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Research and Analysis of a New Protection Method for Traction Networks Based on Fault Current Characteristics

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Abstract

The relay protection of traction network is the key to ensure the reliable operation of high -speed railway traction power supply system, but the reliability of the current relay protection scheme cannot meet the requirements of high- speed railway. The reliability of the current relay protection scheme cannot meet the requirements of high- speed railway. In this paper, a new protection algorithm for fault feature extraction based on skewness and kurtosis is presented according to the asymmetry and amplitude of current waveform. It can effectively improve the performance of relay protection, and the concept is clear and the algorithm is simple.

Keywords

High-speed railroad power supply system; traction network protection study; fault waveform characteristics; partial degrees; kurtosis.

1. Introduction

At present, the relay protection technology adopted by China's high-speed railway is developed on the basis of the general railway, but in the high-speed railway, the traction load current is larger than the general railway, and the performance of the relay protection system of the general railway will be weakened when applied to the high-speed railway, and in some cases the phenomenon of rejection and misoperation will occur.[1] When a short-circuit fault occurs in the AC traction network, the short-circuit process is an unstable state, which contains a DC component and a non-periodic component, and decays exponentially, so the current waveform is unstable at the moment of short-circuit.[2] The fault current waveform undergoes a certain degree of distortion and there are singularities, so it is possible to determine whether a fault has occurred based on the symmetry of its distribution shape and the steepness of the waveform. Here, the skewness of the data and the kurtosis of the data are used to analyse the fault and load currents and to construct a protection scheme based on a combination of kurtosis and skewness.[3]

Figure 1 below shows the fault current waveform obtained after sampling and processing the fault data during a fault on the existing high-speed railway traction network, while Figure 2 below shows the intercepted current waveform at the moment of the fault and after amplification.[4]

As can be seen from the available short-circuit waveform data, in the event of a fault in the traction network, the current waveform is steeper and sharper than normal, i.e. the amplitude rises much more steeply. The fault current waveform is very similar to a sinusoidal waveform. However, the current waveform after a fault has a tendency to be left-skewed; the current waveform is smoother at the time of the fault than during normal operation, so the fault current has less harmonic content compared to normal load current.[5]

By analyzing these waveform data, we obtain the following characteristics of the fault currents.

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(1) The duration of the short-circuit transient process is relatively short, and the slope of the current waveform is relatively large at the moment of fault in the traction network, with obvious singularities, and the roughness of the waveform has increased after the short circuit.

(2) The moment a short-circuit fault occurs at the near end, there is a sudden change in magnitude; at the far end, the current increment is not large and the magnitude is closer to the load current.

(3) When a short circuit occurs, there is an obvious asymmetry in the first cycle if the short circuit current is taken positive.

(4) The waveform is unstable at the moment of the short circuit, but after a sustained period of time (very short), the steady state is restored and the short circuit current is essentially symmetrical. Based on the characteristics of the traction network during faults and operation, a new type of protection algorithm for the traction network supply arm can be constructed.

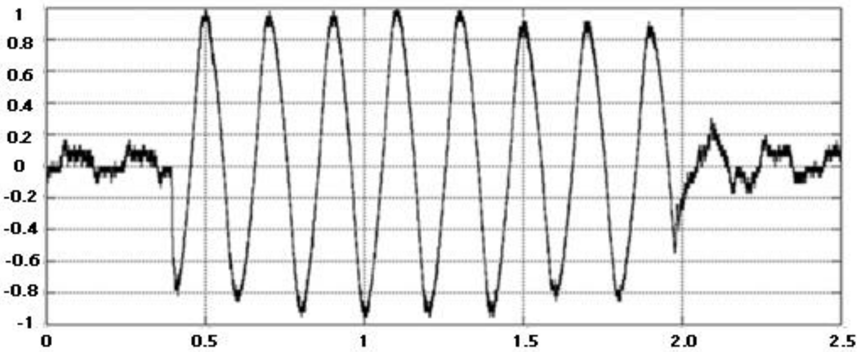

Fig 1: Fault currents in the traction network

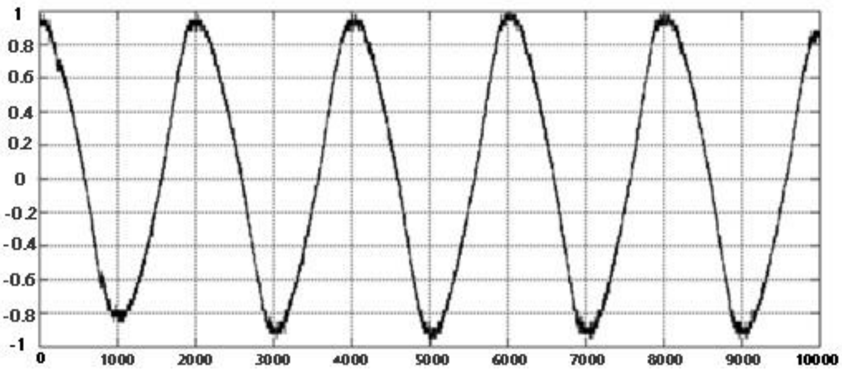

Fig 2: Intercepted fault current

2. Current waveform singularity metric theory and algorithm

Fault waveforms can accurately and intuitively reflect many of the characteristics of a fault, and a clear analysis of these characteristics, combined with fault recordings, can easily identify and differentiate between fault waveforms and normal load current waveforms. The use of skewness and kurtosis, which describe the degree of asymmetry of the data, is therefore an appropriate measure of the singularity of the current waveform.

2.1. Kurtosis and skewness

The height and width of a curve can be expressed in terms of kurtosis. The normal distribution curve is generally used as a reference to describe the flatness of the curve, or it can be used to describe the concentration level of the data distribution. When a set of data has a kurtosis value of zero, it is fully consistent with a Gaussian distribution. The kurtosis value is greater than zero if there is a strong tendency for the distribution to be concentrated, i.e. the data waveform is relatively sharp. If there is a strong tendency to disperse the data, i.e. the waveform is relatively flat, then the kurtosis value will be less than zero. The kurtosis coefficient is generally defined using the kurtosis statistic, i.e. the fourth order central moment, as follows:

$$K = \frac{n(n+1)\sum(x_i-\bar{x})^4-3\left[\sum(x_i-\bar{x})^2\right]^2(n-1)}{(n-1)(n-2)(n-3)s^4} \tag{1}$$

where n is the number of data; the i-th data of x_i; the mean of the data $\bar{x}$; and s4 is the fourth power of the sample standard deviation. In general, skewness is used to indicate the degree of deviation of the data, that is, the degree of symmetry of the data. The magnitude of the skewness can be positive, less than zero, or even undefined. If a set of data waveforms is relatively homogeneous (in this case occurring equally on both sides of the mean), then it has a skewness coefficient of zero. If the data are not evenly distributed, then the skewness coefficient is not zero. When the number of data on either side of the mean is not equal, and the left side is less than the right side, then it is called left skewed, and the skewness value is less than zero. The skewness coefficient is generally defined by the third-order central moment, which is defined as:

$$SK = \frac{n\sum(x_i-\bar{x})^3}{(n-1)(n-2)s^3} \tag{2}$$

where n is the number of data; the i-th data of x_i; the mean of the data $\bar{x}$; s3 the third power of the standard deviation.

2.2. New algorithm for fault feature extraction

In order to implement a transient protection based on a combined kurtosis and skewness algorithm, it is first necessary to define a fault characteristic protection action value based on kurtosis and skewness, and when the combined skewness and kurtosis value exceeds the action value, a fault is considered to have occurred. The kurtosis is defined in terms of the fourth order centre distance, while the skewness is defined in terms of the third order centre moment When the centre distance after a fault is smaller than 1, the change in the skewness will be greater than the change in the kurtosis, so the kurtosis value for each cycle is integrated, and through extensive data analysis and calculation, the action characteristic value can be defined as:

$$Y = \frac{35K+K}{2} \tag{3}$$

where Y is the combined value based on skewness; K is the kurtosis coefficient; and SK is the skewness coefficient.

3. Protection scheme calibration and validation of reasonableness

When the short circuit fault point is at the end of the supply arm, the fault current amplitude is small and the fault transient process is of very short duration[3] , so the fault current is approximately the same as the normal load current in terms of waveform. In order to make the rectified fault characteristic more sensitive, the current waveform amplitude after the fault is considered to be approximately the same as the load current waveform amplitude and it is assumed that the waveform of the fault current is a standard sinusoidal waveform for all cycles except the first one, when the kurtosis of the first cycle can be compared with the kurtosis of the other cycles and if the calculated value exceeds the set protection action value, a fault point is considered to have occurred. The kurtosis values of the first and second cycles of the fault current are obtained to determine whether a fault has occurred. To verify the correctness of the method, the kurtosis and kurtosis are calculated for the third, fourth and fifth cycles of the fault current waveform and the results are recorded in Table 1.

Table 1: Calculation of eigenvalues for five cycles after the point of failure

Number	Skewness SK	Kurtosis K	Eigenvalue Y
one cycle	-0.1078	1.9319	0.8043

second cycle	-0.4645	1.9389	0.2728
triple cycle	-0.4999	1.9355	0.2179
quadruple cycle	-0.5003	1.9335	0.2163
five cycles	-0.5004	1.9335	0.2162

As can be seen from Table 1, the calculated eigenvalues for each cycle of the short-circuit current decrease after the occurrence of a short-circuit fault, with the calculated eigenvalues for the first cycle of the current waveform after the fault occurring being much larger than those for subsequent cycles. The analysis leads to the conclusion that the method can reliably distinguish whether a short-circuit fault has occurred or not, i.e. the fault current can be distinguished. The test was carried out using fault waveform data collected during a realistic traction network fault. To find the characteristic values here, we use the positive current kurtosis value for one cycle of normal load current compared to the kurtosis value for the first cycle of fault current to see if the fault current can be determined. Table 2 shows a few sets of data from the fault waveform data obtained when a fault occurred in a real substation.

Table 2 Measured short circuit fault data

	Normal data			Fault data		
Request item	K1	SK1	Y1	K2	SK2	Y2
Data 1	0.0337	0.1850	0.2943	0.3401	0.4633	0.8650
Data 2	0.0389	0.1310	0.2160	0.1521	0.6009	0.9774
Data 3	0.0266	0.1167	0.1884	0.1901	0.5924	0.9836
Data 4	0.0529	0.1541	0.2576	0.2269	0.5474	0.9346
Data 5	0.0312	0.1332	0.2154	0.1899	0.6013	0.9969
Data 6	0.0510	0.1089	0.1889	0.1651	0.5431	0.8972
Data 7	0.0334	0.1311	0.2134	0.2470	0.5234	0.9086
Data 8	0.0275	0.1075	0.1793	0.2531	0.5891	0.9680
Data 9	0.0360	0.1657	0.2667	0.2733	0.5001	0.8868

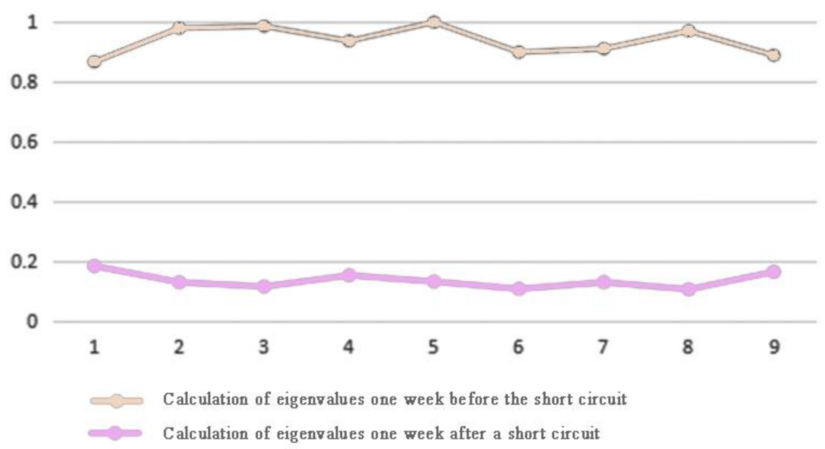

Fig 3: Eigenvalues of the one-cycle combination before and after the failure

For comparison purposes, the short-circuit eigenvalues and the fault eigenvalue data in the table are made in the same line graph, as shown in Figure 3. Both the line graph and the data clearly show that the fault eigenvalues are much larger than the combined eigenvalues at load

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current, so that the algorithm can reliably distinguish between fault currents. Here the combined eigenvalue can be taken as 0.5, i.e. the protection will act if it is greater than 0.5.

4. Conclusion

The new protection algorithm based on the combined kurtosis value overcomes the confusion when traditional distance protection distinguishes between fault and start currents. When using the combined eigenvalues to distinguish between fault and load currents, the fault current combined eigenvalues are larger, typically above 0.63; the load current combined eigenvalues are smaller, typically less than 0.3, then the spatial margin between the fault and load currents is larger, i.e. the respective combined eigenvalues of the fault and load currents do not overlap and can reliably distinguish between fault and non-fault currents, therefore The combination algorithm is therefore more reliable than distance protection.

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