Multi-Objective Approach for Solving Directional Overcurrent Relay Problem Using Modified Firefly Algorithm

M.H. Hussain, I. Musirin, A.F. Abidin, and S.R.A. Rahim

Abstract— **This paper presents multi-objective approach for solving directional overcurrent relay (DOCRs) problem using Modified Firefly Algorithm (MFA). DOCRs coordination problem is formulated as Mixed-Integer Non Linear Programming (MINLP) problem. The efficiency of the proposed technique is compared with those obtained using Artificial Bees Colony (ABC) and have been tested successfully on 8 bus test system. The simulation results indicated that the MFA algorithm is capable to minimize operating time of primary relays and the minimum relay coordination time in the system as well as solving miscoordination problem.**

Keywords— ***directional overcurrent relay; modified firefly algorithm; mixed-integer non linear programming; relay operating time; relay coordination time***

I. Introduction

In recent years, the coordination problems in electrical power system have become widely increasing due to fault that occurs in transmission network. DOCRs are commonly used as primary protection for distribution systems and secondary protection for transmission systems. An appropriate settings of time multiplier setting (TMS) and pickup current (I_p) of DOCRs plays an important role to secure protection for the entire system. The process of DOCRs coordination gets more difficult if the line is installed with multi loop configuration and with multi-source complex network structures.

Several methods have been proposed for the process of DOCRs coordination. In the 60's, protection engineers have to spend more time in calculating and manipulating the graphics in order to coordinate a set of relays according to some technical constraints. The major problems involved the computation burden which changes in settings of one relay leading to the changes in other relays and large quantities of information to be coped [1]. Nowadays, optimization techniques have been proposed for the optimal coordination of DOCRs. Many researchers used linear programming (LP) for optimizing TMS while I_p is a fixed value based on the load and fault data. There are also researchers that used non-linear programming (NLP) for optimal settings of I_p, while optimization of TMS settings is determined using simplex method [2].

Lately, meta-heuristic approaches based on Nature Inspired Algorithms (NIA) techniques have been proposed to solve complex optimization problems. Intelligent search algorithms such as Particle Swarm Optimization (PSO) and Artificial Bees Colony (ABC) had been used in [3-5] to calculate the relay settings in which TMS is adjusted in order to minimize the relay operating as well as to minimize the relay coordination time. PSO sometimes trapped in local optima while ABC suffers to look for better solution although good at exploration. In [6], mono-objective for DOCRs problem using FA was proposed to find an optimal settings of TMS and I_p of each relay. The purpose is to minimize the operating time of all relays considering the series compensation of power system.

In this paper, Modified Firefly Algorithm (MFA) is proposed for multi-objective DOCRs problem since FA contributes more miscoordination for each relay pairs. The multi-objectives of the problem are primary relay operating time and relay coordination time. Both objectives are needed to be minimized to ensure reliable operation of the relays in power system. The DOCRs problem is formulated as Mixed-Integer Non Linear Programming (MINLP) problem which continuous TMS and discrete I_p are optimized simultaneously. The proposed method has shown promising results in minimizing primary relay operating and minimizing relay coordination time on 8 bus test system.

II. Problem Formulation

The aim of the DOCRs coordination problem is to determine the optimal TMS and I_p of each relay and optimal objective function. These requirements should be fulfilled according to relay operational characteristic whether linear or non-linear, relay type, primary and backup relay constraints and coordination constraints [7].

A. Linear or Non-Linear Relay Characteristic

The non-linear relay characteristics function is based on the standard ANSI/IEEE C37.112-1996 [8]. The characteristic of this relay is extremely inverse type. The operating time for this type of relay can be represented as follows:

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$$t_i = \left[\frac{K}{\left({I_{sc_i}}/{I_{p_i}} \right)^{\alpha} - 1} + L \right] TMS_i \quad (1)$$

where I_{sci} is the short circuit and I_{pi} is the pickup current setting of the ***i***-th relay. The TMS values range continuously from 0.05 to 1 and I_p values range discretely between 100 and 1000 with a step size of 1. The constant factor, K = 28.2, L = 0.1217 and α = 2.

B. Coordination Constraints

Both the primary relay and backup relay are related with coordination constraints. It is common thing that every primary protection must have backup protection for protective system. The time interval known as continuous time interval (CTI) should be included for coordination purposes. This CTI depends on relay types; microprocessor or electromechanical, speed of circuit breaker (CB), relay overshoot time and other system parameters. The CTI between the primary and backup relay pairs can be described as follows:

$$\Delta t_{pb} = t_b - t_p - CTI \quad (2)$$

Where; t_b is the operating time of the backup relay, t_p is the operating time of the primary relay and *CTI* varies from 0.1s – 0.5s depends on different circumstances.

With faster modern CBs and lower relay overshoot time, 0.2s is used in this study. This is related to digital microprocessor that had been used in the system.

C. Objective Function

The objectives are to minimize the total operating time of primary relays and total relay coordination time with optimized values of TMS's and I_p's. To achieve this, the objective function is formulated as follows:

$$OF = \min\left(\alpha_1 \sum_{i=1}^{N} t_i^{\,q} + \alpha_2 \sum_{j=1}^{P} (\Delta t_{pb} - \beta_2 (\Delta t_{pb} - |\Delta t_{pb}|))^r \right) \quad (3)$$

where t_i is the i^{th} relay operating time for near-end fault of the i^{th} relay, Δt_{pb} is the coordination time for each relay pairs, *N* is the number of relays, *P* denotes the number of primary/backup relay pairs, *i* represents each relay and varies to *N*, α_1 control the weight of $\sum_{i=1}^{N} t_i^{\,q}$, α_2 control the weight of $\sum_{j=1}^{P} (\Delta t_{pb} - \beta_2 (\Delta t_{pb} - |\Delta t_{pb}|))^r$ and β_2 is the parameter which refer to miscoordination. The *q* and *r* represents the power number.

Weight coefficients of α_1, α_2 and β_2 and power number of *q* and *r* are optimized in this paper to prevent miscoordination of relay pairs and have faster relay operating time.

III. MODIFIED FIREFLY ALGORITHM

Firefly Algorithm (FA) inspired by the social behavior of fireflies was developed by Yang in 2007 for solving complex optimization problems [9], [10].

This algorithm was developed using these three idealized rules; i) all fireflies are unisex, one firefly will be attracted to other fireflies regardless of their sex, ii) the degree of attractiveness of firefly is proportional to brightness, for any two flashing fireflies, the less brighter will attract to brighter firefly, both decrease as their distance increases and if there are no fireflies brighter than a given firefly, it will move randomly, iii) the brightness of firefly is determined by the landscape of the objective function.

In FA, the attractiveness function *β(r)* of the firefly is determined by:

$$\beta(r) = \beta_o e^{-\gamma r^2} \quad (4)$$

where; β_o is the attractiveness at $r = 0$ and γ is the light absorption coefficient

The distance r_{ij} between two fireflies *i* and *j* at x_i and x_j is the cartesian distance denoted as follows [11].

$$r_{ij} = \|x_i - x_j\| = \sqrt{\sum_{k=1}^{d} (x_{i,k} - x_{j,k})^2} \quad (5)$$

where $x_{i,k}$ is the k^{th} component of the spatial coordinate of the j_{th} firefly and *d* is the number of dimensions

The movement of a firefly, *i* when attracted to another brighter firefly *j* is determined by following equation:

$$x_i^{'} = x_i + \beta(r)(x_i - x_j) + \alpha(rand - 0.5) \quad (6)$$

where $x_i^{'}$ is the next generation of firefly, x_i and x_j are the current position of fireflies, α is the randomization parameter and 'rand' is a number generated uniformly but distributed between 0 and 1 [6].

The main problem occurs with multi-objective for DOCRs coordination problem using FA is it can get easily trapped into local optima. In this paper, MFA is introduced to overcome this situation and improve the performance and efficiency of FA. This is to ensure the particles explore into global best region and escape more easily from local optima.

In MFA, the parameter of alpha is introduced into FA original pseudo-code to increase convergence. Alpha parameter is setting using the following equation:

$$delta = 1 - (10^{(-4)} / 9)^{({1}/{MaxGen})} \quad (7)$$

$$alpha = (1 - delta) * alpha \quad (8)$$

where *alpha* and *delta* are parameters to increase convergence [9].

In addition, the bounds or limits are also introduced to make sure the fireflies are within the specific range. Fig. 1 simplifies the formulation of DOCRs coordination and MFA execution process.

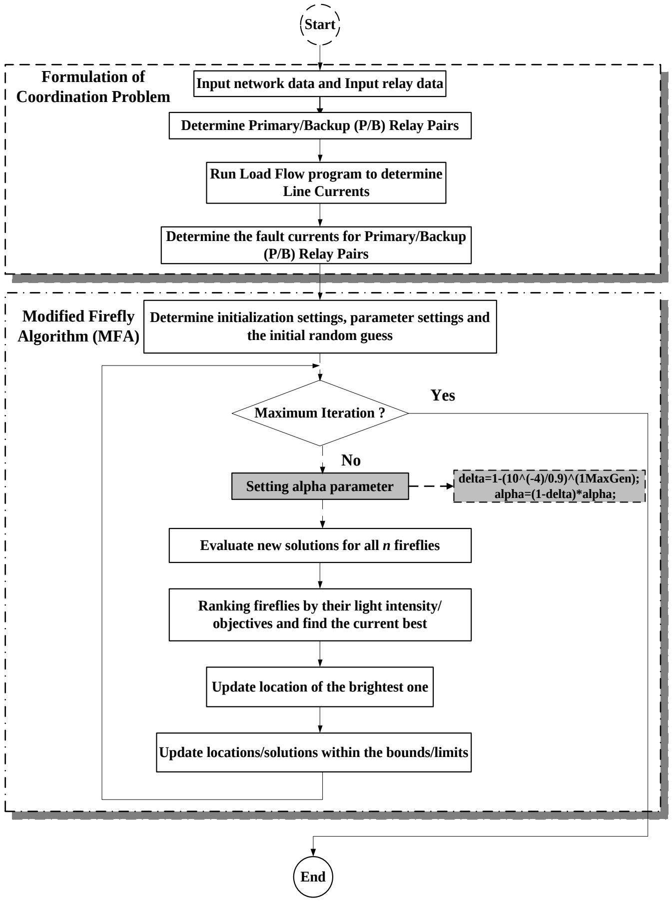

Fig. 1: Flowchart of MFA technique

IV. Results and Discussion

An optimization engine was developed to implement the MFA technique. The technique was executed on Intel Core i5 2.53 GHz with 4 GB RAM and simulated in MATLAB. The value of parameters α_1, α_2, β_2, q and r are optimized respectively. The study revealed the feasibility of the MFA technique to solve DOCRs problem. The proposed method was compared with ABC algorithm and has been tested on 8 bus test system. The test system comprises of 8 buses, 7 lines, 2 transformers, 2 generators and 14 DOCRs. The control parameters of MFA technique are listed in Table I. The single line diagram of the test system is depicted in Fig. 2 and system parameters with fault current for primary relay and backup relay is in [12]. It can be observed that the faults occurred in a transmission line is the symmetrical balanced three phase fault and there are 20 primary/backup relay pairs.

TABLE I. MFA Control Parameters

Parameters	Value
Number of fireflies population, n	100
Number of Iterations	300
Randomness, α	0.1
Attractiveness at r = 0, β	0.1
Absorption coefficient, γ	1.0

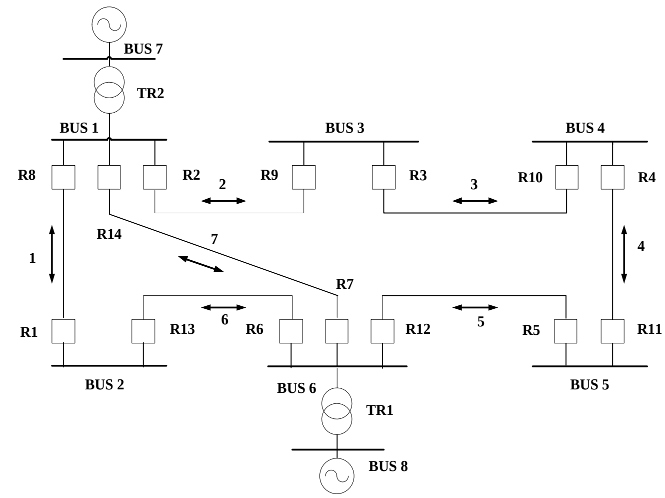

Fig. 2: Single line diagram of 8 bus test system [5]

Table II tabulates the TMS and I_p values for the 14 DOCRs in 8 bus test system. After exhaustive experiment for heuristic method, fixed weight coefficients of α_1=1, α_2=1, β_2=100 and fixed power number: q=2, r=2 are considered the best results to give lesser total TMS's for both MFA and ABC technique. It took more time to achieve this desired result. It can be seen that MFA technique exhibits the best results among 50 runs with 300 iterations as compared to ABC. For optimized method, α_1=2, α_2=1 and β_2=164 and optimized power number: q=2, r=2 are considered the best results among the 50 runs for MFA technique as compared to ABC technique. Although both heuristic methods and optimized method of total TMS's contribute same results; 1.78s but optimized method shows shorter time. For I_p, optimal MFA technique contributes lesser total pickup current as compared to heuristic MFA technique.

Table III indicates that the total operating time of primary relay for MFA technique exhibits approximately 6% lesser time, i.e. 1.3956s than ABC, i.e. 1.4864s for the heuristic method. For optimized method, it seems that ABC technique contributes lesser time than MFA technique with 0.1% reduction.

In Table IV, although ABC technique exhibits lesser total relay coordination time, i.e. 0.6492s compared to MFA technique, i.e. 0.7737s for heuristic method, but in optimized method, MFA technique contributes lesser relay coordination time, i.e. 0.7038s. In addition, the computational time required for ABC technique is much longer, i.e. 186.3311s as compared to MFA technique which required 68.1441s. In terms of minimum fitness, it can be revealed that MFA technique exhibits shorter time, i.e. 0.1989s for optimized method as compared to ABC technique and both techniques for heuristic method. It can be seen also that from this table, some values of Δt are zero. Example, the coordination between relays 8 and 9. This is because relay 8 which is connected to a generator-transformer bus. In such case, there is no need to study coordination. Other primary relays with Δt equal to zero are also connected to generator-transformer buses.

TABLE II. TIME MULTIPLIER SETTING AND PICKUP CURRENT FOR 8-BUS TEST SYSTEM

Time Multiplier Setting (TMS)					Pickup Current (I_p)				
Parameters	Heuristic Method [fixed weight coefficients: α_1=1, α_2=1, β_2=100]		Optimized Method [optimized weight coefficients: α_1=2, α_2=1, β_2=164(MFA),β_2=127(ABC)]		Parameters	Heuristic Method [fixed weight coefficients: α_1=1, α_2=1, β_2=100]		Optimized Method [optimized weight coefficients: α_1=2, α_2=1, β_2=164(MFA),β_2=127(ABC)]	
	[fixed power number: q=2, r=2]		[optimized power number: q=2, r=2]			[fixed power number: q=2, r=2]		[optimized power number: q=2, r=2]	
Techniques / TMS No	MFA	ABC	MFA	ABC	Techniques / I_{pi} No	MFA	ABC	MFA	ABC
TMS_1	0.06	0.14	0.06	0.33	I_{p1}	404	304	414	185
TMS_2	0.19	0.36	0.25	0.50	I_{p2}	845	630	803	520
TMS_3	0.10	0.36	0.11	0.05	I_{p3}	737	379	701	992
TMS_4	0.16	0.29	0.10	0.25	I_{p4}	624	401	681	415
TMS_5	0.10	0.06	0.05	0.13	I_{p5}	411	437	429	112
TMS_6	0.16	0.40	0.18	0.20	I_{p6}	755	431	675	768
TMS_7	0.12	0.14	0.11	0.27	I_{p7}	611	579	617	399
TMS_8	0.12	1.00	0.17	0.18	I_{p8}	842	205	759	630
TMS_9	0.08	0.10	0.05	0.24	I_{p9}	439	131	406	100
TMS_{10}	0.16	0.50	0.14	0.05	I_{p10}	621	274	582	956
TMS_{11}	0.13	0.36	0.18	0.05	I_{p11}	681	392	566	986
TMS_{12}	0.26	0.17	0.20	0.17	I_{p12}	757	986	861	928
TMS_{13}	0.06	0.11	0.05	0.05	I_{p13}	409	320	436	469
TMS_{14}	0.08	0.27	0.13	0.14	I_{p14}	703	382	551	536
total time setting multiplier (s)	1.78	4.26	1.78	2.61	total pickup current (A)	8839	5851	8481	7996

TABLE III. PRIMARY RELAY OPERATING TIME

Primary Relay Operating Time (s)				
Parameters	Heuristic Method [fixed weight coefficients: α_1=1, α_2=1, β_2=100]		Optimized Method [optimized weight coefficients: α_1=2, α_2=1, β_2=164(MFA), β_2=127(ABC)]	
	[fixed power number: q=2, r=2]		[optimized power number: q=2, r=2]	
Techniques / t_i No	MFA	ABC	MFA	ABC
t_1	0.0342	0.0523	0.0356	0.0708
t_2	0.1349	0.1605	0.1630	0.1709
t_3	0.1392	0.1609	0.1392	0.1255
t_4	0.1459	0.1284	0.1068	0.1164
t_5	0.0974	0.0653	0.0526	0.0238
t_6	0.0897	0.1053	0.0848	0.1152
t_7	0.0618	0.0664	0.0575	0.0778
t_8	0.0808	0.1538	0.0966	0.0770
t_9	0.0827	0.0201	0.0449	0.0402
t_{10}	0.1381	0.1315	0.1079	0.0972
t_{11}	0.1444	0.1591	0.1435	0.1139
t_{12}	0.1548	0.1589	0.1475	0.1427
t_{13}	0.0398	0.0496	0.0369	0.0419
t_{14}	0.0519	0.0743	0.0576	0.0596
total operating time of primary relays (s)	1.3956	1.4864	1.2744	1.2729

TABLE IV. RELAY COORDINATION TIME FOR EACH RELAY PAIRS

Relay Coordination Time for each relay pairs, Δt_{pb}				
Parameters	Heuristic Method [fixed weight coefficients: α_1=1, α_2=1, β_2=100]		Optimized Method [optimized weight coefficients: α_1=2, α_2=1, β_2=164(MFA), β_2=127(ABC)]	
	[fixed power number: q=2, r=2]		[optimized power number: q=2, r=2]	
Techniques / Δt_{pb}	MFA	ABC	MFA	ABC
Δt_{89}	0	0	0	0
Δt_{87}	0.1335	0.0770	0.0913	0.1150
Δt_{27}	0.0793	0.0703	0.0248	0.0211
Δt_{21}	0.0080	0.0648	0.0003	0.0039
Δt_{32}	0.0057	0.0131	0.0713	0.0445
Δt_{43}	0.0086	0.0146	0.0434	0.0336
Δt_{54}	0.0492	0.0048	0.0065	0.0239
Δt_{65}	0	0	0	0
$\Delta t_{6,14}$	0.0914	0.0591	0.0795	0.0552
$\Delta t_{14,1}$	0.0910	0.1510	0.1057	0.1152
$\Delta t_{14,9}$	0	0	0	0
Δt_{16}	0.0461	0.0008	0.0181	0.0915
$\Delta t_{9,10}$	0.0386	0.0150	0.0022	0.0119
$\Delta t_{10,11}$	0.0170	0.0054	0.0294	0.0133
$\Delta t_{11,12}$	0.0076	0.0281	0.0037	0.0286
$\Delta t_{12,14}$	0.0263	0.0055	0.0169	0.0277
$\Delta t_{12,13}$	0.0050	0.0205	0.0022	0.0767
$\Delta t_{13,8}$	0.0684	0.0062	0.1163	0.0175
Δt_{75}	0	0	0	0
$\Delta t_{7,13}$	0.0980	0.1130	0.0922	0.1417
Total Δt_{pb}	0.7737	0.6492	0.7038	0.8213
Iteration	300			
Computation time (s)	49.0555	70.5903	68.1441	186.3311
Objective Function (s)	0.2252	0.2466	0.1989	0.2093

Fig. 3 depicts the convergence of MFA and ABC to the optimal solution for heuristic method. It demonstrates that MFA nearly reaches global optimum after 135 iterations while ABC reaches at 292 iterations. It can be seen that MFA results show better fitness function values over ABC technique. For optimized method, Fig. 4 exhibits that MFA reaches global optimum at 148 iterations while ABC takes 287 iterations.

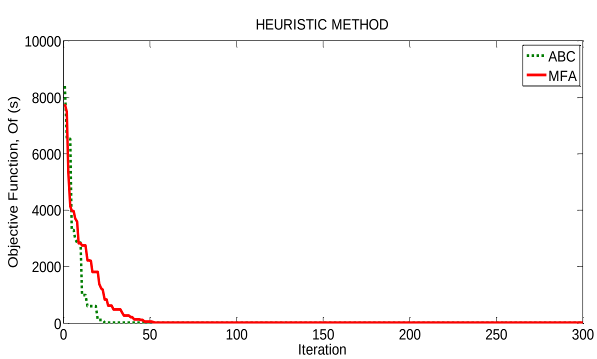

Fig. 3: Convergence of MFA and ABC to the optimal solution for heuristic method

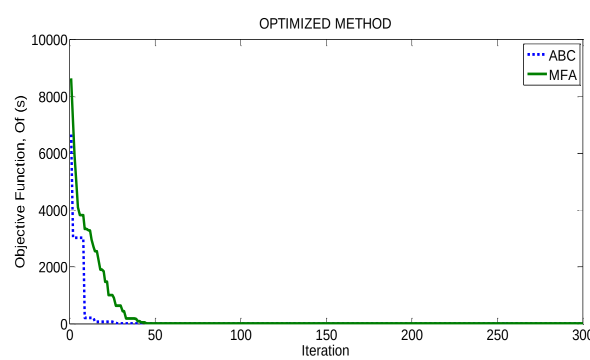

Fig. 4: Convergence of MFA and ABC to the optimal solution for optimized method

V. CONCLUSION

Modified Firefly Algorithm technique has been presented in this paper to solve DOCRs problem. From the results, it can be revealed that the proposed technique demonstrates significant result for optimized method rather than heuristic method to avoid miscoordination in relay operation compared to ABC. The suitable answer is for optimized method that based on the less computation time and minimum fitness value for every number of simulations. Moreover, the proposed technique is faster in terms of computation time than ABC technique which is feasible to be implemented in a larger system.

ACKNOWLEDGMENT

The authors would like to acknowledge The Institute of Research Management and Innovation (IRMI) UiTM, Shah Alam and Ministry of Higher Education Malaysia (MOHE) for the financial support of this research. This research is supported by MOHE under the Exploratory Research Grant Scheme (ERGS) with project code: (File No: 600-RMI/ERGS 5/3(21/2013).

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