Optimal Overcurrent Relay coordination Using GA, FFA, CSA Techniques and Comparison

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Abstract - *The relays in the power system should be coordinated correctly so as to prevent mal-operation and therefore to avoid the unneeded outage of healthy section of the system. The overcurrent relays are usually the foremost protection product in a distribution system. Overcurrent relay is typically used as backup protection. But in a number of situations it may become the only protection supplied. Power system includes many variety of equipment. A lot more amount of circuit breakers and relays are necessary to protect the system. Optimization of over current relay settings is a major problem in protection of electrical power systems. This paper describes the Firefly algorithm for optimal time coordination of these relays. The algorithm has been implemented in MATLAB and tested on a radial system, as well as a single end fed system with a parallel feeder. The results obtained by the Firefly algorithm (FA) are compared with those obtained by the Cuckoo search Algorithm (CSA) and Genetic algorithm (GA). The novel feature of this paper is the application of the Firefly algorithm to the problem of over-current relay coordination.*

Key Words: Interconnected networks, Directional overcurrent relaying, optimal coordination, Firefly Algorithm, Cuckoo Search Algorithm, Genetic Algorithm, TMS, PS.

1. INTRODUCTION

Overcurrent relays are used as back up relays. The problem of coordinating protective relays in protection systems consists of their suitable settings such that their fundamental protective function is met under the requirements of sensitivity, selectivity, reliability, and speed. The main function of protective relays on power system is to detect and remove the faulted parts as fast and selectively as possible. Directional overcurrent relays (DOCRs) have been commonly used as an economic alternative for the protection of sub-transmission and distribution system or as a secondary protection of transmission system. DOCRs have two types of settings: pickup current setting and time multiplier setting (TMS). Basically, to determine these settings, two different approaches are used; conventional approach, and optimization techniques. The basis of the conventional protection approach is the concept of pre-determinism (i.e., analysis of all faults, abnormal operating conditions, and system contingencies are predetermined).

In optimization problem, if the objective function and all the constraints are linear function of variables, the problem is called Linear Programming Problem (LPP). In this work optimal relay coordination problem is considered as LPP and nonlinear programming problem (NLPP) both with variable Plug Setting (PS) and Time Multiplier Setting (TMS) of the relay and operating time of each relay is considered as a linear function of its TMS and as a nonlinear function of TMS and PS. The solution to this problem has been obtained using classical methods and metaheuristic algorithms. The MATLAB programs had been developed to implement the metaheuristic methods and MATLAB optimization toolbox had been used. The programs were successfully tested for various systems.

If fault occurs, relay must protect the zone under its primary protection. Only if the primary protection does not clear the fault, the back-up protection should clear the fault. The power system consists of hundreds of equipment and even more protection relays to protect the system. Each relay in the system needs to be coordinated with the relay protecting the adjacent equipment. If backup protections are not well coordinated, mal-operation can occur and, therefore, overcurrent relay coordination is a major concern of power system protection. Each protection relay in the power system needs to be coordinated with the relays protecting the adjacent equipment. The overall protection coordination is thus very complicated.

In a system where there is a source at more than one end of the line terminals, fault and load currents can flow in either direction. Relays protecting the lines are, therefore, subject to fault currents flowing in both the directions. If non–directional over-current relays were used in such system, they would have to be coordinated with, not only the relays at the remote end of the line, but also with relays behind them. Since directional relays operate only when the fault current flows in the specified tripping direction, they avoid coordination with the relays behind them.

In this paper a different approach towards the optimum solution of relay coordination is assessed. As the most important protection is provided by primary protection only, the major concentration is made on the optimization of time of operation (TOP) of the primary protecting relay. In achieving so hybridization of different algorithm with NLP is made and also the consideration on the coordination time interval (CTI) between P/B pair is secured to lowest possible values. Various three algorithms e.g. Genetic Algorithm (GA), Cuckoo Search Algorithm (CSA) and Firefly algorithm (FFA) are analyzed and finely tuned to get the optimum possible TMS and PS by themselves only.

1.1 Power System Protection

The protection is organized in a very logical fashion. The idea is to provide a ring of security around each and every element of the power system. If there is any fault within this ring, the relays associate with it must trip all the allied circuit breaker so as to remove the faulty element from the rest of the power system. This 'ring of security' is called the zone of protection.

Faults within the zone are termed internal faults whereas the faults outside the zone are called external faults. External faults are also known as through faults. Ideally, a relay looking after a protection of a zone should operate only for internal faults. It should restrain from operating for external faults. The farthest point from the relay location, which is still inside the zone, is called the reach point. The distance between the relay location and the reach point is termed as the reach of the relay.

It might be mentioned here, in passing, that though the zone of protection, as a notion, is a very clearly marked out area, in practice; it may become fuzzy and keep on expanding and contracting. How far the zone is crisply carved out depends upon the relaying principle used. In general, it can be said that the differential relaying gives a much more crisply carved out zone than over-current or distance relaying. Directional relaying creates a zone with infinite reach in the tripping direction.

2. Problem Formulation of Optimal OCRs Coordination

2.1 Objective Function formulation

OCR important variables for optimum coordination are the time setting multiplier (TSM) and the plug setting (PS). TMS determines the operating time of the relay for optimum coordination of OCRs and PS influencing the relay operation. Therefore, TMS and PS are minimized by FA to obtain the optimum coordination. The objective function shows an optimization problem, which it is obtained in eq. (1).

$$\min z = \sum_{p=1}^{m} w_i . t_{i.k} \qquad (1)$$

Where, m - number of relays,
$t_{i;k}$ - operating time of relay Ri for a fault at point k,
W_i - weight for relay operating time.

In distribution systems, equal weights (W_i=1) are assigned for operating times of all the relays as the lines are short and are of approximately equal length. The above objective function is to be minimized within the following four set of constraints.

2.2 Formulation of constraints

2.2.1. Bounds on the TMS of each relay

The TMS of relays directly influences the operating time of relays and are bound by the equation

$$TMS_{i;min} \le TMS \le TMS_{i;max} \qquad (2)$$

Where, $TMS_{i;min}$ and $TMS_{i;max}$ are minimum and maximum values of TMS of relay Ri. Typically they are 0.025 and 1.2 respectively.

2.2.2. Bounds on PS of each relays

The bounds on PS can be given as

$$PS_{i;min} \le PS \le PS_{i;max} \qquad (3)$$

Where, $PS_{i;min}$ and $PS_{i;max}$ are minimum and maximum values of PS of relay Ri. Typically they are 0.625 and 1.111 respectively.

2.2.3. Coordination time interval

The occurrence of fault must be sensed by primary as well as backup relays. However, backup relay should operate only after a certain delay known as selective time interval explained above. If R_j is any backup relay corresponding to a primary relay Ri for a fault at point k, then selective time interval constraint can be given as:

$$t_{j;k} - t_{i;k} \ge STI \qquad (4)$$

Where, $t_{j;k}$ – operating time of jth backup relay for fault in zone k, $t_{i;k}$ – operating time of ith primary relay for fault in zone k.

2.2.4. Bounds on Relay characteristics

The linear and nonlinear relay characteristics is given by the equation

$$t_{op} = 0.14 * (TMS)/PMS^{(0.02)} - 1 \qquad (5)$$

Where, t_{op} - relay operating time, Irelay - relay operating coil current, PS - plug setting. The values of and are taken for inverse definite minimum time (IDMT) relay as 0.14 and 0.02 respectively. This characteristic is incorporated in (1) to form the objective Function.

2.3 Algorithm Used

2.3.1. Genetic Algorithm

This algorithm was first presented systematically by Holland in 1960s. The basic ideas of its analysis and practices are based on biological evolution such as on the principles of natural genetics and natural selection. Basically GA imbibes

Darwin's theory of the "survival of the fittest". These genetic operators form the essential part of the genetic algorithm as a problem-solving strategy. Since then, many variants of genetic algorithms have been developed and applied to a wide range of optimization problems, from graph colouring to pattern recognition, from discrete systems to continuous systems, and from financial market to multi-objective engineering optimization. The two most noticeable advantages of genetic algorithms over traditional optimization algorithms are: the ability of dealing with complex problems and parallelism. Genetic algorithms can deal with various types of optimization whether the objective function is stationary or non-stationary, linear or nonlinear, continuous or discontinuous, or with random noise. As multiple off-springs in a population act like independent agents, the population can explore the search space in many directions simultaneously. This feature makes it ideal to parallelize the algorithms for implementation. Different parameters and even different groups of encoded strings can be manipulated at the same time.

The essence of genetic algorithms involves the encoding of an optimization function as arrays of bits or character strings to represent the chromosomes, the manipulation operations of strings by genetic operators, and the selection according to their fitness with the aim to find a solution to the problem concerned. This is often done by following procedure: -

I. Encoding of the objectives or optimization functions.

II. Defining a fitness function or selection criterion.

III. Creating a population of individuals.

IV. a) Evolution cycle or iterations by evaluating the fitness of all the individuals in the population,

b) Creating a new population by performing crossover,

c) Mutation,

d) Fitness proportionate reproduction etc, and

e) Replacing the old population and iterating again using the new population.

V. Decoding the results to obtain the solution to the problem.

2.3.2. Cuckoo Search Algorithm

Different species of the cuckoo birds follows a distinct type of progeny parasitism. Unlike other living generations they don't build their own asylum to provide the fittest safety to next generations instead they make a search of various fittest nests of other species to lay their eggs. This search of finding fittest nest for laying eggs is really magnificent as if the host birds come across the knowledge of an unfamiliar egg in their nest they either throw off alien eggs or either abandon their nest. Inspiring from this distinct formulation of the survival of the fittest, an optimization technique called cuckoo search algorithm has developed. As cuckoo species search for fittest nest out of several choices similar an optimization objective problem can be formulated to get global optimum solution within the problem boundaries and the multiple constraints set. The progeny progress showed by cuckoo species depends on some policies like a) unambiguous brood parasitism b) breed assistance c) captivating over host nests [5].

2.3.3 Firefly Algorithm

Based on the flashing patterns and the behaviour of fireflies in nature, the Firefly Algorithm (FA) was first introduced by Xin-She Yang in 2007 and 2008 at Cambridge University. According to study, nearly two thousand different types of species of firefly are observed, and they can be distinguished from each other by their specific production of rhythmic and short flashes. Point to be noticed in this phenomenon is that for a specific species of firefly generation the pattern is observed with flashes generation. The attraction of both the males and females to each other depends on several factors like i) the rhythm in which the flashes produced ii) flashing rate iii) time recorded until completion of flash pattern observation. Observing different male flash patterns Female species respond individually for further production process [5]. This newly developed nature inspired algorithm can also be implemented for relay coordination problem.

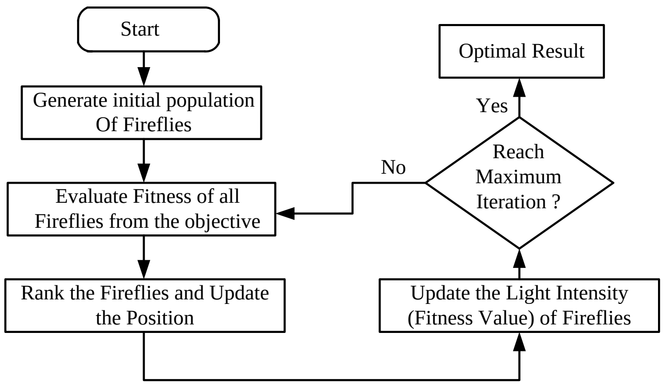

Fig.-1: Flowchart of FA

3. Simulation Results and Discussion

The entire model is implemented and simulated on Matlab/Simulink platform; version R2013a. The nature inspired meta-heuristic algorithms have been studied and are applied to the three applications of power system explained in the previous chapters which are Directional over current relay (DOCR) coordination, Dual characteristics for DOCR and DOCR–Distance relay coordination. Also, comparisons among different meta-heuristic algorithms and with classical approaches have been discussed showing the dominance of nature inspired techniques over classical methods.

3.1 TEST SYSTEM I [3]

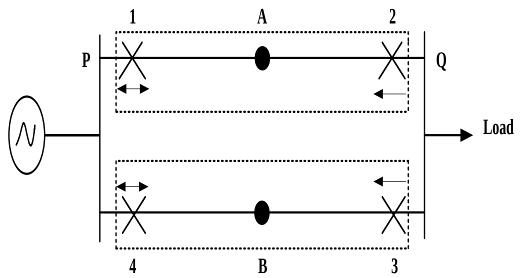

Fig.-2: Single-end-fed two bus system with parallel feeders

A two bus parallel feeder system as shown in fig.-2 with two non-directional OCRs at source end and two DOCRs at load end is tested for simple OCR coordination. The specifications for the system are referred from [11]. The above system for DOCR coordination has been tested by three methods, the results of which are detailed in table 1 as: -

TABLE-1: RESULTS FOR CASE I

S.No.	TMS/PS	GA	CSA	FA
1	TMS1	0.078	0.087	0.061
2	TMS2	0.024	0.025	0.025
3	TMS3	0.024	0.025	0.025
4	TMS4	0.077	0.085	0.056
5	PS1	1.000	0.852	0.922
6	PS2	1.000	1.059	0.842
7	PS3	1.000	0.964	0.685
8	PS4	1.000	0.907	1.109
	Total Operating Time Z(s)	1.630	1.672	1.382

3.2 TEST SYSTEM II [3]

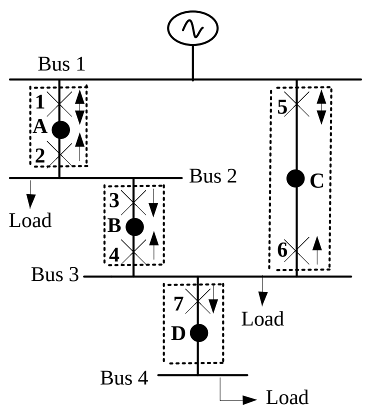

Fig.-3: Single-end-fed four bus distribution system

A single-end-fed distribution system shown in fig.-3 with seven OCRs is considered. A variety of OCRs is taken. The relay type, operating time, CT ratio and their plug settings followed by primary-back-up relationship and maximum fault current through the relays for different fault points are referred from. The above system for DOCR coordination has been tested by three methods, the results of which are detailed in table -2 as: -

TABLE-2: RESULTS FOR CASE II

S.No.	TMS/PS	GA	CSA	FA
1	TMS1	0.3280	0.129	0.083
2	TMS2	0.3500	0.155	0.198
3	TMS3	0.0319	0.990	0.027
4	TMS4	0.0277	0.025	0.025
5	TMS5	0.0250	0.025	0.025
6	PS1	1.0000	1.053	1.109
7	PS2	1.0000	1.101	0.643
8	PS3	1.0000	0.845	0.699
9	PS4	1.0000	0.725	0.651
10	PS5	1.0000	0.625	0.638
	Total Operating Time Z(s)	13.102	6.401	6.295

4. CONCLUSIONS

The problem of optimal coordination has been solved using the Firefly algorithm. The programs have been developed in MATLAB, so as to solve the problem for many numbers of relays and many numbers of primary back-up relationships. Two cases have been presented in this paper. The first case though trivial, illustrates the basics of the problem. It is also a very practical example. As the number of relays goes on increasing the highly constrained nature of the problem becomes more visible. The results obtained show that the firefly algorithm is more efficient than the other approaches. This is crucial because, as the relay operating time decreases, the damage caused by the fault can get limited. Still, different network topologies as in should be tested. Also it should be tried on the non-linear coordination problem as well, where the plug setting of the different relays can be considered as optimization variables.

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