Optimization of Dynamic Economic Load Dispatch Using Bat Algorithm

A Dissertation submitted in fulfilment of the requirements for the Degree
of

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Submitted by

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DECLARATION

I hereby declare that the work which has been presented in dissertation entitled, "**Optimization of Dynamic Economic load Dispatch using BAT algorithm**", 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 an authentic record of my own work carried under the supervision of **Dr. Nitin Narang**. It refers others researcher work which is appropriately recorded in the reference section. The matter contained in this dissertation has not been submitted, neither partially nor in full to some other degree to whatever other college or organization aside from as detailed in content and references.

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

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ABSTRACT

Dynamic Economic Load Dispatch (DED) is a real time power system problem, which is an extension of conventional economic load dispatch. DED is considered to minimize the fuel cost of the generating station considering equality and non-equality constraints. In this dissertation work, to optimize the DED problem, BAT algorithm (BA) has been implemented. Bat algorithm, inspired by nature, imitates the echolocation property of micro-bats found in nature. Loudness and rate of pulse are variable factors through which global best solution is being reached. Parameter control, frequency tuning and automatic zooming are some of the advantages provided by bat algorithm. In this work for further improvement in the exploration and exploitation capabilities of BA, the characteristics like inertia weight and impact factors has been introduced in the BA. The inertia weight factor is implied for improving the convergence speed and impact factor is implied for protecting the best solution from being struck around the local minimum. Two test system has been considered for checking the effectiveness of these modifications over the standard algorithm. Test system-I consists of the five thermal generating units and test system-II consists of the ten thermal generating units taking into consideration their generation level constraint and valve-point loading effect for duration of 24 hours. Performance of modified bat algorithm is compared with standard bat algorithm and other state of art algorithms *i.e.* harmony search algorithm, evolutionary algorithm and sequential quadratic programming. Convergence characteristics of modified and standard bat algorithm is presented to consolidate the robustness of the algorithm.

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NOMENCLATURE

k	Index variable for bat particle
j	Index variable for time
i	Index variable for generating unit
F	Total operating cost over the whole dispatch duration
$F_{it}(P_{it})$	Fuel cost as function of its real power output P_{it} at time t
a_i , b_i , c_i , e_i , f_i	Fuel cost coefficients of the i^{th} unit
$P_i^{\min}$ $P_i^{\max}$	Maximum & minimum power of the i^{th} unit
N_K	Population size of bat particle
N_T	Time-period of scheduling
N_G	Total quantity of generating units
P_{it}	Real power output of i^{th} unit at time t
$f_{\max}$ & $f_{\min}$	Maximum & minimum frequency of a particle
$v_{\max}(i)$ & $v_{\min}(i)$	Maximum & minimum velocity of i^{th} particle
$P(k, j, i)$	Power of k^{th} particle for i^{th} producing unit at time step j
$f(k, j, i)$	Frequency of k^{th} particle for i^{th} producing unit at time step j
$v(k, j, i)$	Velocity of k^{th} particle for i^{th} producing unit at time step j
$al_{\max}$ & $al_{\min}$	Maximum and minimum values of loudness
r	Rate of pulse emission
ω	Inertia weight factor
ζ_1 & ζ_2	Impact factors
ζ_{init}	Initial impact factors of ζ_1 & ζ_2

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ABBREVIATION

ABC	Artificial Bee Colony
BA	Bat Algorithm
DE	Differential Evolution
DED	Dynamic Economic Dispatch
GSA	Gravitational Search Algorithm
HNN	Hopfield Neural Network
HGA	Hybrid Genetic Algorithm
HS	Harmony Search Algorithm
PSO	Particle Swarm Optimization
QP	Quadratic Programming
SA	Simulated Annealing

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Chapter-1 Introduction

1.1 Introduction

Increase in energy demand with population and lack of conventional energy reserves has forced modern day researcher's to think of obtaining a method for increasing the efficiency of usage of presently energy resources. It is predicted that if the condition of detection and consumption of non-conventional energy resources like petroleum products continues in the same manner, then it is estimated that by 2038, they will get extinct [1]. This aggressive use of petroleum products for the likes of production of electricity and its subsidiaries is the major cause of global warming effect. The main requirement is to maximize the efficiency of generating stations for producing the electricity and for that, the term optimization of economic load dispatch has been devised. Economic load dispatch problem can be categorized into two categories: conventional (static) and dynamic. Static problem is devised for fixed particular hour and the dynamic problem (DED) is devised for time duration interval.

Economic load dispatch is being regarded as the most important step in the allocation of committed units, following all concerned constraints obligatory, among all the units involved in grid operation. The operation is done in such a way that cost of producing energy in units ($/h) or btu (British thermal unit) from committed units remains minimum. The major objective of this problem is to attain minimum distribution of cost incurred from generation towards thermal increases as even a penny low saving within the process of the generating system results in a big reduction in the disbursement of the facility plant

The study of the economical distribution of generation output from the committed units among the plant is carried out at the first step. This method can be applied to the economic scheduling of plant outputs for a given system load without taking transmission loss into consideration. Determining the output of each of the plants to meet the power demand is the next logical step.

Various research work of researchers have been published previously for optimization of dynamic scheduling of committed generator units in a power plant. Many algorithms like conventional deterministic and nature inspired stochastic algorithm have been formulated for efficiently optimizing the DED problem. Conventional methods generally gets failed when the cost function employed in the economic dispatch is having convex characteristics and also when the size of the system involved is large. Mathematically programming based heuristic methods involve algorithms like Lambda-iterative method, gradient projection method, Lagrange-relaxation method, linear/non-linear, interior point methods, dynamic programming method. Increase in computational time is also one of the main dis-advantages of classical approach algorithms. Hence global search techniques like genetic algorithm (GA), ant colony optimization, differential evolution (DE), ant swarm optimization, bacterial foraging, particle swarm optimization (PSO), artificial bee colony, gravitational search technique, bat algorithm (BA) came into existence. These algorithms are suitable for the non-smooth characteristic allowing the improvement of convergence rate and reduce the dependency over the initial point of solutions. The drawback associated with these techniques of trapping around local optimum solution is discussed later in the dissertation.

1.2 Literature review

The importance of economic load dispatch in the power system operations has gone up as it is one of the major aspects involved in estimating a system. In a rapidly developing nation like India, electricity generated from generating stations will only be viable when it is feasible to the masses in terms of its cost. Hence, it should be ensured that the power generated from the power utility be in such a way that load demanded must be met by the generating units with an aim to minimize the total generation cost for economic operation of the system.

Static and dynamic are the two categories of problem. The static problem can be defined as conventional problem that relies upon the static behaviour of generating units that attempts to minimize the cost of supplying power subjected to constraints. It is assumed in static problem that the amount of power supplied through the committed units of a particular generating station is constant for a given time period. For scheduling load for a particular hour [2-3] static problem can be approached but scheduling for 24 hours dynamic problem comes into the scenario.

Dynamic economic load dispatch is the second category under the economic load dispatch problem. In accordance with the change in load variation, power generation must serve the load demanded. Dynamic economic load dispatch is a real time power system problem that is used to schedule the committed units of generating station for a load cycle of 24 hours. It is used to determine the minimum cost of dispatch by satisfying hourly load demands, load balance constraints and other constraint limits as proposed by Xia [4]. Morgan *et al*. [5] and Han *et al*. [6] proposed a cost function of quadratic type for thermal generators, but practically when the steam is made to pass through the valve some ripple effect is seen which is termed as the valve-point effect (VPE) [7-9]. Due to this problem and also multiple fuel option, the cost function of thermal generators becomes non-linear, non-smooth and non-convex as shown by

Victoire *et al*. [10]. Therefore, it is a very challenging problem to serve the load demanded by the consumer by optimizing the committed set of units of a power generating plant at minimum cost.

In order to solve dynamic economic load dispatch problem, various optimization methods have been devised. The term ‘optimization’ in laymen terms can be defined as the action and methods applied in obtaining the best possible (optimal) solution under given circumstances. The main aim is to either curtail or enhance the wanted advantage of a system. All the optimized systems involve decision variables besides objective function that upset the functionality of the system [11]. Two types of algorithms are being developed in order to solve the DED problem which can be categorized as conventional deterministic optimization algorithms and stochastic algorithm.

Conventional deterministic techniques produce the same result until initial conditions are not disturbed. Also, these types of techniques do not contain an operator that causes randomness and hence they are perfect for uni-modal functions having one global optimum solution. Stochastic algorithms produce different solutions for each run even when initial conditions are not disturbed. Although they have, universal slow convergence speed as shown by Yang [12] and Noel [13], they are preferred for multi-model functions having numerous local optima or functions having flat regions or where the incline is small.

Stochastic algorithms can be further categorized into two further groups, which are as following heuristic and meta-heuristic algorithms. Heuristic algorithms involve trial and error method to produce precise results in an acceptable computational time. The solutions that come out from these techniques may not be an optimum value or they may be approximate value but still, they may be valuable. They are generally stimulated by nature that is why these procedures are also known as nature motivated algorithms. Meta-heuristics refers to the level beyond the heuristics. “The prefix *meta* stands for upper level”. Easily implementation and flexibility make them a very popular choice to solve a particular structure as proposed by Blum *et al*. [14] and Gandomi [15].

The problem of economic load dispatch can be solved through a number of traditional methods that can be classified as given below:-

- Mathematically programming based heuristic methods.
- Methods based on artificial intelligence
- Hybrid methods

Mathematically programming based heuristic methods involve algorithms like lambda-iterative method, gradient projection method, Lagrange relaxation method, linear/non-linear, interior point methods, dynamic programming method. Hindi *et al*. [16] used Lagrange relaxation method for solving DED problem of large-scale power system network. Wood [17] proposed a proficient algorithm for the resolution of reserve constrained economic dispatch in which static optimization technique was used in each interval eradicating the customary search space problem and lessens the problem to a backward order of dispatch complications with the generator limits prudently adjusted. Bechert *et al*. [18] used dynamic programming for showing the optimal dispatch of five generators with valve-point loading and singular solutions taken into consideration. An algorithm was formulated which employs the concept of dynamic programming and linear programming for solving the DED problem by Travers *et al*. [19]. System generation costs were made through determination of dispatch decisions. Adaption of quadratic programming technique with a linear programming re-dispatch technique as proposed by Somuah *et al*. [20] was applied to solve the problem of DED allocation. Abdelaziz *et al*. [21] implemented a hybrid approach of Hopfield neural network (HNN) and quadratic programming (QP) for solving DED problem. In this problem, HNN solves static part and QP solves the dynamic part of economic dispatch problem. Papageorgiou *et al*. [22] proposed an approach which uses a mixed integer quadratic programming model for the optimization of economic dispatch of electrical power generators. Lin *et al*. [23] proposed an extension of interior point algorithm known as the predictor–corrector interior point quadratic programming algorithm for solving the bid-based dynamic economic dispatch. This approach includes multi player and multi-period, allowing bids from both demand and supply side, subjected to large number of constraints.

Swarm intelligence based methods can be categorized into following like GA, DE, PSO, simulated-annealing, bat algorithm (BA) etc. Basu [24] solved the DED problem by introducing a sorting GA. The adaptive tactic has a decent execution in finding a different set of arrangements and in converging close to the genuine pareto-ideal set. Morgan *et al*. [5] proposed a hybrid GA to solve the dynamic economic load dispatch problem considering the various operational limits. Hong *et al*. [25] proposed an another strategy in light of GA for best dispatch among multi-plant (cogeneration frameworks) through multi co-generators, which transmit MW to assigned purchasers (load buses) by means of wheeling. Hosseini *et al*. [26] proposed a strategy for dynamic economic dispatching a restructured power system using GA. The considered constraints are least and most extreme power generation of units and limit of transmission lines. Zang *et al*. [27] proposed another method in which a new hybrid genuine coded GA with semi simplex strategies were adapted to explain a DED problem with a non-smooth cost function. Besides, a novel approach to create starting population was also presented to accelerate the search procedure. Another strategy by Panigrahi *et al.* [28] was introduced for DED problem in view of a simulated annealing (SA) method for the assurance of the global or close global ideal dispatch arrangement. Numerical outcomes for an example test framework have been displayed to show the execution and pertinence of the proposed technique. Balamurugan *et al.* [29] adopted another strategy that exhibited an enhanced DE technique to take care of the DED issue of creating units bearing in mind valve-point impacts. Heuristic hybrid procedure and gene swap operator are acquainted in the recommended approach for the DE calculation. Natarajan *et al.* [30] suggested a new methodology for solving DED problem where it decides the ideal settings of generator units with anticipated load request over a specific timeframe with the help of evolutionary programming. Abido *et al.* [31] proposed a new mult-objective evolutionary algorithm for environmental/economic power dispatch (EED) problem where the EED problem is described as a nonlinear multi-objective optimization problem subjected to constraints. Another approach to solve the DED problem by PSO was adopted by Ansari *et al.* [32]. PSO was used to search the optimal schedule of all committed generating units supplying load demand at minimal cost. Simulation of simple social system helped in developing the method of PSO. Sun *et al.* [33] proposed an improved PSO for solving the DED problem. A random dimension velocity parameter was introduced for updating the PSO in the given method.

BA, which is one of the most recent artificial intelligence based algorithm, has come long way since its inception in the year 2010. Standard or modified BA forms have been used to solve various electrical optimization problem recently. Xiao *et al.* [34] adopted modified BA along with conjugate gradient method for proposing a multi-step wind speed forecasting structure in order to analyse the reliability and controllability of wind power system. Chakri *et al.* [35] proposed directional BA that embedded the directional echolocation property with standard BA. Proposed technique discuss the issues relating to premature convergence of standard BA, exploration and exploitations capabilities. Elsisi *et al.* [36] implied BA for developing the design of controllers for load frequency control used in damping the oscillations of power system. BA was used to minimize the time-domain based objective function by searching the optimal control parameters. Chaib *et al.* [37] proposed a hybridization of fractional order PID controllers and power system stabilizer using the characteristics of BA for improvement in power system reliability. The problem of this stabilizer is seen as optimization problem by involving various performance indexes and using BA to search the optimal parameters of stabilizer. Premkumar *et al*. [38] used BA to optimize the design of two types of controller by involving various performance indexes in order to control the speed of brushless DC motor. Coelho *et al*. [39] proposed an approach of reducing the power consumption of air-conditioning system through swarm-based intelligence enhanced BA. Besides maintaining 24 hour cooling profile, daily optimal chiller loading was obtained with the help of BA in achieving the objective of minimizing the power consumption. Kumar *et al*. [40] proposed a way of analysing the effect on economic dispatch by dynamic loads with the help of BA. The comprehensive study was done in the presence of interline power flow controller for increasing the effectiveness of objective.

Munshi *et al*. [41] implied BA presented an approach of analysing the impact of integrating the photo-voltaic systems into an external grid. Various objective functions in photovoltaic power pattern clustering were optimized through the use of BA. Yuvaraj *et al*. [42] proposed a technique of BA for finding the optimal sizing and voltage stability index was used for searching optimal location of DSTATCOM in the radial distribution network. The optimal placement done by this method is for reducing the power losses in system network. Rao *et al*. [43] presented a method of generation reallocation with or without using unified power flow controller. BA was used to minimize the real power losses with or without unified power flow controller. Flexible ac transmission device then leads to the development of controllers that provide the flexibility and controllability to the power system network. Gherbi *et al.* [44] proposed a hybrid meta-heuristic approach to solve EED problem. BA and firefly algorithm characteristics are combined together to evaluate its performance. Banati *et al*. [45] presented an approach of improving the exploitation capability of standard BA by bringing out the hybridization of BA and shuffled frog leap algorithm. Shuffled BA, for enhancing the exploitation, unites the shuffling and reorganizing techniques of shuffled frog algorithm. Following this, enhanced shuffled bat was proposed in this paper. Neagu *et al*. [46] adapted an approach for reactive power compensation in distribution network with the help of BA. To minimize the voltage deviation index, number of capacitor banks were optimally placed with the use of BA in the network buses. Gautham *et al*. [47] presented an approach for solving the economic load dispatch using novel BA. The primary objective of this ELD problem is to minimize the fuel cost of committed generators involved in the power system generation network. BA uses the idea of Doppler effect and bat movements to different habitats.

1.3 Objective of work

The objective of the dissertation is to optimally schedule the generating units of the thermal power plant by implementing the bat algorithm. Monitoring of the variation of variables like loudness and rate of pulse emission are the important steps of this technique. For improving the results factors like inertia-weight factor and an impact factor is introduced. Therefore, results are presented of modified version in order to compare it with the standard BA.

1.4 Organization of dissertation

The dissertation titled as “Dynamic Economic Load dispatch Using Bat Algorithm” has been explained in six chapters. In **Chapter-1** introduction and literature review related to dissertation has been mentioned, in addition to this objective of work is also provided. **Chapter-2** gives the introduction about dynamic economic load dispatch, thermal power plants and the cost function involved in the total cost of generation. DED objective function and the constraints involved in it are also explained. **Chapter-3** gives an over-view about standard bat algorithm. Standard bat algorithm main functionality such as echolocation, movement of bats and control of parameters to move those bats has been explained. Chapter also involves some of the brief description of variants of the bat algorithm done recently, application and its advantages along with the enhancements done in order to improve the results from standard bat algorithm. **Chapter-4** is all about the methodology which tells how a standard bat algorithm is applied to DED problem. **Chapter-5** highlights the test system used to check the efficiency of standard bat algorithm used and of modifications done to the standard bat algorithm. Potential future scope work and the dissertation conclusion is being discussed in **Chapter-6.**

Chapter-2 Dynamic Economic Load Dispatch

2.1 Introduction

A power system is expected to meet the load demand and transmission losses. One of the most vital tasks of generating station is to source the electricity to the customers carefully by satisfying all units equality and inequality constraints. DED is an additional branch of the conventional economic dispatch problem. DED is a method of defining the least possible system budget dispatch of generators, taking into contemplation the constrictions obligatory on the system. This is the utmost precise formulation of the economic dispatch problem and it is also utmost challenging to solve because of its large dimensionality. Various researches in this field got started to appear from 1972 and additional research papers in this field then were published after 1980's as they cover the various approaches to solve this problem.

It is a real time problem unresolved due to the nature of power system operation and the load variations. It models the electric power system and dispatches the available generation in most economical way. The overall objective of minimizing the total generation cost can be achieved by following steps. To achieve the overall objective whole problem is divided into individual static intervals that should be dispatched economically. Following this lower and upper economic limit of each generating units is checked. After this downward and upward regulating margin along with the supply demand is met in order to dispatch the generation economically. One problem that arises with the standard economic dispatch problem is that cost function which is considered as convex, whenever there is a small increment in load it results into new dispatch that might involve a significant increase of output of one generator and a decrease in another one vice-versa. The resulting dispatch may be economical one but it did not give us control parameter and it might violate the constraint limits for several units of the system. This increases the dimensionality of a problem. So, in order to solve this large dimensionality, certain equality and inequality constraints are added which form the basis of DED problem.

2.2 Thermal Power Plants

It is a type of power plant which has its prime-mover energized by the steam. A conventional thermal unit in general entails of a boiler, steam turbine, besides generator. The input to the boiler is being fed by burning the fuel which boils the water in the boiler and a highly dense steam follows to the steam turbine works as output and it is being treated as electricity with the help of generator. The water is being put into the boiler and coursed with vitality to be extended at the steam turbine to offer effort to the rotor shaft of the generator and then it is being distributed through a certain transmission medium. In this way, water acts like working fluid.

The input of the turbine-generator unit is the amount of steam and output of the generator unit is electricity. The whole input-output characteristic of the entire generating unit can be obtained by merging the input-output characteristics of both boiler and the turbine-generator unit. It comes out to be a convex curve [28].

2.3 Cost Function

Let F_i be represented as the cost of generating the energy from the i^{th} unit in Rs/hrs. The real power generation has the major impact as it can be increased by increasing the prime-mover torque which in turn increases the expenditure of generating unit. The reactive power generation does not have any major influence on the cost function as it is meticulous by the field excitation. Therefore, the specific generation cost of a generator unit is expressed as the function of real power and the total overall cost of the generating station can be considered as given in eq. (2.1).

The optimal proficiency of generators, fuel cost, and transmission losses are the factors affecting the power generation of a station. The total cost of generation is the function of the sum of the cost of each individual generating unit which can take values in the permissible constraint region. The input to the committed generating unit is measured in Btu/hr and the output power which is active power is measured in MW. A basic input-output curve of a thermal unit is known as a heat-rate curve [48].

Design calculations or results of heat rate tests are generally used to obtain the fuel cost function. It can be represented with second order polynomial in the following way:-

$$F_{it}\left(P_{it}\right) = a_i + b_i P_{it} + c_i P_{it}^{\;2} \qquad i = 1,2,......N_g\,;\ t=1,2,....,N_T \qquad (2.1)$$

For large steam turbine generators, these characteristics are not smooth. They will have a number of steam admission valves that are opened to obtain increasing output of the unit. In all practical sense, the cost function of the individual generator with valve point loading can be expressed as the quadratic function [49].

$$F_{it}\left(P_{it}\right) = a_i + b_i P_{it} + c_i P_{it}^{\;2} + \left| e_i \times \sin\left\{ f_i \times \left(P_i^{\min} - P_{it} \right) \right\} \right| \qquad i=1,2,......N_g\,;\ t=1,2,....,N_T \quad (2.2)$$

where a_i, b_i, c_i are the fuel cost coefficients of the i^{th} unit and e_i, f_i are the fuel cost coefficients of the i^{th} unit with valve point effects subjected to subsequent constraints. $P_i^{\min}$ is the minimum real power output of the generator ‘*i*’.

2.4 DED objective function

The objective function of the DED problem [26] which is used to minimize the operating cost of a generating unit can be formulated as:

$$Min \rightarrow F = \sum_{t=1}^{N_T} \sum_{i=1}^{N_g} F_{it}\left(P_{it}\right) \tag{2.3}$$

where,

F is the total operating cost over the whole dispatch period; P_{it} is the real power output at stint 't'

N_T is the number of hours in the time horizon

N_g is the total number of units to dispatch.

$F_{it}\left(P_{it}\right)$ is the fuel cost as function of its real power output P_{it} at time 't'

2.5 Constraints

Constraints are the limitation or barrier imposed by the user to obtain the desired results while satisfying the problem objectivity. DED problem involves the various type of constraints such as following:

1. Demand Constraints

   The total real power generated must balance out the total load power demand .

   $$\sum_{i=1}^{N_g} P_{it} - P_{Dt} = 0 \tag{2.4}$$

   where,

   P_{Dt} is the forecasted total power demand at time '*t*'

2. Generating Limits of units

   Sometimes the real power generation of a particular generator may violate its operating generating area and this problem can be corrected by either fixing them with lower or upper limit of the power generation level allowable.

   $$P_i^{\min} \le P_{it} \le P_i^{\max}$$

   $P_i^{\max}$ & $P_i^{\min}$ are the maximum and minimum real power output of the generator '*i*'.

Chapter-3 BAT algorithm

The standard bat algorithm is the nature-inspired algorithm. It is based upon the echolocation or bio-sonar capabilities of micro-bats. In the following section, a brief outline of echolocation has been given which is followed by details of bat algorithm.

3.1 Echolocation of Bats

Bats are one of most fascinating and interesting animal. It is the only mammal which has wings of their own. They account for the 20% population of mammals living on the earth. Further bats can be classified as mega-bats and micro-bats. They are differentiated according to their size and wings span. Mega-bats do not use the echolocation property but most of the species of this mammal especially micro-bat use this echolocation property extensively. Therefore, for micro-bats especially, in order to find their prey and detect their place where their colonies are residing, they use a very special property of echolocation [50]. It is a form of sonar that is used to identify the prey, avoid hurdles, and track down their roosting services in the dark. They radiate the high-frequency sound and analyse the position of objects nearby them by recognizing how the sound bounce back from the object. Various researches have shown that the angle at which sounds bounce back gives the idea of object size to the bats. Their signal bandwidth of pulses can be increased by changing the harmonics and it varies upon different species of bats. Micro-bats generally use frequency-modulated signals to sweep through the area whereas other uses constant-frequency signals for echolocation. Hence, their pulse properties vary from one species to other species of bats.

3.2 Acoustics of Echolocation

Considerably much of the bats have very sensitive small sense and very few have good eye-sight. In all, they have to use all senses in an efficient and maximum way for detection of prey and smooth navigation through the dark. Studies have shown that micro-bats use time-difference between the echoes to detect the object [50]. Echoes emitted by the micro-bats and the bounce-backed echo detected by them have a certain time delay. They use this time-delay and the loudness variation in order to create the three dimensional scenario of the surrounding to navigate and detect their prey. Studies show that the because of the Doppler Effect induced due to the fluttering of wings by targeted insect is used by the micro-bats, they are able to discriminate the targets. In this way, they detect the distance and the shape of the target, kind of prey and the moving speed of prey.

Echolocation depends upon varied wavelength pulses and these pulses only lasted for few thousands of seconds generally vary from 8 to 10 msec. However, they have the constant typical frequency zone between 25 kHz to 150 kHz and some species produce more than 150 kHz. While hunting for their prey, they can increase the rate of pulse emission that represents their fantastic capability of signal processing power [50]. As the speed of sound is generally around 340 m/s, the constant frequency emitted ultra-sonic sound will lie in the region of 2 mm to 14 mm. The characteristic frequency range of 25 kHz to 150 kHz for such sound are found to be in the equivalent order of their target sizes. The loudness of emitted pulse is generally around 110 dB for micro-bats, which lie in the ultrasonic region, and this loudness can be varied according to the vicinity of prey.

3.3 Standard Bat algorithm

Observing above depictions and attributes of bat echolocation, Yang [50] put together up the three well-regarded main points of BA:

1. All bats utilize echolocation to detect separation, and they additionally "know" the difference between sustenance/prey and foundation boundaries in some supernatural way;
2. Bats fly haphazardly with speed "v_i" at position "x_i" having a recurrence "$f_{\min}$", differing wavelength “λ” and loudness “A” to look for prey. They can subsequently change the wavelength (or recurrence) of their radiated beats and alter the rate of pulse emission discharge r ε [0, 1], contingent upon the closeness of their objective;
3. Despite the fact that the loudness can fluctuate from multiple points of view, we accept that the loudness shifts from an extensive (positive) “A_{max}” to a base steady esteem “A_{min}”.

Additional undeniable simplification is that no ray tracing is exploited as a part of assessing the time delay and three dimensional topography. In spite of the fact that they are decent component for the application in computational geometry; in any case, they are not utilized, as it is additionally computational broad in multidimensional circumstances.

After this, the frequency f in a range [$f_{\min}$, $f_{\max}$] compares a range of wavelengths [λ_{min}, λ_{max}]. For illustration, a frequency range of [20 kHz, 500 kHz] compares to a range of wavelengths from 0.7mm to 17mm.In the genuine condition wavelength range can be adjusted by changing the frequency and for a given problem, any likewise wavelength can be used for the sake of problem of implementation. The unique range should be elected with the true objective that it is practically identical to the degree of the territory of interest, and a while later molding down to more diminutive scopes. Besides, these wavelengths are not generally used themselves by any extend of the creative ability, rather, frequency can similarly be changed while fixing the wavelength ‘λ’. This is because of ‘λ’ and ‘f’ are connected as ‘λ* f’ and they are steady. We will utilize this approach later in our execution.

For effortlessness, f ∈ [0, $f_{\max}$] is expected. As it is known fact that higher frequency generally, communicate to shorter wavelengths and in the case of bats it is very few meters. The rate of pulse can generally extend to [0,1] where ‘0’ tends to no pulse rate and ‘1’ generally refers to its most extreme value.

In view of the above approximations and glorification, the essential strides of the Bat Algorithm (BA) can be compressed into the pseudo code appeared in section 3.5.

In the standard bat algorithm, virtual bats is to be utilized. Guidelines are defined to tell the way of updating positions x_i and speeds v_i in a d-dimensional pursuit space. The new arrangements of position x^t_i and velocities v^t_i at a time step ‘t’ [50] is given by

$$f = f_{\min} + rand() \times (f_{\max} - f_{\min}) \tag{3.1}$$

$$v_i^{t+1} = v_i^t + \left(x_i^t - x^*\right) \times f_i \tag{3.2}$$

$$x_i^{t+1} = x_i^t + v_i^t \tag{3.3}$$

where $rand()$ ∈ [0, 1] is an arbitrary vector drawn from an identical distribution. Here x* is the current global best solution which is positioned subsequent to looking at all the solutions among all the n bats at every emphasis ‘t’. As the item $\lambda_i f_i$ is the speed increase, f_i (or λ) can be utilized to alter the speed change while fixing the other element λ_i(or f_i), contingent upon the kind of the issue of intrigue. In our usage, $f_{\min}$ = 0 and $f_{\max}$ = 1 is to be utilized, contingent upon the space dimensions of the issue of intrigue. At first, each bat has haphazardly referred a frequency which is given consistently from [$f_{\min}$, $f_{\max}$].

For the local search fragment, once an answer is chosen amongst the present best solutions, alternative fresh solution for each bat is produced in the vicinity utilizing casual walk:

$$x_{new} = x_{old} + \varepsilon A_t \tag{3.4}$$

where ε is an irregular quantity which can be drawn from an identical circulation in [−1, 1] or a Gaussian dispersion, while $A^t = \langle A^t_i \rangle$ is the average loudness of the considerable number of bats as of now stage. The updating of the velocities and locations of bats have approximately likeness to the method in the customary particle swarm optimization, as f_i basically controls the pace and scope of the development of the teeming particles. To a certain extent, bat algorithm can be well-thought-out as an adjusted mix of the standard particle swarm optimization and the escalated nearby hunt controlled by the loudness and pulse rate.

Moreover, the loudness A_i and the rate r_i of pulse emission essentially be updated as the iterations carry on. As the loudness, as a rule diminishes once a bat has discovered its prey while the rate of pulse emission expands, can be picked as any estimation of accommodation. For effortlessness, $A_0=1$ and $A_{min}=0$ can be applied, accepting $A_{min}= 0$ implies that a bat has quite recently grabbed the prey and briefly quit producing any sound. Presently the expressions are:

$$r_i^t = r_i^0[1-\exp(-\gamma t)] \tag{3.5}$$

$$\mathrm{A}_i^{t+1} = \alpha A_i^t \tag{3.6}$$

where α and γ are the constants

The assortment of parameters necessitates some testing as each bat ought to have assorted assessments of loudness and pulse emission rate which can be consummate by randomization. For instance, the core loudness A_i^0 can regularly be around [1, 2], while the essential emission rate r_i^0 can associate with zero, or any esteem $r_i^0 \in [0, 1]$. Loudness and pulse emission proportions of them will be refreshed just if the new solutions are enhanced, which implies that these bats are stirring in the direction of the ideal arrangement.

3.4 Variants of Bat algorithm

The average bat calculation has numerous focal points, and one of the crucial favourable circumstances is that it can give hasty convergence at an exceptionally starting stage by changing from exploration to exploitation. This makes it an efficient calculation for applications, for example, classifications and others when a brisk arrangement is required. In the event the algorithm is switched to exploitation stage by differing A and r too rapidly, it might prompt stagnation after some underlying stage. With a specific end goal to enhance the execution, numerous techniques and procedures have been endeavoured to build the differing qualities of the algorithm and accordingly to improve the execution, which created a couple of good variations of bat algorithm. Some of them have been briefly described below:-

- Improved bat algorithm [51] :- In this modified approach the bat calculation were done with a decent mix of Levy flights and unpretentious varieties of loudness as well as pulse emission rates.
- Differential operator and Levy flights Bat algorithm [52] : - In this modified approach variation of bat process utilizing differential operative and Levy flights to take care of

the task of optimization issues were discussed. Differential operative familiarized strikes the resemblance with the mutation strategy in the differential algorithm is used to accelerate the convergence speed. Levy flights make sure the diversity of the population is against premature convergence and make the algorithm jump out of the local minima.

- Binary Bat algorithm [53]: - This variant of bat algorithm deals with the context of feature selection. Feature selection can be viewed as the optimization problem as it aims to find out important information from given set of features. Combination of the power of exploration of the bats is done with the speed of optimum-path forest classifier to find the set of features from the five experimental public data-sets in order to show it results.
- Chaotic Bat algorithm : - It offered a chaotic bat set of rules using Levy flights and chaotic maps to carry out parameter valuation in vigorous biological structures [54]. In general, chaotic variables has special characteristics i.e. ergodicity, pseudo-randomness and irregularity.
- Multi-objective bat algorithm [55]: - The projected multi-objective bat system (MOBA) is first approved beside a division of test functions, and after that connected to tackle multi-target design issues, for example, welded beam outline.
- Fuzzy Logic Bat Algorithm [62] : It offered a variation by bringing together fuzzy logic into the bat algorithm, they called their variant fuzzy bat algorithm.
- k-Means Bat Algorithm [56]: It presented an amalgamation of k-means and bat algorithm (KMBA) for efficient assembling. The combination of both these algorithms is used to resolve the k-means cluster problem.

3.5 Enhancement to standard Bat Algorithm

The standard bat algorithm pseudo code can be given as: -

```
1. Initialize the population of bats $x_i$ (i=1,2,3,...........,$N_k$) and velocity $v_i$
2. Initialize the frequency, pulse rate $r_i$ and Loudness $A_i$
3. While (t< maximum no. of iterations)
4. Generate new solution by adjusting frequency
5. Updating velocities using eq. (3.2) & locations using eq. (3.3)
6. If (random no. > $r_i$)
7. Select a solution among the best solution and update local solution around the best
   solution using eq. (3.4)
```

8. End if
9. Generate a new solution by flying randomly
10. If (random no. < A_i & $f(x_i) < f(x^*)$)
11. Accept the new solutions and increase r_i and A_i
12. End if
13. Rank the bats and find the current best x^* and end the while loop.

Exploration and exploitation capability of standard BAT can be improved further. The general procedure of new hopeful solutions around the best solution builds exploitation capacity; while the way toward updating solution expands exploration ability of BA. It is understood that if new solutions are created around the current best solution, algorithm will tend to have more exploitation capability instead of exploration capability. Hence calculation can without much of a stretch get caught into nearby local minimum on multimodal functions. Really, the rate of pulse emission (r) is an element which forms a balanced bridge amongst exploration and exploitation.

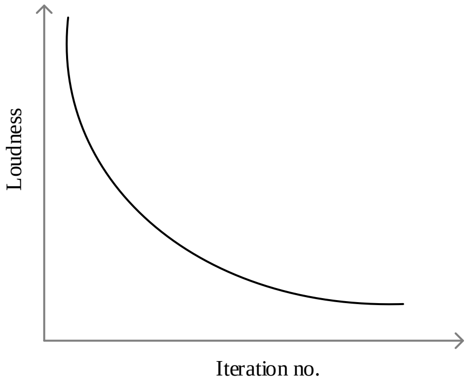

Fig. 3.1 Loudness vs iteration number

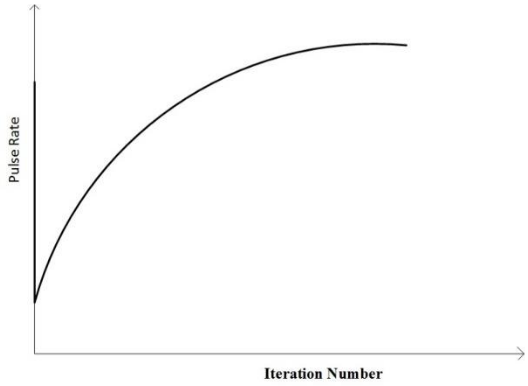

Fig. 3.2 Pulse rate vs iteration number

The increasing rate of pulse emission r is relative to a number of iterations that can be observed from figure 3.1 and 3.2. Thus, the instance of (rand > r_i) is doubtlessly acknowledged toward the start of repetitions then new competitor solutions will revolve around a solution which chose among the best arrangements. The likelihood of (rand > r_i) diminishes as the cycle continues. This implies exploitation will be connected at initial steps of iterations and exploration will be connected at the accompanying iterations. To challenge the above stated problem, two factors have been anticipated for the novel algorithm.

3.5.1 Inertia weight factor and Impact Factor

The updating process of velocity and locality which is proposed in this section has approximately striking resemblance with PSO [57]. To overawed the deficiencies of standard bat algorithm modifications have been done from the study of [58]. As velocity equation is examined, it can be divided into two parts. The first term of the equation is a variable that stipulates velocity of populace specifically step estimate, while the second term is additional element influencing the velocity of the ith arrangement with the direction of the best solution (x*). Contribution to global and local search capability is being done by the first and second term of the equation respectively. Convergence speeds reduce rapidly once if the only first term of eq. (3.2) is considered for updating because of the space overflow by solutions. Solutions may face premature convergence problem if the only second term of the equation is considered as solutions will converge somewhere in the region around the global best solution (x*).The modified equation is given below.

$$v_i^t = \omega(v_i^{t-1}) + (x_i^t - x^*) f_i \tag{3.7}$$

where ω is linearly decreasing inertia weight factor and be further elaborated as:

$$\omega_{iter} = (iter_{\max} - iter) * (\omega_{\max} - \omega_{\min}) / iter_{\max} + \omega_{\min} \tag{3.8}$$

where, $\omega_{\max}$ & $\omega_{\min}$ are the maximum and minimum inertia weight factors respectively and $iter$ is the current iteration value and $iter_{\max}$ is the maximum iteration number.

As per the above, that second term of eq. (3.7) provides the local search capability. If this term is used exclusively, it may cause premature convergence which may force solution to get struck around the local minimum. In order to compensate it we introduce another kth solution which affects the ith solution, velocity equation has been identified in following way: -

$$v_i^t = \omega(v_i^{t-1}) + (x_i^t - x^*) f_i \zeta_1 + (x_i^t - x_k^t) f_i \zeta_2 \tag{3.9}$$

where, x_k^t is one among the best solution randomly selected among the population ($i \neq k$). This modification process intensifies the effect of second term of above velocity equation towards the end of the optimization process.

$$\zeta_1 + \zeta_2 = 1 \tag{3.10}$$

The outcome of the best solution (x*) increases as a comparison to x_k^t when the value ζ_1 increases. As the iteration proceeds, the solutions can switch from global to local by changing the value of ζ_1 as given below:-

$$\zeta_1 = 1 + (\zeta_{init} - 1) * (it_{\max} - it)^n / (it_{\max})^n \tag{3.11}$$

where n is non-linear modulation index and ζ is impact factor.

3.6 Applications of Bat algorithm

With the advent of bat algorithm in the year 2010, enhancement and development of new variants of it also have come into existence. Due to this, this heuristic algorithm has been implied in several important applications till date. Several diverse applications field like optimization; engineering design, image processing, scheduling, data mining, feature selection, planning sports training session etc. are implemented through standard or its improvised versions.

- Continuous optimization: - This field in the perspective of engineering design is comprehensively studied and implemented with the use of bat algorithm. This demonstrates that this algorithm can deal with complex non-linear problems and can get optimal solution accurately [15]. Several numeral optimization problems were solved by bat algorithm as shown in Tsai *et al*. [59]. In addition to this, this algorithm is also good in handling various multi-objectives problems efficiently. For problems like related to brushless dc motor, bat algorithm approach is also used recently.
- Image processing: - In order to overcome the shortcomings of traditional image matching for computing the fitness of every pixel in searching space a bat variant was developed by Diu *et al.* [60]. Other than this, the problem of full-body articulated human motion tracking from multi-view video data recorded in the laboratory was dealed with the help of bat modelled algorithm.
- Data mining, classification, and clustering: - k-means clustering using bat algorithm was studied to increase the efficiency and its performance. Using fuzzy bat algorithm, a study on clustering problem for office workplaces was demonstrated by Khan *et al*. [61]. Then they also presented a clustering problem with the bi-sonar optimization variant of bat algorithm. In addition to this, hybrid flow shop scheduling problem with the help of bat algorithm is also studied.
- Engineering optimization problems like the design of power system stabilizer, size optimization of skeletal structures consisting of truss and frame structures, loading pattern optimization of nuclear core, non-linear economic dispatch optimization problem has been studied with the help of bat algorithm.
- Inverse problems and parameter estimating: - A chaotic Levy flight bat algorithm was demonstrated for estimation of parameters in non-linear dynamic biological systems is shown in [62]. Study of topological shape optimization in micro-electronics using bat algorithm was presented by yang *et al.* [63] to show that materials with different thermal

properties can have efficient heat transfer capability under stringent conditions. Parameter estimation as an inverse problem is done here.

- Fuzzy logic: - For studying fuzzy systems and exergy model alterations in gas turbines, bat algorithm is implied by lemma *et al.* [64]. Optical capacitor placement for loss reduction by combining fuzzy systems with bat algorithm is another application applied in distribution system

3.7 Advantages of Bat algorithm

A natural question arises: -what are the success factors of bat algorithm? By carefully updating equations and analysing various parameters, various advantages of using bat algorithm to another meta-heuristic algorithm can be summarized as:

- Parameter control: - By varying the values of amplitude and rate of pulse, bat algorithm does its parameter control. In contrary to that, some of the other meta-heuristic algorithms use pre-tuned algorithm-dependent parameters. This is one of the major advantages over another meta-heuristic algorithm as when the algorithm is approaching the optimal solution it automatically shifts from exploration to exploitation [50].
- Frequency tuning: - Bat algorithm contains some of the similar properties as some swarm-intelligence based algorithms. Bat algorithm uses echolocation and frequency tuning to reach to their optimal solution [50]. Though echolocation is not mirrored in the true sense, frequency variation does. These capabilities represent similar to some functionalities other algorithms like particle swarm optimization and harmony search.
- Automatic zooming: - Due to its high converging rate, bat algorithm has the capability of automatically zooming around the possible optimal solution region. This zooming is followed by an automatic switch from global exploration to local intensive exploitation [50]. Thus, this is the distinct feature of bat algorithm from other meta-heuristic algorithm and because of this it has high convergence rate at the start of iteration as compared to other algorithms.
- In addition to this, bat algorithm provides definite global convergence properties under some permissible state and also it is used for used for solving large scale problems.

Chapter-4 Implementation of Bat Algorithm on DED

The process of applying the Bat Algorithm on dynamic economic load dispatch (DED) can be summarized as given below:-

4.1 Problem Formulation

$$Min \rightarrow F = \sum_{t=1}^{N_T} \sum_{i=1}^{N_g} F_{it}\left(P_{it}\right) \tag{4.1}$$

$$F_{it}(P_{it}) = \mathrm{a_i} + \mathrm{b_i}\, P_{\mathrm{it}} + \mathrm{c_i}\, P_{\mathrm{it}}^{\;2} + \left| e_i \times \sin\left\{ f_i \times (P_{it\min} - P_{it} \right\}\right| \tag{4.2}$$

where,

F is the total operating cost over the whole dispatch period; P_{it} is the real power output at time '*t*'

N_T is the time-period of scheduling

N_G is the total number of generating units

$F_{it}(P_{it})$ is the fuel cost as function of its real power output P_{it} at time '*t*'

$\mathrm{a_i}$, $\mathrm{b_i}$, $\mathrm{c_i}$ are the fuel cost coefficients of the i^{th} unit

e_i, f_i are the fuel cost coefficients of the i^{th} unit with valve point effects.

4.2 Steps of implementation

Step-1

The structure of DED problem consists of a set of decision variables that represents individual power generation of the individual unit. Over the span of scheduling period, this set of decision variables is produced through the random number, having their value lying between the maximum and minimum value respectively. It is given as follow:

$$P(k,j,i) = P_i^{\min} + rand() \times (P_i^{\max} - P_i^{\min}) \qquad (k = 1, 2............ N_K);\ (j = 1, 2........N_T)\ \ (i = 1, 2............N_G) \tag{4.3}$$

where,

k is index variable for bat particle

j is index variable for time over which dispatch problem is to be done

i is index variable for generating unit

$P(k, j, i)$ is power of k^{th} particle for i^{th} generating unit at time step *j*

$P_i^{\max}$ is maximum power of i^{th} unit, $P_i^{\min}$ is minimum power of i^{th} unit

N_K is the population size of bat particle

$rand()$ is the random number ε [0,1]

For a system of N_G generating units, N_K represents the vector length of the particle. The user gives an initialized value of the loudness and rate of pulse emission. Every bat particle fly randomly with certain velocity and frequency in order to catch the prey. Before they start exploring the velocity and frequency of a bat particle is to be initialized. For the initialization part, the frequency get initialized through following way:

$$f(k,j,i) = f_{\min} + rand() \times (f_{\max} - f_{\min}) \tag{4.4}$$

where,

$f(k,j,i)$ is the frequency of k^{th} particle for i^{th} generating unit at time step j

$f_{\min}$ is the minimum frequency of a particle

$f_{\max}$ is the maximum frequency of a particle

$rand()$ is the random number ε [0,1]

In a similar way velocity get initialized through following way: -

$$v(k,j,i) = v_{\min}(\mathrm{i}) + rand() \times (v_{\max}(\mathrm{i}) - v_{\min}(\mathrm{i})) \tag{4.5}$$

$v(k,j,i)$ is the velocity of the k^{th} particle for i^{th} generating unit at time step j

$v_{\min}(i)$ is the minimum velocity of unit 'i'

$v_{\max}(i)$ is the maximum velocity of unit 'i'

These velocity parameters are used to reach the optimum value for objective function. These minimum and maximum values of velocities get updated through following equations:

$$v_{\max}(i) = \Psi * P_i^{\max} \tag{4.6}$$

$$v_{\min}(i) = \theta * \mathrm{P}_i^{\min} \tag{4.7}$$

where Ψ & θ are variable parameters

Maximum and minimum values of pulse emission rate and loudness factors are initialized at the start. All these parameters like frequency, velocity, loudness, and frequency are checked whether they lie between maximum and minimum range or not. If these parameters violate the range, then they are corrected either by equalling with their maximum or minimum values.

Step-2

This step involves the calculation of fitness of population and storing the best value. Fitness value of population is premeditated with the help of cost function equation as given above and error defined below, as the dynamic economic load dispatch (DED) problem involves the total cost of all generators that is calculated by summing the cost value and error value of all generators of a particular particle for each individual hour. After calculating the cost of each particle, best value according to the objective is found out by first initializing the value of a particle as best and then comparing it with other particle's value. This value serves as the first global value. The equations for the subsequent paragraph can be written as following:-

$$\mathrm{F(k)} = \sum_{j=1}^{N_T} \sum_{i=1}^{N_g} F(P_{k,\mathrm{j},i}) + q \times (\mathrm{E(k,\,j)})^2 \tag{4.8}$$

where,

F(k) is the total objective value of particle 'k'; q is the penalty factor implied.

$\mathrm{E(k,\,j)}$ is the difference between supply demanded and generation.

$$\mathrm{E(k,\,j)} = P_D(\mathrm{j}) - P(k,\,j,\mathrm{i}) \tag{4.9}$$

P_D is the power demanded.

Step-3

This step involves the calculation of average loudness. After this sub-step iteration gets started. Within the start of the iteration, this step includes the movement of the bat which can be done through updating the equations of velocity, power (position). The updating of velocity involves the following equation:

$$v(k,\,j,i) = v(\mathrm{k,\,j,i}) + (P(k,\,j,i) - Pgb(\mathrm{j},i)) \times f(k,\,j,i) \tag{4.10}$$

where,

$Pgb(\mathrm{j},i)$ are the set of global best values of power (position) of a bat particle after comparing it with N_k particles at iteration step. The power (position) has been updated by following the given equations: -

$$P(k,\,j,i) = P(k,\,j,i) + v(k,\,j,i) \tag{4.11}$$

Next, involves the calculation of fitness function and finding out updated global best value, which intends to tell that optimum value has shifted.

Step-4

This step involves the pulse emission rate checking. The condition involved in this is that if the random number '$rand()$' is greater than the rate of pulse emission 'r' then it involves the generation of local solutions around the selected best solution. This updating can be done through following way:-

$$P(k,\,j,i) = Pgb(j,i) + (((2 \times rand()) - 1) \times m) \tag{4.12}$$

where $rand()$ is the random number which ε [-1,1]

"m" refers to the average loudness value

After this calculation of fitness function of newly generated population is done.

Step-5

If the condition of step-4 does not satisfy its condition bat algorithm jumps to step-5 which involves checking of loudness. This step constitutes a condition which involves above calculated fitness value to be less than the current global best value and also the random number to be less than loudness. If this condition satisfies, then global best value gets updated. This step also involves the updating of the rate of pulse emission and loudness value for each iteration step till the optimum value is obtained by the following equation: -

$$A = A_{\max} - ((\mathrm{A}_{\max} - A_{\min}) \times \mathrm{z}) / \mathrm{z}_{\max} \quad (4.13)$$

$$r = r \times (1 - \exp(-1 \times 0.9 \times (z))) \quad (4.14)$$

where,

r is rate of pulse emission

z is iteration count number, $\mathrm{z}_{\max}$ is maximum iteration count

A is loudness value, $A_{\max}$ & $A_{\min}$ are the maximum and minimum values of loudness.

Step-6

If the step-5 condition does not satisfy, then rank the bats and obtain the best solution. Check if the termination condition is satisfied or not. If it satisfies, then it is the optimal solution and if it does not satisfies then return to step-3.

Chapter-5 Results & Discussions

The BAT algorithm and its modification have been implemented over the dynamic economic dispatch problem. The related information for the two test system framework is portrayed in Appendix A.

5.1 Test System

Test system-I consists of five thermal generating units with their cost coefficients given in the appendix A.1. Test system-II consists of ten thermal generating units with their cost coefficients given in the appendix A.2 .The hourly load demand for both test systems-I and II is provided in appendix A.3 and A.4 .The valve point loading effect has been handled and losses have been neglected in both the cases.

5.1.1 Parameter settings

The techniques, which are applied for utilization in the optimization of dynamic economic load dispatch, is made to run in FORTRAN 90 compiler. The parameter settings associated with standard bat algorithm for test systems-I and II are pre-arranged as following population size, maximum and minimum frequency limits, loudness and rate of pulse emission in table 5.1. The parameter settings associated with modified bat for test system-I and II contains same pre-arranged settings of the standard bat and contains the inertia-weight factor and impact factor which is shown in table 5.1.

Table 5.1 Parameter Settings of different cases

		Values			
		System-I		System-II	
Sr. No.	Parameters	Bat	Modified Bat	Bat	Modified Bat
1	Population Size	50	50	50	50
2	Iteration Count	850	1200	1000	1500
3	f_{max} , f_{min}	6.3,-0.4	1.2,-0.99	1,-1.149	0.95,-1.1
4	Loudness	0.65	0.9	0.9	0.9
5	Rate of pulse emission	0.1	0.1	0.1	0.1
6	Penalty factor	10^3	10^3	10^3	10^3
7	Maximum & Minimum inertia weight	-	0.9,0.25	-	0.9,0.3
8	Initial Impact factor	-	0.6	-	0.55
9	Non-linear modulation index	-	3	-	3

5.1.2 Simulation results for Heuristic optimization technique

The adopted technique employed in solving the problem of optimization of dynamic economic load dispatch for test system-I and II. Using the standard parameters involved in table 5.1, bat algorithm and modified bat algorithm is implied. Table (5.2-5.5) show the optimal schedule of respective test system with these two algorithm approaches. Table 5.6 for system-I shows the comparison of costs with other techniques. Table 5.7 for test system-II shows the comparison of costs obtained with standard and modified BA.

Table 5.2 24-h optimal schedule of five-unit system with standard bat

	Power Generation (MW)				
Hour	P_1	P_2	P_3	P_4	P_5
1	14.321	65.565	114.870	106.716	108.523
2	12.081	20.247	90.841	112.696	199.124
3	74.980	124.993	65.792	44.100	165.127
4	32.432	63.285	103.323	148.525	182.438
5	24.523	90.422	133.527	44.553	264.978
6	10.003	121.875	48.056	215.223	21.840
7	59.310	124.981	123.407	160.682	157.609
8	74.974	40.839	160.813	220.232	157.131
9	56.911	93.611	137.508	102.010	299.972
10	45.457	124.905	56.296	238.246	239.075
11	66.566	124.869	174.997	249.978	103.575
12	74.831	101.404	38.638	225.379	299.736
13	74.973	23.287	159.421	206.788	239.534
14	64.952	110.055	96.390	222.160	196.437
15	56.291	87.522	38.718	198.461	273.014
16	49.623	47.414	113.289	208.970	160.674
17	41.693	105.374	158.248	146.556	106.120
18	15.429	66.697	141.723	84.161	299.989
19	74.991	125	45.356	249.999	158.638
20	20.755	90.959	127.744	227.603	236.919
21	33.582	124.641	174.645	227.186	119.926
22	17.609	97.403	30.025	187.025	272.938
23	64.908	64.557	59.181	195.156	143.210
24	52.611	44.369	174.979	56.779	134.282

Table 5.3 24-h optimal schedule of five-unit system with modified bat

	Power Generation(MW)				
Hour	P1	P2	P3	P4	P5
1	13.59	71.52	116.16	107.24	101.46
2	18.59	95.03	67.16	40	213.49
3	74.96	89.05	46.22	46.62	217.23
4	35.36	89.13	105.5	249.99	50
5	24.46	82.86	119.99	40.64	290.02
6	12.92	93.53	37.74	168.76	295.03
7	60.06	74.74	133.95	170.7	186.53
8	46.25	48.37	36.12	227.15	296.08
9	51.35	88.04	173.28	78.83	298.47
10	43.95	120.52	50.15	249.87	239.49
11	27.66	124.55	167.54	234.39	165.84
12	43.29	124.85	76.59	249.99	245.25
13	10.01	123.27	75.3	247.09	248.3
14	71.71	124.98	105.98	186.92	200.36
15	56.31	120.84	135.06	232.97	108.76
16	53.37	48.01	106.73	231.65	140.21
17	36.03	105.21	158.09	160.16	98.46
18	12.86	98.03	159.18	92.98	244.9
19	74.99	112.96	174.99	118.32	172.71
20	17.16	122.23	168.1	249.99	146.49
21	31.92	101.08	56.01	225.95	265.01
22	28.07	124.93	174.82	166.87	110.26
23	67.42	78.62	79.69	106.59	134.46
24	56.21	49.07	175	56.55	126.16

Table 5.4 24-h optimal schedule of ten-unit system with standard bat

	Power Generation(MW)									
Hour	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}
1	175.25	197.64	241.40	72.16	73.014	57.063	55.976	51.331	57.137	55
2	150.15	176.577	97.842	60.116	186.337	151.079	129.964	47.065	55.848	55
3	362.38	295.614	110.127	60.001	73.014	64.969	121.781	95.09	20.002	55
4	320.57	145.241	236.204	189.55	236.059	83.254	20.007	100.08	20.061	55
5	324.46	410.096	179.26	60.098	92.357	153.928	50.772	119.98	34.021	55
6	156.27	321.63	334.472	299.97	84.32	104.256	129.882	63.088	79.086	55
7	469.93	396.33	73.68	268.61	73.018	133.98	105.027	47.004	79.998	55
8	336.97	459.989	73.002	298.30	242.97	90.316	20.012	119.44	79.989	55
9	327.04	446.932	294.788	171.62	141.075	159.988	129.954	118.7	78.874	55
10	469.88	459.918	118.644	261.65	242.929	159.906	129.718	94.329	79.935	55

	Power Generation(MW)								
11	469.98	459.994	228.32	297.00	243	159.996	129.958	47.079	55.707	55
12	469.97	459.984	339.995	193.47	242.986	159.487	125.611	100.49	73.085	55
13	469.93	441.613	261.243	299.98	212.997	160	79.823	53.194	38.205	55
14	363.80	397.436	339.976	110.03	236.827	121.311	126.249	107.63	65.697	55
15	469.99	408.771	275.043	60.027	238.566	81.924	110.973	47.044	28.631	55
16	254.35	135.028	272.947	299.90	180.392	91.892	65.138	119.34	79.961	55
17	248.02	135.007	316.343	206.84	204.034	116.065	75.456	47.024	76.202	55
18	428.84	360.757	116.827	249.94	87.379	90.87	111.347	47.015	79.998	55
19	313.49	404.521	225.287	156.89	243.00	60.729	129.986	107.08	79.997	55
20	469.96	459.98	304.47	299.99	192.283	95.979	54.384	119.91	20.006	55
21	238.40	458.049	321.424	299.99	242.936	99.232	107.458	53.267	48.219	55
22	428.2	135.018	193.372	221.39	242.996	136.012	89.626	102.88	23.49	55
23	251.86	135.008	339.897	81.71	152.185	138.824	20.008	77.603	79.859	55
24	150.0	135.063	122.644	213.14	242.966	57.048	68.214	119.98	20.048	55

Table 5.5 24-h optimal schedule of ten-unit system for improved bat

	Power Generation(MW)									
Hour	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}
1	150.22	135.023	192.812	60.019	123.034	122.855	129.795	47.174	20.009	55
2	150.031	135	268.037	60.035	122.876	122.407	129.577	47.022	20.008	55
3	226.047	215.080	309.442	60.118	73.026	122.544	129.634	47.065	20.047	55
4	178.756	302.253	180.324	299.435	73.04	122.406	127.702	47.012	20.061	55
5	316.923	309.59	339.96	60.002	121.562	110.642	99.235	47.018	20.076	55
6	362.753	455.673	311.933	60.037	73.072	121.402	121.053	47.061	20	55
7	379.916	459.975	300.617	78.127	172.481	57.01	129.595	49.329	20	55
8	380.015	396.715	297.243	120.356	242.973	86.907	129.691	47.076	20.025	55
9	455.633	455.714	297.393	299.982	73.077	90.659	129.548	47	20	55
10	469.81	397.547	297.684	227.739	242.816	80.84	129.718	119.952	50.843	55
11	456.466	396.820	339.999	248.41	225.219	153.84	129.958	85.319	54.962	55
12	450.916	459.984	307.949	299.999	222.63	155.923	129.89	85.329	52.366	55
13	459.159	397.578	302.646	239.424	210.31	138.481	127.18	119.99	22.528	55
14	456.518	396.825	294.284	191.393	172.966	160	129.992	47.003	20.00	55
15	469.876	456.461	211.851	60.03	73.00	140.314	120.558	108.88	80.00	55
16	306.856	397.127	281.948	122.28	173.13	122.565	28.144	47.014	20.027	55
17	158.314	459.9	339.754	75.382	242.797	58.834	20.008	48.174	21.794	55
18	150.01	178.837	339.723	299.948	242.969	60.541	101.138	119.914	79.899	55

	Power Generation(MW)									
19	466.922	459.991	73.092	208.727	227.287	57.021	27.981	119.99	79.997	55
20	184.844	459.98	339.933	299.99	242.883	159.553	129.834	119.994	79.973	55
21	190.214	459.983	339.996	146.359	242.936	159.899	129.747	119.932	79.932	55
22	469.636	135.018	73.053	299.967	242.895	139.237	20.005	118.818	74.36	55
23	166.339	135.008	339.876	70.963	242.991	159.968	34.779	47.075	79.98	55
24	154.142	135.063	152.178	299.985	120.05	57.048	20.006	119.512	70.939	55

Table 5.6 Comparison of cost for test system-I

Sr.No.	Optimization Technique	Standard Deviation	Minimum Cost	Average	Maximum Cost
1	Modified Bat	26.88	51298	51346.55	51398
2	Bat	30.64	52612	52671.25	52720

	1	50	55	82	106	130	230	300	500
Standard	2.59E+08	1889768	1556303	564255.9	178142.8	162694.1	79628.47	73764.72	52658
Improved	2.66E+08	1.09E+07	9766805	942417	95936	60527.58	57458.05	52538	51313

Fig. 5.1 Graph showing the cost comparison of test system-I

The figure 5.1 depicts the convergence characteristics of BA and modified BA for test system-I. The following graph conveys that modified BA reaches to its optimum objective value more efficiently than standard BA.

Table 5.7 Comparison of cost for test system-II

S.No.	Optimization Technique	Standard Deviation	Minimum Cost	Average	Maximum Cost
1	Modified Bat	45.45	1043790	1043858	1043927
2	Bat	37.55	1045642	1045718	1045772
3	HS [7]	-	1046726	-	-
4	EP [65]	-	1048638	-	-
5	SQP [65]	-	1051163	-	-

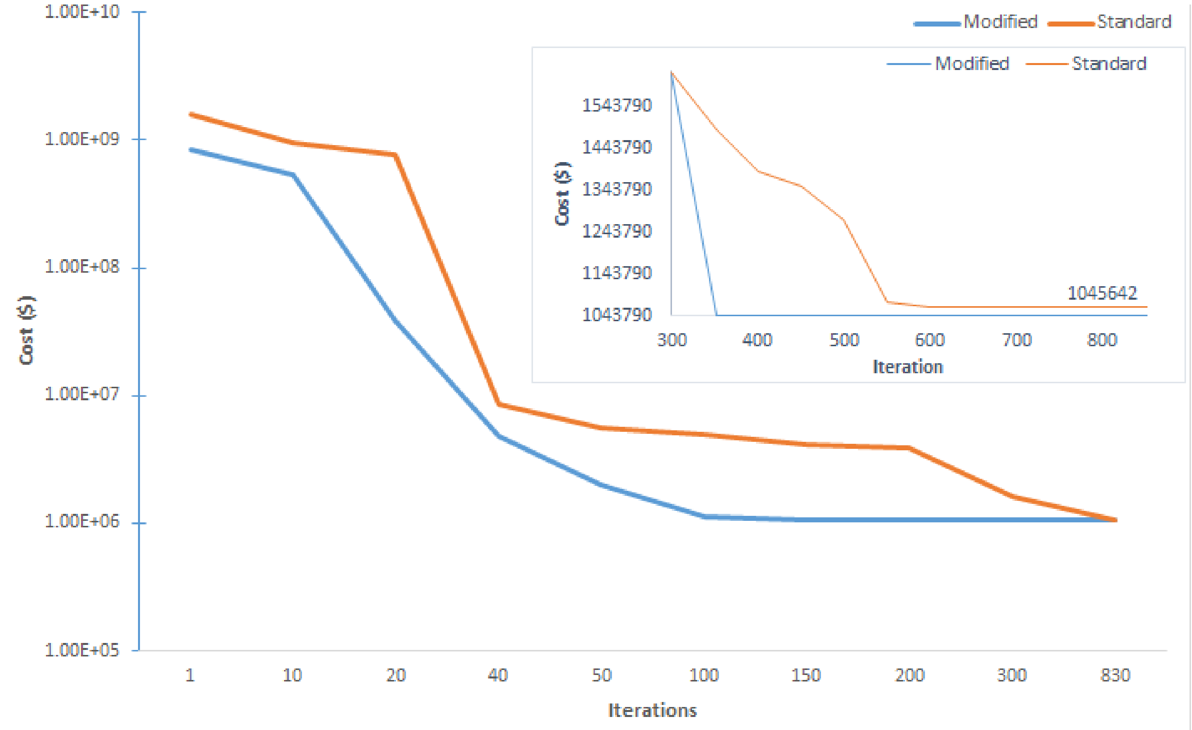

Fig. 5.2 Graph showing the cost comparison of test system-II

The figure 5.2 depicts the convergence characteristics of BA and modified BA for test system-II. The following graph conveys that modified BA reaches to its optimum objective value more efficiently than standard BA.

Chapter-6 Conclusion and Future scope of work

6.1 Conclusion

In this dissertation, the BAT and modified BAT algorithm has been implemented on DED problem. Parameter control, frequency tuning and automatic tuning are some of the traits, which makes implementation of bat algorithm on optimization problems more popular. However, as due to inefficiencies in exploration and exploitation capability of bat algorithm some modifications like inertia weight and impact factor have been considered. The inertia weight modification is done on velocity updating equation in order to intensify the process of generating the i^{th} particle velocity at the beginning and affects the local solution around global optimal solution at the end. The impact factor is introduced for solving the problem of best solution being struck around the local minimum. The effectiveness of the considered technique is illustrated by means of two test system consisting of five and ten thermal generating units considering valve-point loading. The results obtained are compared with some of the algorithms mentioned in the literature. Following this, convergence characteristics bat algorithm & modified bat algorithm is compared to illustrate the effectiveness of algorithm on DED problem.

6.2 Future scope of work

- In the dissertation, the dynamic economic dispatch problem can be solved taking into consideration ramp rate, transmission losses and prohibited operating region.
- For improvement in convergence speed and computational time, hybridization of algorithms can be applied to this problem.
- Best control strategy to switch from exploration to exploitation at right time further needs to be studied more.

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Appendix

Table A.1

Generating unit's characteristics in 5-unit system

Unit	a_i	b_i	c_i	e_i	f_i	P_{min}	P_{max}
1	25	2	0.008	100	0.042	10	75
2	60	1.8	0.003	140	0.04	20	125
3	100	2.1	0.0012	160	0.038	30	175
4	120	2	0.001	180	0.037	40	250
5	40	1.8	0.0015	200	0.035	50	300

a_i , b_i , c_i : fuel cost coefficients of the i^{th} unit

e_i , f_i : fuel cost coefficients of the i^{th} unit with valve point effects subjected to following constraints

Table A.2

Generating unit's characteristics in 10-unit system

Unit	a_i	b_i	c_i	e_i	f_i	P_{min}	P_{max}
1	0.00043	21.6	958.2	450	0.041	150	470
2	0.00063	21.05	1313.6	600	0.036	135	460
3	0.00039	20.81	604.97	320	0.028	73	340
4	0.0007	23.9	471.6	260	0.052	60	300
5	0.00079	21.62	480.29	280	0.063	73	243
6	0.00056	17.87	601.75	310	0.048	57	160
7	0.00211	16.51	502.7	300	0.086	20	130
8	0.0048	23.23	639.4	340	0.082	47	120
9	0.10908	19.58	455.6	270	0.098	20	80
10	0.00951	22.54	692.4	380	0.094	55	55

Table A.4

Hourly load profile in 5-unit system

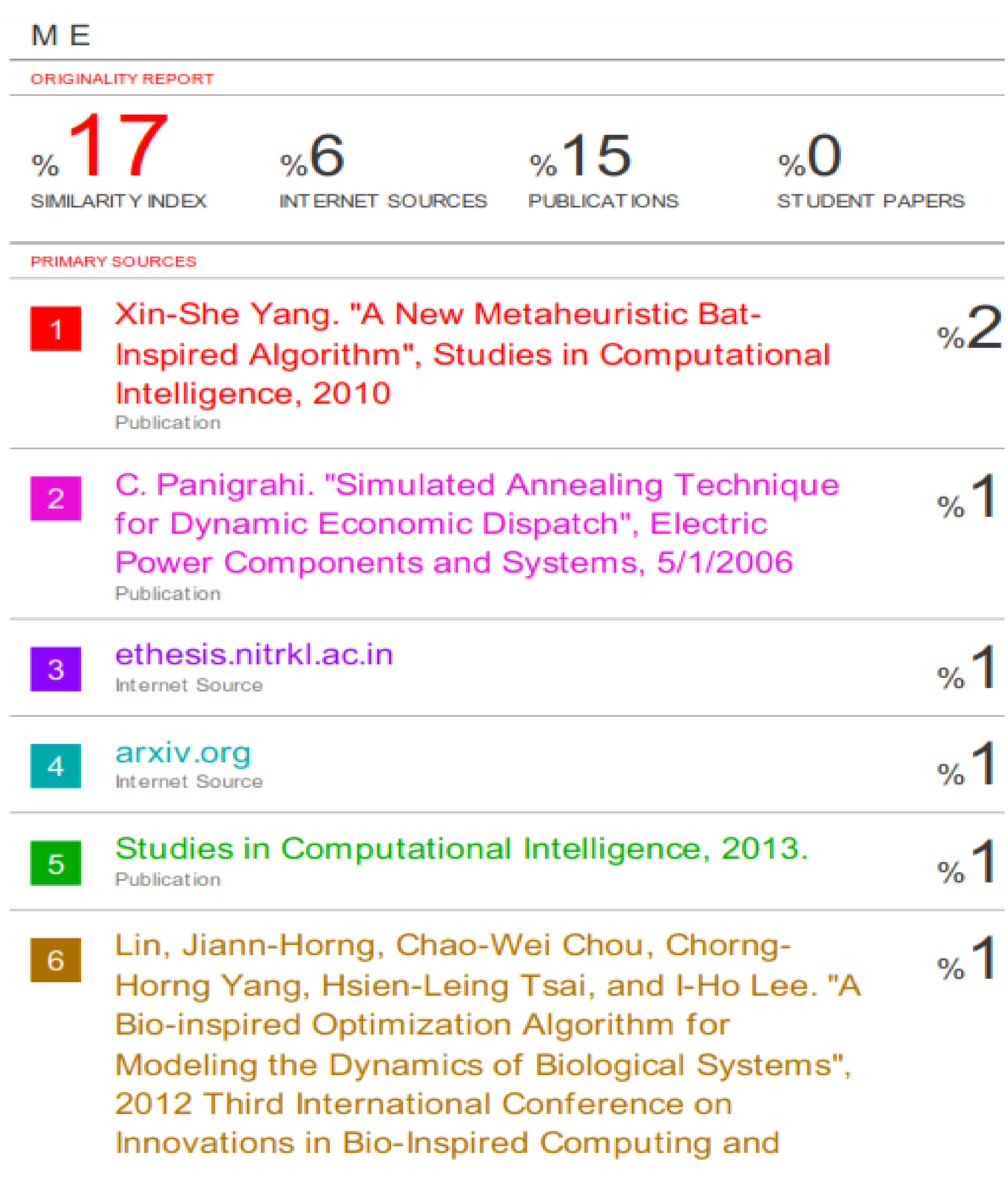
Hour	Load	Hour	Load	Hour	Load
1	410	9	690	17	558
2	435	10	704	18	608
3	475	11	720	19	654
4	530	12	740	20	704
5	558	13	704	21	680
6	608	14	690	22	605
7	626	15	654	23	527
8	654	16	580	24	463

Table A.3

Hourly load profile in 10-unit system

Hour	Load	Hour	Load	Hour	Load
1	1036	9	1924	17	1480
2	1110	10	2072	18	1628
3	1258	11	2146	19	1776
4	1406	12	2220	20	2072
5	1480	13	2072	21	1924
6	1628	14	1924	22	1628
7	1702	15	1776	23	1332
8	1776	16	1554	24	1184

PLAGIARISM CERTIFICATE



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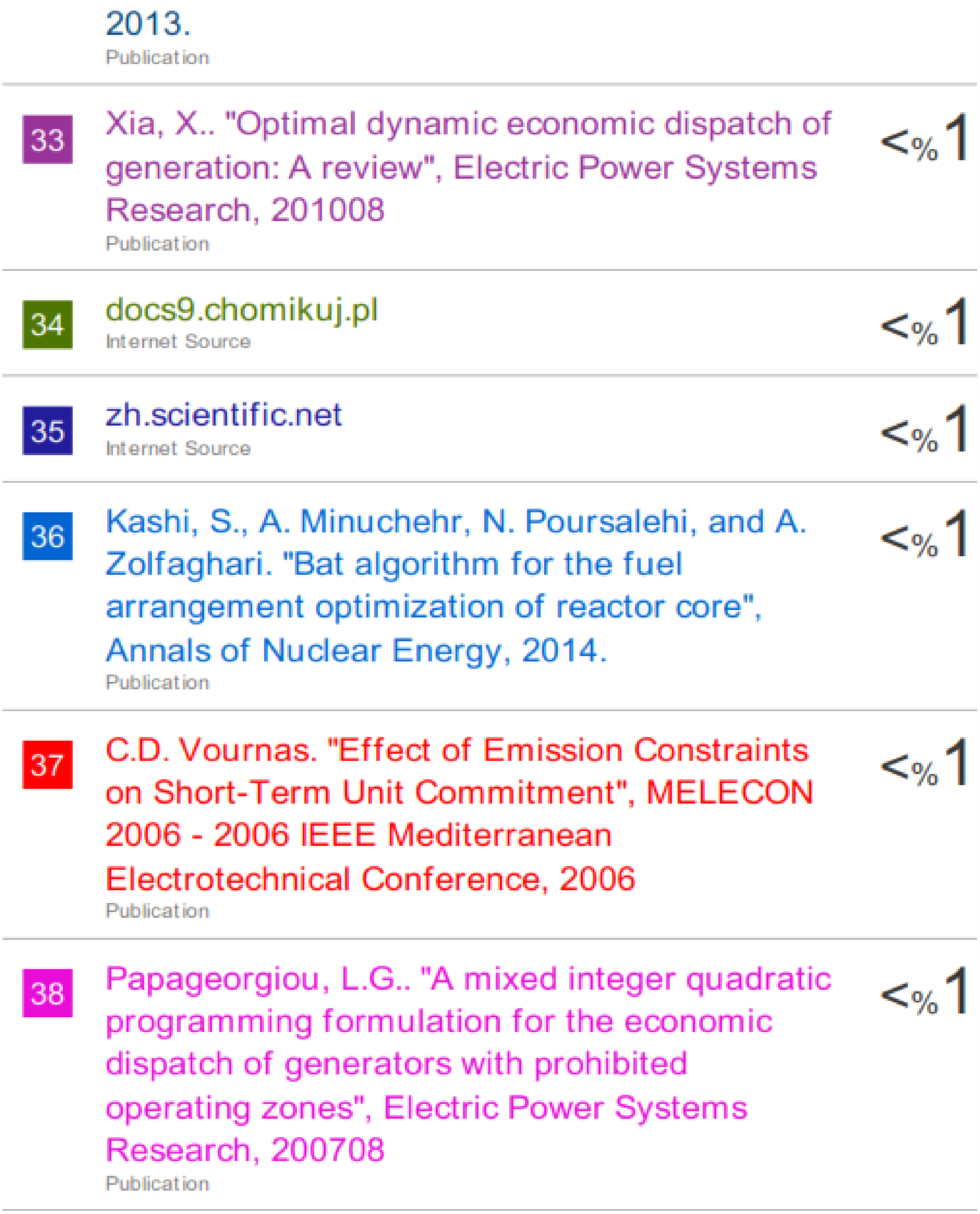

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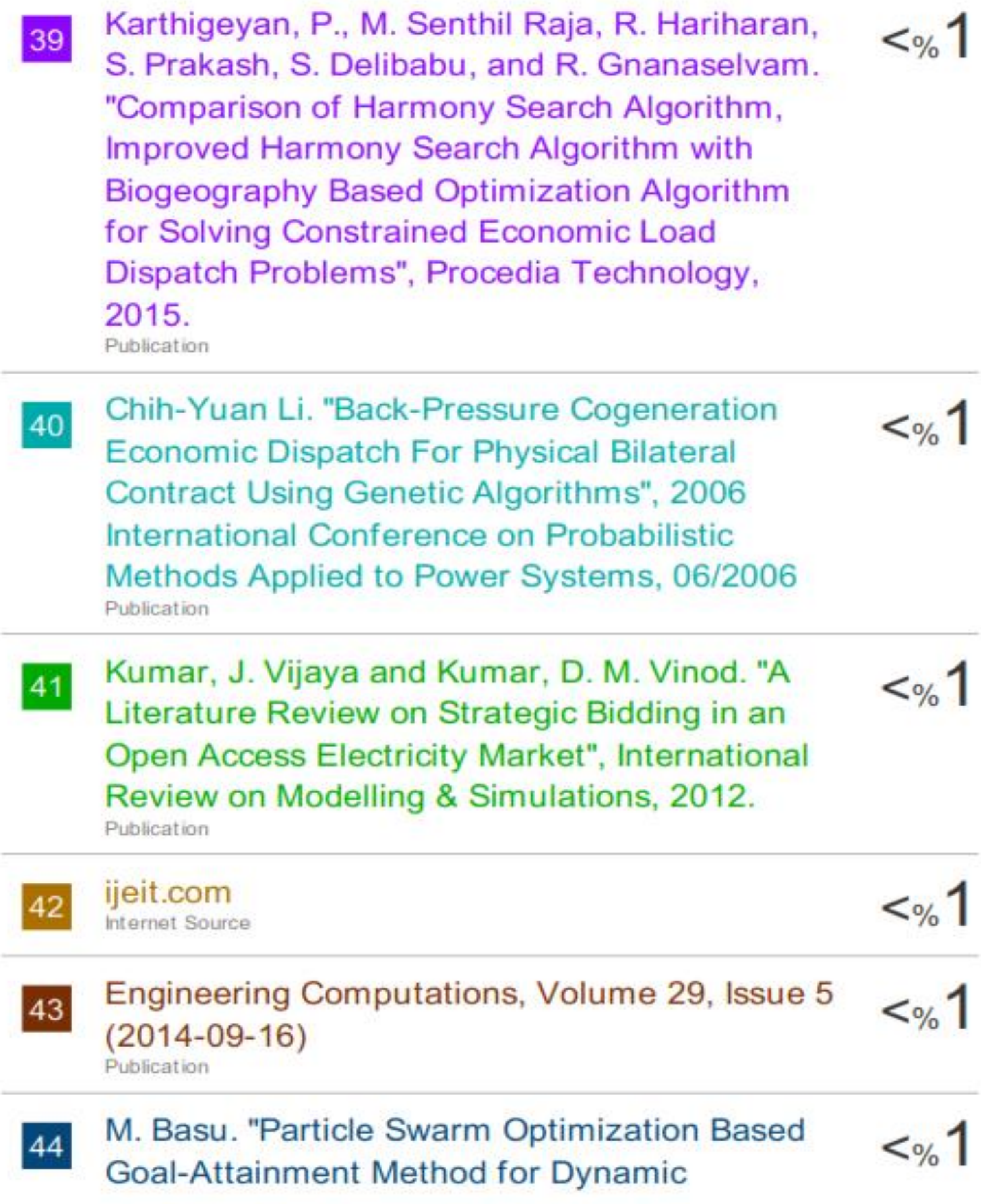

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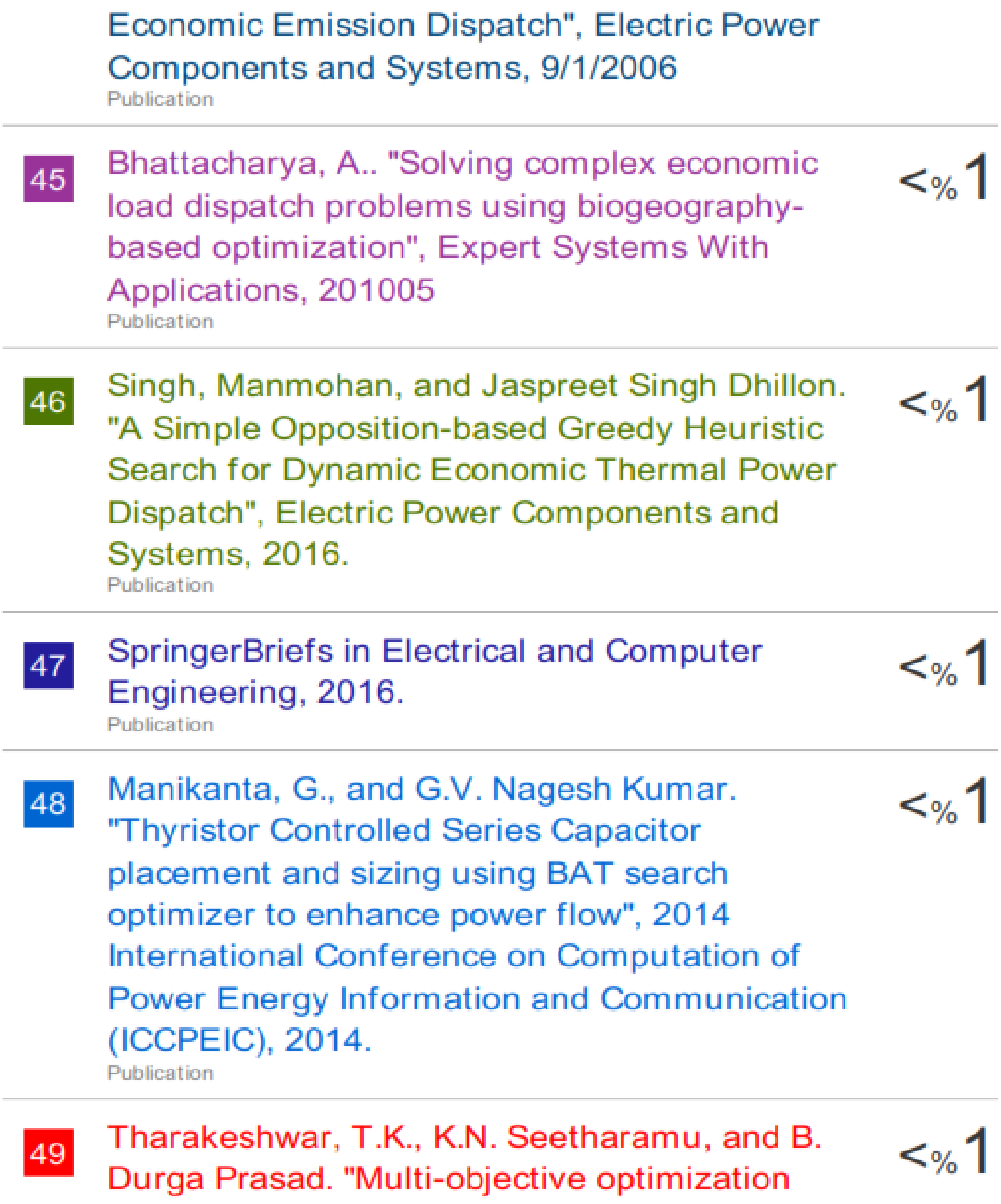

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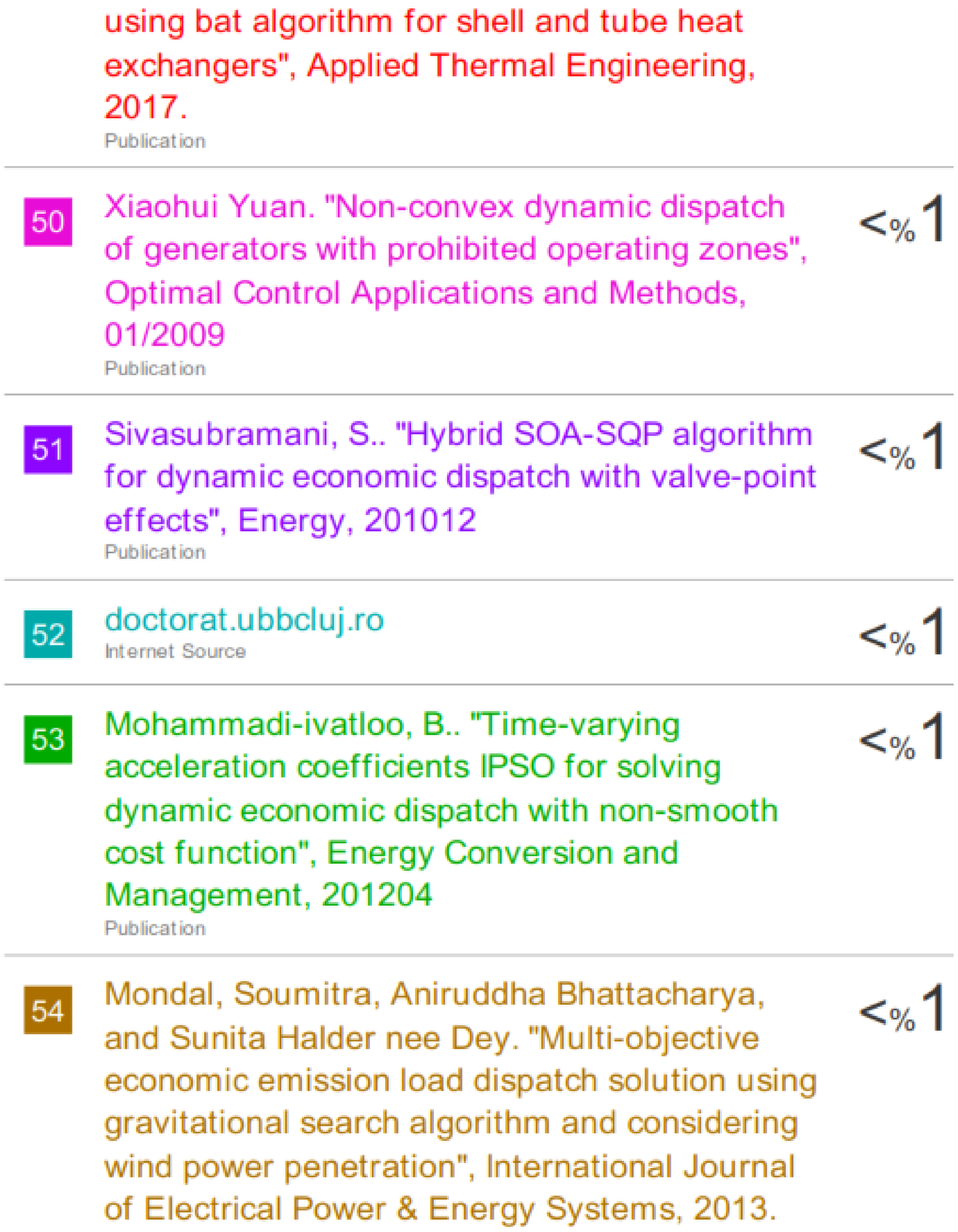

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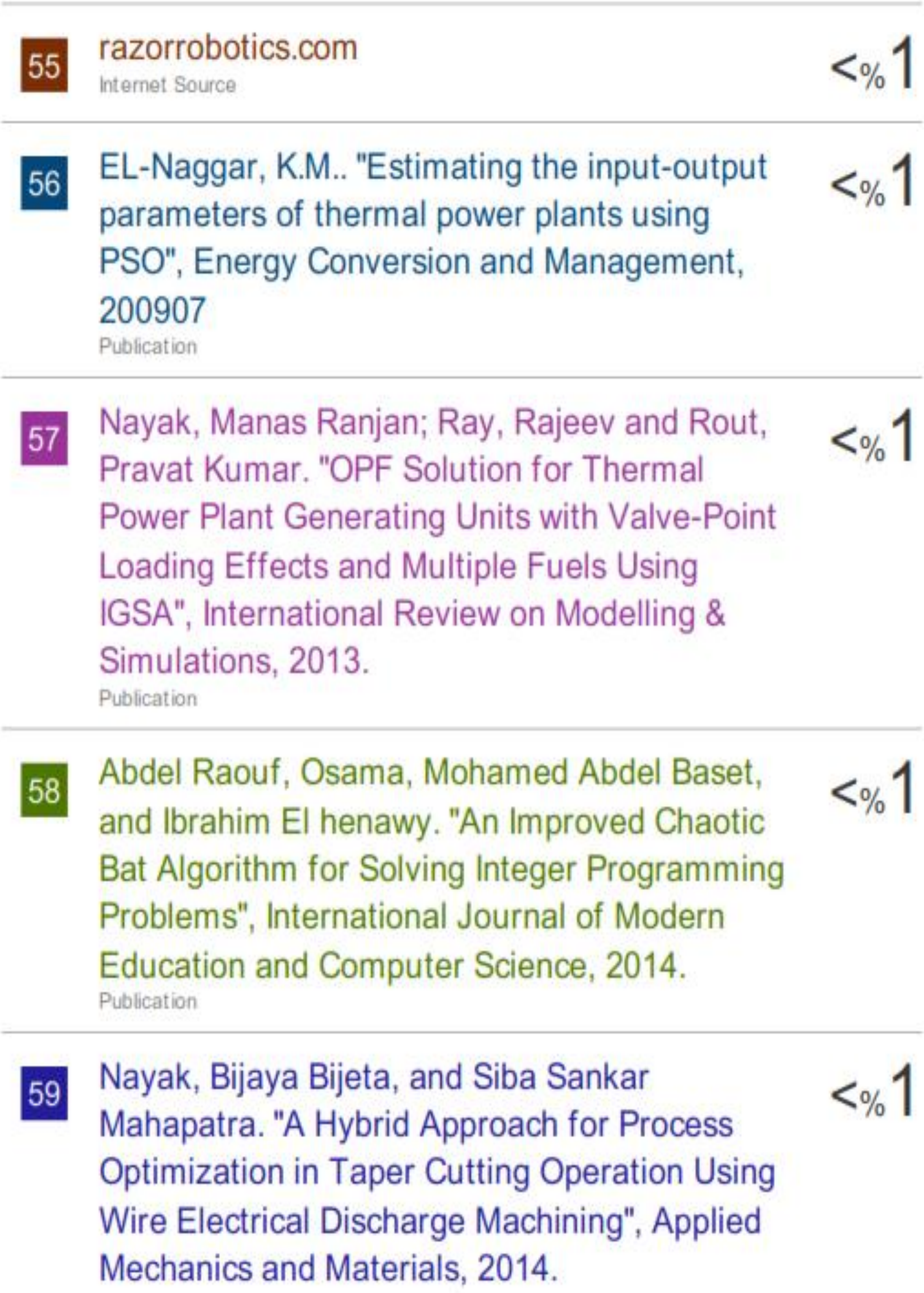

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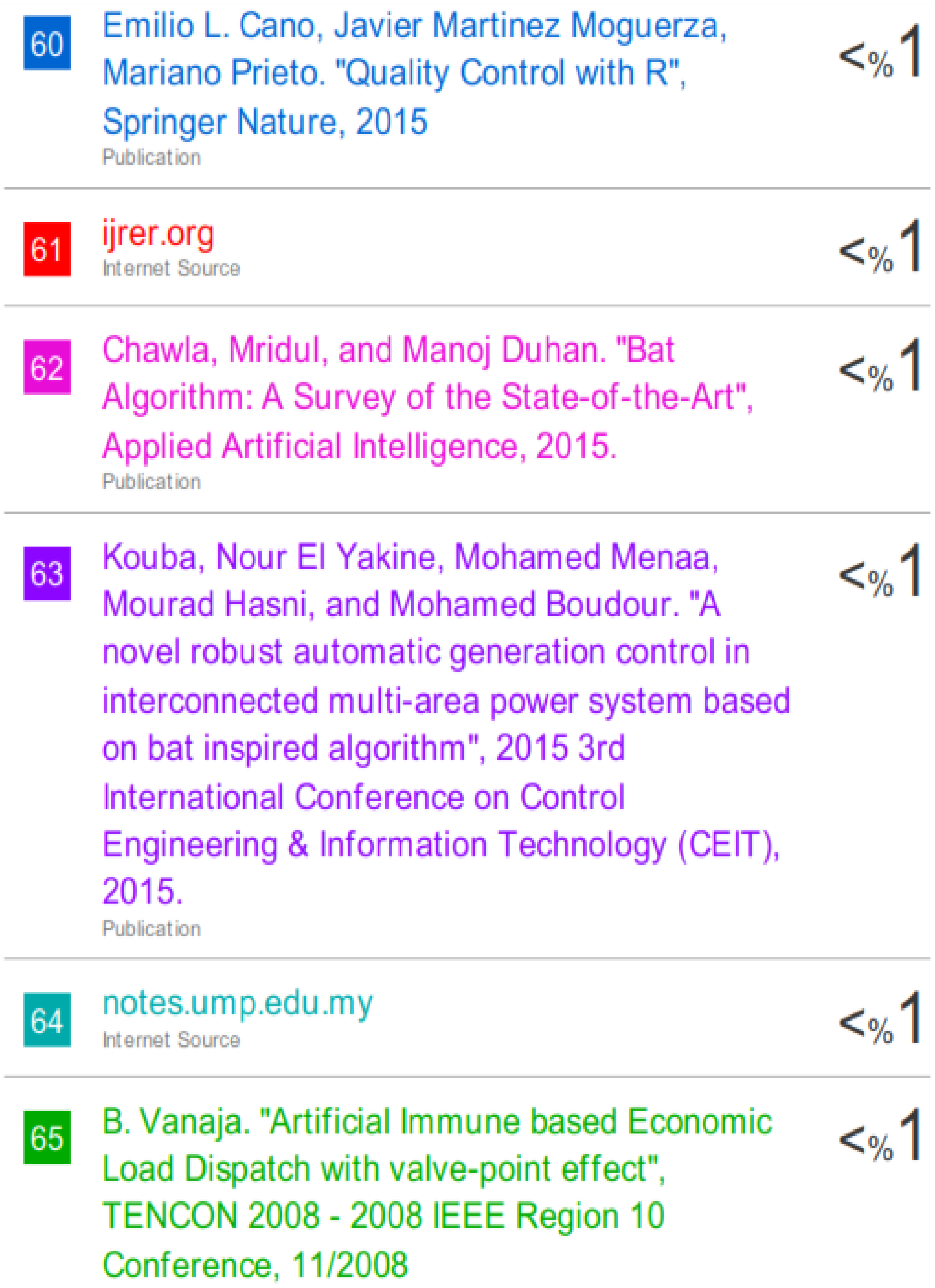

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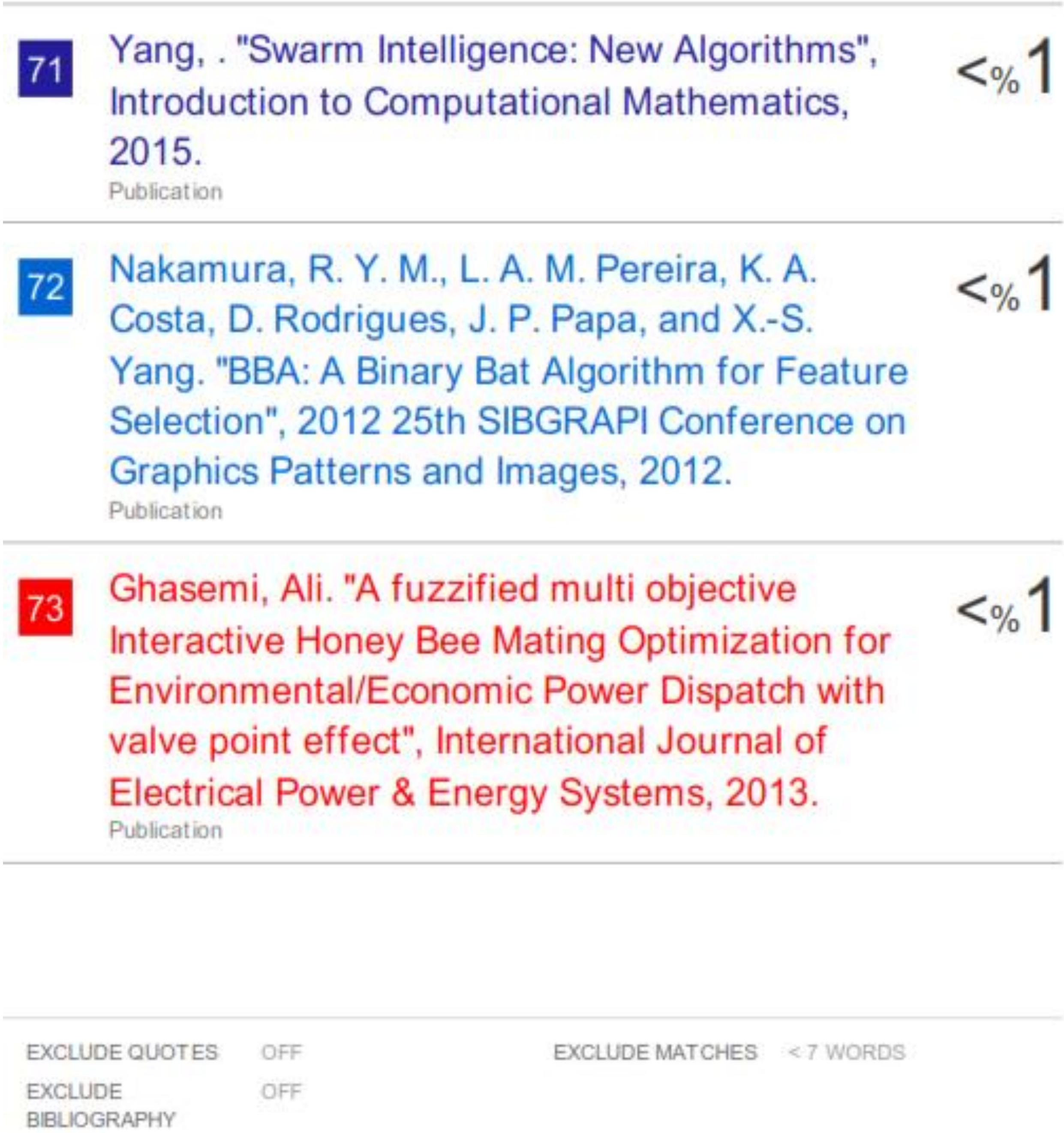

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