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Optimal Overcurrent Relay Coordination: A Review

M. H. Hussain[a,]*, S. R. A. Rahim[a], I. Musirin[b]

[a]*School of Electrical Systems Engineering*
Universiti Malaysia Perlis
Kangar, Perlis

[b]*Faculty of Electrical Engineering*
Universiti Teknologi Mara
Shah Alam, Selangor

Abstract

This paper presents an overview on optimal overcurrent relay coordination in protection system and protective relays. Efforts have been made to include all methods used for the coordination of overcurrent relays. It includes techniques, such as Artificial Intelligence (AI) and Nature Inspire Algorithm (NIA) as well as other conventional methods used for overcurrent protection. A brief mentioned is made about conventional methods while more prominence is given on the application of AI and NIA for the protection of overcurrent relays. This paper presents a set of references of all respective papers related and provides a brief summary of the research work. In addition, the results of these techniques also provided in the respective references.

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Keywords: overcurrent relay coordination; protection system; protective relays; artificial intelligence; nature inspire algorithm.

1. Introduction

Power system protection is a bough of electrical power engineering and it is designed to continuously monitor the power system to ensure maximum continuity of electrical supply without damaging equipment. Since power system developments change its structure, the power system protection becomes very vital. As the designer or engineer of the system struggles with devising a system arrangement, the engineer simply cannot build a system which will never fail regardless of any reasons. This is where protection system and protective relays become important. In electrical engineering, a protective relay is a complex electromechanical apparatus, designed to calculate operating conditions on an electrical circuit and trip circuit breakers when fault is detected. For designing the protective relaying, understanding the fault characteristics is required. Related to this, protection engineer should be conversant about tripping characteristics of various protective relays. The design of protective relaying has to ensure that relays will be able to detect abnormal or undesirable conditions and then trip the circuit breaker to disconnect the affected area without affecting other undesired areas. According to statistical evidence, large numbers of relay tripping are due to improper or inadequate settings rather than to genuine faults [1].

* Corresponding author. *E-mail address:* muhdhatta@unimap.edu.my

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While the operating quality of automatic operation such as auto-reclosing and monitoring equipment which collects data on the system, protective relay is always critical device. Protective relay is a device which gives instruction to a circuit breaker to disconnect a faulty part of the system. The importance of designing protective system and considering different strategies are arising regularly due to faults, overload, under-frequency and over-voltage in power system. Such conditions cause interruption to the supply and may harm equipment connected to the system. Removing and detecting the faulted parts as fast as possible is the main function of the protection in power system. In addition, time coordination among protective devices such as protective relay and protective circuit breaker are also essential. Primary devices, which closed to the fault should act first before backup devices which are located farther. Fault analysis may be divided into two steps: a) determination of the maximum currents that components must endure and switching devices must interrupt and b) coordination of circuit protection [2]. As pointed in [1], the most visible effect of a shunt fault is sudden built up of current. So it is natural that the magnitude of current be utilized as positive sign for the existence of a fault. Therefore, the overcurrent protection is the most widely used form of protection in distribution system [1, 3, 4]. One of the mainly common protective relays used in power systems from various faults is the overcurrent relay.

2. Overcurrent relay

Basically, overcurrent relay (OCR) is a type of protective relay which operates when the load current exceeds a preset value. Overcurrent relays generally have current setting multipliers ranging from 50 to 200% in steps of 25% which is referred to as plug setting (PS). PS for each relay is determined by two parameters; the minimum fault current and the maximum load current [5-7]. The coordination of this protective relay is set up during the process of system design based on the fault current calculation. To clear faults properly within a definite time, each protective relay has to coordinate with other protective relays located at all adjacent buses. Their coordination is an important factor of the protection system design. Relay coordination problem is to determine the sequence of relay operations for each possible fault location so that the faulted section is isolated with sufficient margins and without excessive time delays [8]. In the coordination problem of overcurrent relays, the objective is to determine the time setting multiplier (TSM) and plug setting multiplier (PSM) of each relay, so that the overall operating time of the primary relays is minimized properly. For optimal coordination, these parameters should fulfill all constraints under the shortest operation time. Besides TSM and PSM, optimum method, objective function (OF), type of network either radial or interconnected network, non-linear relay characteristic proportional to TSM and PSM are to be important aspects for an optimal coordination.

3. Conventional Methods

Several methods have been proposed in the past four decades since 1960s for the coordination of overcurrent relays. These methods can be classified into three classes which are trial and error, topological analysis method and optimization method [9-13]. Trial and error approach was used but it has slow convergence rate as a result of large number of iterations needed to reach a suitable relay setting [8, 14]. To minimize the number of iterations required for the coordination process, a technique to break all the loops called breakpoint and locate the starting relays at these points is recommended. Finding the breakpoints is the significant part to initiate the coordination process. Topological methods which include functional and graph theory are used to determine break points [14]. The solution found using this method is the best of option settings considered but not optimal in any strict sense. Meaning that, the TSM or time dial settings (TDS) of the relays are high. Furthermore, due to the complexity of the system, trial and error approach and topological analysis are time consuming and not optimal.

In cases where the distribution system has more than one source connected, directional overcurrent relays turn out to be the convenience choice. Birla et al. in [15], classified the previous works on directional overcurrent relay into three categories: curve fitting technique, graph theoretical technique and optimization technique. The curve fitting techniques are used to determine the finest function to represent data. The relay characteristic is modeled mathematically by polynomial form using curve fitting techniques [16, 17]. Second category is graph theoretical techniques, were also reported in [18]. The system structure is utilized for analyzing the information on minimum set of breakpoints, sequence for setting relay and all primary or backup relays and line directionality for directional relays.

4. Optimization Techniques

The optimization techniques generally overcome the conventional approach which relays were arranged in a sequence before considered for coordination [19] and due to its advantages, it becomes popular among researchers. Furthermore, optimization techniques eliminate the need to find the set of breakpoints. Urdaneta et al. [20] was the first researcher to describe the application of the optimization theory in the coordination of directional overcurrent relay. In the optimization method, some researchers used non-linear programming to solve the coordination problem but these methods are complex and time consuming [21]. In [20], [22] and [23], the relay coordination problem is formulated as mixed integer non-linear programming (MINLP) and is solved by using General Algebraic Modeling System (GAMS) software. However, the use of binary variables to take into account the discrete pickup currents, I_{ps} increases the complexity of the coordination problem [15]. Due to the complexity of this technique, the coordination of overcurrent relays is commonly performed by linear programming (LP) techniques such as Simplex, dual Simplex and two-phase Simplex methods [6, 7, 10, 15, 22]. The drawback of these techniques is that this is based on an initial guess and may be trapped in the local minimum [24]. In these methods, pickup current, I_p settings are assumed to be known and the operation time of each relay is considered as linear function of its TSM or TDS. In [3], Big-M method has been proposed to find the optimum value of TMS of overcurrent relays in which the PS are assumed to be known and fixed. Bedekar et. al in [25-27] proposed Simplex, dual Simplex and two-phase Simplex methods to solve the directional overcurrent relay problem in ring fed distribution system. After proposed LP techniques and Big-M method, proceeding paper in [28] compared the four methods and it was shown that dual-Simplex method was better as compared to others. In addition, Ezzedin et. al [13] did state that although LP techniques are simple and easily converge to optimal solutions, only values of TSM can be optimized but pickup current, I_p has to be selected by experience of fault data and load. Generally, this is not the global optimum answer or solution of the problem. Hence, the use of these LP techniques has boundaries in term of low number of constraints.

5. Artificial Intelligence and Nature Inspire Algorithm

Nowadays, artificial intelligence (AI) and nature inspired algorithms (NIA) based optimization methods are applied to solve both overcurrent relays and directional overcurrent relays coordination problem. Some of the AI methods such as fuzzy logic reported in [29] and recently expert system rules consideration in [19] have also been applied to solve this problem. In [19], the expert rules of previous papers are modified and weighted to determine the priority of constraints. With AI techniques, if linear formulation is used, only TSM can be optimized but the optimization of both relay settings requires non-linear formulation of the coordination problem. In [10] and [30-34], Genetic Algorithm (GA) was implemented successfully for optimal coordination overcurrent relay to overcome miscoordination problem and minimizing the operation time of relays. Some of the researchers come with better idea such as Razavi et. al [7], Noghabi et. al [22] and Bedekar et.al [23, 35] to solve miscoordination problem both for continuous and discrete TSM or TDS, improve the convergence of GA and finding global optimum values using Non-Linear Programming (NLP) method. Other optimization technique which is reliable to solve optimization technique is Evolutionary Programming (EP).

EP application in protection system was first applied by So et. al in 2000 but it has two problems; miscoordination between relays and discrete TSM changed to continuous [36]. Later, Zieneldin et. al, Mohamed et. al and Rathniam et. al proposed a modified particle swarm optimization (PSO) to calculate the optimal relay settings [14, 37, 38]. Asadi et. al [39] convinced that PSO can handle miscoordination problems much better for both continuous and discrete TSM and PSM rather than EP and GA but Bashir et. al come out with a better solutions with less iteration compared to GA and LP method as reported in [40]. In 2010, Barzegari et. al used Harmony Search Algorithm [11] leads better solution compared to GA and LP method while Rashtchi et. al proposed Honey Bee Algorithm [6] which results in less TSM. One year later, Uthisunthorn et. al showed that in [41], Artificial Bees Colony (ABC) can converge towards better solution slightly faster than PSO and Quasi-Newton (BFGS).

6. Conclusion

A comprehensive review on overcurrent relay coordination have been done appropriately. Many methods and techniques are proposed and implemented for the past four decades and to meet present day requirements, mathematical tool such as AI and NIA based optimization methods seems to be reliable and fast. This is an effort to present author's works on the subject of techniques used in overcurrent relay coordination, the presence of oversight is bound to be there. The author would like to apologize for any error or any oversight and hope that additional references will be discuss on this publication.

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