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An algorithm for sensitive directional transverse differential protection with no voltage inputs

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ABSTRACT

Transverse differential protection of double lines in double-fed networks has been discussed by many papers. This paper investigates algorithms based on current increments for directional transverse differential protection with no voltage inputs in radial networks. Weak points of the algorithms are identified and discussed. A new algorithm based on phase-change of double-line currents with improved sensitivity is proposed. For testing purposes, three-phase power system model has been created. On the basis of detailed simulation tests, advantages of the new algorithm are presented. In order to ensure protection sensitivity even in the cases of faults from open circuit regime, current register locking technique has been developed and used in combination with new algorithm.

1. Introduction

Double-circuit line systems enable the exchange of larger amounts of electric power at the same distances, compared to single-circuit line systems. In highly industrialized countries radial networks with double-circuit lines are not uncommon. Parallel lines on the same tower provide lower costs and less demanding land area. The main negative sides of this type of transmission are: double damage in the case of mechanical failures on the transmission towers and complex relay protection.

Protection of double-circuit lines has been extensively investigated over the past two decades and many modern digital algorithms have been developed. A big step forward has been made with development of digital directional transverse differential current protection (no voltage inputs) [1–3]. The algorithm based on increments of mean values of double-line currents in double-fed networks has been proposed and investigated in papers [1,2]. Improved algorithm based on increments of instantaneous values of double-line currents, also applicable in radial networks, has been presented in [3]. An interesting protection schemes based on wavelet transforms [4], sequence and superimposed signals [5], fuzzy logic systems [6,7] and traveling waves [8,9] have been proposed, but sensitivity issues in radial networks have not been analyzed in none of them. The possibilities of fault events from open circuit regime have been completely ignored.

Faulted double-circuit lines and typical issues of protective schemes have been discussed in detail in publication [10]. Algorithms for directional transverse differential protection with no voltage inputs are very fast, simple and robust. The main advantages of these algorithms over a distant-based protection are: elimination of voltage sensors, lower relay tripping times, immunity to mutual coupling effect, better selectivity properties in the cases of high-resistance and cross-country faults, etc.

The algorithm using instantaneous values of currents [3] is applicable in both, double-end supplied and radial networks. It is very difficult to find disadvantages and further improve protection characteristics. Search for weak points should be directed to radial networks with low consumption or with no consumption (open circuit). By analyzing fault direction estimation method based on phase change in sequence current [11] and digital phase comparator [12,13], an idea for development of a new algorithm for directional transverse differential protection with no voltage inputs has been emerged.

2. Algorithms for directional transverse differential protection with no voltage inputs

2.1. The algorithm based on increments of mean values of current signals(A-mvcs)

This algorithm is based on increments of mean values of double-line currents. Computational signals D_1 and D_2 are defined as increments of absolute values of currents:

$$D_1(k) = D_1(k-1) + |i_1(k)| - |i_1(k-m)|, \quad (1)$$

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$$D_2(k) = D_2(k-1) + |i_2(k)| - |i_2(k-m)|, \tag{2}$$

where $i_1(k)$ and $i_2(k)$ are samples of line currents 1 and 2, respectively and m is the number of samples within the basic period T.

Fault indicator is defined as difference of previously considered computational signals:

$$D_{12}(k) = D_1(k) - D_2(k). \tag{3}$$

The difference of increments of mean values of double-line currents determines the position of the fault. If the following condition is fulfilled, the fault is located on power line 1:

$$D_{12}(k) > D, \tag{4}$$

where D is properly chosen threshold value.

In the opposite, the location of the fault is on power line 2, which is defined as:

$$D_{12}(k) < -D. \tag{5}$$

If the fault is outside of the protected zone, then next condition is fulfilled:

$$|D_{12}(k)| < D. \tag{6}$$

2.2. The algorithm based on increments of instantaneous values of current signals (A-ivcs)

The second, improved algorithm is based on the idea that uses increments of instantaneous values, instead of mean values of double-line currents. Increments are defined by following relations:

$$D_1(k) = i_1(k) - i_1(k-m), \tag{7}$$

$$D_2(k) = i_2(k) - i_2(k-m). \tag{8}$$

Fault indicator is calculated according to the formula:

$$D_{12}(k) = D_{12}(k-1) + |D_1(k)| - |D_2(k)|. \tag{9}$$

From the previous formula it is evident that the difference of absolute values of increments is used. The location of the fault is determined by the same conditions as in the case of first algorithm: (4)–(6).

2.3. The new algorithm based on a phase change in double-line currents

The new algorithm also uses only current signals, which enables application to the directional transverse differential protection with no voltage inputs, without disrupting its basic principles.

2.3.1. Theoretical basis of the new algorithm

Proposed approach is explained on the example of the power system with single-end supply, as shown in Fig. 1a Corresponding phasor diagrams of double line currents at relay locations, for the fault located within protective zone, are shown in Fig. 1b (relay 1) and Fig. 1c (relay 2).

When the fault occurs in power line 1 (within protective zone), as shown in Fig. 1a, current phasors will be approximately allocated, as shown in Fig. 1b and c. It is assumed that prefault current phasor corresponds to the case of slightly inductive load (I_{pre}). During the fault, the following relations take place from the side of relay 1:

$$|\underline{I}_{k11}| > |\underline{I}_{k21}|, \tag{10}$$

$$|\Delta\phi_1| > |\Delta\phi_2|, \tag{11}$$

where $\underline{I}_{k11}$ and $\underline{I}_{k21}$ are fault current phasors of lines 1 and 2, respectively (relay 1 side); $\Delta\phi_1$ and $\Delta\phi_2$ are phase-shifts of fault current phasors of lines 1 and 2 compared to prefault current phasor (relay 1 side).

From the side of relay 2 the next relations are valid:

$$|\underline{I}_{k12}| > |\underline{I}_{k22}|, \tag{12}$$

$$\Delta\phi_1 > 0, \tag{13}$$

$$\Delta\phi_2 < 0, \tag{14}$$

where $\underline{I}_{k12}$ and $\underline{I}_{k22}$ are fault current phasors of lines 1 and 2, respectively (relay 2 side).

A-mvcs avoids the phase relations and relies only on magnitude readings, which makes it inapplicable in single-end supply systems. A-ivcs relies on both, magnitude readings and phase relations, which makes it applicable in single-end supply systems, but with sensitivity issues in the cases of low consumption and open circuit. The new algorithm incorporates all five relations (10)–(14) in order to improve characteristics of previous algorithms in single-end supply systems.

2.3.2. Implementation of the new algorithm

The idea of digital phase comparator (dpc), presented in previous work [12,13], is modified and applied to only current signals. A new input parameter for dpc is artificially time-shifted current $i(t-T/4)$. In steady-state conditions (without fault event), phasors of signals $i(t)$ and $i(t-T/4)$ are phase-shifted by $\pi/2$ and value of dpc is equal to zero, as shown in Eq. (15).

$$\int_{t-T/2}^{t} i(t)i(t-T/4)dt = 0. \tag{15}$$

In grounded neutral systems, fault loops are inductive. So, when fault occurs the new current samples are time-shifted and dpc has positive value, as shown in Eq. (16). For ideal inductive fault loops, time-shift between currents $i(t)$ and $i(t-T/4)$ is equal to zero and dpc has maximum positive value.

$$\int_{t-T/2}^{t} i(t)i(t-T/4)dt > 0. \tag{16}$$

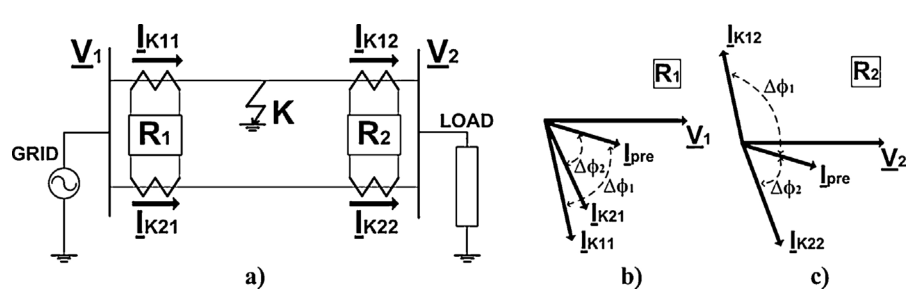

Fig. 1. (a) Fault located within protective zone in the system with single-end supply; (b) phasor diagram of double-line currents for relay 1; (c) phasor diagram of double-line currents for relay 2.