Electrical Power and Energy Systems 92 (2017) 42–52

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Comprehensive coordination of combined directional overcurrent and distance relays considering miscoordination reduction

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ARTICLE INFO

Article history:
Received 28 October 2016
Received in revised form 16 March 2017
Accepted 17 April 2017

Keywords:
Miscoordination reduction
Directional overcurrent relay
Distance relay
Pickup current
Different overcurrent relay characteristics

ABSTRACT

This paper presents a novel approach to solve the miscoordination problem of combined directional overcurrent and distance relays in transmission and subtransmission systems. In order to reduce relays miscoordinations, a general objective function is presented to find optimum directional overcurrent relays time setting multipliers, characteristics, and pickup currents by optimization algorithms. In previous researches, different approaches have been presented but they cannot find a reliable solution to avoid from having negative discrimination times between the backup and main relay (miscoordination), which means operation of the backup relay before the main relay. Using proposed approach, not only the number of miscoordinations can be greatly decreased but also the positive discrimination times can be minimized. The proposed method is tested on 9-bus and 39-bus test system. Genetic algorithm and human behavior-based optimization are used as optimization tools to find optimum settings. The results indicate that the proposed approach is capable of solving the miscoordination problem, in addition to minimization of discrimination and relay operation times compared with previous approaches.

1. Introduction

Well coordination of relays is the procedure of finding the suitable settings, which result in the operation of the nearest relay to the fault location before other primary relays. Directional overcurrent and distance relays play an important role in protection of transmission and subtransmission power systems; therefore, their coordination should be seriously taken into consideration. To achieve a safe protection of power systems, a common solution is the application of a backup protection beside the main protection [1,2]. In transmission and subtransmission lines, directional overcurrent and distance relays are mainly used for protection. In this protection scheme, the directional overcurrent relays and the first zone of the distance relays are used for the main protection. In addition, the directional overcurrent relays with a delay time, and the second zone of the distance relays are used as backup protection.

In order to have a reliable protection, the backup relay should not operate before the main relay. For this, a coordination time interval (*CTI*) [3–5] should be added to the operation time. For overcurrent relays optimal coordination, valuable researches have been conducted based on the linear programming techniques like simplex [6] and dual simplex [7] methods.

To achieve comprehensive coordination, both directional overcurrent and distance relays should be coordinated, and the discrimination time between the backup and main relay should not be less than *CTI* [8,9]. In coordination problems, the aim is to minimize the discrimination time (Δt) between the backup and main relay. So the coordination problem can be considered as an optimization problem, which can be solved by artificial intelligence methods. In these methods the coordination constrains are involved in the objective function (OF) [10].

In [11], an approach has been introduced for only the coordination of the overcurrent relays and the time setting multipliers (*TSMs*) have been selected by using evolutionary algorithms. In [12], another approaches have been introduced and the same approach has been used by using genetic algorithm (GA). In [13], the overcurrent relays coordination has been achieved by particle swarm optimization (PSO) method, as meta-heuristic algorithm, and the *TSMs* have been selected. In [1], hyper-spherical search algorithm has been used to coordinate overcurrent relays considering different relay characteristics. In [5], critical fault point for calculation of short circuit current has been investigated using an analytical approach and overcurrent relays have been coordinated considering the calculated critical fault current.

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http://dx.doi.org/10.1016/j.ijepes.2017.04.008
0142-0615/

In all aforementioned papers, the optimal coordination has been performed only for overcurrent relays, while in power transmission and subtransmission lines, the overcurrent and distance relays are simultaneously used in protection schemes. Therefore, both of them should be coordinated. In addition, the characteristic of the relays and the pickup currents have been assumed to be fix, and only the *TSMs* have been optimally selected.

In [14], the optimal coordination of the overcurrent relays and the second zone of the distance relays have been studied using linear programming techniques, and the *TSMs* have been selected. In [15], by using a new OF, the coordination of both the overcurrent and distance relays have been optimized using GA, and the *TSMs* and the characteristics of the overcurrent relays have been selected, but still the pickup currents have been assumed to be fixed values.

In all mentioned papers, the miscoordinations are still the main problem and has not been solved. Some the relays in the previous works meet the miscoordination problem. In this paper, a new approach for coordination of combined directional overcurrent and distance relays will be introduced and GA and human behavior-based optimization (HBBO), as the optimization algorithms, will be used to find the best *TSMs* as well as best characteristics of the directional overcurrent relays and pickup currents. It will be shown that by using the proposed approach, the miscoordination will be decreased, and the discrimination times will be minimized and in many cases, it will be close to zero. In addition, it will be shown that by selecting the proper pickup currents, the coordination will be improved. It should be noted that this paper investigates the steady-state condition of the system for relay coordination. Similar to the previous works [16], at first the proper approach for optimal coordination of the power system should be found and then in another study, the proper approach to adapt the proposed approach should be discussed. Transient behavior will be our future work.

The contributions of the paper can be summarized as follows:

- Considering miscoordination reduction in the coordination of distance and directional overcurrent relays problem
- Optimally selecting pickup currents for each directional overcurrent relay in the proposed approach.
- Simultaneously considering optimal selection of overcurrent pickup current, characteristics, *TSMs* and miscoordination reduction in the proposed approach.
- Applying a novel optimization algorithm to the problem of relay coordination and comparing its results with GA.

2. Problem statement

In power networks, both the directional overcurrent and distance relays can operate as the main or backup relays; therefore, it will be four different types of protection scheme.

Type 1:	Main directional overcurrent relay and backup directional overcurrent relay (OC-OC protection type)
Type 2:	Main directional overcurrent relay and backup distance relay (Dis-OC protection type)
Type 3:	Main distance relay and backup directional overcurrent relay (OC-Dis protection type)
Type 4:	Main distance relay and backup distance relay (Dis-Dis protection type)

The coordination of the Dis-Dis protection type should be performed before the coordination of others and the impedance settings for three zones of the distance relays should be calculated. These settings will be used for the coordination of the remaining protection types. To calculate the directional overcurrent relay operation time, the fault locations should be specified. These fault locations, specified in [15,13], are shown in Figs. 1 and 2. Then, the discrimination times between the backup and main relays, for each fault locations should be checked for OC-OC protection type as follows:

$$t_{bOC|F_1|} - t_{mOC|F_1|} \geqslant CTI_1 \tag{1}$$

$$t_{bOC|F_2|} - t_{mOC|F_2|} \geqslant CTI_1 \tag{2}$$

where $t_{bOC|F_i|}$ and $t_{mOC|F_i|}$ are the backup and main directional overcurrent relays operation times for the fault that occurs in the location F_i, and the CTI_1 is the coordination time interval of the OC-OC protection type. For OC-Dis protection type, the following expressions should be checked:

$$t_{bOC|F_3|} - t_{z_1} \geqslant CTI_2 \tag{3}$$

$$t_{bOC|F_4|} - t_{z_2} \geqslant CTI_2 \tag{4}$$

where t_{z_1} and t_{z_2} are the distance relays operation times for the first and second zones, and the CTI_2 is the coordination time interval of the OC-Dis protection type. At last, for the Dis-OC protection type, the following expression should be checked:

$$t_{z_2} - t_{mOC|F_5|} \geqslant CTI_3 \tag{5}$$

where CTI_3 is the coordination time interval of the Dis-OC protection type.

3. Proposed method

As it mentioned before, the negative discrimination time means that the backup relay operates before the main relay. Therefore, in coordination process, it is necessary to minimize the number of these miscoordinations, and then, the discrimination times, and also the operation times of the relays should be minimized.

In proposed OF, for each protection type, the number of negative discrimination times will be counted. Then its value will be increased by an amplification factor, namely γ, and it will be a penalty factor for both discrimination times and the operation times. This OF is formulated as follows:

For OC-OC protection type:

$$OF_{oc-oc} = (m_1+1)^{\gamma_1} \times \left(\alpha\sum_{i=1}^{N} t_i + \beta_1\sum_{k_1=1}^{P_1}\left|\Delta t_{mbOC|F_1|}\right| + \beta_2\sum_{k_1=1}^{P_1}\left|\Delta t_{mbOC|F_2|}\right|\right) \tag{6}$$

It will guaranty the constraints (1) and (2). For OC-Dis protection type, we have:

$$OF_{oc-dis} = (m_2+1)^{\gamma_2} \times \left(\beta_3\sum_{k_2=1}^{P_2}\left|\Delta t_{mbOCDis|F_3|}\right| + \beta_4\sum_{k_2=1}^{P_2}\left|\Delta t_{mbOCDis|F_4|}\right|\right) \tag{7}$$

It will guaranty the constraints (3) and (4). For Dis-OC protection type, the OF is the same as one proposed in [15] that will guaranty the constraint (5):

$$OF_{dis-oc} = \beta_5\sum_{k_3=1}^{P_3}\left|\Delta t_{mbDisOC|F_4|}\right| \tag{8}$$

where $\Delta t_{mbOC|F_i|}$ is the discrimination time of directional overcurrent relays in OC-OC protection type for the fault occurred at the location F_i and can be obtained as follows:

$$\Delta t_{mbOC|Fi|} = t_{bOC|F_i|} - t_{mOC|F_i|} - CTI_1 \tag{9}$$