Imperial Journal of Interdisciplinary Research (IJIR)
Vol-3, Issue-4, 2017
ISSN: 2454-1362, http://www.onlinejournal.in

Study of Wavelet based line protection & fault detection on transmission line

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Abstract: *Power swing caused by various disturbances will affect distance relay behavior and may result in relay misoperation. In This paper provides a new wavelet-based method for detection and classification of transmission line faults on transmission line. The multi-resolution analysis based on wavelet transform (WT) has the ability to decompose the analyzed signals into different frequency bands. With the wavelet transform of the voltage and current signals acquired by distance relays, the different faults will be identified by feature extracting from the D5 component of Daubechies-8 (Db8) wavelet. The proposed approach is verified by using IEEE reference model implemented using EMTP. The test results, which include ground fault and phase fault, have been presented in this paper. This proposed method can be used for relay operation blocking or monitoring.*

Keywords: *Wavelet transform, fault detection, fault classification, power swing, Travelling Wave*

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1. Introduction

Modern extra high voltage (EHV) and ultra high voltage (UHV) networks require faults to be cleared rapidly and selectively as an effective method to increase power transfer and improve transient stability. This has motivated research on ultra high-speed (UHS) protection. The UHS directional protection has been widely used in EHV and UHV power systems as it can quickly isolate the fault and needs only limited data communication. Traveling wave-based directional protection [1], [2] is one of the typical UHS directional identification schemes. These schemes can quickly determine the fault direction according to the fault traveling wave signal. Correct discrimination is limited with the first arrival of the traveling wave since the following traveling wave is affected by the reflected and transmitted wave. Also, the sensitivity of these methods greatly depends on the fault inception angle. Other schemes of directional protection have been developed in recent years. With the advent of the artificial intelligence techniques, artificial neural networks (ANNs)-based schemes have been proposed to discriminate fault direction. Since ANN is a powerful tool in pattern recognition and the fault direction identification problem can just be treated as a pattern classification problem, the ANN-based approaches [3]–[5], [12] can detect the fault direction fast and reliably. One problem encountered with these schemes is that the neural networks require a substantial amount of field data to train, which sometimes may be difficult to obtain. A different approach to directional protection, based onthe wavelet transform of fault transients is presented in thispaper.Wavelet transform is a relatively new concept yet it has successful applications in many fields. Its application in power systems has been researched and developed for the past several years. Typical applications include fault location [7], high-impedance fault detection [8], power quality detection, and classification [9], etc. Unlike traditional Fourier transform, a wavelet transform is capable of providing the time and frequency information simultaneously, and hence, gives a time-frequency representation of the signal. This ability can be well adapted for finding the fault location and spatial distribution of a singular signal.

2. Wavelet Composition of traveling wave

For convenience in analysis and calculation, modal transformation is used to decouple three phases of the transmission system into three independent systems. A modal component of Clarke transformation has been employed [10]. For instance, the component of voltage is $\mu_\alpha(t) = (2\ \mu_A(t)-\ \mu_B(t)-\ \mu_C(t))/3)$. The rest of the phases may be deduced by analogy. Since the B-spline wavelet does not have phase distortion under certain precision [11], it is used to decompose voltage and current traveling waves. By using Mallet's pyramid algorithm, the transient signal is decomposed as below

$$\begin{cases} c_{j+1}(t) = \sum\limits_k \frac{h(k-2t)c_j(k)}{\sqrt{2}} \\ d_{j+1}(t) = \sum\limits_k \frac{g(k-2t)c_j(k)}{\sqrt{2}} \end{cases} \tag{1}$$

where K stands for the index of wavelet coefficients number,$C_{j+1}(t)$ and $d_{j+1}(t)$ are smooth and represent detail of the original signal, respectively, under dyadic wavelet scale 2^{j+1}. In (1), forj=0,$C_j(k)$, is a discrete original signal, namely sampled values of voltage and current. h (k-2t) and g (k-2t) is a pair of conjugate filters, respectively, corresponding to a pulse response sequence of the low-pass filter and the band pass filter. Discrete wavelet transformation (DWT) is achieved by iteratively calculating (1).

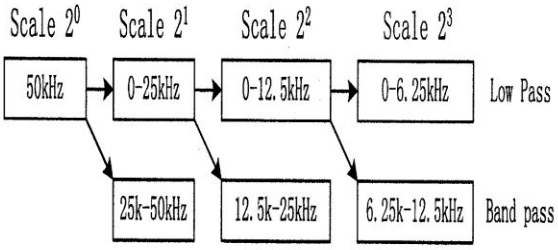

Fig.1.Dyadic wavelet decomposition for traveling wave sampled at 100 kHz.

Since the traveling wave directional protection to determine the fault direction uses the initial traveling wave of fault transient signal, one can utilize the results of the wavelet transformation, that is to say, the details d_{j+1} in (1).The details of wavelet decomposition in different scale can provide the magnitude and phase information at corresponding frequency band [11]. In order to extract a transient traveling wave that contains frequency components mainly between 10 and 100 kHz, the sample rate of the microprocessor-based protection must be between 20 and 200 kHz, according to the Nyquist criterion. Considering various aspects including cost, it is suggested that a 100 kHz sample rate is appropriate. The original signal can be divided into several frequency bands with DWT as depicted in Fig. 1. Obviously, the main components of the traveling wave distribute between scales 2^1 and 2^3 .

3. Schemes of Wavelet Transform

3.1. Floating Threshold Fault Detection Criteria:

In order to improve the ability of protection and to overcome the effect of noise in normal operation, a power frequency fault component based adaptive algorithm is used in this paper to detect fault. The criterion given below greatly decreases the chance of mal operation of protection

$\Delta I(t) > k_1 \Delta I\ (t-2T) + k_2$ Iad.

Here $\Delta I(t)$ is the magnitude of the current fault component at time . In order to track the unbalance in system and avoid the frequent pickup of protection, (4) includes $\Delta I\ (t-2T)$ which is the magnitude of current fault component prior to the fault occurrence. Iad.is load current before the fault. $K_1$and K_2 are constants.

3.2.Wavelet Decomposition and Directional Comparison:

After the fault is detected, the back tracing sampled data utilizes (1) to fulfill DWT. The results of wavelet decomposition dj(t) corresponding to voltage and current are W j[Δu(t)] and , respectively. According to the definition of the modulus maxima of wavelet transform [13], in each scale, the corresponding ecomposed voltage and current can constitute the local modulus maxima of instantaneous power

$$M\left\{W_j\left[\Delta u(k)\right] \times W_j\left[\Delta i(k)\right]\right\}$$

Here is the location of local modulus maxima in decomposed signal and represents local modulus maxima. Eliminating the noise by the propagating property of the modulus maxima of wavelet transform and appropriate threshold, the local modulus maxima caused by initially arrived traveling wave can be searched through back tracing. According to (2) and (3), the principle of wavelet-based traveling wave directional protection can be described as below

$$M\left\{W_j\left[\Delta u(k_0)\right] \times W_j\left[\Delta i(k_0)\right]\right\} < 0, \quad \text{Forward} \quad (5)$$

$$M\left\{W_j\left[\Delta u(k_0)\right] \times W_j\left[\Delta i(k_0)\right]\right\} > 0, \quad \text{Backward.} \quad (6)$$

In (5) and (6),Ko ϵ {k} is the location of local modulus maxima caused by the initially arrived traveling wave..

4. Wavelet Transforms

Wavelets were first applied in the area of geophysics. Today, Wavelet Transforms are employed in a variety of applications, from detecting High Impedance arc type faults [4, 6] to compression of fingerprint files. A brief overview of Wavelets is given below [7]. Consider a signalx(t), with bandwidth 0 to π.Letφ(t)be another selected function defined as

φm(t)=φ(t−m). (1)

φ(t/2)is a dilated version of φ(t). φ(t)and the translated version of φ(t) expressed as φ(t −m) can be used to completely represent φ(t/2)as follows.

$$\phi\left(\frac{t}{2}\right) = \sqrt{2}\sum_{m=0}^{N} h'(m)\phi(t-m), \qquad (2)$$

Where h ^{1}(m) are some specified coefficients. The function φ(t) in (2) is called the “scaling function”. For φ(t),(2) becomes

$$\phi(t) = \sqrt{2}\sum_{m=0}^{N} h'(m)\phi(2t-m). \qquad (3)$$

The equivalent "wavelet function",ψ(t), is obtained from
the scaling function as

$$\psi(t) = \sqrt{2}\sum_{m=0}^{N} -(-1)^m h'(N-m)\phi(2t-m), \quad (4)$$

5. POWERSYSTEM

The single line diagram of the sample EHV, meshed transmission interconnected power system is shown in Figure1. The local source is a 13.8 kV, 2000 MVA generating station and is modelled by an equivalent 60 Hz, 13.8 kV Thevenin's source in series with a 0.2437mH inductance and a 0.025Ωresistance. The source voltage is stepped up to 500 kV using a Δ-Y transformer bank. The remote source is a 500 kV, 3200 MVA system and is modelled by an equivalent 60 Hz, 500 kV Thevenin's source in series with a 207mH inductance and a 7.8Ωresistance. The phase difference between the local source and the remote source is 10◦.The transmission line is a single circuit, 322 km 00 miles)'Long Transmission Line'. It is transposed at 80 km (50 miles), 161 km (100 miles), and 282 km (175 miles) intervals. Conductors are bundled with 3 conductors per bundle per phase. The transmission line is modelled using the frequency dependent Jos´ e Marti Model [12] using EMTP-ATP [13].

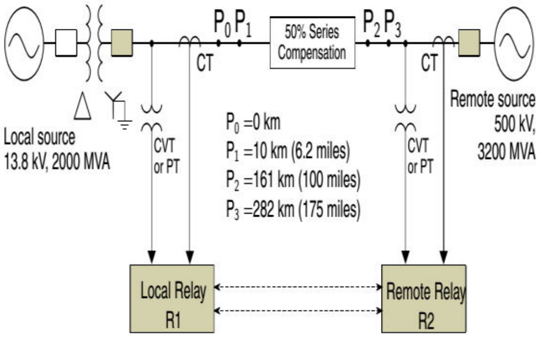

Fig. 3: Single Line Diagram of the Meshed, 500 kV, 322 km (200 miles) Transmission System

4. Conclusion

Principle and application of the wavelet-based ultra high speed traveling wave directional transmission line protection is analyzed and discussed in this paper. According to the analysis and results of simulation studies, the following conclusions can be drawn. The modulus maxima of wavelet transform can easily detect transient traveling wave and eliminate the influence of noise.

It is a powerful tool to achieve the traveling wave-based protective relay. The proposed scheme overcomes many problems that traveling wave protection faces as the oscillations caused by the faults close to impedance discontinuities, the effect of widely used CCVT, the influence of fault resistance, and line trap. The extreme cases relevant to inherent disadvantage of traveling wave, fault inception angle near or at zero crossing is unable to be solved by wavelet theory. It means that under these situations, other means should be adopted. Obviously, an omnipotent principle does not exist. In general, the wavelet-based ultra high speed traveling wave directional detective scheme has many advantages. Further research and development is necessary and is in progress.

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