



A Review on Fault Location Techniques in Long HVDC Transmission Lines

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ABSTRACT: In this paper, an analytical study has been done on the typical HVDC transmission line problems, faults and the previous methods which were used for the fault location purpose. The previous techniques and the recent CWT technique has been presented. The CWT technique relies on the traveling-wave principle and requires the fault-generated surge arrival times at two ends of the dc line as inputs. With the help of exact surge arrival times obtained from time-synchronized measurements, the proposed theory or technique can accurately predict the faulty segment as well as the exact fault location. Continuous wavelet transform coefficients of the input signal which are used to calculate the accurate time of arrival of traveling waves at the dc line terminals gives us location of the fault.

KEYWORDS: Transmission lines, Fault location, Traveling waves, Wavelet transform.

I. INTRODUCTION

The Accuracy in the location of faults in power transmission systems can save time and resources for the electric utility industry. Mostly line searched faults are costly and also cannot be concluded fast. Thus, it is very important that the information must be accurate, immediate and acquired promptly in a form which is most useful to the person handling the power system. A high-voltage, direct current (HVDC) electric power transmission system uses direct current for the bulk transmission of electrical power. For long-distance transmission, HVDC systems are less expensive and give lower electrical losses. Most of the power projects are situated far away from the load centers, because of the availability of the raw material required for the power plant such as coal, water etc. Thus, it requires an efficient power transmission in order not to lose the much needed power in the transmission line. If higher is the transmission voltage, then lower are the transmission losses. It is well known that High voltage is required for the transmission of electrical power in order to reduce the energy loss in the line. The length of the transmission lines is very long i.e. up to 2000km long lines. Now, if fault occurs in such lines, it is very tedious work to locate the exact point where the fault has been occurred. Accurate fault location in such long dc lines is a challenging task. Hence, it is very necessary to establish a technique which gives the precise location of the fault to power engineer, in the minimum possible time.

Theme of this paper is, to investigate a method for location of fault in a long overhead HVDC transmission line. The lines may be 2000km long depending upon the necessity of that area. Fault is located using the two-terminal travelling wave method, in this project. This paper proposes use of various different techniques used in location of fault along with the continuous wavelet transform technique.

II. LITERATURE REVIEW

Travelling Wave Phenomenon

The transmission line conductors have resistances and inductances distributed uniformly along the length of the line. Travelling wave fault location methods are usually more suitable for application to long lines. Transmission lines cannot be analysed with lumped parameters, when the length of the line is considerable compared to the wavelength of the signal applied to the line. Power transmission line, which operates at 50-Hz and is more than 80-km long, is considered to have distributed parameters. These lines have the properties of voltage and current waves that travel on the line with finite speed of propagation. Travelling wave methods for transmission lines fault location have been reported since a long time. Successive developments engage high speed digital recording technology by using the travelling wave transients created by the fault. It is well known that when a fault occurs in overhead transmission lines



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systems, the abrupt changes in voltage and current takes place, at the point of the fault. This generates high frequency electromagnetic impulses called travelling waves which propagate along the transmission line in both directions away from the fault point. These transients travel along the lines and are reflected at the line terminals. Propagation of transient signals along multiphase lines can be better observed by decomposing them into their modal components. If the times of arrival of the travelling waves in the two ends of the transmission line can be measured precisely, the fault location then can be determined by comparing the difference between these two arrival times of the first consecutive peaks of the travelling wave signal. Travelling-wave-based line fault location principle has been successfully applied to transmission line fault location in the conventional HVDC systems with two terminals.

Previous Methods for Fault Location in Long HVDC Transmission

There were few techniques used for the location of the fault as per the inventions and availability of the tools in that particular time period. As development in all the fields took place, the upgradation in this technique also was done. The various methods used previously in fault location are presented here.

2.1 Radio Repeater Station

Initially, fault location in long HVDC systems was achieved by the repeater stations. Extra hardware was installed at the repeater stations, which were required to locate line faults using the existing technology, increases the cost of these transmission projects. A radio repeater is a combination of a radio receiver and a radio transmitter that receives a weak or low-level signal and retransmits it at a higher level or higher power, so that the signal can cover longer distances without degradation. All stations using the repeater transmit on the repeater's input frequency and receive on its output frequency. Since the repeater is usually located at an elevation higher than the other radios using it, their range is greatly extended. A repeater is usually installed on top of a tall building or on a mountain, and is equipped with an efficient antenna system, so it can receive weak signals and have wide transmission coverage. A repeater can extend the effective communication range of a low-power handheld radio to dozens, or maybe hundreds, of miles. Repeaters are sometimes linked together to further extend the range of communication.

In a Radio Repeater Station, a repeater is an automated radio station that extends the range of communications. It consists of a receiver tuned to one frequency and a transmitter tuned to a different frequency, linked together with a controller device. When the receiver receives a signal, the controller activates the transmitter, which then simultaneously retransmits the received signal. Thus, CWT method looks for, whether the faults can be located accurately only using the terminal measurements, hence eliminating the cost of extra hardware required in the repeater stations.

2.2 Time Domain Method

A lot of attempts have been done to determine the fault location using signal analysis in the time domain because it's feasible. Here, some of these techniques are explained, which are applied to traveling wave fault location. The objective of signal feature extraction is to represent the signal in terms of a set of properties or parameters. The most common measurements in statistics are the arithmetic mean, standard deviation and variance. All these parameters actually compute the value about which the data are centred. In fact, all measures of central tendency may be considered to be estimates of mean.

2.3 Frequency Domain Method

Fault location methods which are Fourier transform-based, have been proposed since a long time. Most of the methods use voltages and currents between fault initiation and fault clearing. To find out the frequency contents of the fault signal, several transformations can be applied, such as, Fourier, wavelet etc. among which the Fourier transform is the most popular and easy to use.

2.3.1 Fourier Transform

Fourier transform (FT) is the widely used transformation that can be applied to traveling wave signals to obtain their frequency components which appear in the fault signal. Usually, the information that cannot be readily seen in the time domain can be seen in the frequency domain. The FT gives the frequency information of the signal, but it does not tell us when in time these frequency components exist. The Fourier Transform, FT (ω) for given signal $I(t)$ defined by:

$$FT(\omega) = \int_{-\infty}^{\infty} I(t) \cdot e^{-j\omega t} \cdot dt$$



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where ω is the continuous frequency variable. The information provided by the integral corresponds to all time instances because the integration is done for all time intervals. It means that no matter where in time the frequency f appears, it will affect the result of the integration equally. This is why FT is not suitable for non-stationary signals. The FT has good results in the frequency-domain but very poor results in the time domain.

2.4 Time-Frequency-Domain Method

The traveling wave based fault locators utilize high frequency signals, which are filtered from the measured signal. Discrete Fourier Transform (DFT) based spectral analysis is the dominant analytical tool for frequency domain analysis. However, the DFT cannot provide any information of the spectrum changes with respect to time. The DFT assumes the signal is stationary, but the traveling wave signal is always non-stationary. To overcome this deficiency, the Short Time Fourier Transform and the Wavelet Transform allow the signal to be in both time and frequency domain through time windowing functions. Short Time Fourier Transform and the Wavelet Transform must be selected to extract the relevant time-amplitude information from a TW signal.

2.4.1 Short Time Fourier Transform

In the STFT, the signal is divided into small segments which can be assumed to be stationary. The signal is multiplied by a window function within the Fourier integral. If the window length is infinite, it becomes the DFT. In order to obtain the stationary signal, the window length must be short enough. Narrower windows afford better time resolution and better stationary, but at the cost of poorer frequency resolution. The STFT is defined by following equation:

$$\text{STFT}(t, \omega) = \int_{-\infty}^{\infty} I(t) \cdot W(t - \tau) \cdot e^{-j\omega t} \cdot dt$$

Where $I(t)$ is the measured signal, ω is frequency, $W(t-\tau)$ is a window function, τ is the translation, and t is time. The flaw with the STFT is that one cannot determine what spectral components exist at what points of time. One can only know the time intervals in which certain band of frequencies exist. The signal is to be divided into small enough segments, where these segments (portion) of the signal can be assumed to be stationary. To get better information in time or frequency domain, parameters of the window can be changed. As before mentioned, narrow windows give good time resolution, but poor frequency resolution. Wide windows give good frequency resolution, but poor time resolution. Thus, it is required to compromise between the time and frequency resolutions.

2.5 Wavelet Transform

A wavelet is a waveform of effectively limited duration that has an average value of zero. On comparing wavelets with sine waves, which are the basis of Fourier analysis, it is seen that sinusoids do not have limited duration - they extend from minus to plus infinity. And where sinusoids are smooth and predictable, wavelets tend to be irregular and asymmetric. Fourier analysis consists of breaking up a signal into sine waves of various frequencies. Similarly, wavelet analysis is the breaking up of a signal into shifted and scaled versions of the original (or *mother*) wavelet. One of the types of such wavelets is 'Haar' Wavelet. Shape of the 'haar' mother-wavelet is shown in Fig. 1 and it is considered the simplest mother wavelet type available. Therefore, it is expected to be computationally less demanding and requires less resources when implementing in hardware.

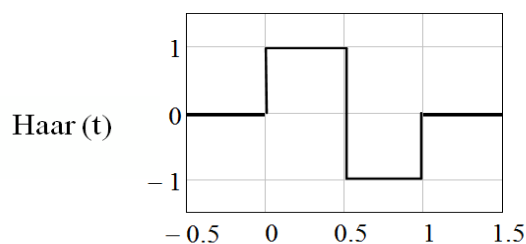


Fig. 1 The Haar mother wavelet

2.5.1 Continuous Wavelet Transform

In the CWT, the analysing function is a wavelet, i.e. ψ . The CWT compares the signal to shifted and compressed or stretched versions of a wavelet. Stretching or compressing a function is collectively referred to as dilation or scaling



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and corresponds to the physical notion of scale. By comparing the signal to the wavelet at various scales and positions, a function of two variables is obtained. If the wavelet is complex-valued, the CWT is a complex-valued function of scale and position. If the signal is real-valued, the CWT is a real-valued function of scale and position. For a scale parameter, $a > 0$, and position, b , the CWT is:

$$C(a, b; f(t), \varphi(t)) = \int_{-\infty}^{\infty} f(t) \frac{1}{\sqrt{a}} \varphi * \left(\frac{t - b}{a} \right) dt$$

Where $*$ denotes the complex conjugate. Not only do the values of scale and position affect the CWT coefficients, the choice of wavelet also affects the values of the coefficients. By continuously varying the values of the scale parameter, a , and the position parameter, b , you obtain the cwt coefficients $C(a, b)$. Note that for convenience, the dependence of the CWT coefficients on the function and analysing wavelet has been suppressed. Multiplying each coefficient by the appropriately scaled and shifted wavelet yields the constituent wavelets of the original signal.

2.6 Related Work

The technology used for the location of the fault at Chandrapur power station, is Travelling Wave Transducer (TWT), for the Chandrapur-Padghe Transmission line. TWT method is also a method based on the travelling wave concept. Whenever the fault occurs on the transmission line, abrupt changes occur in the travelling wave which gives birth to the electromagnetic impulses. These impulses travel to and fro all over the transmission line. Thus wavefront of such impulses is taken by recording the time instant at the arrival point of the travelling wave. This time instant is recorded by the transducer attached to the receiving and sending terminal. Thus transducer converts it into the required form of data. TWT is tuned to its maximum sensitivity point so that any change in the signal other than the reference signal, is recorded. Under the normal conditions a 50A, 5V signal is given to the PC in which TWT's programming is fed. But, the major limitation of this technique is, it cannot give the fault location if only one terminal records the fault. If due to miscommunication, the other terminal couldn't record the abrupt change in the signal, then location of fault cannot be measured. Thus, the power engineer has to do line patrolling in such cases, which is tedious hectic, time consuming thus, increasing the chances of more losses.

III. USE OF CWT IN TRAVELLING WAVE BASED DC LINE FAULT LOCATION

Travel times of the fault initiated surges are used to find the dc line fault location in the travelling wave based fault location method. Fig. 1 shows the flow of the travelling waves along a dc line with length L . Assume that these waves are initiated due to a fault located at distance X_f away from terminal- T_1 and the waves travel at a constant velocity denoted by v .

DC line fault location can be calculated as shown in equation (1) using the travelling wave arrival time with respect to a single terminal (T_1). This method is called a single-ended method or Type A method.

$$X_f = \frac{(tr1 - tr2) \times v}{2} \dots \dots \dots (1)$$

Fault location can also be found as shown in (2) using the initial travelling wave arrival time at both the terminals. This method is called double-ended method or Type D method.

$$X_f = \frac{(L - (tl1 - tr1) \times v)}{2} \dots \dots \dots (2)$$

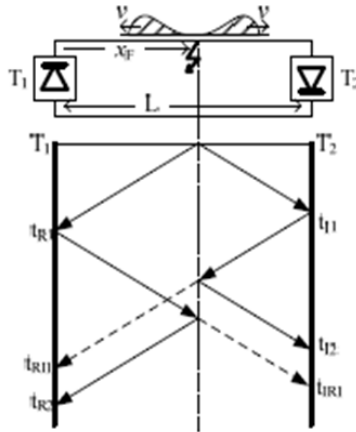


Fig. 2 - Lattice diagram to illustrate the travelling wave flow along the dc line

In the single-ended method the analysis of the waveforms has to be more sophisticated. As an example consider the case shown in Fig. 1, where the fault location X_f is greater than $L/2$. The reflected wave from the T_2 terminal arrives before (Wave arrival time: tr_1) the second reflection (Wave arrival time: tr_2). Therefore, signature analysis may be required to distinguish the two waveforms. The double-ended method is based on timings from the initial surges and hence the reflected waves are not involved. However double-ended method requires both an accurate method of time synchronization and an easy means of bringing the measurements from the two terminals to a common point.

3.1 Identification of the Surge Arrival Time

Precise identification of the surge arrival time is very important to have high accuracy in the travelling wave based line fault location method. Conventional edge detection methods such as Short-Time Fourier Transform (STFT) and Finite Impulse Response (FIR) filtering based methods, will not provide adequate accuracy in identifying the travelling wave arrival time. Wavelet transform can be used to identify the wave-front arrival time because of its simultaneous time and frequency localization capabilities. Recently man researches have put their efforts to use wavelet transform in HVDC fault location.

3.1.1 Wavelets transform to identify the surge arrival time

Wavelet transform is a linear transformation similar to the Fourier transforms. However, it is different from Fourier transform because it allows time localization of different frequency components of a given signal. In the case of the wavelet transform, the analysing functions are called mother wavelets and are defined as (3),

$$\varphi_{\rho, \tau}(t) = \frac{1}{\sqrt{\rho}} \varphi * \frac{(t-\tau)}{\rho} \dots\dots\dots (3)$$

A given mother wavelet (φ) has a location or time shift (τ) and a scale or duration (ρ). In the wavelet transform these shift and scale values are adjusted. This is called multi resolution analysis and it is useful for analyzing fault transients. The CWT still uses discretely sampled data, however the shifting process is a smooth operation across the length of the sampled data, and the scaling can be defined from the minimum (original signal scale) to a maximum chosen value. Therefore CWT provides finer resolution. The trade-off for this improved resolution is an increased computational time and memory required to calculate the wavelet coefficients. The trade-off can be compensated for the accuracy since the dc line fault locator performs off-line calculations. The corresponding DWT values are poor in time resolution and also are smaller in magnitude compared with CWT coefficients. That is the main reason why the CWT based fault location method gives better accuracy than DWT based fault location method.

3.2 Algorithm for Fault Location in the HVDC Line

The proposed simplified fault location algorithm which is an offline calculation is illustrated in Fig. 3. This calculation can be initiated once the primary protection scheme identifies the dc line fault. The fault location scheme maintains a

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runtime input data buffer, which will be saved when a fault is detected. The size of this buffer depends on factors such as the primary protection time delay, sampling time and the transmission line length of the specific HVDC scheme.

The largest time delay in the system is used to estimate the buffer size.

In this, both terminal voltage and surge capacitor current measurements are tested as potential input signals. Sampling is assumed synchronized and time tagged using GPS clock signals. Wavelet transform either CWT is applied to the input signal and the magnitude values of the wavelet coefficients are extracted. A threshold to identify the surge arrival point is set about 15% above the maximum value of the wavelet coefficient of the corresponding input signal under the normal conditions. The safety margins are required to allow for the noise. Different threshold values are found for each coefficient scale considered in the algorithm.

The time when the magnitude of the considered coefficient rises above the threshold is recognized as the time of arrival of a surge at the terminal, from the measurements at the other end of the transmission line, the time of arrival of the surge in that terminal is received via telecommunication channel. Fault location is calculated by using the travelling wave principle according to equation (2).

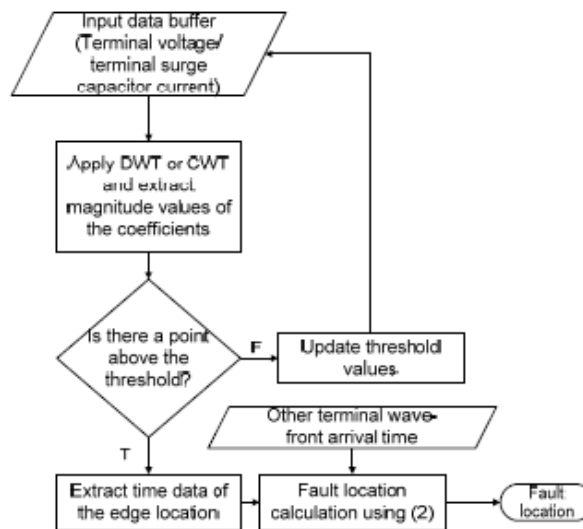


Fig.3 - Simplified fault location algorithm

As different coefficient scales or levels represent different frequency bands in the signal, the velocity of propagation at each of these frequency bands could slightly differ. The algorithm attempts to find an arrival of surge in the current data buffer, and if it did not find an edge, then the buffer window is shifted and the procedure is repeated. If the signal processing can be done in real time, the occurrence of a fault can be detected by continuously observing the wavelet coefficients, without depending on an external initiation signal.

IV. CONCLUSION

In this paper, the concept of traveling wave, its behaviour when fault occurs and hence, to use this quality of a travelling wave for the purpose of location of the fault, is presented. The traveling wave based fault detection methods are developing the interests of the power engineer because of accuracy and prompt measurement of the location of the fault from the receiver or sending terminal. The various methods used previously for locating the fault point in the long HVDC transmission line are also presented in this paper. In the method Radio Repeater Station, the limitation part is extra hardware required for tracing the impulsive signal. Also, the installation of extra hardware increases the overall cost of the HVDC transmission system thus, making it expensive. Another method, the time domain approach gives us the time parameter but limiting the frequency parameter, so it cannot be used as reliable method. Then the conventional methods of edge detection of the wave-front such as Short-Time Fourier Transform (STFT) and Finite Impulse Response (FIR) filtering does not provide adequate accuracy in identifying the travelling wave arrival time.



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The wavelet transform technique has become more reliable for the power engineers because of its accurate and precise measurement of the faulty segment and the exact location of the fault. It saves the time as well as the further damage which happens due to the fault. The CWT technique works offline which again saves the time irrespective of the internet. Thus, the Fault detection in long transmission line using Continuous Wavelet Transform method is becoming the field of attraction for many of the electrical power system engineers.

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