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Computational Intelligence Based Technique in Optimal Overcurrent Relay Coordination: A Review

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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 Inspired Algorithm (NIA) as well as other conventional methods used for overcurrent protection. A brief review is made on conventional methods while more prominence is given on the application of AI and NIA for the protection of overcurrent relays. This paper presents a review of previous works on optimal overcurrent relay and its relevant issues. Numerous papers have been reviewed for this purpose. In addition, the results of these techniques also provided in the respective references.

Keywords— *overcurrent relay coordination; protection system; protective relays; artificial intelligence; nature inspired algorithm*

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I. INTRODUCTION

Nowadays, the modern society has come to depend heavily upon continuous and reliable availability of electricity and a high quality of electricity too [1]. Applications such as process industries, banking and telecommunication networking cannot function without a reliable source of electric power. Thus, maintaining a continuous supply of electricity is essential if electric supply fail to deliver. This is where power system protection becomes an important asset. In general, power system protection main functions are safeguard the entire system to maintain continuity of supply, minimize damage and repair costs where it senses a fault and ensure safety of personnel [2]. These requirements are necessary for early detection, localization of faults and prompt removal of faulty equipment from service. Since power system developments change its structure, the power system protection becomes very vital. The continuous of power systems expansion with inconsistent increase of transmission loadability leads to protection systems which are required to perform with realibility and security in the network [3-5].

In order to carry out power system protection main functions, protection must fulfill the following criteria; reliability, selectivity (discrimination), sensitivity, stability and speed [6-15]. Besides of power system protection requirements, protective relays are the most important part in power system. 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. 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. 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].

Protective relay is always critical device rather than the operating quality of automatic operation such as auto-reclosing and monitoring equipment which collects data on the system. The importance of designing protective systems 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. The faulted components must be identified and isolated to guarantee the energy supply to the largest number of consumers as possible. Furthermore, time coordination among protective devices such as protective relay and protective circuit breaker are also essential.

Primary devices, which is close to the fault location should act first before backup devices which are located farther. The primary device must respond to the fault as fast as possible. These primary devices and backup devices must be coordinated together and coordination time interval (CTI) is the criteria to be considered for coordination [12]. It is predefined CTI and it depends on the type of relays. For electromagnetic relays, CTI is 0.3 to 0.4s while for microprocessor based relay, CTI is 0.1 to 0.2s [12]. The backup devices should not act first unless the primary devices fails to operate.

In reference [16], 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. As pointed in [1], the most visible effect of a shunt fault is sudden built up of current. So it is acceptable that the magnitude of current is considered with positive sign for the presence of a fault. Therefore, the overcurrent protection is the most widely used form of protection in distribution system [1, 7, 17-23]. Protection against current was naturally the earliest protective system to evolve. Generally, Figure 1 comprises five types of protective relays which are overcurrent relays, directional relays, differential relays, distance relays and pilot relays. One of the mainly common protective relays used in power systems from various faults is the overcurrent relay.

This paper presents the review of optimal overcurrent relay coordination. Numerous past works have been critically and rigorously reviewed in order to identify the gap within the current relevant researches. From the exhaustive investigations, it is discovered that artificial intelligence based technique is a promising approach to accurately identify the operating current coordination.

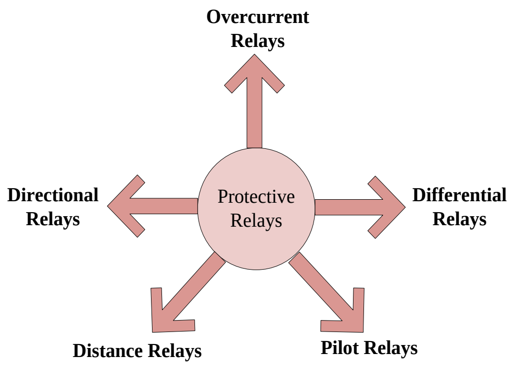

Fig. 1 Five types of Protective Relays

II. OVERCURRENT RELAY COORDINATION

Basically, overcurrent relay (OCR) is a type of protective relay which operates when the load current exceeds a preset value. It has a single input in the form of ac current. The output of the relay is normally open-contact and can changes to closed state when the relay trips. Relay has two settings which commonly known as time setting and plug setting. The function of time setting is to decide the operating time of the relay while plug setting decides the current required for the relay to pick up.

The overcurrent relay is widely used in many protection applications throughout power systems. When a fault occurs, huge amount of current flows which may damage power system components. Therefore, overcurrent relay must de-energize the faulted line as soon as possible to protect the system from the faults. Overcurrent relay is used for overcurrent protection, connected to a current transformer and calibrated to operate at or above specific current level. When the relay operates, one or more contacts will operate and energize a trip coil in a Circuit Breaker (CB) and open the CB. Figure 2 illustrate the process frameworks of overcurrent relay on distribution system with its current setting and coordination time.

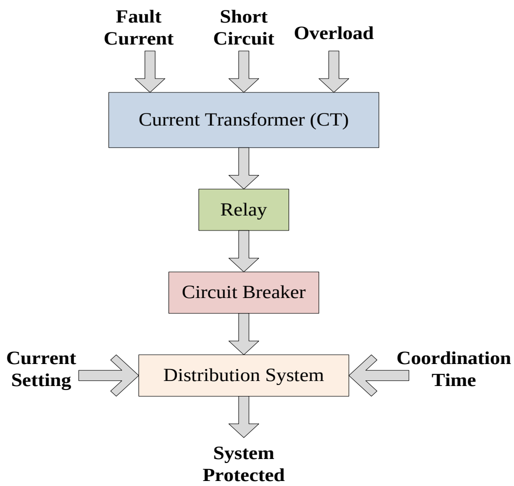

Fig. 2 Illustration of overcurrent relay process frameworks on distribution system

Overcurrent relays generally have current setting multipliers ranging from 50 to 200% in steps of 25% which is referred to as plug setting (PS) [24-26]. PS for each relay is determined by two parameters; the minimum fault current and the maximum load current [24-26]. These devices provide fast operation at high current and slow operation at low current and as the fault current is a function of the fault location the coordination with other overcurrent devices is possible [27]. 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 time is an important factor of the protection system design. Thus, the overall protection coordination is very complicated.

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 [28]. This sequence selection is a function of network topology, relay characteristics and protection philosophy [29]. In distribution system, the overcurrent relay coordination problem can be defined as constrained optimization problem. The objective in the coordination problem of overcurrent relays 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. Other authors aim is to determine the TSM and pickup current setting for each relay, so that the overall operating time of the primary relays is minimized. For optimal coordination, these parameters should fulfill all constraints under the shortest operation time. Besides TSM, PSM and pickup current setting, 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.

III. Conventional Methods Vs Optimization Techniques Applications

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 [8-9, 16, 30-32]. 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 [28, 33]. 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 [33]. In the functional method, the constraints on the relay settings are formulated by a set of functional dependencies. Other topological analysis which is linear graph theory has been extended to analyze all simple loops of the network in both directions considering the minimum set of breakpoints and so as the primary and backup relay pairs. 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 connected source, directional overcurrent relays turn out to be the convenience choice. Birla et al. in [34], 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 [35, 36]. Second category is graph theoretical techniques, were also reported in [37]. 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. Figure 3 below shows classical or conventional method used for optimal overcurrent relay coordination.

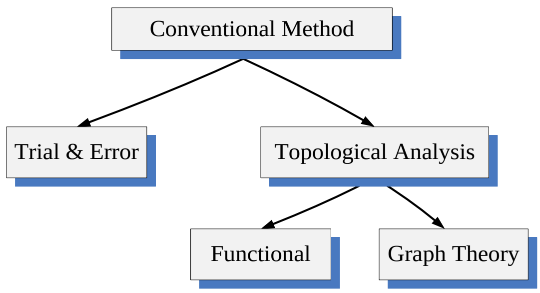

Fig.3 Conventional Method Approach

The optimization techniques generally overcome the conventional approach which relays were arranged in a sequence before considered for coordination [38] 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. [39] was the first researcher to describe the application of the optimization theory in the coordination of directional overcurrent relay. The values of TSM have been calculated using Linear programming (LP) model, simplex method for a given values of pickup current, I_p. In the optimization method, some researchers used non-linear programming to solve the coordination problem but these methods are complex and time consuming [40]. This is due to the non-linear programming approach, based on the relay characteristic, TSM and I_p are optimized simultaneously. In [39], [41] and [42], 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 [34]. 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 [25, 26, 31, 34, 41]. The drawback of these techniques is that this is based on an initial guess and may be trapped in the local minimum [43]. 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 [7], Big-M (penalty) 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. This method is based on the simplex algorithm used to find optimum solution in linear programming problem. It introduces artificial variables in the objective function to get an initial basic feasible solution known as IBFS. Bedekar et. al in [10, 44-45] also 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 (penalty) method, proceeding paper in [46] compared the four methods and it was shown that dual-Simplex method was better as compared to others. The authors did state that the number of calculations per iteration in dual-Simplex method is much less than the other three methods. However, Ezzedin et. al [9] 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.

IV. 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. Different categories of Computational Intelligence (CI) with different techniques are specifically categorized in Figure 4.

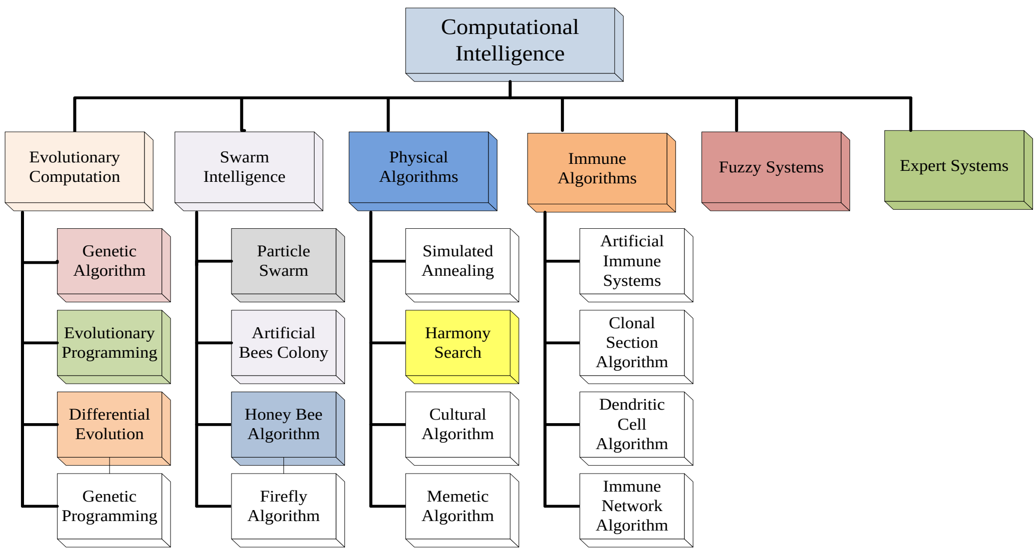

Fig 4. Computational Intelligence categories with different methods

Some of the AI methods such as fuzzy logic reported in [47] and recently expert system rules consideration in [38] have also been applied to solve this problem. In [38], 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. A new method for modeling overcurrent relay characteristics curves based on a combined adaptive network and fuzzy inference system (ANFIS) also was proposed in [48]. Overcurrent relay modeling was done using ANFIS for two types of overcurrent relays (RSA20 and CRP9) with different types to bring out the optimal design.

In [11-12, 31, 49-51] Genetic Algorithm (GA) was implemented successfully for optimal coordination overcurrent relay to overcome miscoordination problem and minimizing the operation time of relays. Singh et.al in [52] determine the operating time of the relays using GA for both linear objective functions and non linear objective functions. Some of the researchers come with better idea such as Razavi et. al [26] and Noghabi et. al [41] to solve miscoordination problem both for continuous and discrete TSM or TDS and improve the convergence of GA using Hybrid GA. Bedekar et.al [42, 53] contribute in finding global optimum values of TMS and PS using Hybrid GA with Non-Linear Programming (GA-NLP) method and proposed Continuous Genetic Algorithm (CGA) to minimize the operation time of relays and avoid the mal-operation of the relays. 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 [54]. Later, Zieneldin et. al, Mohamed et. al and Rathniam et. al proposed a modified particle swarm optimization (PSO) to calculate the optimal relay settings [13, 28, 55]. Asadi et. al [14] 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 [15].

In 2010, Barzegari et. al used Harmony Search Algorithm (HSA) [8] leads better solution compared to GA and LP method. This HSA then is applied to developed a new Improvised Harmony Search Algorithm (IHSA) to solve the optimal coordination of directional overcurrent relay problem. In same year, Rashtchi et. al proposed Honey Bee Algorithm (HBA) [20] which results in less TSM. One year later, Uthisunthorn et. al showed that in [56], Artificial Bees Colony (ABC) can converge towards better solution slightly faster than PSO and Quasi-Newton (BFGS). In the middle of 2012, Rodporn et. al in [57] employed Differential Evolution (DE) to solve for solutions for optimal relay coordination. This DE algorithm was originally developed from GA but the structure is much simpler. Later, Amraee T in [58] proposed seeker technique which capable of finding superior TDS or TMS and PMS settings in linear and non-linear model. A hybrid Nelder-Mead simplex search method and Particle Swarm Optimization (NM-PSO) recently proposed by Liu, A. and Yang, M.T [59]. This method is used to improve the efficiency of the PSO for rapid convergence, computation speed and feasibility.

To get a clear view on how the process works, Figure 5 illustrates Intelligent Control & Monitoring act as a “brain” with different Computational Intelligence methods to determine an optimal results for overcurrent relays. Different methods that had been proposed by resepective authors or researchers with specific references for overcurrent relays also were summarized in Figure 6.

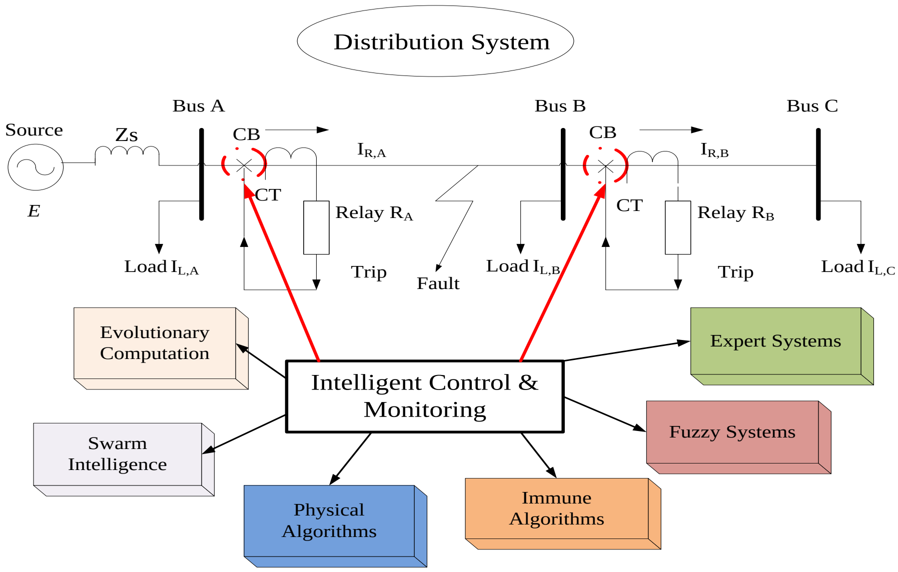

Fig. 5 An illustration example of overcurrent relays for feeder protection with Intelligent Control & Monitoring in distribution system

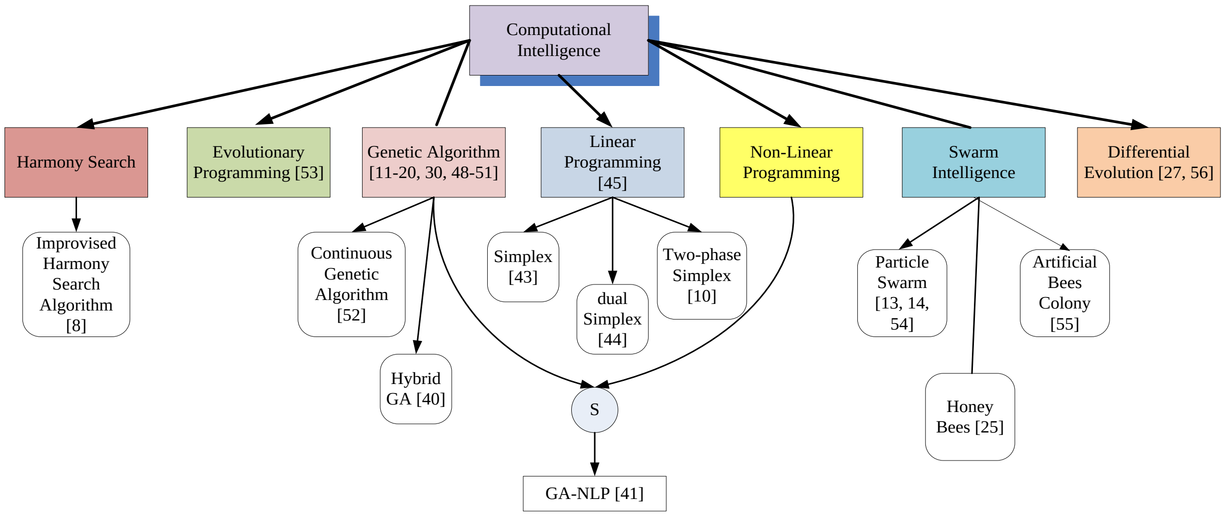

Fig. 6 Different methods that had been proposed by researchers for overcurrent relay coordination

V. NEXT FRONTIER

Recently, different countries represented by United States of America and the European Union propose to build a flexible, clean, safe, economical and friendly smart grid and regard the smart grid as the future direction of the power grid [60-62]. This is due to the expansion of power grid scale and construction of ultra high voltage (UHV) power grid that lead to short circuit increasing [63]. Thus, it will affected the electrical equipment operations and the reliability of the system. In addition, the development of micro-grid technology also will cause problems such as coordinating of backup protections and multi-way power flows. This will lead difficulties for conventional relay protection setting and operation [63]. Thus, with the studies of smart grid, the overcurrent protection area is catching more attention.

Applying conventional methods to solve the matters related to power systems have been almost replaced by advanced schemes and technologies [64], namely computational intelligence. With the characteristics of smart grid such as enabling new services, markets, provide the power quality, optimizing asset utilization and operating efficiency, hopefully it could bring a new dimension or next frontier in overcurrent protection research. Figure 7 illustrates the integration between smart grid and distribution system applications with intelligent system monitoring and operation.

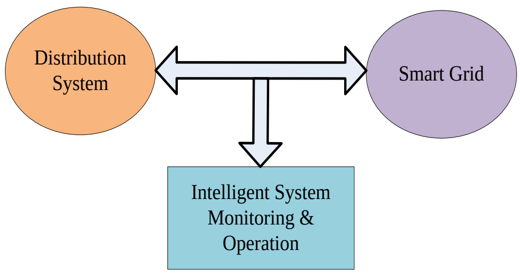

Fig. 7 Integration between smart grid and distribution system with intelligent system monitoring and operation

VI. CONCLUSIONS

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. Future work is proposed here to improve the overcurrent relay coordination with the existence of smart grid. The author would like to apologize for any error or any oversight and hope that additional references will be discussed on this publication.

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