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Voltage and Reactive Power Control of Power Systems Using Intelligent Control Techniques

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Abstract: The establishment of voltage control using Optimal Power Flow method for an IEEE 118 bus system by using intelligent techniques was proposed followed by establishing a comparison between them. Intelligent control is the process of using past inputs as a memory to manipulate and analyze the voltage, real power and reactive power of the system. This paper resolves the voltage instability problem and establishes voltage control through the use of Optimal Power Flow Algorithm. Voltage, real power and reactive power are controlled through equality and inequality constraints. Using the iterations from the Newton Raphson's Method and optimizing voltage through the use of intelligent algorithms such as GA, PSO and BAT Algorithm, this project has bettered the generator cost and Optimal Power Flow is established. With the help of the learning abilities of these intelligent algorithms, a fast and self-healing voltage control is realized and the performance of the system is improved over time. Improvement of performance of the power systems will take place simultaneously by the use of a sufficient and efficient memory learning process. Reduction in generator cost and improvement of the output voltage are the main objectives of this paper.

Key word: Voltage Control · Particle Swarm Optimization (PSO) · Genetic algorithm (GA) · BAT Algorithm · Reactive Power Control

INTRODUCTION

Normally, in power system, bus voltage and generator reactive power should be maintained within the specified limits. When it is not maintained within the limits, it leads to system instability. So facts devices are used to maintain within the limits. Through the use of Optimal Power Flow algorithm, this project has established an efficient method to optimize generator cost and establish Coordinated Voltage Control. Voltage, Real Power and Reactive Power are controlled using intelligent algorithms such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and BAT Algorithm. Optimal Power Flow algorithm such as Newton Raphson's iterative method are used to obtain voltage corrections for N number of iterations. A novel design approach based on BAT algorithm to reach the optimal values of the Proportional-Integral-Derivation (PID) controller parameters in order to improve the load frequency control (LFC) and automatic voltage regulator (AVR) [14]. The GA was compared with an integer programming-based solution method, in which GA showed a considerably reduced calculation time [2]. A new intelligent scheme was proposed based on a genetic learning progress for optimal voltage control [1]. This learning control scheme combines the GA with a memory which saves knowledge accumulated from past experiences. In each run of search by GA, past experiences in memory are exploited to speed up the searching of GA and improve the quality of the solutions while the knowledge in memory is also re?ned by the new solutions [3]. GA combined with Linear Power Flow algorithm should be used to minimize the number of control actions and real power loss. The Linear Power Flow algorithm is used to provide accurate results and GA is used to reduce the calculation time [2]. Initialization of the general particle populations in particle swarm optimization algorithm are generated randomly [11]. This paper is organized as follows: system modeling of GA,

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PSO and BAT algorithm is displayed in Section 2, brief prologue to genetic algorithm is talked about in Section 3, PSO and BAT Algorithm is explained in section 4, last two Section 5 and 6 individually describe simulation result and conclusion of this paper.

System Modeling of Intelligent Algorithms: The three intelligent algorithms that have been put to use in this project are GA, PSO and BAT Algorithm. GAs are heuristic search techniques inspired by the evolutionary theory. High-quality genes (memory) have higher chance of being kept to the next generation. PSO, in its historical version, is a collective, anarchic (in the original sense of the term), iterative method with emphasis on cooperation; it is partially random and without selection. The BAT inspired algorithm (BA) is a metaheuristic search algorithm which is based on the echolocation behavior of micro bats to optimize voltage, real power, generative power and generation cost. The intelligent algorithms are used inside the iterative process of Newton Raphson's Method. The algorithm evaluates the iterative result and compares the previous results including parameters, which are part of the intelligent algorithm and gives a result. It also updates the iterative result after optimizing. These iterative results are used as memory for further iterative calculations. The main use of these three algorithms is to minimize cost and optimize generator voltage. The output of the iterations will change based on the parameters inside the algorithm. This project involves the use of three different intelligent algorithms to enhance the voltage and reduce the generation cost. There are two constraints to overcome Coordinated Voltage Control problem. The two constraints are:

- Equality Constraints: These include the generators' upper and lower limits.
- Inequality Constraints: These include external factors such as transmission losses and heating losses.

Objective Function for GA: By the following energy balance equation in every node m of a electricity supply system, the theoretical background of bus voltage control and generator reactive power control problem will be presented.

$A_{Pm} = P_{Gm} - P_{Lm}$

$$\sum_{j=1}^{n} \mathrm{Em\ Ej\ [Gmj\ cos(\theta j - \theta m) - \ Bmj\ sin(\theta j - \theta m)]} \quad (1)$$

$A_{Qm} = Q_{Gm} - Q_{Lm}$

$$\sum_{j=1}^{n} \mathrm{Em\ Ej\ [Gmj\ sin(\theta j - \theta m) + \ Bmj\ cosn(\theta j - \theta m)]} \quad (2)$$

Where

A_{Pm}, A_{qm},	active and reactive power energy balance of bus m;
P_{Gm}, Q_{gm},	generated active and reactive power at bus m;
P_{Lm}, Q_{lm},	active and reactive power of load at bus m;
E_m, E_j,	voltage amplitudes at buses m and j;
Gmj, Bmj,	active and reactive parts of line admittance between buses m and j;
θ_m, θ_j,	voltage phase angles at bus m and j; n number of buses.

To obtain the solution of power flow problem, the variables and constants mentioned above are classified as:

$\vec{l}$ *state variables* (reactive power of generator and voltage phase angle, load voltage amplitude and phase angle);
$\vec{x}$ *control variables* (active power of generator and voltage amplitude);
$\vec{y}$ *disturbance variables* (active and reactive power of load);
$\vec{c}$ *constants* (admittance of line and transformer ratio).

Normally for all buses the energy balance is represented by vector f. When $\vec{f}(\vec{l},\vec{x},\vec{y},\vec{c})=\vec{0}$, load flow solution is obtained where $\vec{y},\vec{c}$ are constants. Voltage constraint violations are eliminated by adjusting the voltages of generator, transformer ratio and switching shunt devices. This shows that the transformer ratio and load reactive power are considered as controlled quantities. The main aim of emergency control is to find a proper combination ($\vec{x},\vec{y},\vec{c}$) such that

$$\vec{f}(\vec{l},\vec{x},\vec{y},\vec{c})=\vec{0} \quad (3)$$

while enforcing the constraints $\hat{g}$ to variables like generator loads, bus voltage, controlled quantities and line currents together represented by $\vec{g}$

$$\vec{g}(\vec{l},\vec{x},\vec{y},\vec{c})\leq\hat{g} \quad (4)$$

Generally, the number of possible solutions is more with the given various combinations of $\vec{x},\vec{y},\vec{c}$ and an optimal selection of control actions is possible. In case of optimization problem, the equations become

Optimize $\vec{h}(\vec{l},\vec{x},\vec{y},\vec{c})$ subject to

$$\vec{f}(\vec{l},\vec{x},\vec{y},\vec{c})=\vec{0}$$

$$\vec{g}(\vec{l},\vec{x},\vec{y},\vec{c})\leq\hat{g} \tag{5}$$

Objective Function for PSO: Voltage integrated control and Reactive power is normally used the control variables such as adjust on-load tap changing ratio, reactive power compensation capacitor capacity and generator terminal voltage to reduce active power losses and increase power factor to ensure the voltage within the specified limit. This paper adopted smallest active power loss as the control optimization objective function, generator reactive power and nodes' voltages as state variables, on-load tap changing ratio and reactive power compensation capacitor capacity and generator terminal voltage as the control variables, mathematical model are as follows:

$$minf=\sum_{x=1}^{N_n} P_{lossx}=\sum_{\substack{i\in N_g\\ j\in N_s}} G_{ij}(E_i^2+E_j^2-2E_iE_j\cos\Theta_{ij}) \tag{6}$$

The flow calculation equation is the quality constraint:

$$P_i-E_i\sum_{j=1}^{N_j}E_j\left(G_{ij}\cos\Theta_{ij}+B_{ij}\sin\Theta_{ij}\right)=0 \tag{7}$$

$$Q_i-E_i\sum_{j=1}^{N_j}E_j\left(G_{ij}\sin\Theta_{ij}-B_{ij}\cos\Theta_{ij}\right)=0 \tag{8}$$

The control variable inequality constraints:

$$E_{Gi,min}\leq E_{Gi}\leq E_{Gi,max},\ i\in N_G \tag{9}$$

$$T_{ki,min}\leq T_K\leq T_{K,max},\ K\in N_T \tag{10}$$

$$Q_{ci,min}\leq Q_{Ci}\leq Q_{Ci,max},\ i\in N_C \tag{11}$$

The state variable inequality constraints:

$$E_{i,min}\leq E_i\leq E_{i,max},\ i\in N_B \tag{12}$$

$$Q_{gi,min}\leq Q_{Gi}\leq Q_{Gi,max},\ i\in N_G \tag{13}$$

Where the N is set of branches number, N_i is the collection of nodes number associated with the node i, N_{PQ} is the collection of nodes number for the P-Q node, N_B is the total number of nodes, N_G is the nodes number set for generators, N_T is the transformer branches set, N_C is the compensate capacitor nodes set; S is the balance nodes; P_{lossk} is active power loss of branch k, G_{ij} is the conductance of branch ij; B_{ij} is the susceptance of branch ij, P_i, Q_i is the active and reactive power of the node i, V_i, V_j is the voltage amplitude of the node i and j, V_{ij} is the voltage phase angle difference of nodes i, j; Q_{Gi} is the generator reactive power of the node i, Q_{Ci} is the reactive power compensation capacity of node i.

Objective Function for Bat Algorithm: In the flow calculation, equality constraints are used. The control variables inequality constraints can be satisfied in the algorithm and the state variables inequality constraints adopted penalty function to introduce the objective function,

$$\sum_{i=1}^{n} f_i=f_{min}+(f_{max}-f_{min})\beta \tag{14}$$

$$\sum_{i=1}^{n} V_i^t=\sum_{i=1}^{n} V_i^{t-1}+(x_i^t-x_o)f_i \tag{15}$$

$$\sum_{i=1}^{n} x_i^t=\sum_{i=1}^{n} x_i^{t-1}+V_i^t \tag{16}$$

Where,

β = arbitrary vector drawn from uniform distribution (0<â<1)

f_i = frequency or wavelength

x = current best global best location of bats

v_i = velocity in a d-dimensional search space

Genetic Algorithm: Genetic Algorithm is the technique that provides solutions for all optimization problems. For the problem of optimization, previous publications shows a wide range of objective functions like cost minimization of control action and the use of the number of controls and time required for control actions to complete [4]. To save cost and to eliminate the violations of constraint, one or more of the control actions in a set are needed. Less number of control actions is suitable for manual control actions. Mixed integer programming [5] involves both discrete and continuous variables and applied to voltage control problem. But calculation time is long in this method. Based on the supervisor's experience, expert systems have been developed in recent years [1] which does not optimize any objective function. Linearity and differentiability of objective function is not required for GA. Hence GA is more effective in dealing with objectives and with discrete control devices. For bus voltage and generator reactive power problem, many GA applications exist for planning and optimal allocation of reactive power sources [6][7] and also for voltage security enhancement by preventive control [8]. In some publications, optimal power flow (OPF) problem also been involved [9]. But in OPF solution, control actions results in loss or cost optimization. The main aim of this paper is to eliminate constraint violations. Through a preselection of control devices, minimization of the number of control actions are included in the paper [10]. The continuation of the paper published [10] with improvements in algorithm and results are presented in the paper. In case of corrective control problem, for improving the calculation time of GA, the initial step is the proper selection of control devices. The algorithm below gives the advantages of both the model of linear system and GA.

(i) For each control devices, sensitivity coefficients are calculated.
(ii) To reduce the constraint violations based on the ability of control devices, first set of number of controls was selected which are involved in the next calculation stage.
(iii) To identify the proper set of control action, GA is used. The number of controls used and the remaining constraint violations finds the fitness of a solution. The flowchart of GA is shown in fig. 1.

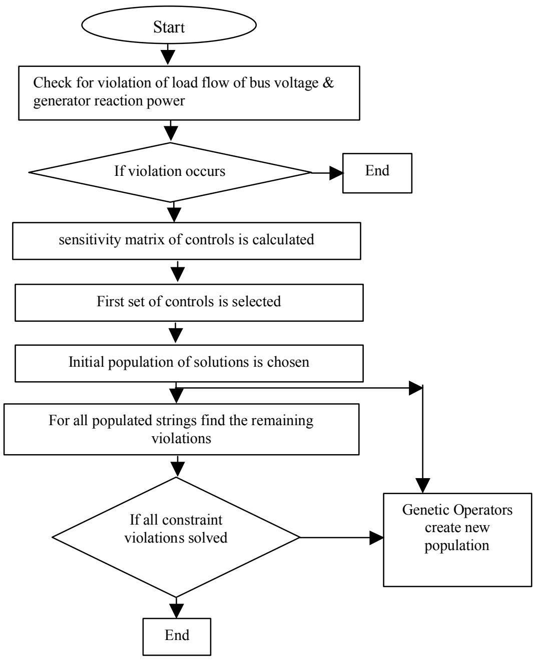

Fig. 1: Flowchart of Genetic Algorithm

PSO & BAT Algorithm: The PSO algorithm and Genetic Algorith (GA) are almost similar, because they both are derived from the simulation of natural biological behaviors and both are multi-point algorithms based on iterative random search. Though in the implementation, the process of PSO, compared with GA, is simple and has not complicated crossovers and mutation operations. Control variables are small, fast convergence and more converge to the global optimal solution. Though PSO algorithm's pre-search is fast [12], the particles in the search continue to a later stage in which the two "best values" tend to be same, so that the search algorithm is slowed down. Hence, if the particle plunges into the local optimization at this time, it is difficult to jump out and it must reduce accuracy of the ultimate convergence of the algorithm [13]. Today, more scholars are dedicated to the improvement of particle swarm optimization algorithm. This paper presented a particle swarm optimization algorithm applied it to the voltage and reactive power control. By using mixed real-coded method which consisted of Continuous variables and discrete variables, it could include the following steps:

Step 1: Raw data reading, that is inputting the dimension N of control variables and upper and lower limits X_{imax} =[$X_{i,1max,}$ $X_{i,\,2max}$, … …], setting the limit of state variables ($V_{i,}$ $Q_{Gi);}$ setting up the size of group particles as M=20, maximum number of iterations t_{max}=50, inertia weight value interval [0.2, 0.4]; according to the literature [6] speed limits use 20% * $X_{imax.}$

Step 2: Initializing uniformly that is put iteration times t=0, clear the count time; according to uniform distribution function, take 20 variables in the control vectors of each dimension variable interval [-Ximax, Ximax] and form the 20 initial vectors, that is 20 initial particles. The initial velocity of each particles was set to zero.

Step 3: The current particle velocity and position is updated and estimate whether all particles locations exceed their limits. So if any of them exceeded its limit, modify its value.

Step 4: Then calculate the fitness value to determine a feasible solution. Calculate each particle fitness and verify whether it is a feasible solution of the problem. Hence, if it was a feasible solution, sorting it from small to large according to the value and record all iteration results.

Step 5: The optimal value is updated if the particle was a feasible solution of the problem and the fitness value is better than the optimal value of the historical groups and update the groups optimal value. Then choose the first 4 best particles in the feasible solutions of the problem as the best solutions to instead of the history particles to update the speeds.

Step 6: Chaotic mutation that is if the nearest three generations of particles fitness no change or change in the rate of less than a minimum value, the fitness of this particle was not the group optimal value and deem this particle to have plunged into a part optimization. Hence modify the variables in each dimension in accordance with Logistic equation.

Step 7: Find the termination condition that is if the iteration reached the maximum times or the groups optimal value was less than a certain value, stop the optimization and output the results, otherwise the number of iterations plus one, counting time plus one, repeat step3.

The BAT inspired algorithm (BA) is a metaheuristic search algorithm which is based on the echolocation behavior of micro bats to optimize voltage, real power, generative power and generation cost. BAT inspired algorithm is one of the newest attempts at power optimization through a metaheuristic approach [15] and hence, it was not possible to gauge the performance of the algorithm on a power system. In the case of the BAT inspired algorithm, complete voltage control was introduced due to the lesser number of buses used (30 buses were used). The voltage optimization becomes even harder and hence, cost optimization is also difficult.

RESULTS AND DISCUSSIONS

This paper has aimed to bring about a new dimension to power system optimization through the use of a new algorithm called BAT Inspired Algorithm and have implemented it on a 30 bus system. This paper has also implemented older algorithms such as GA and PSO for a higher bus system, i.e., IEEE 118-bus system. The fitness function is the key to use the GA. The most essential stride in applying GA tuning strategy is to pick the target work that is utilized to assess the fitness value of every chromosome.

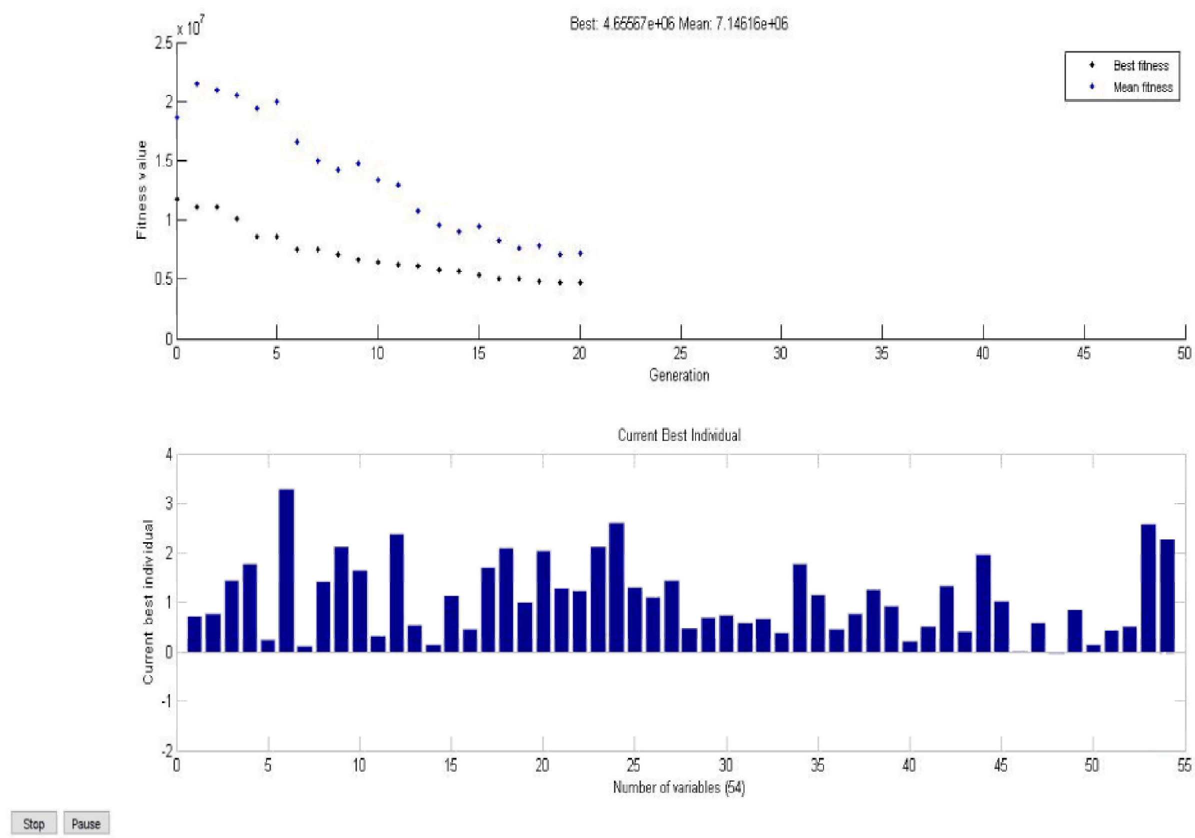

Fig. 2: Output of Genetic Algorithm

Cost Optimization: Cost optimization is the process of economizing the cost without compromising on the quality of the output. Cost optimization is done to make the generation from the buses available at the best cost. Therefore, with the use of the objective cost function mentioned in section 2.

COST Optimization of GA: In fig. 2 for generation number 20, it can be seen clearly that the output cost function f(x) as defined in section 2 shows gradual decrease and gives the most optimum value of cost. The data for the 19th and 20th iteration are shown below.

	Best	Mean	Stall	
Generation	f-count	f(x)	f(x)	Generations
19	800	4.656e+06	7.035e+06	0
20	840	4.656e+06	7.146e+06	1

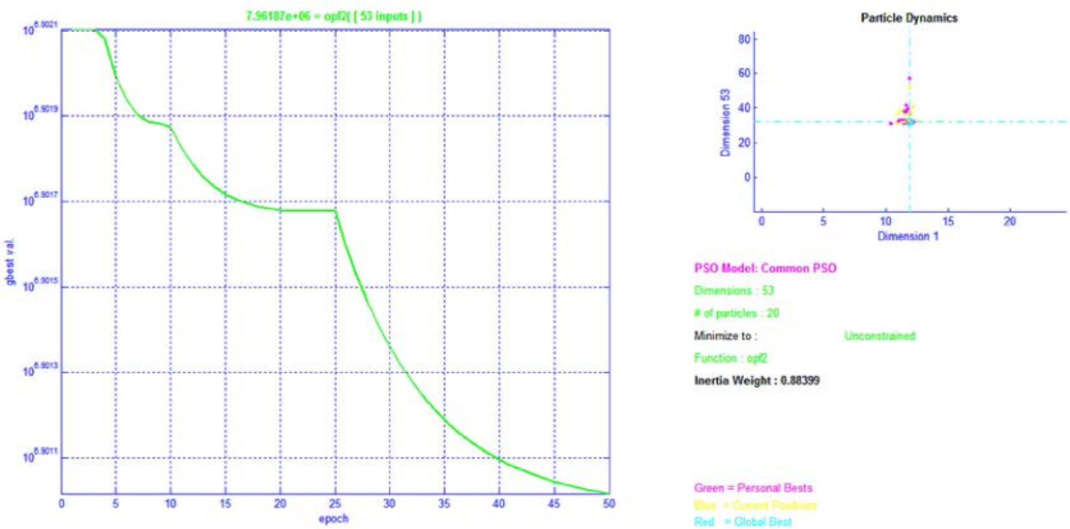

Fig. 3: Output of PSO

COST OPTIMIZATION OF PSO

PSO: 1/50 iterations, G_{Best} = 7927773.0219071107.
PSO: 10/50 iterations, G_{Best} = 7919868.2389082452.
PSO: 20/50 iterations, G_{Best} = 7915334.1705612.
PSO: 30/50 iterations, G_{Best} = 7898649.0694836471.
PSO: 40/50 iterations, G_{Best} = 7893281.6893112473.
PSO: 50/50 iterations, G_{Best} = 7828249.4674299723.

G_{best} is the best cost value for the iteration. As it can be seen, the cost keeps on reducing, thereby obtaining cost optimization from PSO. The 50th iteration has the lowest value, therefore giving us the graph in fig. 3.

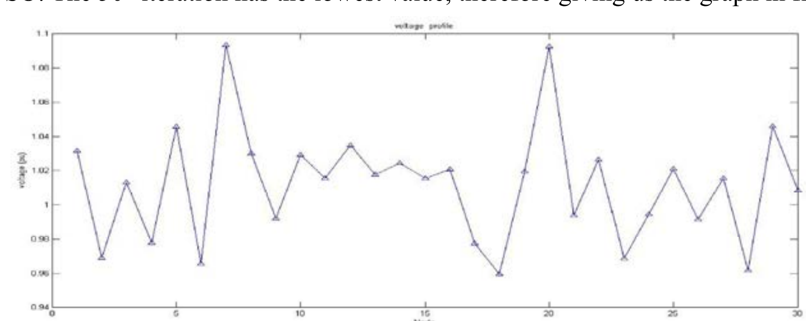

Fig. 4: Output of BAT Algorithm

COST Optimization of BAT: BAT algorithm optimizes cost and obtains an F value equal to 921.558 for the 30 buses of data taken. The 30 bus system of IEEE has 6 generator buses and it gets optimized. From fig. 4, P_{gen} gives the value of the optimized generator buses. It uses a metaheuristic approach for optimization.

F1 = 921.5588
TL = 8.1000

F1 gives the cost for the execution of BAT Inspired Algorithm for a 30 bus system and the TL value denotes the total losses of the system after optimization. Table I shows the comparison between PSO and GA.

Comparison of Outputs:

Table 1: Comparison table between PSO and GA

Comparitive Value/ Algorithm	PSO	GA
Best Cost (F Value)	7.8189e+06	6.8557e+06
Voltage Optimization within value (number of buses per every thirty bus)	31	41
TL Value	3.1048e+03	2.6943e+03
Number of iterations	50	20
Optimization of Voltage	Low	High
Approach Used	Particle Dimension	Gene and Fitness
Stop Criteria	Iteration	Time

CONCLUSIONS

This paper has achieved the objectives through the efficient use of three different algorithms, namely, PSO, GA and BAT. Nevertheless, in the case of the BAT inspired algorithm, complete voltage control was introduced due to the lesser number of buses used (30 buses were used). This means that the voltage optimization becomes even harder and hence, cost optimization is also difficult. However, with the use of intelligent algorithms, better output values than previous attempts were obtained. The future scope of this project lies in the ability to device much better intelligent algorithms and optimize BAT inspired algorithm for a larger bus system and effectively compare the three algorithms along with other different algorithms.

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