Bat Algorithm 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

Submitted by

Tushar Sharma

801541025

Under the Guidance of

Dr. Nitin Narang

Assistant professor, EIED

Electrical and Instrumentation Engineering Department
Thapar University, Patiala, Punjab (India) – 147004

July, 2017

DECLARATION

I hereby certify that the work which is presented in dissertation entitled, "**Bat Algorithm 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 & Instrumentation Engineering Department of Thapar University, Patiala is as 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 section. 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.

Tushar

Place: Patiala
Date: 18/07/2017

(Tushar Sharma)
801542025

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

N Narang

Date: 18/07/2017

Dr. Nitin Narang
Assistant Professor
EIED

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 thanks **Ms. Manbir Kaur**, Associate Professor, EIED, to provide all the useful guidelines for making this dissertation.

I am also thankful to my batch mates who devoted their valuable time for the successful completion of this dissertation. I extend my gratitude to the researchers and scholars whose hours of labor have produced the papers that I have used in this dissertation.

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.

Tushar Sharma

801541025

ABSTRACT

In the field of modern power system, protection devices attains a powerful role. The performance of any protection network is the result of combined operation of relays, breakers etc. Two types of relays, primary and backup relays are installed for increasing the reliability of power system. A primary relay is setup for the fast response of any faulty condition. If it fails, then backup relay perform the same task after some time gap. This simultaneous operation of primary and backup relays require some attention for preventing any malfunction occurring due to improper time gap between them. Due to this, it becomes a highly constrained optimization problem and structure of large power system increases its non-linearity.

This dissertation presents a technique for estimating the optimal settings of relays which in turn provide the faster operating time for primary relays and suitable coordination time interval for the backup relay effective operation. The settings for relay operation includes TMS, PSM and pickup current settings. A very popular swarm based meta-heuristic Bat Algorithm (BA) is implemented for the calculation of optimal solution.

This coordination problem is divided in to two categories: (I) Continuous settings optimization for TMS and pickup current, (II) Mixed integer settings optimization for TMS and PSM. For first category conventional form of bat algorithm and binary version of BA for second category is utilized. The IEEE 8 bus system with and without external grid is used to validate the proposed technique. The techniques based on bat behavior proves to generate optimal solution providing better convergence rate.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1. OVERVIEW

The aim of electrical protection network is to segregate the defective part of our power network. This must be implemented so that remaining safe parts of network continue to work in normal conditions. In reality, circuit breakers prevents the working areas of electrical network from defective sections. CBs have the provision to open the circuit for imbalanced condition, as soon as receive the tripping pulse from protective relays. The ideology behind every protective mechanism is that there is no ability to stop the imbalance or transient current is present, yet instantly removal of the bad portion from network can be obtained.

Fuse is the primary device used for removing the bad parts from any electrical circuit. The advantage in utilizing a security which relies on breaker is its simplicity and meanness. But this is hard to regulate the duration of the outing with the help of fuses. Hence it arises the issues related to primary-backup matching action. Fuse also possesses a big disadvantage of replacing every time it melts during faults. So, it require to perform the remote action [1]. These actions are the key for introduction of an overcurrent relay.

The term ‘overcurrent’ gives a sight that there is a talk about an inherent higher boundary for the practical value of the current. That preset value is the maximum load current sustained by any load during their uninterrupted action. The main reason for overcurrent can also be given by short circuit faults. The current in the equipment is noted. This current is stepped down using a CT ratio. A cross examination with preset value of maximum load current is performed. The probability of a fault is more if a positive sign appears. Here proportion of current with preset value is also called as a Plug Setting Multiplier (PSM).

This is a usual theory that all individual primary relays have their backup relay for the provision of alternative protection network. The execution interval for primary relay must be earlier than the starting of operation of backup relay for smooth protection mechanism. This concludes that safety provided by primary scheme of protection implement as early as possible, which ensure breaking of the faulty portion of electrical network. Certain time gap is necessary which is called as Coordination Time Interval (CTI). This should be provisioned between the execution intervals of both protection schemes [2]. Overcurrent relays also offer primary protection as well as their backup protection.

Protective relaying is very much desirable for the sound performance of electrical networks. The goal of coordination of relays is to effectively secure the power network by instantly isolating bad areas to maintain power supply in other healthy areas. Some tremendous achievement are taken place in the development and working of relays for the purpose of secure operation of power systems over last few decades. Directional Overcurrent Relays (DOCRs) have been utilized in the field of solutions for the primary as well as backup protection of power networks [3].

The coordination of power protection relays comes under the area of optimization problem. The primary relays must operate as fast as possible for the safety of remaining balanced portion of electrical network. But if there is some type of malfunction occurred in the working of primary relay and it unable to provide safety. Then backup relay should be in the position to handle this situation. For the starting of backup relays, a constraint in the form of a fixed interval of time, known as CTI, is necessary to avoid simultaneous working of both relays. In the presence of CTI constraint, this problem counts as a typical optimization problem. This optimization possess a objective function for minimization of tripping time for primary relay, having the constraints related to boundaries for interval of tripping for each relay and related to CTI.

For the solution of the above presented optimization problem, many techniques are developed in a different span of time. The conventional optimization approaches have the limitations of pre mature convergence which leads to ineffectiveness in their operation. In case of handling of more complex and non-linear problems, conventional optimization models are inaccurate and not feasible. In spite of more drawbacks, conventional optimization methods are preferable where the fast rate of operation is required in comparison to the accuracy of obtained solution.

Global optimization algorithms tries to find best possible solution which is more robust and effective. In such type of real world application, global optimization modes are preferred. The solution obtained from global optimization techniques are more accurate and preferable. Bat algorithm is one of the best available techniques, which provides the global optimized results. BA possess the advantages of both particle swarm optimization (PSO) and harmony search (HS). Furthermore, adjustment of parameters gives fast convergence of output. Application of BA is more complex because it combines the benefit of previous popular algorithms. It seems to provide well solution in many real world problems. This is the reason, BA is to be utilized in the optimization problem of directional overcurrent relays.

1.2. LITERATURE REVIEW

Several optimization schemes have been utilized from the past 20-30 years for the best coordination solution of DOCRs. There are many researchers who published their work for the purpose of minimization of tripping interval of DOCRs. The desired intention to reduce time of primary relay is to facilitate the reliable operation of electrical power network. The optimization problems were computed manually using very large and complex calculations, when computers were not developed. These procedure takes very much time and are not accurate enough. Nowadays, many metaheuristic approaches are developed, that makes the solution more reliable and accurate. The complete work in this field can be divided into some categories:

1. Topological approach
2. Classical linear techniques
3. Non-linear formulation
4. Global optimization techniques

Topological approaches involves the techniques based on graph theory and function developments. Albrecht *et al.* [4] tried to compute the solution for diverse settings of relays in order to design an electrical network layout. The digital computer aided interface for complex calculation was utilized to propose a sequential procedure for it. Damborg *et al.* [5] designed an approachable procedure for estimation of P/B relay pairs, settings for directional OC and distance relays utilizing the computer system tools. Urdaneta *et al.* [6] implemented the optimization approach relay coordination in grid networks. Various direct and decomposed mechanisms for suitable results of DOCRs up to 30 bus network were designed. Sankara *et al.* [7] proposed the requirement of sequence networks, starting from break points. Their approach is to cut the number of break sockets with the help of computer mathematical packages. Jenkins *et al.* [8] also adopted the procedure involving break points representing in the form of a matrix to design a dependent function for more exiting technique.

Classical linear techniques involves the use of linear functions with simple computational efforts. Restrepo *et al.* [9] used the linear formulation for the small level variation in a network for which change in settings is not desired, hence require less computation. Chattopahyay *et al.* [10] proposed a mechanism using simplex technique for auto updating settings in two phases. First phase checks for constraints and second phase computes the best possible settings. Abyaneh *et al.* [11] focused only on the covering of constraints. This technique start form lower values of settings and then taking higher values iteratively.

The Evolutionary Algorithms (EA) and Covariance Matrix Adaptation ES (CMA-ES) are also the classical approaches available for coordination problem. Sueiro *et al.* [12] proposed a novel scheme for DOCR's problem inside a meshed circuit. A combination of evolutionary as well as linear schemes gives the answer for current and time multiplier factors. Singh *et al.* [13] applied a co-variance mechanism using matrix auto updating tools. With the help of LINKNET, combinations of P/B relays are generated. Birla *et al.* [14] provide the effects of using distant faults and multiplication constants on the results of coordination problems. It is true that output does not change much but we lost a little accuracy of coordination constraints.

The mechanism utilizing non-linear formulation are also developed for the computation of minimum trip time for relays. Saleh *et al.* [15] developed a tripping curve for time, current and voltage for decrease in the execution time of relays established in the hybrid distributed generation networks. Miguez *et al.* [16] discussed a hybrid EA and linear programming (LP) approach to perform the coordination optimization problems. If output is not feasible, then a partial solution is obtained neglecting particular constraints.

The global optimization techniques started the discussion from genetic algorithm (GA) and their variants. Marcolino *et al.* [17] performed the solution approach based on the GA that contains the system properties and adjusting factors. Razavi *et al.* [18] used the genetic algorithm for the new and improved formulation to minimize the tripping time of both discrete and continuous time settings. Bedekar and Bhide [19] designed the continuous GA for coordination optimization of a looped network. Noghabi *et al.* [20] applied the hybrid GA for the variations that may come across the system causes increase in the number of constraints and makes solution more practical. Bedekar *et al.* [21] discussed the hybrid scheme for solving the limitations of GA and non-linear programming (NLP) for DOCRs problem. Adelnia *et al*. [22] proposed a GA mechanism for reducing the violation of constraints in finding suitable operation time for relays with the help of upgrading the current function to a new enhanced function. Moravej *et al.* [23] emphasis on minimizing the time delay from backup to primary relays, with the help of NSGA-II. Damchi *et al*. [24] performed their work on interval LP for solution of undetermined and constrained factors in case of randomness of network system. Thakur *et al.* [25] included the conversion of bounded cross over and mutation into real coded GA for approaching more practical problem.

PSO and their variants are also proved to be efficient. Asadi *et al.* [26] described PSO as a powerful mechanism for solving the relay problems for both types of decision variables using quantized approach. Zellagui *et al.* [27] developed approach for inverse relays in wind farms. A single objective formulation is implemented with the help of mixed integer PSO. Mansour *et al.* [28] proposed a method improving the conventional PSO for relay coordination due to its easy implementation. Leite *et al.* [29] presented an evolutionary PSO technique for large coordination problem. Zeineldin *et al.* [30] presented a new objective function and modified PSO for relay coordination of mixed integer type of problem using plug setting as a discrete variable. Farzinfar *et al.* [31] developed a different superior approach for improve the swarm diversity to find the operation time of distance relays, as they are back up by DOCRs.

Gravitational search (GS) mechanism also used in some researches. Radosavljevic *et al.* [32] developed a hybrid approach using GS and sequential quadratic programming for solving relay problems. Srivastava *et al.* [33] prescribed the hybrid PSO-GS for relay problems. A design of wind and PV sources is utilized for the verification purpose.

Differential evolution (DE) approach and their variants provide a new dimension in the field of relay coordination. Biswarup *et al.* [34] discussed a relative analysis on various solution strategy such as GA, PSO, HS and DE on DOCRs problem. DE comes out to be better in all other algorithms. Pant *et al.* [35] proposed three modified DE for small area search to calculate the time and plug settings for relays. It can be gained by expansion of nearby space of best result obtained. Mohseni *et al.* [36] provides the auto updating mechanism for DE, which seems to fit the results of overcurrent relay coordination. Moirangthem *et al.* [37] developed a technique based on DE to find suitable discrete time and plug settings as the problem is a non-linear problem. Thangraj *et al.* [38] presented five different methods for the traditional DE approach. Laplace distribution is utilized instead of constant scaling approach. Chelliah *et al*. [39] used the superbly constrained and nonlinear network of DOCRs. Two branches of opposition based chaotic DE schemes; OCDE1 and OCDE2 were proposed. Panigrahi *et al.* [40] discussed an auto upgraded re-clustering DE scheme for DOCRs problem with the help of LINKNET structure. Conde *et al*. [41] performed a study on different DE approaches regarding optimal coordination and provide a comparison based upon their time, sensitivity, power quality, life time and fast detection of faults.

Teaching learning-based optimization (TLBO) and hybrid biogeography based optimization with linear programming (BBO-LP) are also developed. Abhyankar *et al.* [42] adapted the utilization of TLBO approach for Directional Overcurrent relays problem in a meshed electrical network. New function is used for suitable time of operation in between secondary to primary relay. Kalage *et al.* [43] proposed an improved variant of TLBO with the help of variable range of TMS. The range for PSM is kept constant. Albasri *et al*. [44] utilized the hybrid structure of BBO and LP for the minimization of operating time of DOCRs.

Some more meta-heuristics are also utilized for approaching the coordination part of relays. Singh *et al.* [45] estimated the non-linear constrained optimization problem of OC relays with the help of extended discrete artificial bee colony technique for the proper application of electro-mechanical relays. Amraee [46] presented seeker algorithm for mixed integer function of DOCR formulation. This work is depended upon the transformative detection of search space and interval size. Alipour *et al.* [47] developed a new improved group search optimization algorithm which enhances the convergence rate of traditional scheme. Othman *et al*. [48] proposed a new backtracking search scheme and a new target function for DOCRs problem. Benabid *et al.* [49] designed a mechanism based on firefly algorithm for a highly constrained relay problem. The effect of IFCL on the computed results are also examined. Bouchekara *et al*. [50] started their work for DOCRs based on the electromagnetic field optimization and perform some modification to get a new modified version.

In past few years, a variety of work have been completed in the area of machine learning. This information also encourage some peoples to get focused in the area of protection system like coordination problem of relays. Artificial Neural Network (ANN) is also utilized for DOCRs problem of very large looped power systems. Emmanuel *et al.* [51] provides the method for finding the relay settings as per time-current curve. A hybrid GA-ANN approach is utilized with the help of a new fitness function to achieve global values.

The wide range of global optimization techniques had been developed from the natural and/or physical activities. Every techniques possess some advantages and disadvantages. BA was developed in 2010 with the intention to provide the advantages of major mechanisms. The main theme is based on the food searching mechanism of bats. Bat algorithm is the effective technique in the field of optimization. Some of the optimization problems are resolved with the help of BA.

A review of all these literatures is discussed in a systematic manner to clarify the impression of both bat algorithm and its extended variants proposed. These are as follows,

Xin-She Yang [52] presented a latest super heuristic algorithm, the bat algorithm, which gets formulated due to echolocation action of bats. The advantage of adjustment capability for rate of convergence is also observed. Rahman *et al.* [53] performed the recording of shifting of persons in an experimental space setup. BA proved to be better from particle filter and PSO. Fong *et al.* [54] developed BA for organizing various topological regions for micro-electronic equipment. Liao *et al.* [55] utilized the moving direction of bats for increasing the accuracy of maximization requirements for computing velocity for right zooming. Parika *et al.* [56] interpreted the BA in the field of cellular building network. They handle it as a non-computational function-time. Hannan *et al.* [57] presented their research work on stabilizer creation with the searching ability of BA. Gupta *et al.* [58] implemented a cross mixed BA to improve the search, hence to achieve the objective with the help of new results obtained. Jose [59] proposed an effective and durable answer to the problem of economic load discharge for wind power. BA handle those errors in a sensible way to give better solution.

Hemis *et al.* [60] utilized the formulation of BA for the audio watermarking purpose. They disintegrate the genuine signal in many sectors. Manohar *et al.* [61] comes out with the methodology of decreasing the order of any multi-order system. BA is applied for leading structuring integral square approach. Tsai *et al.* [62] performed an experiment on joining the continuously variable and straightly reducing dc wave. Evolved BA proved to be much trust-worthy. Jyoti *et al.* [63] comes out with the calculation based on cloud with the help of BA. This is further utilized in load equating. Seifi *et al.* [64] choose the field of optimum power discharge. BA is utilized for computing the superior fixing of control parameters. Gupta and Sharma [65] performed the maximization scheme for revenue increment of hydro operated units with the help of BA. Neagu *et al.* [66] implemented BA for finding the best location of placing capacitor bank for voltage regulation in a distribution network. Kulkarni *et al.* [67] prepared a unique BA for calculating crop kind detection with the help of multi scope space craft pictures.

Xin-She Yang [68] extended his past work of bat algorithm to multi objective optimization problems. Niknam *et al.* [69] presented a multi-function self-growing bat scheme for calculating reserve bounded load dispatch. A new approach for settling the unprimed results comes out with the help of chaos BA technique. Yilmaz and Kucuksille [70] improved the BA by three replacements for evaluation of proposed style of technique. Yılmaz *et al.* [71] improved the inspection approach of the bat algorithm. This is achieved by modification in the relations of wave exertion rate and sound intensity of bats with their previous values. Topal *et al.* [72] proposed a dynamic virtual BA for universal maximization on the character rooted finding criteria. Wang *et al.* [73] transformed BA into modified BA reducing the problem of collecting sound intensity and wave rate.

Aadil *et al.* [74] proposed the mechanism of primal reactive power discharge with the utilization of BA and performed simulation in DigSILENT Power Factory and python. Komarasamy and Wahi [75] proposed a composition of K-means with BA to gain the advantage of effective clumping. Yammani *et al.* [76] performed their work on the integration of distributed energy resources applying BA. Oscar *et al.* [77] presented BA with improvement helping a fuzzy network for variably adaption of its factor. Othman *et al.* [78] proposed a scheme for spacing of photovoltaic setup in an interconnected network. The part involving BA is for finding the best location of module and inverter.

Nakamura *et al*. [79] designed binary BA for feature selection using a wrapper approach, which is a combination of bat behavior and optimum-path forest classifier. Shukla *et al.* [80] studied the advantages of multi-parameter bat algorithm in the form of a discrete version of BA. Djelloul *et al.* [81] performed the operation to satisfy the graph coloration condition with the help of BBA for solving maximization situations. Yang *et al.* [82] also discussed about the discrete version of previously described bat algorithm. Application of BBA on a real world problem of optical buffer was performed. Rajalaxmi *et al.* [83] utilized the BBA on the feature selection process with addition of error square to be their objective relation. Ramesh *et al.* [84] emphasis on finding the person, who is sending spams in social sites utilizing BBA. Doreswamy *et al.* [85] highlighted the use of BBA in the field of breast cancer data selection. They designed a hybrid approach including neural network.

1.3. SOLUTION APPROACH

Apart from previously developed mechanism, BA for optimal coordination of DOCRs is chosen. The main reason for picking up the bat algorithm is its reliable operational approach and proves to be better in many other optimization mechanisms. Bats use the ability of sound bursts formation for day to day work. This quality helps them to easily locate the foods and any type of hurdles in the path. Bats can also distinguish between various kinds of bugs without the utilization of light waves. To apply this property of bats on coordination problem, few theoretical models of their capability are required. One major concern is its complex implementation in comparison to another optimization models. Even the use of BA proves to be very much fruitful as provides a stable solution. BA provides the results after fine updating of frequencies, loudness and pulse emission rates. Loudness and rate of impulse does not affect the solution directly, but very much desirable to get a finer solution. The usefulness of BA can be increased with the help of provision of new model for wavelength or frequency changes [52].

The prime involvement of this dissertation is to develop a bat-inspired algorithm for the optimal coordination of directional overcurrent relays. In this dissertation the optimal time of DOCRs is derived in two ways: as a non-linear programming (NLP) and as a mixed integer nonlinear programming (MINLP) problem where both the time multiplier Settings (TMS) and pickup current (I_p) or plug setting multiplier (PSM) settings are optimized to minimize the relay operating times. The discrete behavior of PSM is utilized with the help of using the new variant of conventional BA in terms of binary mode. This makes our model to be suitable for the application in real world practical problems.

1.4. ORGANIZATION OF DISSERTATION

The dissertation titled as "**Bat Algorithm for Optimal Coordination of Directional Overcurrent Relay System**" has been explained in six chapters. In **Chapter 1** dissertation detailed overview is mentioned, problem related literature survey and dissertation objective is provided. **Chapter 2** introduces about problem formulation for minimal coordination of directional overcurrent relays. In **Chapter 3** the overview, details and formulation of conventional BA mechanism and binary variant of BA is discussed. **Chapter 4** describes the details about implementation for both continuous and mixed integer types of coordination approaches. **Chapter 5** highlights and discuss the results for test system-I and test system-II. The dissertation conclusion and potential scope of work has been mentioned in **Chapter 6** followed by the references and also the appendix.

CHAPTER 2

PROBLEM FORMULATION FOR DIRECTIONAL OVER-CURRENT RELAYS COORDINATION

The most important thing for calculation of optimized coordination of directional overcurrent relays focus to estimation of best suitable relay settings. These settings must guarantees that in every zones of protection, primary relays should operate first and prevent the system from any disturbance. If due to some reason, primary relays fails to operate, then with inclusion of certain predefined interval of time, known as CTI, backup relays must be in working mode. This complete process of protection should be feasible if they fulfil all the constraints [50]. The above description proves that, protection problem with several electrical sources comes under the category of optimization problem. Therefore, the protection system issues in estimation of operating time relays formulated with the help of an objective function and set of constraints, which must fulfil for feasible solution.

The general steps for any optimization problem are to be followed, includes the estimation of objective function fulfilling all the system constraints. A procedure diagram of coordination of DOCRs is shown below:

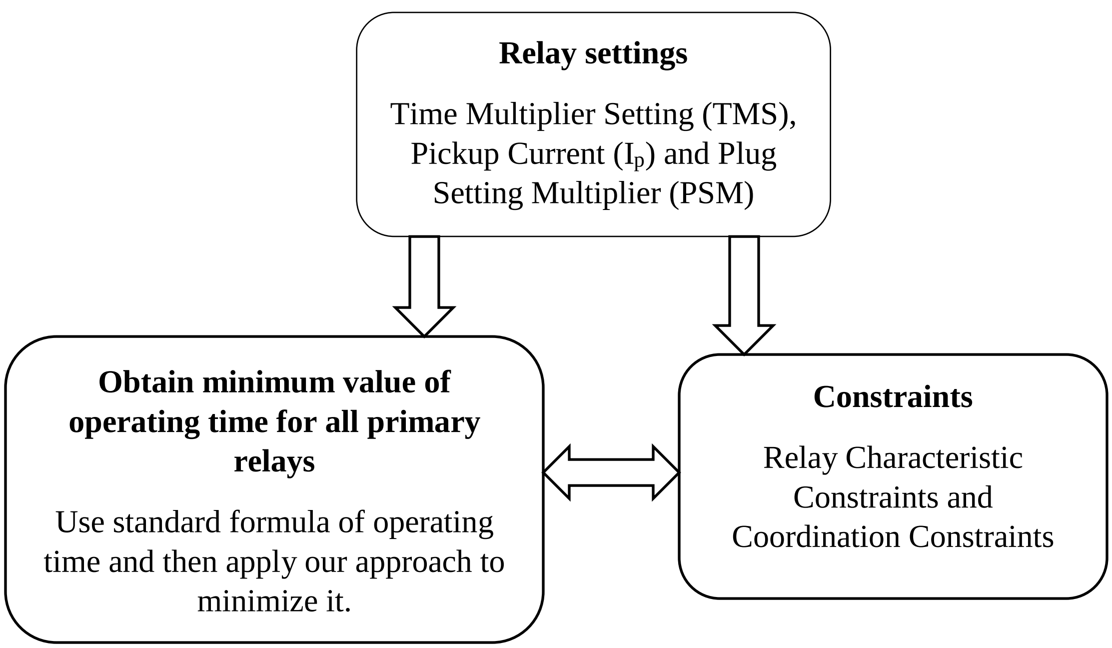

Fig 2.1: Solution process for DOCRs problem

For better understanding, assume a fault situation, which is symmetrical balanced three phase fault. In the abnormal situation, both corresponding relays will identify the condition and initiate the process at same time. Relays will takes the ongoing data generated by the individual CT. A tripping pulse is provided to the corresponding CB. This will ensure that unbalance will not hunt the whole electrical network [2].

The required time for the operation of overcurrent relay can be estimated using the proper settings of PMS and TSM. IEC gives an inverse characteristic curve shown in fig 2.2 for operating time of these relays based on their types like standard inverse, very inverse or extremely inverse. There must be need of a separate protection scheme is to employ for individual status of operating voltage in DOCRs.

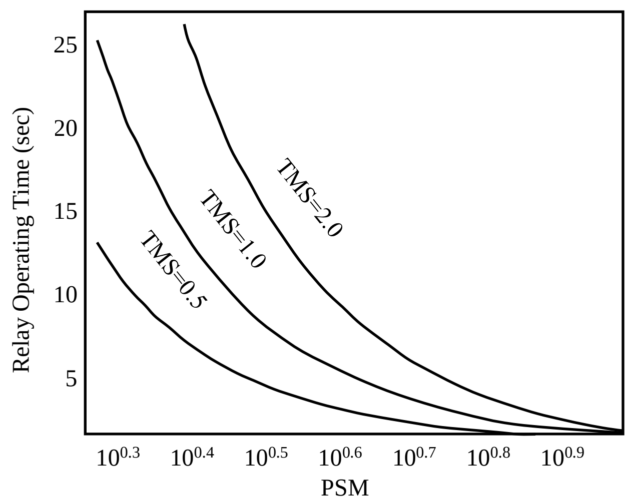

Fig 2.2: Effect of TMS on operating time

Protective relay coordination is the approach of estimating the "most suitable" operation of current breaking for any electrical imbalance arise. The aim of coordinating the DOCRs is to come across change in settings that reduce the process time to maximum possible value for faults inside the protective zone while at the same time there should present some pre-determined time backup for relays that are in the neighboring zones [86].

Two different approaches for the estimation of optimum relay settings are utilized. In first method, TMS and I_p are chosen as the decision variables and both of them are considered to contain the continuous values. Another approach includes continuous TMS and discrete PSM as their decision variables for mixed integer type problem. The formulation for both methods are discussed below:

2.1. PROBLEM FOR CONTINOUS DECISION VARIABLES

2.1.1. Objective Function

The fitness function for coordination of DOCRs contains the addition of tripping time of all primary relays [87]. The discussed relation of relay settings problem is focused to find the optimum value for aggregate burdened addition of execution intervals of primary relays. This is essential for maintaining the execution of backup relays to be organized. In accordance with all, the fitness function can be formulated as shown [47]:

$$\text{Fitness Function:} \qquad \sum_{i=1}^{n} \omega_i T_i \tag{2.1}$$

where ω_i and T_i are allocated burden and starting time of the i^{th} relay.

For simplification purpose, consider ω_i is equal to 1. According to the relation provided by IEC standards, operating time for inverse characteristic overcurrent relays are given as,

$$T_i = \frac{\alpha \times TMS^i}{\left(I_F^i / I_p^i\right)^{\beta} - \gamma} \text{ , } i = 1,2, \ldots\ldots N \tag{2.2}$$

where, TMS^i represents the time multiplier setting for i^{th} relays,

I_p^i represents the pickup current of the i^{th} relay,

I_F^i represents the magnitude of fault current passing from the i^{th} relay,

α and β are fixed parameters, which are useful for deciding the type inverse relay i.e. standard inverse, very inverse or extremely inverse. All work is performed on standard inverse type, thus values are as, $\alpha = 0.14$, $\beta = 0.02$ and $\gamma = 1$.

2.1.2. Constraints

The purpose for determining the lowest sum of execution intervals of all relays contains some constraints to be fulfilled. These boundary consists the variables related to operation of relays and parameters maintaining balance between primary and backup protection.

(a) Relay settings constraints

These constraints includes the limitations on TMS and I_p. The limitations on parameters influencing the objective function directly are shown below [48]:

$$T_{min}^i \leq T^i \leq T_{max}^i \tag{2.3}$$

$$TMS^i_{min} \leq TMS^i \leq TMS^i_{max} \quad (2.4)$$

$$Ip^i_{min} \leq Ip^i \leq Ip^i_{max} \quad (2.5)$$

where, T^i_{min} and T^i_{max} are the minimum and maximum ranges for operating time of the i^{th} relay.

TMS^i_{min} and TMS^i_{max} are the minimum and maximum ranges for the TMS of the i^{th} relay.

and, Ip^i_{min} and Ip^i_{max} are the minimum and maximum ranges for the I_p of the i^{th} relay.

Additionally, there are some more boundaries to be mentioned. First check that the pickup current values should always be small than lowest value of short- circuit current. Secondly, values of pickup current should also be more than the highest value of load current. This indicates that I^i_p should be obtained very specifically. This happens because it seems to be a settlement in developing a more safe and flexible protection system. For dealing with the continuous values of TMS and I_p, our solution may be proceed to some less optimized output or to solution which is not practically possible.

(b) Relay Coordination Constraints

These constraints are relevant to combined working of primary and backup relays as a protection mechanism. Whenever any fault is occurred, both protection gets the alert signal at the same time. Due to parallel working of these devices, one must provide a safety tool, which prevent backup relay to send trip signal and perform mal-operation.

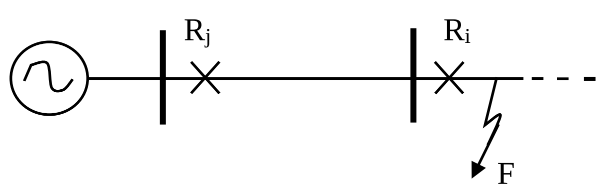

Fig 2.3: Primary and Backup relay representation

This safety tool is CTI in coordination case, which provide a balance between both types of protection module. CTI should be selected so as to provide a time difference in which primary relay tries to clear the fault first. Hence CTI involves the addition of time taken by circuit breaker (CB) of primary relay to operate, the outreach duration for backup relay and some additional security time-gap. In case of fig. 3, the backup relay R_j should provide some certain delay of time for the proper operation of the primary relay R_i. It is a very tough task to fulfil the usage of both protection mechanism. The relation for coordination balance is termed as:

$$T_{backup} - T_{primary} \geq CTI \tag{2.6}$$

where, $T_{primary}$ and T_{backup} are the execution intervals for primary and backup relay.
The range for the CTI can be selected in between 0.2 sec and 0.5 sec, which is based upon various criteria and situations [88].

2.2. PROBLEM FOR MIXED-INTEGER DECISION VARIABLES

This problem is stated as mixed integer because usage of both types i.e. continuous as well as discrete type of decision variables is stated. TMS is taken as continuous while PSM is taken as in discrete steps. The size or length of steps for PSM is dependent on the required problem.

2.2.1. Objective Function

The intention for solving the problem regarding the balancing of the DOCR operation is to estimate the lesser and possible executing interval of the primary relays for sound protection scheme. The fitness function for discrete or mixed-integer type problem is similar to continuous problem. Hence equation (2.1) is same.
The formula for calculation of operating time contains some different part. These change occur due to the inclusion of PSM instead of I_p. This is provided as follows:

$$T_i = \frac{\alpha \times TMS^i}{\left(\frac{I_F^i}{PSM^i * CTR_i}\right)^{\beta} - \gamma}, \; i = 1,2, \ldots\ldots N \tag{2.7}$$

where, TMS^i, I_F^i, α, β and γ have the same meaning as stated in previous problem formulation.
PSM^i represents the plug setting multiplier for i^{th} relay.
and, CTR_i represents the current transformer ratio for i^{th} relay.

2.2.2. Constraints

Some of the constraints are similar to constraints applied in the continuous optimization problem. Some more boundaries are still considered, which is due to introduction of new variable. Here, constraints can be divided in two parts as:

(a) Relay settings constraints

The expression shown in equation (2.3) and (2.4) will remain same. But instead of boundaries on pickup current, consider the range for PSM. This can be shown as:

$$PSM_{min}^{i} \leq PSM^{i} \leq PSM_{max}^{i} \tag{2.8}$$

where, PSM_{min}^{i} and PSM_{max}^{i} are the minimum and maximum ranges for the PSM value of the i^{th} relay, respectively.

Furthermore, in case of providing protection to phase, the value of PSM should be more than the highest load current and smaller than lowest fault current for every relay. The lowest value for TMS represents the speed for relay operation. The relay should maintain proper time for relay operation as it will not cause any type of false switching, whenever some transient situation arises. On the other hand, the highest value for TMS represents the greatest feasible duration for prevention of power network from any fault.

The lower value PSM for the relay is the highest for the minimum accessible tap setting and a 4/3 of the highest load current flowing from it. On the other hand, the higher value of PSM taken to as 2/3 of the lowest fault current experience by the backup relay. All these criteria are selected to stop the tripping, if load gets increased on the system. The higher ranges are approximated to the minimum possible tap settings, while the smaller values are approximated to the maximum possible tap settings [89].

(b) Relay Coordination Constraints

The boundaries applied on the coordination time of both relays contains the same relation as stated in equation (2.6).

CHAPTER 3
BAT ALGORITHM

3.1. INTRODUCTION

The solution procedure followed for coordination optimization problem is centered on bat algorithm. This term ‘bat algorithm’ is firstly used by Xin-She Yang in 2010. This method slowly triggered people's solid observation. Since then it is growingly exerted to various areas. Bat-aroused algorithm is acceptable for computing non-linear and global optimization problems. Yang [52] is interested to take the benefits of previous theories for creation a new bat algorithm. From through foundation and illustration of its utilization, this is finalized that the prescribed approach is superior in compared with other living theories, including genetic algorithms and particle swarm optimization.

Yang [52] comes out with a positive outcome of a Bat Algorithm for steady constrained optimization programs. This algorithm seems to be probably more convincing in comparison to PSO, GA and HS. This can be understood because BA uses a sound composition of prime benefits of these theories in specified way. Bat algorithm gives better formulation of the variables that causes a fast convergence rate. One drawback of BA is his more complex implementation in comparison to other evolutionary algorithms. But its advantages can overcome this limitation. The solutions gets updated by changing frequencies, sound intensity and rates of wave exertion. The results achieved by Yang advocate that further analysis will likely be required to execute the sensitivity inspection, for understanding the pace of algorithm zooming. To enhance the zooming pace even better. A large scale correlation learning will cause fresh problems to the algorithms. For better application, vast span of present approaches with the help of toughest test operations in increasing dimensions are used. Such correlations will likely disclose the nobility and limitation of all the algorithms of concern.

Two forms of bat algorithm are adopted in this thesis work. These two forms are:

(i) Traditional bat algorithm, and

(ii) Discrete or binary bat algorithm.

A meaningful discussion about both of methods including their preferable usage conditions are written below.

3.2. BAT ALGORITHM

The method for solution adopted is described in a suitable way. The starting of algorithm requires the understanding of behavior of a fascinating mammal bat. They possess a unique structure among mammals with their wings and a capability of echolocation. Among bats micro-bats are more preferable as they use echolocation extensively while mega bats are not. They used sonar, known as echolocation, to notice prey, escape from barriers and to get to their vents. They convey a very strong sound burst and hear for the reflection that rebound back from the bodies. Some bats prefer short frequency modulated pulse, while others use constant frequency signals [64].

Though each pulse only last in the range of 8-10 ms, it has an unchanged frequency in the span of 25-150 kHz. Because pace of sound in wind is normally v = 340 m/s and wavelength λ of the supersonic burst for a fixed frequency is [52],

$$\lambda = \frac{v}{f} \tag{3.1}$$

This appears to come in the span of 2-14 mm. The loudness of sound burst also deviates from the loudest when detecting prey and becomes calm when approaching near the prey. Studies provides that the incorporation time of the bat ear is commonly ranges from 300 to 400 µs. Micro bats have ability to control the evade barriers like compact as fine human hairs.

Researches proved that micro bats utilize the time difference from the release and discovering of the echo. They distinguish action duration between their ears, and the intensity changes for the reflections to create a three dimensional plot of the scenarios.

3.2.1. Approximate or idealized rules

For a better model inspired from behavior of bats, idealization of some of its characteristics is required. The following approximations are [54]:

1) All bats explore echolocation to determine position. They can predict the dissimilarity in bread/prey and obstacles in some mystical manner.

2) Bats glide uncertainly having velocity v_i at distance x_i for a constant frequency f_{min}, unfixed wavelength λ and intensity of sound A_0 to hunt for food. Bats can reflectively maintain the wavelength (or frequency) of produced waves and maintain the rate of wave extinction. Here r comes in range of [0, 1], defined with nearness of required aim.

3) The intensity burst can change in distinct paths. The intensity burst changes from a high value of A_0 to a small fixed value A_{min}.

In addition to these assumption, consider the frequency f for a span [f_{min}, f_{max}] analogous to a span of wavelengths [λ_{min}, λ_{max}]. Additional evident interpretation is that no beam uncovering is adopted in computing the time differences and three dimensional profile.

3.2.2. Pseudo code of the bat algorithm

An artificial code for the formulation of bat inspired method is given as shown below [52],

Proposed function $f(x)$, for design parameter $x = (x_1, ..., x_d)T$

Give starting bat native x_i $(i = 1, 2, ..., n)$ and velocities v_i

Decide beat frequency f_i at each x_i

Initialize beat rates r_i and the intensity of sound A_i

while (t <Max number of iterations)

Produce new parameters by varying frequency, and upgrading velocities and locations/solutions.

if (rand > r_i)

Choose a solution from the leading solutions

Create regional solution from the available best solution

end if

Produce a fresh output by flying uncertainly

if (rand < A_i & $f(x_i) < f(x^*)$)

Acquire new outputs

Rise r_i and decrease A_i

end if

Grade the bats and compute the present best x^*

end while

Print the output

3.2.3. Updating frequency, velocity and location

To make this algorithm working, the equation for updating the parameters involved in the computation process are also provided. The updated positions x_i^t and velocities v_i^t at iterative step t are [52],

$$f_i = f_{min} + (f_{max} - f_{min})\,\beta \quad (3.2)$$

$$v_i^t = v_i^{t-1} + (x_i^t - x^*) f_i \quad (3.3)$$

$$x_i^t = x_i^{t-1} + v_i^t \quad (3.4)$$

where, $\beta \in [0, 1]$ is a arbitrary vector selected using uniform dispatch.

x^* is present global best position which is computed after analyzing all the solutions.

For confined regional search, once a output is chosen from the present top outputs, a fresh output for every bat is produced regionally with casual march [52],

$$x_{new} = x_{old} + \epsilon A^t, \quad (3.5)$$

where, $\epsilon \in [-1, 1]$ is a arbitrary number,

A^t is average sound intensity of each bats at iteration t.

Moreover, sound intensity A_i and rate r_i of impulse should be upgraded consequently as the iterations advance. The relations are as,

$$A_i^{t+1} = \alpha\, A_i^t\ ; \qquad r_i^{t+1} = r_i^0[1 - \exp(-\gamma t)] \quad (3.6)$$

where, α and γ are fixed numbers in the range of $0 < \alpha < 1$ and $\gamma > 0$.

For exchanging the alterations of the frequency f_i using any arbitrary generated factor and substitute $A_i = 0$ and $r_i = 1$, the bat algorithm basically get the form of standard PSO. Likewise, if velocities are neglected, but utilize a constant sound intensity and rate: A_i and r_i. For example, $A_i = r_i = 0.8$, process nearly get the form of HS. The designed new scheme is prospectively more effective. Therefore it should be scrutinized more in various implementations of engineering and industrial maximization studies.

3.3. BINARY BAT ALGORITHM

Along with conventional bat algorithm, another robust part of BA, known as binary bat algorithm, is also utilized. BBA seems to be very useful for handling the discrete behavior of plug setting multiplier in directional overcurrent relays. This becomes very helpful in developing a practical solution for coordination problem. In spite of availability of several optimization approaches in the market, our preference is given to BBA due to some underlined points:

1. Closeness to optimal value: BA and their product are more suitable to get the nearest global optimum value.

2. Self-intensive: BBA is proved to get the capacity to search the complete space for encouraging results within less interval.
3. Self-controlling: Search intensity is preferably depends upon self-driven control of mechanism. This property helps in diversion from exploration to exploitation, which is very much needed for any optimization approach. The effectiveness of algorithm become high with the help of self-driven controlling mechanism.
4. Parameter handling: BA is very much useful in terms of better handling of their parameters. Unlike other optimization approaches, they continuously change their parameters in every iteration. This ability is also beneficial for self-driven switching.
5. Adjustment of Frequency: Frequency plays a vital role in creation of fine mirror copy of natural Bats. This adjustment of frequency is also shown in particle swarm optimization, CS, HS etc. Therefore this property gives the principal attributes of many other meta-heuristic models.

Furthermore, with the references from other literature available, it will be more suitable to get global minimum or maximum values from the application of bat inspired products [85].

Binary version of BA is theoretically identical to the conventional Bat algorithm. Naturally Bats fly in an uninterrupted system area. And the working area for BBA is lies inside binary space. Binary area is confined for 0's and 1's. Therefore previous relations for updating location and velocity of bats as described in equation (3.3) and (3.4) are not useful in this case. To use the search space of 0s and 1s, another approach is required. Hence the path of relation mechanism is chosen and velocities are compared with some predefined function to get new location vector. That predefined function are chosen according to the requirements of problem. Generally, V-shaped (hyperbolic tangent function) or sigmoid function are preferred. The only condition to choose a suitable function is that its output should always lies in the range of [0, 1]. The mapping result of described function would directly reflect in updating of the velocity. After understanding these requirements, the function useful to their solution approach can be predicted very easily.

A binary working area can be identified in the form of a hypercube. The working factors (parameters) of any binary optimization mechanism have only two option of moving either to closer and distant ends of the chosen hypercube. This can be achieved with the help of twisting different digits of bits [90]. Therefore, it is clear that to develop some strategy with the help of binary aspect of BA, few fundamental relation changing criteria must be regulated.

The continuous aspect of BA, uses the digital bats. These bats are used as search capable species throughout the solution area. They are better in searching with the help of location and velocity factors. These factors are constantly got changed as the iteration precedes in the real number range. And, change in position vector can be done simply by adding velocity term to position term. But here in case of discrete search area, this is quite different [91].

Whenever discussion is made for a discrete search area, change in position contains the overlapping of digits from ‘‘0’’ to ‘‘1’’ or vice-versa. The whole overlapping criteria is decided with the help of velocities and a decision making function. The difficulties arising from the process of change in position in discrete search area makes this more complicated. In reference of [92–94], the process of updating the location of any particle is directly proportional to the probability of velocity vector of that particle.

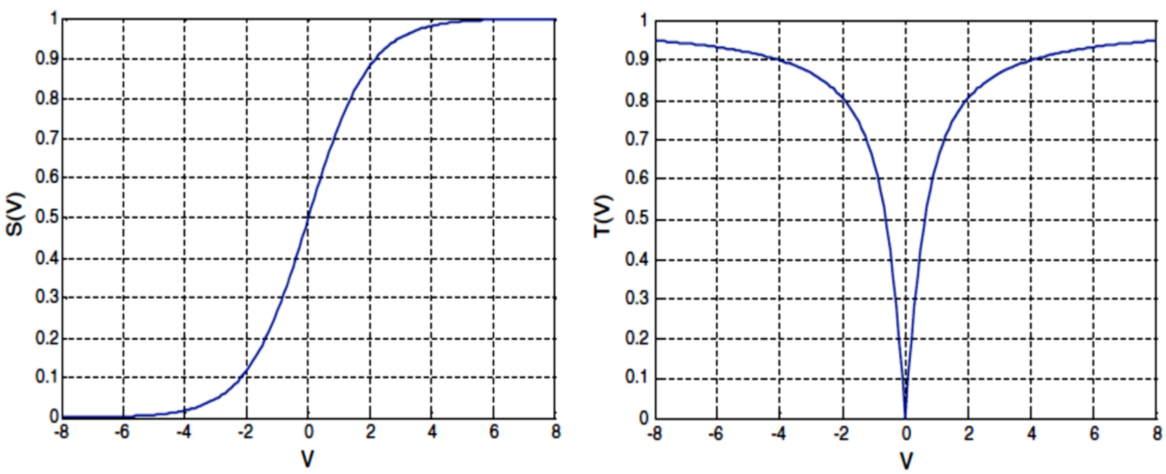

Fig 3.1: Sigmoid and V-shaped transfer function [91]

To understand the complete process, a transfer function is designed. This formulation is important to relate velocity vector to its probability results. Then these results will change the particle’s position. In another way, a mathematical formulation is required for estimating the probability of updating the positions between 1 and 0. Therefore transfer functions can be called as the driving cause for any particles to make his displacement limited to binary area. Rashedi et al. [92] described that, some points are necessary to be followed for proper application of binary version of bat algorithm or for maintaining the position vector inside binary space:

• The selected transfer function should have a range in between 0 and 1. This is required because transfer function are equivalent to probability vector.

• This will be better if the selected function choose higher probability for updating the location for higher magnitude of velocity. Particles with higher magnitudes, are preferably at distant from their optimum values. Since they require to change current positions.

• Similarly, for lesser magnitude, probability of updating the location should be less.

• The output from the decision formula should be directly proportional to the velocity. For distant particles, probability will be large as it will ensure that previous values should be restored.

Above mentioned points are surety for any transfer function. This confirms their capability to relate the work of maintaining a continuous solution area to a binary solution area. These rules are also essential for continuing the basics of any optimization mechanism.

There are two famous transfer function. Any one of them can be chosen based on requirements. Sigmoid transfer function is presented as:

$$S\left(v_i^k(t)\right) = \frac{1}{1+ e^{-v_i^k(t)}} \tag{3.7}$$

where, $v_i^k(t)$ represents velocity for i^{th} particle in k^{th} dimension at t iteration.

Once the values of above mentioned function for each particle are calculated, the new position is given according to relation described below [22]:

$$x_i^k(t+1) = \begin{matrix} 0 & if\ rand \leq v_i^k(t+1) \\ 1 & if\ rand\ \geq v_i^k(t+1) \end{matrix} \tag{3.8}$$

where, $x_i^k(t+1)$and $v_i^k(t+1)$ represents the position and velocity of i^{th} particle at iteration t in k^{th} dimension.

The sigmoid function model lacks their performance as it provide 0 and 1 values unwillingly [91]. This makes the updating process of position obsolete because in spite of increase in velocity, position does not changes. The solution to above problem is given with the help of developing a new different transfer function. Another V-shaped transfer function is described below with their relations for change in positions:

$$V\left(v_i^k(t)\right) = \left|\frac{2}{\pi}\arctan\left(\frac{\pi}{2}v_i^k(t)\right)\right| \tag{3.9}$$

$$x_i^k(t+1) = \begin{matrix} x_i^k(t)^{-1}\ \ if\ rand \leq V\left(v_i^k(t+1)\right) \\ x_i^k(t)\ \ if\ rand \geq V\left(v_i^k(t+1)\right) \end{matrix} \tag{3.10}$$

where, $x_i^k(t)$ and $v_i^k(t)$ represent the position and velocity of i^{th} particle at iteration t in k^{th} dimension, and $x_i^k(t)^{-1}$ and $x_i^k(t)$ are conjugate or inverse of each other.

V-shaped function is preferred instead of sigmoid function for the problem regarding calculation of plug settings of relays. Hence this will relate the velocities of BBA's bats to the output of transfer function. This will in turn switch the position vectors of every particle.

The pseudo codes are very much similar to BA. The changes will happen in the updating part of velocity and position vectors. One more change is to hold in the local search part of bat algorithm. There also, same transfer function is used, with average loudness being the dependent variable. This can be shown as follows:

$$V\big(\epsilon A(t)\big) = \left|\frac{2}{\pi}\arctan\left(\frac{\pi}{2}\epsilon A(t)\right)\right| \tag{3.11}$$

$$x_i^k(t+1) = \begin{matrix} x_i^k(t)^{-1} \;\; if\ rand \le V\big(\epsilon A(t+1)\big) \\ x_i^k(t) \;\; if\ rand \ge V\big(\epsilon A(t+1)\big) \end{matrix} \tag{3.12}$$

where, *A(t)* is the average loudness for iteration *t*.

These two changes are the difference in the operation of conventional and binary aspect of bat algorithm. Other steps of BBA are similar to conventional bat algorithm.

CHAPTER 4
BAT ALGORITHM FOR DIRECTIONAL OVERCURRENT RELAY SYSTEM

4.1. IMPLEMENTATION FOR CONTINOUS DECISION VARIABLES

Bat algorithm is a metaheuristic optimization procedure motivated by one of special types of flying insects i.e. micro-bats. The approach of pursuit and how bats handle the obstacles in their way is utilized in this dissertation work. Step-wise procedure of applying micro-bats behavior is discussed below:

4.1.1. Reading the input values

Read the minimum and maximum value of time multiplier settings (TMS), pickup current (I_p), operating time with the fault current level (I_F) (primary and backup) and CTI for each relay. The minimum and maximum value of parameters used in bat algorithm like loudness and rate of impulse are also assigned.

4.1.2. Defining starting values for particles

Every optimization technique requires a group of possible results of desirable length *N*. The possible results are identified as individual bat particle in case of BA. Initially, results are predicted randomly with the consideration of their boundaries. The distribution is setup uniformly throughout the whole search area.

If $x = (x_1,\ x_2,\ x_3, \dots\dots\dots\dots\ x_n)$ is a particle result, minimum and maximum range for *x* is shown by x_j^l and x_j^u, respectively. Here, 'j' denotes the chosen bat particle for decision variable x_j. As final destination is to find the position of prey, which is uncertain at the starting of mechanism. A mathematical equation is applied to get some approximations resides in their boundary ranges. Let us assume that whole set of solution is represented by vectors. The solution vector possess dimension *d* and particle count *N*, under considering the minimum and maximum range. Then, approximated initial position of prey are estimated as [95],

$$x_{ji} = x_{min} + \phi(x_{max} - x_{min}) \tag{4.1}$$

where, *j = 1, 2. . . N*, *i = 1, 2. . . d*, x_{max} and x_{min} are maximum and minimum limits for element *i*, respectively. ϕ is a random number lies between *0* and *1*.

For problem of coordination of DOCRs, decision variable, $x = \{TMS, I_p\}$. Therefore, equation (4.1) changed as follows,

$$TMS_j^i = TMS_{min}^i + \phi\left(TMS_{max}^i - TMS_{min}^i\right) \tag{4.2}$$

$$I_{p_j}^{\ i} = I_{p_{min}}^{\ i} + \phi\left(I_{p_{max}}^{\ i} - I_{p_{min}}^{\ i}\right) \tag{4.3}$$

where, TMS_j^i is the time multiplier setting for i^{th} dimension of j^{th} bat-particle, and

$I_{p_j}^{\ i}$ is the pickup current for i^{th} dimension of j^{th} bat-particle.

4.1.3. Estimating frequency, velocity and new positions

The initial fitness result for all particles is calculated with the help of random decision variables obtained in previous steps as discussed in chapter 2. A complete set of frequencies (f_j) for each decision variable have been calculated previously using equation (3.2). Obtained frequencies are utilized for the calculation of velocity (v_i) for each decision variable using equation (3.3). This is shown as,

For *TMS*, $$v_{Tji}^t = v_{Tji}^{t-1} + \left(TMS_{ji}^t - TMS^*\right)f_j \tag{4.4}$$

For I_p, $$v_{pji}^t = v_{pji}^{t-1} + \left(I_{p_{ji}}^{\ t} - I_p^{\ *}\right)f_j \tag{4.5}$$

where, f_j is the frequency related to the j^{th} bat-particle, TMS_{ji}^t and $I_{p_{ji}}^{\ t}$ are the time multiplier setting and pickup current for i^{th} dimension of j^{th} bat-particle at t^{th} iterative step, respectively. TMS^* and $I_p^{\ *}$ are time multiplier setting and pickup current for i^{th} dimension of j^{th} bat-particle corresponding to present optimum or best solution at t^{th} iterative step, respectively. v_{Tji}^t and v_{pji}^t are velocity for time multiplier setting and pickup current for i^{th} dimension of j^{th} bat-particle at t^{th} iterative step, respectively.

New positions (x_{ji}) or decision variables are estimated with the help of updated velocities using equation (3.4). This is shown below:

For *TMS*, $$TMS_{ji}^t = TMS_{ji}^{t-1} + v_{Tji}^t \tag{4.6}$$

For I_p, $$I_{p_{ji}}^{\ t} = I_{p_{ji}}^{\ t-1} + v_{pji}^t \tag{4.7}$$

The steps for estimation of fitness function are performed using new decision variables and the best estimated value is selected to be global solution. The decision variables corresponding to the best solution will be assigned as present optimum variables.

4.1.4. Exploitation ability of the mechanism

The results based on the uniformly distributed decision variables are generated. The effectiveness of exploitation strength of proposed approach should be utilized. The local search process is provided in the algorithm. A mathematical formulation is given so that bat particle should enhance their output in the premise of present outputs. This equation is discussed in equation (3.5). For coordination problem approach, it can be stated as,

For *TMS*, $$TMS_{new} = TMS_{old} + \epsilon A^t \tag{4.8}$$

For I_p, $$I_{p_{new}} = I_{p_{old}} + \epsilon A^t \tag{4.9}$$

where, A^t is the mean value for loudness corresponding to all bat-particle at t^{th} iteration.

ϵ is uniformly estimated arbitrary real number lies between -1 and 1.

TMS_{old} and $I_{p_{old}}$ are used as current values of decision variable.

and, TMS_{new} and $I_{p_{new}}$ are used for updated values of decision variables.

4.1.5. Updating loudness and rate of impulse

The exploitation quality of bat centered technique is already utilized. Additional checks on two major parameters of bat algorithm are still performed. Bats tend to decrease the loudness as they are approaching towards prey, while the rate of sound impulses are tends to increase.

A comparison of present loudness with randomly generated number and another comparison between current global fitness function and present fitness function are performed. If loudness and present fitness function appears to be greater, only then the formula for changing the current values of loudness as well as rate of impulse will be applied. This calculation utilize the mathematical equation discussed previously in equation (3.6). Therefore as the iteration proceeds, variations occur in the present values of loudness (A_i) and rate of impulse (r_i).

Finally, the results obtained from all the bats are compared, and the best optimal solution utilizing the fitness function are chosen. The flow-chart showing the complete steps for solution process is shown in fig. 4.1.

4.2. IMPLETATION FOR MIXED-INTEGER DECISION VARIABLES

Mixed integer optimization aspect of coordination problem utilized both types of variables i.e. continuous as well as discrete. Most of the part for problem implementation will remain same. Binary version of bat algorithm is used for dealing with the discrete part of problem. The calculation for fitness function were discussed in equation (2.1) and (2.7).

4.2.1. Reading the input values

This step remain same except that in place of defining the lower and upper values of pickup current, the same for PSM will be defined. Two more change takes place in terms of defining the current transformer ratio (CTR) for each available relay and step size (*ds*) for the discrete decision variable PSM. All other values will remain similar as discussed in previous case.

4.2.2. Defining starting values for particles

There will also be two decision variables. But one of them will be discrete in nature. The decision variables for mixed-integer optimization problem are,

$$x = \{TMS, PSM\}$$

TMS is continuous, while PSM is discrete. Therefore, steps for calculating the initial values of TMS will be same using equation (4.2). But for PSM, some modifications are required. The minimum value of PSM in every dimension (i.e. relays) for each bat-particle is selected as initial solution. This can be written as,

$$PSM_j^i = PSM_{min}^i \tag{4.10}$$

where, PSM_j^i is the plug setting multiplier value for i^{th} relay of j^{th} bat-particle, and

PSM_{min}^i is the minimum PSM value for i^{th} relay.

4.2.3. Estimating frequency, velocity and new positions

For TMS, all the steps remain same as discussed in continuous optimization problem. But process for PSM is different. The velocities for PSM are estimated using mathematical equation:

$$v_{Pj}^i(t) = v_{Pj}^i(t-1) + \left(PSM_{ji}^t - PSM^*\right)f_j \tag{4.11}$$

where, $v_{Pj}^i(t)$ is the value of velocity for PSM for i^{th} dimension of j^{th} bat-particle at t^{th} iteration,

PSM_{ji}^{t} is the PSM value for i^{th} dimension of j^{th} bat-particle at t^{th} iteration, and

PSM^{*} is the value of PSM corresponding to the present optimum fitness function.

The V-shaped function is used for the binary aspect of bat algorithm. This utilization takes place with the help of velocities calculated in equation (4.11). It can be shown as [96],

$$V\left(v_{Pj}^{i}(t)\right) = \left|\frac{2}{\pi}\arctan\left(\frac{\pi}{2}v_{Pj}^{i}(t)\right)\right| \tag{4.12}$$

$$b_j^i(t) = \begin{matrix} -1\,; & if\ rand \le V\left(v_{Pj}^{i}(t)\right) \\ +1\,; & if\ rand \ge V\left(v_{Pj}^{i}(t)\right) \end{matrix} \tag{4.13}$$

$$PSM_{ji}^{t} = PSM_{ji}^{t-1} + \left(b_j^i(t) * ds\right) \tag{4.14}$$

where, $b_j^i(t)$ is the binary parameter for i^{th} dimension of j^{th} bat-particle at t^{th} iterative step, which provide the feasibility for discrete operation of PSM values. And, ds is the step length for PSM.

4.2.4. Exploitation ability of the mechanism

In the local search part, again all the equations related to TMS will remain similar to previous case. But different approach for PSM is required. The V-shaped function is utilized for the discrete value of decision variable PSM. This can be formulated as shown [96],

$$V\left(\epsilon A(t)\right) = \left|\frac{2}{\pi}\arctan\left(\frac{\pi}{2}\epsilon A(t)\right)\right| \tag{4.15}$$

$$b_j^i(t) = \begin{matrix} -1\,; & if\ rand \le V\left(\epsilon A(t)\right) \\ +1\,; & if\ rand \ge V\left(\epsilon A(t)\right) \end{matrix} \tag{4.16}$$

$$PSM_{new} = PSM_{old} + \left(b_j^i(t) * ds\right) \tag{4.17}$$

where, PSM_{new} and PSM_{old} are the updated and current values for decision variable PSM.

4.2.5. Updating loudness and rate of impulse

The final step includes the updating of loudness and rate of impulse for each bat-particle. The mathematical part will remain similar to the previous case independent from type of variables. Finally, compare results obtained from all the bats, and choose the best optimal solution utilizing the fitness function.

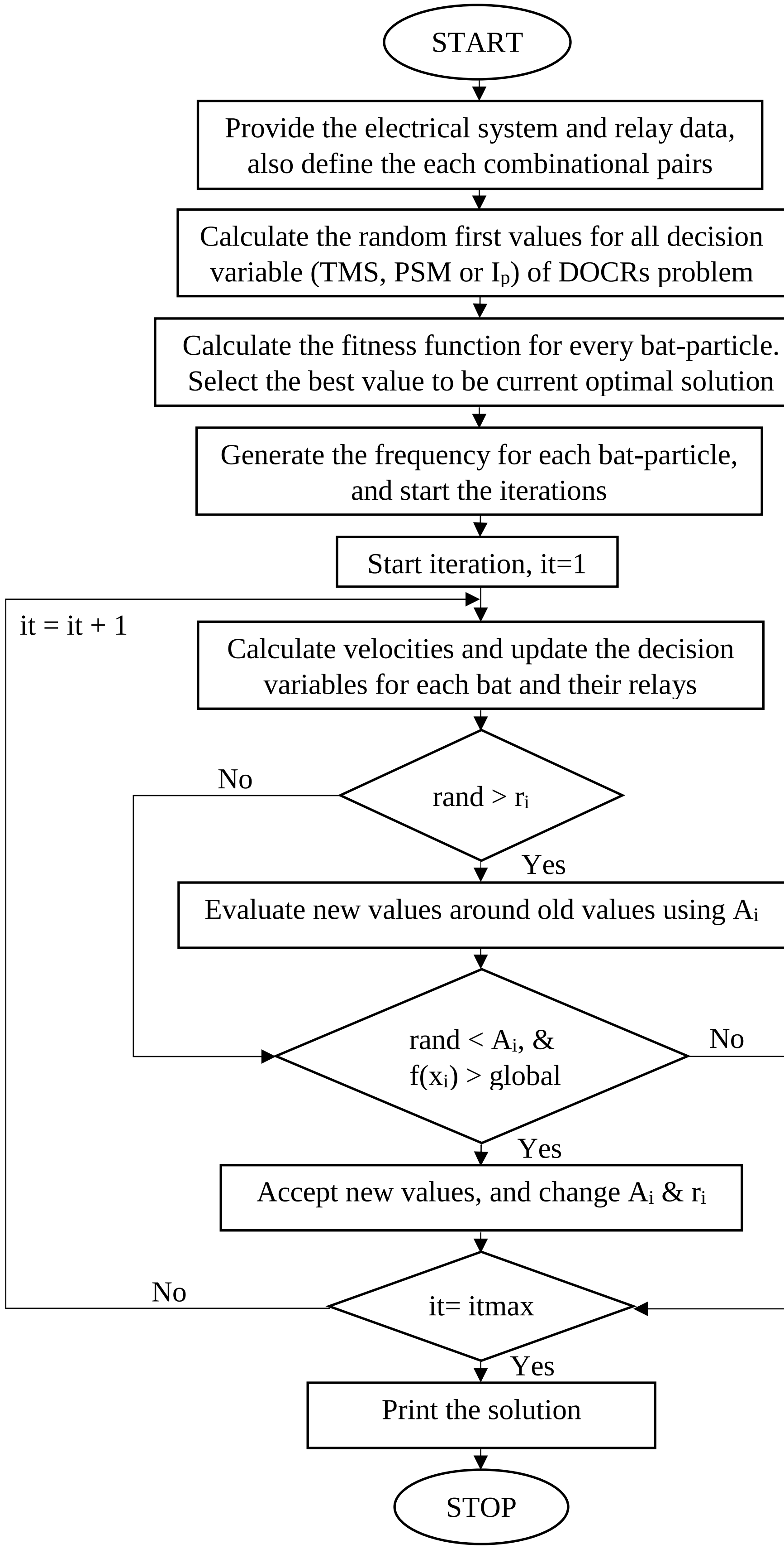

Fig 4.1: Flow-chart Process for DOCRs problem implementation

CHAPTER 5
RESULTS AND DISCUSSION

The discussed meta-heuristic swarm based bat algorithm and its binary variant has been utilized for the feasible minimization of the operating trip time of directional overcurrent relays for the purpose of optimal coordination of protection system. This method is applied in two IEEE bus systems for verification purpose. The bus system includes the combination of generators, transformers, transmission lines and directional overcurrent relays. All the data used from the bus system have been detailed in Appendix A.

For the execution of discussed mechanisms, some sets of codes in the form of a computer program are written. The software employed is Fortran PowerStation 4.0 developed by Microsoft Dev Studio. The computer system having Intel (R) Core™ *i3-5005U* CPU @ 2.00 GHz Processor and 4.00 GB-RAM under Windows 10 pro environment have been operated. To work and validate the effectiveness of the utilized BA and BBA for the minimization of operating time required for coordination of relays, two different cases have been investigated using two test systems consisting their separate design variables.

5.1. TEST SYSTEM 1

5.1.1. Description of 8-bus test system-1

The first network for testing purpose, which is utilized in the report is IEEE 8-bus test network depicted in Fig. 5.1. There is no link is provided for another network or any external grid. This system consists of 8 buses, 2 electrical sources, 2 T/Fs, 7 transmitting lines and 14 directional-relays.

Furthermore, the lower and higher settings with respect to the minimum and maximum limits of *TMS* are chosen 0.05 and 1.1, respectively. The settings for CTI is considered as 0.3 and upper limit for duration for tripping of every relay is chosen as T_{max} = 2(s). It shows that, bus network consists 28 design variables (14 + 14, for TMS and I_p) and 40 constraints (20 + 20, for CTI and T_{max}, respectively).

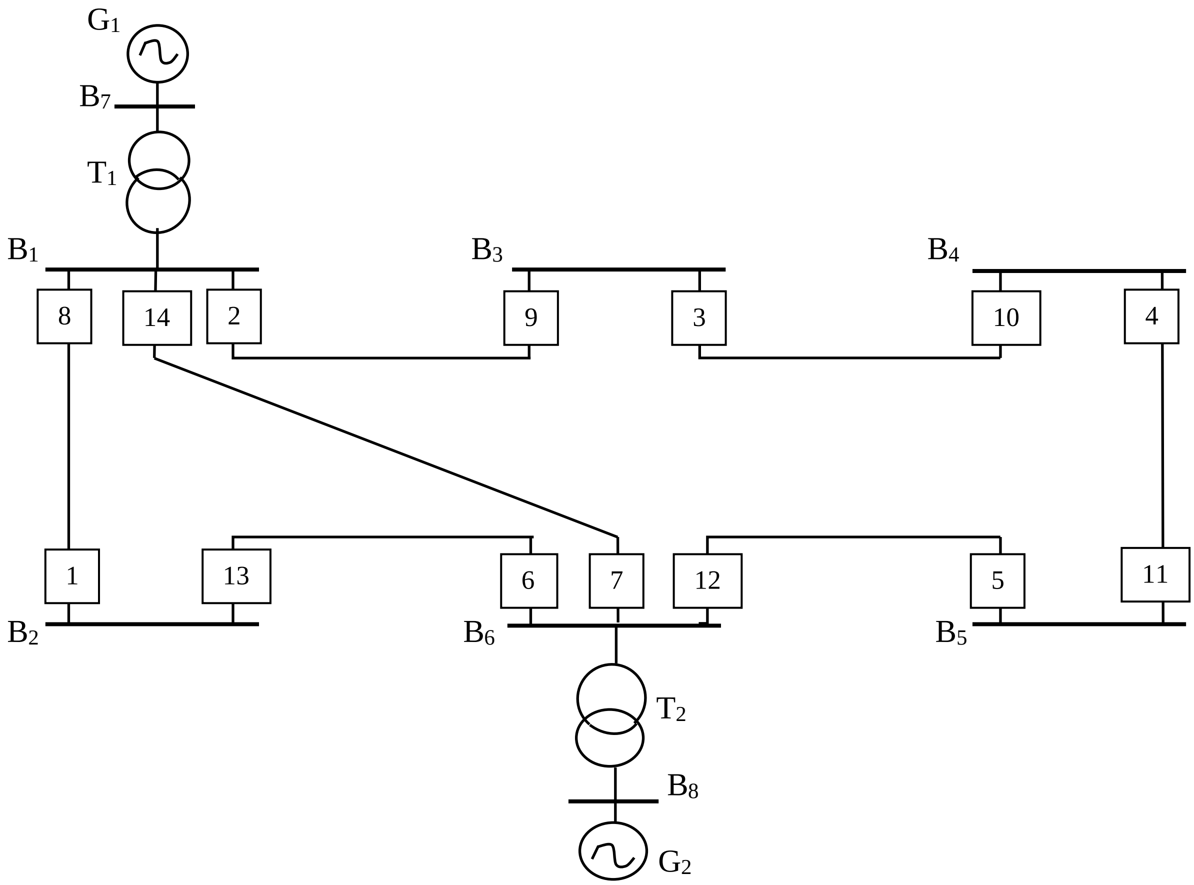

Fig 5.1: Connection-Diagram for IEEE 8 bus network (without external grid) [97]

5.1.2. Setting of parameters

The setting of parameters for both test system under BA and BBA are as shown:

i. N_population = 100 bat-particles
ii. f_{min} = -1 and f_{max} = +1
iii. cA_{min} = 0.1 and A_{max} = 0.8
iv. r_{min} = 0.3 and r_{max} = 0.9
v. alpha = 0.8 and gamma = 0.8

5.1.3. Obtained simulation output

The implementation of bat algorithm has been applied in the computation of optimized settings of time multiplier and pickup current for determination of minimum possible operating time of directional OC relays. Applying the parameters shown above, problem for continuous relay settings is computed. The table 5.1 shows the coordination criteria for every combination of primary and backup relays. The solution for TMS and I_p is provided in table 5.2. A comparison of output for test system-1 is given in table 5.3. The curve for total operating time and error obtained in each iteration is depicted in fig 5.1. The fig 5.2 shows the variation of operating time for each relay corresponding to their coordination time interval.

Table 5.1: P/B relay pairs and their coordination time interval for test system-1

Primary Relay	**Backup Relay**	**Coordination Time Interval (in sec)**
1	6	0.443759229
2	1	0.772366496
2	7	0.409386586
3	2	0.503118229
4	3	0.393492985
5	4	0.33546824
6	5	0.473558263
6	14	0.428243057
7	5	0.418815208
7	13	0.362414745
8	7	0.724896088
8	9	0.466780606
9	10	0.418502972
10	11	0.353572783
11	12	0.301457972
12	13	0.300097102
12	14	0.311182359
13	8	0.342650958
14	1	0.981852852
14	9	0.360757459

Table 5.2: Optimal relay settings and their corresponding operating time for test system-1

Relay	TMS	I_p (amp.)	$T_{primary}$ (sec)	T_{backup} (sec)
1	2.123749E-01	367.4811	0.735379781	1.881866601
2	4.100184E-01	431.5169	1.109500105	1.376974028
3	3.152213E-01	283.1635	0.873855799	1.050303191
4	2.815073E-01	120.3419	0.656810206	0.799527426
5	1.227719E-01	216.5255	0.464059186	1.371512559
6	3.517292E-01	344.7491	0.897954296	1.179139011
7	3.897926E-01	262.2001	0.952697351	1.51888669
8	3.292817E-01	295.8777	0.793990602	1.062147098
9	1.273637E-01	199.7853	0.445595273	1.260771208
10	2.607722E-01	179.4607	0.695909773	0.864098245
11	3.658836E-01	213.53	0.892820817	1.049482557
12	4.458960E-01	271.9565	1.015014994	1.194278789
13	2.649729E-01	200.4584	0.71949614	1.315112096
14	4.305324E-01	166.1103	0.900013749	1.326197353

Table 5.3: Result comparison for test system-1

Algorithm	Operating Time (secs)
BAT	11.153
HS [50]	11.921
BH [50]	12.775
EM [50]	18.489
PSO [30]	20.797

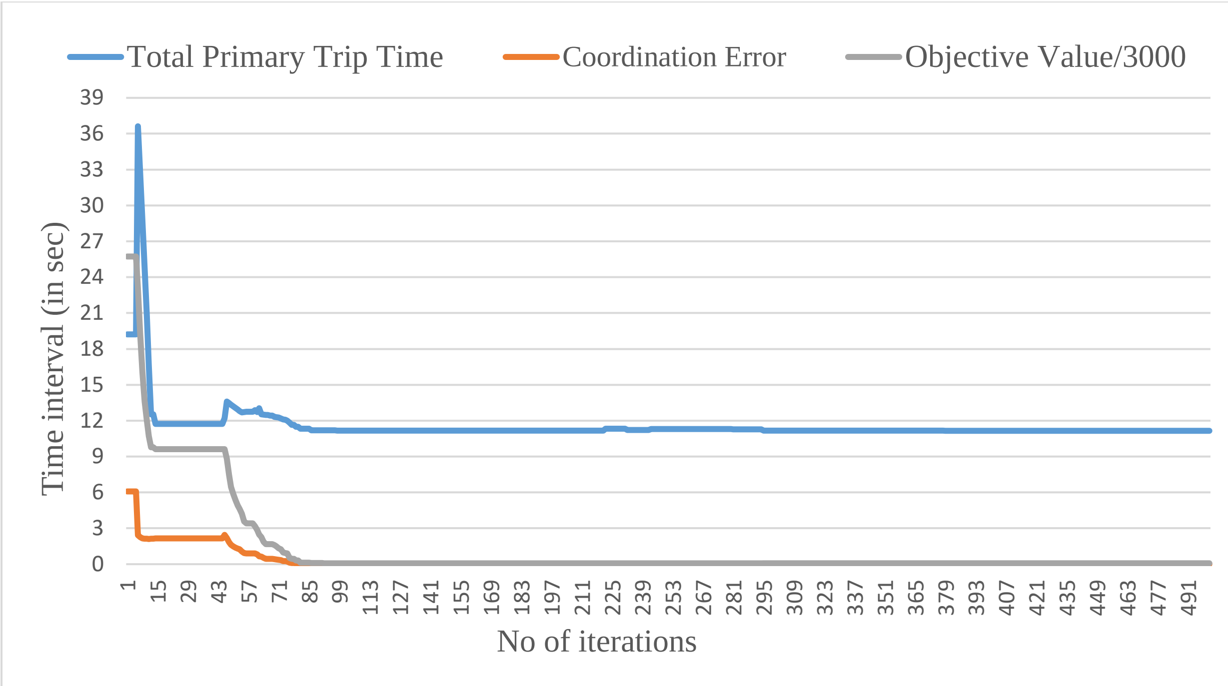

Fig 5.2: Total operating time and Coordination error over iterations for test system-1

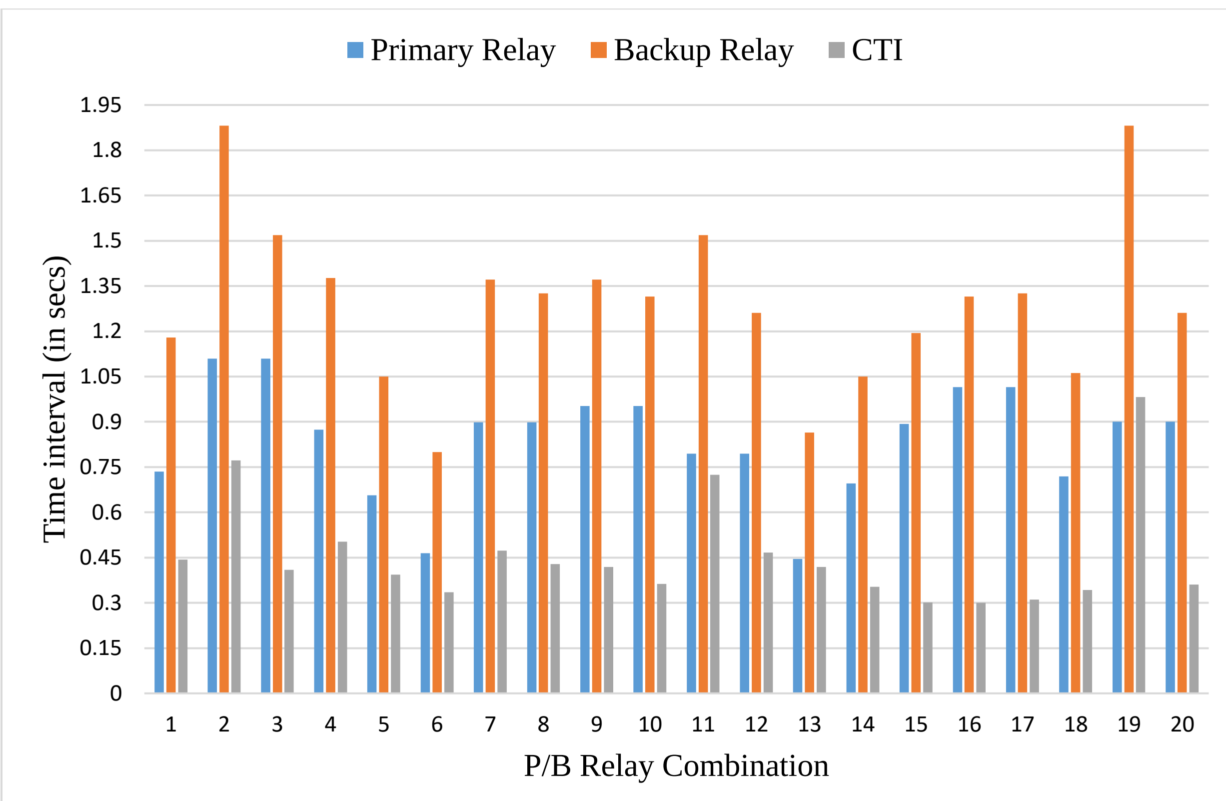

Fig 5.3: Operating times of P/B relays and CTI for test system-1

5.2. TEST SYSTEM 2

5.2.1. Description of 8-bus test system-2

The second network for testing purpose, which is utilized in the report is IEEE 8-bus test network depicted in Fig. 5.4. A connection is provided for another network or any external grid, which is developed by the short circuit rating of 400 MVA at bus 4. This system also consists of 8 buses, 2 electrical sources, 2 T/Fs, 7 transmitting lines and 14 directional-relays.

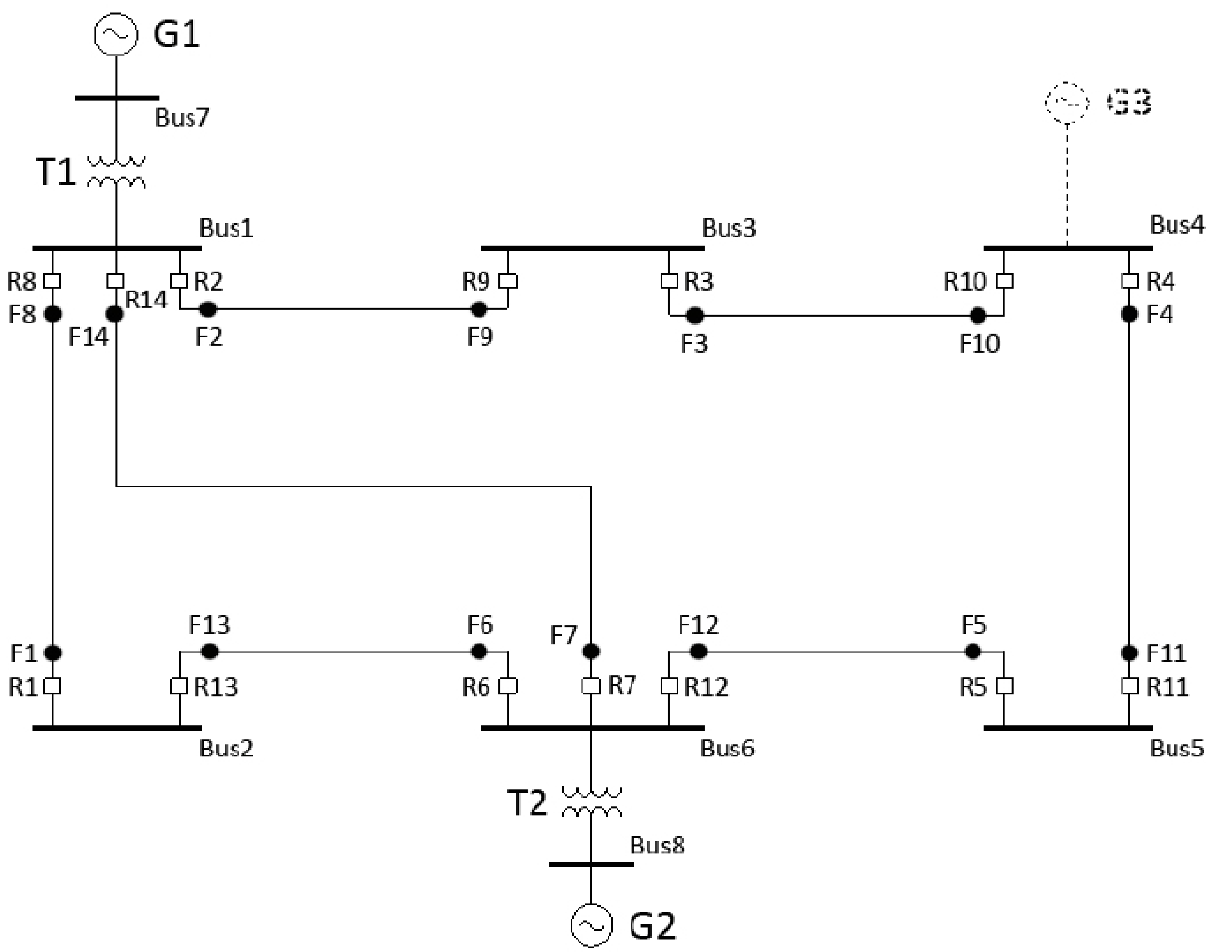

Fig 5.4: Connection-Diagram for IEEE 8 bus network (including external grid) [97]

Furthermore, the lower and higher settings with respect to the constraints for TMS are chosen 0.1 and 1.1, respectively. And, the boundaries of PSM are 0.5 to 2.5. This is utilized in discrete numbers consisting of step length of 0.1. The settings for CTI is considered as 0.3 and upper limit for duration for tripping of every relay is chosen as T_{max} = 2(s). It shows that, bus network consists

28 design variables (14 + 14, for TMS and PSM) and 40 constraints (20 + 20, for CTI and T_{max}, respectively).

The Test system-1 and Test system-2 have a fully separate 3-phase fault currents as discussed in Appendix-A. Additionally, TMS and I_p are selected as continuous variables in test network-1, while TMS are the continuously changing variables and PSM are the discretely changing variables in the test system-2. One more difference is depicted in the lower bounds of TMS (0.05 in network-1 and 0.1 in network-2).

5.2.2. Setting of parameters

The setting of parameters for both test system under BA and BBA are as shown:

i. N_population = 100 bat-particles
ii. f_{min} = -1 and f_{max} = +1
iii. A_{min} = 0.1 (PSM), 0.3 (TMS) and A_{max} = 0.8
iv. r_{min} = 0 (PSM), 0.5 (TMS) and r_{max} = 0.5 (PSM), 1.1 (TMS)
v. alpha = 0.8 and gamma = 0.8

5.2.3. Obtained simulation output

The implementation of bat algorithm has been applied in the computation of optimized settings of time multiplier and pickup current for determination of minimum possible operating time of directional OC relays for 8 bus network containing an external grid. Applying the parameters shown above, problem for mixed integer relay settings is computed. The table 5.4 shows the coordination criteria for every combination of primary and backup relays. The solution for TMS and PSM is provided in table 5.5. A comparison of output for test system-2 is given in table 5.6. The curve for aggregate operating time obtained in each iteration is depicted in fig 5.4. The fig 5.5 shows the operating time for each combination of primary and backup relays with respect to the CTI.

Table 5.4: P/B relay pairs and their coordination time interval for test system-2

Primary Relay	Backup Relay	Coordination Time Interval (in sec)
1	6	0.271357
2	1	0.276642
2	7	0.295576
3	2	0.216745
4	3	0.149648
5	4	0.220412
6	5	0.391711
6	14	0.492149
7	5	0.293318
7	13	0.385469
8	7	0.391207
8	9	0.323034
9	10	0.292027
10	11	0.209763
11	12	0.185596
12	13	0.261462
12	14	0.269749
13	8	0.326636
14	1	0.324671
14	9	0.275434

Table 5.5: Optimal relay settings and their corresponding operating time for test system-2

Relay	TMS	PSM	$T_{primary}$	T_{backup}
1	3.858971E-01	6.000E-01	0.841555	1.36994
2	6.026580E-01	6.000E-01	1.0933	1.27388
3	5.953225E-01	5.000E-01	1.05713	1.20872
4	5.405284E-01	5.000E-01	1.059074	1.2254
5	4.433032E-01	5.000E-01	1.004982	1.31834
6	5.412326E-01	5.000E-01	0.926631	1.11291
7	6.092360E-01	6.000E-01	1.025024	1.38888
8	5.542635E-01	6.000E-01	0.99767	1.24057
9	4.829029E-01	6.000E-01	1.005614	1.3207
10	5.432436E-01	6.000E-01	1.116632	1.29764
11	5.436512E-01	6.000E-01	1.133959	1.3264
12	6.326308E-01	6.000E-01	1.149031	1.31955
13	4.336682E-01	5.000E-01	0.913936	1.41049
14	6.205245E-01	6.000E-01	1.04527	1.41878

Table 5.6: Result comparison for test system-2

Algorithm	Operating Time (secs)
BBA	14.36
GAMS [32]	17.25
MPSO [32]	17.33

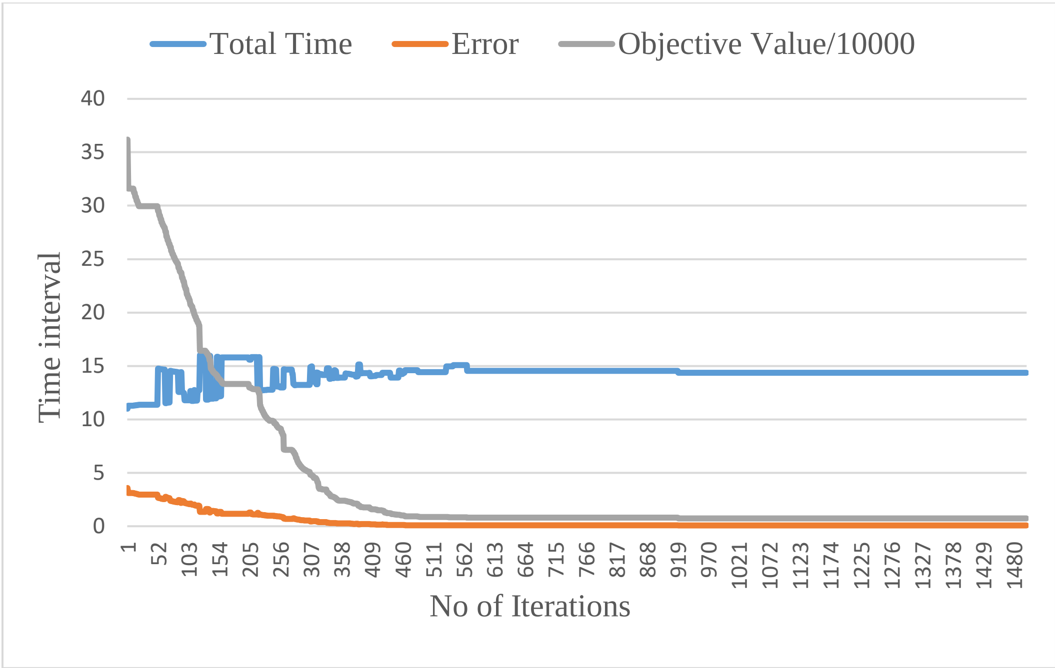

Fig 5.5: Total operating time, Error and Objective value over iterations for test system-1

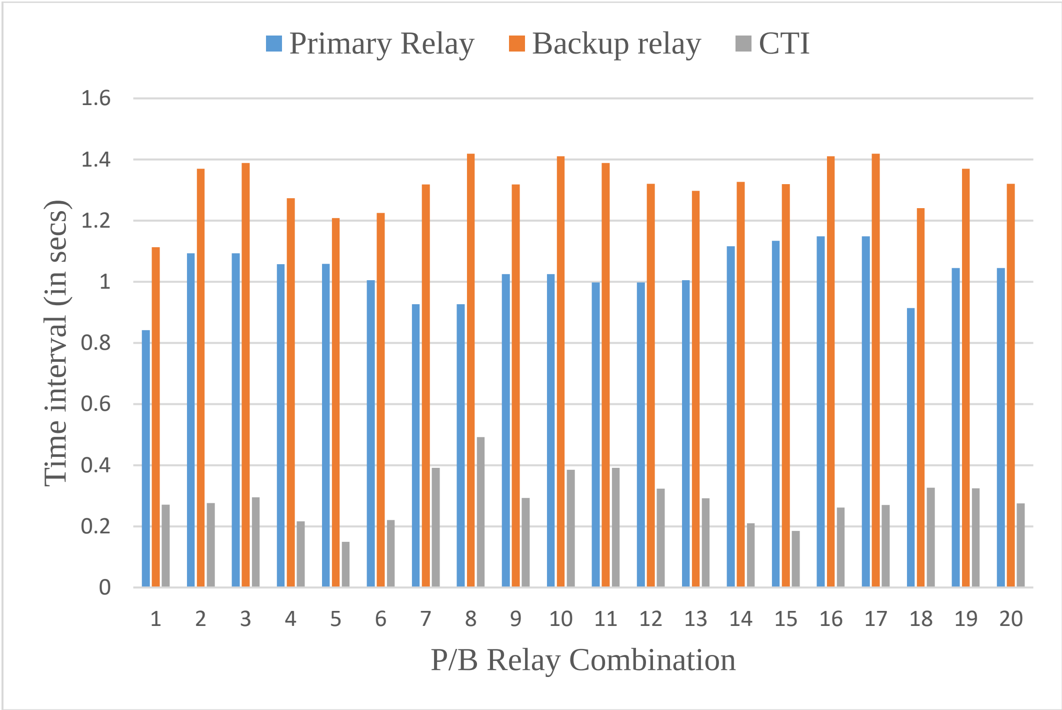

Fig 5.6: Operating times of P/B relays and CTI for test system-1

CHAPTER 6
CONCLUSION

6.1. CONCLUSION

Namely various metaheuristic algorithm schemes, bat algorithm enjoy the benefits of easiness and elasticity. BA adopt sound bursts and frequency matching to unfold problems. The sound burst is not applied straight to simulate the true behavior in actuality, frequency deviations are also adopted. BA has a functionality of automatically zooming into a region thus followed by the instinctive channel from investigative passes to local concentrated profiteering. BA also applied parameter control.

In the discussed approach, the tests on IEEE 8-bus system for computation of trip time in relay coordination is conducted. The given bus network can be designed in two models: 1) No connection to external grid and 2) connected to external grid, having a short circuit capacity of 400 MVA. The aim of work is to provide the constrained outputs for given networks.

Eventually, discussed bat algorithm and its binary variant are very capable. There is quiet a chance for upgrading the mechanism and boost the implementation more. Although, increased rate of convergence for an algorithm is quiet a very daring dispute for huge variety of problems in actual practical-life accomplishment.

6.2. FUTURE SCOPE OF WORK

- A modified bat-algorithm can be implemented with following heuristics:
  - (a) Inertia weight updating of velocity
  - (b) Adaptive formulation for alpha etc.
- Further, to improve the performance of BAT algorithm, it can be integrated with other optimization technique.
- The proposed approach can be tested to solve high dimension problems.
- The provision of discrete settings for the plug settings multiplier values can also be extended to the time multiplier settings for checking of results obtained.
- A more suitable fitness function can also be developed which may increase rate of convergence and provide better settings for the relays.

REFERENCES

[1] Arthur Wright, P. Gordon Newbery "Electric fuses 3rd edition", Institution of Electrical Engineers (IET), 2004, ISBN 0-86341-379-X, pp. 2–10.

[2] Hussain, M. H., I. Musirin, A. F. Abidin, and S. R. A. Rahim. "Modified swarm firefly algorithm method for directional overcurrent relay coordination problem." *Journal of Theoretical & Applied Information Technology* 66, no. 3 (2014).

[3] Yang, Ming-Ta, and An Liu. "Applying hybrid PSO to optimize directional overcurrent relay coordination in variable network topologies." *Journal of Applied Mathematics* (2013).

[4] Albrecht, R. E., M. J. Nisja, W. E. Feero, G. D. Rockefeller, and C. L. Wagner. "Digital computer protective device co-ordination program I-general program description." *IEEE Transactions on Power Apparatus and Systems* 83, no. 4 (1964): 402-410.

[5] Damborg, Ramaswami, S. S. Venkata, and J. M. Postforoosh. "Computer aided transmission protection system design part I: Alcorithms." *IEEE Transactions on Power Apparatus and Systems* 1 (1984): 51-59.

[6] Urdaneta, Alberto, Ramon Nadira, and Perez Jimenez. "Optimal coordination of directional overcurrent relays in interconnected power systems." *IEEE Transactions on Power Delivery* 3, no. 3 (1988): 903-911.

[7] Rao, Bapeswara, and Sankara Rao. "Computer aided coordination of directional relays: determination of break points." *IEEE transactions on power delivery* 3, no. 2 (1988): 545-548.

[8] Jenkins, H. P. Khincha, Shivakumar, and P. K. Dash. "An application of functional dependencies to the topological analysis of protection schemes." *IEEE transactions on power Delivery* 7, no. 1 (1992): 77-83.

[9] Urdaneta, Alberto, Restrepo, Marquez, and Jorge Sanchez. "Coordination of directional overcurrent relay timing using linear programming." *IEEE Transactions on Power Delivery* 11, no. 1 (1996): 122-129.

[10] Chattopadhyay, Bijoy, M. S. Sachdev, and T. S. Sidhu. "An on-line relay coordination algorithm for adaptive protection using linear programming technique." *IEEE Transactions on Power Delivery* 11, no. 1 (1996): 165-173.

[11] Abyaneh, H. Askarian, Majid Al-Dabbagh, H. Kazemi Karegar, Seyed Hesameddin Hossein Sadeghi, and RA Jabbar Khan. "A new optimal approach for coordination of overcurrent relays in interconnected power systems." *IEEE Transactions on power delivery* 18, no. 2 (2003): 430-435.

[12] Sueiro, José A., Eloy Diaz-Dorado, Edelmiro Míguez, and José Cidrás. "Coordination of directional overcurrent relay using evolutionary algorithm and linear programming." *International Journal of Electrical Power & Energy Systems* 42, no. 1 (2012): 299-305.

[13] Singh, Manohar, and Rohan Mukherjee. "Optimum coordination of overcurrent relays using CMA-ES algorithm." In *Power Electronics, Drives and Energy Systems (PEDES), 2012 IEEE International Conference on*, pp. 1-6. IEEE, 2012.

[14] Birla, Dinesh, Rudra Prakash Maheshwari, and H. O. Gupta. "A new nonlinear directional overcurrent relay coordination technique, and banes and boons of near-end faults based approach." *IEEE transactions on power delivery* 21, no. 3 (2006): 1176-1182.

[15] Saleh, Khaled A., H. H. Zeineldin, Amer Al-Hinai, and Ehab F. El-Saadany. "Optimal coordination of directional overcurrent relays using a new time–current–voltage characteristic." *IEEE Transactions on Power Delivery* 30, no. 2 (2015): 537-544.

[16] J. A. Sueiro, E. Diaz-Dorado, Edelmiro Míguez. "Coordination of directional overcurrent relay using evolutionary algorithm and non-linear programming." *International Journal of Electrical Power & Energy Systems* 42.1 (2012): 289-307.

[17] Marcolino, Matheus Henrique, J. Boas Leite, and J. R. Sanches Mantovani. "Optimal Coordination of Overcurrent Directional and Distance Relays in Meshed Networks Using Genetic Algorithm." *IEEE Latin America Transactions* 13, no. 9 (2015): 2975-2982.

[18] Razavi, Farzad, Hossein Abyaneh, Majid Al-Dabbagh, R. Mohammadi, and H. Torkaman. "A new comprehensive genetic algorithm method for optimal overcurrent relays coordination." *Electric Power Systems Research* 78, no. 4 (2008): 713-720.

[19] Bedekar, Prashant P., and Sudhir R. Bhide. "Optimum coordination of overcurrent relay timing using continuous genetic algorithm." *Expert Systems with Applications* 38, no. 9 (2011): 11286-11292.

[20] Noghabi, Abbas Saberi, Javad Sadeh, and Habib R. Mashhadi. "Considering different network topologies in optimal overcurrent relay coordination using a hybrid GA." *IEEE Transactions on Power Delivery* 24, no. 4 (2009): 1857-1863.

[21] Bedekar, P. Prabhakar, and S. R. Bhide. "Optimum coordination of directional overcurrent relays using the hybrid GA-NLP approach." *IEEE Transactions on Power Delivery* 26, no. 1 (2011): 109-119.

[22] Adelnia, Farhad, Zahra Moravej, and Mehdi Farzinfar. "A new formulation for coordination of directional overcurrent relays in interconnected networks." *International Transactions on Electrical Energy Systems* 25, no. 1 (2015): 120-137.

[23] Moravej, Zahra, Farhad Adelnia, and Fazel Abbasi. "Optimal coordination of directional overcurrent relays using NSGA-II." *Electric Power Systems Research* 119 (2015): 228-236.

[24] Thakur, Manoj, and Anand Kumar. "Optimal coordination of directional over current relays using a modified real coded genetic algorithm: A comparative study." *International Journal of Electrical Power & Energy Systems* 82 (2016): 484-495.

[25] Damchi, Yaser, Javad Sadeh, and Habib Rajabi Mashhadi. "Applying Hybrid Interval Linear Programming and Genetic Algorithm to Coordinate Distance and Directional Over-current Relays." *Electric Power Components and Systems* 44, no. 17 (2016): 1935-1946.

[26] Asadi, M. R., and S. M. Kouhsari. "Optimal overcurrent relays coordination using particle-swarm-optimization algorithm." In *Power Systems Conference and Exposition'09. IEEE/PES*, pp. 1-7 (2009).

[27] Zellagui, Mohamed, Rabah Benabid, Mohamed Boudour, and Abdelaziz Chaghi. "Mixed integer optimization of IDMT overcurrent relays in the presence of wind energy farms using PSO algorithm." *Periodica Polytechnica. Electrical Engineering and Computer Science* 59, no. 1 (2015): 9.

[28] Mansour, Mohamed M., Said F. Mekhamer, and Nehad El-Kharbawe. "A modified particle swarm optimizer for the coordination of directional overcurrent relays." *IEEE transactions on power delivery* 22, no. 3 (2007): 1400-1410.

[29] Leite, H., J. Barros, and V. Miranda. "The evolutionary algorithm EPSO to coordinate directional overcurrent relays." (2010): 43-43.

[30] Zeineldin, H. H., E. El-Saadany, and M. A. Salama. "Optimal coordination of overcurrent relays using a modified particle swarm optimization." *Electric Power Systems Research* 76, no. 11 (2006): 988-995.

[31] Farzinfar, Mehdi, Mostafa Jazaeri, and Farzad Razavi. "A new approach for optimal coordination of distance and directional over-current relays using multiple embedded crossover PSO." *International Journal of Electrical Power & Energy Systems* 61 (2014): 620-628.

[32] Radosavljević, Jordan, and Miroljub Jevtić. "Hybrid GSA-SQP algorithm for optimal coordination of directional overcurrent relays." *IET Generation, Transmission & Distribution* 10.8 (2016): 1928-1937.

[33] Srivastava, Adhishree, Jayant Mani Tripathi, Soumya R. Mohanty, and Bhagabat Panda. "Optimal over-current relay coordination with distributed generation using hybrid particle swarm optimization–gravitational search algorithm." *Electric Power Components and Systems* 44, no. 5 (2016): 506-517.

[34] Alam, M. Nabab, B. Das, and Vinay P. "A comparative study of metaheuristic optimization approaches for directional overcurrent relays coordination." *Electric Power Systems Research* 128 (2015): 39-52.

[35] Thangaraj, Radha, Thanga Raj Chelliah, and Millie Pant. "Overcurrent relay coordination by differential evolution algorithm." In *Power Electronics, Drives and Energy Systems (PEDES), 2012 IEEE International Conference on*, pp. 1-6. IEEE, 2012.

[36] Mohseni, Mojtaba, Amir Afroomand, and F. Mohsenipour. "Optimum coordination of overcurrent relays using SADE algorithm." In *Electrical Power Distribution Networks (EPDC), 2011 16th Conference on*, pp. 1-10. IEEE, 2011.

[37] Moirangthem, Joymala, K. R. Krishnanand, Subhransu S. Dash, and Ramas Ramaswami. "Adaptive differential evolution algorithm for solving non-linear coordination problem of directional overcurrent relays." *IET Generation, Transmission & Distribution* 7, no. 4 (2013): 329-336.

[38] Thangaraj, Radha, Millie Pant, and Kusum Deep. "Optimal coordination of over-current relays using modified differential evolution algorithms." *Engineering Applications of Artificial Intelligence* 23, no. 5 (2010): 820-829.

[39] Chelliah, Thanga Raj, Radha Thangaraj, Srikanth Allamsetty, and Millie Pant. "Coordination of directional overcurrent relays using opposition based chaotic differential evolution algorithm." *International Journal of Electrical Power & Energy Systems* 55 (2014): 341-350.

[40] Singh, Manohar, Bijaya K. Panigrahi, Abhijit R. Abhyankar, and Swagatam Das. "Optimal coordination of directional over-current relays using informative differential evolution algorithm." *Journal of Computational Science* 5, no. 2 (2014): 269-276.

[41] Yen Shih, Meng, and Arturo Conde. "Implementation of directional over-current relay coordination approaches in electrical networks." *Electric Power Components and Systems* 43, no. 19 (2015): 2131-2145.

[42] Singh, Manohar, B. K. Panigrahi, and A. R. Abhyankar. "Optimal coordination of directional over-current relays using Teaching Learning-Based Optimization (TLBO) algorithm." *International Journal of Electrical Power & Energy Systems* 50 (2013): 33-41.

[43] Kalage, Amol A., and Nitin D. Ghawghawe. "Optimum Coordination of Directional Overcurrent Relays Using Modified Adaptive Teaching Learning Based Optimization Algorithm." *Intelligent Industrial Systems* 2, no. 1 (2016): 55-71.

[44] Albasri, Fadhel A., Ali R. Alroomi, and Jawad H. Talaq. "Optimal coordination of directional overcurrent relays using biogeography-based optimization algorithms." *IEEE Transactions on Power Delivery* 30, no. 4 (2015): 1810-1820.

[45] Singh, Manohar, Bijaya Ketan Panigrahi, and Abhijit R. Abhyankar. "Optimal coordination of electro-mechanical-based overcurrent relays using artificial bee colony algorithm." *International Journal of Bio-Inspired Computation* 5, no. 5 (2013): 267-280.

[46] Amraee, Turaj. "Coordination of directional overcurrent relays using seeker algorithm." *IEEE Transactions on Power Delivery* 27, no. 3 (2012): 1415-1422.

[47] Alipour, Manijeh, Saeed T., and Heresh Seyedi. "Improved group search optimization algorithm for coordination of directional overcurrent relays." *Swarm and Evolutionary Computation* 23 (2015): 40-49.

[48] Othman, Ahmed M., and Almoataz Y. Abdelaziz. "Enhanced backtracking search algorithm for optimal coordination of directional over-current relays including distributed generation." *Electric Power Components and Systems* 44, no. 3 (2016): 278-290.

[49] Benabid, Rabah, Mohamed Zellagui, Abdelaziz Chaghi, and Mohamed Boudour. "Application of firefly algorithm for optimal directional overcurrent relays coordination in the presence of IFCL." *International Journal of Intelligent Systems and Applications* 6, no. 2 (2014): 44.

[50] Bouchekara, H. R. E. H., M. Zellagui, and M. A. Abido. "Optimal coordination of directional overcurrent relays using a modified electromagnetic field optimization algorithm." *Applied Soft Computing* 54 (2017): 267-283.

[51] O. Emmanuel, M.L. Othman, H. Hizam, N. Rezaei, M.M. Othman, “Time-current characteristic curve prediction for directional overcurrent relays in interconnected network using artificial neural network.” ARPN J. Eng. Appl. Sci.10 (2015) 10679–10685.

[52] Yang, Xin-She. "A new metaheuristic bat-inspired algorithm." *Nature inspired cooperative strategies for optimization (NICSO 2010)* (2010): 65-74.

[53] Akhtar, S., A. R. Ahmad, and E. M. Abdel-Rahman. "A metaheuristic bat-inspired algorithm for full body human pose estimation." In *Computer and Robot Vision (CRV), 2012 Ninth Conference on*, pp. 369-375. IEEE, 2012.

[54] Yang, Xin-She, Mehmet Karamanoglu, and Simon Fong. "Bat algorithm for topology optimization in microelectronic applications." In *Future Generation Communication Technology (FGCT), 2012 International Conference on*, pp. 150-155. IEEE, 2012.

[55] Chen, Bin-Yih Liao, Chin-Feng Lee, Wu-Der Tsay, and Mei-Chiao L. "An Adjustable Frequency Bat Algorithm Based on Flight Direction to Improve Solution Accuracy for Optimization Problems." In *Robot, Vision and Signal Processing (RVSP), 2013 Second International Conference on*, pp. 172-177. IEEE, 2013.

[56] Parika, Wipada, Wipada Seesuaysom, Srisatja Vitayasak, and Pupong Pongcharoen. "Bat algorithm for designing cell formation with a consideration of routing flexibility." In *Industrial Engineering and Engineering Management (IEEM), 2013 IEEE International Conference on*, pp. 1353-1357. IEEE, 2013.

[57] Islam, Naz Niamul, M. A. Hannan, Hussain Shareef, and Azah Mohamed. "Power system stabilizer design using BAT optimization algorithm in multimachine power system." In *Research and Development (SCOReD), 2013 IEEE Student Conference on*, pp. 540-544. IEEE, 2013.

[58] Gupta, Neha, and Kapil Sharma. "Optimizing intermediate COCOMO model using BAT algorithm." In *Computing for Sustainable Global Development (INDIACom), 2015 2nd International Conference on*, pp. 1649-1653. IEEE, 2015.

[59] Jose, Julia Tholath. "Economic load dispatch including wind power using Bat Algorithm." In *Advances in Electrical Engineering (ICAEE), 2014 International Conference on*, pp. 1-4. IEEE, 2014.

[60] Hemis, Mustapha, Bachir Boudraa, and Thouraya Merazi-Meksen. "Bat inspired optimization approach for audio watermarking algorithm." In *Computer Systems and Applications (AICCSA), 2015 IEEE/ACS 12th International Conference of*, pp. 1-7. IEEE, 2015.

[61] Sambariya, D. K., and H. Manohar. "Model order reduction by integral squared error minimization using bat algorithm." In *Recent Advances in Engineering & Computational Sciences (RAECS), 2015 2nd International Conference on*, pp. 1-7. IEEE, 2015.

[62] Tsai, Pei-Wei, Jing Zhang, Sunmiao Zhang, Lyu-Chao Liao, Jeng-Shyang Pan, and Vaci Istanda. "Deceleration Convergence Strategy for Evolved Bat Algorithm." In *Robot, Vision and Signal Processing (RVSP), 2015 Third International Conference on*, pp. 167-170. IEEE, 2015.

[63] Abdhullah, Sinha Sheikh, Kiran Jyoti, Shabnam Sharma, and U. S. Pandey. "Review of recent load balancing techniques in cloud computing and BAT algorithm variants." In *Computing for Sustainable Global Development (INDIACom), 2016 3rd International Conference on*, pp. 2428-2431. IEEE, 2016.

[64] Abatari, H., M. Seyf Abad, and H. Seifi. "Application of bat optimization algorithm in optimal power flow." In *Electrical Engineering (ICEE), 2016 24th Iranian Conference on*, pp. 793-798. IEEE, 2016.

[65] Gupta, Shrey, and Kapil Sharma. "Optimization of revenue generated by hydro power plant by Bat Algorithm (BA)." In *Computing for Sustainable Global Development (INDIACom), 2016 3rd International Conference on*, pp. 3576-3580. IEEE, 2016.

[66] Neagu, Bogdan Constantin, Ovidiu Ivanov, and Gheorghe Georgescu. "Reactive power compensation in distribution networks using the bat algorithm." In *Electrical and Power Engineering (EPE), 2016 International Conference and Exposition on*, pp. 711-714. IEEE, 2016.

[67] Senthilnath, J., Sushant Kulkarni, Jón Atli Benediktsson, and Xin-She Yang. "A novel approach for multispectral satellite image classification based on the bat algorithm." *IEEE Geoscience and Remote Sensing Letters* 13, no. 4 (2016): 599-603.

[68] Xin-She Yang, "Bat Algorithm for Multi-objective Optimization." *Int. J. Bio-Inspired Computation*, Vol. 3, No. 5, pp.267-274 (2011).

[69] Niknam, Taher, Rasoul Azizipanah-Abarghooee, Mohsen Zare, and Bahman Bahmani-Firouzi. "Reserve constrained dynamic environmental/economic dispatch: A new multiobjective self-adaptive learning bat algorithm." *IEEE Systems Journal* 7, no. 4 (2013): 763-776.

[70] Yilmaz, Selim, and Ecir U. Kucuksille. "Improved bat algorithm (IBA) on continuous optimization problems." *Lecture Notes on Software Engineering* 1, no. 3 (2013): 279.

[71] Yılmaz, S., E. Ugur Kucuksille, and Y. Cengiz. "Modified bat algorithm." *Elektronika ir Elektrotechnika* 20, no. 2 (2014): 71-78.

[72] Topal, Ali Osman, and Oguz Altun. "Dynamic virtual bats algorithm (dvba) for global numerical optimization." In *Intelligent Networking and Collaborative Systems (INCoS), 2014 International Conference on*, pp. 320-327. IEEE, 2014.

[73] Wang, Gai-Ge, Bao Chang, and Zhaojun Zhang. "A multi-swarm bat algorithm for global optimization." In *Evolutionary Computation (CEC), 2015 IEEE Congress on*, pp. 480-485. IEEE, 2015.

[74] Latif, Aadil, Ishtiaq Ahmad, Peter Palensky, and Wolfgang Gawlik. "Multi-objective reactive power dispatch in distribution networks using modified bat algorithm." In *Green Energy and Systems Conference (IGSEC), 2016 IEEE*, pp. 1-7. IEEE, 2016.

[75] Komarasamy, G., and Amitabh Wahi. "An optimized K-means clustering technique using bat algorithm." *European Journal of Scientific Research* 84, no. 2 (2012): 26-273.

[76] Yammani, Chandrasekhar, Sydulu Maheswarapu, and Matam Sailaja Kumari. "Optimal Placement and Sizing of DER's with Load variations using Bat Algorithm." *Arabian Journal for Science and Engineering* 39, no. 6 (2014): 4891-4899.

[77] Pérez, Jonathan, Fevrier Valdez, and Oscar Castillo. "Proposed augmentation of the Bat Algorithm using fuzzy logic for dynamic parameter adaptation." In *Fuzzy Information Processing Society (NAFIPS) held jointly with 2015 5th World Conference on Soft Computing (WConSC), 2015 Annual Conference of the North American*, pp. 1-6. IEEE, 2015.

[78] Othman, Zulkifli, Shahril Irwan Sulaiman, Ismail Musirin, and Khairudin Mohamad. "Bat inspired algorithm for sizing optimization of grid-connected photovoltaic system." In *SAI Intelligent Systems Conference (IntelliSys), 2015*, pp. 195-200. IEEE, 2015.

[79] Nakamura, Rodrigo YM, Luis AM Pereira, K. A. Costa, Douglas Rodrigues, João P. Papa, and X-S. Yang. "BBA: a binary bat algorithm for feature selection." In *Graphics, Patterns and Images (SIBGRAPI), 2012 25th SIBGRAPI Conference on*, pp. 291-297. IEEE, 2012.

[80] Sur, Chiranjib, and Anupam Shukla. "Adaptive & Discrete Real Bat Algorithms for Route Search Optimization of Graph Based Road Network." In *Machine Intelligence and Research Advancement (ICMIRA), 2013 International Conference on*, pp. 120-124. IEEE, 2013.

[81] Djelloul, Halima, Sara Sabba, and Salim Chikhi. "Binary bat algorithm for graph coloring problem." In *Complex Systems (WCCS), 2014 Second World Conference on*, pp. 481-486. IEEE, 2014.

[82] Mirjalili, Seyedali, Seyed Mohammad Mirjalili, and Xin-She Yang. "Binary bat algorithm." *Neural Computing and Applications* 25.3-4 (2014): 663-681.

[83] Rani, A. Sylvia Selva, and R. R. Rajalaxmi. "Unsupervised feature selection using binary bat algorithm." In *Electronics and Communication Systems (ICECS), 2015 2nd International Conference on*, pp. 451-456. IEEE, 2015.

[84] Rajalaxmi, R. R., and A. Ramesh. "Binary Bat Approach for Effective Spam Classification in Online Social Networks." *Australian Journal of Basic and Applied Sciences* 8, no. 18 (2014): 383-388.

[85] Doreswamy, Umme Salma M. “A binary bat inspired algorithm for the classification of breast cancer Data”, *International Journal on Soft Computing, Artificial Intelligence and Applications (IJSCAI)*, Vol.5, No.2/3 (2016).

[86] Glover J. D., Sarma M. S., Overbye T. J. “Power System and Analysis 5th Edition.” Cengage Learning, Pg 548-549 (2010).

[87] Shih, Meng Yen, Arturo Conde Enríquez, Tsun-Yu Hsiao, and Luis Martín Torres Treviño. "Enhanced differential evolution algorithm for coordination of directional overcurrent relays." *Electric Power Systems Research* 143 (2017): 365-375.

[88] Ezzeddine, Mazhar, and Robert Kaczmarek. "A novel method for optimal coordination of directional overcurrent relays considering their available discrete settings and several operation characteristics." *Electric Power Systems Research* 81, no. 7 (2011): 1475-1481.

[89] Azari, Afshin, and Mahdi Akhbari. "Optimal coordination of directional overcurrent relays in distribution systems based on network splitting." *International Transactions on Electrical Energy Systems* 25, no. 10 (2015): 2310-2324.

[90] Mirjalili, SeyedAli, and Siti Zaiton Mohd Hashim. "BMOA: binary magnetic optimization algorithm." *International Journal of Machine Learning and Computing* 2, no. 3 (2012): 204.

[91] Mirjalili, Seyedali, and Andrew Lewis. "S-shaped versus V-shaped transfer functions for binary particle swarm optimization." *Swarm and Evolutionary Computation* 9 (2013): 1-14.

[92] Rashedi, Esmat, Hossein Nezamabadi-Pour, and Saeid Saryazdi. "BGSA: binary gravitational search algorithm." *Natural Computing* 9, no. 3 (2010): 727-745.

[93] Kennedy, James, and Russell C. Eberhart. "A discrete binary version of the particle swarm algorithm." In *Systems, Man, and Cybernetics, 1997. Computational Cybernetics and Simulation. IEEE International Conference on*, vol. 5, pp. 4104-4108. IEEE, 1997.

[94] Tasgetiren, Mehmet Fatih, Ponnuthurai N. Suganthan, and Quan-Qe Pan. "A discrete particle swarm optimization algorithm for the generalized traveling salesman problem." In *Proceedings of the 9th annual conference on Genetic and evolutionary computation*, pp. 158-167. ACM, 2007.

[95] Yılmaz, Selim, and Ecir U. Küçüksille. "A new modification approach on bat algorithm for solving optimization problems." *Applied Soft Computing* 28 (2015): 259-275.

[96] Alam, Mahamad Nabab, Biswarup Das, and Vinay Pant. "An interior point method based protection coordination scheme for directional overcurrent relays in meshed networks." *International Journal of Electrical Power & Energy Systems* 81 (2016): 153-164.

[97] Rajput, Vipul N., and Kartik S. Pandya. "On 8-bus test system for solving challenges in relay coordination." In *Power Systems (ICPS), 2016 IEEE 6th International Conference on*, pp. 1-5. IEEE, 2016.

APPENDIX-A

System Data for Test Systems

Table A.1: Values of 3 phase short circuit currents corresponding to their relay pairs

Primary relay	I_{F1}^{p} (A)	I_{F2}^{p} (A)	Backup relay	I_{F1}^{b} (A)	I_{F2}^{b} (A)
1	2666.3	3232	6	2663	3232
2	5374.8	5924	1	804.7	996
2	5374.8	5924	7	1531.5	1890
3	3325.6	3556	2	3325.6	3556
4	2217.1	3783	3	2217.1	2244
5	1334.3	2401	4	1334.3	2401
6	4975	6109	5	403.6	1197
6	4975	6109	14	1533	1874
7	4247.6	5223	5	403.6	1197
7	4247.6	5223	13	805.5	987
8	4973.2	6093	7	1531.5	1890
8	4973.2	6093	9	403.2	1165
9	1420.9	2484	10	1420.9	2484
10	2313.5	3883	11	2313.5	2344
11	3474.3	3707	12	3474.3	3707
12	5377	5899	13	805.5	987
12	5377	5899	14	1533	1874
13	2475.7	2991	8	2475.7	2991
14	4246.4	5199	1	804.7	996
14	4246.4	5199	9	403.2	1165

Table A.2: Properties of relays for both test system

Relay	CT Ratio	Pickup Current (A)	
		Lowest Value	Highest Value
1	1220/5	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

Table A.3: Boundary values for Decision Variables

TMS_{min}	0.05 (Continous), 0.1(Discrete)
TMS_{max}	1.1
PSM_{min}	0.5
PSM_{max}	2.5
CTI	0.3

CURRICULUM VITAE OF AUTHOR

I. Personal background

NAME: Tushar Sharma

FATEHR'S NAME: Mr. Mukesh Kumar Sharma

DATE OF BIRTH: 24/06/1993

E-mail: tusharbhardwaj721@gmail.com

II. Educational Qualification

Qualification	Name of College/ Institute	Board/ Uniersity	Year of Passing/ Appearing	Percentage/ CGPA
M. E. (Power System)	TIET, Patiala	Thapar University	2017	8.39 (3rd sem)
B. Tech. (Electrical)	Dr. BRAECIT, Banda	UPTU, Lucknow	2014	74.02 %
Intermediate	GCPS, MZN	CBSE	2009	75.80 %
X Class	LJPSVM, MZN	UP Board	2007	78.67 %

PLAGIARISM CERTIFICATE

ORIGINALITY REPORT

%4	%1	%3	%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Xin-She Yang. "A New Metaheuristic Bat-Inspired Algorithm", Studies in Computational Intelligence, 2010 Publication	%1
2	heliland.20m.com Internet Source	%1
3	Studies in Computational Intelligence, 2015. Publication	%1
4	Pujiantara, Margo and Abdillah, Muhammad. "DIRECTIONAL OVER CURRENT RELAYS (DOCRs) COORDINATION BY INTERVAL TYPE 2 FUZZY ADAPTIVE PARTICLE SWARM OPTIMIZATION (IT2FAPSO)", International Journal of Academic Research, 2012. Publication	<%1
5	tesisenxarxa.net Internet Source	<%1
6	www.cse.dmu.ac.uk Internet Source	<%1

7	Xing, Bing, Rong Gan, Guodong Liu, Zhongfang Liu, Jing Zhang, and Yufeng Ren. "Monthly Mean Streamflow Prediction Based on Bat Algorithm-Support Vector Machine", Journal of Hydrologic Engineering, 2015. Publication	<%1
8	Liu, An, and Ming-Ta Yang. "A New Hybrid Nelder-Mead Particle Swarm Optimization for Coordination Optimization of Directional Overcurrent Relays", Mathematical Problems in Engineering, 2012. Publication	<%1
9	Liping Xie. "An Extended Artificial Physics Optimization Algorithm for Global Optimization Problems", 2009 Fourth International Conference on Innovative Computing Information and Control (ICICIC), 12/2009 Publication	<%1
10	Yang, Ming-Ta, and An Liu. "Applying Hybrid PSO to Optimize Directional Overcurrent Relay Coordination in Variable Network Topologies", Journal of Applied Mathematics, 2013. Publication	<%1
11	Mirjalili, Seyedali, Seyed Mohammad Mirjalili, and Xin-She Yang. "Binary bat algorithm", Neural Computing and Applications, 2014. Publication	<%1

12	Srivastava, Adhishree, Jayant Mani Tripathi, Soumya R. Mohanty, and Bhagabat Panda. "Optimal Over-current Relay Coordination with Distributed Generation Using Hybrid Particle Swarm Optimization–Gravitational Search Algorithm", Electric Power Components and Systems, 2016. Publication	<%1
13	Lecture Notes in Computer Science, 2013. Publication	<%1
14	Engineering Computations, Volume 29, Issue 5 (2014-09-16) Publication	<%1
15	www2.uel.br Internet Source	<%1
16	hermes-ir.lib.hit-u.ac.jp Internet Source	<%1
17	"Heuristic Optimization Method for Power System Protection Coordination — An Intelligent Tool for Energy Efficiency Improvement", Energy Efficiency Improvements in Smart Grid Components, 2015. Publication	<%1
18	ce.colorado.edu Internet Source	<%1

19 Ibrahim, Doaa Khalil, Essam El Din Abo El Zahab, and Saadoun Abd El Aziz Mostafa. "New coordination approach to minimize the number of re-adjusted relays when adding DGs in interconnected power systems with a minimum value of fault current limiter", International Journal of Electrical Power & Energy Systems, 2017. <%1

Publication

20 Ahmadianfar, Iman, Arash Adib, and Meysam Salarijazi. "Optimizing Multireservoir Operation: Hybrid of Bat Algorithm and Differential Evolution", Journal of Water Resources Planning and Management, 2015. <%1

Publication

21 Thakur, Manoj, and Anand Kumar. "Optimal coordination of directional over current relays using a modified real coded genetic algorithm: A comparative study", International Journal of Electrical Power & Energy Systems, 2016. <%1

Publication

22 Dan Cristian, Petru, Constantin Barbulescu, Attila Simo, Stefan Kilyeni, and Florin Solomonesc. "Load flow computation Particle Swarm Optimization algorithm", 2012 47th International Universities Power Engineering Conference (UPEC), 2012. <%1

Publication

EXCLUDE QUOTES	ON	EXCLUDE MATCHES	OFF
EXCLUDE BIBLIOGRAPHY	ON		