The Journal of CPRI,
Vol. 11, No. 2, June 2015 pp. 287-296

Intelligent distance to over current relay coordination in sub-transmission networks

Manohar Singh*, Manikya Sastry** and Lalitha SVNL***

Sub-transmission power networks are primarily protected by distance relays and over current relays are used as backup relay due to their poor operational speed. Coordination of distance to over current relays is achieved in this research paper by optimally selecting the over current relay parameters which constitutes relay time-inverse characteristics and relay parameters and zone-2 setting of distance relays. Solving such type of combine distance to over current relay coordination problems is tedious job using the conventional optimization methods. Therefore an evolutionally based optimization techniques is applied in this research paper which selects the optimal over current relay parameters, user defined time inverse relay characteristics and zone-2 settings of the distance relays

Keywords: *Relay coordination, distance relay, over current relay, sub transmission system, differential evolution*

1.0 INTRODUCTION

At the sub transmission level power networks, where fast clearances of faults are prime requirement of protection coordination schemes. In such application over current relays are not suitable as primary protective relays due to their sluggish inherent operating time response [1]. Distance relays are fast in operation and are more suitable for primary protection schemes in the sub transmission level power networks. However, backup protection is provided from the over current relays in these power networks [2]. Three zones characteristics of distance relay are coordinated with inverse time characteristics of over current relays. Coordination among the distance and over current relay is achieved by formulating the relay coordination problem as optimization problem which is solved with the help of a solver. Optimal selection of Time Dial Setting (TDS), Plug Setting (PS) of time-inverse over current relays in the over current relays and zone-2 settings of distance relays makes the over current relay coordination problem a nonlinear optimization problem [3]. Application of linear programming techniques fails to solve such type of optimization problems. Uses of nonlinear based optimization techniques based on mixed integer nonlinear programming are reported in the literature [4]. In these techniques sequential quadratic programming and random search technique, gradient based solvers are used [5]. In the recent past, the applications of fast mathematical computational algorithm which are based on heuristic methods are reported in the literature [6-7]. They are broadly classified as evolution based and swam based. Differential evolution is one of evolution based optimization algorithm which solves the highly non-linear combine distance to over current relay coordination problem efficiently [8-9]. In other literature papers, the application of swam based optimization algorithm such as particle swam optimization [10], artificial bee colony, honey bee

*Engineering officer, PSD, CPRI, Bangalore - 560 080, India. Mobile : 9632940855, E-mail: manoharsingh@cpri.in
**M Tech student, Electrical Department, KL University, Andhra Pradesh - 522 502, India. E-mail: manikyasastry@gmail.com
***Professor, Electrical Department, KL University, Andhra Pradesh - 522 502, India. E-mail: lalitha@kluniversity.in

algorithm and teaching learning algorithms [11] are also reported.

This paper describes a new problem formulation technique for combine distance to over current relay coordination in which the user defined time-inverse over current relay characterizes are utilized [12]. In addition to optimal selection of over current relay parameter, optimal zone-2 setting of distance relays also achieved in this paper. This research paper is organized in four sections. In section-1.0, introduction in the area of distance to over current relaycoordination is discussed. Section-2.0, disused the combine distance to over current relay coordination problem formulation technique. A brief review on the DE algorithm is presented in the section-3.0. Implementation of scheme in section-4.0, Result and discussion in section-5.0 and conclusions are given in the section-6.0 of this paper.

2.0 PROBLEM FORMULATION

In relay coordination problems, the main objective is to minimize the summation of operating time of all primary over current relays under the selectivity constraints.

The objective function is defined in Eq. (1) as the sum of operating time of all primary over current relays

$$F = M \sum_{i=1}^{NR} t_i \quad ....(1)$$

$$t_i = \frac{TDS x \alpha}{M^{\beta} - 1} \quad ....(2)$$

Where

α=0.14

β=0.02

are relay parameters as per IEC standard inverse relay characteristics.

$$M = \left(\frac{I_f}{CTR * I_p}\right)^{x} \quad ....(3)$$

I_f = Fault current I_p = Pickup settings

In combine distance to over current relay coordination studies it is essential to find the critical fault locations. For coordination of over current to over current relay and over current to distance relay, five different critical fault locations. At these critical fault location discrimination time gap between main and backup is minimum and chance of occurrence of mal-operation among the over current relays is high if the relays were not properly coordinated at these critical points

In Figure 1, these points are marked as F_1 and F_2 for over current to over current relay coordination for near and far ends faults respectively. In case of near end and far end faults at F_1 and F_2, the over current main relay at Bus M and it should operate earlier than the backup over current relay located at bus B and corresponding selectivity constraints are as under in Eq.(4) and Eq.(5)

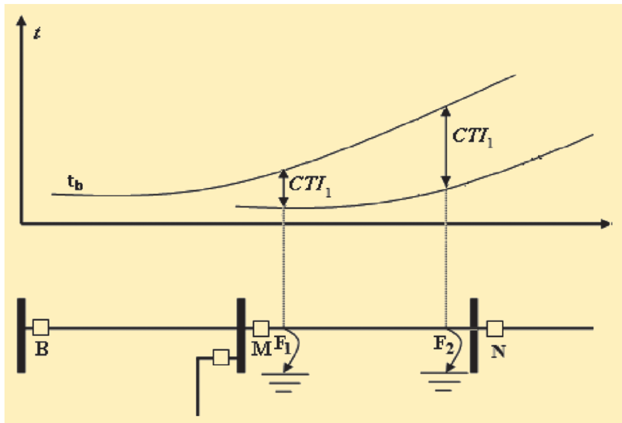

FIG. 1 NEAR AND FAR END FAULTS

$$T_b(F1) - T_m(F1) \geq CTI \quad ....(4)$$

$$T_b(F2) - T_m(F2) \geq CTI \quad ....(5)$$

Where T_b represents operating time of backup relay and Tm represents operating time of main relay. CTI is abbreviated as coordination time interval is the minimum time gap to be maintained between main and backup relay operation in order to avoid mal-operation and is usually taken in between 0.2-0.5 s. In addition to F_1 and F_2 critical fault points, three more critical fault locations are identified for combine distance to over current relay coordination studies. Thesepoints are F_3, F_4 and F_5 as shown in Figure 2 The critical point F_3 is identified as the start of zone-1 of main distance relay and F_4 is marked at end of zone-1 of main distance relay. F_5 is marked a end of zone-2 of main distance relay. For fault in the zone 1 of main distance relay ant Bus M should first than its back over current relay at Bus B for fault near to F_3. Similarly for fault near to F_4, the main distance relay should operate from its zone-2 as main relays and is backed by over current from Bus B. The corresponding selectivity constraints Equation for F_3 and F_4 are given in Eq.(6) and Eq.(7) respectively below

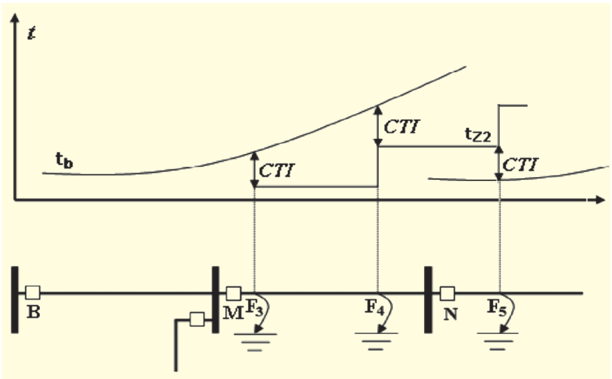

FIG. 2 CRITICAL POINT FOR DISTANCE-OVER CURRENT RELAY COORDINATION

$$T_b(F3) - T_{z1} \geq CTI \quad ....(6)$$

$$T_b(F4) - T_{z2} \geq CTI \quad ....(7)$$

Where, T_{z1}, T_{z2} represents the time of operation of distance relay zone-1 and zone-2 respectively. The $T_{z1}$is instantaneous operating time of zone-1 of distance relays and its value is consider as 0.01 in this research work and while T_{z2} is zone-2 operating time of distance relays and its value is consider as 0.2 to 0.6 during optimization of zone-2 of distance relays. In some industrial systems, the over current relays on the main distance relay bus is set in such a way that it should operate before the zone-2 of main distance relays as per the Eq.(8) below.

$$T_{z2} - T_m(F5) \geq CTI \quad ....(8)$$

3.0 DIFFERENTIAL-EVOLUTIONARY ALGORITHM

Differential Evolutionary algorithm is introduced by Storn and Price [13]. It is simple and efficient with less parameter to tune. Flow diagram of DE is shown in Figure 3 and its brief description is as follows

3.1 Initialization

In this Step population is uniformly randomized from *NP* individuals within a *D*-dimensional real parameter search space. And the initial population covers the entire search space with the prescribed constrained minimum and maximum bounds

$$X_{(i)}^{g} = \{x_{(i,1)}^{g}, x_{(i,2)}^{g} \dots\dots\dots\dots x_{(i,D)}^{g}\} \quad ....(9)$$

g = 1, 2, ..., G and i = 1,2, ... , N,

where G is the maximum number of generations, N is the population size and D is the dimension of the problem For initial generation j[th] element in the i[th] vector is initialized randomly as follows

$$x_{(i,j)}^{1} = x_j^{min} + rand_{(i,j)} * (x_j^{max} - x_j^{min}) \quad ....(10)$$

3.2 Mutation

Mutate vector also called donor vector, is obtained through the differential mutation operation with each individual, known as target vector, in the present population. For each target vector from the current population, the donor vector is created with certain mutation technique.

$$V_{(i)}^{g} = \{v_{(i,1)}^{g}, v_{(i,2)}^{g} \dots\dots\dots\dots v_{(i,d)}^{g}\} \quad ....(11)$$

Many mutation methods were in practice. One of the simplest and popular mutation method scan be given as

$$V_{(i)}^{g} = X_{(\beta)}^{g} + F \times (X_{(\gamma)}^{g} - X_{(\delta)}^{g}) \quad ....(12)$$

Where β, γ and δare mutually exclusive integers randomly generated in given range [1, NP], which are different from the base vector index . These β, γ and δ indices are randomly generated for each mutant vector. The difference of any two of these three vectors is scaled by a mutation weighting factor F.

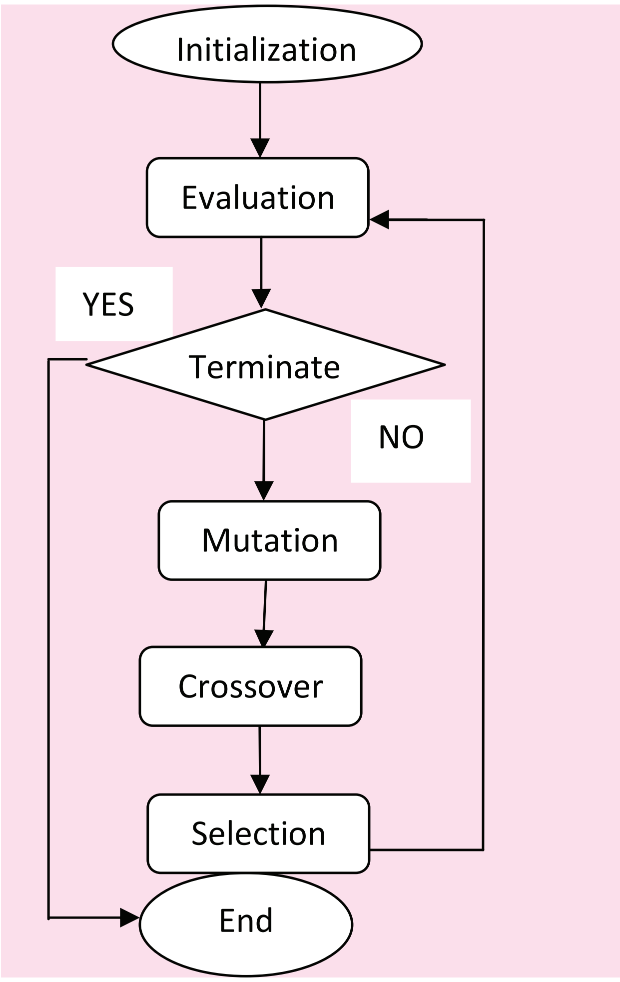

FIG. 3 FLOW CHART OF DE ALGORITHM

3.3 Cross Over

After mutation step , for each target vector and corresponding donor vector , a trail vector is produced by performing crossoveroperation. Then Trail vector is

obtained by carrying out Binomial crossover operation and is shown below

$$u^g_{(i,j)} = \{v^g_{(i,j)} \text{if} rand_{(i,j)} CR \text{ or } \mathrm{j} = \mathrm{jrand} \quad x^g_{(i,j)} \; otherwise\} \quad ....(13)$$

where CR is the crossover rate and is in the range [0 1] defined by the user and restrains the feasibility of parameter values hired from donor vector, j_{rand} is randomly selected integer from[1, NP]

3.4 Selection

The fitness function value is evaluated on every trail and is compared with that of its corresponding target vector in the current population. For minimization problem, if the fitness value of trial vector is less that of target vector, the target vector will be replaced by the trial vector in the population of the next generation. Else the target vector will be maintained in the population of the next generation. Thus selection operation is given as follows

$$X_i^{g+1} = \{u_i^g \; if \;\; f(u_i^g) \le f(x_i^g) \quad x_i^g \;\; otherwise\,\} \quad ....(14)$$

4.0 IMPLEMENTENTATION OF PROPOSED SCHEME

4.1 Network details

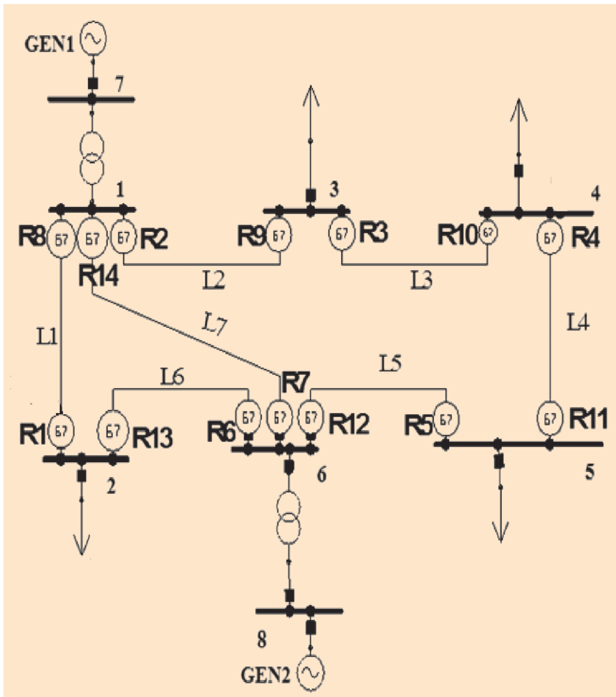

FIG. 4 SINGLE LINE DIAGRAM OF 8 BUS SYSTEM

A 8 bus test distribution system is considered for implementation of proposed combined distance to over current rely coordination. This test distribution system has seven branches, 14 over current relays, 14 distance relays. Generators parameters, line parameters and transformer details are given in reference [13-14].

4.2 Result and discussions

The proposed non-linear relay optimal coordination problem is optimized using proposed DE optimization algorithm. The proposed relay coordination problem is optimized for two cases as under:

Case-1: Coordination of standard time-inverse over current relay with distance

In this all the over current relay are assumed as standard time-inverse in nature. Their TDS and PS are optimized in which a way so that desired coordination time interval is maintained with respect to distance relays all five critical fault locations discussed in section-2 of this paper. In Table 2, operating time of primary and backup over current relay along with coordination time interval for all five critical points are mentioned. In Table 2, all the CTI are more than 0.2 which signifies that there is proper coordination among the over current and distance relays at all five critical fault locations. Optimized TDS, PS for over current relays and zone-2 settings for the main distance relays are mentioned. The minimized value of the objective function is also mentioned in the last row of Table 1 (Figure 5 & 6).

Case-2: Coordination of over current relay and distance relay with proposed technique.

In this case, coordination of over current and distance relay is carried out by assuming over current relay characteristic constants alpha, beta as optimizing variables along with TDS, PS. In Table 4, operating time of primary and backup over current relays along with coordination time interval for all five critical points are mentioned. In Table 4, all the CTI are more than 0.2 which signifies that there is proper coordination among the over current and distance relays at all five critical fault locations. Optimized TDS, PS α, β for over current relays and zone-2 settings for the main distance relays with proposed method are listed. The minimized value of the objective function is also mentioned in the last row of Table 3 below. Using the user defined over current relay characteristics the objective function reduces from 9.10 to 5.88

TABLE 1

OPTIMIZED SETTINGS TDS, PS, TZ2 STANDARD INVERSE TIME CHARACTERISTICS

Relay	TDS	PS	T_{z2}	F1CP
R1	0.18	1.77	0.32	0.53
R2	0.22	2.49	0.37	0.68
R3	0.19	2.50	0.21	0.66
R4	0.23	1.00	0.42	0.82
R5	0.24	0.83	0.32	0.89
R6	0.21	2.50	0.90	0.55
R7	0.36	0.50	0.37	0.64
R8	0.19	2.49	0.89	0.51
R9	0.21	1.08	0.58	0.72
R10	0.20	1.70	0.75	0.60
R11	0.19	2.50	0.64	0.66
R12	0.25	2.50	0.68	0.72
R13	0.15	1.54	0.88	0.50
R14	0.28	0.78	0.54	0.62
F	9.10			

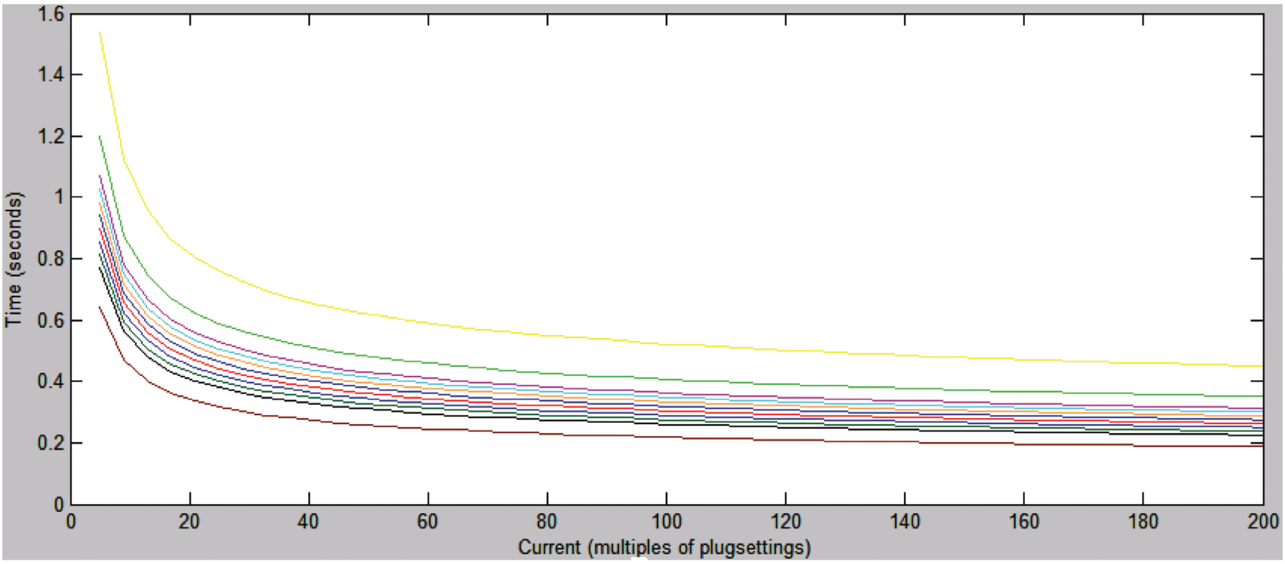

FIG. 5 OVERCURRENT RELAY CHARACTERISTICS OF 14 RELAYS STANDARD INVERSE CHARACTERISTICS

TABLE 2

OPERATING TIME OF MAIN, BACKUP RELAYS AND CORRESPONDING COORDINATION TIME MARGIN FOR CRITICAL FAULTS WITH STANDARD INVERSE OVER CURRENT CHARACTERISTICS

Main	Back up	Near end Fault F1			Far end Fault F2			Fault at F3		Fault at F4	
		T_p (F1)	T_b (F1)	EV1	T_p (F2)	T_b (F2)	EV2	T_b (F3)	EV3	T_b (F4)	EV4
R1	R6	0.53	0.73	0.20	1.06	1.77	0.70	0.73	0.53	1.23	0.91
R2	R1	0.68	1.09	0.41	0.85	3.35	2.49	1.09	0.89	2.32	1.95
R2	R7	0.68	0.88	0.20	0.85	1.23	0.38	0.88	0.68	1.13	0.76
R3	R2	0.66	0.86	0.20	1.01	1.41	0.40	0.86	0.66	1.25	1.04
R4	R3	0.82	1.02	0.20	1.08	1.61	0.53	1.02	0.82	1.42	1.00
R5	R4	0.89	1.09	0.20	2.24	4.73	2.49	1.09	0.89	2.23	1.92
R6	R5	0.55	2.37	1.81	0.73	0.93	0.20	2.37	2.17	3.37	2.47
R6	R14	0.55	0.92	0.36	0.73	1.27	0.54	0.92	0.72	3.39	2.49
R7	R5	0.64	2.40	1.75	0.87	2.40	1.52	2.40	2.20	2.56	2.20
R7	R13	0.64	1.07	0.43	0.87	1.07	0.20	1.07	0.87	2.28	1.91
R8	R7	0.51	0.88	0.37	0.69	1.14	0.45	0.88	0.68	3.04	2.15
R8	R9	0.51	1.95	1.45	0.69	0.89	0.20	1.95	1.75	3.38	2.49
R9	R10	0.72	0.92	0.20	1.85	4.28	2.44	0.92	0.72	1.91	1.32
R10	R11	0.60	0.80	0.20	0.91	1.53	0.62	0.80	0.60	1.25	0.50
R11	R12	0.66	0.86	0.20	0.80	1.04	0.24	0.86	0.66	1.00	0.37
R12	R13	0.72	1.06	0.34	0.86	3.36	2.50	1.06	0.86	2.31	1.63
R12	R14	0.72	0.92	0.20	0.86	1.36	0.51	0.92	0.72	1.34	0.66
R13	R8	0.50	0.70	0.20	1.03	1.62	0.59	0.70	0.50	1.16	0.28
R14	R1	0.62	1.11	0.49	0.91	1.11	0.20	1.11	0.91	2.05	1.51
R14	R9	0.62	1.98	1.36	0.91	1.98	1.07	1.98	1.78	2.33	1.79

TABLE 3						
OPTIMIZED SETTINGS TDS, PS, T_{Z2}, A, B WITH USER DEFINED CHARACTERISTICS						
Relay	**TDS**	**PS**	**α**	**β**	**T_{z2}**	**T_p**
R1	1.78	0.76	2.82	0.90	0.44	0.31
R2	0.83	0.70	13.50	0.99	0.54	0.39
R3	1.13	0.60	8.32	0.94	0.20	0.41
R4	1.74	0.57	2.31	0.83	0.69	0.57
R5	0.42	0.55	4.55	0.58	0.71	0.69
R6	1.79	0.53	7.70	0.94	0.80	0.29
R7	0.10	0.51	7.84	0.29	0.83	0.40
R8	2.04	0.54	7.23	0.99	0.86	0.25
R9	1.06	0.53	3.03	0.74	0.90	0.51
R10	0.80	0.92	5.54	0.89	0.68	0.35
R11	1.91	2.45	1.36	1.00	0.25	0.40
R12	1.23	0.84	5.95	0.75	0.22	0.59
R13	0.95	0.52	6.71	1.00	0.22	0.28
R14	0.52	0.51	3.63	0.48	0.31	0.43
F	5.88					

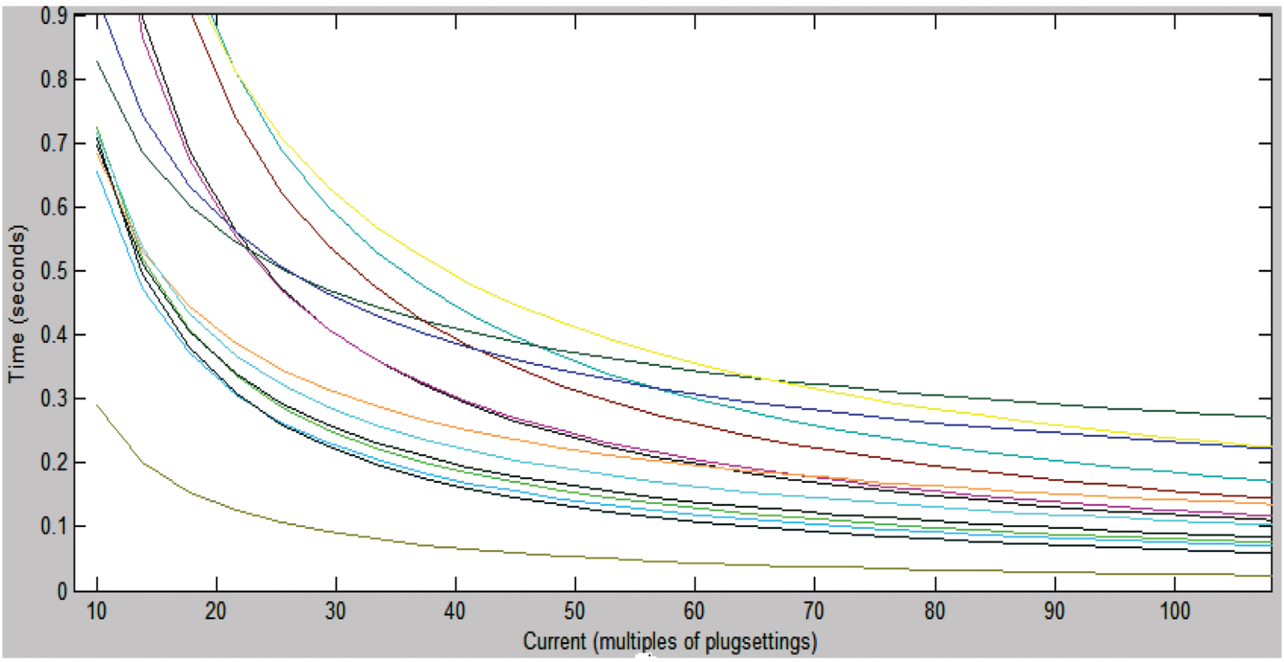

FIG. 6 OVERCURRENT RELAY CHARACTERISTICS OF 14 RELAYS WITH USER DEFINED CHARACTERISTICS

TABLE 4

OPERATING TIME OF MAIN ,BACKUP RELAYS AND CORRESPONDING COORDINATION TIME MARGIN FOR CRITICAL FAULTS WITH PROPOSED TECHNIQUE

Main	Back up	Near end Fault F1			Far end Fault F2			Fault at F3		Fault at F4	
		T_p (F1)	T_b (F1)	EV1	T_p (F2)	T_b (F2)	EV2	T_b (F3)	EV3	T_b (F4)	EV4
R1	R6	0.31	0.52	0.21	0.98	1.65	0.67	0.52	0.32	1.15	0.71
R2	R1	0.39	1.02	0.63	0.60	2.53	1.92	1.02	0.82	2.04	1.50
R2	R7	0.39	0.64	0.26	0.60	1.01	0.41	0.64	0.44	0.91	0.37
R3	R2	0.41	0.61	0.20	0.80	1.25	0.45	0.61	0.41	1.07	0.87
R4	R3	0.57	0.81	0.24	0.89	1.30	0.41	0.81	0.61	1.16	0.47
R5	R4	0.69	0.90	0.21	2.00	3.57	1.57	0.90	0.70	2.09	1.38
R6	R5	0.29	2.10	1.81	0.52	0.73	0.22	2.10	1.90	2.77	1.97
R6	R14	0.29	0.81	0.52	0.52	1.22	0.71	0.81	0.61	3.07	2.27
R7	R5	0.40	2.12	1.72	0.64	2.12	1.49	2.12	1.92	2.25	1.41
R7	R13	0.40	0.94	0.54	0.64	0.94	0.30	0.94	0.74	1.74	0.91
R8	R7	0.25	0.65	0.39	0.50	0.91	0.41	0.65	0.45	2.99	2.13
R8	R9	0.25	1.68	1.42	0.50	0.71	0.20	1.68	1.48	2.44	1.58
R9	R10	0.51	0.78	0.27	1.60	3.36	1.76	0.78	0.58	1.89	0.99
R10	R11	0.35	0.61	0.26	0.76	1.81	1.05	0.61	0.41	1.34	0.65
R11	R12	0.40	0.82	0.41	0.60	1.08	0.48	0.82	0.62	1.02	0.77
R12	R13	0.59	0.93	0.34	0.81	2.11	1.30	0.93	0.73	1.76	1.53
R12	R14	0.59	0.80	0.21	0.81	1.33	0.52	0.80	0.60	1.30	1.08
R13	R8	0.28	0.51	0.23	0.90	1.59	0.69	0.51	0.31	1.11	0.90
R14	R1	0.43	1.03	0.60	0.79	1.03	0.24	1.03	0.83	1.87	1.56
R14	R9	0.43	1.69	1.26	0.79	1.69	0.90	1.69	1.49	1.92	1.61

From Table 1 (with Standard time-inverse relay characteristics) and Table 3 (with proposed user defined time-inverse relay characteristics) we have seen that the overall operating time of 14 over current relays reduces to very small and zone-2 setting of main distance relay are optimized between 0.2 to 0.6 under desired value of the coordination time interval at all five critical fault points.

5.0 CONCLUSIONS

The proposed combine relay coordination method gives faster operation of backup over current relays by better minimized value of the fitness function. This is achieved by utilizing the user defined time-inverse over current relay characteristics of backup over current relays and variable zone-2 settings of the main distance relays. Proposed differential based optimization algorithm help in solving the non-linear combine distance to over current relay coordination in this research paper successfully.

REFERENCES

[1] L G Perez, A J Urdaneta, "Optimal coordination of directional over current relays considering definite time backup relaying", IEEE Transactions on Power Delivery, Vol. 14, pp. 1276-1284, 1999

[2] A J Urdaneta, Nadira Ramon and Luisjimnez, “Optimal coordination of directional relaysin inter-connected power system”, IEEE Transactions. on Power Delivery, Vol. 3, pp. 903-911, July 1988.

[3] T S Sidhu, D S Baltazar, R M Palomino, M S Sachdev, "A new approach for calculating zone-2 setting of distance relays and its use in an adaptive protection system", IEEE Transactions on Power Delivery, Vol. 19, pp. 70-77, 2004.

[4] D Birla, R P Maheshwari & Gupta, "A new nonlinear directional over current relay coordination technique, and banes and boons of near-end faults based approach.", IEEE Transactions. on Power Delivery, Vol. 21, pp. 1176-1182, June 2006.

[5] V R Pandi, Widong Xiao, Zeineldin "Determining Optimal Location and Size of Distributed Generation Resources Considering Harmonic and Protection Coordination Limits", IEEE Transactions on Power Systems Vol. 28, pp. 1245 - 1254, 2012.

[6] M Yen Shih, A Conde Enríquezand Luis Martín Torres Trevi" On-line co-ordination of directional over current relays Performance evaluation among optimization algorithms", Electric Power Systems Research, pp. 122–132, 2014.

[7] M Singh, B K Panigrahi and A R Abhyankar, Swagatam Das "Optimal Coordination of directional over current relays using informative Differential Evolutionary Algorithm", Journal of Computer Science, Vol. 5, pp. 269-276, March 2014.

[8] M Singh, B K Panigrahi and A R Abhyankar "Combined Optimal Distance to Over Current relay Coordination", International Conference on Power Electronics, Drives and Energy Systems, Bangalore, India, December 2012.

[9] S S Reddy, A R Abhayankar "Faster Evolutionary Algorithm based Optimal Power Flow using incrementalvariables" International Journal of Electrical Power Energy Systems Vol. 54, pp. 198-210, 2014.

[10] Mansour, M Mohamed, Mekhamer, S F Elkharbawe ,"A Modified Particle Swarm Optimizer for the Coordination of Directional Over current relays", IEEE Transactions on Power Delivery, Vol. 22, pp. 85-95, 2007.

[11] M Singh, B K Panigrahi and A R Abhyankar "Optimal Coordination of directional over current relays using Teaching Learning based Optimization", International Journal of Electrical power and Energy Systems Computer Science, Vol. 50, pp. 33-41 , September 2013.

[12] R M Chabanloo, Hossein Askarian Abyaneh, Hashemikamangar, Somayeh Sadat and Farzad Razavi, “Optimal combined overcurrent and distance relays coordination incorporating intelligent overcurrent relay characteristics selection”, IEEE Transactions. on Power Delivery, Vol. 26, pp. 1381-1319 July, 2011.

[13] Storn and K Price, “Differential evolution a simple and efficient heuristic for global optimization over continuous spaces,” Journal Global Optimization Vol. 11, pp. 341-359, 2007.

[14] Z Moravej, M Jazaeri, Mehdi Gholamzadeh "Optimal Coordination of distance and over currentrelays in series compensated systems based on MAPSO", Energy Conversion and Management, Vol. 56, pp.140–151, 2012.