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An algorithm for longitudinal differential protection of transmission lines

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ABSTRACT

This paper describes a new algorithm for longitudinal differential protection of transmission lines. Classic stabilization is an unreliable method for avoiding unnecessary relay tripping in case of current transformer saturation during faults outside the protected zone. There are various methods for detecting current transformer saturation. The paper's thesis is that rather than the stabilization current, the direction of the currents introduced into the relay should be monitored. The proposed algorithm has been compared to the algorithms used by renowned relay producers. Different types of faults have been simulated, both within and outside of the protected zone, and the paper demonstrates how the relay trips when the algorithm in question is used. The results have proven that current transformer saturation does not affect protection operation, and that a prompt relay response is obtained for faults occurring within the protected zone.

1. Introduction

Analogue longitudinal differential protection is used for shorter, single-circuit transmission lines in double-fed networks. If optical ground wires (OPGW) are used, the length of the line ceases to be a limiting factor. The longitudinal differential protection principle is based on the comparison of the currents located at the beginning and at the end of the line, resulting in a quick, sensitive and simple protection concept that ensures that the faulted line is disconnected from the network. The protected zone is defined by the position of the current transformers from which signals are brought into the differential relay [1–3].

There are two types of algorithms for differential protection: those that use phasors [4–6] and those that use instantaneous values of electrical quantities [7]. In addition to the classic approach, which uses current signals exclusively, there are solutions which require voltage inputs [8–10] too.

The major problem related to differential protection operation is current transformer saturation [11]. Namely, during a fault located outside the protected zone (external fault), high fault currents can saturate current transformers. If the characteristics of the current transformers set at the opposite ends of the line are not identical, a high differential current starts flowing through the relay. This current may cause unnecessary relay tripping. There are various methods that can prevent such occurrences. The leading relay protection manufacturers offer different solutions [3,12–15].

The study presented in this paper is based on the idea that a current direction indicator should be used instead of the stabilization current. The direction indicator is defined by the phase comparison illustrated in [16–18], using the currents brought from either end of the line. The procedure described in the paper was compared to the conventional solutions which have been implemented in practice. An advantage of the proposed approach is a prompter response with a minimum of mathematical operations. What is more, the algorithm is insensitive to current transformer saturation.

2. Classic approach

Fig. 1 shows the longitudinal differential protection operating principle and the tripping characteristic of the differential relay. If the fault occurs outside of the protected zone, the left and right-end currents have the same direction and approximate intensities, i.e. their difference is negligible and the protection does not trip. Should the fault occur within the protected zone (internal fault), the right-end's current changes its direction, establishing a significant current through the differential relay M, causing its tripping.

The minimum tripping current (I_{min}) defines the minimum relay tripping threshold and is set to 20–50% of the rated transformer

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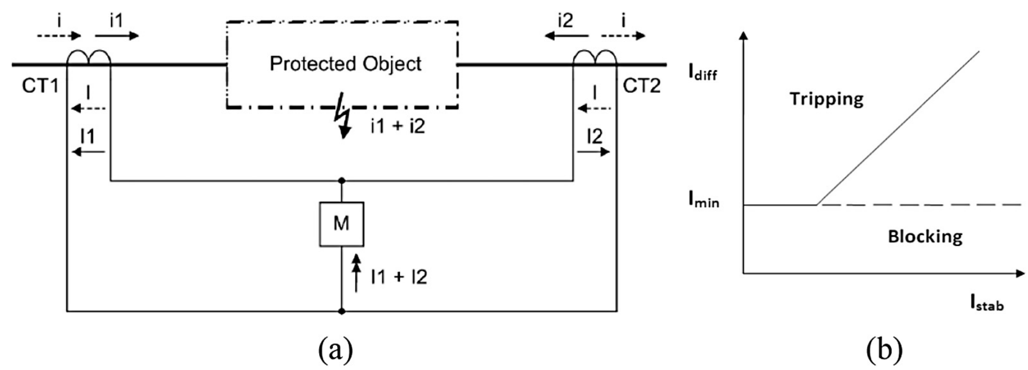

Fig. 1. Longitudinal differential protection of transmission lines. (a) Longitudinal differential protection operating principle. (b) Relay tripping characteristic.

current. This quantity is defined since in an actual system, in a non-fault condition, there is always a difference between the currents measured at the opposite line ends due to the current transformers' imperfection and the charging current [1–3].

The relay trips if the operating point, defined by the differential and stabilization currents' RMS values, is located within the relay tripping area (Fig. 1b).

3. Existing algorithms

In a classic longitudinal differential protection algorithm, a problem may occur in case of current transformer saturation due to a fault outside the protected zone. This phenomenon leads to unnecessary relay protection tripping. The leading relay protection manufacturers have different methods for tackling this problem. What follows is an overview of principles based on additional stabilization and the negative sequence current component.

3.1. Additional stabilization principle

The Siemens corporation uses conventional differential protection logic, supplemented by the additional stabilization principle.

Eqs. (1) and (2) are used for calculating the stabilization and differential currents, for each phase individually [3,12]:

$$I_{stab} = |\underline{I}_L| + |\underline{I}_R| \tag{1}$$

$$I_{diff} = |\underline{I}_L - \underline{I}_R| \tag{2}$$

with the following explanation:

$\underline{I}_L$ – basic harmonic phasor of the left-end phase current,
$\underline{I}_R$ – basic harmonic phasor of the right-end phase current.

Fig. 2 shows the typical operating points depending on fault position (either within or outside the protected zone). The operating point is defined by the RMS values of the differential and stabilization relay currents. Point A corresponds to the non-fault operating condition. Should the fault occur within the protected zone – in the middle of the line, for example – the differential and stabilization currents become virtually identical. The new operating point will be located on the line forming a 45° angle with the abscissa axis. This line is represented as the dash-dot-dash line, whereas the new operating point is marked by the letter D. In such a setting, the relay operates properly [3,12,13].

The dashed line in Fig. 2 illustrates the movement of the operating point during a fault outside the protected zone, when current transformers are saturated. Soon after the fault occurs, the operating point moves to position B. Only then does the operating point move to position C, located within the relay tripping area. The relay detects this trajectory and blocks if it registers that the operating point first moved into the additional stabilization zone, and afterwards reached the protection tripping zone. The relay block ceases after a set time delay (of several basic periods) or when the measured differential current drops below the tripping current [3,12,13].

A problem may occur when current transformers are saturated with the alternating current component during a fault outside the protected zone. This may be the cause of unnecessary relay tripping, since the relay block ceases after a set time delay, while the relay remains active due to the saturation with the alternating component of the fault current.

3.2. Negative sequence component principle

In order to prevent unnecessary relay tripping during faults outside the protected zone, ABB's relays use the negative sequence component principle as a supplement to the classic approach to differential protection.

The differential current is calculated according to Eq. (2), individually for each phase, while the universal stabilization current (the stabilization current for all phases) is taken to be the maximum value of all the phase currents which are brought into the relay from both ends of the line [14,15]:

$$I_{stab} = \max\left\{\underline{I}_L^A, \underline{I}_R^A, \underline{I}_L^B, \underline{I}_R^B, \underline{I}_L^C, \underline{I}_R^C\right\} \tag{3}$$

The negative sequence component principle presupposes that by the isolation of this component we may determine whether the fault is located within or outside the protected zone.

The relay simultaneously performs multiple checks. The first-line check is an instance of classic differential protection, operating according to the principle of calculating the differential and stabilization currents. The second-line analysis is the isolation of the second and fifth harmonics; however, this function is inactive in most cases. The third-line and the most important analysis in terms of unnecessary relay tripping is based on the negative sequence component. The analysis is based on the comparison of negative sequence currents obtained from both ends of the transmission line. If the phase difference between these two currents is larger than 60°, it is assumed that the fault occurred within the protected zone, and a signal for breaker activation is sent. Otherwise, the signal will not be sent. To secure a proper reaction, the modules of the negative sequence components need to exceed the minimum set value. Usually the minimum value equals 4% of the base value (I_{base}). The secondary rate current of the current transformers is taken as the base value. If I_{stab} exceeds 150% of the base value, the minimum value is the sum of 0.04 × I_{base} + 0.1 - × I_{stab}. If at least one negative sequence component per module is lower than the set component, the relay ignores the third-line analysis. The relay trips if the results of all the analyses indicate