Optimal coordination of Overcurrent and Distance Relays by a New Particle Swarm Optimization Method

A.Akbar Motie Birjandi , Mohsen Pourfallah

***Abstract*: Nowadays, overcurrent relays play more important impression role on protection of power systems and the existence of distance relay accost of overcurrent relay causes protection increment and also complicating coordination between these relays. In recent years, intelligent optimal methods are being used more in comparison of mathematic optimal methods because of advantages -such as solving non linear problems; up speed; avoid using complicated mathematic problems, etc.**

For coordination of relays, at first, with detection of critical points, short circuit is done in those locations, then problem constraints are generated and the problem is solved by new method. In this paper, new method - named LP-PSO- has been suggested. This model is a combination of Linear Programming and Particle Swarm Optimization. The aim of LP (Linear Programming) is to decrease object function in any way that there are some constraints. Executed studies and comparison of results with other optimal method –Genetic algorithm -presents that coordination of relays has been done favorable.

***Keywords*:** Overcurrent and Distance relay, Optimal coordination, PSO algorithm, Linear programming

I. INTRODUCTION

Power systems are transferred to the continuous systems at their evolutional development. In addition to many of advantages, this kind of systems has created problems. Among this problems are protection problems. They are the complication of coordination between overcurrent and distance relays which are studied in this paper. For coordination of relays, many methods have been proposed in different papers from 1964. Applying the optimization technique was presented in setting and coordination of overcurrent relays in the year 1988[1].

Manuscript published on 30 December 2011.
* Correspondence Author (s)
Ali Akbar Motie Birjandi*, Department of Electrical and Computer Engineering, Shahid Rajaei Teacher Training University, Tehran, Iran, (motiebirjandi@srttu.edu).
Mohsen Pourfallah, Department of Electrical and Computer Engineering, Shahid Rajaei Teacher Training University, Tehran, Iran, +989122614550,(mohsen41420@yahoo.com).

Mathematic optimization methods (simplex, dual-simplex, etc) have been applied in some papers [2], [3], [4]. In the years after, evolutional algorithms like genetic algorithm and particle swarm optimization as intelligent optimization methods are used for coordination of overcurrent relays [5],[6],[7]. In this field of coordination of overcurrent and distance relays, the papers also have been presented by genetic algorithm [7]. The main purpose of this paper is to present new method for optimal coordination of overcurrent and distance relays. For the coordination problem, the main objective is to calculate the Time Setting Multiplier (TSM) and Pickup Current (Iset) in overcurrent relays, which would minimize the time of operation of the relays and each part of system is protected by a main and backup relay and no interference could occur in relays operation. Thus, the minimum time setting of overcurrent and distance relays is the main purpose of this paper in a way that they be coordinated with each other. In transmission lines, distance relay commonly is applied as a main or backup relay and overcurrent relay is applied as a backup relay. In this paper a new optimal coordination method based on PSO is introduced. It is combination of Particle Swarm Optimization (PSO) algorithm and Linear Programming (LP). In continue, both of them are presented. Then, the results are compared with the other evolutional algorithms.

In this paper, initially, LP has been used and the more perfect solutions have been send to evolutional algorithms and the results of algorithm are compared with other evolutional algorithms, then the more perfect algorithm is introduced.

II. CONSTRAINTS FOR OPTIMAL COORDINATION OF OVERCURRENT AND DISTANCE RELAYS

For coordination of relays, at first, system critical locations must be found. The critical locations are the locations at which, the discrimination time between the backup and main relays is at its minimum. Then in return for short circuit at their locations, constraints of coordination problem have been formed. In case of fault occurrence, at first, distance relay acts and in the case of not acting, line overcurrent relay will act, so in this case if not acting, backup distance relay and finally the backup overcurrent relay will act. Therefore, TSMs of all overcurrent relays and the operation time of the second zone of all distance relays must be determined for critical conditions. The critical condition is defined and shown in Fig.1. there are overcurrent relay and distance relay both at B and M. Therefore, the expressions below must be appointed at the critical fault locations, F1 and F2.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

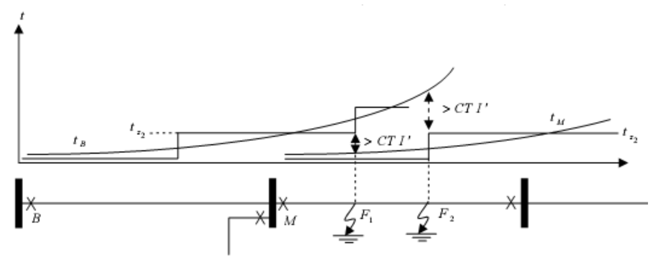

Fig.1 input variables in proposed algorithms

$$t_B(F1) - t_{z2} \geq CTI \quad (1)$$

$$t_{z2} - t_M(F2) \geq CTI \quad (2)$$

Where t_B and t_M are respectively operation time of backup and main overcurrent relay and t_{z2} is second zone of operation time of distance relay for the fault at F1and F2. CTI is the coordination time interval and it can take a value between 0.2 and 0.5 seconds. Bounds on current setting and operation time setting of relays is follows:

$$TSM_i^{min} \leq TSM_i \leq TSM_i^{max} \quad (3)$$

$$I_{set_i}^{min} \leq I_{set_i} \leq I_{set_i}^{max} \quad (4)$$

Where TSM and I_{set} are respectively time setting multiplier and pickup current setting of relays R_i. TSM can take a value between 0.1 and 1.0 as a continuous variable but I_{set} is a discontinuous variable that is limited to relay settings.

III. Object Function

For the coordination problem, the main objective is to calculate the TSM and I_{set}, which would minimize the time of operation of the relays. The coordination problem of overcurrent relays in a power system can be stated as follows:

$$object\ function = \min \sum_{i=1}^{n} w_i t_i^k \quad (5)$$

Where t_i^k indicates the operation time of relays R_i for a fault in zone k and w_i is a coefficient which indicates the probability of the occurrence of the fault on a line and is usually set to 1, thus assuming equal probability of fault occurrence on each line.

IV. Relay Characteristics

Various equals have been applied for overcurrent relays characteristics simulation. Here the overcurrent relay is conformed to the following IEC and BS characteristic. The following formula is used to approximately represent the inverse overcurrent relay characteristics.

$$t_i^k = \frac{k_1 \times TSM_i}{\left(\frac{I_i^k}{I_{set_i}}\right)^{k_2} - 1} \quad (6)$$

Where I_i^k is the short circuit current passing through the relay for a fault in zone k.

Where k_1 and k_2 are constants that depend on the relay characteristics.

Identical overcurrent relays with inverse characteristic have been used in the paper, so that k_1=0.14, k_2=0.02.

There is a distance relay on every line that is considered with Mho characteristic curve (Mho distance relay). The operation time of the second zone of the distance relays are assumed t_{z2}.

V. Combination Of LP And Pso Algorithm

Relays coordination is an optimization problem with lots of constraints and many local optimal points. In usual methods, such as LP, NLP (Non Linear Programming), IP (Integer Programming), because optimization is beginning from first point, final solution intensely is depending on that point and it may achieve a local optimal solution. PSO algorithm start searching solution from a population of primary points. Thus trapping probability of these algorithms in local optimal points is very rare. Main difficulty of PSO algorithm is achieving the time of solutions. In massive problems with many constraints maybe that necessary time to accept optimal solution becomes so much. In the proposed method to remove this quandary, all of constraints are put in LP and just convergence criteria of LP is put in PSO .

Furthermore, to constitute algorithms and LP, input values decrease and search space and achieving time to optimal solution intensely decrease.

VI. Input Variables

Evolutional algorithms input variables for relays coordination, consist of current setting and time dialing setting for all relays.(fig.1)

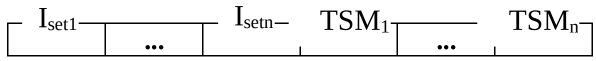

Fig.1 input variables in general algorithms

But in the proposed method, just I_{set} is input value and TSM is obtained by LP.(fig.2)

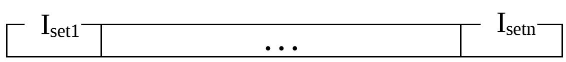

Fig.2 input variables in proposed algorithms

A network is assumed with 14 relays and it is supposed that each relay has 10 setting points for TSM and 5 setting points for I_{set}. In general method, search space equals $5^{14} \times 10^{14}$ positions. But in proposed method, search space equals 5^{14} positions. In other words search space in the proposed method decrease 10^{14} positions in regard of general method. However, in the proposed method to execute LP in each PSO iteration, execution time is farther than general method. But in the proposed method, this time increment per iteration, no matter how much it maybe, in comparison with 10^{14} is of less important.

VII. Particle Swarm Optimization

Particle swarm optimization (PSO) is one of the evolutionary computational approaches developed by Kennedy and Eberhart in 1995 [8]. PSO is initialized with a population of random solution. The individual in a population is called a particle. The position of each particle is a potential solution. The velocity of each particle represents the distance to be moved at the next step.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

The fitness of a particle is calculated by putting its position into a designated objection function. Each particle adjusts its position by considering the record of its previous best position, the information of the previous global best position, as well as its current position and current velocity.

These processes enable a PSO system to combine the local search methods with global search methods. Suppose that the searching space of a problem is a N-dimensional space. Then, the position of nth particle at iteration k is represented by a N-dimensional vector $X^k_n=(x_{n1},\ldots x_{nN})$, in addition, the nth particle's flying velocity is also a N-dimensional vector, denoted by V=(v,…v). A velocity is usually updated by the following formula:

$$v_{k+1}^i = w_k v_k^i + c_1 r_1 (p_k^i - x_k^i) + c_2 r_2 (p_k^g - x_k^i) \quad (7)$$

Where Pbest is the best position of the nth particle so far, Gbest is the best position so far by all particles in the population, w is an inertial weight, c1 and c2 are the positive constants, and r1 and r2 are the random numbers between 0 and 1. The position of each particle at the next iteration is updated according to the following equation:

$$x_{k+1}^i = x_k^i + v_{k+1}^i \quad (8)$$

Particles velocities on each dimension are limit amaximum velocity of V_{max}. If the sum of the accelera… causes the velocity on that dimension to exceed V_{max}, a parameter specified by the user, then the velocity on that dimension is set to V_{max}.

VIII. Linear Programming

This section briefly describes Linear Programming that all of the power systems can be solved by using it. maybe, Linear Programming is the most common method of programming. LP follow to reduce value of object function at the same time that there is a collection of optimal solution that object function, Eq.8, would minimize.

$$Z=c_1x_1+c_2x_2+\ldots+c_nx_n \quad (9)$$

The presented LP in this paper is upper-boundir… Linear Programming. In order to solve the problem … method, there should be added an extra variable to every constraint. Value of this variable is equal to the difference between a constraint and that upper bounding.

This variable can change an inequal constraint to equal constraint. For this reason that the extra variables have been added to all constraints, the equations have called "canonical form". There is a variable in every constraint at least and that coefficient is equal zero in other equations. These variables have called basis variables.

Solving the problem of Linear Programming algorithm is based on pivot operation, it can exchange a nonbasis variable to a basis variable. In fact, pivot operation is to get a variable in according to other variable in equation and replacing this obtained variable in other equations.

Upper-bounding dual Linear Programming approaches with simple steps. When a variation is done, in fact, a pivot operation has been executed in a suitable row and column. Nonbasis variables have been kept in upper bounding and lower bounding. While basis variables can take different values with no regard to the upper and lower bounding. The solving is finished at the time when all constraints are in acceptable range.

IX. Proposed Algorithm

Fig.3 illustrated the general algorithm for the mixed algorithms used to calculate the optimal setting of the relays. Initialize the relays current settings with random values. Now, input variables of LP are current setting (I_{set}) values. (It is obvious when I_{set} is known, relays coordination problem convert to a linear programming problem). By solving LP, the TSM for all relays is calculated and for each relay defined its fitness value using the fitness function.

Then, those strings having more cost are selected and with executing mention equations in PSO, the relay's I_{set} are changed and this rotation is repeated to achieve final solution. The stopping criterion of algorithm is not to change solution for much iteration.

With solving LP, TSM of all relays are specified in a way that operation time of each relay becomes minimum value and the constraints are satisfied. But LP probably doesn't achieve feasible solution and the whole constraints are not satisfied. Thus, such variables must not be selected at next iterations. In those matters by adding, a penalty factor to fitness value of that string in a way the qualifications are prepared so that the sting won't be selected at next iterations.

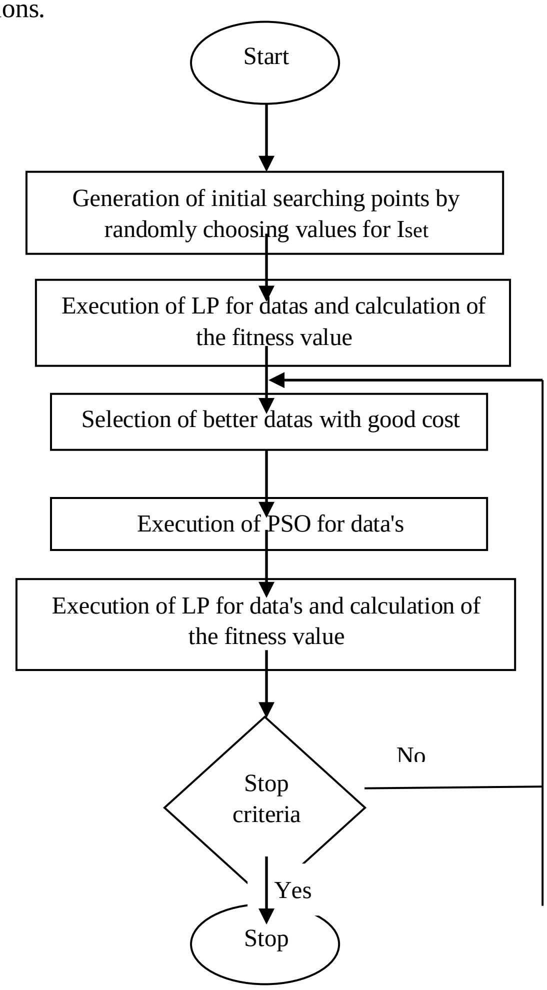

Fig.3 proposed flowchart of the algorithms

X. Numerical Results

The proposed method for solving the new problem formulated for optimal coordination of protective relays will be illustrated using

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

the 8-bus system shown in Fig. 4, which has a link to another network, modeled by a short circuit power of 400MVA.

In this network, there are 14 overcurrent relays and 14 distance relays. TSM of relays can take a value between 0.1 and 1 and current setting multiply can take a number of 0.6, 0.8, 1.0, 1.5, 2.0, 2.5.

The operation time of second zone of distance relays is selected 0.3(sec). The CT ratio of relays is given in table V. CTI value has been considered 0.3(sec) too.

There are overcurrent relay and distance relay both at the beginning and end of every line.

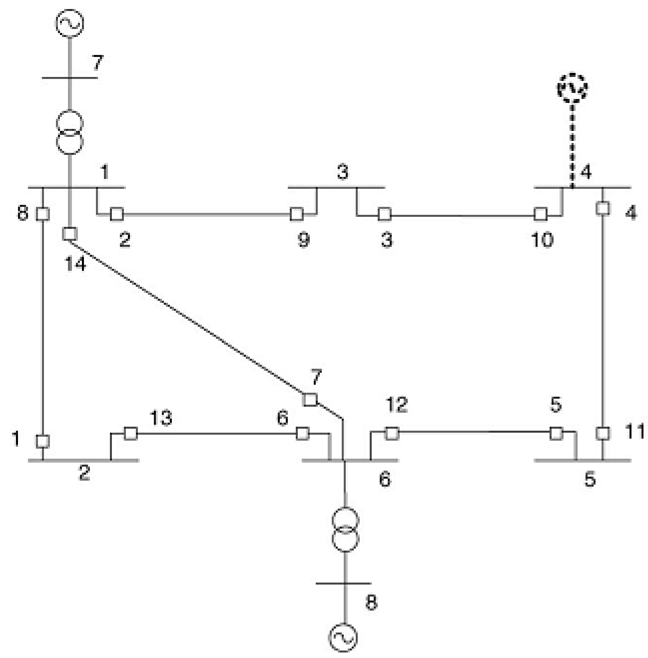

Fig.4 single line diagram of the 8-bus network

Tables' I–IV present the 8-bus system data. At bus 4, there is also a link to another network modeled by a short circuit power of 400MVA.

TABLE I
LINES CHARACTERISTIC

Nodes	R(Ω/km)	X(Ω/km)	Y(S/km)	Length(km)
1-2	0.004	0.05	0.0	100
1-3	0.0057	0.0714	0.0	70
3-4	0.005	0.0563	0.0	80
4-5	0.005	0.045	0.0	100
5-6	0.0045	0.0409	0.0	110
2-6	0.0044	0.05	0.0	90
1-6	0.005	0.05	0.0	100

TABLE II
TRANSFORMER DATA

Nodes	S_n(MVA)	V_p(kV)	V_s(kV)	X(%)
7-1	150	10	150	4
8-6	150	10	150	4

TABLE III
GENERATOR DATA

Node	S_n(MVA)	V_p(kV)	X(%)
7	150	10	15
8	150	10	15

TABLE IV
LOAD DATA

Node	P(MW)	Q(MVar)
2	40.0	20.0
3	60.0	40.0
4	70.0	40.0
5	70.0	50.0

TABLE V
CT RATIO DATA

Relay no.	CT ratio
1	240
2	240
3	160
4	240
5	240
6	240
7	160
8	240
9	160
10	240
11	240
12	240
13	240
14	160

The short circuit calculations and load propagation is coded in MATLAB. Algorithms presented in fig 3, is coded in MATLAB. Object function is assumed operation time summation of main relays for fault front of them. (eq.1)

In table VI, it's been presented the comparison between proposed and usual algorithms. In the proposed algorithm, it is obvious that the execution time and iteration numbers is lesser than usual algorithm.

TABLE VI

COMPARISON OF PROPOSED METHOD AND GENERAL METHOD

	Execution time	Iteration number
Proposed method	8 minutes	30
General method	3 hours	30000

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-1 Issue-2, December 2011

Simulation results are given in table VII. Table VII presents the numerical value for the TSM and pickup current settings obtained for both the mixed PSO and GA. As for the mixed PSO, the results obtained are close to optimal as compared with the results of the GA. The results in this section prove that the mixed PSO is working properly and is capable of finding a close optimal solution for this network in comparison with GA.

By applying the hybrid PSO, discrimination time between the main distance and backup overcurrent relays are obtained. These $\Delta t_{mbDISOC}$ values are given in Table VIII.

TABLE VII
OPTIMAL SETTINGS OF THE RELAYS

Relay no.	TSM (LP-PSO)		GA	
	I_{set}	TSM	I_{set}	TSM
1	480	0.1342	600	0.1517
2	480	0.1489	640	0.1648
3	500	0.2100	300	0.2019
4	800	0.1629	640	0.1886
5	600	0.1000	600	0.1000
6	400	0.2000	400	0.2585
7	600	0.2210	600	0.2702
8	500	0.2011	400	0.2639
9	480	0.1090	800	0.1000
10	500	0.1100	400	0.1000
11	600	0.2500	300	0.2456
12	500	0.1750	400	0.1759
13	600	0.1695	600	0.1738
14	800	0.2190	800	0.2433
Objective Function	17.9 (sec)		19.8 (sec)	

$\Delta t_{mbDISOC}$ is the discrimination time between the main distance and backup overcurrent relays which is obtained from the equation below:

$$\Delta t_{mbDISOC} = t_{bOC} - t_{mDIS} - CTI$$

Where t_{bOC} is the operation time of backup overcurrent relay for the fault at the end of the first zone of main distance relay (critical fault locations), t_{mDIS} is the operation time of the second zone of main distance relay.

TABLE VIII
OPTIMAL SETTINGS OF THE RELAYS

Main Relay No.	Backup Relay No.	$\Delta t_{mbDISCO}$
14	1	0.0400
3	2	0.2613
4	3	0.0015
5	4	0.0400
1	6	0.2109
2	7	0.1691
8	7	0.0024
13	8	0.0523
9	10	0.0400
10	11	0.0171
11	12	0.2024
7	13	0.0400
6	14	0.0400
12	14	0.2201
2	1	0.0310
12	13	0.0201

All $\Delta t_{mbDISOC}$ values are positive and most of them are small. That means, the relay settings are accurate, fit and have not any miscoordination.

XI. CONCLUSION

A new problem formulation was presented in this paper for the optimal coordination of distance and overcurrent relays.

In this paper to solve the problem, PSO algorithm has been deployed with combination of linear programming (LP). Applying of this method decrease search space and increase PSO efficient. In the proposed method other number of constraints can be added to coordination problem because of search space decrement. All discrimination time values of between the main distance and backup overcurrent relays are positive and have not any miscoordination. In this paper, both of mixed PSO and Genetic algorithm are compared with each other.

The mixed PSO succeeded in finding a close to optimal solution for the coordination problem as compared with the mixed GA. For a greater problem, the mixed PSO was capable of finding a much better solution than mixed GA.

ACKNOWLEDGMENT

This research is supported by the Faculty of Electrical and Computer Engineering in Shahid Rajaee Teacher Training University (SRTTU), Tehran,Iran.

REFERENCES

1. A.J. Urdaneta, R. Nadira and L.G.Perez , "Optimal coordination of directional overcurrent relays in interconnected power systems," IEEE Trans. Power Deliv. Vol.3 pp.903-911, 1988.
2. A.J. Urdaneta, H. Restrepo, S.Marquez and J. Sanchez, "Coordination of directional overcurrent relay timing using linear Programming," IEEE Trans. Power Deliver. vol.1, pp.122–129, 1996.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

3. B. Chattopadhyay, M.S. Sachdev and T.S. Sidhu, "An online relay coordination algorithm for adaptive protection using linear programming technique," IEEE Trans. Power Deliv. vol.11, pp. 165–173, 1996.
4. A.J. Urdaneta and L.G. Perez, "Presolve analysis and interior point solution of the linear programming coordination problem of directional overcurrent relays," Electric Power and Energy Systems vol.23, pp. 819-825, 2000.
5. C.W. So and K.K. Li, "Overcurrent relay coordination by evolutionary programming", Electric Power Systems Research, vol.53, pp.83–90.
6. C.W. So, K.K. Li, K.T. Lai and K.Y. Fung, "Application of genetic algorithm for overcurrent relay coordination", IEE 6th International Conference on Developments in Power System Protection , Nottingham , UK, pp. 66–69, March 1997.
7. H.H. Zeineldin, E.F. El-Saadany and M.M.A. Salama, "Optimal coordination of overcurrent relays using a modified particle swarm optimization",Electric Power Systems Research76, pp.988–995, 2006.
8. J.Kennedy, R.Eberhart, "*Particle swarm optimization*", Proc. IEEE Int. Conf, 1995.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)