Summary of Fault Location of HVDC Transmission Line

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Abstract

Due to the influence of geographical environment, HVDC transmission lines have many faults, so it is necessary to use more accurate locating method to locate faults. This paper summarizes the development of DC transmission line location method in recent years, and summarizes the traveling wave method, fault analysis method and the emerging artificial intelligence method, and proposes improvement to the follow-up research based on the existing problems of the current location method.

Keywords

HVDC transmission, Fault location, Traveling wave method, Fault analysis, Artificial intelligence algorithm.

1. Introduction

Nowadays, electric energy is widely used in all walks of life, which makes the stable operation of electric power system more and more important. HVDC is an important part of power system, its stable operation is related to the security of the whole power grid. As the lifeblood of the power system, the importance of DC transmission line is self-evident. Improving the relay protection performance of DC transmission line plays a key role in improving the security of power system. It is necessary to ensure that the fault parts of the transmission lines are cut out quickly and accurately when faults occur. This requires the rapid location of fault points and troubleshooting after the failure, to speed up the recovery of normal power supply lines, reduce the unnecessary economic losses caused by the power failure. Therefore, it is necessary to study and analyze the fault detection and location technology of HVDC transmission line[1,2].

Based on the previous researches, this paper summarizes the methods of fault location of HVDC lines in recent years, from traveling wave method, fault analysis method, and artificial intelligence algorithm, summarizes the fault location methods of transmission lines, and makes some assumptions about the development of fault location methods.

2. Fault location technique

Accurate and reliable fault location method can greatly shorten the troubleshooting time of fault points, quickly restore power supply, and reduce economic losses caused by power failure. Throughout the development of transmission line fault location technology, it can be divided into three stages.

The first stage: mainly by the experienced staff on the basis of the fault wave chart, integrated user feedback information, fault location prediction, and then send people through the line inspection to confirm the fault location[3]. The defects of this method are obvious, such as slow detection speed, long fault removal time, serious waste of manpower and material resources and impact on people's production and life.

The second stage: combined with the electric measuring instrument, using the data of measuring points at both ends of the line to calculate the fault location through the fault location principle, which greatly saves the troubleshooting time. The rapidity and accuracy of fault location of transmission lines have been further developed.

The third stage: the artificial intelligence algorithm is introduced into the fault location technology, the line data is uploaded in real time by the communication network, and the line information is processed. The fault location can be obtained in real time and accurately, which is conducive to reducing the burden of the staff and quickly restoring the power supply.

3. Fault location method

According to the characteristics of HVDC transmission lines, the positioning methods are mainly divided into three types: traveling wave method, fault analysis method and artificial intelligence method. The traveling wave method is an algorithm that uses the time difference to measure the distance by extracting the reflection time of the traveling wave between the fault point and the measuring point, or the time when the initial wave head of the traveling wave reaches the measuring point at both ends. The fault analysis method is to calculate the fault distance of the DC line according to the system structure and parameters by using the single or double terminal fault electric quantity, which is complex to calculate and difficult to obtain the actual line parameters, and the ranging accuracy is not high. The artificial intelligence algorithm mainly relies on the extraction of fault features, and the strong learning ability of neural network is used to learn and train the features, so as to determine the fault location.

3.1 Traveling wave method

At present, fault location of DC transmission line mainly adopts the method of identifying traveling wave. The traditional traveling wave method includes single end method and double end method, while the modern traveling wave method includes wavelet transform method, mathematical morphology method, Hilbert-Huang transform method(HHT), independent component method, natural frequency method, S transform method, etc. The key of the two-end method is to identify the first traveling wave head, which needs to exchange the fault traveling wave data on both sides of the line. The key of single end traveling wave method is to identify the second traveling wave head. For DC transmission lines, due to the physical boundary formed by the flat wave reactor and the DC filter on both sides of the line, the traveling wave head will be distorted and the polarity will be reversed, which makes it difficult to correctly identify and calibrate the second traveling wave head. The traveling wave method cannot locate the fault accurately once the wave head recognition fails.

In the case of failure, the propagation process of traveling wave is shown in figure 1.

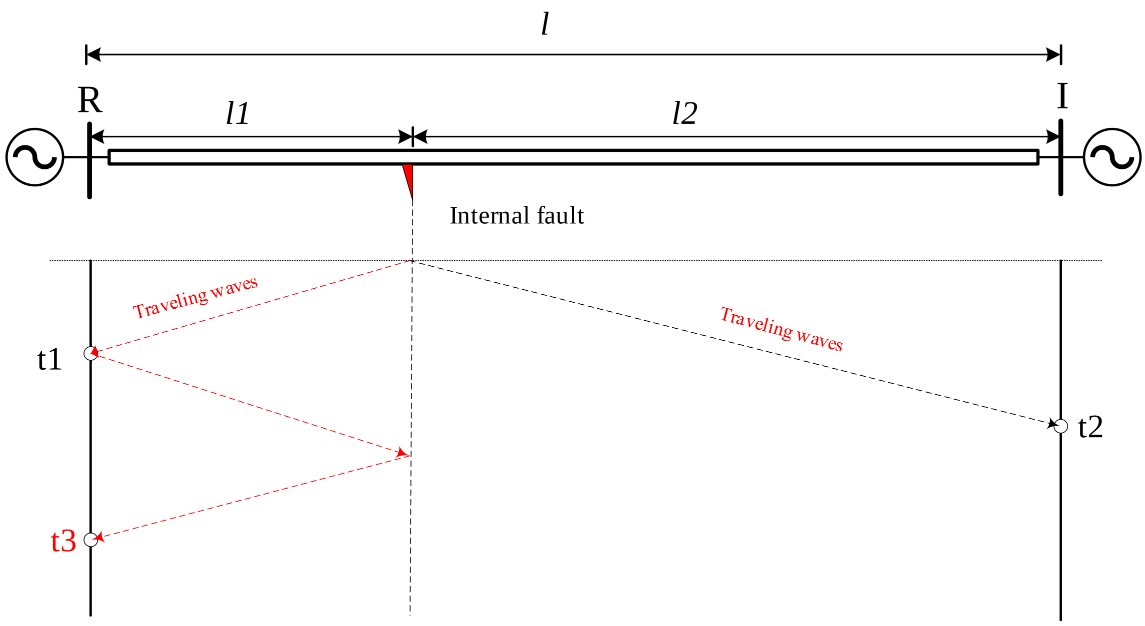

Figure 1 traveling wave propagation process

The fault location formula of single-ended traveling wave method is as follows:

$$l_1 = \frac{l-(t_3-t_1)v}{2}$$

Where, l_1 is the distance from the fault point to the rectifying side R, l is the full length of the high-voltage transmission line, and t1 and t3 are the first and second time for the initial travelling wave to reach the R end after the failure, respectively, and is the upstream wave velocity of the transmission line.

The fault location formula of double-end traveling wave method is as follows:

$$l_1 = \frac{l-(t_2-t_1)v}{2}$$

Where, t_2 is the time when the initial traveling wave first arrives at the I end of the contravariant side after the fault.

Traveling wave locating method depend on the accurate extraction of line Bob, but limited by the sampling frequency, cannot accurately detect the wave head, literature[4] by detecting the second-order b-spline wavelet transform modulus maxima of the current location to determine the wave front arrival time, literature[5] for high-voltage DC system fault location accuracy losing shortage problem, the S transform for fault before and after a certain time window of travelling wave modulus of current and voltage frequency signal groups are extracted, solved the time-frequency domain HVDC fault traveling wave signal accurate frequency of the main problems. On this basis, literature[6] uses the superior high-frequency characteristics of S transformation and Teager energy operator to extract the arrival time of two-end traveling wave heads, so as to achieve accurate detection of traveling wave heads. In literature[7], from the perspective of energy, local mean decomposition (LMD) is combined with Teager energy operator to detect the wave head, and the three-point method is used to improve the detection accuracy of traveling wave velocity and the ranging accuracy. The modular traveling wave head has accurate phase information. The single-phase grounding fault positioning is carried out by using the phase relation of the same high-frequency component in the two-terminal measuring point zero mode and line-mode voltage traveling wave head, which can overcome the error of the traditional identification method of the modular traveling wave head[8].

The arrival time of the fault component wave head is extracted by various mathematical tools and the traveling wave characteristic to calculate the fault distance. Therefore, in literature[9], fault areas are judged according to the phase characteristics of fault area recognition function in different fault areas, and accurate fault location is realized by fault distance expression. In literature[10], on the basis of literature[9], multiple positioning results obtained by moving redundant data Windows are removed by using distance-based data processing method, and the mean value of the remaining data is taken as the fault positioning result. Literature[11] deduces the functional relationship between phase Angle difference and fault distance of ground mode differential current and wire mode differential current at both ends based on the difference of traveling wave propagation velocity in ground mode and wire mode. The advantages of traveling wave ranging are inherited and the influence of most factors on the ranging accuracy is overcome. Compared with the zero-mode component, the line-mode component has higher stability and slower attenuation rate, and the positive and reverse wave surges can be separated by using the mathematical morphological gradient transformation, which can not only obtain the moment when the transient traveling wave signal breaks, but also have certain anti-interference, and there is no time window length problem[12,13]. In reference[14], according to the general invariable characteristics of the distribution network structure, the whole network lines are divided equally, and the time difference matrix of the traveling waves of each node reaching the end of each line is established. After the fault, the wavelet transform is used to extract the time when the initial traveling wave reaches the end of each line, and the actual arrival time difference matrix of traveling wave between each branch line is established. Then, the difference matrix of travel wave arrival time difference before and after the fault is compared, and the fault location is found through the matrix difference value to achieve fault positioning[15]. The analysis of fault signals is not limited to time domain or frequency domain. Literature[16] comprehensively uses time-frequency multi-scale observation of traveling wave panoramic waveform to achieve positioning, which effectively overcomes the defect of low protection reliability caused by the existing single-terminal method based on local fault information, and reduces the dependence on accurate detection of wave head and modulus wave speed.

Literature[17] analyzed the parameter characteristics of the hybrid line, and proposed a fault location method based on voltage amplitude comparison for fault characteristics in the UHV overhead line-cable hybrid line. Literature[18] overcomes the influence of uncertainty of line length and line parameters on ranging accuracy by calculating line parameters and asynchronous angles in real time. Literature[19] collects the voltage and current phasor of the measuring points at both ends of the distribution line to obtain the voltage and current phasor matrix, and then establishes the positioning function by combining the line fault coefficient matrix and line impedance parameters to achieve fault positioning. Literature[20] compares the discrimination method and logic of setting fault interval for the ratio and difference of voltage change rate at both ends of a current-limiting reactor, and uses local information to determine the fault location. Single ended traveling wave fault location method without communication equipment, is easy to implement in engineering[15,21-23].reference literature section before the thought of positioning, literature[24] based on the single and the amount of power frequency segment deduction fault section method, the preliminary delimit fault distance interval, and through the analysis of the traveling wave propagation law in a defined range, construct the fault point precise positioning method. Traveling wave fault location in all kinds of distance measuring method has obvious advantage theory, the traveling wave fault location for the larger development, both at home and abroad have a traveling wave fault location system is developed and practical application.

3.2 Fault analysis

Fault analysis can be divided into several categories according to different standards. According to the source of electricity, it can be divided into single-end method and double-end method. If it is based on the line model, it can be divided into centralized parameter model and distributed parameter model. If it is divided according to the form of electrical quantity, it can be divided into frequency domain method and time domain method. The common methods are distributed parameter method and parameter identification method[25].

In the fault analysis method, there are mainly two kinds of single terminal measurement method and double terminal measurement method[26]. In the single-terminal method, the measurement can be realized only by relying on the information of the local side, but it will have a certain negative impact on the contralateral system. Although the two-terminal quantity method has no impact on the contralateral system, the contralateral information can only be obtained through communication technology. In the communication process, practical problems such as data synchronization and too much computation often have a direct impact on the measurement results. Compared with other methods, the accuracy of fault analysis method is better and the sampling rate is relatively low. It has to be mentioned that line accuracy can basically determine the final result of fault analysis, so it is obviously inferior to traveling wave fault positioning method in terms of accuracy. Literature[27] calculated the voltage and current distribution along the fault line based on the Berger online model, and obtained the fault location by using the modulus relationship. Literature[28] for DC circuit with double towers of different polar failure size has the characteristics of obvious difference, the modulus by using two line weight calculation of the voltage distribution along, and in proportion to the synthesis of mixed voltage distribution along the modulus, based on the hybrid modulus calculated from both ends of the voltage distribution along the fault points difference in the most stable characteristics to locate. Literature[29] combined the traditional impedance method with the Bergeron model, and proposed a fault location scheme based on the Bergeron model. The two methods cooperate and complement each other to overcome the bottleneck of impedance legal position fault. According to the characteristics of equal voltage at fault points and equal current flowing through both sides of the series complement device, the series complement voltage and current on the side near the fault point in the transmission equation are eliminated. The fault locating function is constructed by using the pure resistive property of the transition resistance at the fault, the position of the fault point relative to the series complement is not predicted, and the fault distance is searched in one dimension[30]. In literature[31], the time-domain Hilbert transformation method is used to determine the fault location by taking advantage of the fact that the transition resistance is of pure resistance, and the fault point voltage and the current injected into the transition resistance should have the same phase at all times. In literature[32], the total energy of the characteristic frequency band of transient capacitor current is extracted by fast Fourier transform, the fault point direction is determined by comparing the total energy of each branch, and the fault interval is determined by tree graph search. Then the fault distance is calculated by using the load current and the residual voltage at the end of the fault interval. In literature[33], the starting point of the fault is taken as the moment of current mutation, and the polarity of the data of the half cycle after the fault is calculated. Fault location is realized by comparing the polarity of fault currents at adjacent detection points. In literature[34], the two-terminal voltage difference and the single-terminal current of the line are projected to the cartesian coordinate system to obtain the corresponding elliptic trajectory diagram. According to the elliptic trajectory diagram obtained under different fault conditions, the focus and rotation Angle are different, and the fault trajectory atlas is established. Finally, the location of the fault is determined by comparing the focus and rotation Angle. In literature[35], based on the analysis of time-frequency characteristic equations of voltage and current in the DC distribution system based on voltage source transformation(VSC), the current differential equation is derived, and the fault positioning equation is derived according to the initial value of fault current differential. The simultaneous loop equation solves the problem of transition resistance, and the interpolation algorithm is used to improve the traditional difference algorithm, and the problem of high sampling frequency and large error is solved. In literature[36], the fault section is determined by comparing the rate of change of DC capacitance discharge voltage at the VSC outlet side. After the fault section is determined, the calculation formula of fault location is derived by using the discharge circuit formed by short-circuit fault. In the literature[37], multiple sets of photoelectric sensors are installed on the transmission line for section division. On this basis, by calculating the Pearson coefficient between the initial fault matrix and the training matrix, the matrices that meet the conditions are selected, and these matrices are standardized to calculate the mean value of the fault location to further reduce the positioning error.

3.3 Artificial intelligence algorithms

Artificial intelligence fault location method uses some intelligent algorithms to find an uncertain relationship between the characteristic quantity and fault distance, and finally realizes the prediction of fault distance through a large amount of data learning in the early stage by using the algorithm's fitting and infinite approximation. The implementation process is shown in figure 2.

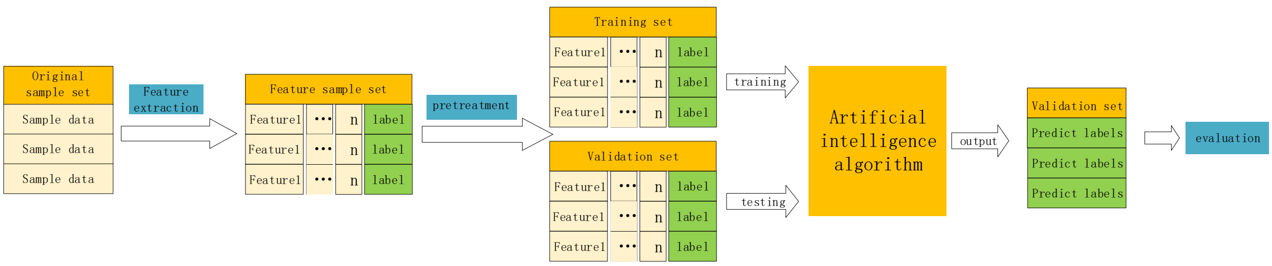

Figure 2 Intelligent algorithm ranging process

Traveling wave in the transmission on the transmission line, there is a frequency amplitude attenuation, component literature[38] uses the virtual fault point method, in guarantee under the premise of universality and less training samples, using radial basis function(RBF) neural network fitting line initial Bob 2 different frequency component amplitude ratio of fault distance and the nonlinear relations between fault accurate positioning. In literature[39], the genetic algorithm introduces the solution process of fault location, uses the same signal source of transmitted wave, and establishes the target equation according to the initial fault time derived from each transmitted wave. In literature[40], fault location is realized by combining fault current and genetic algorithm. In literature[41], the ultimate learning machine is used as the fault location network, and the traveling wave head frequency and the power supply inductance value are used as the characteristic quantities, which improves the accuracy of fault location. Literature[42,43]used the voltage waveform under different fault conditions as the characteristic quantity to conduct neural network training.

With the continuous development of fault location technology, in order to improve the accuracy of fault location, researchers began to make breakthroughs in feature extraction and artificial intelligence algorithms. No longer meet the simple fault characteristics, began to fault signal analysis at a deeper level, algorithm improvement, not limited to a single intelligent algorithm, will be combined with different algorithms, complementary advantages. In literature[44], the multi-scale decomposition of fault traveling wave is carried out by using wavelet transform, and the wavelet spectrum energy under different frequency bands is selected as fault feature to conduct fault localization of neural network, which effectively solves the problem that traveling wave fault ranging wave head is difficult to identify and the natural frequency cannot be accurately extracted. In literature[45], the wavelet packet decomposition and the improved prony algorithm were used to extract the initial feature of the single terminal voltage, then the RRelif algorithm was used to further screen the feature, and fault location was conducted through a variety of neural networks. Artificial neural network algorithm has good nonlinear fitting characteristics, while genetic algorithm has better global characteristics and higher convergence characteristics. The combination of artificial intelligence algorithm and genetic algorithm can ensure fast fitting between samples and accurate correction of results, which is especially suitable for systems requiring multiple judgments[46]. The fault location method for HVDC transmission lines based on genetic algorithm can achieve fault location in a range containing the true values of line parameters through optimization. However, at the current sampling frequency of the recorder, the error of measurement results is very large. The introduction of neural network algorithm to correct the ranging results can improve the ranging accuracy[47]. Literature[48] combined the global search advantage of the distribution estimation algorithm with the local search advantage of the bacterial foraging chemotactic operator, which enhanced the local search ability of the distribution estimation algorithm and accelerated the early convergence rate. Reference[49] refers to the mutation and crossover mechanism in differential evolution to realize the coordination between the bacterial foraging algorithm in the refinement search and the expanded new area, and improves the optimization accuracy and global optimization ability of the algorithm. Literature[50] improved the harmony algorithm, improved its global optimization ability, convergence speed and fault tolerance rate, and applied it to fault location of distribution network with distributed power supply to improve the speed of fault location.

Artificial intelligence algorithm in addressing the problem of fault line selection and the range is easy to fall into local optimal solution and difficult to meet the accuracy and robustness, literature[51] of particle swarm optimization neural network algorithm (PSO and BP) was improved, using chaos optimization algorithm is further enhanced particle swarm optimization(PSO) algorithm convergence ability, improve the performance of the neural network. Literature[52] uses variational modal decomposition(VMD) algorithm combined with Hilbert transformation(Hilbert) to determine the arrival time of the fault traveling wave by detecting the singularity of the first instantaneous frequency. TT transform is developed from S transform. Compared with S transform, TT transform has stronger time domain analysis ability. It has good capability of frequency domain analysis[53]. In literature[54], S transformation and TT transformation are used to extract fault feature information, and the binary classification algorithm of support vector machine is used to divide the fault section, and then the calculation formula is used to locate the fault. In literature[55], the voltage amplitude is used as fault characteristic signal, and the fault is accurately located by support vector regression machine(SVR). In the literature[56], Hilbert-Huang transformation(HHT) is introduced on this basis, and the frequency signal, energy attenuation signal and high frequency energy signal are added as the input characteristics of SVR for training. The parameters of SVR are optimized by bat algorithm to obtain the optimal fault distance. In literature[57], discrete wavelet transform(DWT) and deep neural network(DNN) were used to locate faults of a series of compensated three-terminal transmission lines. In literature[58], two one-dimensional convolutional neural networks are used to determine the segment first and then locate the fault. By this method, the interval length of fault location is reduced and the high-precision positioning is realized.

4. Follow-up prospects

From the above discussion, it can be seen that in fault positioning of DC transmission lines, the application of traveling wave positioning has been relatively mature, and the artificial intelligence algorithm still has a huge room for improvement. The subsequent research mainly focus on the intelligent positioning algorithm, with the following three assumptions.

1. In view of the current traveling wave method is limited by the hardware sampling frequency, which leads to the low accuracy of fault ranging, the intelligent algorithm should be combined to avoid the sampling frequency problem, and other fault traveling wave characteristics should be used for fault ranging.

2. Fault analysis method depends on accurate line parameters. When the line parameters have certain errors or obvious frequency variation characteristics, the accuracy of fault location will be affected. The relationship between line parameters and fault distance is studied, and the line parameters that affect fault distance are used as the training feature of intelligent algorithm for fault location.

3. The artificial intelligence algorithm itself has a high ranging accuracy and a large research space in network parameter adjustment; In addition, there are certain requirements on the number of samples, which can be studied from the aspect of reducing the training samples of the network.

5. Conclusion

In this paper, the fault location method of DC transmission line is summarized. The traveling wave method is mature, but its accuracy and reliability need to be improved. The fault analysis method has high reliability, but it is seriously affected by the operating environment and line parameters. Intelligent positioning algorithm develops rapidly, but limited by samples and features, it cannot be widely used at present. In the fault location work of HVDC transmission lines, the most effective measures should be taken to enhance the efficiency of fault location work based on the existing situation of fault location, that is, the problems existing in the application process of traveling wave fault location and fault analysis. The fault characteristics of traveling wave method and fault analysis method can be combined with intelligent algorithm to further improve the ranging accuracy.

Acknowledgements

The research was supported by the Artificial Intelligence Key Laboratory of Sichuan Province (Grant No.2019RYY01) and Enterprise informatization and Internet of things measurement and control technology key laboratory project of Sichuan provincial university (Grant No.2018WZY01)

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