An Enhanced Adaptive Algorithm to Mitigate Mis-coordination Problem of the Third Zone of Distance Relays

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ABSTRACT
Cascaded tripping of power lines due to mal-operation of zone 3 distance relays is one of the main causes of many blackouts worldwide. The improved protection technique for zone 3 can help to prevent such mal-operation and, thus, more reliable power systems can be envisaged. This paper presents a novel zone-3 setting scheme based on impedance seen by distance relays in order to calculate zone-3 setting of the relays when faults are simulated on the reach of zone-2 of primary distance relays. The new technique is also enhanced to be used in an adaptive protection system. Since three phase fault rarely occurs in the system and in order to have better demonstration of effectiveness of the proposed scheme, it is tested for various type of faults such as, two phase (AB), single phase to ground (AG) and two phase to ground (ABG) as well as three-phase (ABC) using data simulated through DIgSILENT in the IEEE 30-bus test system during different topologies. The simulation results show that the novel zone 3 distance relay elements using the proposed method operate correctly for various events.

Keywords: Power system, Adaptive distance protection, Distance relay zone-3, Zone-3 setting, Seen impedance.

1. Introduction

Zone 3 of a distance relay is traditionally used to provide the remote backup protection in case of the failure of the primary protection at the remote substation and is typically set to cover about 120% of the longest adjacent line. Moreover, this zone is given a delay time twice that associated with zone 2 times to achieve time selectivity, and the time delay is typically set in the range of 1–2 s. On account of covering an adjacent line by zone 3, a large infeed from the remote terminal causes the relay to under-reach. Likewise, a large outfeed causes an over-reach. Thus, a very large load at the remote terminal may cause distance relays to mal-operate which, in turn, leads to loss of security due to undesirable zone 3 trip-ping [1-3]. Some approaches like adaptive relaying where proposed for this situation. The concept of adaptation has been introduced to protection relays [4], [5], which has received increasing interest during the last decade due to the advancement of computers, communication systems and software techniques [6], [7]. The benefit of adaptive protective relaying arises from the integration with substation control and data acquisition functions and interfacing with central energy management system [8]. In [9] a new method is presented to increase the second-zone coverage of distance relays without causing over-reaching problems. A novel method to optimize the settings of the resistive and reactive reaches of the zones of the distance relays is represented in [10]. The method considers the probabilistic behavior of the variables that affect the apparent impedance seen by relays: pre-fault load flow, fault type, faulted line, distance up to the fault, fault resistance, and measurement errors. A new algorithm based on two new criteria: 1) the maximum value of the transient monitoring function obtained from three-phase currents and 2) the phase angle of the positive-sequence impedance is addressed in [11] to support zone 3 of the distance relay. The equivalent expression of the operation margin expressed by a function of bus voltage is established, and a preventive control model based on the sensitivities of the operation margin to power injection is proposed in [12] to overcome the overreaching property of zone 3 impedance relays (mho relays). A zone-3 revisited to re-examine the application of zone 3, to describe situations where it can be properly utilized, where it can be removed without reducing the reliability of the system protection and, if used, to explore the ways it can be set, is presented in [13]. Zone-1 reach settings for transmission line distance relays to prevent overreach resulting from coupling capacitor voltage transformer (CCVT) transients is studied on [14]. This scheme focuses on digital distance relays and determining appropriate relay reach settings to account for the effects of CCVT transients during faults for CCVTs with active ferro-resonant suppression circuits. A new algorithm for adaptive setting of Zone 3 of distance relays during severe voltage fluctuations is proposed in [15]. The developed algorithm is based on dynamic adjustment of zone 3 setting of distance relays to avoid mal-operation. An adaptive first-zone distance protection scheme for line with fixed series compensation connected at one end using local measurements is proposed in [16]. Impedance offered by series capacitor in this technique is estimated using relay end fault current. The integration of the series capacitor (SC) into the transmission line makes the coordination problem more complex. The under-reaching and over-reaching of distance protection for transmission line is more severe with SVC at mid-point of the transmission line [17]. In order to mitigate the mal-operation of the distance protection, the adaptive scheme is presented based on recursive simulation study. A method based on calculating voltage across faulted open port and faulted electric parameters is proposed in [18] to improve calculation accuracy of relay setting and coordination. A new algorithm is proposed in [19] that utilizes Synchronized Phasor Measurements (SPM) to enhance the operation of distance protection zone 3 in many aspects such as distinguishing between actual system faults and load encroachment and not affecting the tripping decision by the value of fault resistances as well. A synchrophasor data-based technique for correct zone 3 operations is accomplished in [20] using impedances calculated from voltage and current signals from synchrophasors placed at strategic locations. In order to significantly change with the operating conditions, an adaptive zone 2 distance relay characteristics for multi-terminal power transmission system using PMU data is proposed in [21] in which the apparent impedance equation includes infeed, outfeed and line shunt capacitance of the multi-terminal system. Ref. [22] proposes an algorithm based on the detection of remote breaker operation following zone 2 fault detection by local distance relay and it uses as a basis the monitoring of changes on a proposed signal. Proposed algorithm allows the trip acceleration on zone 2 of non-communicated distance relays for cases where faults are located inside the protected line. The conventional methods of distance relay coordination usually disregard the effect of the fault current in-feed at the remote buses. This impact causes the impedance presented to the relay to be much greater than the actual impedance and leads to the under-reach of the relays. This problem is more effective in the zone-3 setting of the distance relay and makes this zone be identified as one of the contributing causes of blackouts. Hence, determining the accurate zone-3 setting of the distance relay is an important issue. This paper proposes a new technique for determining settings of zone-3 distance relays. The proposed technique uses impedance seen by distance relays to calculate zone-3 setting of the relays when faults are simulated on the reach of zone-2 of primary relays. Results show that better backup protection and higher line coverage are provided using both adaptive and non-adaptive versions of the proposed technique. The adaptive version of the proposed method is utilized under normal circumstances, but during failures, such as communication failures its non-adaptive version is activated.

2. Zone-3 reach setting

2.1 Conventional method

Two different scenarios can be considered due to its significance for the third zone setting of a distance relay. According to Figure 1, these scenarios are as follows:

Scenario 1. The longest line emanating from the remote bus B should be seen by the third-zone relay located near the local bus A (R_{AB}):

$$Z_3(R_{AB}) = k_1 \times (Z_{AB} + Maximum\{Z_{BCi}\ ;\ i = 1, 2, ..., k\}) \tag{1}$$

Where $Z_3(R_{AB})$ is the impedance setting for the third zone of the relay R_{AB}; k_1 is a safety margin within the range of 1.1 to 1.2; Z_{AB} is the positive sequence impedance of the protected line A-B and Z_{BCi} is the positive sequence impedance of the next line B-C_i. In this scenario, $Z_3(R_{AB})$ may overlap