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A novel fast distance relay for long transmission lines

Minghao Wen *, Deshu Chen, Xianggen Yin

State Key Laboratory of Advanced Electromagnetic Engineering and Technology, Huazhong University of Science and Technology, Hubei, China

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ABSTRACT

The measuring accuracy and the measurement stability of conventional distance relay will be influenced by complex and remarkable harmonic components due to the large capacitance of the line when it is used for a long line. Correspondingly, the tripping speed will be delayed to some extent. To solve this problem, a fast distance relay for long transmission lines is presented, which is on the basis of the differential equation algorithm using π transmission line model and the theory of Equal Transfer Process of Transmission Lines (ETPTL). The shortcomings of π model differential equation algorithm due to the impact of high frequency components can be overcome by using a low-pass filter. The problem resulting from the difference between the transfer feature of the voltages used by the distance protection and that of the currents due to the transient characteristic of coupling capacitor voltage transformers (CCVT) can be solved by using virtual digital CCVT. Then, the new distance relay can trip quickly by re-structuring the voltage at the fault point and iterative calculations. A variety of ATP simulation tests show that the new relay has fast tripping speed and high reliability when applied to the long transmission lines.

Introduction

The voltage level of long-distance transmission lines is usually up to 500-kV or higher. The distance relay acts as the foremost back-up protection of transmission lines [1–6]. Traditional distance relays usually employ a simple *R–L* transmission line model. When a fault occurs on a long line, relatively large magnitude harmonic components of current and voltage are superimposed on the fundamental frequency component due to the large capacitance of the line. This harmonic component can cause oscillation of the distance measurement [7,8]. In China, in the case of an electric power system of 330-kV and above, coupling capacitor voltage transformers (CCVT) are extensively used at present, which may lead to the transient overreach of distance protections and endanger the security and stability of power systems [9–14]. These two factors cause the speed and accuracy problems of distance relays of long transmission lines.

Different distance relays utilizing the distributed parameter line model to achieve accurate fault detection can be found in literature [15,16]. However, protection schemes using the Bergeron line model require a given sampling frequency and complex algorithms [17]. At present, the usual approach preventing the protection from the overreach due to CCVT transients is to add additional time delay [18,19]. Some adaptive methods are proposed, e.g., transient error estimation based method. Different time delay strategies are adopted according to the quantity of error [20]. A charging current compensation (CCC) method was proposed in the literature [7]. However, the authors did not consider the overreach problem due to CCVT transients. Transmission line models and the overreach due to CCVT transients are the critical problems of a fast distance protection for long transmission lines and the difficult ones to solve.

According to the theory of ETPTL [21,22], the relationship between the distributed voltage and the current of a transmission line does not change if they are transformed by the same linear circuit and still comply with the distribution parameter model of the original transmission line. The shortcomings of distance relay due to the impact of high frequency components can be overcome by using a low-pass filter. The transient characteristics of CCVT distort the linear transfer relationship between the secondary voltage injected to the protection device and the primary voltage of the line. A virtual digital transfer method is adopted, which can ensure that the currents at the relay point and the voltage at the fault point pass the virtual digital transfer link whose transfer characteristic is the same as that of the actual CCVT equipped at the relay point. It is proved that the voltages and the currents transformed by the two transferring links still satisfy the original distributed parameter based transmission line model. The distance relay could trip quickly. A fast distance protection for long transmission lines was presented. Five major steps of the new method

* Corresponding author. Tel./fax: +86 2787540945.
E-mail addresses: swenmh@mail.hust.edu.cn (M. Wen), dschen@mail.hust.edu.cn (D. Chen), xgyin@mail.hust.edu.cn (X. Yin).

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are demonstrated: the differential equation algorithm using π transmission line model, the low-pass filter, the virtual digital transfer method, restructuring the voltage at the fault point and iterative calculations of the fault distance.

Fast distance relaying for long transmission lines

Solving the R–L differential equation

The differential equation algorithm using π transmission line model includes solving the *R–L* differential equation and the calculation of π transmission line model.

The implementation of *R–L* differential equation algorithm in the new protection scheme is demonstrated by taking the single-phase-to-earth fault as an illustration. When a single phase to earth fault via the fault resistance R_f occurs at point *F* on the line, we have

$$u_m(t) = u_f(t) + \left[L_1 \frac{d(i_m(t) - i_{m0}(t))}{dt} + R_1(i_m(t) - i_{m0}(t)) + L_0 \frac{di_{m0}(t)}{dt} + R_0 \cdot i_{m0}(t)\right] \cdot l \quad (1)$$

where,

$u_m(t)$ – faulty phase voltage at the relay point;
$i_m(t)$ – faulty phase current at the relay point;
$u_f(t)$– faulty phase voltage at the fault point *F*;
$i_{m0}(t)$ – zero sequence current at the relay point;
L_1 and R_1 – positive sequence inductance and resistance of the line per unit length;
L_0 and R_0 – zero sequence inductance and resistance of the line per unit length;
l –distance from the relay point to the fault point *F*;
R_f – fault resistance.

Here, $u_f(t)$ is the function of R_f as described in Section ‘Restructuring the voltage at the fault point’. One-point differential algorithm is adopted to perform the differential calculation, as given by

$$\left[\frac{d(i_m(t) - i_{m0}(t))}{dt}\right]_{t=n\Delta t} = \frac{[i_m(n+1) - i_{m0}(n+1)] - [i_m(n) - i_{m0}(n)]}{\Delta t} \quad (2)$$

where Δt is the sampling interval and n is the index of the samplings.

If a series of samplings in a certain period are substituted into (1), a series of differential equations are available correspondingly. They can compose of a set of the equations. In this paper, the least square algorithm is used to calculate the distance from the relay point to the fault point.

The calculation of π transmission line model

The transmission line model between the bus M (the relay point) and the fault point *F* consists of a π section as shown in Fig. 1. i_c is the charging current that flows into the capacitance at the relay point. i_c of phase A can be calculated, as given by

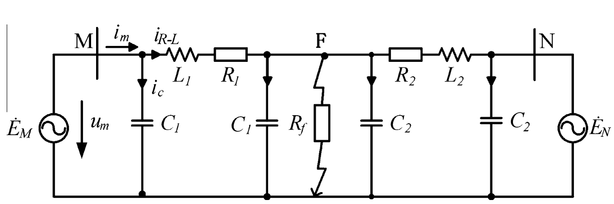

Fig. 1. π Transmission line model.

$$i_{ca}(t) = 0.5l \cdot c_{s0}\frac{du_{ma}(t)}{dt} + 0.5l \cdot c_{m0}\frac{d[u_{ma}(t) - u_{mb}(t)]}{dt} + 0.5l \cdot c_{m0}\frac{d[u_{ma}(t) - u_{mc}(t)]}{dt} \quad (3)$$

where,

$u_{ma}(t)$, $u_{mb}(t)$, $u_{mc}(t)$ –three-phase voltages at the relay point;
c_{s0} – the line-to-ground capacitance of the line per unit length;
c_{m0} – the phase-to-phase capacitance of the line per unit length.

The phase-A current flowing through the *R–L* circuit in Fig. 1 can be calculated as below:

$$i_{aR-L}(t) = i_{ma}(t) - i_{ca}(t) \quad (4)$$

where $i_{ma}(t)$ is the phase-A current flowing through the relay. In the same way the phase-B current $i_{bR-L}(t)$ and the phase-C current $i_{cR-L}(t)$ can be obtained.

Low-pass filter

The low-pass filter is introduced to overcome the shortcomings of distance relay due to the impact of high frequency components. According to the theory of ETPTL, the voltages and the currents at the relay point and the voltage at the fault point should pass the same low-pass filter. A second-order Butterworth Filter is introduced to restrict the frequency components of the voltages and the currents around power frequency.

Virtual digital transfer method

A virtual digital CCVT transfer method is adopted, which can ensure that the currents at the relay point and the voltage at the fault point pass the virtual digital transfer link whose transfer characteristic is the same as that of the actual CCVT equipped at the relay point.

When the virtual digital CCVT transfer processing is conducted on the current through the relay location, the inputs of the virtual digital CCVT are the samplings captured by the A/D of the relay, and the outputs are the new samplings processed by the virtual digital CCVT. To implement the method of virtual digital CCVT transfer, the transient recursive calculation equations for the inductance components and capacitors of CCVT circuit are required to be deduced. In this event, the CCVT transient equivalent circuit can be simplified as a DC circuit only containing three kinds of components at each sampling moment, that is, the input voltage source, the current source and the resistance of the equivalent circuits. Then the current sampled value transformed by the virtual digital CCVT can be calculated. The more detailed process of the virtual transfer method can refer to literature [21].

On the other hand, when the virtual digital CCVT transfer processing is conducted on the voltage at the fault point, the inputs of virtual digital CCVT are the voltage samplings at the fault point. Similarly, the outputs are the new voltage samplings processed by the virtual digital CCVT.

The distance relay will adopt these new samplings to implement the corresponding measurement algorithm. So the problem resulting from the difference between the transfer feature of the voltages at the relay point and that of the currents due to the transient characteristic of CCVT can be solved.

Restructuring the voltage at the fault point

This step is demonstrated by taking the single-phase-to-earth fault as an illustration. The faulty phase voltage measured by the conventional distance relay is actually the faulty phase voltage difference between the relay location and the fault point in the case of bolted faults. It is because that the faulty phase voltage at the fault