Journal of Theoretical and Applied Information Technology
31st August 2014. Vol. 66 No.3

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

MODIFIED SWARM FIREFLY ALGORITHM METHOD FOR DIRECTIONAL OVERCURRENT RELAY COORDINATION PROBLEM

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ABSTRACT

Computational intelligence method such as Nature Inspired Algorithms (NIA) or meta-heuristic algorithms based optimization methods known to be successful in coordination of directional overcurrent relay. It has also been reported that it outperformed the conventional approach. Due to its advantages, it has gained more popularity among the researchers. Some of the conventional optimization techniques such as linear programming method and non-linear programming method were proposed but these methods is time consuming and complex to achieve optimal solution. Thus, a search for better optimization technique to reduce computation burden has become urgency. This paper presents the implementation of Modified Swarm Firefly Algorithm (MSFA) in solving directional overcurrent relay coordination problem. The effect of population sizes were considered to investigate the performance of MSFA technique. The coordination of directional overcurrent relays is formulated as linear programming problem and the objective function is introduced to minimize the operating time of the primary relay. Operating time of the relay depends on time setting multiplier (TSM) which leads to no miscoordination between relay pairs. The proposed method have been applied and tested successfully on 8-Bus test system and 9-Bus test system. The results revealed that MSFA outperformed Particle Swarm Optimization (PSO) in terms of computation time.

Keywords: *Directional Overcurrent Relay (DOCR) Coordination, Modified Swarm Firefly Algorithm (MSFA), Particle Swarm Optimization (PSO), Time Setting Multiplier, Computation Time*

1. INTRODUCTION

Undesirable conditions such as faults, overvoltage, overcurrent, over frequency and under frequency conditions can occur frequently and leads to damaging equipment, interrupting power supply connected to the power system. When these situations occurred, the faulted components should be ready to isolated and maintain system stability. This is known as power system protection. Protection power system normally comprises of five components. There are current transformers, voltage transformers, protective relays, circuit breakers, batteries and fuses in a distribution system. By taking consideration of this undesirable condition, a reliable protective power system is required.

The protective relay plays the most significant part in power system protection which senses the undesirable conditions with the aid of current transformers and circuit breaker. For protection system, Current Transformer (CT) usually designed to reproduce the largest current fault while the relay carries out the information provided by the CT in accordance with some predetermine logic and compares it with relay settings to take a trip or no-trip decision [1]. If fault happens, the relay initiates the operation of the Circuit Breaker (CB) by issues tripping signals to open the CB. This is to ensure the defected element will be isolate from the rest of the system. Nowadays, transmission system and distribution system are very complicated. Due to this, a large number of protective relays are required to cooperate with each other to ensure reliable and secure operation of a whole system.

Protection system is organized accordingly which can be divided into several zone. Each of the zones may be implemented using different relaying principle [1]-[2]. In typical power system, there are many zones to be protected such as generator zone, bus zone, transformer zone, transmission line zone, etc. This system is called as main protection system. In order for the reliable protective relay to act accordingly if the main protection system failed, the

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

backup protection system should operate to ensure reliability. Time grading margin or commonly known as time delay is the criteria to be considered for coordination when primary relays and backup relays coordinated together. It means that the operating time of backup relay must be delay by an appropriate time over that of the primary relay. When fault started to strike, both primary relay and backup relay start operating simultaneously. In case the main protection system operates successfully, the backup protection system resets without issuing a trip command. If main protection system fails to operate, the backup protection system waits until the main protection cleared the fault and then issues the trip command to its circuit breakers. According to [3]-[4], protective relays comprises of five types which are overcurrent relays, directional relays, differential relays, distance relays and pilot relays.

The most common relay used in power system is the overcurrent relay. This relay has two settings which are plug setting and time setting. The function of plug setting is to determine the current required for the relay to pick up while time setting is to decide the operating time of the relay [1], [3]-[4]. The overcurrent relay normally used for overcurrent protection and must de-energized the undesirable conditions as quickly as possible to protect the system. Basically, overcurrent relays have Current Setting Multiplier (CSM) starting from 50% until 200% in steps of 25% [4]. This is commonly known as Plug Setting (PS) which the value is determined by maximum load current and minimum fault current.

Several methods have been proposed and applied by the researchers for the last four decades. These methods can be categorized into trial and error, curve fitting, graph theoretical and optimization method [2]-[6]. In classical approach, fault analysis is conducted, after that ring network are break into radial type, relay which at far-end is set first and then backup relays are set. This process is repeated continuously until all the relays are taken into consideration. Due to the complexity of the power system, both trial and error approach, graph theoretical technique and topological technique is time consuming [2]-[3]. The optimization techniques outperformed the classical approach which one of its advantages is fast convergence rate to achieve a suitable relay setting and eliminate a breakpoint technique.

Urdaneta et. al in 1988 [7] did state that the proposed new methodology based optimization theory determines the optimal solution to the coordination problem in efficient way. Indeed, optimization techniques are more efficient for the network with multisource and multi looped system.

In the last fifteen years, computational intelligence methods such as Evolutionary Computation (EC) are applied to solve overcurrent relays coordination problem. In [8]-[9], C.W. Soo et al. proposed Genetic Algorithm (GA) and Evolutionary Programming (EP). GA was implemented to overcome non-linear programming problem and EP produces two problems which are miscoordination occurred between primary/backup relays and discrete TSM relays changed to continuous. Thus, to overcome this problems, Razavi et al. in 2008 [10] introduced a new comprehensive GA to solve two main problems occurred by C.W. Soo et al. Although GA was implemented in this paper but for binary-coded GA, it needs to change to binary encoding, required longer time to converge and sometimes struck to local minimum solution [11].

Other category is Swarm Intelligence Algorithms which has becoming the most popular nature inspired optimization techniques used to solve engineering problems. In [12], algorithms based on nature have been said effective and efficient in order to solve difficult optimization problems. Modified Particle Swarm Optimization (MPSO) was proposed by H.H. Zieneldin et al. in 2006 [13] to compare with Particle Swarm Optimization (PSO). M.M. Mohamed et al. and M.H. Hussain et al. also were proposed the same method in [14]-[15]. According to [16], PSO have two major drawbacks which are suffers from premature convergence when problems with multiple optima are being optimized. The second drawback is the performance of PSO is very sensitive to parameter settings. Artificial Bees Colony was also reported in [17]-[18] and sometimes good at exploration (global search) but poor exploitation (local search) where it suffers to look for better solution. In [19], Honey Bee Algorithm (HBA) was proposed by V. Ratschi et al. but it has several parameters need to be tuned properly. Lately, Firefly Algorithm (FA) have been widely used in structural optimization and numerical optimization problems [20]-[21]. Although FA to seems to be better in speed of convergence but FA has some of disadvantage such as getting trapped into several local optima [22]. In [23], H. Zhang et al. stressed that Nature Inspired Algorithm (NIA) can be hybridized together with other algorithms to enhance itself to be more efficient, faster, robust and can reach global optima.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

This paper presents Modified Swarm Firefly Algorithm (MSFA) method in solving Directional Overcurrent Relay Coordination problem. The study discovered that the new algorithm known as MSFA which integrates both PSO and a part of Firefly Algorithm (FA) can improve the performance of PSO. In order to verify its performance, MSFA is applied to minimize relay operating time accordingly with an optimal TSM and with a given pickup current settings. The results from the study revealed that the proposed technique outperformed the PSO technique in terms of computation time.

2. PROBLEM FORMULATION

Directional overcurrent relay coordination problem can be stated as a constraint optimization problem. Directional overcurrent relay coordination setting becomes more difficult when there are many overcurrent relays to be coordinated in a system. This is where optimization method is required to search an optimal setting for the overcurrent relays. A. Mahari and H. Seyedi in [24] stated that in linear model programming problem, only TDS or TSM are optimized while I_{ps} are fixed at values between minimum fault current and maximum load current. In non-linear programming problem, TDS or TSM and Ips are optimized simultaneously. Therefore, the main objective of the directional overcurrent relay coordination in this paper is to find optimal TSM or TDS, objective function, relay characteristic, primary/backup relay pairs constraints, coordination constraints, type of relay that had been considered, boundary limits of the relays and discrete or continuous TSM or TDS relays. All of these requirements should be satisfied. In [14], M.M. Mohamed et al. did mentioned that directional overcurrent relay coordination allow for continuous TSM or TDS but discrete pickup current setting.

2.1 Objective Function

According to F. Razavi et al. in [10], the GA method cannot solve two major problems which are miscoordination problem between primary and backup relay pairs and discrete or continuous TSM of the relays. Thus, a new objective function and a new comprehensive GA are introduced to rectify the problems.

In order to solve heuristic optimization problem, a penalty method is used. This penalty method is introduced by adding penalty constraints such as Δ_t of primary and backup relay pairs to the original objective function. The penalty method is set carefully with high of order, 10^5. The objective function used in this paper is given below [10, 15]:

$$OF = \min\left(\alpha_1 \sum_{i=1}^{N} t_i^{\,2} + \alpha_2 \sum_{j=1}^{P} (\Delta t_{pb} - \beta_2(\Delta t_{pb} - |\Delta t_{pb}|))^2\right) \quad (1)$$

where

t_i	the i^{th} relay operating time for a fault near to the Circuit Breaker (CB) of the i^{th} relay
Δt_{pb}	the operation time difference for relay pairs
N	the number of relays
P	the number of primary/backup relay pairs
i	represents each relay and varies to N
α_1	control the weight of $\sum_{i=1}^{N} t_i^{\,2}$
α_2	control the weight of $\sum_{j=1}^{P} (\Delta t_{pb} - \beta_2(\Delta t_{pb} - \lvert\Delta t_{pb}\rvert))^2$
β_2	the parameter to consider miscoordination

In this study, the value of β_2 is determined by using the heuristic technique. The convenience value of β_2 is fit to the equation which miscoordination can be avoided. It should be noted that the objective of the directional overcurrent relay coordination problem is to minimize the summation operating times of primary relays, minimize the objective function and to avoid miscoordination problems occur between primary/backup relays.

2.2 Relay Characteristic

In this paper, the following equation (2) is used to approximately represent the inverse overcurrent relay characteristics and it is called the Sachdev model. It is assumed that all overcurrent relays have normally inverse overcurrent type and more commonly formulated by the following equation according to relay characteristics which are linearly proportional to TSM or TDS [10, 15, 25, 26].

$$\frac{t}{TSM} = a_1 + \frac{a_2}{M-1} + \frac{a_3}{(M-1)^2} + \frac{a_4}{(M-1)^3} + \frac{a_5}{(M-1)^4} \quad (2)$$

where M or Plug Setting Multiplier (PSM) is the ratio of relay short circuit current to the actual pickup current $M = \frac{I_{sc}}{I_{pickup}}$.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

a_1, a_2, a_3, a_4 and a_5 are the scalar quantities which characterized the particular device being simulated while t is the relay operating time.

Although today, digital relays or microprocessor relays with ANSI and IEC standard curves are used, however for static and electromechanical relays either ANSI or IEC standard formula or the equation 2 can be applied [10, 15, 26, 27].

2.3 Primary/Backup Relay Pairs and Coordination Constraints

Coordination constraints are associated to primary and backup relays. It is a common thing that every primary relay has its own backup relay to ensure dependable protection system. The primary relay operating time should be less than the backup relay to assure the protection system [15, 26]. This indicates that primary protection must clear fault as fast as possible in order to disconnect the part of the network system. Time grading margin called the Coordination Time Interval (CTI) must be included between the primary and backup relays operating time. Consider fault occurring is symmetrical balanced three phase fault. The relay is phase relay type. Relay p and b are the primary relay and backup relay, respectively. Figure 1 display where the fault occurred.

When fault occurs, both relays detect fault signal and start to operate simultaneously. These relays carry out the processing information provided by the Current Transformer (CT) and then issues trip signal to the Circuit Breaker (CB) so as the fault does not affect the whole system [15, 26]. Consider the fault happens near Relay R_{A1}. Relay R_{A1} is the primary relay while Relay R_{B1} is the backup relay. If Relay R_{A1} fails to operate, Relay R_{B1} will take action to operate. An appropriate time delay of the backup relay is set; R_{B1} is done in order to allow R_{B1} operates accordingly once the primary relay fails to operate.

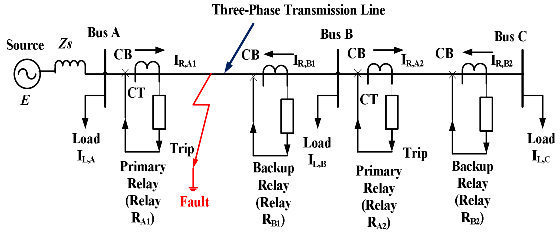

Figure 1: Example application of directional overcurrent relay for feeder protection

It should be noted that the coordination constraint should be expressed in equation below.

$$\Delta t_{pb} = t_b - t_p - CTI \tag{3}$$

where

t_b is the operating time of the backup relay due to fault

t_p is the operating time of the primary relay due to fault

CTI is the coordination time interval varies from 0.1 – 0.5s under different condition

To explain the role of coordination constraint, Δt_{pb}, consider the value is positive, the $(\Delta t_{pb} - \beta_2(\Delta t_{pb} - |\Delta t_{pb}|))$ will be equal to Δt_{pb}. However if Δt_{pb} is negative value, the expression will becomes:-

$$(\Delta t_{pb} - \beta_2(\Delta t_{pb} - |\Delta t_{pb}|)) = (1 + 2\beta_2)(\Delta t_{pb}) \tag{4}$$

Normally, the CTI used for microprocessor relays around 0.1 to 0.2s while CTI for electromechanical relays is 0.3 to 0.4s. CTI usually depends on type of relays, relay timing errors, CT error, speed of the circuit breaker and the overshoot time of the relay.

2.4 Bounds on Relay Operation Times and Bounds on TSM and PSM

Relay constraints covers the limits or ranges of relay operating time and settings. Based on the relay type, the operating time of relay is determined according to inverse curves. The bound is denoted as follows:

$$t_i \min \le t_i \le t_i \max, \quad i = 1,...m \tag{5}$$

where t_i min and t_i max are the minimum and maximum operating times of the i^{th} relay at the primary fault location.

The boundary constraints of TSM and I_p which is due to the limits in the value of relay settings are denoted as follows:

$$TSM_i \min \le TSM_i \le TSM_i \max, \quad i = 1,...m \tag{6}$$

$$I_{p_i} \min \le I_{p_i} \le I_{p_i} \max, \quad i = 1,...m \tag{7}$$

Journal of Theoretical and Applied Information Technology
31st August 2014. Vol. 66 No.3

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

The load currents should be less than pickup current and the pickup current should be lower than the minimum fault current with a reasonable security margin [28].

2.5 Continuous or Discrete TSM or TDS Relays

In [10], the author stressed that in order to find optimal coordination for relays setting, the TSM's or TDS's are based on continuous form for continuous TSM or TDS method. If TSM's or TDS's of the relays are in discrete form, the output programming results for each relay is rounded to the next upper allowable discrete value of the relevant relay [10]. Moreover, this method may affect coordination between primary/backup relays and may produce inaccuracies value.

However, for discrete TSM or TDS method, the output programming results are discrete directly [10]. The TSM's or TDS's are to be said discrete inherently. This means that for each relay, the TSM or TDS is in binary code. Therefore, there is no solution for relays inherently if TSM or TDS are in continuous form [10].

3. MODIFIED SWARM FIREFLY ALGORITHM (MSFA)

PSO was developed by Eberhart and Kennedy based on the analogy of swarm birds and schooling fish [29] but it suffers from a major drawback which is convergence to a local optimum and not to the global optimum. The premature convergence sometimes happened in a case of high dimension. The main reason why premature convergence happened is because the information flow between particles during optimization process can lead to increasing of being trapped in one of the local optimums [30]. In PSO, for the initial phase simulation, exploration is needed due to high velocities but after sufficient time, the velocities becomes smaller and even the nearest solution to the space is almost impossible to approach [31]. Many efforts have been made to address these issues. With the issues of having multiple local optima, it is proposed here that this problem can be addressed by modified the velocity equation so that the particles explore into region containing global best and converge to the best position.

In this paper, MSFA is developed and introduced to improve the search capability of PSO. The part of Firefly Algorithm (FA) which is the cartesian distance between two swarm fireflies is used in the PSO algorithm to accelerate convergence speed. In addition, MSFA is developed to solve optimization problems and slow convergence occurred by PSO. Generally, MSFA is incorporated into directional overcurrent relay coordination problem. Firstly, the primary/backup relay pairs are identified. Then, for each primary/backup relay pairs, the short circuit currents are calculated. The followings are the parameters that had been used during initialization.

Step 1: Initialization

In the first step of MSFA process, the parameters are assigned within a certain limits to ensure the particles cannot overfly the region. The followings are some of the parameters during initialization:

ω_{max}	maximum inertia weight
ω_{min}	minimum inertia weight
c_1	weight learning factor
c_2	weight learning factor
α	control parameter
P_a	mutation probability, ($0<P_a<1$)

Both maximum and minimum inertia weight will be explained in Step 3 while two positive constant, c_1 and c_2 are the learning factors. In MSFA algorithm, c_1 is a cognitive parameter which expresses the particle towards its own experience while c_2, a social parameter reflects the particle's confidence towards its neighbor.

According to Z. Wen and L. Yutian in [32], the setting with $c_1 = c_2$ indicates in both the *pbest* and *gbest* of the particles population are considered equally during the searching process. This condition is the best option in order to obtain the best solution. J. Kennedy and R. Eberhart in [28] defined that value of 2 is the most suitable value for the particles' exploration in the search space.

The control parameter, α value is selected carefully to ensure the particles explore of the search space within region while the mutation probability, P_a, is selected as 0.9 [33]. The mutation probability task is to control the behavior of the algorithm and improve the performance of PSO. Furthermore, P_a is required to prevent the premature convergence of the PSO to suboptimal solutions.

Journal of Theoretical and Applied Information Technology
31st August 2014. Vol. 66 No.3

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

The MSFA generate variable x_i. This x_i depends on the number of population size, number of dimensions and other variables. The value of N population sizes or particles varies from 50 to 150. This is to seek which population sizes in MSFA method produces better results for directional overcurrent relay coordination. Moreover, it is important that this parameter need to be addressed properly so as it can improve convergence speed. The dimension of the particles is referred to number of relays. The TSM's sets, i.e. (TSM_1, TSM_2,…TSM_{14}) which belong to relay R_1, R_2, …R_{14} are initially randomly selected. These TSM's sets of relays are rounded.

Step 2: Generate maximum velocity

In the basic PSO, velocities of particles on each dimension are clamped to a maximum velocity, V_{max}. The value of velocity is clamped between the range of $-V_{max}$ and V_{max} to ensure the particles don't fly out of the search space. According to [34], if the search space is defined by the bounds $-X_{max}$ and $X_{max,}$ the value of V_{max} is set as follows:

$$v_{\max} = kx_{\max} \tag{8}$$

where $0.1 \le k \le 1$

Step 3: Generate an inertia weight

An inertia weight is assigned to enable the population of the particles to have a high chance in obtaining global optimum results [15, 35]. This parameter plays an important task to determine the probability of the particles to search for global optimum search. This inertia weight is determined using linearly decaying proposed by author in [36]. It can be calculated by using eq. (9) below:

$$\omega_i = \omega_{\max} - \frac{\omega_{\max} - \omega_{\min}}{k_{\max}} \times k \tag{9}$$

where ω_{max} and ω_{min} are the maximum and minimum inertia weight, while k and k_{max} are the current and maximum iteration respectively.

In [36], the inertia weight value for maximum is specified as 0.9 while the minimum inertia weight ends at 0.4. This inertia weight value is selected properly to ensure the particles of the MSFA tend to have more global search ability in the beginning of initial searching.

Step 4: Fitness function evaluation

Each particle or population sizes in MSFA moves around in a multi-dimensional search space in order to look for the best solution. The swarm firefly memorizes its current position by evaluating the fitness function, the best position and the velocity during its searching space. This is referred as personal best or known as *pbest*. The *pbest* indicates the highest fitness value for that particle. The best position among all the *pbest* positions is commonly known as global best or *gbest*. M.M. Mohamed et al. in [14] explained that for minimizing a function, the position of having a smaller value is regarded as higher fitness.

Step 5: Update distance

In the FA, the distance between two fireflies' increases when the brightness of one firefly is decreases compared to the other one. The parameters r_{ij} as the distance between the i^{th} and j^{th} firefly can be evaluated in the Cartesian framework. However, in the MSFA, the distance between position, x_i and $pbest_i$ (in PSO algorithm) respectively is considered in the Cartesian framework:

$$\begin{aligned} r_{px} &= \| pbest_i - x_i(t) \| \\ &= \sqrt{\sum_{k=1}^{D} (pbest_{i,k} - x_{i,k})^2} \end{aligned} \tag{10}$$

where r_{px} is the distance between two swarm fireflies, p_{best} and x_i

As in PSO algorithm, *gbest* is also taken into account. The distance between position, x_i and $gbest_i$ can be evaluated in the Cartesian framework as follows:

$$\begin{aligned} r_{gx} &= \| gbest_i - x_i(t) \| \\ &= \sqrt{\sum_{k=1}^{D} (gbest_{i,k} - x_{i,k})^2} \end{aligned} \tag{11}$$

where r_{gx} is the distance between two swarm fireflies, g_{best} and x_i

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Step 6: Particle velocity calculation

When the value of *pbest* and *gbest* are determined, the velocity of particle is randomly mutated using MSFA equation (12):

$$v_i^{k+1} = \begin{cases} \omega v_i^k + c_1 rand \times (pbest_i - x_i^k) \\ + c_2 rand \times (gbest_i - x_i^k) \end{cases}, rand \le P_a$$

$$else \qquad (12)$$

$$v_i^{k+1} = \begin{cases} \omega v_i^k + rand \times e^{(-r_{px}{}^2)} \times (pbest_i - x_i^k) \\ + rand \times e^{(-r_{gx}{}^2)} \times (gbest_i - x_i^k) + \alpha(rand - 0.5) \end{cases}$$

where v_i^k is the earlier velocity of particle *i*, *rand* is the random numbers in the range of 0 and 1, c_1, c_2 are two positive constants, ω is the inertia weight, α is the control parameter.

Step 7: Update particle position

The new position of the particle can be calculated using equation (13) below:

$$x_i^{k+1} = x_i^k + v_i^{k+1} \qquad (13)$$

where x_i^k is the old position of the particle *i*, v_i^{k+1} is the new updated velocity of particle *i*.

Step 8: End condition

When the maximum number of iteration has been reached, MSFA will stop its processes. The complete algorithm of the MSFA into directional overcurrent relay coordination problem can be summarized in Fig. 2.

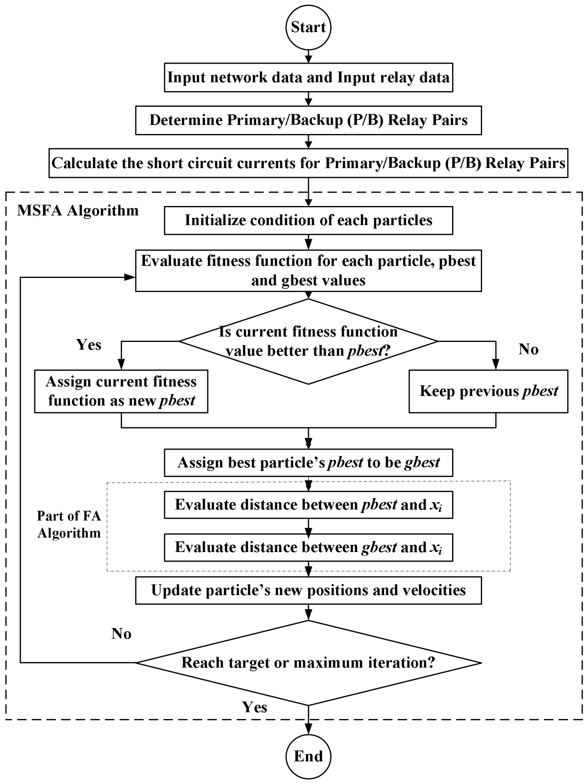

Figure 2: Complete Algorithm for MSFA

4. RESULTS AND DISCUSSION

The development of the MSFA method was simulated using MATLAB and executed on Intel Core i5 2.53 GHz with 4 GB RAM. The effectiveness of the proposed method was tested involving 8-Bus system and 9-Bus system. The effect of population or particle sizes to MSFA method is also investigated for both cases. In each case, the achieved results are compared with PSO algorithm.

To prove the effectiveness of MSFA technique, determination of α_1, α_2 and β_2 are important factor in order to evaluate the objective function. The variations of α_1, α_2 and β_2 are listed in Table 1.

Table 1: Parameter Variations.

Case Number	α_1	α_2	β_2
Case 1	1	2	100
Case 2	1	2	0

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

It is assumed that the TSM's of the relays varies from 0 to 1. The information of data network can be found in [10]. The characteristic coefficients; a_1, a_2, a_3, a_4 and a_5 for the directional overcurrent which are dependent on the type of relay are given in Table 2.

Table 2: Characteristic Coefficients.

a_1	a_2	a_3	a_4	a_5
1.98772	8.57922	-0.46129	0.0364465	-0.0003199

Case 1: Eight-Bus Test System

This case considers 8-Bus System which consists of 8 buses, 7 lines, 2 generators, 2 transformers and 14 overcurrent relays. The single line diagram of the test system is shown in Figure 3.

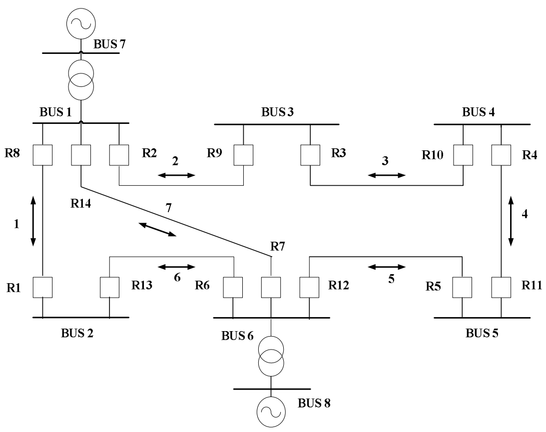

Figure 3:8-Bus test system

The short circuit current calculation for primary relay and backup relay is based on 100 MVA and 150 kV. The short circuit current of primary and backup relay is calculated for the fault near to the CB of the primary relay for each primary/backup relay. The units for primary relays and backup relays current are in Amperes. The information on pickup current settings for the 14 relays can be found in [27]. For phase protection, the pickup current is set 1.2 times maximum load current.

Table 3, Table 4 and Table 5 depicts the results of comparative studies between MSFA and PSO for Case 1, 8-Bus test system. These tables are considered as the best results among 30 runs for each population sizes and two cases of parameter variations with 500 iterations. Table 5 indicates the results for TSM values between different number of population size using MSFA and PSO techniques. For Case 1, when β_2 is 100, both MSFA and PSO contributes total TSM's with 1.63s. It can be observed that, the suitable population size is 100 compare to 50 and 150. This is due to lesser total TSM's compare to 50 but for 150, it took more computation time to produce 1.63s. For Case 2, when β_2 is not considered, the total TSM's for PSO technique seems to be much lesser than MSFA when number of population is 50 and 100 but MSFA exhibits much lesser total TSM's compare to PSO for 150 population size. By suitable selection of parameters values, Case 1 is considered the best choice in this study. This indicates that the selection of α_1, α_2 and β_2 for Case 1 is correct in ensuring miscoordination is avoided.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Table 3: Time Setting Multiplier Value of 8-Bus system

No. of Population Size												
	50				100				150			
Time Setting Multiplier (TSM)												
Cases	Case 1 [weight: α_1=1, α_2=2, β_2=100]		Case 2 [weight: α_1=1, α_2=2, β_2=0]		Case 1 [weight: α_1=1, α_2=2, β_2=100]		Case 2 [weight: α_1=1, α_2=2, β_2=0]		Case 1 [weight: α_1=1, α_2=2, β_2=100]		Case 2 [weight: α_1=1, α_2=2, β_2=0]	
Techniques / TSM No	MSFA	PSO	MSFA	PSO	MSFA	PSO	MSFA	PSO	MSFA	PSO	MSFA	PSO
TSM_1	0.08	0.09	0.04	0.04	0.08	0.08	0.04	0.04	0.08	0.08	0.04	0.04
TSM_2	0.21	0.22	0.07	0.06	0.21	0.21	0.08	0.07	0.21	0.21	0.08	0.08
TSM_3	0.14	0.14	0.03	0.01	0.14	0.14	0.05	0.01	0.14	0.14	0.05	0.05
TSM_4	0.04	0.04	0.03	0.01	0.04	0.04	0.02	0.01	0.04	0.04	0.02	0.01
TSM_5	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
TSM_6	0.22	0.19	0.10	0.10	0.18	0.18	0.10	0.10	0.18	0.18	0.10	0.10
TSM_7	0.14	0.18	0.06	0.06	0.14	0.14	0.08	0.08	0.14	0.14	0.08	0.08
TSM_8	0.16	0.19	0.03	0.07	0.16	0.16	0.09	0.09	0.16	0.16	0.09	0.09
TSM_9	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
TSM_{10}	0.07	0.07	0.03	0.03	0.07	0.07	0.04	0.01	0.07	0.07	0.01	0.04
TSM_{11}	0.16	0.14	0.05	0.04	0.14	0.14	0.06	0.01	0.14	0.14	0.04	0.06
TSM_{12}	0.29	0.27	0.09	0.07	0.27	0.27	0.11	0.09	0.27	0.27	0.11	0.11
TSM_{13}	0.06	0.06	0.02	0.01	0.06	0.06	0.03	0.03	0.06	0.06	0.03	0.03
TSM_{14}	0.13	0.12	0.06	0.06	0.12	0.12	0.06	0.06	0.12	0.12	0.06	0.06
Iteration	500											
total time setting multiplier (s)	1.72	1.73	0.63	0.58	1.63	1.63	0.78	0.62	1.63	1.63	0.73	0.77

Table 4: Relay Operating Time of 8-Bus system

No. of Population Size												
	50				100				150			
Relay Operating Time for a fault near to Circuit Breaker (CB) (t_i)												
Cases	Case 1 [weight: α_1=1, α_2=2, β_2=100]		Case 2 [weight: α_1=1, α_2=2, β_2=0]		Case 1 [weight: α_1=1, α_2=2, β_2=100]		Case 2 [weight: α_1=1, α_2=2, β_2=0]		Case 1 [weight: α_1=1, α_2=2, β_2=100]		Case 2 [weight: α_1=1, α_2=2, β_2=0]	
Techniques / t_i	MSFA	PSO	MSFA	PSO	MSFA	PSO	MSFA	PSO	MSFA	PSO	MSFA	PSO
t_1	0.3144	0.3536	0.1572	0.1572	0.3144	0.3144	0.1572	0.1572	0.3144	0.3144	0.1572	0.1572
t_2	0.7304	0.7652	0.2435	0.2087	0.7304	0.7304	0.2782	0.2435	0.7304	0.7304	0.2782	0.2782
t_3	0.5388	0.5388	0.1154	0.0385	0.5388	0.5388	0.1924	0.0385	0.5388	0.5388	0.1924	0.1924
t_4	0.2654	0.2654	0.1991	0.0664	0.2654	0.2654	0.1327	0.0664	0.2654	0.2654	0.1327	0.0664
t_5	0.0766	0.0766	0.0766	0.0766	0.0766	0.0766	0.0766	0.0766	0.0766	0.0766	0.0766	0.0766
t_6	0.6709	0.5794	0.3049	0.3049	0.5489	0.5489	0.3049	0.3049	0.5489	0.5489	0.3049	0.3049
t_7	0.4941	0.6353	0.2118	0.2118	0.4941	0.4941	0.2823	0.2823	0.4941	0.4941	0.2823	0.2823
t_8	0.4880	0.5795	0.0915	0.2135	0.4880	0.4880	0.2745	0.2745	0.4880	0.4880	0.2745	0.2745
t_9	0.0696	0.0696	0.0696	0.0696	0.0696	0.0696	0.0696	0.0696	0.0696	0.0696	0.0696	0.0696
t_{10}	0.3212	0.3212	0.1377	0.1377	0.3212	0.3212	0.1836	0.0459	0.3212	0.3212	0.0459	0.1836
t_{11}	0.6294	0.5507	0.1967	0.1574	0.5507	0.5507	0.2360	0.0393	0.5507	0.5507	0.1574	0.2360
t_{12}	0.8589	0.7997	0.2666	0.2073	0.7997	0.7997	0.3258	0.2666	0.7997	0.7997	0.3258	0.3258
t_{13}	0.2799	0.2799	0.0933	0.0466	0.2799	0.2799	0.1399	0.1399	0.2799	0.2799	0.1399	0.1399
t_{14}	0.5151	0.4755	0.2378	0.2378	0.4755	0.4755	0.2378	0.2738	0.4755	0.4755	0.2378	0.2378
Iteration	500											
total operating time of primary relays (s)	6.2527	6.2904	2.4017	2.1341	5.9532	5.9532	2.8915	2.2790	5.9532	5.9532	2.6752	2.8252

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From Table 4, there are fourteen relays operating time, t_1 to t_{14}. It is discovered that in Case 1 for 100 and 150 population sizes, both MSFA and PSO consumes same total operating time of primary relays, i.e. 5.9532s whereas MSFA and PSO consumes 6.2527s and 6.2904s for 50 population size. Both total operating time of primary relay using MSFA and PSO technique for population size 100 and 150 have been reduced to 4.79% and 5.34% compare to 50 population sizes respectively. This implies that both MSFA and PSO consume lesser time for 100 and 150 population sizes. However, it can be observed that the suitable population size is 100 compare to 150 due to execution time. It is also discovered that for Case 2, both MSFA and PSO consumes lesser time for 50, 100 and 150 population sizes. For 50 population size, MSFA consumes 2.4017s and PSO consumes 2.1341s. It can be seen also that there is slightly difference time for both techniques in 100 and 150 population sizes. The range of time is between 0.15s to 0.61s. The results obtained indicate that for 150 population size, MSFA consumes lesser time compare to PSO.

Table 5: Relay Coordination Time for each Relay Pairs of 8-Bus system

No. of Population Size												
	50				100				150			
Relay Coordination Time for each relay pairs, Δt_{pb}												
Cases	Case 1 [weight: α_1=1, α_2=2, β_2=100]		Case 2 [weight: α_1=1, α_2=2, β_2=0]		Case 1 [weight: α_1=1, α_2=2, β_2=100]		Case 2 [weight: α_1=1, α_2=2, β_2=0]		Case 1 [weight: α_1=1, α_2=2, β_2=100]		Case 2 [weight: α_1=1, α_2=2, β_2=0]	
Techniques / Δt_{pb}	MSFA	PSO	MSFA	PSO	MSFA	PSO	MSFA	PSO	MSFA	PSO	MSFA	PSO
** Δt_{89}	0	0	0	0	0	0	0	0	0	0	0	0
Δt_{87}	0.252	0.487	-0.002	-0.124	0.252	0.252	-0.022	-0.022	0.252	0.252	-0.022	-0.022
Δt_{27}	0.003	0.292	-0.157	-0.122	0.003	0.003	-0.030	0.004	0.003	0.003	-0.030	-0.030
Δt_{21}	0.067	0.182	-0.044	-0.009	0.067	0.067	-0.079	-0.044	0.067	0.067	-0.079	-0.079
Δt_{32}	0.037	0.084	-0.189	-0.159	0.037	0.037	-0.220	-0.112	0.037	0.037	-0.220	-0.220
Δt_{43}	0.045	0.045	-0.446	-0.415	0.045	0.045	-0.278	-0.415	0.045	0.045	-0.278	-0.212
Δt_{54}	0.065	0.065	-0.070	-0.341	0.065	0.065	-0.205	-0.341	0.065	0.065	-0.205	-0.341
** Δt_{65}	0	0	0	0	0	0	0	0	0	0	0	0
$\Delta t_{6,14}$	0.354	0.336	-0.047	-0.047	0.367	0.367	-0.047	-0.047	0.367	0.367	-0.047	-0.047
$\Delta t_{14,1}$	0.318	0.512	-0.021	-0.021	0.357	0.357	-0.021	-0.021	0.357	0.357	-0.021	-0.021
** $\Delta t_{14,9}$	0	0	0	0	0	0	0	0	0	0	0	0
Δt_{16}	0.203	0.038	-0.140	-0.140	0.036	0.036	-0.140	-0.140	0.036	0.036	-0.140	-0.140
$\Delta t_{9,10}$	0.027	0.027	-0.256	-0.256	0.027	0.027	-0.185	-0.398	0.027	0.027	-0.398	-0.185
$\Delta t_{10,11}$	0.115	0.011	-0.276	-0.328	0.011	0.011	-0.269	-0.393	0.011	0.011	-0.236	-0.269
$\Delta t_{11,12}$	0.009	0.016	-0.274	-0.306	0.016	0.016	-0.242	-0.117	0.016	0.016	-0.163	-0.242
$\Delta t_{12,14}$	0.156	0.107	-0.013	0.046	0.107	0.107	-0.072	-0.013	0.107	0.107	-0.072	-0.072
$\Delta t_{12,13}$	0.180	0.239	-0.186	-0.367	0.239	0.239	-0.006	0.052	0.239	0.239	-0.006	-0.006
$\Delta t_{13,8}$	0.021	0.152	-0.361	-0.139	0.021	0.021	-0.145	-0.145	0.021	0.021	-0.145	-0.145
** Δt_{75}	0	0	0	0	0	0	0	0	0	0	0	0
$\Delta t_{7,13}$	0.613	0.472	-0.109	-0.306	0.613	0.613	0.071	0.071	0.613	0.613	0.071	0.071
Iteration	500											
Computation time (s)	**126.33**	**123.61**	**142.949**	**174.777**	**217.897**	**224.436**	**288.714**	**269.445**	**359.371**	**370.090**	**383.575**	**450.656**
Objective Function (s)	**5.102**	**5.634**	**1.857**	**2.257**	**4.712**	**4.712**	**1.479**	**1.886**	**4.712**	**4.712**	**1.568**	**1.548**

Table 5 indicates 20 relay pairs for 50, 100 and 150 population sizes with computation time and objective function for both MSFA and PSO techniques as well as two cases. For Case 1, the objective function for both MSFA and PSO with 100 population size is considered as the best results, i.e. 4.712s compare to 50 and 150 population sizes. This is because 100 population sizes contribute less execution time. MSFA technique reaches global optimum after 275 iterations while PSO reach global optimum after 332 iterations. This shows that results by PSO technique reveal poor convergence compare to MSFA. In terms of computation time, MSFA exhibits 217.8976s which is 3% faster than PSO.

Journal of Theoretical and Applied Information Technology
31st August 2014. Vol. 66 No.3

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

The convergence curves for each method with 100 population size can be illustrated in Fig. 4.

It can also be seen that from Table 5, some values of Δt_{pb} are zero. For instance, the coordination time between relays 6 and 5 does not require coordination time as marked (**) in the table. This is due to relay 6 which is associated to a generator-transformer bus. In such case, coordination study is unnecessary [10]. Other primary relays with Δt_{pb} equal to zero are also linked to generator-transformer buses such as relays 8 and 9, relays 14 and 9 and relays 7 and 5.

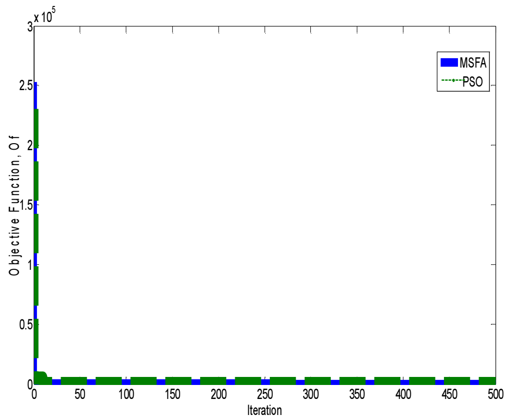

Figure 4: Convergence of MSFA and PSO for Case 1 with 100 population size 8-Bus test system

Case 2: Nine-Bus Test System

This case considers 9-Bus System which consists of 9 buses, 6 lines, 3 generators, 3 transformers and 12 overcurrent relays. The single line diagram of the test system is shown in Figure 5. The information on pickup current settings for the 12 relays can be found in [37]. For phase protection, the pickup current is set 1.5 times maximum load current.

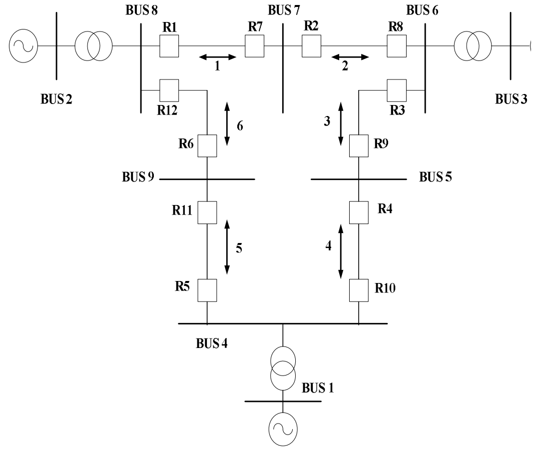

Figure 5:9-Bus test system

Table 6, Table 7 and Table 8 depicts the results of comparative studies between MSFA and PSO for Case 2, 9-Bus test system. These tables are considered as the best results among 30 runs for each population sizes and two cases of parameter variations with 500 iterations.

Table 6 indicates the results for TSM values between different number of population size using MSFA and PSO techniques. For Case 1, β_2 is 100, MSFA contributes total TSM's with 3.73s compare to PSO with 3.77s. It can be observed that, the suitable population size is 100 compare to 50 and 150. This is due to lesser total TSM's compare to 50 but for 150, it took more computation time to produce 3.73s. For Case 2, when β_2 is not considered, the total TSM's for PSO technique seems to be lesser when number of population is increased from 50 to 150 but MSFA exhibits same total TSM's which is 0.85s.

From Table 7, there are twelve relays operating time, t_1 to t_{12}. It is discovered that in Case 1 for 150 population size, both MSFA and PSO consumes same total operating time of primary relays, i.e. 12.2314s while PSO consumes 12.3742s and MSFA consumes 12.2314s for 100 population size. As for 50 population size, both MSFA and PSO consume 12.6196s and 12.4439s. This implies that both MSFA and PSO consume lesser time for 100 and 150 population sizes.

It is also discovered that for Case 2, MSFA consumes more total operating time of relays for 50, 100 and 150 population sizes compare to PSO technique.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Table 6: Time Setting Multiplier Value of 9-Bus system

	No. of Population Size											
	50				100				150			
	Time Setting Multiplier (TSM)											
Cases	Case 1 [weight: $\alpha_1=1$, $\alpha_2=2$, $\beta_2=100$]		Case 2 [weight: $\alpha_1=1$, $\alpha_2=2$, $\beta_2=0$]		Case 1 [weight: $\alpha_1=1$, $\alpha_2=2$, $\beta_2=100$]		Case 2 [weight: $\alpha_1=1$, $\alpha_2=2$, $\beta_2=0$]		Case 1 [weight: $\alpha_1=1$, $\alpha_2=2$, $\beta_2=100$]		Case 2 [weight: $\alpha_1=1$, $\alpha_2=2$, $\beta_2=0$]	
Techniques TSM No	MSFA	PSO	MSFA	PSO	MSFA	PSO	MSFA	PSO	MSFA	PSO	MSFA	PSO
TSM_1	0.42	0.42	0.09	0.09	0.42	0.43	0.09	0.01	0.42	0.42	0.09	0.01
TSM_2	0.34	0.34	0.07	0.07	0.34	0.35	0.07	0.01	0.34	0.34	0.07	0.01
TSM_3	0.34	0.34	0.08	0.08	0.34	0.35	0.08	0.03	0.34	0.34	0.08	0.01
TSM_4	0.17	0.17	0.04	0.04	0.17	0.18	0.04	0.01	0.17	0.17	0.04	0.01
TSM_5	0.33	0.32	0.08	0.08	0.32	0.32	0.08	0.01	0.32	0.32	0.08	0.01
TSM_6	0.29	0.29	0.07	0.07	0.29	0.29	0.07	0.01	0.29	0.29	0.07	0.01
TSM_7	0.30	0.30	0.06	0.02	0.29	0.29	0.06	0.06	0.29	0.29	0.06	0.05
TSM_8	0.50	0.47	0.10	0.01	0.46	0.46	0.10	0.10	0.46	0.46	0.10	0.08
TSM_9	0.31	0.30	0.07	0.03	0.29	0.29	0.07	0.07	0.29	0.29	0.07	0.06
TSM_{10}	0.33	0.32	0.07	0.04	0.31	0.31	0.07	0.07	0.31	0.31	0.07	0.05
TSM_{11}	0.18	0.18	0.04	0.01	0.17	0.17	0.04	0.04	0.17	0.17	0.04	0.01
TSM_{12}	0.34	0.34	0.08	0.04	0.33	0.33	0.08	0.08	0.33	0.33	0.08	0.05
Iteration	500											
total time setting multiplier (s)	3.85	3.79	0.85	0.58	3.73	3.77	0.85	0.50	3.73	3.73	0.85	0.36

Table 7: Relay Operating Time of 9-Bus system

	No. of Population Size											
	50				100				150			
	Relay Operating Time for a fault near to Circuit Breaker (CB) (t_i)											
Cases	Case 1 [weight: $\alpha_1=1$, $\alpha_2=2$, $\beta_2=100$]		Case 2 [weight: $\alpha_1=1$, $\alpha_2=2$, $\beta_2=0$]		Case 1 [weight: $\alpha_1=1$, $\alpha_2=2$, $\beta_2=100$]		Case 2 [weight: $\alpha_1=1$, $\alpha_2=2$, $\beta_2=0$]		Case 1 [weight: $\alpha_1=1$, $\alpha_2=2$, $\beta_2=100$]		Case 2 [weight: $\alpha_1=1$, $\alpha_2=2$, $\beta_2=0$]	
Technique t_i	MSFA	PSO	MSFA	PSO	MSFA	PSO	MSFA	PSO	MSFA	PSO	MSFA	PSO
t_1	1.1825	1.1825	0.2534	0.2534	1.1825	1.2106	0.2534	0.0282	1.1825	1.1825	0.2534	0.0282
t_2	1.0285	1.0285	0.2117	0.2117	1.0285	1.0587	0.2117	0.0302	1.0285	1.0285	0.2117	0.0302
t_3	0.9034	0.9034	0.2126	0.2126	0.9034	0.9300	0.2126	0.0797	0.9034	0.9034	0.2126	0.0266
t_4	0.9856	0.9856	0.2319	0.2319	0.9856	1.0435	0.2319	0.0580	0.9856	0.9856	0.2319	0.0580
t_5	1.0610	1.0288	0.2572	0.2572	1.0288	1.0288	0.2572	0.0322	1.0288	1.0288	0.2572	0.0322
t_6	1.0111	1.0111	0.2440	0.2440	1.0111	1.0111	0.2440	0.0349	1.0111	1.0111	0.2440	0.0349
t_7	1.0986	1.0986	0.2197	0.0732	1.0619	1.0619	0.2197	0.2197	1.0619	1.0619	0.2197	0.1831
t_8	1.2922	1.2146	0.2584	0.0258	1.1888	1.1888	0.2584	0.2584	1.1888	1.1888	0.2584	0.2067
t_9	1.0554	1.0213	0.2383	0.1021	0.9873	0.9873	0.2383	0.2383	0.9873	0.9873	0.2383	0.2043
t_{10}	1.0506	1.0188	0.2229	0.1273	0.9869	0.9869	0.2229	0.2229	0.9869	0.9869	0.2229	0.1592
t_{11}	1.0216	1.0216	0.2270	0.0568	0.9648	0.9648	0.2270	0.2270	0.9648	0.9648	0.2270	0.0568
t_{12}	0.9291	0.9291	0.2186	0.1093	0.9018	0.9018	0.2186	0.2186	0.9018	0.9018	0.2186	0.1366
Iteration	500											
total operating time of primary relays (s)	12.6196	12.4439	2.7957	1.9053	12.2314	12.3742	2.7957	1.6481	12.2314	12.2314	2.7957	1.1568

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Table 8: Relay Coordination Time for each Relay Pairs of 9-Bus system

No. of Population Size												
50					100				150			
Relay Coordination Time for each relay pairs, Δt_{pb}												
Cases	Case 1 [weight: α_1=1, α_2=2, β_2=100]		Case 2 [weight: α_1=1, α_2=2, β_2=0]		Case 1 [weight: α_1=1, α_2=2, β_2=100]		Case 2 [weight: α_1=1, α_2=2, β_2=0]		Case 1 [weight: α_1=1, α_2=2, β_2=100]		Case 2 [weight: α_1=1, α_2=2, β_2=0]	
Techniques	MSFA	PSO	MSFA	PSO	MSFA	PSO	MSFA	PSO	MSFA	PSO	MSFA	PSO
Δt_{pb}												
Δt_{16}	0.052	0.052	-0.258	-0.258	0.052	0.024	-0.258	-0.371	0.052	0.052	-0.258	-0.371
Δt_{21}	0.014	0.014	-0.302	-0.302	0.014	0.018	-0.302	-0.395	0.014	0.014	-0.302	-0.395
Δt_{32}	0.001	0.001	-0.344	-0.344	0.001	0.013	-0.344	-0.441	0.001	0.001	-0.344	-0.388
Δt_{43}	0.019	0.019	-0.301	-0.301	0.019	0.003	-0.301	-0.334	0.019	0.019	-0.301	-0.416
Δt_{54}	0.014	0.047	-0.310	-0.310	0.047	0.133	-0.310	-0.345	0.047	0.047	-0.310	-0.345
Δt_{65}	0.053	0.009	-0.288	-0.288	0.009	0.009	-0.288	-0.390	0.009	0.009	-0.288	-0.390
Δt_{78}	0.109	0.012	-0.298	-0.441	0.017	0.017	-0.298	-0.298	0.017	0.017	-0.298	-0.325
Δt_{89}	0.027	0.050	-0.270	-0.259	0.020	0.020	-0.270	-0.270	0.020	0.020	-0.270	-0.273
$\Delta t_{9,10}$	0.031	0.020	-0.323	-0.321	0.009	0.009	-0.323	-0.323	0.009	0.009	-0.323	-0.379
$\Delta t_{10,11}$	0.024	0.056	-0.295	-0.445	0.006	0.006	-0.295	-0.295	0.006	0.006	-0.295	-0.477
$\Delta t_{11,12}$	0.021	0.021	-0.287	-0.287	0.035	0.035	-0.287	-0.287	0.035	0.035	-0.287	-0.244
$\Delta t_{12,7}$	0.037	0.037	-0.345	-0.418	0.019	0.019	-0.345	-0.345	0.019	0.019	-0.345	-0.308
Δt_{16}	0.052	0.052	-0.258	-0.258	0.052	0.024	-0.258	-0.371	0.052	0.052	-0.258	-0.371
Iteration					500							
Computation time (s)	**80.361**	**93.601**	**87.889**	**86.641**	**153.450**	**164.181**	**152.520**	**139.238**	**249.593**	**238.964**	**255.703**	**257.266**
Objective Function (s)	**13.437**	**13.021**	**2.859**	**3.118**	**12.574**	**12.897**	**2.859**	**3.190**	**12.574**	**12.574**	**2.859**	**3.370**

Table 8 indicates 12 relay pairs for 50, 100 and 150 population sizes with computation time and objective function for both MSFA and PSO techniques as well as two cases. For Case 1, the objective function for both MSFA and PSO with 100 population size is considered as the best results, i.e. 12.5740s compare to 50 and 150 population sizes. This is because 100 population sizes contribute less execution time. MSFA technique reaches global optimum after 265 iterations while PSO reach global optimum after 244 iterations. Although MSFA technique slightly reveals poor convergence compare to PSO, MSFA still contributes minimum fitness function compare to PSO. In terms of computation time, MSFA exhibits 153.4509s which is 10.7308s faster than PSO. The convergence curves for each method with 100 population size can be illustrated in Fig. 6.

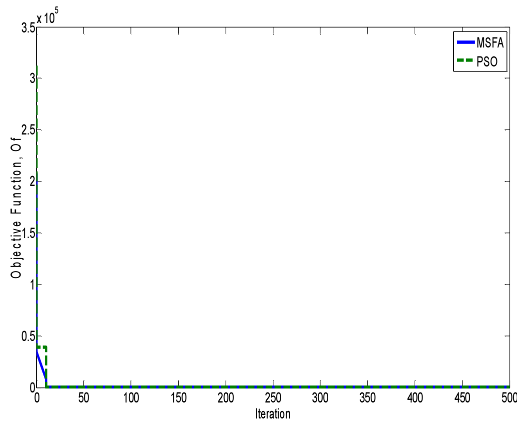

Figure 6: Convergence of MSFA and PSO for Case 1 with 100 population size 9-Bus test system

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

5. CONCLUSION

This paper has presented the new method called as MSFA in solving directional overcurrent relay coordination problem. The effectiveness of MSFA was successfully implemented and tested on the 8-Bus test system and 9-Bus test system. From the results, it can be revealed that the proposed MSFA technique demonstrates significant results in 50, 100 and 150 population sizes for two cases to avoid miscoordination in relay operation as compared to PSO. As conclusion, the suitable population size for the two cases is 100 based on the less computation time and minimum fitness value for every simulation. In terms of computation time, MSFA is faster than PSO which is feasible to be implemented in a larger system.

ACKNOWLEDGEMENT

The authors would like to acknowledge The Research Management Institute (RMI) 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).

REFRENCES:

[1] Y. G. Painthakar and Bhide, S.R., "Fundamentals of Power System Protection," 5th ed: Prentice-Hall of India Private Limited, New Delhi, 2007.

[2] P.M. Anderson, “Power System Protection”, McGraw-Hill, New York, 1999.

[3] M.H. Hussain, I. Musirin, S.R.A. Rahim, and A.F. Abidin, “Computational Intelligence Based Technique in Optimal Overcurrent Relay Coordination: A Review”, *The International Journal of Engineering And Science (IJES)*, Vol.2, Issue 1, Jan 2013, pp. 01-09.

[4] M.H. Hussain, S.R.A. Rahim, I. Musirin, “Optimal Overcurrent Relay Coordination: A Review”, *Procedia Engineering 53*, 2013, pp. 332-336.

[5] S.A. Raza, T. Mahmood, S.B.A. Bukhari, M.K. Nawaz, “Application of Optimization Techniques in Overcurrent Relay Coordination – A Review”, *World Applied Sciences Journal,* vol 28, issue 2, 2013, pp. 259-265.

[6] V. S. Chaudhari, V.J. Upadhyay, "Coordination of overcurrent relay in interconnected power system protection," in *National Conference on Recent Trends in Engineering & Technology*, 2011.

[7] A. J. Urdaneta, Nadira, R. and Perez, L., "Optimal coordination of directional overcurrent relay in interconnected power systems," *IEEE Transactions on Power Delivery,* vol. 3, 1988, pp. 903-911.

[8] C. W. So, K.K. Li, K.T. Lai, K.Y. Fung, "Application of genetic algorithm for overcurrent relay coordination," in *IEEE Conference Developments in Power System Protection,* 1997, pp. 66-69.

[9] C. W. So, K.K. Li, "Overcurrent relay coordination by evolutionary programming," *Electric Power Systems Research,* vol. 53, 2000, pp. 83-90.

[10] F. Razavi, Abyaneh, H.A., Al-Dabbagh, M., Mohammadi, R., Torkaman, H. , "A new comprehensive genetic algorithm method for optimal overcurrent relays coordination " *Electric Power Systems Research,* vol. 78, 2008, pp. 713-720.

[11] D.P. Kothari, “Power System Optimization”, *2nd National Conference on Computational Intelligence and Signal Processing (CISP)*, 2012, pp. 18-21.

[12] J. Senthilnath, S.N. Omkar and V. Mani, “Clustering using Firefly Algorithm: Performance Study”, *Swarm and Evolutionary Computation*, vol.1, 2011, pp. 164-171.

[13] H. H. Zeineldin, E.F. El-Saadany, M.M.A. Salama, "Optimal coordination of overcurrent relays using a modified particle swarm optimization," *Electric Power Systems Research,* vol. 76, pp. 988-995, 2006.

[14] M. M. Mohamed, Said, F.M., Nehad, E.E., "A modified particle swarm optimizer for the coordination of directional overcurrent relays," *IEEE Transactions on Power Delivery,* vol. 22, 2007, pp. 1400-1410.

[15] M.H. Hussain, I. Musirin, S.R.A. Rahim, A.F. Abidin, A. Azmi, “Optimal Overcurrent Relay Coordination Using Particle Swarm Optimization”, *2013 International Conference on Electrical, Control and Computer Engineering, (InECCE 2013),* 2013, pp.42-47.

[16] A. Kordon and A.K. Kordon, “Swarm Intelligence: The Benefits of Swarms”, Springer-Verlag Berlin Heidelberg, *Applying Computational Intelligence,* pp. 145-174, 2010.

[17] D. Uthitsunthorn, Pao-La-Or, P., Kulworawanichpong, T. , "Optimal overcurrent relay coordination using artificial bees colony algorithm " in *ECTI-CON 2011 - 8th Electrical*

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Engineering/ Electronics, Computer, Telecommunications and Information Technology (ECTI) Association of Thailand - Conference 2011, 2011, pp. 901-904.

[18] M.El-Mesallamy, W. El-Khattam, A. Hassan, H. Talaat, "Coordination of directional overcurrent relays using Artificial Bees Colony", 22nd *International Conference and Exhibition on Electricity Distribution (CIRED 2013*, 2013, pp. 1-4.

[19] V. Rashtchi, Gholinezhad, J., Farhang, P. , "Optimal coordination of overcurrent relays using Honey Bee Algorithm " in *2010 International Congress on Ultra Modern Telecommunications and Control Systems and Workshops, ICUMT 2010* 2010, pp. 401-405.

[20] A.H. Gandomi, X.S. Yang, A.H. Alavi, "Mixed variable structural optimization using Firefly Algorithm", *Journal Computer and Structures*, vol. 89, 2011, pp. 2325-2336.

[21] S.L. Tilahun, H.C. Ong, "Modified Firefly Algorithm", *Journal of Applied Mathematics*, Hindawi Publishing Corporation, vol. 2012, pp. 1-12.

[22] S.K. Pal, C.S. Rai, A.P. Singh, "Comparative Study of Firefly Algorithm and Particle Swarm Optimization for Noisy Non-Linear Optimization Problems", *International Journal Intelligent Systems and Applications*, 2012, pp. 50-57.

[23] H. Zang, S. Zhang and K. Hapeshi, "A Review of Nature-Inspired Algorithms", *Journal of Bionic Engineering*, vol.7, supplement, 2010, pp. S232-S237.

[24] A. Mahari, H. Seyedi, "An analytic approach for optimal coordination of overcurrent relays", *IET Generation, Transmission & Distribution,* Vol.7, Issue 7, 2013, pp. 674-680.

[25] H. A. Abyaneh, M. Al-Dabbagh, H.K. Karegar, S.H,H Sadeghi and R.A.H. Khan, "A new optimal approach for coordination overcurrent relay s in interconnected power systems," *IEEE Transactions on Power Delivery,* vol. 18, 2003, pp. 430-435.

[26] M.H. Hussain, I. Musirin, A.F. Abidin, S.R.A. Rahim, "Directional Overcurrent Relay Coordination Using Modified Swarm Firefly Algorithm Considering the Effect of Population Size", *2014 IEEE 8th International Power Engineering and Optimization Conference (PEOCO 2014)*, 2014, pp. 591-596.

[27] R. Mohammadi, Abyaneh, H.A., Razavi, F., Al-Dabbagh, M., Sadeghi, S.H.H., "Optimal relays coordination efficient method in interconnected power systems," *Journal of Electrical Engineering,* 2010, vol. 61, pp. 75-83.

[28] Amraee, T., "Coordination of Directional Overcurrent Relays Using Seeker Algorithm", *IEEE Transactions on Power Delivery*, 2012, vol.27, pp. 1415-1422.

[29] J. Kennedy and R. Eberhart, "Particle Swarm Optimization", *Proceedings of IEEE International Conference on Neural Networks (ICNN'95) Perth, Australia: IEEE Press*; Vol. IV, 1995, pp. 1942-1948.

[30] B. Yang and Q. Zhang, "*Frame Sizing and Topological Optimization Using a Modified Particle Swarm Algorithm*", Second WRI Global Congress, Intelligent Systems (GCIS), 2010, pp. 43-46.

[31] F. Van Den Bergh and A.P. Engelbrecht, "A New Locally Convergent Particle Swarm Optimizer", 2002 IEEE International Conference On Systems, Man and Cybernetics", Vol.3, 2002.

[32] Z. Wen and L. Yutian, "Reactive power optimization based on PSO in practical power system", *IEEE Power Engineering Society General Meeting*, Vol.1, pp. 239-243, June 2004.

[33] Z. Pengjun, L. Sanyang and C. Guo, "Modified Particle Swarm Optimization for Optimization Problems", Journal of Theoritical and Applied Information Technology, Vol. 46, No. 2, 2012, pp. 610-614.

[34] F.V.D. Bergh, "An analysis of particle swarm optimizer", Ph. D. dissertation, University Pretoria, Pretoria, South Africa, 2001.

[35] L.Y. Wong, M.H. Sulaiman, S.R.A. Rahim & O. Aliman, "Optimal Distributed Generation Placement using Hybrid Genetic-Particle Swarm Optimization", *International Review of Electrical Engineering (IREE)*, Vol.3, Issue 6, June 2011.

[36] Y. Shi and R. Eberhart, "Empirical study of particle swarm optimization", *Proceedings of the 1999 congress on the Evolutionary Computation*, Vol.3, Washington DC, July 1999.

[37] S. Niyomphant, T. Kulworawanichpong, U. Leeton and N. Chomnawang, "Application of Linear Programming for Optimal Coordination of Directional Over-current Relays", " in *ECTI-CON 2012 - 9th Electrical Engineering/ Electronics, Computer, Telecommunications and Information Technology (ECTI) Association of Thailand - Conference 2012,* 2012, pp. 978-981.