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Optimal Coordination of Overcurrent Relays using Dual Simplex Method and Genetic Algorithm

Rutuja A. Darne[1], Pragati N. Korde[2],
GHRIET, Pune, India
[1]rutujadarne01@gmail.com
[2] pragati.korde@raisoni.net

Abstract: - In a power system, when the abnormal operating state occurs, protective relays are coordinated optimally to ensure that only the faulted zone of the system will be detached. The interconnected system and deregulated environment and also the increased user demand force the utilities to implement optimally coordinated protection scheme to increase reliability of the power system. In succession, procedure for computation of minimum breakpoint of relays requires systematic enumeration of all the possible simple loops in the power system. In this paper, a comprehensive comparison is made in order to find out the abilities and limitations of each random search the algorithm for solving the relay Coordination problem. The algorithms chosen for comparison are - Dual Simplex Method and Genetic Algorithm (GA). The results of the techniques, their convergence speed and reliability of techniques have been compared

Index Terms — **optimally coordinated protection; protective relays; systematic enumeration**

I. Introduction

Nowadays, the modern society is depended upon continuous and reliable availability of electricity supply and a high quality of electricity too. Applications likewise process industries; telecommunication networking and many more cannot work without a reliable source of electric power or supply. Hence, maintaining the continuous supply of electricity is necessary, if an electric supplier fails to deliver. This is where the protection of power system becomes an important issue. In any power system, the protection of the system should be designed such that protective relays isolate the faulty portion of the system as soon as possible, to prevent equipment damage, injury to operators and to ensure minimum system interference empower continuity of service to a healthy portion of the network. Overcurrent relay generally used in the protection of radial and circular power systems. These relays used for primary protection of distribution lines and secondary protection of transmission lines. In the overcurrent relays coordination problem, the aim is to find out the time setting multiplier (TSM) and plug setting multiplier (PSM) of each relay, hence all the operating time of primary relays will minimize accordingly. For optimal coordination, TSM and PSM parameter should satisfy all constraints within the shortest operation time [1]. So, the reliable protective system is required for the operation.

The primary relays, which are close to the faulty section, should act first before backup relays which are placed beside. The primary device should respond to the fault as early as possible. There is a possibility that, if the primary relays fails to operate the backup relay should respond to protect reliability. For optimal coordination of these primary and backup relays, the optimization methods are used. There are multiple methods are proposed in the past four decades for optimal coordination of the over-current relays, the relay coordination problem was defined as Mixed Integer Non-Linear Programming (MINLP) and it is solved using General Algebraic Modeling System (GAMS) software [2]. To avoid the problems of the MINLP technique, the OCR coordination problem is commonly expressed as a linear programming problem (LPP). Various LPP techniques are for over-current relay coordination.

The values of the time setting multiplier (*TSM*) are calculated using LP (simplex method) for a given value of the pick-up currents (*Ip*). In earlier day the interest in applying Artificial Intelligence in optimization has increased. Thus Genetic algorithm (GA) and Evolutionary Algorithm (EA) are used to find an optimal coordination setting of the protective relays. After that a new Evolutionary Computation (EC) technique was proposed which is known Particle Swarm Optimizer (PSO) [3].

In this paper, the comparisons of the relay coordination problem of the directional overcurrent relay using a Dual Simplex Method and Genetic Algorithm are discussed.

II. Literature review

Prashant P. Bedekar et. al. [4] Presents two phase relay coordination system to solve the problem of Overcurrent in Overcurrent relay. Using simplex method linear programming problem of ring fed distribution networks is solved. This method introduces artificial variables to calculate the basic practical solution.

Manisha Mishra et. al. [5] Proposed two algorithms to solve Overcurrent relay coordination problem viz. Dual simplex and improved harmony search. The system uses three radial networks to identify TMS. Results show that both the system gives a better solution in less time.

Prashant P. Bedekar, Sudhir Bhide, Vijay Kale [6], present dual simplex method to solve relay coordination problem. Two illustrations were present in which minimum operating time was considered as 0.2 Sec and CTI has taken as 0.57 s & 0.6s. According to relay breaking specification and condition optimal coordination obtained accurately.

Manohar Singh, et. al. [7] Proposed, an optimization methodology is given to solve the problem of coordinating directional overcurrent relays in an interconnected power system. There are some advantages of the proposed method such as the absolute optimal point, the ability to be applied to large networks, the ability to consider both linear and nonlinear characteristics of relays discovered by him.

Joymala Moirangthem et. al. [8] to solve the coordination problem, he has given an effective approach based on adaptive differential evolution (ADE) algorithm. And he has compared the results obtained by ADE with different algorithms on different model test systems and found to be robust, feasible and efficient.

Reza Mohammadi Chabanloo et.al. [9] Genetic Algorithm is applied to two different power systems. He proposed in this method, the (OF) of optimal O/C relays coordination has been totally modified by adding some new terms which give the optimal combined coordination of distance and overcurrent relays. He has discovered that in the practical power system networks this method can obtain suitable and effective solutions for optimal coordination.

Cheng-Hung Lee and Chao-Rong et. al. [10] He used, modified genetic algorithm technique to perform the IDMT (Inverse Definite Minimum Time) overcurrent relay coordination, which is applied in an industrial plant (radial power distribution system) for getting the result of the coordination comparing with the computer-aided software of traditional method.

III. Formulation of problem

Formulation of the problem

In the fact of distance relays, the best selection for local backup of the distance relays from the economical and technical point of view, the Directional Over-Current Relays (DOCRs) are the best selection, but it is also complicated to coordinate these relays together. In this case, coordination should be done in the given case:

The coordination of Directional and distance Overcurrent relays with together.

The coordination of distance relays with together.

The coordination of distance relays as main protection with Directional Overcurrent Relays as backup protection [2].

Therefore, this segment presents the relay coordination problem, and these are stated as below.

DOCR's coordination problem

A model inverse time over-current relay consists of two units: (a) Instantaneous unit and (b) Time-delay unit. There are two values to be set in the time - delay unit, the pickup current value (IP) it is the minimum current value for which the relay will operate and the Time Dial Setting (TDS). The TDS adjusts time-delay before a relay operates at any moment the fault current reaches a value equal to or greater than the (Ip). In the coordination problem of overcurrent relays, the aim is to find out the TDS and Ip of each relay, hence we can minimize the overall operating time of the primary relays. Therefore the objective function is given as follows:

$$\text{Min} \sum_{i}^{n} \text{Wi Tik} \ldots\ldots\ldots\ldots(1)$$

Where, T_{ik} gives the operation time of DOC Ri for a fault in zone K and Wi is a coefficient which is depends upon the fault occurring in each protection zone, Wi is generally set to 1.

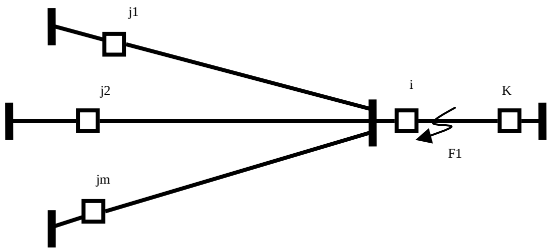

Fig.1. Primary and Backup Relays

Relay characteristics

The typical current–time characteristic of a typical overcurrent relay is shown in Fig. 2.

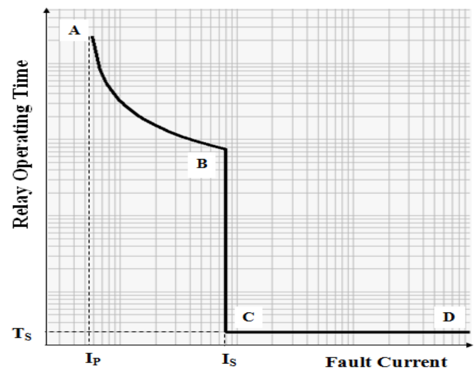

Fig.2. Current Time Characteristics of an Over-Current Relay

In Fig.2, Curve A-B is the inverse characteristic of the relay and is used to protect the equipment from excessive currents less than serious short circuit fault levels, but large enough, that if allowed to sustain for a certain period would damage the components it is meant to protect. Furthermore, Curve B-C-D is meant for instantaneous, high speed clearing of serious short circuits (>IS) by decreasing the clearing time to only Ts [2].

$$Tms = \frac{0.14 * TDSi}{\left[\frac{\text{Ii}}{\text{Ipi}}\right]^{0.02} - 1} \quad \ldots\ldots\ldots\ldots(2)$$

Where, TDSi is the time dial setting and Ipi is the pickup current setting of the i^{th} relay, the I_i is the short circuit current passing through the i^{th} relay.

Selectivity constraints for primary – backup relays:

In the selectivity constraint whenever a fault occurs, the area which is isolated by the protective relay should be as small as possible, with only the operation of the primary protection relay.

If the possibility of the failure of a protective relay is considered, the other relay must operate as backup protection. In order to fulfill the requirement of selectivity, the following constraint should be considered:

$$T_{back-up}^{F1} - T_{primary}^{F1} \leq CTI \dots\dots\dots\dots (3)$$

Or

$$T_j^{F1} - T_i^{F1} \leq CTI \dots\dots\dots\dots (4)$$

Where, T_j^{F1}, T_i^{F1} are the operating time of its primary relay ($T_{primary}^{F1}$) and j[th] backup relay ($T_{back-up}^{F1}$) respectively for the near end fault F1 as shown in figure 1.

The CTI is the amount of time allowed between a primary device and its upstream backup. CTI depends upon the speed of the circuit breaker, type of relays and the safety margin, which is normally selected between 0.2 s and 0.5 s.

Bounds on relay settings

The limits on the relay parameter can be given as follows:

$$TDS_{imin} \leq TDSI \leq TDS_{imax} \dots\dots\dots\dots (5)$$

$$\max\left(I_{load_i}^{max}, I_{p_i}^{min}\right) \leq I_{p_i} \leq \min\left(I_{fault_i}^{min}, I_{p_i}^{max}\right) \dots. (6)$$

Relays minimum pickup current setting is the maximum value between the minimum available current setting $I_{p_i}^{min}$ and maximum local current $I_{load_i}^{max}$ which passes through it. Likewise, the maximum pickup current setting is to be selected minimum value between $I_{p_i}^{max}$ on the relay and minimum fault current $I_{fault_i}^{min}$ which passes through it.

Limits on primary operation time

$$T_{imin} \leq T_i \leq T_{imax} \dots\dots\dots\dots (7)$$

This constraint inflicts constraint on each term of objective function to lie between 0.05 s and 1s.

IV Proposed coordination techniques

A. Simplex method

The simplex method given by Dantzig is a robust technique for obtaining a basic practical solution for a LPP (Linear Programming problem). When optimal solution is not obtained, then that method provides steps for finding a nearer basic practical solution that is a better solution. This process is continuously repeated till an optimum solution is found and in a finite number of steps. Because of the nature of the objective function (OF) and constraints, the simplex method can't be applied to the problem [5]. The conventional ways out of such a difficult apply the two phase simplex and big-M is also called as penalty method. But these methods require more computation time and memory. In this paper, after the formulation of the LPP, its dual is taken and then a simplex algorithm is applied to get the optimal values of the primal problem.

The primal problem to find the optimum time coordination of OCRs is of a minimization type; thus, its dual will be of a maximization type. Also, dual will have all the constraints as inequalities of the less-than or equal-to type [2]. The simplex algorithm applied to the dual to get the solution of primal is presented here.

1. Start.
2. State the time coordination problem (primal problem) of OCR.
3. Form dual of primal problem. (The objective function will be in maximization form, and the constraints will be inequalities of the greater-than or equal-to type.)
4. Convert all the constraints into equality constraints by adding non-negative (slack) variables to the left-hand side of each constraint. Assign zero-cost coefficient for these in the objective function.
5. Form the first simplex table by taking slack variables as basics and original variables as non-basics.
6. Form the cost coefficient row ($C_j - \sum c_i\, e_{ij}$)
7. In this step two possibilities can be possible
   a. As soon as all the elements in a row get negative, then the optimal solution is reached. And then go to Step 14.
   b. If at least single element in this row is positive, then further optimization is possible. Then go to step 08.

8. Identify the key column, i.e. the column having the maximum positive value in the cost coefficient row (the $C_j - \sum c_i\, e_{ij}$Row). This will decide variable that will enter as the basis in the next iteration.
9. Find out the ratio for each row.

$$Ratio = (bi)/(aij)\dots\dots\dots (8)$$

Here b_i is the RHS of the i[th] constraint in the current iteration, and a_{ij} is the entry into i[th] row corresponding to the j[th] (key) column.

10. Again two possibilities are possible in this step.

    a. If all the elements in the column are negative, then there exists an unbound solution to the problem. Go to step 15.
    b. If at least single element in the column is positive then further optimization is possible. Go to step 11.

11. Now decide the key row, i.e. row of smallest positive ratio. This will decide which variable will leave from basics in the next iteration.

12. Identify pivots element (element corresponding to the key column & the key row) and proceed for the formation of the next simplex table. The method of formation of a new simplex table is as below:

a. If a pivot element is 1, then the row remains the same in the new simplex table.
b. If the pivot element is other than 1, then total elements in key row are divided by pivot element and find out new values.
c. The new values of elements of remaining rows, for the new simplex table, can be obtained by performing the elementary row operation on all rows so that all the elements (except the pivot element) in key column are zero.

13. Go to step 06.
14. Then Print the results. (The TMS of relays appears in the cost coefficient row under the columns of slack variables with reversed sign).
15. Stop.

B. Genetic Algorithm

In 1975, John Holland invented Genetic Algorithms (GAs). He proposed GA as a heuristic method. The important features of Genetic Algorithm are (i) it is a stochastic algorithm; (ii) randomness of genetic algorithms. The genetic algorithm can compound different solutions to get better ones.

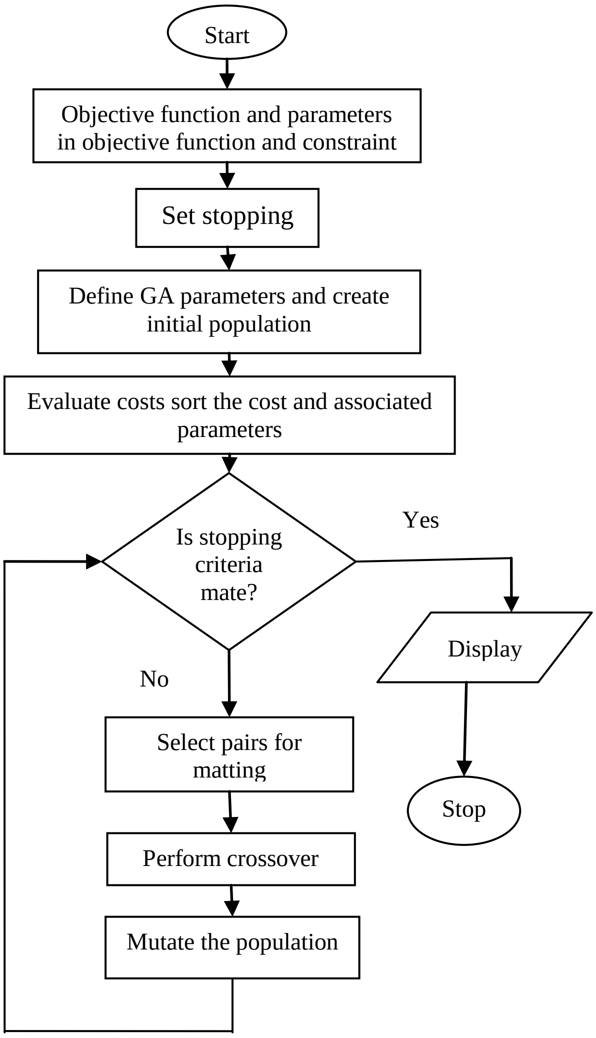

Fig.3. Flowchart of Genetic algorithm

It can be summarized briefly step-by-step as follows.

1. **Initialization:** Population is initialized randomly and set them in the search space.
2. **Evolution:** To create an offspring population apply genetic operators, as the sequence below,
   a. **Selection:** By using a random procedure, from the set of the mating pool with the same number of the population on size, e.g. The roulette wheel or tournament schemes with the assumption that each chromosome has a different chance possibility to survive. If higher the fitness value, then there is a higher the chance or possibility.
   b. **Crossover:** This operation is applied to a subset of the mating pair it includes taking chromosomes pair called the parent.
   c. **Mutation:** For the chromosomes, which are to be mutated, the values of a few positions in the string are randomly modified.
3. **Fitness Test:** In this test, evaluate the fitness value for the generated offspring population.
4. **Convergence Check:** Check for infraction of all termination criteria.

V. Result

For computer modeling MATLAB is mostly used software. A program of proposed systems, i.e. simplex based and genetic based were developed in MATLAB. This developed program is used to evaluate the TSM value of OC relay.
This program is tested on different distributed systems. Both algorithms give good result. The example for this is illustrated below:

A. Illustration 1: using the simplex method
The system to test is shown below

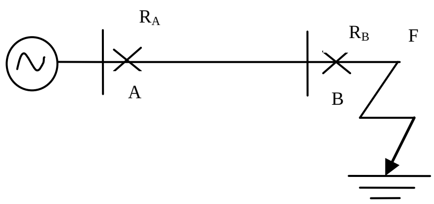

Fig.4.Radial feeder for single phase system

The initial parameter for a relays are

1. Maximum fault current for Relay A and relay B are 4000A and 3000A respectively.
2. CT ratios for ratio for RA are 300:1 and for RB is 100:1.
3. A minimum operating time for every relay is considered as 0.2 Sec and the CTI is taken as 0.57 Sec.

Considering x_1 and x_2 as a TMS of relays A & B then the problem can be stated as

$$minz = 2.63x_1 + 2x_2 \dots\dots\dots (9)$$

Subject to

$$2.97x_1 - 2x_2 \geq 0.57$$
$$2.63x_1 \geq 0.2$$
And
$$2x_2 \geq 0.2$$

Theoretically and with Matlab programming, we solve this LPP. We got two values for TMS i.e. TMS_1

=0.256 and TMS_2 = 0.1 for RA and RB respectively. Similarly for two bus systems, single end fed with parallel feeder and with four relays is shown below

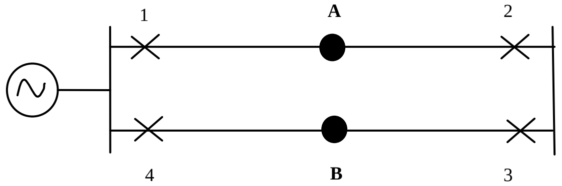

Fig.5. Radial feeder for two phase system

The initial parameter for a relays are

1. Maximum fault current for each relay is taken as 4000A.
2. CT ratios for the ratio are taken as 300:1. Relay 4 is the backup relay for fault occur at A and relay 1 is a backup relay for fault occur at B

Considering x_1, x_2, x_3 and x_4 as a TMS of relays 1, 2, 3, 4 then the problem can be stated as

$$\text{Min } z = (2.97 + 5.749)x_1 + 5.749x_2 + 5.749x_3 + (2.97 + 5.749x_4 \ldots\ldots\ldots\ (10)$$

Subject to

$$2.97x_1 \geq 0.1$$
$$5.749x_2 \geq 0.1$$
$$5.749x_3 \geq 0.1$$
$$2.97x_4 \geq 0.1$$

Theoretically and with Matlab programming, we solve this LPP. We got two values for TMS i.e.

TMS_1 = 0.077183, **TMS_2 =** 0.025,
TMS_3 = 0.025 **& TMS_4 =** 0.077183

for fault at relay 1, 2, 3, 4 respectively.

B. Illustration 2: Using genetic Algorithm

In this study, to ensure optimal performance, the parameters of GA were configured as follows:

1. **Population size**: 100
2. **Mutation rate**: 0.15
3. **Selection:** 0.5
4. **Maximum iteration**: 10
5. **Crossover**: single point
6. **Generation**: 1000

The primary purpose of this relay co-ordination problem is to find the optimal time for a tradeoff between primary and backup relay. Results obtained using above parameters is as follows

1. **Fitness value(s)** = 0.69572
2. **Main operating time (s) TMS_1**= 0.23529
3. **Backup operating time (s) TMS_2** = 0.19608

The results for two phase system with four is shown below (refer equation no. 10)

TMS_1 = 0.82353, **TMS_2** = 0.47059**,**
TMS_3 =0.078431**, TMS_4** = 0.35294

CONCLUSION

Two algorithms, i.e. simplex and genetic based method have been proposed to co-ordinate OC relay. Misoperation due to overcurrent can be reduced using by proper selection of relay pair. Good results are obtained using both simplex method and genetic algorithms. As compared to a simplex method, genetic algorithm is speedy. Moreover, the proposed Genetic algorithm minimizes the (OF) more efficiently. We successfully tested our both algorithms for single phase and two phase system. The program execution time of the simplex method and a genetic algorithm is 0.007 Sec and 1.0283 Sec respectively.

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