Electrical Power and Energy Systems 55 (2014) 467–472

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

An improved fault-location method for distribution system using wavelets and support vector regression

Lei Ye*, Dahai You, Xianggen Yin, Ke Wang, Junchun Wu

State Key Laboratory of Advanced Electromagnetic Engineering and Technology, Huazhong University of Science and Technology, Wuhan 430074, China

ARTICLE INFO

Article history:
Received 17 December 2012
Received in revised form 5 September 2013
Accepted 25 September 2013

Keywords:
Fault location
Distribution system
Wavelet transform
Support vector regression

ABSTRACT

This paper presents a wavelets and support vector regression (SVR) based method for locating grounded faults in radial distribution systems. The method utilizes traveling wave data recorded at the substation only. After modal transformation on three-phase traveling waves, the arrival time and amplitude information of modal components are extracted using discrete wavelet transform (DWT). In particular, time delay and ratio between the first Wavelet Transform Modulus Maxima (WTMM) of modal components in each scale are the candidate features for training a SVR which will be used for fault distance prediction. The simulation and SVR process are performed respectively using PSCAD/EMTDC and MATLAB. The result shows the method has high accuracy and good stability.

1. Introduction

Localization of faults on power transmission lines is one of the main concerns for all electric utilities, as accurate fault location can lead to reduction of outage time and costs. So far, various fault location methods have been proposed and can be classified as fundamental components based methods [1–8] and traveling wave based methods [9–16]. All the above methods use the measured data either from single end of the transmission line or from multi-ends. The multi-end method requires synchronized measurement with time stamping and online communication to locate the fault. On the other hand, the single-end method just requires measurement at one end and is suitable for fault location in distribution networks which always only have measurement at substation end.

In recent years, more efforts are devoted to the research on fault location techniques for distribution systems. Many distribution networks are non-effectively earthed systems, which make fundamental components based methods impractical to locate single-line to ground (SLG) fault. Although traveling wave based method is applicable in distribution network, two or multi-end method is expensive to implement because of the inadequate measurements in distribution network. Thus, single-end traveling wave based method is very practical to locate fault in distribution network.

Wavelet transform (WT) is most common tool for analysis on traveling waves in power system. The time, frequency and amplitude (represented by wavelet transform modulus) information of transient traveling waves can be extracted by wavelets analysis. Time-domain reflectometry (TDR) is one of the most common traveling-wave based fault location methods on transmission lines [9–11]. But in distribution network, TDR are not easy to interpret due to reflections in discontinuity points. Regardless of the reflection of traveling waves, grounded fault can be located utilizing time delay of modal components, assuming that the velocities of modal components are constant [12]. But velocity of zero mode component is not stable actually. Recently, by mapping TDR in frequency domain using continuous wavelet transform (CWT), a new approach discussed a correlation between characteristic frequencies and fault location, and showed reduction in the complexity of TDR-based fault location methods in distribution systems [13–16]. But due to the attenuation of traveling waves in propagation and insufficient frequency resolution of wavelets analysis in high frequency spectrum, accurate characteristic frequencies are difficult to obtain and the error is still significant. Moreover, the energy of SLG fault-originated traveling wave in neutral non-effectively earthed system is not large enough to be used to undertake the detection of characteristic frequency in any fault location because of serious refractions and reflections in distribution system with laterals.

To fix the complexity of traveling wave reflection in distribution network, various Artificial Intelligence approaches which employ high-frequency component of fault-originated waveforms have been published [17–20]. In [19], ANN training is performed using the modal frequency and amplitude of the transient current waveform. In [20], the energy information in each scale (frequency band) provided by wavelet multi-resolution analysis (MRA) of the recorded transient voltage is used as training input of ANN.

---

* Corresponding author. Tel.: +86 13476074611.
E-mail address: leavesclub@hotmail.com (L. Ye).

0142-0615/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijepes.2013.09.027

The method in [19,20] just utilize the information of frequency and amplitude extracted by DWT analysis. Since the scale in DWT analysis represents a frequency band in frequency domain, the frequency information extracted by DWT analysis is not in high frequency resolution, and the relation between the inputs and outputs of ANN in [19,20] are not clear, as a result, a large amount of samples must be obtained for seeking this relation in training process of ANN.

This paper is aimed to locate grounded faults in distribution systems of all grounding types. The proposed method is a single-end method using wavelets and SVR, which makes full use of the time, frequency and amplitude information of traveling waves. It is found the time delay and ratio between the first WTMM of modal components in each scale are related with fault distance. Moreover, these relations with fault distance are very clear and these features are very suitable as training input of SVR for fault location. In comparison with former methods, the SVR which integrate these strong relations achieves very good performance with few training samples. At the meantime, the method is accurate and irrespective to the effects of fault inception angle, fault distance and fault impedance.

2. Wavelet transform and SVR

2.1. Wavelet transforms

Wavelet transform (WT) is a power tool in signal processing and can realize both the time and frequency localization. Wavelet transform of sampled waveforms can be obtained by implementing the discrete wavelet transform (DWT). Given a digital signal function $f(k)$, its DWT will be calculated as follows [9]:

$$\mathrm{DWT}(f,m,n) = \frac{1}{\sqrt{a_0^m}}\sum_k f(k)\psi^*\left(\frac{n-ka_0^m}{a_0^m}\right) \quad (1)$$

where the a_0^m and ka_0^m corresponds to the scale factor and shifting factor. If $a_0 = 2$, it is called discrete dyadic wavelet transform (DDWT) which is fast and popular in singular detection [21].

Implementation of the discrete wavelet transform, involves successive pairs of high-pass and low-pass filters at each scaling stage of the wavelet transform. This can be thought of as successive approximations of the same function, each approximation providing the incremental information related to a particular scale. The first scale will cover a broad frequency range at the high frequency end of the spectrum, and the higher scales will cover the lower end of the frequency spectrum with progressively shorter bandwidths. Conversely, the first scale will have the highest time resolution and lowest frequency resolution and higher scales will cover longer time intervals and shorter frequency ranges [9].

DDWT is utilized for the singular detection of signals in this paper. As illustrated in [21], the WTMM which is a strict local maximum of the wavelet transform modulus is used to detect singular point.

Assuming $Wf(m,n)$ represents wave transform coefficient, the definition of WTMM is:

(1) WTMM is a local extremum at any point (m_0, n_0) such that $(\partial Wf(m_0,n))/(\partial n)$ has a zero-crossing at $n = n_0$, when n varies.
(2) WTMM is modulus maximum at any point (m_0, n_0) such that $|Wf(m_0, n)| < |Wf(m_0, n_0)|$ when n belongs to either a right or the left neighborhood of n_0, and $|Wf(m_0, n)| \leqslant |Wf(m_0, n_0)|$ when n belongs to the other side of the neighborhood of n_0.

The time and value of WTMM represent arrival time and amplitude of traveling waves. In addition, the choice of different wavelet functions has a great impact on singularity detection. In this paper, DDWT is adopted, and wavelet function is quadratic B-spline wavelet.

2.2. Support vector regression

Support vector machines (SVMs) were first developed as a support vector classification (SVC) to solve classification problems, within the area of statistical learning theory and structural risk minimization [22–24] . Although SVMs have been used for fault classification, and transmission lines parameter estimation for fault locations, it can also be applied to regression problems by an alternative loss function. These SVMs are called support vector regression.

SVR uses structural minimization principles to choose discriminative functions that have minimal risk bound, and the necessary training sample size is smaller. Therefore SVRs are less likely to over-fitting data than other classification algorithms such as multilayer perceptron (MLP) neural network classifiers. SVR results in a global solution because they are trained as a convex optimization problem. They have been shown to be an attractive and more systematic approach to learn linear or nonlinear decision boundaries [25]. SVR includes linear SVR and nonlinear SVR. In this paper, nonlinear SVR is used for estimating fault locations.

3. Fault distance estimation

3.1. Basic ideas

The proposed method utilizes the sampled signals at substation end only. After modal transformation, the three-phase voltage waves recorded at substation are transformed to aerial mode component which is present for any kind of fault and zero mode component whose magnitude is significant only during faults having a path to ground. The main idea of this paper is to use the inherent difference between modal components to locate SLG fault.

Single-end methods [11,12] based on time delay between modal components was presented before, and its fault location formula is given as follows:

$$s = v_1 v_0 (t_0 - t_1)/(v_1 - v_0) \quad (2)$$

where v_1 and v_0 is the velocity of the aerial mode component and zero mode component of traveling waves separately, accordingly t_1 and t_0 are the arrival times of the two mode components, s is the estimated fault distance.

It is necessary to obtain the arrival times and velocities of aerial mode component and zero mode component accurately in (2). The time delay between modal components can be obtained by wavelet analysis, but the velocity of zero mode component is difficult to be estimated accurately as it varies with fault distance and frequency. In [9], the velocity of zero mode component is considered as a constant, which may result in significant error.

To avoid the complex estimation of the velocity of zero mode component, a SVR based fault location method is presented in this paper. Besides time information, SVR integrates the information of amplitude and frequency, which improve its accuracy and stability. The training samples of SVR are constructed with the features extracted from recorded traveling waves by wavelet analysis and SVR outputs the fault distance at last.

3.2. Features extraction

It is important for SVR to choose the proper and typical training feature which is closely related with fault distance.

For each mode component, its propagating constant γ and velocity v is expressed as follows: