Moth-Flame Optimization Technique for Optimal Coordination of Directional Overcurrent Relay System

A Dissertation submitted in fulfilment of the requirements for the Degree

of

MASTER OF ENGINEERING

in

Power Systems

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DECLARATION

I hereby certify that the work presented in the dissertation entitled, **"Moth -Flame Optimization Technique for Optimal Coordination of Directional Overcurrent Relay System"**, in partial fulfilment of the requirements for the award of the degree of Master of Engineering in power systems, submitted to **Electrical and instrumentation Engineering Department of Thapar Institute of Engineering and Technology**, Patiala, is an authentic record of my own work carried under the supervision of **Dr. Nitin Narang.** It refers other researcher's work which are duly listed in the reference. The matter contained in this dissertation has not been submitted, neither in part nor in full to any other university or institute for award of any degree except as reported in text and references.

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It is certified that the above statements made by the student is correct to the best of my knowledge and belief.

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CERTIFICATE

Certified that the dissertation entitled, "**Moth-Flame Optimization Technique for Optimal Coordination of Directional Overcurrent Relay System**", which is being submitted by **Rahul Dhiman** in fulfilment of the requirements of the award of the Master of Engineering in Power Systems in Thapar Institute of Engineering and Technology, Patiala is a bona-fide record of the candidate's own work carried out by him under my supervision and guidance. The matter contained in this dissertation has not been submitted, neither in part nor in full to any university or institute for award of any degree.

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ACKNOWLEDGEMENT

It is a great pleasure for me to take this opportunity to express my gratitude to all those who assisted me in the completion of this dissertation. I gratefully acknowledge my supervisor **Dr. Nitin Narang** for his understanding, encouragement and personal attention which has provided good and smooth basis for my dissertation work. This work would not have been possible without his guidance, support and encouragement. Under his guidance, I have successfully overcome many difficulties and learned a lot. I would also like to thank **Ms. Manbir Kaur**, Associate Professor, EIED, to provide all the useful guidelines for making this dissertation.

I am also thankful to my seniors and friends who devoted their valuable time for the successful completion of this dissertation. I extend my gratitude to the researchers and scholars for their support.

I also acknowledge with a deep sense of reverence, my gratitude towards my parents and members of my family, who have always supported me morally as well as economically and inherited the strength to carry out dissertation work with sincerity and dedication.

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ABSTRACT

The protection devices have an important role in modern power system. The operation of electric power system network majorly depends on combinatorial working of relays, circuit breakers and other protection devices. The power system reliability is improved majorly by installing two types of relays *i.e.,* primary and backup relays. Initially, the primary relay operates for any faulty condition to give fast response. For any condition primary relay fails to trip, then backup relays perform same task after some time interval. The coordinated operation of primary and backup relay is important to prevent any malfunctioning due to time gap. The coordination between primary and backup relay is a nonlinear optimization problem. In this dissertation work, optimal coordination of directional over current relay is achieved using moth-flame optimization algorithm. The moth-flame optimization is population-based technique applied for calculating optimal settings of the relay with faster convergence for primary relay and better performance coordination with backup relays. Relays setting configurations includes time multiplier settings, plug settings multiplier and pickup current settings. Relay coordination is done using continuous decision variables *i.e.,* time multiplier settings and pickup current. The technique is implemented on IEEE 8-bus test system without external grid and results are compared to other techniques results.

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CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

With the advancement of new technology in modern power system, there are many hazardous activities takes place, which has many disadvantages. To prevent from such activities protection devices are required for safety purpose in the electrical system. The basic aim of every protection mechanism is to stop transient imbalanced current present in system and to isolate the faulty section so that other section remains safe. Earlier, fuse device is mainly used for the removal or avoidance of the high voltage from the circuits. The main advantage of the fuse is utilizing the security of the circuits that basically rely on the breaker that represents its simplicity and efficiency. Once fuse melts, unless it's replaced the energization does not take place instantly. Overcurrent relays also offer primary protection as well as their backup protection. Protective relaying is particularly attractive for the sound execution of electrical system. The directional overall current relay (DOCR) is needed for over current protection. Power system protection comprises of relays, circuit breaker and current transformer. The pre-set value is the maximum load current supported by any load during their continuous activity. In case of fault, current transformer (CT) tends to generate high fault current and relay carries the information provided by the CT and compares with settings of the relay whether to trip or not. The main requirement is to make the primary relays to operate as fast as possible to ensure the safety of the electrical network in balanced conditions. Due to some reasons, there occur some malfunction which causes the interrupted working of the primary relays. This results in the less security of the networks. To avoid such situations and to provide full security to the network, backup relays need to be used to handle such kind of situations. The point of coordinating the DOCR is to run over the adjustment in settings that decrease the procedure time to most extreme values for fault inside the protection zone and there is some pre-decided time for backup relay. It is fundamental that primary relay must have adequate opportunity to protect the zone. If the primary relay fails to operate the backup relay should start operating to clear the fault and a specific time interval must be provided between the operating time of backup relay pairs. Restrepo *et al.* [1] The basic issue is the coordination between primary and backup action. That is the key for basic presentation of an overcurrent relay. The extent of current with pre-set value is set by plug setting multiplier (PSM). The directional overcurrent relay employs a principle of actuation of the relay. When fault current flows into the relay in a specific direction and power flow in inverse direction the relay will not operate. The primary or backup relays are used for protection of power system and increasing the reliability of the system. This is a standard hypothesis that all individual primary relays have their own backup relay for the arrangement of protection network. The execution interval for primary relay must be sooner than the beginning of activity of backup relay for smooth protection mechanism. The certain time interval (CTI) is essential for proper coordination between primary and backup relays.

The DOCR has been utilized as the solution for the primary as well as backup protection of power networks. Primary and backup relays perform simultaneous operation for preventing any disturbance occurring due to improper time interval. Because of this it becomes constraint optimization problem and power system structure may increase its non-linearity. In order to solve this optimization problem and to reduce the overall operating time, the researchers have applied various optimization techniques. The main idea to coordinate relays is to minimize the operating time of DOCR by selecting the appropriate values of relays settings. This problem of optimization can be solved by using several algorithms and techniques. Different algorithms were used and tested that showed the improvement in terms of lower CTI for the circuits. Some of the models are not accurate to handle the complex and non-linear problems of the circuits.

The nature-inspired global optimization algorithms have been proposed to solve hard constraint optimization problems. The global optimization algorithms provide more robust and reliable solution for the real network problems of optimizations. Moth-flame optimization (MFO) algorithm is one of the global optimization algorithms that can provide an efficient and required solution for the optimization problem. The MFO algorithm work on the principles of the moths and flames to find the best optimal solution for the entire population of the moths and have a special navigation technique known as transverse orientation. The MFO algorithm has several advantages as compared to the other algorithms in terms of efficiency and optimization. In this dissertation work, the MFO algorithm is applied to optimize the coordination time interval between the operation of the primary and backup relays and converge to an optimal point in the search space.

1.2. LITERATURE SURVEY

In the past few years, several optimization techniques have been implemented to achieve the best coordination arrangements of a DOCR. In the past, researchers have focussed on minimizing the operating time between primary and backup relay in DOCR. The manual computation of the large complex optimization problems would require more time and were less accurate. In present, the presence of numerous metaheuristic techniques has helped the researchers to attain more reliable and accurate solutions.

The complete literature survey for optimization of DOCR tripping time is based on classical linear techniques, global optimization techniques, artificial based approach and many more techniques in different span of time. Moravej *et al.* [2] focussed on minimizing the time delay from backup to primary relay by applying non-sorting genetic algorithm (NSGA-II). Majid *et al*. [3] concentrated on constraints by which minimization of time dial and value is step by step expanding. Adelnia *et al*. [4] adopted genetic algorithm for optimization problem. The existence of discrimination time is reduced, however multi-loop violation may occur. Albasri *et al.* [5] utilized the hybrid structure of biogeography-based optimization with linear programming for the minimization of operating time of DOCR. Bhide *et al*. [6] have focussed on mal-task of the relay to maintain a strategic distance from the system, which requires less capacity. Singh *et al*. [7] proposed artificial based optimization technique on electromechanical over current relay for looped control network. Ezzeddine *et al*. [8] based on parameter tuning has been applied autonomously, by setting optimal pick up value, time characteristics and TMS discrete value. Panigrahi *et al.* [9] introduced teaching learning-based optimization looped network optimization of operating time of primary and backup relay by utilizing far vector LINKNET structure, data handling with technique for coordination of relay parameters. Thakur *et al.* [10] presented the fuses real coded genetic algorithm, the bounded exponential crossover and power mutation to change the dispose of discoordination. The seeker algorithm for mixed integer function was introduced with their search direction and step length in flexible way. The performance of seeker algorithm is better than TDS and PSM linear and non-linear models which is based on human way procedure [11]. Zeineldin *et al.* [12] have presented the altered version of particle swarm optimization with a population of random arrangement. Pant *et al.* [13] have presented the multi modal objective function and settled scaling factor 'F' based on Laplace appropriation by new mutation technique to solve DOCR problem. This technique enhances convergence up to half and keep up coordination by expanding efficiency. Zellagui *et al.* [14] have presented modified electromagnetic field optimization with different polarity for DOCR problem. Sadeh *et al.* [15] proposed different framework in various plans to avoid blackout in transmission units and new crossover genetic algorithm strategy has been applied to solve DOCR problem. Hussain *et al.*

[16] have descripted different forms of nature inspired or meta-heuristic to decrease calculation burden and strategy is applied to solve DOCR problem. Adelina *et al*. [17] presented optimal coordination of interconnected system by enhancing objective function and reducing the operating time. However, the presence of discrimination time decreased for P/B relay and violation may happen in multi-loop system. Thangaraj *et al*. [18] proposed two opposition based chaotic differential evolution for obtaining optimum solution which is capable of finding superior TDS and PSM settings. Alipour *et al.* [19] proposed improved group search optimization (IGSO) by applying changes to GSO to enhance searching ability and has been applied for DOCR problem. Azari *et al.* [20] have presented a solution through network splitting in two phases, one phase finds the individual optimal solution of sub network and other phase provides optimal setting tie line connecting with sub organize network. Leite *et al*. [21] have presented an evolutionary particle swarm optimization technique for large DOCR coordination problem. Singh *et al.* [22] have proposed a co-variance mechanism utilizing matrix auto updating apparatus with the assistance of LINKNET and blends of primary/backup relays. Albasri *et al.* [23] utilized the hybrid structure of BBO-LP for the minimization of operating time of DOCR. Hizam *et al*. [24] have provided the method to find the settings of relay as per time-current curve. A hybrid genetic algorithm with artificial neural network (GA-ANN) approach is utilized to achieve global values. Biswarup *et al*. [25] have compared the solution strategy on various relative analysis with genetic algorithm, differential algorithm, harmony search, PSO on DOCR problem and concluded that DE provides better performance among others proposed algorithm.

Thakur *et al*. [26] have incorporated the bounded exponential crossover and power mutation into real coded genetic algorithm and produces very efficient settings of TMS and PSM. Alipour *et al*. [27] have presented IGSO by applying a few alterations to the GSO to enhance its searching ability with improved convergence performance for DOCR problem. Albrecht *et al.* [28] tried to investigate that digital computer can replace the routine aspects of diverse settings of the relays. However, it may be done by highly experienced relay engineer to validate a sequential procedure for that solution. Venkata *et al.* [29] presented a design network analysis to find primary and backup relay pairs, settings overcurrent relays and described a problem on distance relays, and using computer aided transmission protection system. Urdaneta *et al*. [30] have solved the problem on interconnected power system by direct and decomposition techniques on large area optimization network upto 30 buses system. Rao *et al.* [31] determined the requirement of sequential network with minimum number of break points. It can be actualized on computer and structure the essential part of the computer aided design for protective system. Jenkins *et al*. [32] developed a topology to set relay at minimal break point in the form of relative sequence matrix with reduces computational costs.

Thangaraj *et al*. [33] developed a modified version of DE, which requires only one parameter *i.e.*, crossover parameter to tune the algorithm with successful convergence rate and has been applied to solve DOCR problem. Moirangthem *et al.* [34] introduced proper settings of the discrete nature of time dial settings and pickup current settings in adaptive DE algorithm by coordinating overcurrent relay. Panigrahi *et al.* [35] presented self-adaptive re-clustering technique for both continuous and discrete with the help of LINKNET graph structure and results have been obtained from hybrid genetic algorithm using non-linear programming. Conde *et al.* [36] compared three approaches conventional, discrete and continuous and real time with the best coordination pairs in electrical networks. The PSO technique has been applied for optimal coordination of DOCR for best suitable settings and increased the performance of the relays. Mansour *et al.* [37] have implemented modified PSO for best optimal results of DOCR to improve the computational speed and memory requirements. Mirjalili *et al*. [38] presented improved binary PSO for DOCR problem which is having, better convergence rate by updating position vectors with the introduction of V-shaped family transfer functions. Asadi *et al*. [39] proposed quantized approach PSO for continuous and discrete decision variables to maintain coordination between the relays. Zellagui *et al*. [40] proposed an approach based on mixed integer in the wind energy farms (WEF) using PSO on inverse time relay.

Restrepo *et al.* [41] have utilized the linear formulation for the system for which change in settings is not required, consequently, it requires less calculation, however it requires high operating time. Chattopadhyay *et al*. [42] have proposed simplex two-phase method, which determines relay optimal settings in the looped distribution system. Moravej *et al*. [43] have solved primary and backup relay coordination problem by NSGA-II. Razavi *et al*. [44] have introduced GA algorithm to reduce the coordination time by searching continuous and discrete settings of TSM and TDS. Damchi *et al.* [45] have performed interval linear programming (ILP) technique on distance and directional overcurrent relay problem. Marcolino *et al.* [46] used GA for over reaching transfer trip with replication of protection schemes. Amraee [47] presented seeker algorithm which is based on non-linear programing and human working method for DOCR problem. Benabid *et al.* [48] presented firefly algorithm with an inductive fault current limiter, which has huge influence on the system coordination. Saleh *et al*. [49] descripted new time-current-voltage to avoid the disturbance in the direct generation tripping by which prominent reduction has been achieved in complete relay coordination.

Birla *et al.* [50] have applied non-linear method of Banes and Boons to achieve near end fault removal optimality. Alipour *et al*. [51] presented an improved GSO and apply some alterations for their better searching ability of DOCR settings. Meng *et al*. [52] have proposed enhanced DE like, dial decrease arrangement, elitism, weakness, mutation index renew arrangement and population reduction and tested on DOCR problem. Alam *et al*. [53] have applied interior point-based scheme in meshed networks and validated the result with comparison to different algorithm like DE, GA on two test system one is small, and another is medium size. Sueiro *et al.* [54] presented evolutionary and linear programming to compute adjustment intensity and time factor in triphasic and biphasic failure. Razavi *et al.* [55] presented embedded crossover PSO (MECPSO) technique for distance relay. Salazar *et al.* [56] have proposed a hybrid scheme for accurate time coordination for inverse time and short-circuit current relays.

Correa *et al.* [57] have done topological change in the network which increases speed and are very sensitive to the faults. Othman *et al.* [58] presented enhanced backtracking algorithm for DOCR in distributed generation. Bedekar *et al*. [59] have introduced a hybrid GA and non-linear programming algorithm for DOCR problem. Adhikari *et al.* [60] have compared the performance of bacteria foraging algorithm for solving the optimal settings of the relays with other techniques and found satisfactory. Thangaraj *et al.* [61] presented the modified differential evolution with local neighbourhood search used for optimal settings of relays. Hussain *et al.* [62] have presented modified swarm firefly algorithm to solve directional overcurrent relay. Zellagui *et al.* [63] have presented a technique based on hybrid particle swarm optimization and applied for coordination of IDMT directional over current relay. Bakar *et al.* [64] torque approach has been used for network relay coordination.

In past years, many global optimization techniques were developed taking into the account the natural or physical activities. Every technique has its own some advantages and disadvantages. Moth-flame optimization algorithm (MFO) was proposed in 2015, with the purpose to offer the advantages of major mechanism. It is a novel nature-inspired heuristic paradigm. The main theme is based on navigation method of moth in nature is called transverse orientation. An evaluation of all the literature is deliberated in a methodical manner to simplify the impression of MFO and its prolonged alternatives proposed, and these are discussed.

Allam *et al.* [65] have tested different techniques for the multi-crystalline solar cell module and found that a moth-flame algorithm is more beneficial in terms of speed and accuracy. Wang *et al.* [66] have compared different techniques on Parkinson's disease and breast cancer and found that chaotic moth-flame technique gives better efficient results. Ewees *et al*. [67] have applied MFO to solve image segmentation problem. Singh *et al.* [68] presented MFO to solve optical network unit optimization problem. Nature based technique can maintain exploration and exploitation and beneficial in solving constrained optimization problem [69]. Das *et al.* [70] presented an MFO for 3-ring structure of concentric circular antenna array (CCAA) problem. Rebecca *et al.* [71] have given MFO to solve optimal reactive power dispatch problem. Jangir *et al*. [72] worked on real challenging constrained optimization by implement MFO and compare with other techniques. Zawbaa *et al.* [73] proposed selection process criteria wrapper-based feature selection method with MFO. Khamron *et al*. [74] solved multilevel threshold problem by applying MFO and compare with different algorithms for image segmentation. Salma *et al.* [75] introduced contingency analysis to reduce the burden on power system security by static synchronous series compensator with implementation of MFO technique. Chauhan *et al*. [76] presented a solution of single level production planning by implementing MFO algorithm. Gope *et al.* [77] provided more and more benefits to consumers under double sided bidding by applying MFO algorithm under congested system. Hemeida *et al*. [78] have applied MFO for radial system for optimum allocation of capacitor bank.

1.3. SOLUTION APPROACH

In this work, the main motive for choosing the MFO algorithm is its effectiveness and robustness in comparison other optimization strategies. The Moths fly in the night by maintaining fixed angle with respect to artificial light source in straight path for longer distances. It works on navigation mechanism *i.e.*, transverse orientation. The MFO shows a fine balance between exploration and exploitation capability which helps to achieve global best solution. In the dissertation work, the MFO technique is applied to solve directional over current coordination problem. The time multiplier setting, and peak current are the decision variables of the problem and it is subjected to various constraints. The standard IEEE test system has been undertaken and results are compared with other published results.

1.4. ORGANIZATION OF DISSERTATION

The dissertation titled as **"Moth-Flame Optimization Technique for Optimal Coordination of Directional Overcurrent Relay System"** has been discussed in five chapters. **Chapter 2** presents problem formulation for optimal coordination of directional overcurrent relays. **Chapter 3** provides an overview about the moth-flame optimization algorithm technique. **Chapter 4** describes the details regarding the implementation of moth-flame optimization algorithm for continuous non-linear coordination approach. **Chapter 5** presents the results and discussion for the test system. The conclusion and future scope has been presented in **Chapter 6** followed by references and appendix.

CHAPTER 2

PROBLEM FORMULATION FOR DIRECTIONAL OVER-CURRENT RELAYS COORDINATION

2.1. BACKGROUND

The need of coordination is to maintain a proper balance between the primary and back up directional overcurrent relays. The coordination provides suitable settings to provide fast response with suitable coordination time interval. The main aim of relay coordination is to secure the power system by rapidly isolating the faulted sections and to protect healthy system. In case, primary relays start operating, the backup relay protection system resets without issuing a trip condition signal. If the primary relay system fails to operate, then back relay should wait for specified coordination time interval and issue a trip command to the relevant circuit breakers. The full protection scheme should satisfy all the constraints. Primary and backup relay perform simultaneously for preventing any disturbances occurring due to the improper time interval between them. Hence, the coordination between primary and backup relay is a complex optimization problem [17]. The relays have different settings *i.e.*, time multiplier settings (TMS), pickup current (Ip) and plug settings multiplier (PSM) to deal with various types of faults. The fundamental requirement of DOCR coordination is to minimize the procedure time with suitable relay setting along with satisfaction of all the constraints. A schematic procedure of optimal coordination of DOCR problem has been shown in Fig. 2.1.

It is evident from Fig. 2.1 every primary relay has its own backup relays for safety purpose. In abnormal condition, both relays should not initiate the tripping signals simultaneously, so that imbalance transient conditions do not occur and whole of the system becomes safe and secure. The proper settings should be done so that relay should trip in required time [42]. The IEC gives an inverse characteristics curve for operating time of different relays based on their configurations or their features *i.e.*, very inverse, extremely inverse and standard inverse.

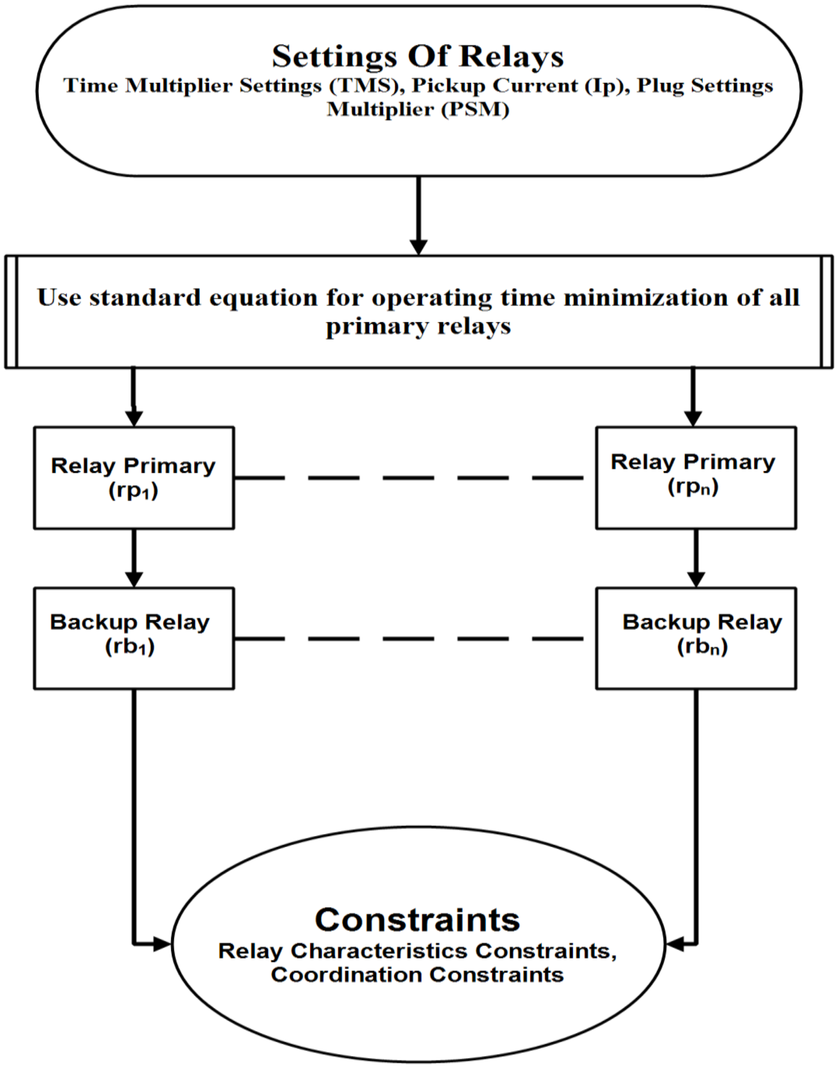

Fig. 2.1: Representation for coordination of DOCR system

2.2 PROBLEM FORMULATION

This problem is stated as an optimization problem. The problem is formulated as a constrained optimization problem and given as follows:

$$\text{Minimize OF(s)} \tag{2.1}$$

$$\text{Subjected to } g(s) = 0 \tag{2.2}$$

$$\text{and } h(s) \leq 0 \tag{2.3}$$

where s is the vector of design variables; OF (s) is the objective function; g (s) is the set of equality constraints; and h (s) is the set of inequality constraints.

2.2.1. Objective function

The main aim of the coordination of DOCR is to minimize the operating time of the relays by proper settings of TMS, and Ip of each relay. The objective function can be formulated as [16]:

$$\text{Objective function (OF):} \quad \sum_{i=1}^{N} \omega_i \, OT_i \tag{2.4}$$

where, weight (ω_i) is the zone protection probability and it is set to 1 for the protection of each zone. The (OT_i) represents operating time of the i^{th} relays, *'N'* is the representation of primary relays.

The IEC provides a relation for inverse characteristics overcurrent relays which is given as:

$$OT_i = \frac{a \times TMS^i}{\left(\frac{I_F^i}{I_P^i}\right)^b - c}, \; i = 1, 2, \ldots\ldots N \tag{2.5}$$

where $a = 0.14$, $b = 0.02$ and $c = 1$ are set for inverse current characteristics.

2.2.2. Constraints

The various constraints need to satisfy for the feasibility of the solution. Broadly, constraints are divided into two categories: (a) Bounds of relay settings constraints and (b) Coordination constraints. These are discussed as:

(a) Bounds of relay settings constraints

Every relay has a range of various settings, in which variables should be set. The operating bounds of the overcurrent relay have shown below:

$$OT_{min}^i \leq OT^i \leq OT_{max}^i \tag{2.6}$$

$$Ip_{min}^i \leq Ip^i \leq Ip_{max}^i \tag{2.7}$$

$$TMS_{min}^i \leq TMS^i \leq TMS_{max}^i \tag{2.8}$$

where OT_{min}^i and OT_{max}^i are the minimum and maximum values for operating time of i^{th} relay, respectively; Ip_{min}^i and Ip_{max}^i are the minimum and maximum values for pickup current of the i^{th} relay, respectively; TMS_{min}^i and TMS_{max}^i are the minimum and maximum values for time multiplier settings of the i^{th} relay, respectively.

(b) Coordination constraints

When primary relay is in proper working condition and at the instant of fault, it should act. However, due to any reason if primary relay fails to operate then backup relay should perform the same function after coordination time interval. The Fig. 2.2 represents the primary and backup relay combined working condition. In this figure, Relay *j* provides the backup protection for Relay *i*.

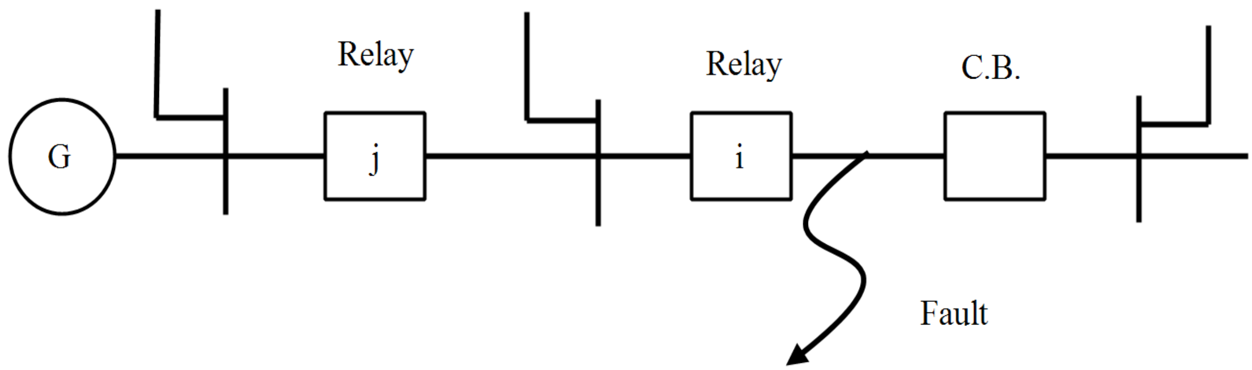

Fig. 2.2: Sample illustration of primary and backup relay fault

Whenever fault condition occurs in the system, the DOCR works in coordination to protect the whole network from unhealthy condition. The coordination constraint is given as [35]:

$$\mathrm{OT}^{backup} - \mathrm{OT}^{primary} \geq CTI \tag{2.9}$$

where OT^{backup} and $OT^{primary}$ are the operating time of primary and backup relays, respectively; CTI is the coordinated time interval and normally it is set in the range between 0.2sec to 0.5sec. To maintain the reliability of the system, CTI should not be high for large current fault.

CHAPTER 3

MOTH-FLAME OPTIMIZATION ALGORITHM

3.1 INTRODUCTION

Moth-flame optimization is proposed in the 2015 by Mirjalili [69], which is the novel nature-inspired heuristic paradigm algorithm. Mirjalili have introduced an MFO technique by taking into consideration of previous approaches and build a new optimal method. This method is slowly established by various researchers those have applied MFO to solve different optimization problems. The MFO technique is growing day by day due to better convergence results. The MFO algorithm is adequate to solve optimization problems and search global best solution. Due to better optimized results, this technique is the best suitable as compared to another globalized algorithm. The results obtained by MFO technique is better as compared to different well-known and recent developed algorithm *i.e.*, binary algorithm, GA, PSO. The MFO algorithm use a population of moths to perform optimization and each moth is required to update their positions with respect to the flame [71]. This process assistance the moth to avoid the local optima entrapment and recover the exploration process in the search space. More specifically, it is based on phenomenon of transverse orientation. The motivation for this work, is obtained from the navigating nature of moth and design. The brief history about algorithm and mathematical solution is discussed below:

3.2 MOTH-FLAME OPTIMIZATION ALGORITHM

Basically, the algorithm is modelled on moth and flame. Moths are the fancy insects having the same species of butterfly and the milestones for their living is larvae [69]. The MFO is based on transverse orientation for navigation due to which it is evolved to fly in night using any artificial source lights by keeping the fixed angle with respect to light and travels along the larger distances path. Artificial source lights are the basic reason that attract the moth such as moon light, man-made lights source etc. This is the reason it maintains particular angle and travel along that in straight line due to inefficiency of the transverse orientation [71]. Moths flying at night by preserving a fixed angle with respect to moon, this special mechanism is very useful for moving in straight path when source of light is away, however when source of light is nearby moths fly in spiral path around it. The search agents are moths that moves close to search space and the best position in search space of moth is the best position of flame updated.

It is illustrated from Fig. 3.1 the light is the main source where convergence of moths takes place by maintaining similar angle and this behaviour is modelled mathematically [69].

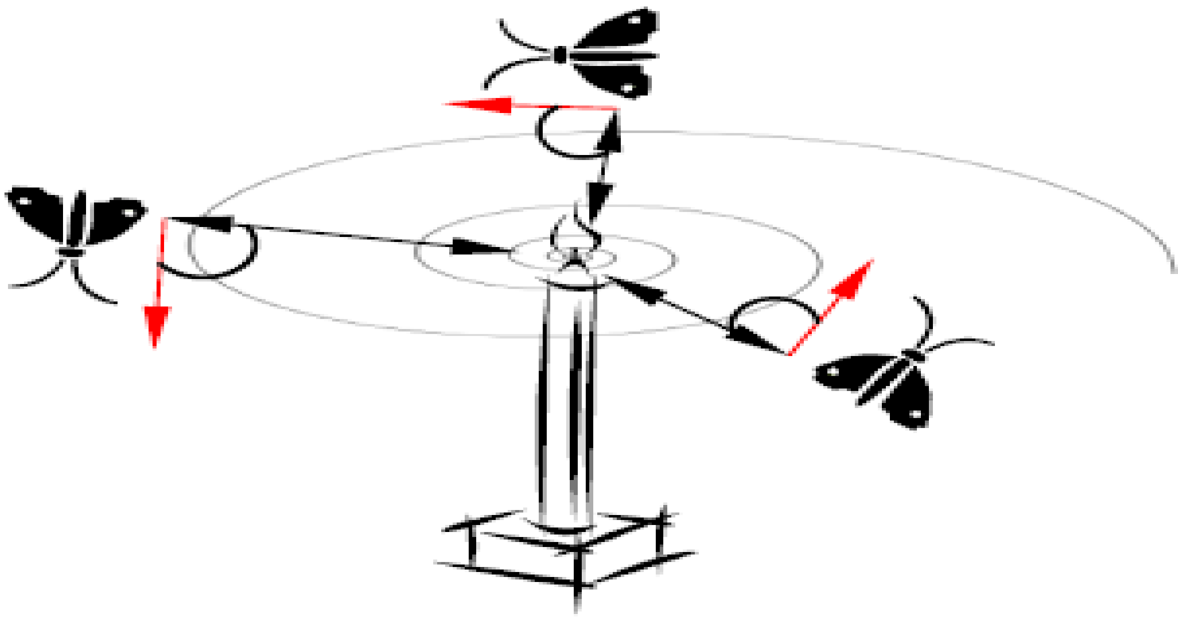

Fig. 3.1: Artificial light source for moths in spiral flying path [69]

3.2.1. Steps for implementing MFO algorithm

(1) The minimum and maximum range of variables, variable dimension, maximum iteration.

(2) The moths are the best solution and flames are the best position of moths. So, each moth search around the spiral path created around the flame to find a best possible position.

(3) The MFO works on the principle of transverse orientation for navigation and maintain a fixed angle with that artificial source lights to find best position.

3.2.2. Pseudo code of the MFO algorithm

The Pseudo code of the MFO algorithm is described as [71]:

Initialization of code:

Initialized moth's positions

while (iteration < max iteration)

if (iteration ==1)

moths first population sorted

flames updated accordingly

else

sort the moths

flames again updated

end if

best flame position updated obtained so far

for (i = 1: size (*NM_1*))

for (j = 1: size (*NM_2*))

if (i $\leq NF$)

update the moths position with respect to its corresponding flame using $M_i = S(M_i, F_j)$

end if

if (i $> NF$)

update the moths position with respect to only one flame

end if

end if

end while

print the best results obtained as output.

where, *'NF'* is the flame number, *NM_1* and *NM_2* are the number of moth's position 1 and 2 respectively.

3.2.3. Mathematical formulation of updating moths, spiral path and distance

The moths and problem variables are the positions of moths in the search space. The first key mechanisms are moth which are given as:

$$M = \begin{pmatrix} m_{1,1} & m_{1,2} & \dots & \dots & m_{1,d} \\ m_{2,1} & m_{2,2} & \dots & \dots & m_{2,d} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ m_{n,1} & m_{n,2} & \dots & \dots & m_{n,d} \end{pmatrix} \quad (3.1)$$

where n represents the number of moths; d represents the number of variables; m represents moths.

The objective function is sorted and represented in an array as:

$$OM = \begin{pmatrix} OM_1 \\ OM_2 \\ \vdots \\ OM_n \end{pmatrix} \tag{3.2}$$

where OM is the objective function value for moth.

The Second key mechanism are flames which is explained below:

$$F = \begin{pmatrix} F_{1,1} & F_{1,2} & \dots & \dots & F_{1,d} \\ F_{2,1} & F_{2,2} & \dots & \dots & F_{2,d} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ F_{n,1} & F_{n,2} & \dots & \dots & F_{n,d} \end{pmatrix} \tag{3.3}$$

where n is the number of moths; and F is flames.

There is an array for storing fitness value of flame

$$OF = \begin{pmatrix} OF_1 \\ OF_2 \\ \vdots \\ OF_n \end{pmatrix} \tag{3.4}$$

where OF is the objective function value which is assigned to the corresponding flame.

Moths & flames represent solutions; however, moths are updated according to flames in each iteration because flames are the best positions for the moths in updating process. To make this algorithm in working mode, the positions of each moth is updated with respect to the different flames and given as [71]:

$$M_i = S\ (M_i, F_j) \tag{3.5}$$

where $'M_i'$ represents the position of i^{th} moth; $'F_j'$ represents the j^{th} flame position; *'S'* represents spiral function to find the best position of moth.

In order to update the moth around the flame the logarithmic spiral function is the main process of MFO algorithm and following conditions should be under consideration.

- Initial updating of moth takes place from spiral starting point.
- The flame position should be finalized where spiral function reaches its final position.
- The spiral function should not violate its range during any type of disturbances occurred.

The Logarithmic spiral equation defined for MFO algorithm is presented as:

$$S\ (M_i, F_j) = D_i .\ e^{bt} .\ \cos(2\pi t) + F_j \tag{3.6}$$

where, $'D_i'$ represents the distance of the i^{th} moth for the j^{th} flame; '*b*' represents shape of logarithmic spiral; *'t'* is random number; $'S'$ is the spiral function.

According to Eq. (3.6) moths tends to shift its position according to flames local optimal position. After updating each moth corresponding to flame, the first position of moth assigned to the best fitness flame and last moth is assigned to the worst flame. If all moths are assigned to single flame, then all converge to search space then exploration occurred high and local optima probability decreases. The distance between flames is computed as:

$$D_i = |\ F_j - M_i\ | \tag{3.7}$$

where $'F_j'$ represent as j^{th} flame position;$'M_i'$ represents as i^{th} moth position.

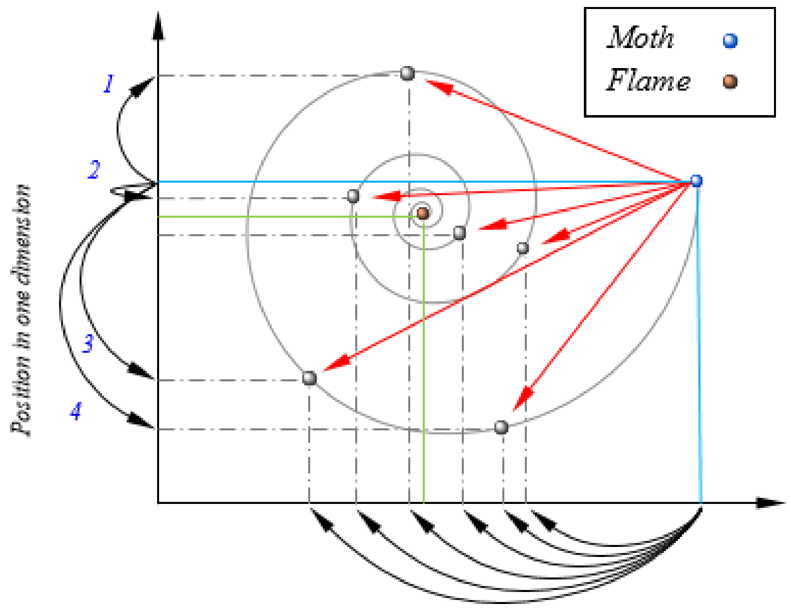

Fig. 3.2: Temporary positions of moths in spiral path around the flame [71]

The spiral path is to guarantee that a moth flies around a flame and not in the space between them. In Fig. 3.2 spiral path around the flame and the moths update their positions. The exploration takes place when positions updating mechanism between the moth and flame space lies to next position outside. However, exploitation takes place, when positions updating device between the moth and flame space lies next position inside. The final step is the best position of moth around the flame in spiral path over course of iteration. The following equation is used for this concern:

$$Flame\ no = round\ (N\text{-}l \times \frac{N-1}{T}) \tag{3.8}$$

where *'l'* specifies present number of iteration; *'N'* signifies maximum number of flames; *'T'* maximum number of iterations.

During every iteration procedure, the number of flames decreases in order to maintain the balance between exploration and exploitation. The steady decrement in the number of flames stabilities exploration and exploitation in the search space. For the best moth position, the best flame should be selected from previous iteration and the best objective function value should be obtained according to the best flame.

CHAPTER 4

MOTH-FLAME OPTIMIZATION ALGORITHM FOR DIRECTIONAL OVER-CURRENT RELAY SYSTEM

4.1 IMPLEMENTATION

Moth-flame optimization is a population-based algorithm inspired by one of the singular types of fancy insects ‘moths’. The greatest motivating fact about moths is the special navigation technique in night to fly using moon light and the transverse orientation mechanism is used. They make spiral path around artificial light provide best objective function value to settle. The step-wise procedure of applying moth-flame optimization algorithm for continuous decision variables is described below:

Read the input values

Relays basic functional values like time multiplier settings *(TMS),* pickup current (I_p), the operating time fault current values (I_f) and coordination time interval *(CTI)* for each relay, minimum and maximum limit of decision variables, parameters of algorithm and termination criteria.

Initialization

The search space has ‘*N’* different locations of moths that should be updated. The best optimal solutions may be achieved after degradation. As per Eq. (3.1) moth’s matrix represents candidate solution. The best solution should be set accordingly in upper bound and the worst solution should be set accordingly in the lower bound.

$$M = (m_{n1}, m_{n2}, m_{n3}......m_{nd})$$

where, *‘n’* no. of moths and *‘d’* no. of dimension.

A mathematical formulation is applied considering within ranges to get approximate result. There are two arrays, upper bound (ub) and lower bound (lb) represented as follows:

$$ub = [ub_1, ub_2, ub_3......ub_{n-1}, ub_n], lb = [lb_1, lb_2, lb_3.........lb_{n-1}, lb_n]$$

where, lb_i represents the minimum limit or lower bound of the i^{th} variable; ub_i represents the maximum limit or upper bound of the i^{th} variable.

The uniformly distributed random number is used, and moths are generated between minimum and maximum values and are given as follows:

$$M_{ji} = (\text{ub(i)} - \text{lb(i)}) \times \text{num} + \text{lb(i)} \quad (4.1)$$

where 'num' is the random number lies between 0 and 1.
In order to apply MFO on DOCR problem, decision variables are time multiplier settings *(TMS)* and pickup current *(Ip)* so, *M = [TMS, Ip]* and these are randomly generated as:

$$Ip_j^i = (Ip_{max}^i - Ip_{min}^i) \times \text{num} + Ip_{min}^i \quad (4.2)$$

$$TMS_j^i = (TMS_{max}^i - TMS_{min}^i) \times \text{num} + TMS_{min}^i \quad (4.3)$$

where, TMS_{min}^i and TMS_{max}^i are the minimum and maximum time multiplier settings of i^{th} dimension, respectively; Ip_{min}^i and Ip_{max}^i are the minimum and maximum of pickup current of i^{th} dimension, respectively; Ip_j^i is the pickup current for i^{th} dimension of j^{th} MFO particle; TMS_j^i is the time multiplier settings for i^{th} dimension of j^{th} MFO particle.

Update moth position

In order to find the best optimal solution around the search space, up gradation of *'n'* different moth's position may degrade the exploitation. The number of flames is decreased over the sequence with iteration as:

$$\textit{Flame no.} = \textit{round}\ (N - l \times \frac{N-1}{T}) \quad (4.4)$$

where *'l'* indicates the iteration count; *'N'* indicates the maximum flame number; *'T'* indicates maximum number of iterations.

To find the distance between the flames and moths Eq. (3.7) is used and for DOCR variables I is given as:

For *IP*, $$DIp_{ij} = | Ipf_j - Ipm_i| \quad (4.5)$$

For *TMS*, $$DTMS_{ij} = | TMSf_j - TMSm_i| \quad (4.6)$$

where, DIp_{ij} and $DTMS_{ij}$ is the distance between Ip and TMS from i^{th} moth for the j^{th} flame; Ipf_j indicates pickup current for j^{th} flame; Ipm_i indicates pickup current for i^{th} moth; $TMSf_j$ indicates time multiplier settings of j^{th} flame; $TMSm_i$ indicates time multiplier settings of i^{th} moth.

For updating moths around the flame, the logarithmic spiral path is chosen. Spiral has some conditions, it start from moth's positions and finally reached around the flame best position. The up-gradation process is take place by using Eq. (3.6) and for DOCR coordination it can be stated as:

For *IP*, $$SIpm_{ij} = dIp_{ij} \times \exp(b \times t) \times \cos(2 \times 3.14 \times t) + IPf_{ij} \quad (4.7)$$

For *TMS,* $$STMSm_{ij} = dTMS_{ij} \times \exp(b \times t) \times \cos(2 \times 3.14 \times t) + TMSf_{ij} \quad (4.8)$$

where, dIp_{ij} and $dTMS_{ij}$ represent the distance of the decision variables from i^{th} moth to j^{th} flame; 't' is the random number between [1, -2]; and 'b' is constant which determines logarithmic spiral shape.

Each position of moths is updated with respect to flames around the spiral path and represented as:

For *IP*, $$M_i = SIpm_{ij} \quad (4.9)$$

For *TMS,* $$M_i = STMSm_{ij} \quad (4.10)$$

The implementation steps are described in flowchart as shown in Fig. 4.1.

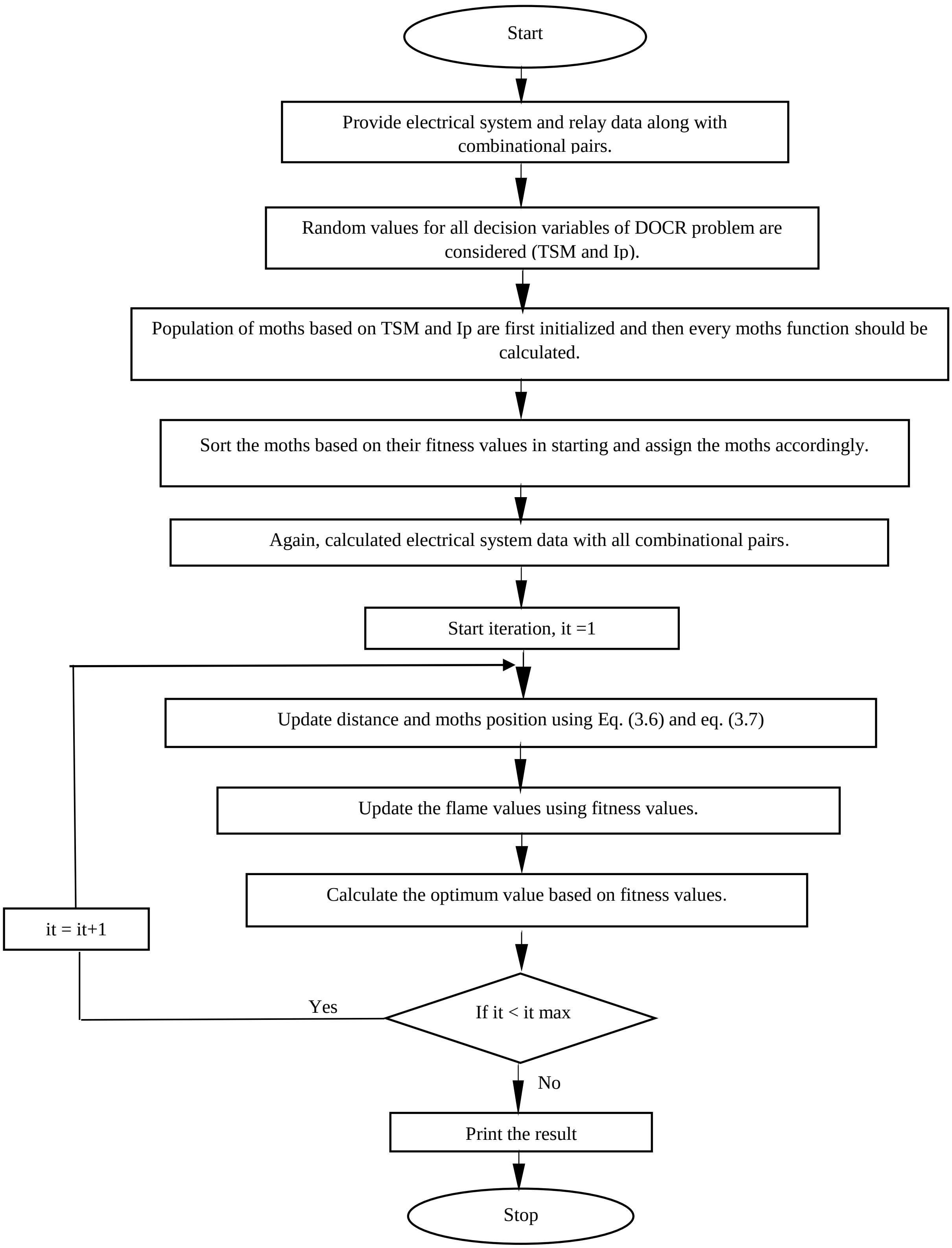

Fig. 4.1: Flowchart for implementation of DOCR problem.

CHAPTER 5

RESULTS AND DISCUSSION

In this work, the coordination of directional over current relay optimization problem has been solved using MFO technique. The optimum coordination is required to minimize the total operating time and for secure operation of power system network. The coordination between primary and backup relay is must for smooth operation. The MFO is a population-based search technique which works on transverse orientation. To test and validate the applied technique an IEEE 8-bus test system has been undertaken. The programme is executed using FORTRAN power station 4.0 on computer system consists of features Intel ® Core (TM) i7-6500U CPU @ 2.50GHz 2.60GHz Processor and 8.00 GB RAM.

5.1. TEST SYSTEM AND RESULTS

The IEEE 8-bus test system is presented in Fig. 5.1. The IEEE 8-bus test system includes fourteen directional relays, two generators, two transformers and seven transmission lines. The minimum and maximum limit of all decision variables are given as input data. The coordination time interval should be set at constant value as 0.3sec and lower limit of tripping time of every relay is set as *Tmin* = 0sec and upper limit of every relay is set as *Tmax* = 2sec. The system consists of 40 constraints (20 constraints for CTI and 20 constraints for *Tmax*) and have 28 design variables (14 for TMS and 14 for Ip).

5.1.1. Parameter settings

The MFO parameters set for IEEE 8-bus test system with no external grid under MFO technique is presented below:

(i) No. of moths = 100
(ii) No. of flames = 100
(iii) No. of iteration = 4000
(iv) ‘t’ is random number = [1, -2]
(v) b =1 (shape of logarithmic spiral)

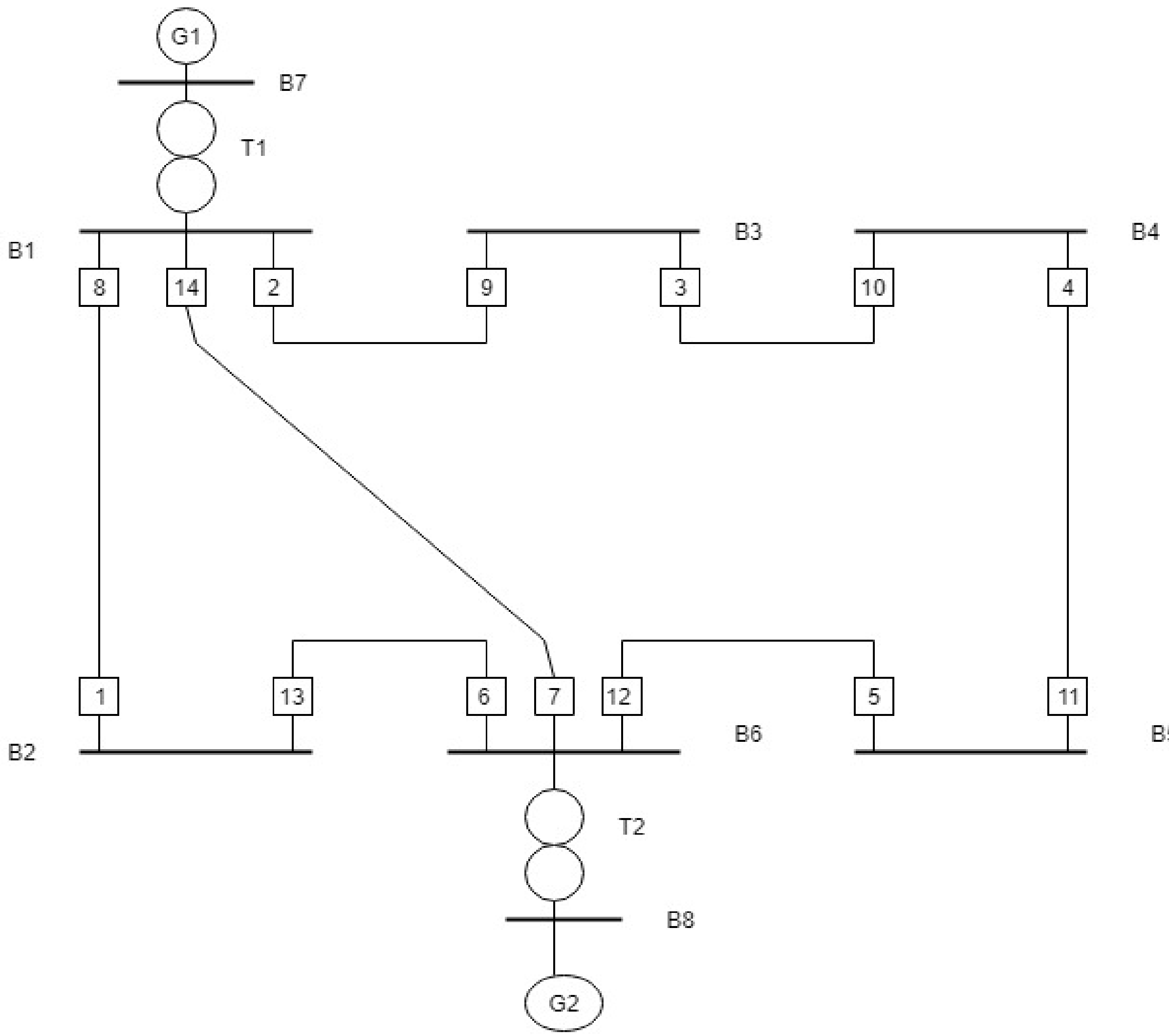

Fig. 5.1: Single line diagram connection of IEEE 8-bus test network with no external grid [79]

5.1.2. Simulation results

The implementation of MFO algorithm has been done as discussed previously for IEEE 8-bus system. The coordination criteria for each and every combination of primary and backup relays is shown in table 5.1. The solution for optimal relay settings and corresponding operating time in table 5.2. A comparison of output for test system is given in table 5.3 and it is evident that MFO is able to search moderate solution. The convergence characteristics is shown in Fig. 5.2 and it is evident from figure, the MFO is able to achieve the smooth convergence with fast rate. The Fig. 5.3 shows the operating time for each combination of primary, backup relays operating time and CTI for all relays and it is concluded that for each relay desired CTI is maintained between primary and backup relay.

Table 5.1: Primary/Backup relay pairs with coordination time interval for IEEE 8-bus test system.

Primary Relay	Backup Relay	Coordination Time Interval (sec)
1	6	0.333295
2	1	0.402231
2	7	0.337991
3	2	0.36322
4	3	0.3712392
5	4	0.4679907
6	5	0.547813
6	14	0.693214
7	5	0.493484
7	13	0.506777
8	7	0.46405
8	9	0.545912
9	10	0.3016025
10	11	0.316765
11	12	0.442842
12	13	0.276754
12	14	0.408862
13	8	0.317228
14	1	0.340572
14	9	0.358194

Table 5.2: Optimal relay settings and corresponding operating time.

Relay No.	TMS	Ip (amp)	$T_{primary}$ (sec)	T_{backup} (sec)
1	0.4709217	120.0000	1.030432	1.694314
2	0.7291536	120.0000	1.292083	1.487303
3	0.6214298	80.0000	1.124083	1.335268
4	0.4135936	120.0000	0.9640238	1.249158
5	0.2753760	120.0000	0.7811673	1.687017
6	0.6293179	120.0000	1.139204	1.363727

7	0.7048870	80.0000	1.193533	1.630074
8	0.6440688	120.0000	1.166024	1.425925
9	0.4002811	80.0000	0.9461625	1.711936
10	0.4567768	120.0000	1.048912	1.247765
11	0.6075998	120.0000	1.221651	1.365677
12	0.8034369	120.0000	1.423556	1.664493
13	0.4942060	120.0000	1.108697	1.700310
14	0.7994451	80.0000	1.353742	1.832418

Table 5.3: Comparison outcome for IEEE 8-bus test system

Algorithm	**Operating time (sec)**
PSO [12]	20.797
EM [14]	18.489
MFO	18.192

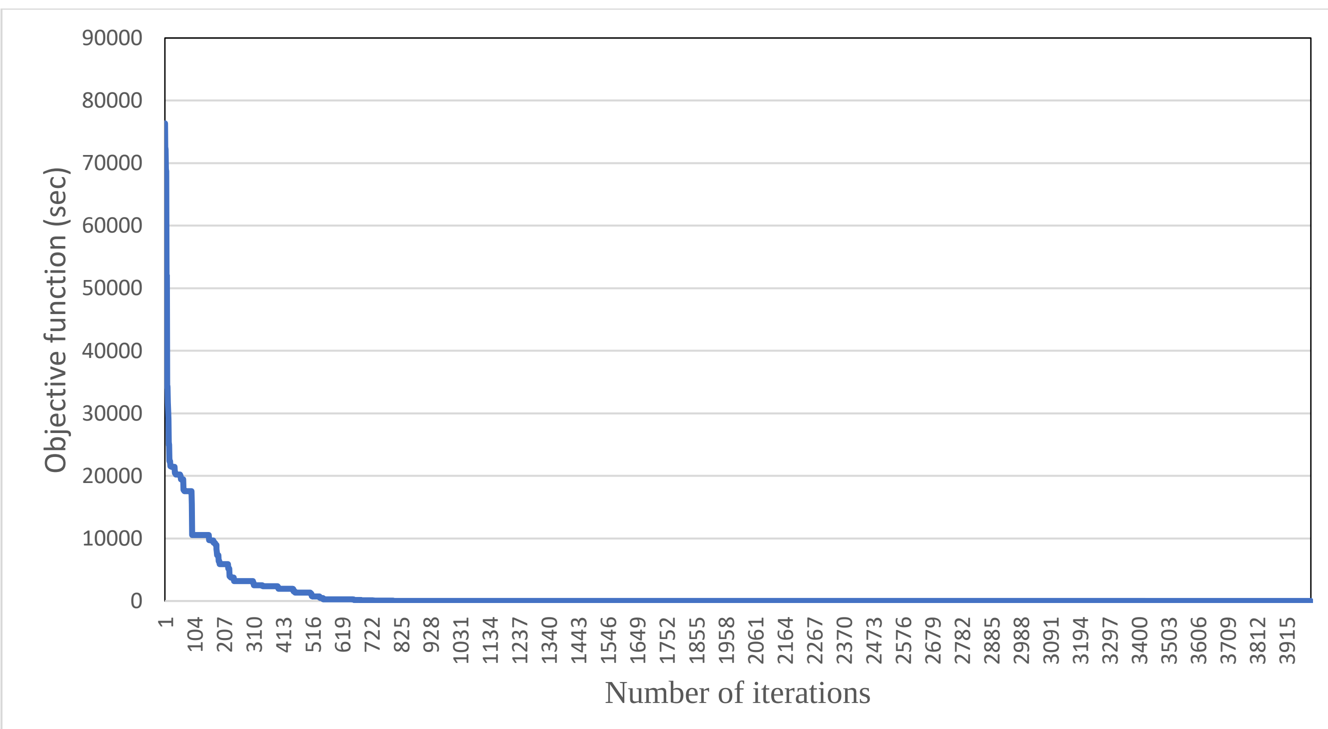

Fig. 5.2: Objective function vs number of iterations for IEEE 8-bus test system

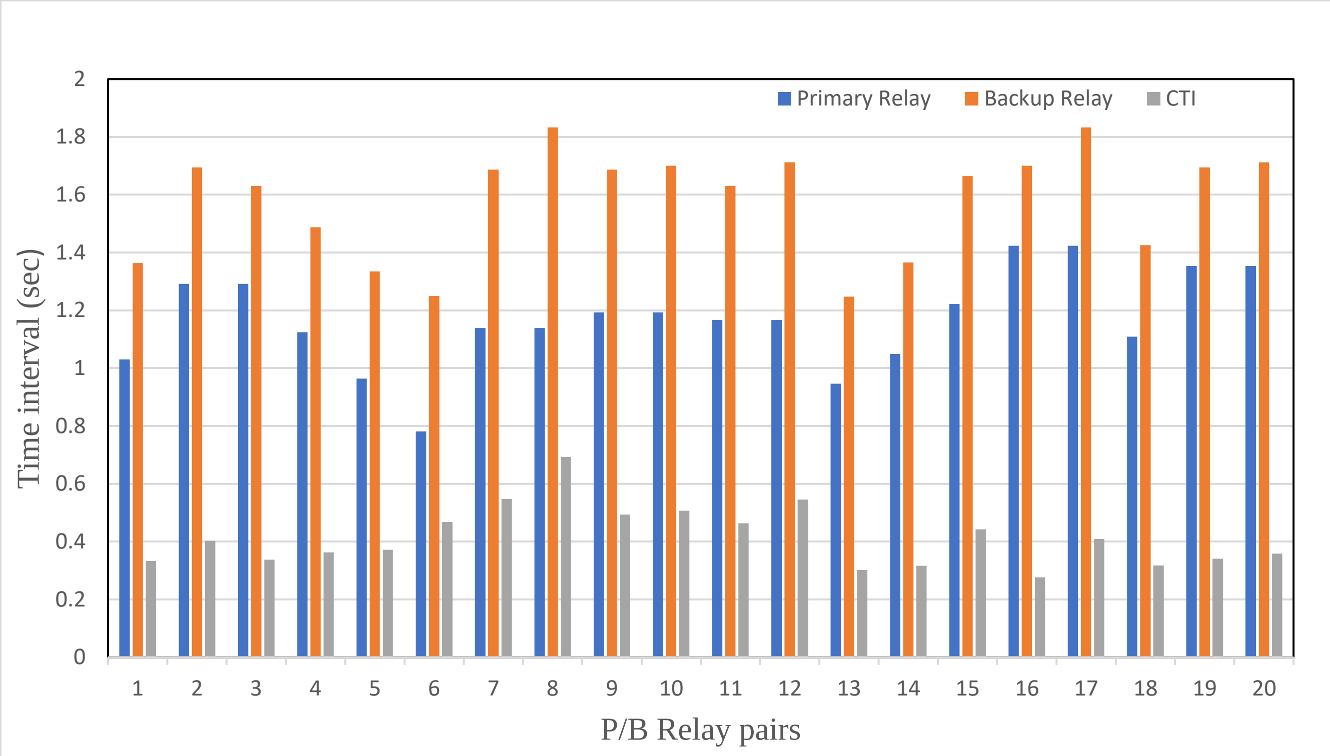

Fig. 5.3: Operating times of Primary/Backup relays and CTI for IEEE 8-bus test system

CHAPTER 6
CONCLUSION AND FUTURE SCOPE

6.1. CONCLUSION

In this dissertation work, moth flame optimization technique has been implemented to solve directional over current relay problem. The IEEE 8-bus system has been undertaken for test purpose. To investigate the credibility of the MFO technique, the results have been compared with the results published in the literature. It has been found that MFO is able to produce more promising results. Further, convergence characteristics has been illustrated and found that MFO technique is able to maintain the fine balance between exploration and exploitation capability during the search process.

6.2. FUTURE SCOPE

- The MFO technique may be applied to solve hard constraint multimodal optimization problem.
- The large size test systems may be undertaken.
- In order to deal with binary variables, binary MFO may be proposed.

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APPENDIX- A

Test System data arrangements:

Table A.1: Different relay pairs according to 3-phase short circuit current values

Primary relay	I_{F1}^{p} **(A)**	**Backup relay**	$I_{F2}^{b}(A)$
1	2666.30	6	2666.30
2	5347.80	1	804.70
2	5374.80	7	1531.5
3	3325.60	2	3325.60
4	2217.10	3	2217.10
5	1334.30	4	1334.30
6	4975.00	5	403.20
6	4247.60	14	1533.00
7	4247.60	5	403.60
7	4247.60	13	805.50
8	4973.20	7	1531.50
8	4973.20	9	403.20
9	1420.90	10	1420.90
10	2313.50	11	2313.50
11	3474.30	12	3474.30
12	5377.00	13	805.50
12	5377.00	14	1533.00
13	2475.70	8	2475.70
14	4246.40	1	804.70
14	4246.40	9	403.20

Table A.2: Summary of participated cases

Cases	Test system	Decision variables	Number of variables	Number of constraints
Case 1	8-bus network	TMS/Ip	28	40

Table A.3: Limit values for Decision variables

TMS_{min} *and* TMS_{max}	*CTI*
0.05 and 1.1	0.3

Table A.4: Characteristics of IEEE 8-bus test system

Relay	CT Ratio	Pickup current (Ip) Minimum Range	Pickup current (Ip)Maximum Range
1	1200/5	120	480
2	1200/5	120	480
3	800/5	80	320
4	1200/5	120	480
5	1200/5	120	480
6	1200/5	120	480
7	800/5	80	320
8	1200/5	120	480
9	800/5	80	320
10	1200/5	120	480
11	1200/5	120	480
12	1200/5	120	480
13	1200/5	120	480
14	800/5	80	320

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CHAPTER 1 INTRODUCTION 1.1 OVERVIEW With the advancement of new technology in modern power system, there are many hazardous activities takes place, which has many disadvantages. To prevent such activities protection devices are required for safety purpose in the electrical system. The basic aim of every protection mechanism is to stop transient imbalanced current present in system and to isolate the faulty section so that other section remains safe. Earlier, fuse device is mainly used for the removal or avoidance of the high voltage from the circuits. The main advantage of the fuse is in utilizing the security of the circuits