Fault section locating method for coalmine high-voltage network based on SVD

Junfeng Li^a, Zhengjun Yao^b, Shujun Bai^c

School of Mechanical Electronic & Information Engineering, China University of Mining & Technology-Beijing, Beijing 100083, China

^alijunfeng_518@163.com, ^byaozhengjun@cumb.edu.cn, ^cbaishujun1991@163.com

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Abstract. According to multi-branch structure of high voltage power network in coal mine, a new method based on singular value decomposition (SVD) was proposed. The characteristics of reflection and refraction of the traveling wave generated by the fault point were studied and the values measured by devices at initial side of each section were decomposed by SVD after Phase-model transformation. Traveling waves will produce mutations, fault section is the one whose first mutation of forward traveling wave is maximum. This method is simple and effective, and it is not affected by grounding resistance and inception angle. This method can be applied to single-phase and multi-phase grounding and phase-phase short.

1. Introduction

In China's underground high voltage power network, electrical energy is transmitted through power cables by means of the neutral point grounded by arc suppression coil with the voltage level of 6/10kV. At present, there are mainly active and passive methods as to the section location. The active method is used to distribute network into a specific frequency, amplitude signal, detection of injection signal through the fault to determine the location of the fault [1-2]. Based on feeder terminal unit, the active method is to detect relevant voltage or current signal and put forward the relevant criteria after a certain mathematical operation[3-4].

According to the arc suppression coil connected to the mine high voltage distribution network, the paper first analyzes the travelling characteristics of the traveling wave generated by the faults to all the branches, followed by the derivation of the solution formula of the forward and backward traveling wave by initial line measurement value. The SVD of forward traveling wave of each line is made before comparing the first P2 components of the fault line.

2. Wave process in a line

2.1 Forward and backward traveling wave.

In order to reveal the propagation of the traveling wave generated by the fault point and the refraction and reflection at the nodal point of each branch, it is assumed that the line is lossless transmission.

Assuming that the voltage and current of the m mode component after decoupling of the measured signal are u_m and i_m respectively, the corresponding forward and backward traveling wave can be obtained as (1) and (2).

$$u_q = (u_m + z \cdot i_m) / 2 \quad (1)$$

$$u_f = (u_m - z \cdot i_m) / 2 \quad (2)$$

2.2 Refraction and reflection of the traveling wave at the nodal point.

When a single phase to ground fault occurs in the line, it is equivalent to a voltage source which is opposite to that of the original voltage. It can be called as virtual power[5]. the access of the virtual power supply is considered with a lossless transmission line. With the prominent fault line, the system schematic diagram is shown in Fig.1.

Fig.1 Sketch map of the traveling wave at the node

When switch K1 is closed, voltage generated by the fault line is invaded by the line A. According to Petersen rules as shown in Fig.2 b, among which, n is the total branch of the node, and U_z is the bus voltage of the moment of the traveling wave intrusion node, which is obtained by the Eq.3.

$$I = \frac{2U_0}{Z + \frac{Z}{n-1}} = \frac{2(n-1)U_0}{nZ} \Rightarrow U_z = I \frac{Z}{n-1} = \frac{2U_0}{n} \quad (3)$$

Thus it can be seen that at the moment when the fault traveling wave reaches the node, bus voltage is $2/n$ of that of the virtual power. Since there are more than two branches in a common node, the voltage of the traveling wave of each branch is less than that generated by the virtual power. Even in the lossless line, after being refracted at the node, the traveling wave generated by the fault line will become small when invading other branches. Actual line need to consider the following factors, such as the wire resistance, the insulation leakage conductance and dielectric loss, which will result in the decrease of the amplitude and steepness of wavefront.

3. Singular value decomposition

One dimensional signal structure Hankel matrix, after the singular value decomposition SVD is similar to the wavelet transform to get the singular value information[6].

SVD means: An arbitrary real matrix $A \in R^{m \times n}$, there are two orthogonal matrix $U = [u_1, u_2, \dots, u_m] \in R^{m \times m}$ and $V = [v_1, v_2, \dots, v_n] \in R^{n \times n}$, meet Eq.(4)

$$A = U \Sigma V^T \quad (4)$$

When $m > n$, $\Sigma = [\text{diag}(\sigma_1, \sigma_2, \dots, \sigma_n), 0]_{m \times n}$; if $m < n$, then $\Sigma = [\text{diag}(\sigma_1, \sigma_2, \dots, \sigma_m), 0]_{m \times n}^T$, where σ_i is singular values and exists $\sigma_1 \geq \sigma_2 \geq \dots \sigma_q > 0$ ($q = \min(m, n)$), matrix A can be written as the product of eigenvalues and eigenvectors:

$$A = \sigma_1 u_1 v_1^T + \sigma_2 u_2 v_2^T + \dots + \sigma_q u_q v_q^T \quad (5)$$

Among the equation, $q = \min(m, n)$. Make $A_i = \sigma_i u_i v_i^T$, then $A = \sum_{i=1}^q A_i$.

Assuming there is a set of discrete signal $X = [x(1), x(2), \dots, x(N)]$ to construct Hankel matrix (6)

$$A = \begin{bmatrix} x(1) & x(2) & \dots & x(n) \\ x(2) & x(3) & \dots & x(n+1) \\ \vdots & \vdots & \ddots & \vdots \\ x(m) & x(m+1) & \dots & x(N) \end{bmatrix} \quad (6)$$

In Eq.(6) $1 < n < N, m+n-1=N$. it is obtained from the equation (9)

$$A_i = \begin{bmatrix} \boxed{x_i(1)} & \boxed{x_i(2)} & \dots & \boxed{x_i(n)} \\ \boxed{x_i(2)} & \boxed{x_i(3)} & \dots & \boxed{x_i(n+1)} \\ \vdots & \vdots & \ddots & \vdots \\ \boxed{x_i(m)} & \boxed{x_i(m+1)} & \dots & \boxed{x_i(N)} \end{bmatrix} \quad \begin{matrix} R_{i,1} \\ \\ \\ C_{i,n} \end{matrix}$$

Fig.2 Component of Pi

In Fig.2, $R_{i,1}$ means the first row of matrix A_i while $C_{i,n}$ means last column that removed the first element. Let $P_i=[R_{i,1}, C_{i,n}^T]$; $R_{i,1} \in R^{1 \times n}$, $C_{i,n} \in R^{(n-1) \times 1}$. In this way, the original discrete signal X can be expressed by $\sum_{i=1}^q P_i$. When $i \geq 2$, P_i is able to indicate information of singular value. Compared with wavelet transform, advantage of SVD is that the phase invariant on each isolated signal is kept as in the original signal.

Wavelet transform needs to intercept data, or there will be a large change at both initial and end stages, which increases the difficulty to identify the required signal. While there is no such phenomenon in SVD.

4. Case study

4.1 Simulation model.

Circuit structure is shown in Fig.3. The system is powered by a 35kV/10kV transformer, and the parameters of the cable in the model are set by the parameters of the MYJV22 model. Arc suppression coil series resistance RL grounding, the system is in a state of over-compensation of 10%. Measurement units are installed in the initial side of each line, respectively, measuring the line phase voltage, phase current, with the sampling frequency of 100k/s.

Fig.3 System structure

4.2 Example analysis

(1) Different initial angle of fault

Assume that a single phase fault occurs at the time of 0.035s at section 3, with the initial fault angle from -90° to 0° , and the grounding resistance of 5Ω . After each section's signal decoupling, the forward traveling wave is obtained and P2 component of SVD amplitudes are shown in Tab.1. It can be clearly seen from table 1, with the initial angle close to 0° , the amplitude of each section has a significant reduction. But the amplitude of fault section 3 is still the largest, which is able to determining the fault section where the method is not affected by initial angle.

(2) Different grounding resistance

Single phase to ground fault occurred at 0.035s of section 3, with the initial fault angle of 15° . The comparison of the different grounding resistance is shown in Table 2. It can be seen that the method can be accurately used to identify the fault section when the grounding resistance is different, with obvious effect.

(3) Different fault types

At present, most of the methods are based on single phase to earth fault which accounts for more than 80% of the electrical fault. This paper presents a method based on the virtual power access method, and it is not affected by fault types. Continuing to use the 3.1 system model, with the fault resistance of $R=5\Omega$, $\theta=30^\circ$, the fault occurred in the 0.035s. Table 3 is the amplitude of P2 after SVD in different fault types. As is seen from table 3, when different types fault occurred, P2 amplitude of section 3 are still the largest.

Tab.1 P2 amplitude of different inception angle

Fault inception angle(°)	1	2	3	4	5	6	7	8	9	10
-90	1129	2445	3847	490.8	1119	2111	482.8	389.9	675	669.4
-60	1009	2182	3433	438	997.9	1884	430.1	347.9	601.4	597.3
-30	616.5	1337	2102	263	612.4	1154	264.8	210.1	369.5	366.8
0	60.58	130.9	206.1	27.15	61.57	114.2	27.73	19.33	38.48	37.03

Tab.2 P2 amplitude of different fault resistance

Fault resistance(Ω)	1	2	3	4	5	6	7	8	9	10
5	233	506.2	796.9	101	230.7	436.7	98.74	82.07	138.3	137.9
100	42.33	92.56	145.8	17.7	41.45	79.05	17.14	15.8	24.25	24.65
500	9.141	19.94	31.48	3.508	8.222	16.81	2.763	4.278	4.155	4.721
1000	4.395	9.541	15.11	1.409	3.455	7.803	0.6937	2.632	1.265	1.858

Tab.3 P2 amplitude of different fault types

Fault types	1	2	3	4	5	6	7	8	9	10
Ag	511.3	1109	1745	217	506.6	957.2	217.9	178.2	304.9	303
ABg	1828	3948	6202	794.5	1806	3397	779.9	629.4	1088	1080
ABCg	1215	2620	4115	526.2	1196	2251	515.9	418.4	719.4	715.8
AB	1419	3069	4830	616.2	1404	2649	604.8	489.8	846.8	838.2
ABC	888.6	1918	3018	384.6	876.1	1654	377.3	306.6	528.2	523.3

5. Summary

In this paper, the transmission at the node of the traveling wave is analyzed, and the fault section is detected by the method of the mutation of the traveling wave based on the refraction and attenuation characteristics. The installation of the first detection device in each section followed by the transformation of the voltage and current phase mode can lead to the solution of the direct wave. After the direct wave is processed by SVD, the fault location is judged according to the size of the first mutation value. According to the analysis of the theory of traveling wave, the maximum value of the fault section represents the fault section. The method, simple, effective and practical, can be used to diagnose the fault area in different initial angle, fault resistance, single phase, multi phase grounding and interphase short circuit.

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