Electric Power Systems Research 144 (2017) 197–207

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Research Paper

A directional protection scheme during single pole tripping

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ARTICLE INFO

Article history:
Received 21 June 2016
Received in revised form 7 November 2016
Accepted 12 December 2016

Keywords:
Directional protection
Discrete Fourier transform
Positive sequence superimposed current
Single pole tripping

ABSTRACT

This paper proposes a positive sequence superimposed current based procedure for the identification of fault directionality accomplished with single pole tripping (SPT) schemes. The proposed procedure decides the fault direction by the angle deviation between pre-fault and faulty positive sequence current components. To realize the ability of the proposed scheme under single pole tripping, several critical cases are addressed such as high fault resistance (HFR), different fault locations, different fault types, change in power flow direction, variation in source capacity and other critical system situations are addressed to prove the correct behavior of the proposed procedure. Numerous fault scenarios have been emulated for variant system configurations (single and double circuit lines) using ATP/EMTP simulation package. The current components are determined using the discrete Fourier transform (DFT). It is proved using extensive simulations tests that the proposed method is accurate and can be used for refurbishing of the conventional directional relays.

1. Introduction

Single pole tripping reclosure trips out only the faulted phase in the case of a single line to ground fault and trips all of the three phases for a multiphase fault [1,2]. Under single pole tripping and during the open interval, unbalance currents and voltages will appear. This leads to produce the zero sequence and negative sequence components in voltages and currents signals. Directional algorithms that used negative sequence or zero sequence components to determine the directional of the faults will find restrictions as the prefault signal that may contain the negative and zero sequence components during single pole tripping [3]. The operation of directional relay is affected by the voltage conditions during different faults events. The mal-operation is expected for the directional relying accomplished by single pole tripping due to increased unbalanced condition. Mal-operation of protective devices that are able to eliminate the disturbances effects, during faulty period, may cause instability in the power system [4].

The sequence components are used as algorithms for many protection relays. In Ref. [5] the sampled values of compensated voltage and fault currents are used to determine the directional of the fault. In Ref. [6], an improvement for directional protection using fuzzy system depending on the phase angle of positive sequence current is presented. In Ref. [7], a directional relaying scheme presented on the basis of average superimposed components. In Ref. [8], a superimposed negative sequence based technique presented for the fault direction estimation during secondary arc at SPT situations. In Ref. [9], the conventional directional relaying is not proper for close in faults are studied. In Ref. [10], the angles of negative sequence fault and pre-fault current was developed to detect the direction of the fault which is affected under high fault resistance as reported in Ref. [8].

In Refs. [11] and [12], the positive sequence components angles are investigated to identify the fault direction. These schemes are affected during close-in fault situation. Also in Refs. [13] and [14], the compensated post fault voltages and zero sequence component or negative sequence component are used to identify the direction of the fault. In Ref. [15], a directional differential current algorithm is presented for double circuit system based on incremental current signals depending on a threshold value to determine the directional of the fault. In Ref. [16], the authors presented a directional relaying for series compensation double circuit system. In Ref. [17], a fuzzy logic technique which was described in Refs. [18,19], is developed to derive the fault direction. Four features were calculated and fed to the fuzzy logic system. These four features were combined with fuzzy logic to derive a reliable fault direction.

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http://dx.doi.org/10.1016/j.epsr.2016.12.011
0378-7796/

The directional comparison relay, non-pilot relay and current-only systems are better during single pole tripping for double and single circuit lines. The negative and zero components ground directional units are used during single pole tripping [20]. The negative sequence pilot protection is used due to its better properties [21]. However, when a system operates during single pole tripping the scheme is not adequate for this application. Another technique is used during single pole tripping to determine the directional of the fault which is presented in Ref. [22]. Ref. [23], presents a method depending on the negative sequence current and voltage components angles; this technique affected by the bus side voltage information. A negative sequence superimposed component procedure was presented to solve the directional relaying problem [24]. Ref. [25] presented a scheme for the radial distribution systems to determine the fault direction.

In this paper, an integrated positive sequence superimposed component procedure of directional relaying is proposed. The main contribution is providing a solution for directional relay during single pole tripping condition without the need for any supporting/compensating algorithm. Various fault study cases have been considered in order to verify protection characteristics, such as different fault type, high fault resistance, fault location, cross country fault for double circuit line, far end fault for double circuit line. Other system conditions are implemented such as change in source capacity, effect of variation in fault location, effect of change in fault resistance and they are found to be accurate. Two different network topologies, namely single and double circuit transmission lines, have been analyzed. The obtained results confirm the reliable response of the proposed technique.

2. Fault analysis using symmetrical vomponent during SPT condition

2.1. Positive sequence current during SPT without fault

Fig. 1a and b shows a three phase power systems for the tested network with the proposed relay at bus M for the two systems. The fault types are classified as forward fault when located at F_y side and reversed fault when located at F_x side. The single circuit system will be analyzed as follow:

Assume AG fault is created in line 2. The circuit breakers poles of the faulted phase will open from both ends of the line. The boundary conditions will be:

$$I_a = 0 \quad (1)$$

$$V_b = V_c = 0 \quad (2)$$

where I_a is the current in phase A after the fault occurrence and V_b and V_c are the voltage drops between M and N. Analyzing the fault boundary conditions equations in terms of the symmetrical component gives:

$$I_{a1} + I_{a2} + I_{a0} = 0 \quad (3)$$

$$\begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} V_{MN} \\ 0 \\ 0 \end{bmatrix} \quad (4)$$

$$V_{a0} = V_{a1} = V_{a2} = \frac{V_{MN}\,(\text{Voltage open pole for phase A at M})}{3} \quad (5)$$

Eqs. (3)–(5) verified that the voltage drops between M to N points are equal at open conductor in phase A in the sequence networks. Fig. 1c represents the sequence diagram [26]. When phase A is opened, the positive sequence component current at the proposed relay located at bus M will be determine by using the loop equation for Fig. 1c. This situation is mathematically similar to the situation in the LLG fault, except that the voltages are measured in a similar procedure. The sequence networks connection will also be the same except that the points considered for connection are different. The positive sequence fault current component at the proposed relay located at bus M will be determined by the following equation

$$I_{1SPT} = \frac{-(V_{M1} + V_{N1})}{Z_{SL1} + Z_{LM1} + Z_{MN1} + Z_{SN1}} \quad (6)$$

where:

Z_{SL1}: Positive sequence impedance component for source A.
Z_{SN1}: Positive sequence impedance component for source B.
Z_{LM1}: Positive sequence impedance component for line 1.
Z_{MN1}: Positive sequence impedance component for line 2.

2.2. Positive sequence current during SPT with fault

When a single pole tripping occurring in the system shown in Fig. 1a, a fault may be at F_x side (reversed) or in F_y side (forward). The two types of the fault will be discussed in the following section:

2.2.1. LG Fault type at reversed side (F_x)

BG fault type is created at F_x side during single pole tripping situation (phase A open), Fig. 1d shows the positive sequence equivalent circuit. The positive sequence component current at the proposed relay at bus M will be determined by the following equation.

$$I_{1SPTFx} = \frac{-I_{a1}(Z_{SL1} + Z_{LF1})}{Z} - \frac{V_{M1} + V_{N1}}{Z} \quad (7)$$

where:

V_{M1}, V_{N1} are the positive sequence component for two current sources.
I_M: Current from right loop.
I_N: Current from left loop.

$$Z = Z_{SL1} + Z_{LM1} + Z_{MN1} + Z_{SN1}$$

Z_F: is the impedance of the two sources current and resistance of the fault

The positive sequence fault current component at the proposed relay located at bus M will determine from, $I_{a1} = I_M - I_N$, where I_M and I_N are the resulting current due to E_L, E_N, V_{M1} and V_{N2}.

2.2.2. LG Fault type at forward side (F_y)

Similarly, as mentioned in the above case, under LG fault at F_y position during single pole tripping, the related positive-sequence equivalent circuit in Fig. 1e.

The positive sequence component fault current at the proposed relay at bus M will determine by the following equation.

$$I_{1SPTFx} = \frac{I_{a1}(Z_{SL1} + Z_{LF1})}{Z} - \frac{V_{M1} + V_{N1}}{Z} \quad (8)$$

3. Description of proposed scheme

Many techniques are used for directional relaying for the conventional transmission line [25,27]. When applying SPT schemes in transmission lines, the zero and negative sequence components presence limits the operation of conventional directional relaying. For the proposed method, the positive sequence components of the current signals are estimated for pre-fault and fault conditions. The positive sequence current angles difference (fault–prefault) is estimated for identifying the direction of the fault. Two faults at F_y and F_x are considered to see the validation of the proposed scheme at F_y and F_x in Figs. 1a, 2a and b show the phasor diagrams of the two faults in reversed (F_x) and forward (F_y) directions. In Fig. 2a, it shows that the positive sequence component determines the fault