

Distance protection based on parameter identification considering transformer characteristics

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Abstract: The distance protection method with parameter identification can distinguish internal fault from external fault correctly and avoid the transient overreach effectively based on the accurate secondary signal data. However, due to the limitation of the frequency band of the electromagnetic transformer, the secondary signal distortion is caused when the transient signal is transmitted, which limits the application of the parameter identification principle. Here, a matching method of line model and transformer type for relay protection is proposed. Analysed the appropriate frequency band of line model and transformer linear transfer frequency band and the electrical signal beyond their intersection should be filtered out. The simulation results show that this method improves the accuracy of the operation. This method not only makes sense to the practical application of distance protection based on the principle of parameter identification, but also has some reference value to other engineering applications.

1 Introduction

With the rapid development of power industry, there has been construction of smart grid and HVDC transmission lines. The power system has higher requirements on the speed and sensitivity of relay protection. Distance protection is widely applied to line protection since it has many advantages [1–3]. However, the traditional distance protection is easily affected by the fault resistance, which occur the overreach happening. The protection principle based on power frequency cannot protect the entire line length and operates with a long time delay due to the calculation process.

Recently, a new kind of distance protection which based on parameter identification has been deeply studied. Based on the theory of electronic network analysis and the model that deals with the relation between the network responses and network parameters, using the responses signal after fault, the parameters of fault line can be estimated by solving the differential equations in time-domain. It will not be influenced by system operation mode, the fault resistance and will be immune to the power system swing [4]. Based on the distributed parameter model, the voltage and current at the setting point is calculated. When the fault point is near the setting point, the line meets the RL model and the calculated fault distance is accurate. When the fault point is far from the set point, there is an error in the calculated distance, though which does not affect the accurate protection action [5]. The algorithm of linear interpolation is introduced to calculate the voltage and current along the lines to calculate the voltage and current distributions along the distributed parameter transmission lines with a low sampling frequency [6]. The simulation results show that this method has good ranging accuracy. This parameter identification method can eliminate the error of single-end distance measurement theoretically and make the distance protection scheme is more accurate. After more than ten years of research and exploration, the method of distance protection based on parameter identification already has a fairly complete theoretical foundation.

On the other hand, with the development of power system, many new typical loads have appeared in power system. The frequency of power system signals is more abundant and there will be a large number of non-power frequency signals after fault occurs. The performance of power devices under wider frequency band signals needs to be greatly enhanced attention. The devices

are mostly designed for power frequency, the performance will be directly affected by Harmonic and non-periodic quantities.

Transformer is a vital equipment which is the connection between the power system primary side and the secondary side, it helps to acquire the grid voltage and current signals in real-time for system measurement and monitoring, also it plays a very important role to the correct operation of relay protection which provides input signals for power system protection devices [7]. Under the condition of non-power frequency, signals beyond a certain frequency range will produce errors in the transmission of transformers, which will affect the follow-up protection calculation. Although the optical transformers can accurately reflect the full current waveform, there are still many problems that need to be solved in industrial applications at present, such as the reliability and stability of long-term operation, optical power fluctuations, the influence of temperature changes etc. So that right now OCT can't comprehensive replace the traditional electromagnetic current transformer in the actual application.

The parameter identification method is based on the network's full response signal. In the past, the theory and simulation were based entirely on the advantage of using an optical transformer to transmit an electrical signal, assuming accurate information about the actual amount of electrical power. In the existing conditions still need to consider the impact of transformer error on relay protection frequency band for $R-L$ model for the filtering to reduce the impact of transformer error on parameter identification methods. With PSCAD, the test system is model and simulation shows that the proposed principle is simple and practical.

2 Methodology

2.1 Line model

In order to describe the actual transmission lines, several line models with different simplifications exist. Based on different protection principles, it is necessary to analyse the types of models that can be used.

The protection of steady-state quantities, using the energy generated by the power supply in the system as the protection criterion, needs to be analysed using circuit theory. Therefore, only the centralised parameter line model can be used. For the protection of transient quantity, the transient quantity is generated by the energy exchange between the storage elements in the circuit,

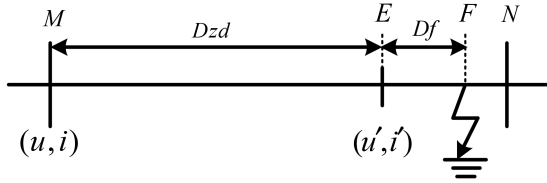


Fig. 1 Simple diagram of protection principle

and the model to be analysed should be with energy storage and energy dissipation elements. The protection method using traveling wave is based on traveling wave transmission theory, which requires that the adopted line model must be a distributed parameters model type.

The mathematic model of the line is a simplification of the actual physical model under certain assumptions, mainly considering the applicable frequency band of the component model. According to the sampling theorem and the difference between mathematical model and the actual physical model to be as small as possible to analyse. So, limiting the frequency to its applicable band can ensure the accuracy of the model. For different length of the line model, it has different frequency bands.

2.2 Distance protection based on parameter identification

Based on the parameter identification theory, the parameters of fault line can be estimated by solving the differential equations in time-domain. For distance protection, differential equations can be established for different centralised parameter models, and the fault distance can be solved. The following is a kind of distance protection based on RL model illustrated.

The following shows a single-phase transmission line as an example to illustrate the basic principle of the distance protection based on parameter identification (see Fig. 1).

First, using the CT and CVT to obtain the sampling data u, i of the relay point M, the voltage u' and current i' at the protection set point E can be calculated by distribution parameter line model in the time domain.

$$\begin{cases} u'(t) = u(Dzd, t) \\ i'(t) = i(Dzd, t) \end{cases} \quad (1)$$

where Dzd represents the distance from the relay point to the setting point, u and i are the voltage and current at the relay point, u' and i' are the voltage and current at the setting point.

$$u(Dzd + Df) = if \times Rg \quad (2)$$

where if represents the fault current, Rg is the transition resistance.

Subtract (1) and (2):

$$u'(t) = u(Dzd, t) - u(Dzd + Df, t) + if \times Rg \quad (3)$$

The voltage drop from setting point E to fault point F can be expressed as the current at the set point E using the RL model:

$$\Delta u = u(Dzd, t) - u(Dzd + Df, t) = \left(ri' + l \frac{di'}{dt} \right) Df \quad (4)$$

where Δu represents the voltage drop, r, l is the resistor and inductor of unit length. Combine (3) with (4), the voltage at the setting point can be described as:

$$u'(t) = \left(ri' + l \frac{di'}{dt} \right) Df + if \times Rg \quad (5)$$

Assume the phase of the current at the fault point if is same as the phase of fault component current ig :

$$if = ig / C_m \quad (6)$$

where C_m is coefficient of measured current distribution, is real. Combined (5) and (6), $u'(t)$ can be calculated as follows:

$$u'(t) = \left(ri' + l \frac{di'}{dt} \right) Df + ig \times Rg' \quad (7)$$

where $Rg' = Rg / C_m$. The fault component current ig at relay point can be obtained from i minus the recorded wave data of the first week, di'/dt and can be obtained by three-point numerical differential.

In formula (7), only two are unknown quantities Df and Rg' . So, after fault, sampling N samples to establish N -dimensional equations, using least squares method for solving the redundant equations and the fault distance Df can be adopted.

When applied to a three-phase system, first uses Clarke transformation to convert the phase voltage and phase current at the protection installation into mutually independent modulus.

$$u'_m(t) = \left(r_m i'_m + l_m \frac{di'_m}{dt} \right) Df + u_{fm} \quad (8)$$

where the value of m is 0, 1, 2, representing different module component.

If a single-phase grounding fault occurs in A phase, the phase voltage at the setting point is:

$$u'_A = u'_1 + u'_2 + u'_0 \quad (9)$$

Combine (8) and (9):

$$u'_A = \left[r_1(i'_A + k_r i'_0) + l_1 \frac{d(i'_A + k_r i'_0)}{dt} \right] Df + R'_f i'_0 \quad (10)$$

where u'_A and i'_A are A phase voltage and current at setting point, i'_0 is zero sequence current, R'_f is equivalent fault grounding resistance.

In the case of phase-to-phase fault or phase-to-phase grounding fault, the fault distance can be used to calculate by:

$$u'_{BC} = \left[r_1 i'_{BC} + l_1 \frac{di'_{BC}}{dt} \right] Df + R'_f i'_{BCg} \quad (11)$$

where u'_{BC} , i'_{BC} are voltage between two faulted phases at setting point, i'_{BCg} is phase fault current component. The derivation is similar to a single-phase fault. The calculation formula of three-phase fault is the same as the two-phase fault.

Using least squares method for solving the redundant equations and the fault distance Df can be adopted. If $Dzd + Df < Dz d$, that an external fault occurs. If $Dzd + Df > Dz d$, that an internal fault takes place at the protected line. Thus, not only an internal fault can be distinguished from an external fault but also its location can be identified.

2.3 Scheme considering transformer

As an important part of power system measurement components, the starting point of structural design and parameter selection of various types of transformers is to ensure that they can correctly measure the power frequency voltage and current under normal operation or fault steady-state conditions, so that they have good transfer characteristics in power frequency. Under the condition of non-power frequency, signals beyond a certain frequency range will produce errors in the transmission of transformers, which will affect the follow-up protection calculation.

Under the common limitation of the sampling frequency of the protection device and the frequency range of the transformer, there is a certain frequency range that the primary-side electric quantity can be accurately obtained by the secondary-side electric quantity, and the data in this range can satisfy various protection algorithm principles to carry out further analysis and calculation. However, in the vicinity of the power frequency within a certain range, the

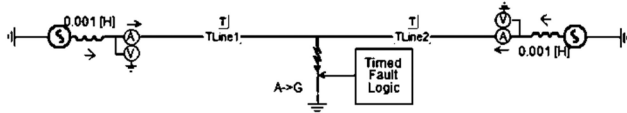


Fig. 2 Structure of transmission system

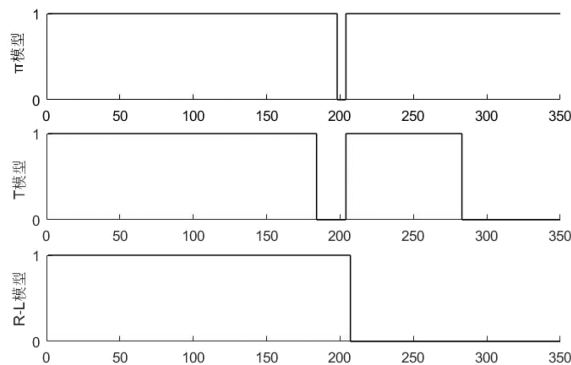


Fig. 3 Applicable frequency band

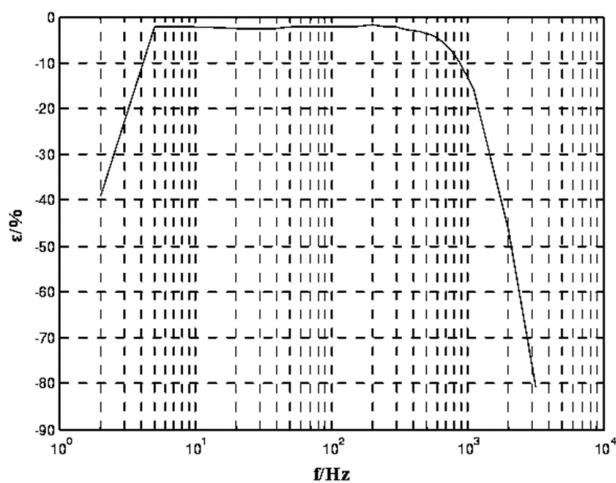


Fig. 4 Amplitude frequency characteristic curve of CT

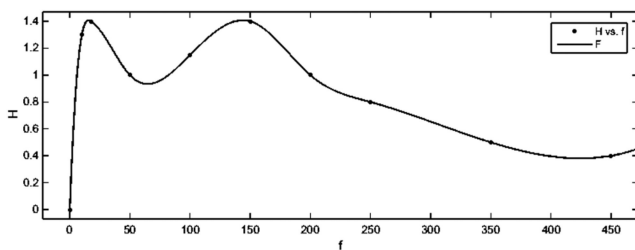


Fig. 5 Amplitude frequency characteristic curve of CVT

transformer can still guarantee a better accuracy to meet the protection calculating requirements.

According to the above analysis, in order to make the protection principle need the matching of the model frequency band and the transformer frequency band, a matching method for line model of relay protection and transformer type is put forward.

First, determine the actual line parameters, simulate fault in different line models. Study the frequency characteristics of the initial impedance network of the fault component network with different frequencies. For distance protection based on parameter identification, setting the phase of the equivalent impedance angle are less than 90° which is the frequency band for RL model. Then determine the sampling frequency of the device and the frequency band range that the transformer can accurately measure.

Compare the frequency band, if the transformer frequency band can be obtained accurately within the applicable frequency band of the model, the most accurate model type can be selected to

improve the accuracy. If the transformer band can be obtained accurately beyond model's applied band range, the signal should be filtered ahead of time according to the model band range.

In determining the line model and transformer type determined, the analysis of the intersection of the two bands to be filtered to reduce the operational error.

3 Results

Use the system established in the transient simulation software PSCAD shown in Fig. 2 for electromagnetic transient simulation calculation. The line $l = 300$ km, $R1 = 0.03629 \Omega/\text{km}$, $L1 = 0.16014 \text{ mH}/\text{km}$, $C1 = 0.01053 \mu\text{F}/\text{km}$, $R0 = 0.03796 \Omega/\text{km}$, $L0 = 0.42262 \text{ mH}/\text{km}$, $C1 = 0.00759 \mu\text{F}/\text{km}$.

First, analyse the applicable frequency band for centralised parameter model, RL model, π model, and T model. For distance protection based on parameter identification, setting the phase of the equivalent impedance angle are less than 90° is the frequency band shown as Fig. 3.

When the corresponding frequency value of 1, it represents the frequency band in the application (i.e. in the frequency of the mathematical model is consistent with the actual line). When the corresponding frequency value of 0 (i.e. in the frequency of the mathematical model and the actual line do not coincide,) it represents the frequency band is not fit. Therefore, the applicable frequency band of the model is the frequency range corresponding 1 of the amplitude of the graph.

Simulate the frequency range over which the transformer used can be accurately measured. The following analysis is taken as an example of CT and CVT. For the RL model, its applicable frequency band is 0–200 Hz.

As transient overreach in distance protection action is caused by the fault at the end of the line or subordinate lines, the fault current is small, will not cause CT saturation. Thus not consider CT saturation conditions, only simulate its frequency characteristics when the magnetic flux is not saturated. After the current transformer model of the frequency domain simulation, current transformer amplitude-frequency characteristic curve is shown in Fig. 4. Similarly, CVT amplitude-frequency characteristic curve in steady state is shown in Fig. 5

Simulate the system, the current and voltage of true value and measured value in normal operation and when single-phase grounding fault occurs is shown as Figs. 6 a and b.

Simulate the frequency range over which the transformer used can be accurately measured. The following analysis is taken as an example of CT and CVT.

By comparing the different frequency band, choose the R-L model to construct the distance protection algorithm. Comparing the model frequency band and current sensor linear transfer frequency range, found in the 20 to 200 Hz frequency range the accuracy can be guaranteed. So it needs after the filter processing of data in advance of fault distance calculation.

Simulate single-phase grounding fault with different distance and different transition resistance, calculate the fault distances. Simulation results is shown in Table 1. Method 1 indicates that the data are filtered after operation, and 2 is direct operation without filtering. It is found that the accuracy of fault distance after filtering is improved.

4 Conclusion

The distance protection based on parameter identification solves the problems traditional distance protection that the affection of fault resistance. It has higher requirements on the accuracy of the model of the protected components and the accuracy of sampling information. Different kinds of models have different adaptive frequency bands in different line lengths. On the other hand, transformer cannot guarantee the linear transmission in the whole frequency band. Exceeded the frequency range, secondary-side measurement data will have a greater error, affecting the follow-up calculation. Therefore, a matching method of line model and transformer type for relay protection is proposed. The frequency

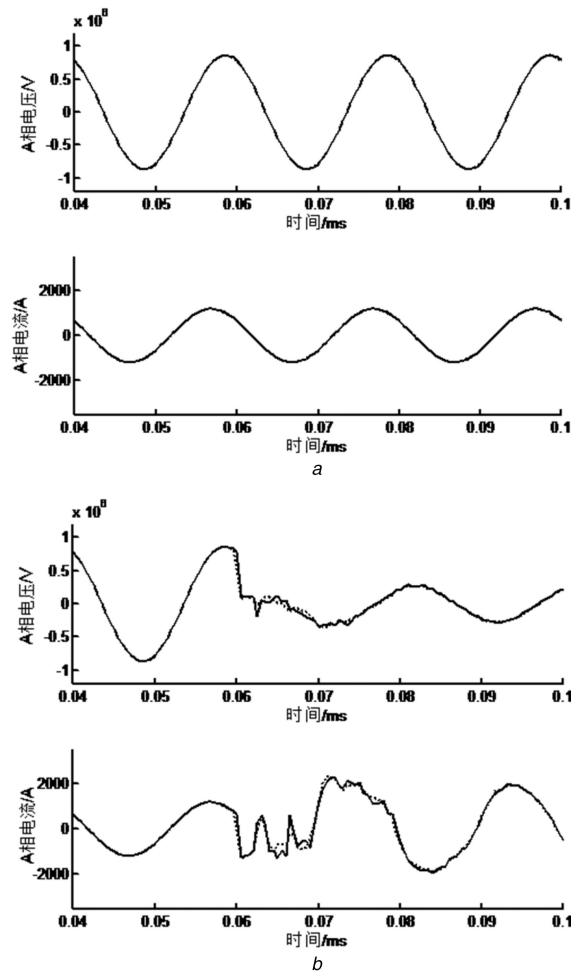


Fig. 6 Current and voltage of primary side and secondary side
(a) The current and voltage in normal operation, (b) The current and voltage in internal-fault condition

Table 1 Simulation results of internal fault

Location, km	Simulation results, km					
	2 Ω		20 Ω		50 Ω	
	1	2	1	2	1	2
50	42.8	41.5	34.8	26.8	33.0	12.97
80	75.7	78.5	68.7	67.1	66.9	54.1
100	96.9	101.9	90.9	91.2	89.0	78.5
150	148.3	166.6	144.8	154.4	103.6	76.6
200	198.7	209.5	196.6	199.7	209.0	187.6
220	218.8	237.9	217.5	227.7	215.9	248.3
250	248.6	255.8	246.2	244.9	248.5	236.8
280	279.2	278.0	274.7	271.6	273.8	267.0

ranges of the above two aspects are analysed and the voltage and current beyond their intersection should be filtered out. The simulation results show that this method improves the accuracy of the operation.

This method not only makes sense to the practical application of distance protection based on the principle of parameter identification, but also has some reference value to other engineering applications such as the instantaneous directional protection, the fault identification of series compensated transmission lines and the fault line selection in the non-solid earthed network.

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