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Line Selection Diagnosis Based on Dyadic Wavelet and Current Fault Record Data from One-End

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Abstract: It's of great significance to make use of fault record data to select the fault line exactly and provide a real-time or quasi real-time referenced decision-making message. The four-rank center B-spline semi-orthonormalt dyadic wavelet is proposed to find out the singular points of the fault currents and the theory basis is discussed in detail. On the basis of the discussion above, the abrupt change characteristic of the fault line currents is analyzed in detail in virtue of the configured time of primary protection and the re-closing interval when a simple fault occurs on lines in local substation and nearby substation of EHV multi-loops power network under several circumstances such as normal relay and breaker, action-resistant relay or breaker, faulty relay or breaker. The result of simulation indicates that this algorithm in this paper is exact, efficient, and practicable.

Key-Words: EHV power network, fault line selection, fault record data, singular points of the fault current, dyadic wavelet.

1 Introduction

When complex faults occur in EHV power network, a lot of fault record data will be produced. Using one-end fault record data to select the fault line effectively, and giving management and running personnel a real-time or quasi real-time referenced decision-making message are of great practical value.

The present fault diagnosis system presented in literatures [1-2] used power frequency fault currents from multi-ends mainly. The algorithms above is mainly applied to line selection in indirectly grounding distribution network and is not suitable for fault line selection diagnosis in EHV power network. In substation, it's reliable to select the fault line through the changed information of breakers and relay nodes and increment of fault phase current under common situation. However, the line selection algorithm above is inexact or even wrong totally, when the breakers or the relay is action-resistant or faulty and loss of digital message because of disturbance of channel.

Based on above reasons, the four-rank center B-spline semi-orthonormalt dyadic wavelet is proposed to find out the singular points of the fault currents and the theory basis is discussed in detail. The abrupt change characteristic of the fault line currents is analyzed in detail in virtue of the configured time of main protection and the re-closing interval when a simple fault occurs on line in local substation and nearby substation of EHV multi-loops power network under several circumstances such as normal relays and breakers, action-resistant relay or breaker, faulty relay or breaker. A certain part of power network in East of China is adopted as the simulation model to validate the algorithm. The result indicates that this algorithm in this paper is exact, efficient, and practicable.

2 Fault line selection principles

The key of fault line selection principle based on one-end analog fault currents is checking the characteristic time of fault currents by means of singularity detection function of wavelet transform and configuration message of protection time.

Take 500KV power network in East of China, shown as fig.1, as the simulation model. Let Dongming substation be local substation, and Sanbao substation be nearby substation.

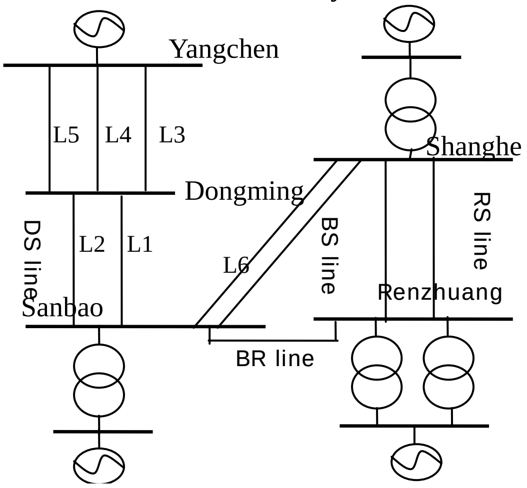

Fig.1. A part of power network in East of China.

2.1 Singularity detection principle

The singularity of signal refers that there is discontinuous point somewhere or a certain order derivative of $f(x)$ is discontinues, the singular point, i.e., the catastrophe point, often contains important information of signal. In mathematics, the singularity of signal is often measured with Lipschitz exponents [3].

The theorem of singularity about WT ensures that all the singular points of the signal $f(x)$ can be achieved by tracing the module maximum of wavelet transform at small scale. As the increase of the decomposed scale, the precision of singularity detection will be worse. The reason is that the support length of wavelet function increases when the scale increases, then numbers of non-zero data increase yet, and the precision decreases. So it's important to choose suitable scale in singularity detection. According to above theorem, all singular points of $f(x)$ can be spotted at small scale eventually, so the coefficient of first scale is chosen to detect the singular points of fault currents in this paper.

2.2 Four-rank center B-spline semi-orthonormalt dyadic wavelet

Dyadic wavelet is suitable for singularity detection, because it keeps the merit of continuous wavelet transform such as invariance of translation and it has fast algorithm.

Both Gauss function and center B spline function are typical smoothing function, but center B spline function has many merits [3].

Therefore, the four-order center B spline semi-orthonormalt dyadic wavelet (shorted for DW) is adopted to detect singular points of fault current. The smoothing wavelet function has compact support and one vanish moment. The length of filter coefficients is limited. According to singularity detection principle, this dyadic wavelet is suitable for singularity detection of fault signal in power system.

2.3 Fault line selection

There are three abrupt catastrophe moments in fault currents with temporary fault, i.e., fault moment, fault remove moment and re-closing moment. There are four abrupt catastrophe moments in fault currents with permanent fault, i.e., fault moment, fault remove moment, re-closing moment and moment of breakers trip again. The DW is adopted to make wavelet transform of currents datum in this paper, and the absolute maximum value of the 1^{st} layer wavelet coefficient is used to detect catastrophe moments above.

The catastrophe of practical signal is a relative concept. The wave of current or voltage is sinusoidal fundamental component of frequency 50HZ under normal condition in power system, so the wavelet coefficient transformed from sinusoidal fundamental wave should be small and the wavelet should be very sensitive to discontinuous point or abrupt point of signal. However, B spline wavelet can't satisfy this request, because the wavelet coefficient is influenced by sinusoidal fundamental wave to a great extent and the real information is always flooded. Therefore it's necessary to eliminate fundamental wave on singularity detection. A digital filter is designed to eliminate the fundamental wave firstly, and wavelet decomposition is done in succession. The digital filter is made by zero-pole placement method, and its transition function is:

$$H_k(z) = 1 - 2r\cos(kw_1T_s)z^{-1} + r^2z^{-2}$$

Let $k = 1$ and $r = 1$, then the fundamental wave can be eliminated completely.

2.3.1 Both relays and breakers are normal

The characteristic of fault line currents can be depicted as following when three-phase short circuit fault occurred on a certain feeder in local substation. In the case of both relays and breakers are normal: the three phase currents are still symmetry, but the amplitudes will increase abruptly (for infinite bulk supply networks connecting with small power supply system, the current will decrease when fault occurs at the side of infinite bulk supply network). For time interval of 40-60 microseconds, which is sum of primary protection and breaker action time commonly, breakers of three phases will trip and the currents become zero(for existence of mutual inductance between parallel double-circuit lines, the currents are not absolutely zero. The concept of zero current can be defined by relative value). If it's temporary fault, the currents will recover after re-closing. If it's permanent fault, the currents will still be very great after re-closing, and they'll be zero after the breakers trip again.

The characteristic of fault line current is the same as that of the symmetry fault, when there is two-phase short circuit or two-phase grounded fault occurring on a certain feeder in local substation.

The characteristic of fault line current can be depicted as following when there is single-phase grounded fault occurring on a certain feeder in local substation: the amplitudes of currents will increase abruptly after a fault happens. There will be induced current of a certain value in fault phase after single-phase tripping because of mutual inductance with neighboring phases. If it's temporary fault, the currents will recover after single phase re-closing. If it's permanent fault, the currents will be zero after breakers of three phase trip after re-closing interval which can be achieved from record file or database of protection setting.

There are three abrupt catastrophe moments in all currents in substation if it's temporary fault: i.e., fault moment, fault remove moment and re-closing moment. Let they be **T1**, **T2**, **T3**, respectively. There are four abrupt catastrophe moments in fault currents of permanent fault, i.e., fault moment, fault remove moment, re-closing moment and time when breakers trip again. Let they be **T1**, **T2**, **T3**, **T4**, respectively.

The dyadic wavelet is adopted to make wavelet decomposition of phase currents of each line to detect all the singular points. The interval between **T1** and **T2** is 40-60ms, i.e., sum of primary protection and breaker action time. As long as the above condition is satisfied, it can be concluded that both relays and breakers are normal.

A little residual currents still exists in fault line after fault is eliminated because of mutual inductance with neighboring line. However, the residual currents is smaller than that of currents in non-fault line. The fault line can be selected through comparing among values of each current after moment **T2**. If there is permanent fault, the currents of fault line will be zero after the breakers trip again (corresponding to catastrophe moment **T4**). If there is temporary fault, the currents should recover after re-closing (corresponding to catastrophe moment **T3)**. Whether the fault is permanent or not can be judged from the currents after the last catastrophe moment). In this paper, the currents of each line in local substation are normalized firstly, i.e., each phase current of lines is divided by value of respective rating phase current. The absolute sampling value of each normalized currents with one-cycle from moment **T2** are summed respectively, and are divided by sampling points of one cycle respectively. The above process is called as 'sum and average algorithm' in below paragraph. If the processed value of current in a certain line is smaller than threshold k which is set according to the residual current, it can be concluded that it is a fault line. Whether the fault is permanent or not can be judged by the currents after the last catastrophe moment. If the currents of fault line are nearly zero, the fault is permanent, or it's temporary.

2.3.2 maloperation of protection or break

The characteristic of mal-operation line currents can be depicted as follow: the symmetry rating three-phase currents become zero suddenly. The mal-operation moment **T1** can be detected by dyadic wavelet decomposition of each phase current of lines. The line whose currents are zero after moment **T1** is the mal-operation line. The digital message must be included to judge whether it's mal-operation of protective relaying or breaker.

2.3.3 Mis-operation of primary protection

The short-range backup protection should be started to cut off fault line. Suppose there is fault on line 1 but the primary protection at Dongming substation side of line 1 failed to act. The characteristic of fault line currents are the same as 2.3.1 no matter the fault is symmetrical or not. The difference is that the backup protection needs 0.3-0.5 to act, and the re-closing dose not start. Because primary protection at Sanbao substation side of line 1 is normal, there will be three catastrophe moments detected by wavelet transform of phase currents of each line if the fault is grounded: **T1**(fault moment),**T2**(moment when breaker at Sanbao substation side trips),**T3**(moment when breaker at local substation side acts). The interval between **T1** and **T3** is about 0.3-0.5s, much longer than 40-60ms, so whether the primary protection misses operation can be judged. For ungrounded fault, the current of fault phase will be zero after breaker of line 1 at Sanbao substation side acts, so it's hard to detect moment **T3**. For line with potential transformer of individual phase, **T3** moment can be detected by wavelet transform of fault voltage signal in local substation, so whether the primary protection misses operation can be judged.

2.3.4 mis-operation of breaker

The breaker failure protection should be started if there is a fault on line 3 in Dongming substation but the breaker in local substation failed to act. For scheme with one-and-half breakers, three phases of failure breakers will trip after short interval about 0.13-0.15s, and all breakers connected with the failure breaker trip after longer interval about 0.2-0.25s, including breaker at the other end of fault line through remote tripping. Because breaker of line 3 in Sanbao substation is normal, i.e., it will trip 40-60ms after fault happens, so three singular points will be detected: **T1** (fault moment), **T2** (moment when breaker of line 3 in Sanbao substation trips), **T3** (moment when fault is eliminated). The interval between **T1** and **T3** is about 0.2-0.25s, so whether the breaker misses operation can be judged. All of the currents in feeders connected with bus will be zero after the breaker failure protection starts if breaker of bus side misses operation, and the middle breaker connected with failure breaker will trip, however, the middle breaker connected with normal breaker will not trip, which breaker is failure and the fault line can be detected according to the above characteristic. If the middle breaker misses operation, two breakers connected with the failure one will trip, the failure breaker and fault line can also be detected. For other main connection schemes, the recognition of failure breaker can be realized in the similar way. For dissymmetrical fault, the fault line can be selected by comparing among values of negative sequence component of each line. For symmetrical fault, the fault line can be selected by comparing among value of high harmonic component of each line.

The fault line selection can also be deal with in local station when a fault occurs in nearby substation according the algorithms above.

3 simulation and test

Take a part of power network in East of China as the simulation model. Let three-phase reclosing and single-phase reclosing intervals be 1.5s and 0.7s, respectively. Let sum of primary protection and breaker action time be 40ms, short-range backup protection interval be 300ms, and breaker failure protection interval be 250ms. Let a fault be happened at 0.09s, and sampling rate be 3000HZ. Let threshold k be 0.1. In order to test the fault line selection algorithm under extreme condition, A-phase fault is set at the end of line with transition resistor 300ohms in local substation, and at the header point of line with transition resistor 0ohms in nearby substation.

(1) Both relays and breakers are normal

A-phase permanent fault occurs at the end of line 1 with transition resistor 300ohms. The waveforms of 1^{st} layer wavelet coefficient of A, B, C phase current of line **1** are shown in fig.2. The y-axis shows wavelet coefficients of each phase current and the x-axis shows sample point. The four module maximum points corresponding to moment **T1**,**T2**,**T3**,**T4**. The singular points and values of Sum of phase currents of each line in Dongming substation determined by wavelet are shown in Table 1. The column of Sum are values of each currents after moment T2 processed by 'sum and average' algorithm.

In Tab. 1, the four catastrophe points **T1,T2,T3,T4** of fault phase current(I_{1a}) detected by wavelet correspond to 0.0907 0.140 0.831 0.880s, respectively. Because of action characteristic of breakers, the time T1 and T2 corresponding to is a litter deviation from the setting time. It's obvious that wavelet transform can detect catastrophe points of signal with error not over 1ms even with great transient resistor at the end of line. All time intervals between T1 and T2 detected from phase currents of each line are shorter than 49ms, so the message that both relays and breakers are normal can be got. Sum value of I_{1a} is smaller than that of other currents obviously, and it's smaller than k, so the fault line is line 1 and the fault phase is A. Do 'sum and average' algorithm on normalized fault phase current after moment T4, then the value 0.00069028 is got. Because 0.00069028 is smaller than k, the fault is permanent.

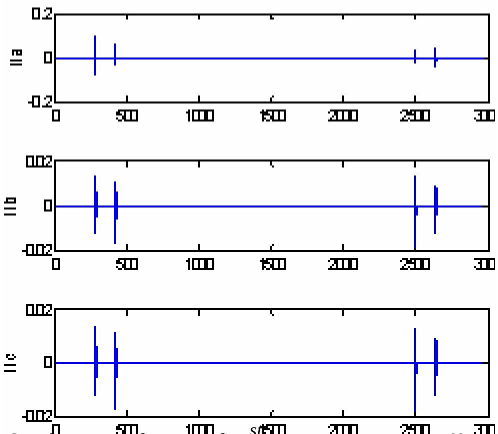

Fig2. The waveforms of 1^{st} layer wavelet coefficient

Tab. 1 the singular points and values of Sum of every currents in Dongming substation determined by wavelet

n	T1	T2	T3	T4	Sum
I1a	272	418	2491	2638	0.000779
I1b	274	418	2491	2638	0.48183
I1c	274	418	2491	2638	0.46712
I2a	272	420	2491	2639	0.85323
I2b	273	420	2491	2640	0.59272
I2c	273	420	2491	2640	0.59228
I3a	272	419	2491	2639	0.44466
I3b	274	427	2493	2639	0.54766
I3c	274	427	2493	2639	0.53862
I4a	272	419	2491	2639	0.44466
I4b	274	427	2493	2639	0.54766
I4c	274	427	2493	2639	0.53862
I5a	272	419	2491	2639	0.44466
I5b	274	427	2493	2639	0.54766
I5c	274	427	2493	2639	0.53862

(2) primary protection misses operation

Let primary protection at Dongming substation side of line 1 miss operation and he short-range backup protection be started. There are three catastrophe points on phase currents of each line, because primary protection at Sanbao substation side of line 1 acts normally, i.e., A-phase current at this side of line 1 will be zero about 40ms after fault happens. The waveforms of 1st layer wavelet coefficient of A,B,C phase current of fault line are can be obtained.

In Tab.2, all intervals between catastrophe points T3 and T1 are about 300ms, so the message that primary protection misses operation and breakers are normal. Sum value of I_{1a} is smaller than that of other currents, and it's smaller than threshold k, so line 1 is the fault line.

The other type faults happed in the local station and nearby substation have been simulated and the conclusions testify the algorithms presented in the paper.

Tab.2 the singular points and values of Sum of every current in Dongming substation determined by wavelet

	T1	T2	T3	Sum
I1a	272	419	1173	0.00071
I1b	274	419	1173	0.48132
I1c	274	419	1173	0.46786
I2a	272	419	1175	0.8527
I2b	273	419	1175	0.59211
I2c	273	419	1175	0.59289
I3a	272	420	1173	0.44449
I3b	274	421	1173	0.54679
I3c	274	421	1173	0.54048
I4a	272	420	1173	0.44449
I4b	274	421	1173	0.54679
I4c	274	421	1173	0.54048
I5a	272	420	1173	0.44449
I5b	274	421	1173	0.54679
I5c	274	421	1173	0.54048

4 conclusion

In this paper, the dyadic wavelet is proposed to find out the singular points of the fault current, as well as he theory basis is discussed in detail. A new algorithm of fault selection in EHV networks based on fault analog message is proposed. The simulation result of East China networks indicates that this algorithm in this paper is exact, efficient, and practicable.

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