TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol. 14, No. 1, April 2015, pp. 55 ~ 61
DOI: 10.11591/telkomnika.v14i1.7629

A Modified Bat Algorithm for Power Loss Reduction in Electrical Distribution System

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Abstract

Losses on Electric Distribution System lines represent a major challenge for electric distribution companies since those losses refer to the amount of electricity injected into the distribution grids that are not paid by users. Network Optimization by system reconfiguration is one of the solutions among many others used to solve this problem. In this paper a modified version of new Meta Heuristic algorithm based on Bat behavior is proposed to find the best system configuration with a low loss rate, we present two different approaches: reduction of search space and introduction of sigmoid function to fit the algorithm to the problem. The main advantages of the proposed methodology are: easy implementation and less computational efforts to find an optimal solution. To demonstrate its efficiency the proposed scheme is tested on 33 Bus distribution system and the results show loss reduction rate of 33%.

Keywords: *bat algorithm, sigmoid function, power losses, optimal reconfiguration, optimal power flow*

1. Introduction

Generally Distribution System (DS) operate in radial configuration with many switches located along the network at strategic points [1]. We have two main switches on DS: Sectionalized Switches (SS) that are normally closed and Tie Switches (TS) that are normally opened. Reconfiguration is a process to change topology of system by changing the state (close/open) of switches. A normally opened TS is closed to transfer a load from one feeder to another while an appropriate closed SS is opened to restore the radial structure [2]. Its present many advantages in two cases: in case of fault occurs, it allows isolating a fault area and restoring load to non-fault area [3] and in case of normal process, it enhances voltage profile, load balancing [4], reliability [5] and reduce network loss [6-8]. In this paper we are most concerned about reducing power loss.

The effect of losses can be compared to a pipe that is being constricted as load and ambient air temperature increases, thus limiting the amount of power and energy available at the end-use. The reduction of power loss can improve efficiency while reducing overall power costs, improving voltage levels, and potentially reducing costly investments in system improvements. Reducing power loss by changing the state of switches can be defined as optimization problem, because we are trying to get a best configuration among many others which gives us a lower power loss while respecting the constraints. The optimization in this case is not considered as a simple one because in DS we have many constraints and a lot of switches which make the problem combinatorial complex and a nonlinear optimization one [9].

Previous researchers have been looking at reducing losses by reconfiguring the system and several methods have been developed in parallel with the technology's improvement and innovations in computer science and mathematics. Thus branches exchange methods have been introduced by Civanlar and Al. since 1988 and several publications have made some comments on the limitation of this method which hasn't able to find the optimum solution[10]. Merlin and Back also introduced Mathematical optimization model based on branches and bound technics that are great but computation time is very long [11]. D. Shirmohammadi introduced optimal flow pattern algorithm that was a heuristic method. This method takes minimizing power loss as objective function [12].

Recently many research papers used artificial intelligence technics to solve combinatorial nonlinear optimization problems to obtain an optimal solution of global minimum.

Received January 8, 2015; Revised March 9, 2015; Accepted March 23, 2015

These technics are called Meta heuristics and have obtained the good results. Typical meta-heuristic methods include Simulated Annealing (SA), Genetic Algorithm [1, 7, 13], Tabu Search [14, 15] Ant Colony Optimization [16, 17], and Particle Swarm Optimization [18]. In reference [19] a Selective Particle Swarm 0ptimization (SPSO) is developed based in search space method.

Since 2010 a new bio inspired algorithm based on bat echolocation behavior was proposed to engineers to solve many optimization problems. It has been demonstrated that unlike other optimization methods the diversity of the solutions in the population proposed by BAT Algorithm can be increased [20]. In the field of electric distribution network loss reduction this algorithm is commonly associated with power dispatch [21, 22], Optimal power flow[23], capacitor placement [24], location and size of DG units [25].

This paper try to associate BAT Algorithm to network reconfiguration by modifying the original one to find the best configuration of distribution network that exhibits the low rate of loss by choosing the state of switches in network. Initially Bat Algorithm is space search algorithm, to adapt it in our situation we input the sigmoid function that changes any function in binary one, so then we can easily decide the switch that should be open and close. This algorithm is tested on IEEE 33 nodes and is compared with other method.

2. Reconfiguration Model of Distribution System

As we mention above the purpose of DS reconfiguration include decreasing the loss, improving voltage quality, power supply and so on. Nowadays many research papers are more interested about minimum network losses and load balance. The main objective in this research paper is reducing power loss. To simplify the study we suppose that the load along a feeder section as constant P, Q loads placed at the end of the lines and every switch is associated with a line in the system as describe in [2].

2.1. Objective Function

The objective function represents the total power loss on the system that we can express with the branch resistance R_i active and reactive power (P_i,Q_i) and branch voltage V_i as:

$$f = P_{Loss} = \sum_{i=1}^{nb} k_i R_i \frac{P_i^2 + Q_i^2}{V_i^2} \qquad (1)$$

The parameters nb represent the number of branch in Distribution Networks, variable k_i is the switch state placed on branch i, this variable can take only 2 values depending on the state of switch, when switch is open then $k = 0$ and reversibly when close $k = 1$. The functions vary with V and k. This function represents also our fitness function. The objective here is to minimize f under certain constraints.

2.2. Constraints

The distribution network performances depends on certain constraints. In this article, we chose to do our research with three constraints that are essential for a minimum system operation:

a) Voltage profile of the system

The network reconfiguration is optimized such that the node voltage magnitude V_i isn't out of the voltage limit:

$$V_{i,\min} \le V_i \le V_{i,\max} \qquad (2)$$

b) Current Capacity of the feeder

The current goes trough the branch I_i should not be higher then the maximum allowable current.

$$I_i \leq I_{i,\max} \quad (3)$$

c) Radial structure of the network

In order to maintain the radially of the system, the number of closed lines in each loop needs to be less than the total number of lines making the loop as proscribed, in other words no loop are allowed in the system where k_i is Switch state 0 or 1 and N_s is Number of switch in DS:

$$\sum_{i=1}^{N_s} k_i \leq N_s - 1 \quad (4)$$

3. BAT Algorithm

Bat Algorithm (BA) is a nature inspired metaheuristic algorithm developed by Xin-She Yang in 2010. BA is based on echolocation that is an important feature of bat behavior. Bats are a fascinating group of mammals that rely on echolocation to detect obstacles in flight, finding their way into roosts and forage for food [26]. The principle of operation of this system is as follow: bats emit a very loud sound pulse and listen for the echo that bounces back from surrounding objects, thus it can determine the distance between them and also can distinguish obstacles and preys [27].

Based on that behavior of bats: the ability to compute the distance between them and object, echolocation can be use in such a way that it can be associated with the objective function to be optimized [21]. To model this algorithm Yang [28] has set some rules as follows:

1) All bats use echolocation to sense distance, and they also guess the difference between food/prey and background barriers in some magical way.

2) Bats fly randomly with velocity v_i at position x_i with a fixed frequency $f_{\min}$ varying wavelength λ and loudness $A_0$to search for prey. They can automatically adjust the wavelength (or frequency) of their emitted pulses and adjust the rate of pulse emission $r \in$[0, 1], depending on the proximity of their target. Although the loudness can vary in many ways, we assume that the loudness varies from a large (positive) A_0 to a minimum constant value A_{min}.

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For each bat b_i , the position $x_{i\,i}$, the velocity v_i and the frequency f_i are initialize. For each time step t, the maximum number of iterations, the movement of the virtual bats is given by updating their velocity and position using Equation (3), (4) and (5) as follows:

$$f_i = f_{\min} + (f_{\max} - f_{\min})\beta \quad (5)$$
$$v_i^t = v_i^{t-1} + (x_i^t - x_*)f_i \quad (6)$$

Where β is a random number between [0, 1], f_i is used to control the pace and range of the bat's movement, x_* is a current best location. Then the new solution or position for the bat can be generated by the equation given below:

$$x_i^t = x_i^{t-1} + v_i^t \quad (7)$$

One solution is selected among the current best solutions and then the random walk is used to obtain a new solution:

$$x^{new} = x^{old} + A_i^t \partial \quad (8)$$

∂ is the average loudness of all Bats, a random number between [0,1]. The local search is launched depending on the pulse rate r_i .

It should be noted that when Bat find prey the rate of pulse emission r_i increase and the loudness A_i decrease[29].For each iteration the loudness A_i and the emission pulse rate r_i are updated, as follows:

$$A_i^{t+1} = \alpha A_i^t \qquad (9)$$

$$r_i^t = r_i^0 \left[1 - \exp(-\gamma t)\right] \qquad (10)$$

Where α and γ are constants. At the first step of the algorithm the values of these two parameters are chosen randomly, generally $A_i(0) \in [1,2]$ and $r_i(0) \in [0,1]$.

Based on the above approximations and idealization, the pseudo-code of the Bat Algorithm (BA) can be summarized below:

Step1: Initialize the bat population or their position r_i and their velocities v_i. Define pulse **frequency** f_i at x_i. Initialize pulse rates *r* and the loudness *A*.
Step2: Generate new solutions by adjusting frequency, and updating velocities and Locations/solutions.
Step3: if ($rand > r$) Select a solution among the best solutions. Generate a local solutionthe selected best solution.
Step4: Else generate a new solution by flying randomly.
Step5: If ($rand > A_i$) and $f(x_i) < f(x_*)$ Accept the new solutions, increase r and reduce A
Step6: Rank the bats and find the current best x_*
Step7: while (iteration < Max number of iterations) Post process results and visualization. The algorithm stops with the total-best solution.

4. Proposed Methodology with Modified BAT Algorithm

To better solve our problem and facilitate its implementation, we change the initial Bat Algorithm on one hand and on the other hand modify the initial design of the distribution network, which allows our algorithm to be effective and fast. The DNR's resolution process that we offer can be divided into three steps described below:

a) Specification of the number of dimensions

In this step radial design of the distribution network is transformed into design loop by closures Tie switch (Normally Open). The number of loops corresponding to the dimensions of numbers. Fig1 show the distribution network with 33 nodes. Blue lines represent sectionalized switch and red lines tie switch. By closing tie switch the system change to multiloop circuit with 5 loops so 5 dimensions.

b) Find search area

Each dimension represents one search area. And this search is the set of all branches forming the loop. The branch is not part of one loop are excluded from the search area, and the branches belonging to several loop must necessarily belong to one and only one loop, this is done randomly.

c) Find optimum solution

The idea here is to find or determine the status of the Switch, which allows us to have a low loss rates. In the original algorithm the position of beats is represented by continuous-valued positions, which is not very adequate for our purpose. Since the switch has two states closed or open, the ideal in this context would be to alter the position of the bat to a series of binary value. This is possible by the sigmoid function that restricts the new position of the bat has only binary values. This method is widely explained in[29, 30]. Thus the following function is used:

$$S(v_i^t) = \frac{1}{1 + e^{-v_i^t}} \qquad (11)$$

And the Equation (6) can be replaced by:

$$x_i^t = \begin{cases} 1 \; if \;\; S(v_i^t) > \sigma, \\ 0 \;\; otherwise \end{cases} \qquad (12)$$

With $\sigma \approx U(0,1)$.

To summarize our method in a simple way, each switch located on each branch is represented by a bat in our algorithm. The new position of the latter determines or not if this switch is open or closed position and the value we assign to the parameter *k* of our objective function. For each iteration power flow is performed, the constraints are checked. This is done until the smallest possible value of the power loss is found.

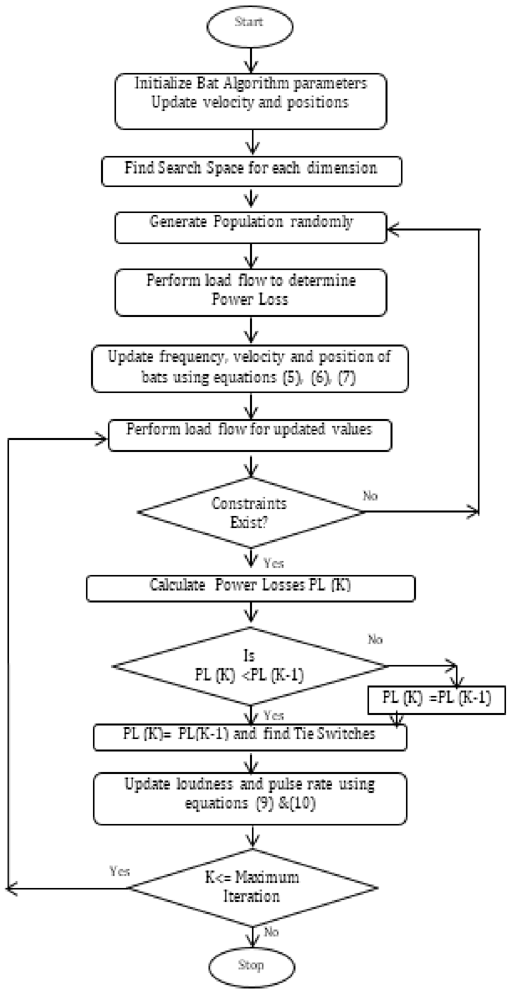

Figure 1. Flow chart of proposed method

5. Simulation, Results and Analysis

The proposed modification of BAT Algorithm is programmed in MATLAB environment and has been tested on IEEE 33 busses of Distribution Network. Figure 2 bellow shows the initial condition of the system that consists of 37 switches whereby 5 of them are tie switches and the remaining 32 are sectionalizing switches if we consider that on each branch there is a switch. The normally opened switches are (9-15), (3-18), (21-28), (12-22), (25-29). For this case, the initial real power loss is 202.68 kW.

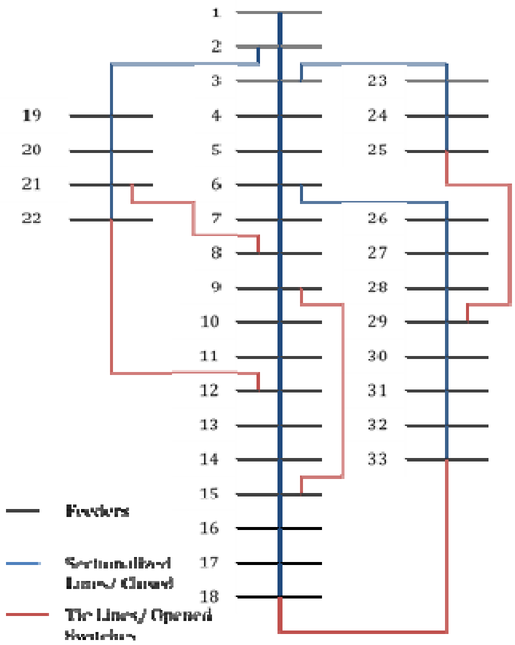

Figure 2. 33 Nodes Test System

Table 1. Modified Bat Algorithm Main Parameters

n	A_0	r_0	f_{min}	f_{max}
40	0.5	0.5	0	2

Table 2. Results obtained and compared

System	Loss Reduction%	Tie Lines
Before Reconfiguration	0	8-21 / 9-15 12-22 / 18-33 25-29
After Reconfiguration using Modified BAT	33	(5-6 / 8-21 23-24 / 25-29 27-26
After reconfiguration using SPSO[19]	31	7-9 / 9-10 14-15 / 25-29 32-33

The result obtained after performed the algorithm is resume in table 2. Calculation here indicates that a percentage reduction in real power loss is 33%. The reduction of the search space has much makes things easier in the sense that the algorithm has no longer to search through the whole system but just a part of the system. The numbers of tie lines in the new configuration doesn't changes.

6. Conclusion

This paper proposed a modification of Bat-inspired algorithm for reduce power loss in Distribution System. Introduction of sigmoid function and reduction of search space are news and played a key role to the implementation of the algorithm. The result demonstrates the effectiveness of this algorithm by high reducing real power loss. This model optimization can be applied to several cases in engineering. The challenge to come is to check its effectiveness on a larger system with integration of Distributed Generation and reduction of switching operation.

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