BAT OPTIMIZATION ALGORITHM FOR SECURITY CONSTRAINED OPTIMAL POWER FLOW

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Abstract- In this work, a new optimization algorithm (BA), which is based on the food foraging behavior of Bat optimization, is proposed for optimal power flow with security constraints (OPF-SC) problem. Security is improved by adjusting the line power flows. The OPF-SC is a nonlinear programming optimization problem with complex discontinuous solution space. BA is a recently developed algorithm known for its simplicity yet good searching capability. The control parameters are the real power generation, generator bus voltage, transformer tap position and SVC settings. The proposed methodology is to be tested on the standard IEEE-30 bus system.

Index Terms; **Exploitation, exploration, bat optimization algorithm, optimal power flow with security constraints, search diversity.**

I. INTRODUCTION

Electric power system is usually considered as the most complicated man-made system due to its large size, different static/dynamic behaviors and complex inter-connected equipment. For operation of such sophisticated system, engineers require qualified tools for optimally determining its different settings and control actions. An important operational function in this regard is optimal power flow(OPF) considered as the backbone tool that has been widely researched since Introducing and the optimal power flow optimizes a power system operating objective function (such as the fuel cost of thermal generators) while satisfying the constraints of the components and system [1]. In its most general formulation, the optimal power flow is a nonlinear, non-convex, large-scale, static optimization problem with both continuous and discrete control variables [2]. By adding on linear security constraints of the power system to the optimal power flow formulation, leading to optimal power flow-security constraints, even a more complex optimization problem is obtained. Thus, optimal power flow and optimal power flow-security constraints problems challenge the numerical optimization techniques. Former optimal power flow solution methods include mathematical programming approaches, such as on Newton method, linear programming (LP), quadratic programming (QP), and interior point (IP) methods. Several stochastic search techniques such as genetic algorithms (GA) [2], particle swarm optimization (PSO) [4], bacteria foraging (BF) algorithm [5], improved bacterial foraging method [6] Bat optimization algorithm have been proposed to solve the optimal power flow problem without any restriction on the shape of the cost curves. The results reported were promising and encouraging for further research in this direction. Despite the performed research works in the area of optimal power flow, more efficient optimal power flow methods are still demanded due to its importance and complexity. Furthermore, Optimal Power Flow-Security Constraints, considered in this paper, is a more comprehensive and more recent concept than optimal power flow and fewer research works on it can be found in the literature.

Contributions of this paper:

A new stochastic search technique, named Bat optimization algorithm (BOA) method, is proposed. New search mechanisms and evolution procedures are incorporated into the classical Improved Bacterial Foraging (IBF) in the proposed BOA to enhance its exploration capability, search diversity and convergence behavior. The proposed BOA has been formulated for the solution of Optimal Power Flow-Security Constraints problem. For this purpose, decision variables of the problem are coded and objective function and constraints of Optimal Power Flow-Security Constraints are modeled within the proposed BOA. The remaining parts of the paper are organized as follows. In the Section II, the formulation of Optimal Power Flow-Security Constraints problem is introduced. The proposed BOA and its application for the solution of the Optimal Power Flow-Security Constraints problem are presented in Section III. Obtained numerical results from extensive testing of the proposed solution are presented in Section IV. Section V concludes the paper.

II. OPTIMAL POWER FLOW-SC FORMULATION

Objective function, constraints and decision variables of Optimal Power Flow-Security Constraints problem are briefly presented in this section. More details about formulation of this problem can be found in [7], and [8].

a. Objective Function

The most common objective function of optimal power flow and Optimal Power Flow-Security Constraints problems is fuel cost of thermal generating units [7], which is conventionally modeled by a quadratic cost function. However, large steam units usually have a number of steam admission valves that are opened in sequence to obtain ever-increasing output of the unit [1]. By considering valve loading effects of thermal units, which introduces rippling effects to the actual input/output curve, an additional sine term representing the valve effects is added to the quadratic fuel cost function. Moreover, usually there are many units in a practical power system supplied with multiple fuels. The fuel cost function of thermal unit i with valve loading effects and fuel type changes is as follows:

$$F_i(P_{gi}) = \sum_{k=1}^{n_{fi}} [F_{i,k}(P_{gi}).U_{(i,k)}], i = 1, ..., NG \qquad (1)$$

Where $F_{i,k}(P_{g,i})$ is as follows:

$$F_{i,k}(P_{gi}) = a_{ik} + b_{ik}P_{gi} + c_{ik}P_{gi}^2 + |e_{ik}\sin(f_{ik}(P_{gik}^{min} - P_{gi}))|$$

if

$$P_{gi,k}^{min} \le P_{gi,k}^{max}, k = 1, ..., n_{fi}, i = 1, ..., NG. \qquad (2)$$

Sum of $F_i(P_i)$ terms over all NG thermal units should be minimized. The other objective functions such as gaseous emissions, transmission real loss, bus voltage deviation, and security margin index for regulated power systems and social welfare and congestion management cost for deregulated electricity markets have also been proposed for the optimal power flow and Optimal Power Flow-Security Constraints problems in the literature.

b. Constraints

The employed Optimal Power Flow-Security Constraints formulation includes the following constraints [9], [10]:

Nonlinear AC power flow constraints and Generators real and reactive power outputs limits. Prohibited operating zone (POZ) constraints of units. Bus voltage magnitude and branch flow limits (static security constraints) in the steady state and post-contingent state of credible contingencies [8]. Limits of discrete transformer tap and phase shifter settings and limits of the discrete reactive power injections of capacitor/reactor banks

AC power flow constraints can be used in two ways. In the first way, these constraints are simply added to the constraints of the optimization problem and the solution method solves the problem subject to all constraints. And slack bus is not required in this way. In the second way, AC power flow is executed in the solution process instead of adding its equations as equality constraints to the optimization problem. For the second way, slack bus should be defined so that the AC power flow can be executed. In the second way, the tight equality constraints of the Optimal Power Flow-Security Constraints problem are processed by an AC power flow solution algorithm and so the optimization method should only handle inequality constraints. Moreover, the proposed BOA has been implemented in the MATLAB software package. There are efficient computer codes in MATLAB for the solution of AC power flow. By the second approach, we can employ high efficiency of these computer codes for the constraint handling of the Optimal Power Flow-Security Constraints problem.

c. Decision Variables

The vector of decision variables of the employed Optimal Power Flow-Security Constraints formulation includes both continuous and discrete decision variables as follows:

$$DV = \Big[\overbrace{P_{g2}, ..., P_{gNG}}^{DV1}, \overbrace{V_{g1}, V_{g2}, ..., V_{gNG}}^{DV2}, \overbrace{T_1, T_2, ..., T_{NT}}^{DV3}, \overbrace{Q_1, Q_2, ..., Q_{NC}}^{DV4} \overbrace{PS_1, PS_2, ..., PS_{NPS}}^{DV5}\Big] \qquad (3)$$

The first sub-vector of DV includes active power generation of all units except the generation of slack bus (P_1) since generation of the slack bus is a dependent variable on the power system load and generation of the other units. The first and second sub -vectors contain continuous decision variables, while those of the third, fourth and fifth sub-vectors are discrete decision variables. Observe from (3) that the Optimal Power Flow-Security Constraints formulation includes NP decision variables as follows:

$$NP = (NG - 1) + NG + NT + NC + NPS. \qquad (4)$$

The real Optimal Power Flow-Security Constraints model considered in this paper is a mixed-integer, nonlinear, non-convex, non -differentiable and non-smooth optimization problem with discontinuous solution space.

III. PROPOSED BAT OPTIMIZATION ALGORITHM (BOA)

In this section, the BOA algorithm is presented and its application for the solution of the optimal power flow-security constraints problem is described [11]. Micro bats use a type of sonar, called, echolocation, to detect prey, avoid obstacles, and locate their roosting crevices in the dark. These bats emit a very loud sound pulse and listen for the echo that bounces back from the surrounding objects. Their pulses vary in properties and can be correlated with their hunting strategies, depending on the species. Most bats use short, frequency-modulated signals to sweep through about an octave, while others more often use constant-frequency signals for echolocation [12]. Such echolocation behavior of micro bats can be formulated in such a way that it can be associated with the objective function to be optimized, and this makes it possible to formulate new optimization algorithms

Bat Algorithm if we idealize some of the echolocation characteristics of micro bats, we can develop various bat-inspired algorithms or bat algorithms. In the basic bat algorithm developed by [13], the following approximate or idealized rules were used.

i. All the bats are following the echolocation mechanism and they could distinguish between prey and obstacle.
ii. Each bat randomly with velocity v_i at position x_i with a fixed frequency f_{min}, varying wavelength λ and loudness A_0 while searching for prey. They adjust the wavelength (or frequency) of their emitted pulses and adjust the rate of pulse emission $r \in [0, 1]$, depending on the distance of the prey.
iii. 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}.

In this algorithm either the frequency or wavelength is varied while the other parameter is kept fixed.

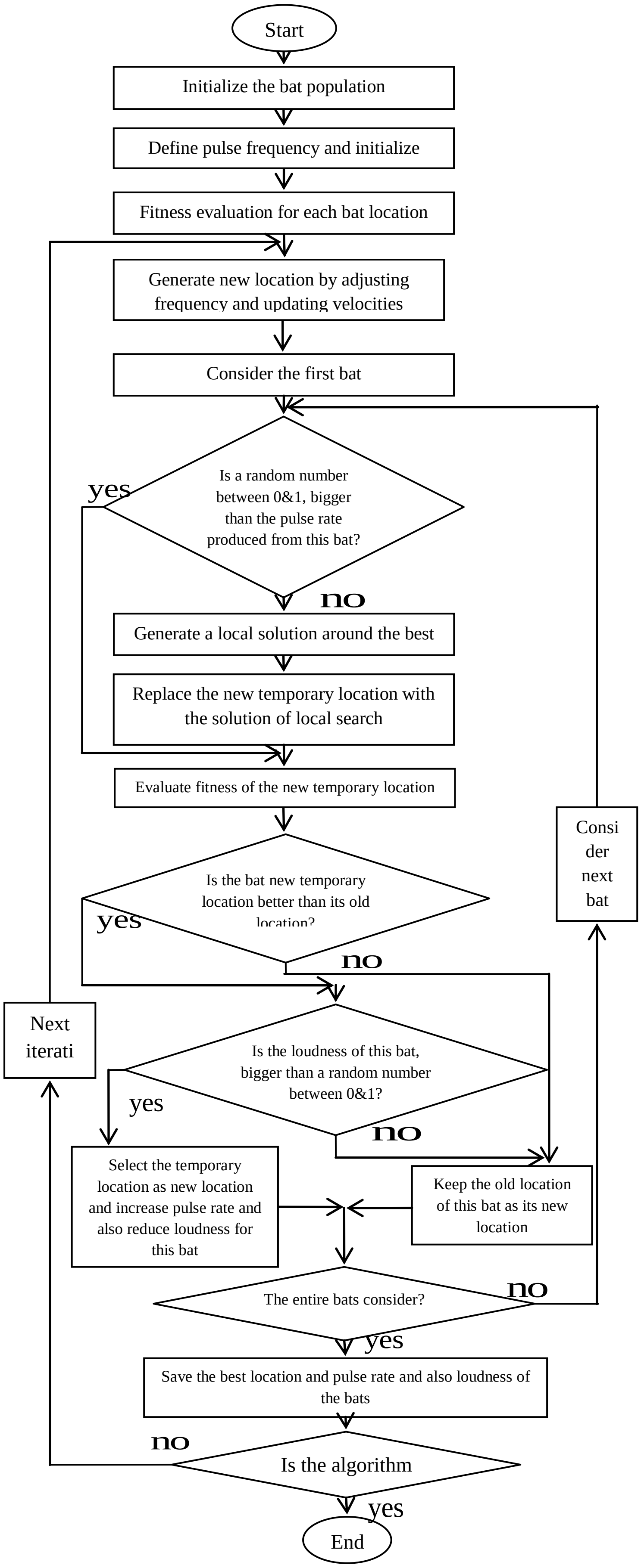

Fig.1. Flowchart for the BOA

i. Movement of virtual bats

Defined rules are necessary for updating the position X_i and velocity V_i. The new bat at the time step *t'* is found by the following equation.

$$f_i = f_{min} + (f_{max} - f_{min})\beta \quad (5)$$

$$V_i^t = v_i^{t-1} + (x_i^t - x_*) \quad (6)$$

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

Where, β is a random number drawn between '0' and '1'.

For most of the applications, $f_{min} = 0$ and $f_{max} = 100$, depending the domain size of the problem of interest. A new solution for each bat is generated locally using random walk.

$$x_{new} = x_{old} + \varepsilon A^t \quad (8)$$

Where, $\varepsilon \in (1, -1)$ is a random number, while f_{min} is the average loudness of all the bats at this time step [12].

ii. Loudness and Pulse Emission

Furthermore, the loudness A_i and the rate r_i of pulse emission Shave to be updated accordingly as the iterations proceed. As the loudness usually decreases once a bat has found its prey, while the rate of pulse emission increases, the loudness can be chosen as any value of convenience. Usually, $A_0 = 100$ and $A_{min} = 1$. For simplicity, we can also use $A_0 = 1$ and $A_{min} = 0$, assuming $A_{min} = 0$ means that a bat has just found the prey and temporarily stop emitting any sound. Now we have

$$A_i^{t+1} = \alpha A_i^t + \gamma A_i^{t+1} = \gamma_i^0 [(1 - \exp(-\gamma_t))] \quad (9)$$

Where, α and γ are constants? In fact, α is similar to the cooling factor of a cooling schedule in the simulated annealing. For any $0 < \alpha < 1$ and $\gamma > 0$ we have

$$A_i^t \to 0, \ \gamma_i^t \to \gamma_i^0 \ \text{as } t \to \infty \quad (10)$$

In the simplicity case, we can use $\alpha = \gamma$, and we have used $\alpha = \gamma = 0.9$in our simulations. The choice of parameters requires some experimenting. Initially, each bat should have different values of loudness and pulse emission rate, and this can be achieved by randomization.

IV Numerical Results

The first test case of this section is an optimization problem with two decision variables θ_1 *and* θ_2 , presented in [14]. As seen, it is a nonlinear optimization problem with multiple local minima. Thus, the enhanced exploration capability of the BOA can appropriately be illustrated on it.

Table of summery

parameter	Optimal value by FOA	Optimal value []
P_{g1}	177.3	178.500
P_{g2}	49.18	44.9791
P_{g5}	12.24	19.0838
P_{g8}	11.19	19.9175
P_{g11}	21.23	12.8417
P_{g13}	21.74	17.3256
V_{g1}	1.060	1.1000
V_{g3}	1.046	1.0825
V_{g5}	1.100	1.0649
V_{g8}	1.077	1.0684
V_{g11}	1.022	1.0447
V_{g13}	1.030	1.1000
T_{p11}	1.0657	0.9882
T_{p12}	0.9000	1.0136
T_{p15}	1.0468	1.0760
T_{p36}	0.9589	1.0431
Q_{svc10}	19.0	8.0364
Q_{svc24}	4.3	2.0000

TABLE- I

Test Case 1: IEEE 30-Bus Test System (References of Data: [9])

The BOA is locally search the area and finds the global optimum. However, there is no guarantee that the random generation produces the initial population within the promising area, especially for Optimal Power Flow-Security Constrained problem with complex solution space and much more dimensions (decision variables). To better illustrate this matter, we changed the initial population of BOA for the optimization problem of Fig. 2

In the following, obtained results for the Optimal Power Flow-Security Constrained test cases are presented and discussed, respectively. Obtained continuous values from the BOA for the discrete decision variables of the Optimal Power Flow-Security Constrained are rounded up/down to the nearest discrete values in these test cases.

Objective function and constraints of this test case are as de-scribed for the previous one. However, it has $NP = 5 + 6 + 4 + 2 + 0 = 17$ decision variables according to (4). Obtained best and average results from the BOA for this test case are rep-resented in Table I. As a sample, the details of the best solution of the BOA for this test case are also represented in Table I. However, due to space limitation and for the sake of conciseness, only the final results are presented for the other test cases of the paper.

Convergence curve

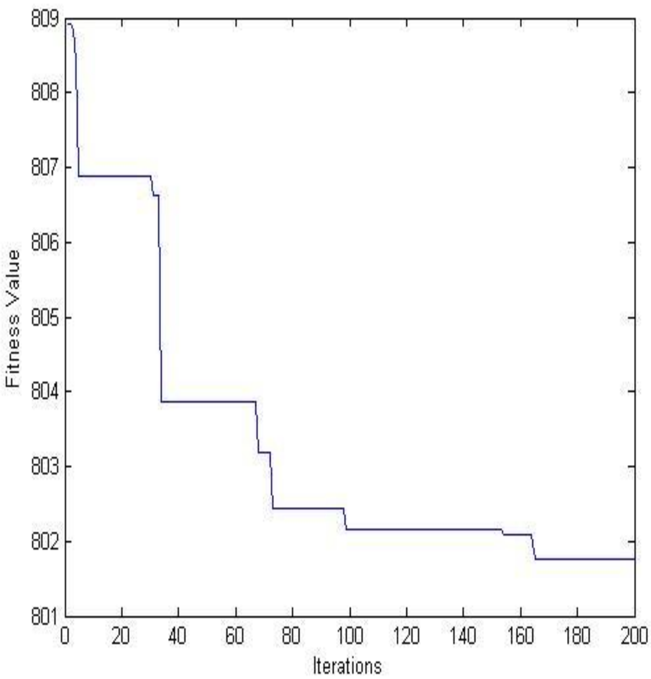

Fig 2: output curve

V. CONCLUSION

Optimal Power Flow-Security Constrained is an important operational function for today power systems. However, Optimal Power Flow-Security Constrained is a non-linear, non-convex and non-smooth optimization problem with complex discontinuous solution space shaped by diverse constraints. Solving this optimization problem by traditionally deterministic optimization methods is very hard, if not impossible. In this paper, a new stochastic search technique is presented to solve the Optimal Power Flow-Security Constrained problem. The proposed method is an improved version of Bat algorithm. BA has high local each and exploitation capabilities due to the swarming behavior of the visual senses. New operators and procedures have been designed in this research work to enhance search diversity, exploration capability and convergence behavior of BA, while saving its positive characteristics. The effectiveness of the proposed method is extensively illustrated on a classical Optimization problem and different Optimal Power Flow-Security Constrained test cases. Superiority of the BA compared with more than 20 other optimization methods, recently published in the literature, to solve the Optimal Power Flow-Security Constrained problem is shown. Moreover, the proposed BA is a robust and easy to use optimization method with low computation burden.

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