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Mitigation of DOCR miscoordination through distance relays and non-standard overcurrent curves

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ABSTRACT

This article presents the application of non-standardized inverse-time curves and distance relays to solve the lack of sensitivity of relays during overcurrent relay coordination. The inclusion of distance relays to replace the insensitive overcurrent is proposed, the effect of underreaching by infeed is considered. Directional overcurrent relays very frequently act as backup protection in sub-transmition networks when line differential relays or pilot protection are used as primary protection. Thus, the directional overcurrent relays (DOCR) coordination application should be evaluated not only in small electrical systems but also in large and meshed networks. The model used of overcurrent relay considers five adjustable settings to enhance the coordination when distance relays are considered. The proposed method reduces the number of relays that do not coordinate, this allows to obtain results with better implementation. The results show a performance improvement in overcurrent relay coordination in several highly interconnected IEEE systems.

1. Introduction

The main purpose of a protection relay is detect and isolate the faulted element as soon as possible, so that the impact with the rest of the system is minimized; leaving undamaged elements intact. The protection principle is used depending on the voltage level of the electrical network, the application criterion is based on the protection performance and related cost. Thus, the directional overcurrent relays (DOCRs) are widely used in sub-transmission systems as backup of line differential relays or pilot protection, and in distribution as both primary and backup protection. The coordination of DOCRs consists of determining the sequence of operation time to achieve the selective operation of the relay, guaranteeing the backup operation by any device located in another location in case that the fault is not interrupted by the primary protection. Although the DOCRs have non-linear characteristic curves, the coordination of a pair of relays is carried out based only on the maximum current. Due to the divergence of the time curves, coordination is guaranteed for lower current values. However, in meshed networks may be very common the crossing time curves because both the fault current and pick-up current is not always bigger in backup relay. Although DOCRs are the simplest and cheapest, they are the most difficult to adjust and coordinate, since they are affected by changes in the power system because their principle of operation depends only on the current.

In the last decades several optimization methods have been proposed to solve the coordination. The problem has been commonly formulated as the minimization of the sum of the total time of operation of relays, the restrictions are established to define a parametric intervals and to establish the coordination criterion. The DOCRs coordination is not considered a solved problem, and although some algorithms present more efficient formulations, none offers a robust solution for all different relay coordination problem. Thus, the continuous search for optimization algorithms subject to more and better restrictions will allow better results to be obtained for the coordination problem, and not only minimizing relay operation times. Since then, different methods have been used to solve the optimization problem. The use of deterministic methods is particularly complex, since the main problem is the requirement of a good initial approximation, the high probability of being trapped in local minimums and it is common that numerous violations of the restrictions occur. For this reason, various heuristic methods of optimization have been proposed, most of them belonging to natural imitation algorithms, due to their ability to find solutions to

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Table 1
Related works on distance and overcurrent relay coordination.

Reference	Year	Adjustable settings	Method	System buses	Total relays
Gastineau et al. [1]	1977	1	Numerical	–	–
Damborg et al. [2]	1984	1	Numerical	5	12
Schultz and Waters [3]	1984	1	Numerical	–	–
Ramaswami et al. [4]	1986	1	Numerical	6	11
Pérez and Urdaneta [5,6]	2001	2	LP	8	16
Khederzadeh [7]	2006	2	LP	8	16
Kojovic and Witte [8]	2001	2	Numerical	8	7
Chabanloo et al. [9]	2008	2	GA	6	14
Sadeh et al. [10]	2008	1	GA	6	14
Sadeh et al. [11]	2011	2	PSO	8	16
Chabanloo et al. [12]	2011	3	GA	8, 30	14, 68
Singh et al. [13]	2012	2	DE	6	14
Moravej et al. [14]	2012	2	PSO	8	14, 64
Nair and Reshma [15]	2013	2	GA	8	14
Farzinfar et al. [16]	2014	2	PSO	8, 14	14, 34
Haron et al. [17]	2013	2	Numerical	6	8
Rahmatian et al. [18]	2014	2	ICA, GA	6	14
Marcolino et al. [19]	2015	2	GA	8, 39	14, 68
Singh [20]	2016	4	SQP	8	14
Ahmadi et al. [21]	2017	3	GA, HBBO	9, 39	12, 39
Bangar et al. [22]	2017	2	JAVA	8	28
Proposed work	2017	5	GA, IWO, SQP	9, 14, 30, 57, 118	12, 30, 68, 130, 340

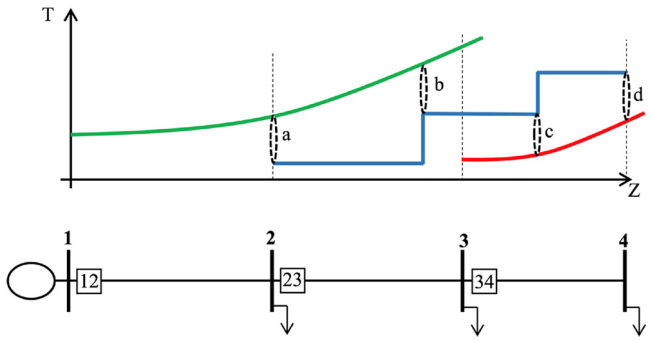

Fig. 1. Critical points between distance and overcurrent relays coordination.

complex problems. Genetic algorithms (GA), particle swarm (PSO), ant colony (ACO) and differential evolution (DE) are the most studied.

The coordination is carried out offline considering the upper limits of the load current and the fault current. However, the distribution and sub-transmission networks have the highest topological dynamics of the entire electric network. As a result, these dynamic changes in the electrical network affect the sensitivity and selectivity of the DOCRs, causing inappropriate operations manifesting in the lack of fault detection capacity and in non-permissible operation times of the protections, affecting the voltage quality of the network and increasing the damage of the primary equipment. In the coordination solution, it is common to find operation times greater than those required by the operating criteria of the electrical network and that several relays are not coordinated. The difficulty in adjusting relays and performing the coordination increases rapidly as the system grows, particularly in highly interconnected power systems. These functional limitations are accentuated by increasing the diversity of operation of the electricity network and, in recent years, the diversity of dynamics of non-regulated generation elements.

The degradation of coordination is often due to the limitation by the overcurrent principle, although the use of non-standard curves offers an alternative, not in all cases it is possible to solve the problem of violation of restrictions; mainly in highly interconnected networks where the lack of sensitivity of relays can be very common. The electric companies have chosen to incorporate different protection principles to improve trip times. However, the problem of lack of sensitivity, mainly in its backup function, is not solved.

In several works the coordination between overcurrent relays and distance relays has been studied. GA has been used frequently in first literatures due to its simplicity, robustness and ease of implementation. In other works, alternative formulations are proposed to improve the coordination between distance and overcurrent relays. Nair and Reshma [15] uses a small six-bus system to obtain the optimal curve selection and time multiplier settings; the genetic algorithm (GA) considers a fixed tripping time for the second zone. The adaptation of a new multiple embedded crossover PSO to optimize the TDS, the pickup current, and the second zone's operating time at three critical coordination points is presented in Farzinfar et al. [16]. Table 1 presents a list of the works reported in the literature.

In this work we propose the incorporation of distance relays only in locations where the overcurrent relay has no sensitivity, so the greater reach of the distance relay will present a solution to the problem of poor coordination and/or lack of sensitivity. The effect of underreaching due to the infeed in the distance relays is considered because it affects the determination of the critical points of coordination with the overcurrent relays. In addition, the incorporation of non-standardized curves to the coordination problem allows to improve the results. These dynamics are included in the proposed algorithm. The implementation of the Invasive Weed Optimization (IWO) is used due it is very attractive to incorporate non-standardized time curve functions, solve optimization problems subject to a large number of restrictions added by distance relays.

2. Overcurrent and distance relay coordination

Coordination in highly interconnected networks generally results in greater complexity due to the large number of restrictions and that, although the same type of curve is used, the loss of coordination due to the crossing of curves can occur because the pickup current of the backup relay may be less than the pickup current of the primary relay. The coordination between DOCRs and distance relays in a radial system