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A generalized method to improve the location accuracy of the single-ended sampled data and lumped parameter model based fault locators ☆

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ABSTRACT

The necessity for very high accuracy in fault location is generally becoming more and more important. In this paper, a new generalized algorithm which can improve the accuracy of all fault location algorithms based on the lumped parameter model and single-ended data is presented. The measured distance resulting from the lumped parameter model can be converted to the positive sequence measured impedance matching with the model. Then, the relation between real distance and positive sequence measured impedance of fault circuit based on Bergeron model can be derived according to the analysis of solid grounded faults. Then the improved algorithm resulting from the relation of real distance and measured distance can be obtained. Theoretically, the proposed algorithm is independent of shunt distributed capacitance of transmission lines. Besides, the algorithm is based on power–frequency voltages and currents, and hence high sampling rate is unnecessary. Therefore, it can be implemented in the existing protection devices easily. This paper presents the theory of the technique and the results of ATP simulation tests to demonstrate its performance.

1. Introduction

High-voltage transmission lines are the vitals of electric power systems. Provided a fault occurs on a transmission line, it is required to detect rapidly and accurately where it takes place. It is very important for the purpose of restore of normal operation of power systems. Generally, fault location methods can be classified into single-ended based fault location and double-ended based fault location. Single-ended information based algorithm only makes use of the electrical parameters of one end of a line, which is easy to obtain, it is simple, convenient, rapid and easy to implement. Thus it is still of importance in the field of fault location.

Available algorithms of single-ended fault location can be categorized into two types: one using power–frequency voltages and currents and the other using transient traveling wave. Although the latter possibly attains high precision and is immune to the influence of the fault resistance and the mode of operation of power systems, it has a low reliability and dead zones, for instance, the fault location will fail when the fault point is close to the busbar. Besides, the method using traveling wave has a high requirement to the sampling rate, so special filter devices are necessary, which increases the investment. In contrast, the method of using power–frequency voltages and currents can be completely implemented with the existing filter or protection devices, so it has greater value in terms of engineering applications [1–4].

In this paper, we will discuss a universal improved location algorithm based on power–frequency measurement. Conventional single-ended fault location methods are usually based on the lumped parameter models. After adopting reasonable assumptions, various single-ended fault location algorithms, which are based on the lumped parameter models, can largely be immune to the impacts of the parameter uncertainty of the opposite end and fault resistance. However, impact of the distributed capacitance in the high-voltage transmission line cannot be removed, which will result in greater negative effect on the precision of the fault location [5–7]. Especially, when the fault occurs at the end of a long transmission line, the measured distance will be obviously longer than the real distance, which is the common problem of various algorithms based on the lumped parameter models. If adopting the distributed parameter models, it is likely to solve this problem. However, the fault location formula will become extraordinary complicated and impractical. In order to solve the above problems, the measured fault distance, which results from a variety of algorithms of the lumped parameter models, can be revised by an appropriate method. In this case, the accuracy of fault location can be improved obviously.

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2. The single-ended fault location algorithm

Several typical single-ended fault location algorithms based on the lumped parameter models are introduced as the reference to highlight the improved effect. Literature [8] presented a typical fault location method based on power–frequency impedance measurement, which can be described by virtue of the transmission line model as presented in Fig. 1.

As shown in Fig. 1, Z is the impedance per kilometer (km) of the transmission line, L is the length of the transmission line, and x is the distance between the fault point and the place where the protection devices are equipped. $\dot{I}_M$ is the current of the fault phase, which is involved with the zero-sequence compensation, that is

$$\dot{I}_M = \dot{I}_p + \frac{z_0 - z_1}{z_1}\dot{I}_0 \tag{1}$$

where $\dot{I}_p$ is the actual current of faulty phase, z_0 is the zero-sequence impedance per km of transmission line, z_1 is the positive sequence impedance per km of transmission line, and $\dot{I}_0$ is the zero-sequence current.

Besides, $\dot{U}_M$ is the voltage of the faulty phase, R_g is the fault resistance, and $\dot{I}_g$ is the fault branch current. According to Fig. 1, the voltage of faulty phase can be given by:

$$\dot{U}_M = \dot{I}_M Z_x + \dot{I}_g R_g = \dot{I}_M Z_x + \frac{\dot{I}_{mg}}{C_M} R_g \tag{2}$$

C_M is the current distributed coefficient at end M, and $\dot{I}_{mg}$ is the fault-component current obtained by the protection devices at end M. Generally, it can be the negative-sequence or zero-sequence current with respect to the faulty phase. Any modern protection device can easily evaluate these kinds of currents using negative-sequence or zero-sequence filter. Multiplying $\overset{*}{I}_{mg}$ (the conjugate of $\dot{I}_{mg}$) at both sides of the (1) and considering C_M as a real number, the fault location equation can be given by

$$x_{\mathrm{meas}} = \frac{\mathrm{Im}[\dot{U}_M \overset{*}{I}_{mg}]}{\mathrm{Im}[Z\dot{I}_M \overset{*}{I}_{mg}]} \tag{3}$$

where the operator Im represents the imaginary part of a complex number.

Eq. (3) is the fault location algorithm of single-phase short-circuited fault. The fault location algorithms of other fault types are detailed in the [8].

The algorithm presented above is used as a reference for the purpose of performance comparison. In order to highlight the necessity and the validity of the improved method presented below, we apply this improved method to several typical fault location algorithms presented in the literature [9]. The algorithms in [9] cover most of typical single-ended fault location methods, including the zero-sequence current phase revising, the fault current iteration, and that solving the differential equation, and so on. For the convenience of description, above algorithms are numbered as algorithm 1, 2, 3 and 4 respectively. The detail formula of these methods can refer to corresponding literatures. The common characteristic of these methods is that the lumped parameter model of transmission line is adopted and therefore the influence of distributed capacitance is ignored. In this case, it will result in great fault location error while a fault takes place at the end of a long line. This scenario will be confirmed by the simulation presented below.

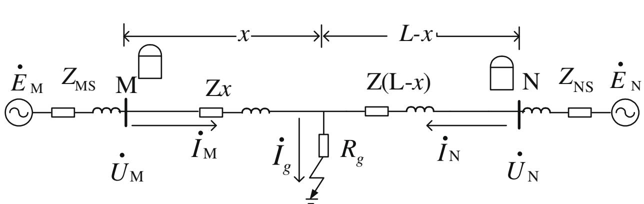

Fig. 1. Single-phase grounded fault in dual-source system.

3. Using Bergeron model to improve the fault distance

The idea to improve the fault distance presented in this paper is shown as follows: Firstly we assume that the fault location errors resulting from the lumped parameter models are only affected by the distributed parameter, that is, we temporarily believe that available single-ended fault location models already eliminate the influence of fault resistance. In this case, various short-circuited faults via fault resistance can be simplified as solid short-circuited fault. Therefore, the relation between the fault distance and the measured impedance can be established based on not only the lumped parameter models but the distributed parameter models. Using the measured impedance, we can relate the measured distance based on the lumped parameter models to the real distance from the fault point to the relay, and then the relevant improved algorithm of fault location can be established.

Taking the single-phase solid grounded short-circuit fault as an example, we can make further explanation.

Adopting the Bergeron model, the three-phase system can be decomposed into positive, negative and zero-sequence systems according to the symmetrical component method. In this case, the electrical parameters of both ends of the transmission line always satisfy the equation of long transmission line based on distributed parameters. It should be pointed out that the characteristics impedance and the propagation constant in the equation should be assigned by the corresponding sequence value. When a fault occurs, the voltage and current equations of the positive sequence network are shown as follows:

$$\begin{cases} \dot{U}_{M1} = \cosh(\gamma_1 x)\dot{U}_{x1} - Z_{C1}\sinh(\gamma_1 x)\dot{I}_x \\ \dot{I}_{M1} = \frac{\sinh(\gamma_1 x)\dot{U}_{x1}}{Z_{C1} - \dot{I}_x\cosh(\gamma_1 x)} \end{cases} \tag{4}$$

where the resistance, induction, capacitance and conductance of the line in positive sequence system can be marked as R_1, L_1, C_1 and G_1, respectively, and x indicates the distance to the fault.

Besides, γ_i is the propagation constant per unit length of long transmission line, which can be given by

$$\gamma_i = \sqrt{(R_i + j\omega L_i)(G_i + j\omega C_i)} \tag{5}$$

And Z_{Ci} is the characteristic impedance which is given by:

$$Z_{Ci} = \sqrt{\frac{R_i + j\omega L_i}{G_i + j\omega C_i}} \tag{6}$$

If a solid grounded fault occurs in the position with a distance x to the relay, the voltage of faulty phase $\dot{U}_{x1}$ will be zero. Substitute $\dot{U}_{x1} = 0$ into (4), then:

$$\begin{cases} \dot{U}_{M1} = -Z_{C1}\sinh(\gamma_1 x)\dot{I}_x \\ \dot{I}_{M1} = -\dot{I}_x\cosh(\gamma_1 x) \end{cases} \tag{7}$$

From (7) the positive sequence measured impedance can be given by

$$Z_{M1} = \frac{\dot{U}_{M1}}{\dot{I}_{M1}} = Z_{C1}\tanh(\gamma_1 x) \tag{8}$$

According to the algorithm based on the lumped parameter models, the fault distance is eventually obtained by measured impedance. And this distance is relevant to the lumped positive sequence impedance, that is: