The Review of High Voltage DC Transmission Lines Fault Location

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Abstract

The present situation of the development of DC transmission lines in home and abroad are reviewed in this paper. Making use of the dividing methods of fault location principle of AC transmission lines, the HVDC fault location principle has carried on the summary, The HVDC transmission lines fault location methods are divided into traveling wave method and fault analysis method. Furthermore, the advantage and disadvantage of the above methods are reviewed respectively, and it is pointed out the fault analysis method has board application prospects. Then In view of the situation of DC transmission lines fault location, my own suggestions are put forward. Finally, the conclusion is summarized for the paper.

Keywords: HVDV transmission lines; fault location; traveling wave method; fault analysis method

1. Introduction

Compared with traditional AC transmission, in the economical and technical aspects, high-voltage direct current transmission has the following advantages: The structure of the tower is simple, the costing of the line is low, the line corridors are narrow, and the loss is small; transportation capacity is not restricted by system operating; it can achieve cross-regional asynchronous network; it is very suitable for high voltage, long distance, and large capacity transmission [1-6].

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In the east and west of our country, the distribution of energy is uneven, a high-voltage DC transmission system plays an important role in China, even in the national grid interconnection. After the Zhoushan HVDC project, our country has constructed and put into operation the Gezhouba-Nanqiao, the three Gorges-Guangdong, Yunnan-Guangdong UHVDC power transmission project etc. At present, the left bank of Xiluodu-Zhejiang Jinhua DC power transmission project has just been put into operation [7, 8].

The high voltage transmission line is the lifeblood of the power system, and shoulders on the responsibility of electricity; it is also the most prone to failure in power system components [1]. After the high-voltage direct current transmission line happens to fail, we can function quickly and accurately; it not only can improve the reliability of power system operation, but also reduce huge losses because of power outages caused. Therefore, the accurate fault location technology has the vital significance to improve the reliability of transmission line operation, to reduce the comprehensive loss caused by power outage, and to reduce the labor intensity of manual patrol[9, 10].

2. Backgroundand of the Transmission Line Fault Location

2.1 HVDC Fault Characteristic

Compared to the AC power, in HVDC power transmission system, due to that fact that the DC circuit structure is simple, and both ends on the wave impedance is very large, the refractive index is almost zero with reflectivity almost equal to 1; when the line internal fault happens, the fault traveling wave almost bounces back and forth between the rectifier and inverter, so it has the advantages of travelling wave protection. In addition, as to the area of failure, because of the effect of the inverter and flat wave reactor, the travelling wave refection to the travelling wave direction device decreases greatly, no matter in amplitude or the wave steepness of the Bob[11].

By the way, AC systems occurred in fault when the voltage is zero, and the line hasn't travelling wave; therefore, the protection has the dead zone, at the same time, and the protection can't act. And DC line does not the voltage phase angle, so there is no dead zone. In a communication system, since the propagation of the voltage current popular wave is greatly influenced by the bus structure change, it is difficult to distinguish the fault point spread travelling wave and the wave reflection and projection of each bus. And DC transmission line structure is simple, so the above problem is relatively simple [12].

2.2 HVDC Fault Location Method

According to the particularity of transmission lines, when the DC transmission line occurs in failure, the fault location methods suitable for DC transmission line mainly include travelling wave method and fault analysis.

Early travelling wave methods are mainly A, B, C, D, E, and F types. The types A, C, E, and F are the single-ended methods; Types B and D are the double side methods. The modern travelling wave method mainly has the wavelet analysis method, mathematical morphology, Hilbert Huang transform, and independent analysis. Fault analysis can be divided into single side and double side methods according to the source of the electric parameters; according to the circuit model, it is divided into lumped parameter model and distributed parameter model; according to the form of electric parameters, it is divided into time domain and frequency domain methods [13-15].

2.3 HVDC Travelling Wave Location Method

Fault location lines mainly depend on the Bob identification and determination of the wave velocity. Travelling wave method mainly detects the fault line Bob.

2.3.1 The Wavelet Analysis Method

Wavelet transforms have good time-frequency localization performance, which can give the travelling wave signal's frequency information in a short time period, so the travelling wave Bob can be grasped rapidly and accurately. The literature [16] puts forward by using a wavelet transform to extract the fault features of fault travelling wave to eliminate the wave dispersion effect on the ranging accuracy. But we need to select suitable wavelets and decomposition scales according to the characteristics of the travelling wave. The literature [17, 18] put forward by using wavelet transform to extract the high frequency transient signal, which can find out the fault lines accurately, and identify the initial fault current Bob; and by using the modulus maxima of the wavelet transform it can realize double-end travelling wave fault location, which can be applied to singled stage and double stage HVDC transmission lines. The literature [19] has the same principle, which realizes the single ended travelling wave fault location. The literatures [20][21] describe the principle of high-voltage direct current transmission line fault location based on the wavelet transform.

However, taking into account the type of wavelet base, the signal sampling rate, decomposition scale, the date window wide, and integral operation are used in the operation and other issues, so the wavelet transform doesn't have its adaptability, and it can't use gens wavelet base to analyze all types of fault location.

2.3.2 The Mathematical Morphology Method

The mathematical morphology is a kind of nonlinear analysis method, which has an advantage in the abrupt change point of the filter and signal detection. The literature [22] proposes a fast Bob detection method of mathematical morphology, by using the multi-resolution morphological gradient for the fault transient voltage travelling wave, and the identification distance measurement method for fault line is put forward. The method not only has high accuracy for distance measurement, but also has good robustness to noise. In order to improve the reliability of travelling wave protection and accurately identify Bob, the literature [23] proposes a multi-scale filtering algorithm based on a mathematical morphology. In the literature [24], for the several similar fault types, the method based on a mathematical morphology can distinguish HVDC fault line, but also can realize the accurate fault location. The literature [25] points out we can separate the positive and reverse voltage waves by using a mathematical morphology gradient transform; if so, we can not only obtain the transient travelling wave mutation point time, but also have anti-jamming performance.

However, the role of structural elements in a morphological operation is similar to the filtering window in the signal processing, whose shape and size have a decisive influence on the result of the mathematical morphology operations. How to choose a more effective structural element has always been the difficulty of a mathematical morphology, so the original signal should consider the interference of the signals in addition, and the requirements and others to maintain the graphic when it should be considered synthetically.

2.3.3 Hilbert–Huang Transform Method

Hilbert Huang transform is a new signal processing method, which has a clear physical significance to deal with nonlinear and non-stationary signals. The literature [26] detects the Bob by Hilbert Huang algorithm, and then calculates the fault distance. The literature [27] shows that using Hilbert Huang can adapt decomposition in the time domain according to the signal itself. There is no function and decomposition scale selection problem. The literature [28] shows that Hilbert Huang transform is applied to the travelling wave protection of a high-voltage direct current transmission; by analyzing the wave form, combined with comprehensive criterion such as the low voltage DC lines, it forms a new scheme of DC transmission line travelling wave protection. The literature [29] points out that the EMD decomposition should consider the envelope fitting problems on the endpoint and decomposition, which should be improved by the algorithm; and we should use cubic spline interpolation to fit and extreme mirror continuation to eliminate endpoint effects.

2.3.4 Independent Component Method

Independent component analysis is a kind of high efficient blind source separation method that is developed gradually in recent years. The literature [30] points out that independent component analysis has been widely used in the feature extraction and the speech recognition aspects due to the little requirement of the environment and the target. The literature [31] shows that we can use FastICA to blind separate the DC voltage and DC current signal that are measured by multi-channels so that the system fault source signal is restored, and the key feature of this method can effectively extract the fault. The literature [32] shows that by FastICA algorithm, we can process the current signal of DC transmission lines after fault, then decompose the current characteristic signal, and finally detect the time of the initial Bob and the second arrive Bob measurement point and polarity relationship, so we can realize fault location.

The constraints of an independent component method mainly require that source signals are independent each other, and there is a Gaussian signal at most.

2.3.5 Natural Frequency Method

Since DC transmission line is only a route, and thus we can extract a natural frequency method to realize fault locations. The literature [33] proposes that there is a mathematical relationship between the fault travelling wave spectrum of transmission line and the fault distance, and a fault travelling wave spectrum can be used to realize a fault location. Based on travelling wave natural frequency range of the principal component, the literature [34] proposes this method isn’t restricted by the Bob recognition; using transient voltage information after the line occurred in fault, through the spectrum analysis, we can get the natural frequency of the travelling wave principle component, and we can realize a fault location. Using the data on both ends of the line, the literature [35] shows that Pronny algorithm is utilized to extract the wave natural frequency; we can’t use line parameters to calculate the wave velocity, but we can realize a precise fault location. Based on the time-frequency characteristics of a travelling wave, the literatures [36][37] propose a single ended travelling wave fault location method based on the travelling wave and inherent frequency method. Integration testing model decomposition is used to extract the high frequency component of the wave, identify the Bob and extract the precise time parameter, and finally solve the problem of wave velocity selection.

2.3.6 Traveling Wave Fault Location Faults

Travelling wave fault location has some difficulty in overcoming technical problems:

1). Travelling wave fault location detects the Bob; once the Bob detection fails even can't detect the Bob, the travelling wave fault location technology will fail;

2). The accuracy of travelling wave fault location is related to the wave velocity. Travelling wave will occur in dispersion in the process of the transmission, so the travelling wave velocity is changing in the process of the transmission wave;

3). Travelling wave fault location precision is related to the sampling frequency. In order to improve the ranging accuracy, the travelling wave device should have a high sampling frequency;

4). Travelling wave fault location needs to identify the Bob, and needs professional personnel to complete; if not, we can't use a computer to realize;

5). Travelling wave fault location is susceptible to interference effects.

2.4 HVDC Fault Analysis

2.4.1 Distributed parameter Method

A distributed parameter method is used for a DC transmission line fault location, which has obvious advantages. Using any piece of data from transient to steady states, we can realize a fault location, and directly use the failure data without the conversion of time domain and frequency domain, which will be a big advantage for its future development.

Combined with the particularity of DC transmission line, and based on the distributed parameter model in time domain, the researchers have already extensive studied. The literatures [38][39] put forward a new principle of the fault location, which is based on a distributed parameter model. Taking use of the both ends of the voltage and current, we can calculate the voltage distribution along the route, and realize the fault location using the equal voltage in fault points. Using the distributed parameter model of circuit, the literature [40] proposes a double ended fault location method of asynchronous, we can realize the fault location using the superposition of normal and fault network. The literature [41] draws lessons from the principle of AC power circuit, the shortcoming of the DC transmission line, puts forward a new kind of wave single-ended fault location method. According to the calculated value of the voltage and current, we can calculate excessive resistance, which has the minimum at fault point prescription difference, thus we can realize fault location. On the basis of the previous literatures, in the case of distribution parameter isn't accurate, the literature [42] can improve the ranging accuracy to the application of genetic algorithm.

To sum up, the fault of the time domain analysis method based on distributed parameters can use any pieces of data for a fault location, which, for low sampling frequency and the high reliability, has a certain applicable value. But the distributed parameter method requires that circuit parameters must be precise; when the circuit parameter has a certain error or frequency characteristics is obvious, it has certain influence on the ranging accuracy. At the same time, the method has a lower ranging precision than the travelling wave method [10].

2.4.2 Parameter Identification Method

In view of the present status of the DC transmission line fault location, the literature [43] proposes the VSC-HVDC fault location method based on a parameter identification; since both ends of the VSC-HVDC have a large capacitor, through the principle of parameter identification, we can write the column by the fault distance and transition resistance for the parameters of the fault location of time domain differential equation, and solving the equation of electric parameters can be realized by the least squares method to finally realize the fault location. As to the AC power lines, the literature [44] proposes an accurate fault location method based on R-L model parameter identification. The algorithm uses the fault distance, excessive resistance and operation parameters as the model identification parameters to improve the accuracy apparently. Research by using the principle of parameter identification for DC transmission line fault location to avoid the problem of the travelling wave Bob detect fails, and the difficulty of the wave velocity is difficult to determine; and solving the changing parameters significantly improve the ranging accuracy and reduce the distance measurement error.

2.4.3 Fault Analysis Method Shortcomings

Fault analysis method isn't a kind of travelling wave fault location method. Compared with the travelling wave method, it has obvious advantages in ranging accuracy. But there are still some shortcomings. For the distributed parameter method, it requires that the parameters of the transmission lines must be accurate; otherwise it will bring certain influence on the fault location. But as we all know, the parameters of the transmission lines are set in advance, because of the natural environment changing, which are bound to a certain influence on the transmission line fault location. For the parameter identification method in the application of DC transmission line, it is still studying in further.

2.5 Intelligence Algorithm

In recent years, the scholars will apply intelligent algorithm to DC transmission line fault location. Along with the development of artificial neural network theory, the artificial neural network is used for the study of transmission line distance protection and fault location, which is attracting more and more attention. The literature [45] shows that the artificial neural network is used in the transmission line fault location, but the actual application for the fault location needs further research. The literature [46] puts forward a kind of DC transmission line fault location method based on an intelligent algorithm. The algorithm uses the double side voltage, and power flow after the line happens to fault in the time domain fault location, which inherited the advantages based on the traditional genetic algorithm, and isn't influenced by fault point location and excessive resistance; the influence to the ranging accuracy is small by the circuit parameter deviation.

In view of this, the intelligent algorithm is applied to AC transmission line fault location, and DC transmission line is also gradually been applied. The ranging precise of intelligent algorithm is significantly higher than the above method, but the sample is very large, which will bring certain difficulty to fault location; therefore, the ranging applications are in the study.

3. DC Transmission Line Fault Location Suggestion

According to the analysis above, DC and AC transmission lines have no difference essentially, so most of the principle of AC transmission line fault location are suitable for DC transmission line. As a result, some advices are given for a DC transmission line fault location:

1). When we use travelling wave fault location method to extract the fault travelling wave, the line may be undetectable to the Bob, and the wave velocity is changing; there are a large number of feature frequency signals in the transient process of DC transmission line, but we can research the method of extracting the natural frequency to avoid the problem of the Bob detection; the curve relationship of the fault distance and velocity is used to overcome the problem of the line wave velocity changes so as to improve the ranging accuracy.

2). In the fault location, the distributed parameter model is widely used in the DC transmission line distance, but if the line parameter is measured before that, the ranging accuracy will be greatly improved.

3). The parameter identification method currently is used for AC transmission lines and the VSC-HVDC lines, but not used for DC transmission line; we can study parameter identification in the application of HVDC line, build fault location principle, and improve the reliability and accuracy of fault location.

4. Conclusion

The principle of DC transmission line fault location was summarized in the paper on the basis of the research status at home and board, and the advantages and disadvantages of existing DC transmission line fault location method were discussed. Finally some suggestions are put forward for the further study of the fault location.

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