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Protection Of Power System By Optimal Co-ordination of Directional Overcurrent Relays Using Genetic Algorithm

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ABSTRACT
In this paper, the optimization of coordination of directional overcurrent relays in an interconnected power system is presented. The objective of protective relay coordination is to achieve selectivity without sacrificing sensitivity and quick fault clearance time. A methodology is adopted for the consideration of backup relays in the optimal coordination of directional overcurrent relays. The calculation of the Time Dial Setting (*TDS*) and the pickup current (*Ip*) setting of the relays is the core of the coordination study. The objective function to be minimized is defined as the sum of the time dial settings of all the relays. The inequality constraints guarantee the coordination margin for each primary/backup relay pair having a fault very close to the primary relay. Using this formulation, the size of the optimization problem is significantly reduced. Genetic Algorithm is the algorithm being applied to minimize the operating times of the relays. Both Linear and Non Linear Equations are framed for the test bus system used and optimized using the Genetic Algorithm in this paper.

Keywords - **Directional Overcurrent Relay, Genetic Algorithm, Pickup Current, Time Dial Setting, Operating Time of Relays.**

1. INTRODUCTION

IN an interconnected power system, abnormal conditions (faults, overload, overvoltage, etc.) can frequently occur. Due to this, interruption of the supply and damage of equipments connected to the power system may occur. During these situations, 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. Therefore a reliable protective system is required. To ensure reliability, a backup protective system should exist in-case the main protective system fails (relay fault or breaker fault). This backup protection should act as a backup either in the same station or in the neighboring lines with time delay according to the selectivity requirement.
Directional over current relay(DOC) are commonly used for power system protection. Optimization method are used for coordination of these relays. In these methods, at first, the coordination constraints for each main and backup relay are determined [1]-[2]. The other optimization methods that have been used for the above problems are simplex method [3] two phase simplex method [4] and dual simplex [5].

1.1 Problems Associated With Above Techniques

A protective relay should trip for a fault in its zone and should not, for a fault outside its zone, except to backup a failed relay or circuit breaker. The problem of coordinating protective relays in electric power systems consists of selecting their suitable settings such that their fundamental protective function is met under the requirements of sensitivity, selectivity, reliability and speed.

1.2 Justification for Using Genetic Algorithms

This paper describes a systematic Overcurrent (OC) protection grading method based on GENETIC ALGORITHM (GA). Genetic Algorithms are computerized search and optimization algorithms based on the mechanics of natural genetics and natural selection. Professor Holland of University of Michigan envisaged the concept of these algorithms in the mid 60's. Thereafter a number of students and other researchers have contributed to the development of this field. Genetic Algorithms are good at taking larger, potentially huge, search space and navigating them looking for optimal combinations of things and solutions which we might not find in a life time.

1.3 Solution Approach

In [5], for Linear Programming, the values of Time Dial Setting (TDS) have been found for given values of pickup currents (Ip) and in [4], for Non-linear Programming, the values of pickup currents (Ip) have been found for given values of TDS using GA subject to the constraints and hence the operating times of the relays is minimized.

2. Optimal Coordination Problem

Directional Overcurrent Relay (DOCR) coordination problem is a parametric optimization problem, where different constraints have to be considered in solving the objective function [1]-[2]. Here the objective function to be minimized is the sum of the operating times of the relays connected to the system, subject to the following constraints.

2.1 Relay Characterstics

A typical Inverse Time Directional Over current relay consists of two elements, an instantaneous unit and a time overcurrent unit. The overcurrent unit has two values to be set: Pick up current value (I_p) and the Time Dial setting (TDS)/TMS. The pickup current value (I_p) is the minimum current value for which the relay operates[4]. The Time Dial Setting defines the operation time (T) of the device for each current value, and is normally given as a curve T vs M, where M is the ratio of relay fault current I, to the pickup current value:

$$M=I/I_p \qquad (1)$$

In general, overcurrent relays respond to a characteristic function of the type:

$$T=f(TDS, I_p, I) \qquad (2)$$

This Function can be approximated as:

$$T= \frac{K_1 * TDS}{\left\{ \frac{I * K_2}{CT\ Ratio * I_p + K_3} \right\}} \qquad (3)$$

Where K_1, K_2 and K_3 are constants that depend upon the specific device being simulated.

The following two cases have been considered in this paper for obtaining the objective function and minimizing it.

Case I

The Linear equation is formulated in terms of TDS by taking Ip to be constant at a particular value in equation (3)

Case II

The Non-Linear equation is formulated in terms of Ip by taking TDS to be constant at a particular value in equation (3).

2.2 Relay Settings

The calculation of the two settings, TDS and I_p, is the essence of the directional Overcurrent relay coordination study. It is very important to mention that in general, directional overcurrent relays allow for continuous time dial settings but discrete (rather than continuous) pickup current settings.

Therefore this constraint can be formulated as:

$$TDSi_{min} \le TDSi \le TDSi_{max}$$

$$I_{Pimin} \le I_{Pi} \le I_{Pimax}$$

2.3 Coordination Problem

In any power system, a primary protection has its own backup one for guaranteeing a dependable power system. The two protective systems (primary and back-up) should be coordinated together. Coordination time interval (CTI) is the criteria to be considered for coordination. It's a predefined coordination time interval and it depends on the type of relays. For electromagnetic relays, CTI is of the order of 0.3 to 0.4 s, while for a microprocessor based relay, it is of the order of 0.1 to 0.2 s.

To ensure reliability of the protective system, the back-up scheme shouldn't come into action unless the primary (main) fails to take the appropriate action. Only when CTI is exceeded, backup relay should come into action.

This case is expressed as:

$$T_{backup} - T_{primary} \ge CTI$$

Where, T_{backup} is the operating time of the backup relay

$T_{primary}$ is the operating time of the primary relay

After considering all these criteria, this problem can be formulated mathematically as:

$$\min \sum\nolimits^{n}_{i=1} T_i$$

Where, n represents the number of relays.

2.4 Optimization Of TDS & I_P

The objective function is found and various coordination time constraints are formulated as proposed earlier. Coordination time constraints are formulated from the relay pair tabulation.

The optimization of the functions is carried out by the GA toolbox by entering data in the appropriate fields.

The objective function and constraints for the three bus and six bus systems are formulated. The proposed methodology has been applied to a 3-bus test system. The coordination time interval of 0.2 seconds is used. The TDS values ranges from 0.1 to 1.1 and I_p from 0.1 to 1.1. The optimum TDS and I_p values are determined using Genetic Algorithm.

For Six bus systems, the P/B pairs and the fault currents for the systems are determined as per the proposed methodology. The TDS are assumed to vary between a minimum value of 0.5 to 1.1 and also I_p from 0.5 to 1.1. A CTI of 0.2 is taken, while the transient changes in the network topology are not considered. The optimum TDS and I_p values are determined using Genetic Algorithm.

3. GENETIC ALGORITHM

Genetic algorithm (GA) is a search technique used in computing, to find exact or approximate solutions to optimization and search problems. Genetic algorithms are categorized as global search heuristics [6]-[7]. Genetic algorithms are a particular class of evolutionary algorithms (EA) that use techniques inspired by evolutionary biology such as inheritance, mutation, selection, and crossover[8]-[9].

3.1 Terminologies Related To Genetic Algorithm

- Fitness Function--A fitness function is a particular type of objective function that prescribes the optimality of a solution (that is, a chromosome) in a genetic algorithm sothat particular chromosome may be ranked against all the other chromosomes.
- Chromosome-- In genetic algorithms, a chromosome is a set of parameters which define a proposed solution to the problem that the genetic algorithm is trying to solve. The chromosome is often represented as a simple string, although a wide variety of other data structures are also used.
- Selection--During each successive generation, a proportion of the existing population is selected to breed a new generation. Individual solutions are selected through a fitness-based process, where fitter solutions are typically more likely to be selected.
- Reproduction--The next step is to generate a second generation population of solutions from those selected through genetic operator crossover.

  For each new solution to be produced, a pair of "parent" solutions is selected for breeding from the pool selected previously. By producing a "child" solution using the above methods of crossover and mutation, a new solution is created which typically shares many of the characteristics of its "parents". New parents are selected for each new child, and the process continues until a new population of solutions of appropriate size is generated.
- Crossover--In genetic algorithms, crossover is genetic operator used to vary the programming of a chromosome or chromosomes from one generation to the next. It is analogous to reproduction and biological crossover, upon which genetic algorithms are based.
- Mutation--In genetic algorithms of computing, mutation is a genetic operator used to maintain genetic diversity from one generation of a population of algorithm chromosomes to the next. It is analogous to biological mutation.

3.2 Outline Of The Genetic Algorithm

It is very clear from flow chart given in Fig. 1.

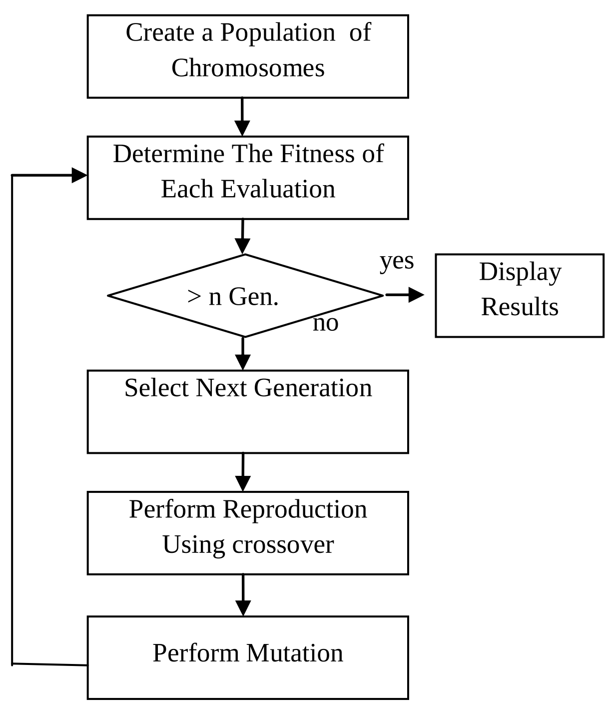

Fig. 1. Flow chart

4. PROPOSED ALGORITHM

Step 1: Generate P/B relay pairs. The knowledge of primary/backup relay pairs is essential in the formulation of the coordination constraints.

Step 2: Load flow analysis is done using Newton-Raphson method to determine line currents. This analysis can be done using any simulation softwares and here we have used ETAP simulation software .

Step 3: Short circuit analysis is done using the same simulation software to find fault currents.

Step 4: Pickup current is calculated based on the load current. Here it will be set at 1.5 times the maximum load current, for phase protection.

Step 5: Minimization of objective function is carried out and optimum values of TDS are determined using linear programming technique in MATLAB.

Step 6: The values of TDS and minimization of objective function is further optimized using Genetic Algorithm (GA) using MATLAB Toolbox.

5. SIMULATION AND RESULTS

The performance of the proposed method is evaluated by, a 3-bus overcurrent relay network shown in Fig. 2. All relays have inverse characteristic and the aim is to find an optimal setting for network relays in order to minimize the final operating time and in such a way that all constraints are satisfied. The coordination time interval (CTI) is assumed to be 0.2 seconds. In order to solve the relay coordination problem first, it needs to determine the primary and backup relay pairs.

For determining the primary and backup relay pairs, first select a relay then determine the relays which install in the far bus of the selected relay, then omitting the relay which is in the same line with selected relay. Now, it can say that the selected relays are the backup relays for the primary relay. Table I shows the primary/backup relays pairs and faults currents. The ratios of the current transformers (CTs) are indicated in Table II.

Fig. 3. shows the convergence of the proposed method and the algorithm converge to the global solution. The result of the proposed method are shown in Table III and Table IV for linear and nonlinear function respectively.

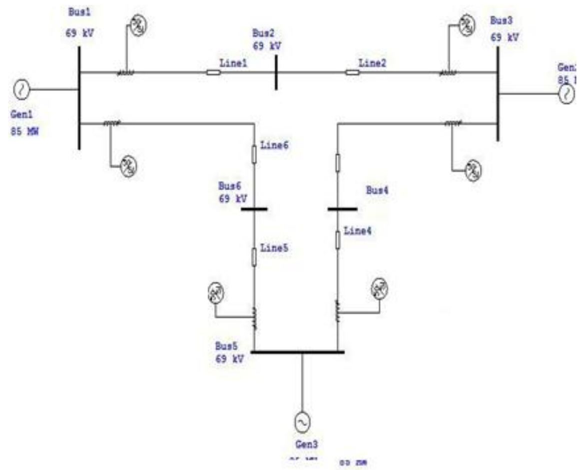

Fig. 2. Three bus system

Table I
Primary/Backup Relay Pairs And Fault Currents

Backup Relay	**Fault current (KA)**	**Primary Relay**	**Fault current (KA)**
5	1.457	1	2.673
4	0.327	2	1.666
1	0.543	3	1.666
6	0.765	4	2.673
3	1.005	5	1.325
2	0.670	6	2.469

Table II
CT Ratio

Relay no.	**CT Ratio**	**Relay no.**	**CT Ratio**
1	400/5	4	400/5
2	200/5	5	300/5
3	200/5	6	200/5

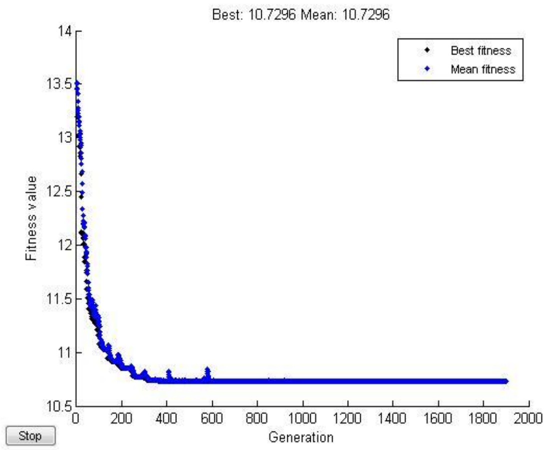

Fig. 3 Convergence of the proposed method

Table III
Result Using GA (For Linear Function)

Time dial Setting	Value Obtained
TDS_1	0.10001
TDS_2	0.18023
TDS_3	0.11908
TDS_4	0.12004
TDS_5	0.15236
TDS_6	0.1192
Fitness Function Value= 1.69083 sec	

Table IV
Result Using GA(For Nonlinear Function)

Pick up Current	Obtained Values
I_{p1}	0.2831
I_{p2}	0.60123
I_{p3}	0.10091
I_{p4}	0.42051
I_{p5}	1.0808
I_{p6}	0.5355
Fitness Function Value= 1.22844 sec	

6. Conclusion

In this paper, an optimization methodology is presented to solve the problem of coordinating directional overcurrent relays in an interconnected power system. The operating time of the relays was determined using GENETIC ALGORITHM for 3 bus system for both Linear Objective Functions and for Non Linear Objective Functions. The value of Time Dial setting (TDS) and Pick up current value (I_p) are found for linear and nonlinear function respectively in such a way that all constraints are satisfied. This method increases coordination and the operation speed of relays. Finding the absolute optimal point, the ability to be apply on large networks, the ability to consider both linear and non-linear characteristics of relays are some of advantages of the proposed method.

The dependency of GA solution on initial condition is weaker and it requires more computing time. These are the some limitations of this method.

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