Rapid Phase Selection Method based on Multi-resolution Morphological Gradient with Series Structure

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Abstract

Protective measures can be rapidly and reliably taken by timely and correctly selecting the fault phase coping with the line protection, as well as the right operation of single-phase tripping and single phase re-closing. Traditional selection method is insensitive and insufficient in dealing with fault resistance, fault position, mutual inductance between closed lines, reactive effect and the in-sufficient for system parameters using power frequency component. This paper has proposed series multi-resolution morphological gradient (SMMG) filter, to extract the deviation of power frequency component of mode current, constructing a new phase selecting component of fault phase component, which provides a solution to fault phase selecting component of fault phase component.

Keywords: *Mathematical morphological, Morphological gradient, SMMG, Mode current, Fault phase selecting*

1. Introduction

The accident in electricity transmission line may induce fatal error for factories, as well as the daily life of society as the complexity of electric system, voltage class and transmission capacity has developed increasingly [1, 2]. Then, higher level of security for the whole system is required, especially for the key point of fault-phase selection in protection measurement.

At present, the domestic method for microprocessor transmission line protection is mainly conducted by combining prompt phase selection and static phase selection, which applies the current difference prompt element as the primary phase selection element after protection starting, and applies subarea phase selection of sequence current as the phase selection element in fault shift and successive operation protection [3]. However, it has been detected that sequence component phase selection element may conduct malfunction in phase selection as for the fault in oscillation link under certain situation.

The traditional phase selection algorithms are conducted upon industrial frequency quantity. The sensitivity of the method would be affected by the fault resistance, fault location, adjacent mutual inductance, and the lack of reactance effect, system parameters and other reasons [4, 5]. Aiming at the problem, some new technologies have been applied in fault phase selection. Traveling-wave is one of the common methods, while this algorithm may require high level of hardware protection devices and in addition, though as a high frequency signal it could not be separated from noise [6]. Wavelet transform has been applied in fault identification and phase selection as a terrific trait extraction tool in recent years. In order to obtain pleasing effect, wavelet filter with longer wave and multi-layer wavelet decomposition should be conducted to the signal which may induce longer processing time and is not profitable for rapid protection requiring strong real-time property [7, 8].

Aiming at the problem of phase selection element and algorithm, this paper has applied the series multi-resolution morphological gradient (SMMG) filter to extract industrial frequency variable of the mode current, which constructed a new mode fault component phase selection element, and provided a new way of thinking for fault component phase selection [9].

2. Mathematical morphology and the gradient

2.1. Mathematical morphology (MM)

Mathematical morphology is a newly proposed method for image processing based on set algebra and topology by scholars of G. Matherom and J. Serra from France. It can provide a full relationship and description of objects in the image by analyzing the geometrical characteristics, assembling and decomposing structural element in a flexible mode, and accomplish processing and analysis with morphology order. The basic idea of mathematical morphology in image processing is to conduct calculation for shift, intersection, and union operation with structural element to obtain the processed image. The idea mentioned above is relatively easy and intuitional, which is appropriate for the processing and analysis of visual information.

Corrosion and inflation are the most basic binary morphology transformation, and corrosion is one of the shrinking transformations, which induces shrinking of the objects and hole expansion, on the other hand, inflation is an expansion method, which induces expansion of objects and shrinking of holes [10].

Defining f(x) as the one-dimension input signal within the fields of $D_f \subseteq E$, g(x) as the constructional element within the fields of $D_g \subseteq E$. The umbra of function g(x) is applied to expand or corrode the umbra of function f(x), in order to obtain umbra of a new function. The direct description is $U(f \oplus g) = U(f) \oplus U(g)$and $U(f \ \Theta \ g) = U(f) \ \Theta \ U(g)$. The expansion and corrosion parameter can be obtained by the formula below:

$$(f \oplus g)(x) = max\{f(x- y) + g(y)\} \qquad (1)$$

$$(f \ \Theta \ g)(x) = max\{f(x + y) - g(y)\} \qquad (2)$$

It can be seen from the formula above that the obtaining of parameters is quite easy with calculation of plus and minus excluding multiplication and division which provides high speed and minimum time delay.

2.2. Multi-resolution morphological gradient transformation (MMG)

Basic Morphology gradient (MG) can be defined on the foundation of inflation and expatiation with the following equation:

$$grad(f) = (f \oplus g)(x) - (f \ \Theta \ g)(x) \qquad (3)$$

Which is remarkable for the equation is that, morphology gradient is apparently different from common gradient in physical fields. The inflation and corrosion of flat structural function embraced calculations of morphology filter taking local maximum and minimum. It can be resulted from above that the calculation structure is determined of affected by the size of structural element and position of zero-point.

Multi-resolution morphological gradient transform (MMG) is a technique designed for power system electromagnetic transient signal. In the multi-resolution morphological gradient techniques, a flat structural element which is variable and has a different origin location is defined as bellows:

$$g^{+} = \{g_1, g_2, \cdots, g_{l-1}, \underline{g_l}\} \tag{4}$$

$$g^{-} = \{\underline{g_1}, g_2, \cdots, g_{l-1}, g_l\} \tag{5}$$

Where, g^+ and g^- are applied to extract for up and down edge of the wave [3].

The gray value multi-resolution morphological gradient can be defined as bellows by the concept of MG and variable flat structure element.

$$\rho_{g^+}^{\alpha}(x) = (\rho_g^{\alpha-1} \oplus g^+)(x) - (\rho_g^{\alpha-1} \Theta g^+)(x) \tag{6}$$

$$\rho_{g^-}^{\alpha}(x) = (\rho_g^{\alpha-1} \Theta g^-)(x) - (\rho_g^{\alpha-1} \oplus g^-)(x) \tag{7}$$

$$\rho_g^{\alpha}(x) = \rho_{g^+}^{\alpha}(x) + \rho_{g^-}^{\alpha}(x) \tag{8}$$

Giving $\alpha = 1, \rho^0 = f$ is the input signal, then the sign of $\rho_{g^+}^{\alpha} > 0$ in formula 6 and in formula 7 corresponds exactly to the up and down edge of transient waveform and ρ_g^{α} in formula 8 can not only locate the transient prompt variation but indicate its polarity.

2.3. Transformation of Series multi-resolution morphological gradient (SMMG)

Multiple MMG filters may form a new filter through the appropriate cascade order together to enhance the transient characteristics of the input signal which is not obvious in order to sense very weak changes and then detect the disturbance of the system. Based on this consideration, the design of a cascade of multi-resolution morphological gradient (SMMG) filtering technology is shown in Figure 1. Where, MF1, MF2 $\cdots$ and MFn are MMG filters.

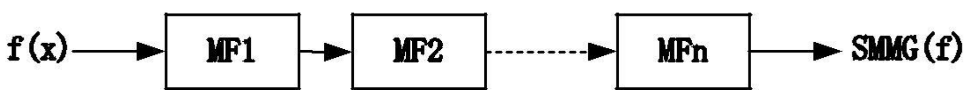

Figure 1. Block Diagram of SMMG

g is a flat structural element, the width of which is described as $l = 2^{\alpha}$, MMG_l is applied as a input signal respecting to series of of g, which is called the multi-resolution morphology transformation. To define a flat-structured order fgig, the length of which is described as $l_i = 2^{\alpha i}$, i=1, 2, 3,$\cdots$,n. $\prod_{i=1}^{n} SMMG_{li}$ is applied to describe the multi-resolution morphology transformation of n-stage series of α_i respecting to the flat structural element order $\{g_i\}$. Especially for it that if all the structural elements are exactly the same with length of L, the respecting transformation shall be $SMMG_L^n$.

The length of SMMG filter is related to the width of structure element and the order of analysis. The length of the MMG1 filter is obtained as follows:

$$W_{SMMG} = 2xd_{MMG_l} - 1 \tag{9}$$

where, $d_{MMG_l} = \sum_{i=1}^{\alpha}(2^{1-i}l - 1)$

The length of the SMMG filter is obtained as follows:

$$W_{SMMG} = 2xd_{SMMG} - 1 \tag{10}$$

where, $d_{SMMG} = \sum_{i=1}^{n} d_{MMG_l}$

With the analysis above, a signal f(x) with length of k may require (m-1)(k-2m+2) calculations with structural element g(x), whose width is m, along with one Gray value corrosion (or inflation) operation. This is essential in evaluating the value of SMMG.

Theoretically speaking, the correct combination order of its cascade structure elements could be found; any weak signal changes can be detected by applying SMMG. The length of the structure elements and cascading order selection in SMMG is not yet supported by a complete theoretical basis; the primary means is heuristics.

The SMMG filter designed in accordance with the principles can conduct a simulation of the existing signal samples, and then determine the sensitivity and reliability to meet the requirements. The shortest length of which may act as the practical filter [4].

1. Weaker the signal is, the higher stages of SMMG are required, along with the length of the filter.
2. The series order with short-structured element set before long-structured one should be primarily considered. To use long and short structured element to testify on the complementarity of robustness and sensitivity of singularity signal, which is also the original reason for strong robustness extraction ability of SMMG.

3. The new phase selection method based on SMMG and mode fault component

3.1. Phase selection element for mode fault component

This paper has proposed a mode current component for fault phase selection in compensation for current component. It can be a new method in fault phase selecting.

The current, voltage is obtained when the system encountered any type of fault can be decomposed into a non-fault component and the fault component. According to the principle of superposition, the fault component in the system of the fault point can be solved as the equivalent power by superposition [5]. By the linear transformation theory, it has shown that the module components can be used to analyze fault component network [6]. Each module are independent of each other, so when the modulus equivalent power is deduced from fault boundary conditions, the independent network of each module can be obtained in order to get the fault components.

The transformation matrix is as follows, applying Clark-type mode transformation:

$$i_{md} = C \cdot i_p \tag{11}$$

where, $C = \begin{bmatrix} 1 & 1 & 1 \\ 2 & -1 & -1 \\ 0 & \sqrt{3} & -\sqrt{3} \end{bmatrix}$, $i_{md} = [i_0 i_1 i_2]^{\mathrm{T}}, i_p = [i_A i_B i_C]^{\mathrm{T}}$, the subscript md indicates the mode component, and subscript p indicates the phase component instead.

A three-stage Butterworth low-pass filter is applied to conduct pre-processing for three input phase-current.

$$\begin{cases} a(n) = [1.0000, -2.5425, 2.1838, -0.6316] \\ b(n) = [0.0012, 0.0036, 0.0036, 0.0012] \end{cases} \quad (12)$$

3.2. Phase selection algorithm

Conduct a design of $SMMG^3{}_2$ $SMMG^1{}_4$filter with a sample rate of 1.8 kHz to extract industrial frequency variable of the mode current. The structure of phase selection element is shown in Figure 2.

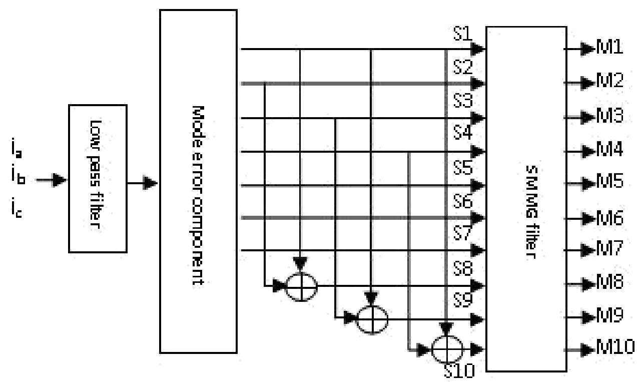

Figure 2. Block Diagram of the Phase Selection

The output value Mi, i = 1,2,⋯, 10 is shown in the figure, and the characteristic patterns is shown in Table 1. Where, ”1” represents the occurrence of an apparent mode extremum in SMMG coefficients; ”0” represents no such value. Characteristics shown in the table can be used to form the fault phase selection element.

Table 1. Charactertstlcs of the Output Pattern of the SMMG Filter

	*M*1	*M*2	*M*3	*M*4	*M*5	*M*6	*M*7	*M*8	*M*9	*M*10
AG	1	1	1	1	0	1	1	1	1	1
BG	1	1	1	1	1	0	1	1	1	1
CG	1	1	1	1	1	1	0	1	1	1
BCG	1	1	1	1	1	1	1	0	1	1
CAG	1	1	1	1	1	1	1	1	0	1
ABG	1	1	1	1	1	1	1	1	1	0
BC	0	0	1	1	1	1	1	1	1	1
CA	0	1	0	1	1	1	1	1	1	1
AB	0	1	1	0	1	1	1	1	1	1
ABC	0	1	1	1	1	1	1	1	1	1

This process may cycle several times. Conduct point-to-point SMMG coefficient calculation from the eighth one to tenth one after the fault point, from which three SMMG coefficients can be obtained for each mode current. To make Mi, i=1, 2,⋯, 10 as the maximum of all three coefficients. By making use of these parameters, the phase selection algorithm can be achieved. The flow chart is shown in Figure 3.

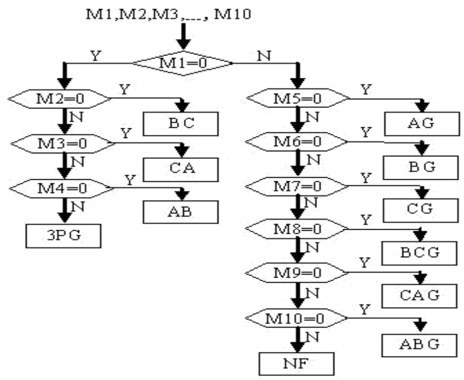

Figure 3. Phase Selection Algorithm Flow Chart

On the basis of Figure 3, the phase selection criteria can be formed from the SMMG mode coefficients:

1. Single phase (take A as example) ground fault

$$(m_1M_5 \leq M_6) \backslash (m_1M_5 \leq M_7);\ m_1 = 3 \text{ s } 5 \tag{13}$$

2. Two phases(take B and C as examples)ground fault

$$(m_2M_8 \leq M_9) \backslash (m_2M_8 \leq M_{10});\ m_2 = 1{:}2 \text{ s } 1{:}5 \tag{14}$$

3. Phase interval (take B and C as examples)ground fault

$$(m_3M_2 \leq M_3) \backslash (m_3M_2 \leq M_4);\ m_3 = 5 \text{ s } 8 \tag{15}$$

4. Three phases fault

$$(M_2 > D) \backslash (M_3 > D) \backslash (M_4 > D) \tag{16}$$

Where, D is selected as the threshold phase of three-phase fault. The parameter value above m1, m2, m3 is set based on a large number of simulations of typical parameter of the high-voltage long-term model.

4. Simulation

EMTP is applied to establish a 500KV simplified system diagram of UHV transmission lines, the structure is shown in Figure 4.

The length of transmission line is 300kmand the structure parameter is shown as bellows:

$R_1 = 0{:}024\Omega{=}Km;\ X_1 = 0{:}27\Omega{=}Km;\ C_1 = 0{:}0132\ F{=}Km;\ R_0 = 0{:}223\Omega{=}Km;\ X_0 = 0{:}87\Omega{=}Km;\ C_0 = 0{:}0082\ F{=}Km$

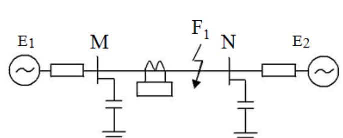

Figure 4. Ultra High Voltage Transmission Line System

Simulation has taken 10 kinds of faults into consideration including single-phase and two-phase ground fault, two-phase short-circuit, three-phase fault. Due to space limitations, this paper only takes the two-phase ground fault as a typical example:

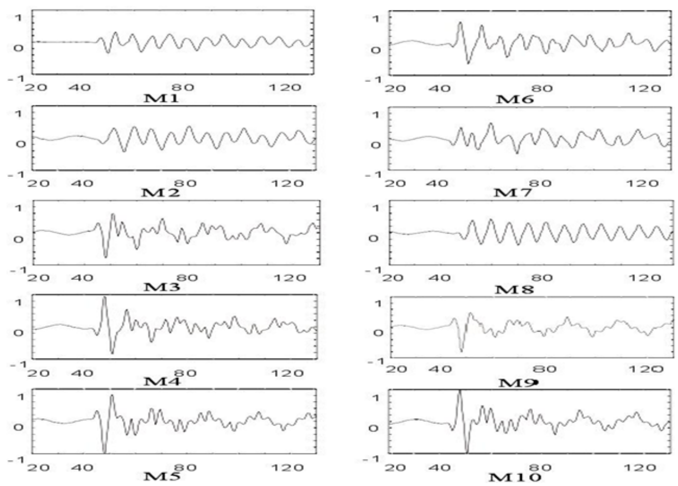

Figure 5. The Mode Current Components SMMG Transformation results for Two-Phase Ground Fault of B and C

Figure 5 indicates the two-phase (B and C) ground fault occurred at around 90% length of the transmission line besides weak power supply. Transformation parameters M1 M10 of mode current can be obtained through low pass filter besides weak power supply. The fault occurred at 45ms. It can be seen from the Figure that a bigger value of M1 may indicate the ground fault; relatively smaller value of M5, M6 and M7 may exclude single-phase ground fault; M8 is apparently smaller than M9 and M10; it can be deduced from equation14 that B and C may suffer two-phase ground fault.

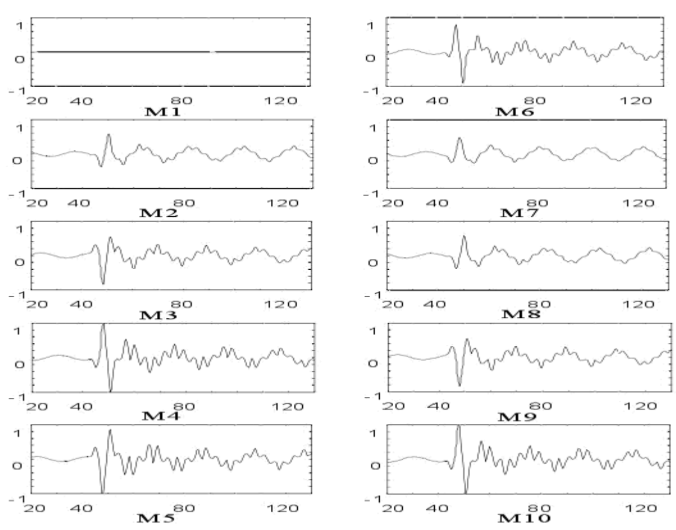

Figure 6. Transmission Results of the SMMG Modular Component of Current for Three-Phase Short-Circuit Fault

The figure above has demonstrated the fault information occurred at 90% of the whole length over weak power supply side, and the transmission coefficients of the SMMG modular component of current after low-pass filter are M1 M10. The fault time is 45ms, and it is apparent that M1 M10 cannot meet any of the conditions of equation13, 14 and 15. Then it can be deduced from equation 16, the fault is three-phase short circuit fault.

5. Conclusion

This paper has applied SMMG filter to extract industrial frequency variable of the mode current, which constructed a new mode fault component phase selection element. The research results of theoretical and experimental has indicated that this element embraces a characteristics of rapid response and sensitivity neglecting the influence of load current, and the influence of power impedance and fault timing is very low. The algorithm of this phase selection element is quite easy with lower hardware requirements, which is ripe to conduct development under current hardware, and it has great application value and broad prospects.

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