Abstract – Coordination of directional over current relays in a modern power system is a challenging task for the protection engineers. This paper gives an overview of the Directional over current relay (DOCR) coordination, mathematical formulation and general history of research and developments in the last 20 years based on many published articles. This paper has been divided into many sections so that reader do not face any difficulty in understanding the DOCR coordination problem in the power system.

Index Terms- Optimal coordination, trial and error method, topological analysis, optimization, artificial neural network, genetic algorithm, particle swarm optimizer.

I. INTRODUCTION

In a modern interconnected power system abnormal conditions (faults, overload, over-voltage, under-frequency, etc.) can frequently occur. Due to this, interruption of the supply and damage of equipments connected to the power system may occur. The faulted components must be readily identified and isolated in order to guarantee the energy supply to the largest number of consumers possible and to maintain the system stability, which allow us to design a reliable protective system. To ensure reliability of the protective system, the back-up protection scheme shouldn’t come into action unless the primary protection scheme (main) fails to take the appropriate action. In other words, it should operate after a certain time delay known as coordination time interval (CTI), giving the Chance for the primary protection to operate. This coordination of protective relays in electric power system can be achieved by selecting their suitable settings such that their fundamental protective function is met under the requirement of sensitivity, selectivity, reliability, and speed [1][2].

Directional over current relay (DOC) are commonly used for power system protection. The function of directional over current relay (DOCR) in an electrical power system is to minimize damage and to limit the extent and duration of the service interruption whenever faults occur at any point in the system.

This paper summarizes different methods used for DOCR coordination in an electrical power system. It also presents a direction on which the new solution techniques evolve with time.

II. GENERAL HISTORY AND CONCEPTS

In the past four decades, various approaches have been developed to the automation of the solution of the coordination problem of directional over current relay in the power system. Conventionally, trial and error approach was used to solve such problem and suffered delays in convergence rate due to a large number of iterations needed to reach a suitable relay setting. In order to reduce the number of iterations needed for coordination process, a technique named break point to break all the loops in the system and locate the starting relays at these points is proposed. Topological methods, such as graph theory and functional dependency, are used to determine the break points [2], [3]. The drawback of these methods is that the time dial setting of the relays is relatively high. In the year 1988, Urdaneta et al. in [4] reported the coordination of DOCR using optimization theory. Recently the interest in applying artificial intelligence (AI) in optimization has grown rapidly as an Artificial Neural Network (ANN) [5], Genetic algorithm [6] and evolutionary algorithm [7] have been used in the literature to find an optimal setting of the DOC relays. In 1995, a new evolutionary computation (EC) technique named as a particle swarm optimizer (PSO) was proposed. PSO proved successful in solving a wide variety of conventional, topological and optimization problems such as ANN training [8], and function minimization [9].

III. COORDINATION PROBLEM FORMULATION

The DOCR object coordination problem can be stated as a parametric problem, where the objective functions to be minimized is the sum of the operating time of the relays connected to the system, subject to the following constraints [10][11]. A typical inverse time over current relay consists of two elements, an instantaneous unit, and a time over current unit. The over current unit has two values to be set, the pickup current value (Ip), and the time dial setting (TDS). The pickup current value is the minimum current value for which the relay operates. The time dial setting defines the operation time (T) of the device for each current value, and is normally given as a curve TVs M.where, M (i.e. The multiple of the pickup current) is the ratio of the relay fault current I, to the pickup current value, i.e. M=I/IP.
In general, over current relays respond to a characteristic function of the type,

\[ T = f(TDS, Ip, I) \] (1)

This, under simplistic assumptions, can be approximated by [12]:

\[ T = \frac{0.14 \times TDS}{(CT Ratio/IP)^{0.02} - 1} \] (2)

The calculation of the two settings, TDS and Ip, is the essence of the directional over current relay coordination study.

A. Problem Statement

The general coordination problem in Eq. (1) can be directly represented as the problem of selecting the settings (TDS, Ip) for a coordinated operation of directional over current relays. In this case, the objective function can be defined as:

\[ Z_k = (TDS, Ip, T) = \sum_{i=1}^{n} \sum_{j} W_{ijk} \cdot T_{ijk} \] (3)

Where, \( k = 1 \ldots n \),

\( T_{ijk} \): the operation time of the relay of zone j for a fault in zone k,

\( w_{ijk} \): the weight, which may depend upon the probability of a fault occurring in each zone of the protective relay.

B. Bounds on Relay Settings

The aspect of the directional over current relay coordination study is the calculation of its TDS and Ip. Thus the bounds are given by:

\[ T_{ij\text{min}} \leq T_{ij} \leq T_{ij\text{max}} \] (4)

\[ I_{p\text{ijmin}} \leq I_{p\text{ij}} \leq I_{p\text{ijmax}} \]

C. Coordination criteria

For the coordination of the protective system of predefined coordination time interval (CTI) must collapse before the backup scheme comes into an action. This CTI depends on the type of the relays, speed of the system and other parameters.

\[ T_{\text{backup}} - T_{\text{primary}} \geq \text{CTI} \]

Where,

\( T_{\text{backup}} \) operating time of the backup relay

\( T_{\text{primary}} \) operating time of the primary relay

IV. METHODOLOGIES AND ANALYSIS

A. Trial And Error Approach

Traditionally the trial and error approach were used to solve the relays coordination problem. But this method requires a large number of iterations in order to achieve the optimal relay setting and suffered a slow rate of convergence [2][13]. Due to increase in complexity of the modern interconnected system, trial and error approach is time consuming and not optimal.

B. Topological Analysis Method

A topological method includes curve fitting, graph theory and functional dependency method. The curve fitting technique: it is used to determine the fitness function to represent data [13]. Using this technique the relay characteristics are modeled mathematically by polynomial form [14][15]. The graph theory and functional dependency: to reduce the number of iterations required for relay coordination process, a technique to break all the loop is called breakpoints and locate starting relay at these points is suggested by Knable [16]. To ensure optimal coordination of the protective relay, detecting break point is significant. V.C. Prasad and L. Jenkins introduced the graph theory and functional dependency method respectively to determine the break points [17]. The solution found using topological method is the best of distinct setting considered, but not optimal because of the time dial setting (TDS) are relatively high[2][13]. Furthermore, due to the multilooped and complex structure of the system, the topological analysis method is also time consuming and not optimal.

C. Optimization Method

Optimization technique generally advantageous over conventional approach as it eliminates the need to find the minimum set of break points. Alberto J. Urdaneta [4] was the first researcher to introduce the optimization technique for coordination of directional over current relay. According to him optimization technique basically defines the coordination process as a linear-programming (LP) problem to reduce the operating time of the relays based on coordination constraints, the relay characteristics and the limits of the relay settings [4][13]. In optimization method, some researcher used non-linear programming such as mixed integer nonlinear programming (MINLP) solved by using General Algebraic Modeling System (GAMS) software for relay coordination problems. In these non-linear programming binary algorithms are used for discrete pick up current, Ip which increases the complexity and time.
To overcome such complexity in DOCR coordination, linear programming such as simplex, dual simplex and two-phase simplex methods are preferred. P.P. Bedekar in 2009 proposed the simplex, dual simplex and two-phase simplex method for DOCR coordination problem in ring fed distribution system [13]. LP techniques are simple and easily converge to the optimal solution, only the pick-up current of each relay, \( I_p \) is assumed to be known and each relay operating time is considered as the linear function of its TMS or TDS and the TMS value can only be optimized which is not the global optimal solution to the problem.

### D. Artificial Neural Network

Artificial neural network (ANN) is an artificial intelligence (AI) based optimization technique. From last two decades, much research is being done on applications of Artificial Neural Network especially in the field of pattern recognition. D. N. Vishwakarma [5] in 2001 proposed directional over current relay using ANN. ANN method overcome the conventional method as it has a non-algorithmic parallel distributed architecture for information processing and better speed of operation.

### E. Genetic Algorithm

Genetic algorithms are defined as the computerized search and optimization algorithm based on the mechanics of natural genetics and natural selection. In the middle of the 60s the professor of Holland of the university of Michigan introduces the concept of genetic algorithm [18]. With AI techniques using LP formulation, only TSM can be calculated for a given value of \( I_p \) but for both relay settings requires NLP formulation of coordination problem [18] [13]. In [18] optimal coordination of DOCR using Genetic Algorithm is being proposed. The new idea of hybrid GA-NLP for DOCR coordination was reported in [19]. The GA-NLP method improves the convergence of the GA and finding global optimal values. Results in reducing the operating time of the relay.

### F. Particle swarm optimizer

In 1995, Kennedy and Eberhart was the first researcher to introduce a technique named as a particle swarm optimizer (PSO). PSO can be defined as the global optimization method which is based on simulation of social behavior [20]. In 2007 Mohamed M. Mansour [2] proposed the modified PSO based coordination of DOCR. PSO technique has gained popularity in the power engineering field and other engineering field due to its superiority to other optimization and conventional method regarding its memory, less computational time requirements and simple mathematical operations.

## V. Conclusion

This paper gives an overview of the concept of the DOCR coordination problem, with a comprehensive survey of relevant background, practical requirements, the historical events, the present state, and techniques. PSO seems to be reliable and faster than conventional, topological and other optimization method such as LP, Genetic algorithm and ANN. The efforts being made to present Author’s work representing different techniques for DOCR coordination based on many research articles published in last 20 years.

## REFERENCES


