Accepted 20 December 2012
Available online 26 February 2013

Keywords:
Fault classification
Neutral non-effectively grounded distribution
Adaptive Neural Fuzzy Inference System (ANFIS)
Wavelet transform

ABSTRACT

Fault classification is very important for power system operation because it is the premise of fault analysis process. In this paper, an ANFIS (*Adaptive Neural Fuzzy Inference System*) based fault classification scheme in neutral non-effectively grounded distribution system is proposed. The transient currents are obtained by wavelet transform after faults occur. According to the statistic characteristic of transient currents in different fault types, the fault identifiers are defined. The fault identifiers can characterize the traits of fault type and show different disciplinarian in different fault types. They are inputted into three ANFISs to obtain the fault type. The proposed approach only needs the voltages and currents measured at substation, and can identify ten types of short-circuit fault accurately. The simulation model is established in PSCAD/EMTDC environment, and the performance of the proposed approach is studied. The results show that it has high accuracy. Besides, the adaptability of proposed approach to the neutral compensated grounding system, different network configurations and so on are verified through simulation. Through simulation, the proposed approach exhibits good performance.

1. Introduction

Once fault occurs in power system, fast and accurate fault classification is very important for post-fault analysis and power supply restoration. On the one hand, fault type information is the premise of fault location. Correct fault classification helps fault diagnosis system select appropriate fault location scheme. On the other hand, as the automation of distribution network advances, a mass of data is uploaded after fault. So, it is impossible for operators to classify fault correctly by their experience.

A lot of work has been focused on the fault classification problem in transmission network [1–6]. It is probably due to the importance of fault classification for relay operations. As the amount of power carried by distribution networks increases during the past decades, the need of effective fault classification scheme becomes more and more necessary for operators. The research of fault classification in distribution network can be summarized to two categories approximately: (1) the schemes using stationary electric components [7–9], and (2) the schemes using transient electric components [10,11]. The method proposed in [7] is widely used in industry. It utilizes the angular relationships among stationary components to identify fault type in isolated distribution. The angular relationships are defined by fuzzy membership functions in [8], afterward, the fault type is obtained by logic reasoning mechanism. As fast sampling devices are installed in modern power systems, the acquisitions of transient electric signals are possible. It highly supports the transient-based post-fault analysis techniques, such as fault location [10], fault line identification [12] and so on. In the paper [10], the transient currents are obtained by stationary wavelet transform. Afterward, by comparison with energies of transient currents, the fault type is identified.

In this paper, an ANFIS-based fault classification approach in distribution network is proposed. It uses transient fault signals to actualize ten types of short-circuit fault classification (AG, BG, CG, ABG, ACG, BCG, ABC/ABCG, AB, AC and BC). The whole classification process contains 3 steps: the transient fault signals are extracted by WT (*Wavelet Transform*) at first. At second, the extracted signals are calculated for the statistic quantities, which are called FIs (*Fault Identifiers*) here. At third, the FIs are inputted into three ANFISs (*Adaptive Network-based Fuzzy Inference Systems*) to obtain the final result. The simulation model is established in PSCAD/EMTDC environment. The classification accuracy of proposed approach is verified under different fault circumstances. Moreover, the adaptability of proposed approach to different distribution operations is thoroughly studied. The results show that its adaptability is good.

The remainders of this paper are constructed as follows. The whole structure of proposed approach is introduced in section 2 for clearness. The regulars of FIs in different fault types are studied in section 3. The ANFIS-based fusion process is introduced in section 4. The classification accuracy of proposed approach is exhibited in section 5. The adaptability of proposed approach is studied in section 6. At last, the conclusion is given in section 7.

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0142-0615/$ - see front matter
http://dx.doi.org/10.1016/j.ijepes.2012.12.005

2. The whole structure

Although it is important how to trig fault classification approach, it is not the certain in this paper. The method proposed in the paper [10] can be employed to trig the fault classification approach and find the fault inception time. The structure of classification approach is depicted in Fig. 1.

In Fig. 1, the inputs of fault classification are the zero-sequence voltage $u_0(t)$ and the fault-components of three-phase currents i''_a, i''_b and i''_c. They are calculated by formulas (1) and (2),

$$u_0(t) = u_a(t) + u_b(t) + u_c(t), \tag{1}$$

$$i''_p(t) = i_p(t) - i_p(t - T). \tag{2}$$

where p stands for phase-a, b, and c, $i_p(t)$ is the phase-p current in the first basic cycle after fault inception at the secondary winding of transformer, $u_a(t)$, $u_b(t)$ and $u_c(t)$ are the three bus voltages in the first cycle after fault inception, and T is the basic cycle (20 ms).

As can be seen from Fig. 1, $u_0(t)$ and i''_p are preprocessed by FFT (*Fast Fourier Transform*) and WT separately. Moreover, the statistic quantities are calculated for WT-extracted signals. The 2 steps above aim at constructing the FIs, which are inputted into ANFISs to obtain the classification result. The FIs and their fusion process are very important for fault classification, because FIs must have distinguished features in different fault types, and the fusion process should fuse FIs effectively to obtain the correct results.

3. Fault Identifiers (FIs)

When fault occurs in power system, transient oscillation is dominant. To utilize the transient electric signals, WT technique is employed for its flexible time–frequency focus. By comparison with Daubechies series wavelets, the quadratic spline wavelet is selected as the mother wavelet in this work because of its good performance in fusion process. The coefficients of wavelet filter given by formulas (3)–(5) are typical, and are adopted in this work.

$$lo = [0.125 \quad 0.375 \quad 0.375 \quad 0.125] \times \sqrt{2}, \tag{3}$$

$$hi = [1.0 \quad -1.0] \times \sqrt{2}, \tag{4}$$

$$hii = [0.015625 \quad 0.109375 \quad 0.34375 \quad -0.34375 \quad -0.109375 \quad -0.015625] \times \sqrt{2}. \tag{5}$$

In (3)–(5), lo is the coefficient of low-pass filter in wavelet decomposition and reconstruction calculation, and hi and hii are the coefficients of high-pass filter in wavelet decomposition and reconstruction calculation respectively.

The current i''_p is implemented 3 levels of wavelet decomposition. The detail coefficients of 2 and 3 levels are reconstructed. The reconstructed signal is denoted by i'_p. As long as the sampling rate is 10 kHz, it can be known that the frequency band of i'_p ranges from 625 Hz to 2.5 kHz. The frequency band employs transient components as much as possible, while avoids the interference of the 3rd–11th harmonics which are normal in power system.

Fig. 2 shows the original currents and WT-extracted currents in ACG fault occurring at 0.1 s.

It can be seen from subfigure (b) in Fig. 2 that the WT-extracted signals of faulty phases (phase-a and -c) vary more intensively than the WT-extracted signal of healthy phase (phase-b). The description is qualitative, so the quantitative description should be found out. As long as i'_p is the signal in one basic cycle, it has 200 sampling points. There would be 600 inputs if i'_a, i'_b and i'_c are inputted into ANFISs directly. This is unpractical. Since the statistic quantities can characterize the shape and energy of signals, six statistic quantities are selected from 12 typical statistic quantities [13], and they are calculated by,

$$s^*_p = \frac{s_p}{s_{\max}} \quad p = a, b, c, \tag{6}$$

$$\rho_{a,b} = \left| \frac{E(i'_a i'_b) - E(i'_a)E(i'_b)}{\sqrt{E(i'_a)^2 - E^2(i'_a)}\sqrt{E(i'_b)^2 - E^2(i'_b)}} \right|, \tag{7}$$

$$\rho_{a,c} = \left| \frac{E(i'_a i'_c) - E(i'_a)E(i'_c)}{\sqrt{E(i'_a)^2 - E^2(i'_a)}\sqrt{E(i'_c)^2 - E^2(i'_c)}} \right|, \tag{8}$$

$$\rho_{b,c} = \left| \frac{E(i'_b i'_c) - E(i'_b)E(i'_c)}{\sqrt{E(i'_b)^2 - E^2(i'_b)}\sqrt{E(i'_c)^2 - E^2(i'_c)}} \right|. \tag{9}$$

In formula (6),

$$s_p = \left(\frac{1}{n-1} \sum_{i=1}^{n} (i'_p(n) - E(i'_p)) \right)^{\frac{1}{2}}, \quad n = 200, \tag{10}$$

$$s_{\max} = \max(s_p). \tag{11}$$

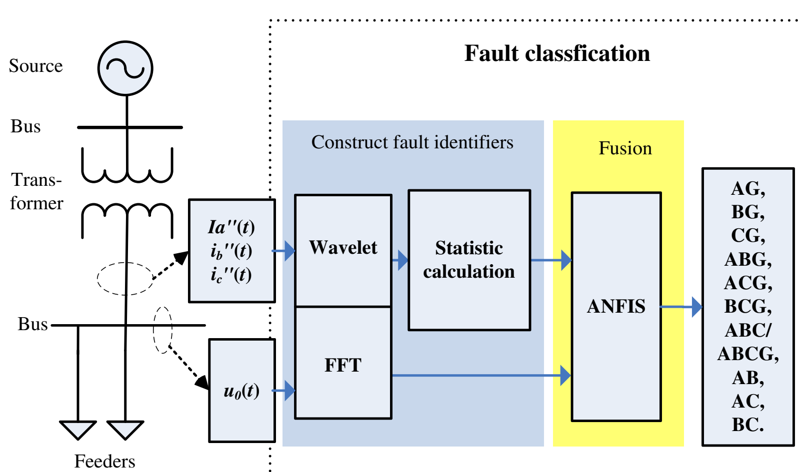

Fig. 1. Structure of fault classification.