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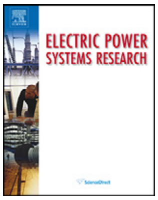

A high speed noncommunication protection scheme for power transmission lines based on wavelet transform

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ABSTRACT

This paper presents a high-speed protection scheme for power transmission lines based on wavelet transform (WT). It is a noncommunication protection scheme as it depends completely on locally measured currents. It utilizes WT, which acts as a multi-level bandpass filter, to extract two distinct bands of frequency from the fault induced high frequency (HF) transient currents; the first band is high while the second band is relatively lower. The spectral energies of the extracted signals are then calculated to form two discriminating signals of the relay (operative and restraint). Based on the ratio between these discriminating signals the relay can distinguish whether a fault is internal or external to the protected line.

The performance of the introduced protection scheme was evaluated by simulating several faults on 400 kV–50 Hz transmission system using an electro magnetic transient program (EMTDC). The simulation results showed distinct performance of the scheme irrespective of the fault type, fault inception angle, fault position and fault resistance. Moreover, it is not affected by a system configuration and system source parameters.

1. Introduction

EHV transmission lines protection schemes can be classified into two main categories: the communication and noncommunication protection schemes. However, each of the aforesaid protection schemes has its own problems. In this respect, the problems of the noncommunication protection schemes, such as distance protection, are: it cannot protect the entire line and its setting is not easy. In this context, the communication protection schemes, such as differential protection, were solved the aforesaid problems, but they need an expensive and complicated communication system. Furthermore, the reliability and cost of the communication protection schemes are function of the reliability and cost of the used communication systems [1]. Hence, a high-speed, low cost and reliable noncommunication protection scheme for the entire transmission line protection is required.

In this respect, the communication protection schemes [2,3] and noncommunication protection schemes [4,5] based on transient components were offered a high-speed protection of the entire line. However, they suffered from several limitations, such as not being able to detect faults with zero phase inception angles, high resistance faults and are affected by any change in a system configuration and system source parameters.

To get rid of the aforesaid limitations, the authors of [6,7] presented a noncommunication protection scheme based on capturing the fault generated HF transient voltages with the help of line traps and stack tuners. They designed special bandpass filters, with 17 floating point coefficients, to extract two distinct signals from the captured signals in order to form the operative and restraint signals and hence to distinguish whether the fault is internal or external to the protected line. However, installing line traps and stack tuners at each end of the line increases the cost and limits the application of the scheme. To solve the aforesaid problem the author of [8] presented an alternative form of noncommunication protection scheme based on the fault generated HF transient currents that does not require line traps and stack tuners. However, the technique in [8] alone has difficulty in distinguishing between a fault on the line close to remote busbar within the protected zone and on the busbar or close to the busbar outside the protected zone. In addition, the use of two needless modal signals in [8] to cover all types of faults at low speed specially designed multi channels filter, with 8 floating point coefficients, may limit its application. The authors of [9] used the so-called 'Chaari' recursive complex WT [10] to extract the aforesaid two distinct bands of frequency. However, the recursive WT requires historical and future data and requires a large number of computations; e.g., it needs 36 real multiplications and 35 real additions for each sample [10]. The authors of [11] used the 'db4' wavelet, which has a bandpass filter of 8 floating-point coefficients, to extract the abovementioned bands of frequency. The authors of [12] augmented the scheme of [8] with line traps

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and used an improved recursive WT that depends only on a historical data. Moreover, they used phase information to discriminate the faulted line. However, in addition to a large number of computations required by the scheme, installing line traps increases the scheme cost and limits its application.

It is obvious from the above survey that the filtering algorithm is the core of the non-communication protection scheme. Hence, suitable choice of the filtering algorithm, in terms of speed and time frequency localization, plays a vital role. Therefore, this paper uses a high-speed wavelet "Piecewise Linear Spline Wavelet", which has a bandpass filter with 3 coefficients, for developing a high-speed noncommunication protection scheme for EHV transmission lines. In this respect, the WT was used to capture two bands of frequencies from the fault induced HF transient currents. The spectral energies of these bands were used for faulted line discrimination. Computer simulation of the scheme showed that the scheme has a high-speed response and distinct performance irrespective of the fault type, fault inception angle, fault position and fault resistance.

2. Theory of wavelet transform

Wavelet is a waveform of effectively limited duration that has an average value of zero. WT is relatively a new signal processing tool for transient signals analysis. It breaks up a signal into shifted and scaled (compressed or dilated) versions of the mother wavelet (basis function). WT has some unique features that make it more suitable for transient signals analysis in a power system [9–13], such as:

- It has the property of time-frequency localization, even, of a small disturbance in a signal.
- WT has a strong capability of extracting the signal components under different frequency bands while retaining the time domain information.

The continuous WT (CWT) of a time dependent signal $f(t)$, is defined as the sum over all times of a signal $f(t)$ multiplied by a scaled and shifted versions of a mother wavelet $\psi(t)$. The mother wavelet $\psi(t)$ can be defined as follows:

$$\psi_{b,a}(t) = \frac{1}{\sqrt{a}}\psi\left(\frac{t-b}{a}\right) \quad (1)$$

where "a" and "b" represent the time scaling and shifting, respectively. The coefficients C_f (a, b), or the CWT, are defined by the following inner product:

$$C_f(a,b) = \int_{-\infty}^{+\infty} f(t)\cdot\psi^{*}_{b,a}(t)\cdot dt \quad (2)$$

where "*" refers to a complex conjugate.

WT of a sampled signal can be obtained using the discrete WT (DWT) relation:

$$\mathrm{DWT}(m,n) = \frac{1}{\sqrt{a_0^m}}\sum_k f(k)\psi^{*}\left(\frac{n-ka_0^m}{a_0^m}\right) \quad (3)$$

where the parameters a and b in (1) are replaced by a_0^m, ka_0^m, respectively, n, k, a_0 are integers; a_0 is some selected spacing factor (usually chosen equal to "2" for dyadic grid), and m is the scaling index 0, 1, 2, 3,. . ..

Generally, WT consists of successive pairs of low and high pass filters [14,15]. For each pair the high-scale, low frequency components of the signal $f(t)$ are called approximations (CA), while the low-scale, high frequency components of the same signal $f(t)$ are called details (CD). After each filtering stage, every second data point is thrown away to avoid redundant data. Fig. 1 depicts the two stages filtering process of a signal $f(t)$.

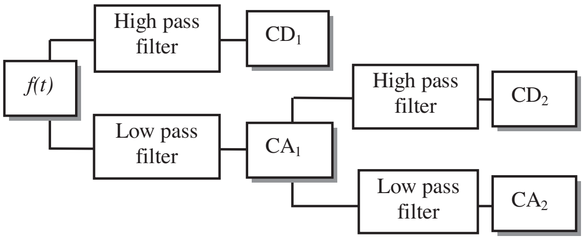

Fig. 1. Two stages filtering process of a signal $f(t)$.

3. Principle of the noncommunication protection

If a fault occurs on a transmission line a wideband of HF transient current signals will be induced at the fault point, then they will travel toward the line's busbars, which constitute a discontinuity points. Accordingly, part of the signals will continue along the adjacent line(s) while the rest will reflect back and forth between a fault point and the line's busbars until a post fault steady state is reached.

The principle of a noncommunication protection scheme can be explained using a 400 kV transmission system (shown in Fig. 2); the lengths of lines are given in figure. The protection relay '$R_{yz'}$' is assumed to be installed on line 'L_2' near busbar 'Y', and is responsible for the protection of the entire line 'L_2'. C_S represents the stray capacitance of the busbar (typically 0.1 μF [6–10]) that has low impedance at high frequency and high impedance at low frequency. In this context, a busbar is normally connected to many power equipments such as power transformers and generating units, the characteristics of these equipments will determine the busbar to ground impedance that is normally conductive in nature. However, at significant high frequencies, the capacitance and capacitive coupling become the dominant factor in the busbar impedance [6,8]. Therefore, a significant amount of the transient current, particularly the higher frequency components, will be shunted to ground through the busbar capacitance. This feature is the key to develop a noncommunication protection scheme in which the busbars at both ends of a protected line can be used as boundaries to the protected zone [8]. When an external fault occurs on a transmission system shown in Fig. 2, e.g., at point F_2 on line 'L_3', the transient current signal I_2, which contains wideband of HF components, will travel toward busbar 'Z'. When this signal reach busbar 'Z' part of it, I_1, will continue to travel into line 'L_2', and the rest, I_o, will be shunted into ground by a busbar capacitance. As a result, the relay 'R_{yz}' will measure an attenuated current, I_1, rather than the initial current I_2. However, the attenuation will be larger at higher frequency than that at lower frequency since the busbar impedance into ground decreases with increasing frequency. In contrast, there is no such attenuation in case of an internal fault, e.g., a fault at point F_1 on line L_2. This important feature can be used to discriminate between internal and external faults.

The introduced high-speed noncommunication protection scheme depends on using high-speed WT, which acts as a multilevel bandpass filter, to capture two distinct bands of frequency, one of low frequency level and the other of higher frequency level. The ratio of the spectral energies of the higher band to the lower band will be used to discriminate between external and internal faults.

4. Relay design description

A block diagram of the introduced protection scheme is shown in Fig. 3.