5th International Conference on Control Engineering&Information Technology (CEIT-2017)
Proceeding of Engineering and Technology –PET
Vol.33 pp.72-77

Optimization and evaluation of Overcurrent Relays Coordination In Benghazi Distribution Network Using Genetic Algorithm

Naser El Naily[1], Saad. M. Saad[2], Jamal Wafi[3], T. Hussein[1], Ibrahim Ighneiwa[1], and Mohamed M. M. Elfituri[4],[1]University of Benghazi, Electrical and Electronics Engineering Department, Benghazi, Libya
[2]College of Electrical and Electrical Technology, Benghazi, Libya
[3]General Electricity Company of Libya, Benghazi, Libya
[4]Authority of Natural Science Research and Technology, Tripoli, Libya

E-mails: { {naseralnaile222 & smuftahndi}@gmail.com,{ jamal_help & melfituri}@yahoo.com, Tawfiq.elmenfy@uob.edu.ly, and Ibrahim.ighneiwa@uob.edu.ly

***Abstract*—When abnormal operating systems occur, the protection systems operate and isolate the affected parts from network to maintain the security of the network by optimally coordinate the protective relays. interconnected systems and the increasing demand for consumers are forcing operators to optimally coordinate protection system for continuous power circulation in the network. Protection Coordination Requires calculations for the breakpoint of protective relays and systematic enumeration of all possible loops in the network. Therefore, protection coordination should be done in an optimal manner to avoid mal-function, thus avoiding the outage and interruption of feeders from the healthy parts. The presence of backup protection in the protection coordination ensures the isolation of faults if the primary protection does not work effectively. In this study, the genetic algorithm was applied to determine optimum protection coordination for Benghazi distribution Network. GA searches it globally. Systems with OC considered and real coded GA is used in software MATLAB and the system will be evaluated by using ETAP software.**

Keywords—Protective relays; protection coordination; distribution network; genetic algorithm (GA); ETAP software.

I. INTRODUCTION

Several factors affect the continuity of power flow to the costumer, most importantly the coordination of protection system in the distribution network. In order to coordinate the protection system, power flow analysis and the short circuit level must be well known for the proper working of the protection system. The arrangement and coordination of protection system ensure the stability, reliability, and sensitivity of the protective relays in the distribution network in case of sudden faults. protective relays are the first line of defense for the distribution network against fault currents and isolating the affected areas from the rest of the distribution network by initiating and activating circuit breakers [1]. The way the relays work depends on the existence of a primary and backup protective relay for each section in the network. backup protective relays are working on isolating the fault in the case of primary protection failure. Optimal coordination of the protective relays ensures that the protection system decisions do not affect the reliability, reduce the damage caused to the equipment and decrease the areas separated by the fault [2]. OCR characteristic, according to International Electro Technical Commission (IEC), uses protection coordination such as normal inverse, very inverse and extremely inverse [3], [4], [5], [6].

Ordinarily, Protective relay detection for fault currents and issues in the distribution network happened when the measured currents increases to exceed the value of the protective relay setting, the two most important variables in the confeguration of overcurrent relay for better coordination between adjacent relays, the time multiplying setting (TMS), and plug setting (PS) for each relay which depends on the knowledge of the minimum fault current and the highest loading current [1], [7], [8]. Optimizing overcurrent relays passes through many stages. Firstly, trial and error [9], in [11] and [12] optimizing overcurrent relays achieved by applying graphical approach using curve fitting technique, [13] suggest employing fixed point coordination curve adjustment, and [14] suggest using computer programming software. In [14] deterministic methods formulated as mixed integer non-linear programming and solved with general Algebraic modeling. Complexity in MINLP assess construct coordination problem of DOCR with linear programming LP technique [10] and [15], in those methods, assumption of pickup current setting and TMS values had been chosen, and allowing operating time of each relay as linear function of TMS, and PS. Pattern search is one of the numerical optimization which require gradient problem to be optimize [16, 17]. Minimizing function of many variables had been done by simulated annealing combinatorial optimization technique [18, 19]. Those previous methods are quite unuseful for the large number of variables in large systems, and require long time analysis and large iteration amounts. Artificial Intelligence methods adapt and moderate

ISSN 2356-5608

those problems by creating predictable feasible solutions. Seeker algorithm is used to identify the optimal solution for the operating time based on human search behavior [20]. Evaluating the pickup current and TMS is obtained by using analytical approach [21]. IN [22] propose using modified particle swarm optimization to mitigate the drawbacks of conventional PSO. Self adaptive re-clustering technique using informative differential evolution DE algorithm had been suggested to optimize values of TMS and plug setting multiplier PSM [23]. In [24] modern opposition based chaotic DE replace conventional DE to optimize the coordination problem. fuzzy logic [25], expert systems [26-29], and Self-Adaptive Differential Evolutionary (SADE) algorithm in [30]. Box-Muller Harmony Search (BMHS) in [31], Zero-one Integer Programming (ZOIP) Approach in [32], Covariance Matrix Adaptation Evolution Strategy (CMA-ES) in [33], Seeker Algorithm (SA) in [34],Teaching Learning-Based Optimization (TLBO) in [35], Chaotic Differential Evolution Algorithm (CDEA) in [36], Artificial Bee Colony algorithm (ABC) in [37], Firefly Optimization Algorithm (FOA) in [38, 39], Modified Swarm Firefly Algorithm (MSFA) in [40], and Biogeography Based Optimization (BBO) is presented in [41].

This paper presents problem formulation of relay coordination in Section II and GA is described in Section III. Section IV presents the distribution System description. Simulation Results and Analysis are presented in section V . conclusion and future work are summarized in Section VI.

II. Problem Formulation of Optimal OCRs Coordination

The operating time of overcurrent relays depends on the fact that the relay operation time is inversely proportional to the value of the curren passing through them. The operating characteristics of any overcurrent relay depend on two important values, namely, pickup current Ip, and time multiplying setting TMS. In the first equation (1) ISC represents the short circuit current. A and B values in the equation determine the operational characteristics of the overcurrent relay. In this study, the values of A, B is 0.14 and 0.02 were sequentially adjusted. In the equation (2). plug multiplying setting adjusted By means of the short circuit current and pickup valu knowledge, and therefore can represent the operating time as in Equation (2). The objective function symbolizes it as T which is the summation of the coordination time for all relays, which is to be reduced by to the minimum limit as represented in Equation (3). Tii symbolizes the operating time of overcurrent relay near the fault location. Therefore, the operating time of each overcurrent relay is an equalization to TMS and representative in equation (4). The value of C of each relay is a function in plug setting multiplier and represented in equation (5). Ci is constant for each individual overcurrent relay and had to be calculated for each fault location represented in Equation (6). The primary problem is to reduce the operating time for different fault location. Calculations of the fault current are involved in section V.

$$t = A\frac{TMS}{\left(\frac{I_{SC}}{I_P}\right)^B - 1} \quad (1)$$

$$t = A\frac{TMS}{(PSM)^B - 1} \quad (2)$$

$$OF = min\,T = \sum_{i=1}^{m} t_{i,i} \quad (3)$$

$$t = C(TMS) \quad (4)$$

$$C = \frac{A}{(PSM)^B - 1} \quad (5)$$

$$OF = min\,T = \sum_{i=1}^{m} C_i(TMS)_i \quad (6)$$

III. Genetic Algorithm

Genetic algorithm (GA) based on the principle of genetic systems to save time and effort in the search problem for the optimum solutions. The method was borrowed from natural genetics. Initially, some random solutions are used. Each element is a chromosome and represents a solution to the problem. Chromosomes are developed through successive repetition called generations [45].

Genetic operators:

- Reproduction: Selection in this process for individuals depends on the values of fitness relative to the population. Therefore, individuals who represent the highest level of fitness are the expected and most likely for mating and create subsequent genetic action.
- Crossover is an operation occurs after the reproduction process. It is an operator that forms the new chromosome called "offspring" of parents by incorporating part of the information from both. Cross Over represents two steps. First, Two individuals are selected from the mating pool generated from the reproduction operator. Then Crossover provides a randomly selected location offspring obtained from Crossover in a new population.
- mutation: This phase is applied after the crossover phase. Occurs when there is a random change of the binary digits in the string occasionally. The change happens from 0 to 1 and vice versa.

IV. Distribution System Description

In Fig. 1, seven medium voltage substations represent a section of Benghazi Distribution Network implemented in

ETAP software [46]. All the system parameters are shown in Table. I The system consists from different bus-bar with different voltage level. The system fed from 220-KV bus-bar through 100MVA, 220 KV/30 KV transformer, which directly connected to North Benghazi Power Plant through 220 KV transmission line system. Each cables have different lengths as L1 = 1km, L2 = 1.8 km; L3 = 2 km; L4 = 4.8 km;L5=2.8km. The current transformer ratio (CT) and Plug setting (PS) for all relays in the network are shown in Table.II.

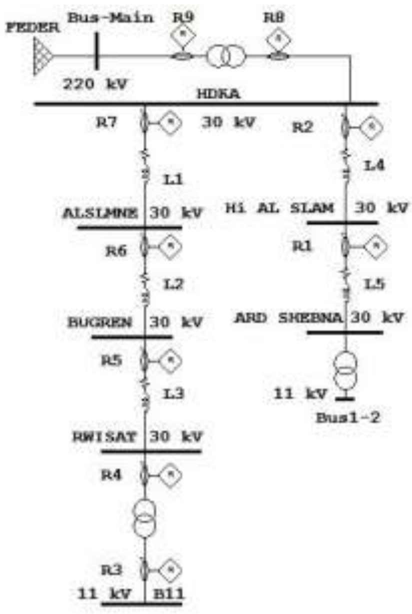

Fig. 1. Typical medium voltage substations

TABLE I. PARAMETERS OF POWER SYSTEM EQUIPMENT

Network Feeder (Bus- Main)	Isc-3 = 6.74 ∟83.5° Isc-1 = 3.3 ∟ 78.9° Z0/Z1 = 4.1272720037 R0/X0 = 0.1961922 R1/X1 = 0.1139356
220/30KV 100 MVA Transformer	Positive sequence data: copper losses=0.4% impedance voltage= 12.76% Zero sequence data: copper losses=0.45% impedance voltage=12%
30/11KV 20 MVA Transformer	Positive sequence data: copper losses=0.43% impedance voltage= 9.88%
XLPE 630mm^2 30KV Cable	R1=0.04 ohm/km X1=0.114 ohm/km R0=0.2587 ohm/km X0= 0.0614 ohm/km

TABLE II. CURRENT TRANSFORMER RATIO AND PLUG SETTING FOR ALL RELAYS

Relay No.	**CT Ratio**	**Plug setting(PS)**
R1	800/1	75%
R2	800/1	80%
R3	1200/1	90%
R4	800/1	62%
R5	800/1	75%
R6	800/1	75%
R7	800/1	80%
R8	2000/1	100%
R9	400/1	100%

V. SIMULATION RESULTS AND ANALYSIS

R_P and R_B in Table III, represents the primary and backup protection in the distribution network respectively. For each protected zone in the network, there is a different pair of protective overcurrent relays. pairs of protective relays are shown in Table III. All Fault currents of power system network have been calculated according to IEC 60909 method. The operating characteristic of each overcurrent relay is calculated based on PSM values. Detailed calculations are shown in Table IV and V.

The TMS value of each relay depends mainly on the value of the fault current measured at each relay location. Therefore, the operating time for all the protective relays is taken as the objective function to be deduced. In equation 7, the objective function, which represents a linear combination of the operating time of all the nine overcurrent relays (X_1-X_9) is represented.

TABLE III. THE PRIMARY AND BACK-UP RELAY FOR DIFFERENT FAULT LOCATIONS

Fault point	**Short circuit current (A)**	**Primary Relay**	**Backup Relay**
Just Beyond B11	8065	R3	R4
Just Beyond RWISAT	9240	R4	R5
Just Beyond BUGREN	10433	R5	R6
Just Beyond	11794	R6	R7

ALSLMNE			
Just Beyond Hi AL SLAM	9240	R1	R2
Just Beyond HDKA	12708	R7 R2	R8 R9
Just Beyond Bus-Main	6740	R9	

TABLE IV. PSM AND RELAY CHARACTERISTIC CONSTANT (C_I) OF OVERCURRENT RELAYS

R_P	PSM	Relay Characteristic Constant C_i	R_B	PSM	Relay Characteristic Constant C_i
R3	7.46	3.41	R4	5.96	3.85
R4	15.4	2.49	R5	15.4	2.49
R5	17.38	2.38	R6	17.38	2.38
R6	19.65	2.28	R7	18.42	2.33
R7	19.85	2.27	R8	6.35	3.71
R1	15.4	2.49	R2	14.43	2.55
R2	19.85	2.27	R8	6.35	3.71
R8	6.35	3.71	R9	4.25	4.76

The main objective is to extract the most suitable TMS, which represents the lowest operating time for each protective relay to conserve the reliability of the protection system which based mainly on the value of TMS value.

$$OF = 2.49X_1+4.82\,X_2+3.41\,X_3+6.34X_4+4.87\,X_5+4.66\,X_6+4.6X_7+3.71\,X_8+7.11X_9 \quad (7)$$

TABLE V. THE CALCULATED VALUES OF RELAY CHARACTERISTIC CONSTANT

Fault Location	Relay Characteristic Constant								
	R1	R2	R3	R4	R5	R6	R7	R8	R9
Just Beyond B11			3.41	3.85					
Just Beyond RWISAT				2.49	2.49				
Just Beyond BUGREN					2.38	2.38			
Just Beyond ALSLMNE						2.28	2.33		
Just Beyond HDKA		2.27					2.27	3.71	4.71
Just Beyond Bus-Main									2.4
Just Beyond Hi AL SLAM	2.49	2.55							

The results obtained from MATLAB for protection coordination have been reported. The problem was developed in the Matlab, and several different faults were tested to achieve the optimal coordination, which produced adequate and reliable results. Table IV shows that the optimal benefit obtained from the genetic algorithm, and optimal coordination of the operating time for all protective relays calculated as a fitness function.

TABLE VI. CALCULATION OF TMS BY GENETIC ALGORITHM

Relay No.	TMS
R1	0.1604
R2	0.3130
R3	0.1170
R4	0.2074
R5	0.3678
R6	0.5356
R7	0.6954
R8	0.5246
R9	0.4979
Fitness Function	16.59

Fig.2 and Fig.3 show the evaluation of the optimal value of TMS that obtained by genetic algorithm, ETAP Software had been used to test the CTI, and the overcurrent coordination between all relay in the system will be convenient.

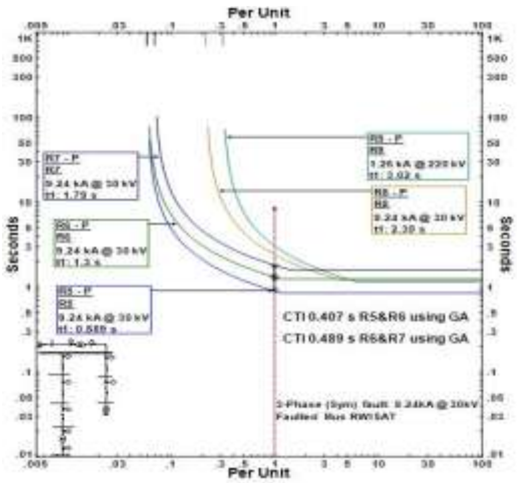

Fig. 2. Relays coordination when the fault occurs in RWISAT

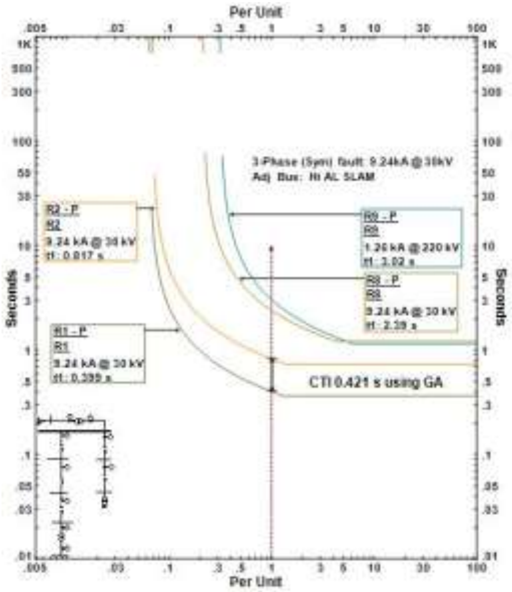

Fig. 3. Relays coordination when the fault occurs in Hi AL SLAM

VI. Conclusion and Future Work

In this study, the genetic algorithm had been applied in case of the Benghazi distribution network to extract and solve the problem of overcurrent coordination, and to represent and formulate the coordination problem as an optimizing problem with systematic improvement procedures. This methodology can be used with any number of protective relays and for the relationships of primary and backup protection pairs for any network. Constraints have been incorporated and resolved using the genetic algorithm.

The algorithm was tested for various network fault locations, and the optimal values for TMS were extracted by the genetic algorithm and yielded satisfactory and acceptable results. Those procedures can be applied to any network easily. A comparative study can be made to compare the different artificial intelligence techniques such as genetic algorithm (GA), particle swarm optimization (PSO) and artificial bees colony (ABC) as a future study. The usefulness of these methods can be investigated to diminishing the challenges in power system and their suitability for broader optimization problems.

References

[1] M.H. Hussain, S.R.A. Rahim, I. Musirin, "Optimal Ovecurrent Relay Coordination: A review", *Malaysia Technical Universities Conference on Engineering & Technology, MUCET 2012.*

[2] C.R. Chen, C.H. Lee, C.J. Chang, "Optimal Overcurrent Relay Coordination in Power Distribution System Using a New Approach", *Electrical Power and Energy Systems 2013; 24:217-222* .

[3] IEEE Standard Inverse-Time Characteristic Equations for OCRs, IEEE Std. C37.112-1996.

[4] A. Tjahjono, A. Priyadi, M.H. Purnomo, M. Pujiantara, "Overcurrent Relay Curve Modeling Using Adaptive Neuro Fuzzy Inference System", *IEEE Makassar International Conference on Electrical Engineering and Informatics, 2014.*

[5] A. Tjahjono, D.O. Anggriawan, A. Priyadi, M.H. Purnomo, M. Pujiantara, "Overcurrent Relay Curve Modeling and Its Application in the Industrial Power Systems Using Adaptive Neuro Fuzzy Inference System", *IEEE International Conference on Computational Intelligence and Virtual Environments for Measurement Systems and Applications, 2015* .

[6] A. Tjahjono, D.O. Anggriawan, A. Priyadi, M. Pujiantara, M.H. Purnomo, "Digital Overcurrent Relay with Conventional Curve Modeling Using Levenberg Marquardt Backpropagation", *IEEE International Seminar on Intelligent and Its Applications, 201.*

[7] F. Razavi, H. A. Abyaneh, M. Al-Dabbagh, R. Mohammadi, H. Torkaman, "A New Comprehensive Genetic Algorithm Method for Optimal Ovecurrent Relays Coordination", *Electric Power Systems Research 2008; 78:713-720.*

[8] R. Mohammadi, H. A. Abyaneh, F. Razavi, M. Al-Dabbagh, S.H.H. Sadeghi, "Optimal Relays Coordination Efficient Method in Interconnected Power Systems", *Journal of Electrical Engineering, Vol. 61, No. 2, pp. 75-83, 2010.*

[9] R.E. Albercht, et al, "Digital Computer Protection Device Coordination Program –I General Program Description", IEEE Trans. on Power Apparatus and Systems, vol. 83, no. 4, pp. 402-410, 1964.

[10] H. B. Elrafie and M. R. Irving, "Linear programming for directional overcurrent relay coordination in interconnected power systems with constraint relaxation," Elect. Power Syst. Research, vol. 27, no. 3, pp. 209-216, Aug. 1993.

[11] "Computer representation of overcurrent relay characteristics," IEEE Trans. Power Del., vol. 4, no. 3, pp. 1659-1667, July 1989.

[12] C. W. Rogers, R. Ramaswami and P. F. McGuire, "Graphical coordination program aids system relaying at Consumers Power," IEEE Comput. Appl. Power, vol. 3, no. 3, pp. 30-35, July 1990.

[13] J.-L. Chung, Y. Lu, W.-S. Kao and C.-J. Chou, "Study of solving the coordination curve intersection of inverse-time overcurrent relays in subtransmission systems," IEEE Trans. Power Del., vol. 23, no. 4, pp. 1780-1788, Oct. 2008.

[14] N. A. Laway and H. O. Gupta, "Integrated software for optimal directional overcurrent relay coordination," Elect. Mach. and Power Syst., vol. 22, no. 1, pp. 125-136, 1994.

[15] A. J. Urdaneta, H. Restrepo, S. Márquez and J. Sánchez, "Coordination of directional overcurrent relay timing using linear programming," IEEE Trans. Power Del., vol. 11, no. 1, pp. 122-128, Jan. 1996.

[16] Tamara G. Kolda, Robert Micheal Lewis, and Virginia Torczon, "Optimization by Direct Search: NewPerspectives onmSome Classical andModern Methods," SIAM REVIEWSociety for Industrial and Applied Mathematics, 2003, vol. 45, no. 3, pp. 385–482.

[17] Micheal Wetter, and Jonathan Wright, "Comparison of generalized patter search and a genetic algorithm optimization method," 8th International IBPSA conference, Eindhoven, Netherlands, August 11-14, 2003.

[18] Rob A. Rutenbar, "Simulated Annealing Algorithms:An Overview," IEEE Circuits and Devices Magazine, vol. 5, pp.19-26, Jan 1989.

[19] Łukasz Dowhań, Artur Wymysłowski, and Krzysztof Urbański, "Simulated Annealing as a Global Optimization Algorithm Used in Numerical Prototyping of Electronic Packaging," 10th. Int. Conf. on Thermal, Mechanical and Multiphysics Simulation and Experiments in Micro-Electronics and Micro-Systems, EuroSimE, 2009

[20] T. Amraee, "Coordination of directional overcurrent relays using seeker algorithm", IEEE Trans. Power Del., vol. 27, no. 3, pp. 1415–1422, July 2012.

[21] A. Mahari and H. Seyedi, "An analytical approach for optimal coordination of overcurrent relays", IET Gen. Trans. Distr., vol. 7, no. 7, pp. 674-680, Feb. 2013.

[22] H. Zeineldin, E. El-Saadany and M. Salama, “Optimal coordination of overcurrent relays using a modified particle swarm optimization,” Elect. Power Syst. Res., vol. 76, no. 11, pp. 988–995, Jan. 2006.

[23] M. Singh, B.K. Panigrahi, A.R. Abhyankar and S. Das, “Optimal coordination of directional over-current relays using informative differential evolution algorithm,” Journal of Computational Science, vol. 5, no. 2 pp. 269-276, Mar. 2014

[24] T. R. Chelliah, R. Thangaraj and S. Allamsetty and M. Pant,“Coordination of directional overcurrent relays using opposition based chaotic differential evolution algorithm,” Int. J. Elect. Power & Energy Syst., vol. 55, no. 0, pp. 341 - 350, Feb. 2014

[25] Abyane H.A., Faez K. and Karegar H.K., 1997, “A new method for over current relay (O/C) using neural network and fuzzy logic”, Proceedings of the IEEE TENCON, Speed and Image Technologies for Computing and Telecommunications, pp.407–410.

[26] Brown K. and Tyle N., 1986, “An expert system for over current protective device coordination”, McGraw Edison power system division, Proceedings of the IEEE Rural Electric Power System Conference, April, pp.20–22

[27] Lee S.F., Yoon S.H. and Jang J., 1989, “An expert system for protective relay setting of transmission systems, Proceedings of the IEEE Power Industry Computer Application (PICA) Conference, Seatle, WA, pp.296–302.

[28] Hong H.W., Sun C.T., Mesa V.M., and Ng, S., 1991, ”Protective device coordination expert system, IEEE Transactions on Power Delivery 6(1), 359–365.

[29] Jianping W. and Trecat J., 1996, RSVIES—“A Relay setting value identification expert system”, Electric Power Systems Research 37,153–158.

[30] M. Mohseni, A. Afroomand, and F. Mohsenipour, “Optimum Coordination of Overcurrent Relays Using SADE Algorithm”, 16th IEEE Conference on Electrical Power Distribution Networks (EPDC), Bandar Abbas, Iran, 19-20 April, 2011

[31] A. Fetanat, G. Shafipour, and F. Ghanatir, “Box-Muller Harmony Search Algorithm for Optimal Coordination of Directional Overcurrent Relays in Power System”, Scientific Research and Essays, Vol. 6, No.19, pp. 4079-4090, 2011.

[32]] J. Moirangthem, S.S. Dash, and R. Ramaswami, “Zero-one Integer Programming Approach to Determine the Minimum Break Point Set in Multi-loop and Parallel Networks”, Journal of Electrical Engineering & Technology (IJET), Vol. 7, No. 2, pp. 151-156, 2012

[33] M. Singh, B.K. Panigrahi, and R. Mukherjee, “Optimum Coordination of Overcurrent Relays using CMA-ES Algorithm”, IEEE International Conference on Power Electronics, Drives and Energy Systems, Bengaluru, India, 16-19 December, 2012

[34] T. Amraee, “Coordination of Directional Overcurrent Relays Using Seeker Algorithm”, IEEE Transactions on Power Delivery, Vol. 27, No. 3, pp. 1415-1422, 2012.

[35] M. Singh, B.K. Panigrahi, and A.R. Abhyankar, “Optimal Coordination of Directional Overcurrent Relays using Teaching Learning-Based Optimization (TLBO) Algorithm”, International Journal of Electrical Power and Energy Systems, Vol. 50, pp. 33-41, 2013.

[36] T.R. Chelliah, R. Thangaraj, S. Allamsetty, and M. Pant, “Coordination of Directional Overcurrent Relays using Opposition based Chaotic Differential Evolution Algorithm”, International Journal of Electrical Power and Energy Systems, Vol. 55, pp.341-350, 2014.

[37] M. Singh, B.K. Panigrahi, and A.R Abhyankar, “Optimal Coordination of Electro-Mechanical based Overcurrent Relays using Artificial Bee Colony Algorithm”, International Journal of Bio-Inspired Computation, Vol. 5, No. 5, pp. 267-280, 2013.

[38] R. Benabid, M. Zellagui, A. Chaghi, and M. Boudour, “Application of Firefly Algorithm for Optimal Directional Overcurrent Relays Coordination in the Presence of IFCL”, International Journal of Intelligent Systems and Applications (IJISA), Vol. 6, No. 2, pp. 44-53, 2014.

[39] S.S. Gokhale, and V.S. Kale, “Application of the Firefly Algorithm to Optimal Over-Current Relay Coordination”, International Conference on Optimization of Electrical and Electronic Equipment (OPTIM), Bran - Romania, 22-24 May 2014

[40] M.H. Hussain, I. Musirin, A.F. Abidin, and S.R.A. Rahim, “Modified Swarm Firefly Algorithm Method for Directional Overcurrent Relay Coordination Problem”, Journal of Theoretical and Applied Information Technology, Vol. 66, No. 3, pp.741-755, 2014

[41] M. Zellagui, R. Benabid, M. Boudour, and A. Chaghi, “Optimal Overcurrent Relays Coordination in the Presence Multi TCSC on Power Systems Using BBO Algorithm”, International Journal Intelligent Systems and Applications (IJISA), Vol. 7, No. 2, pp. 13-20, 2015

[42] Sortomme, E., Venkata, S. and Mitra, J. (2010) Microgrid Protection Using Communication-Assisted Digital Relays.*IEEE Transactions on Power Delivery*, 25, 2789-2796.

[43] Najy, W.K.A., Zeineldin, H.H. and Woon, W.L. (2013) Optimal Protection Coordination for Microgrids with Grid Connected and Islanded Capability. *IEEE Transactions on Industrial Electronics*, 60, 1668-1677.

[44] Prashant P. Bedekar, Sudhir R. Bhide, Vijay S. Kale” Optimum coordination of overcurrent relays in distribution system using genetic algorithm” Third International Conference on Power Systems, Kharagpur, INDIA December 27-29,ICPS – 247,2009.

[45] N.P.Padhy”Artificial intelligence and intelligent systems” 1st edition;2005,pp.459-505.

[46] ETAP PowerStation help manual, available online:http://www.etap.com.