Controlling Voltages and Reduction of Real Power Loss in Power System by Using Crossbreed Spiral Dynamics Bacterial Chemotaxis Algorithm

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***Abstract*—In this paper a new hybrid optimization algorithm, referred to as Crossbreed spiral dynamics bacterial chemotaxis algorithm (CSDBCA) is proposed to solve the optimal reactive power dispatch (ORPD) Problem. CSDBCA synergizes bacterial foraging algorithm (BFA) chemotaxis approach and spiral dynamics algorithm (SDA). The original BFA has higher convergence speed while SDA has better accuracy and stable convergence when approaching the optimum value. This crossbreed approach conserves the strengths of BFA and SDA. So the CSDBCA has the capability of producing superior results. In order to evaluate the proposed algorithm, it has been tested on IEEE 30 bus system consisting 6 generators and compared other algorithms and simulation results show that CSDBCA is more efficient than others in solving the reactive power dispatch problem.**

***Index Terms*—spiral dynamics, bacterial chemotaxis, optimization algorithm, optimal reactive power dispatch, power system.**

I. Introduction

In modern years the optimal reactive power dispatch (ORPD) problem has established a huge attention as a result of the development on economy and security of power system operation. Solutions of ORPD problem plan to minimize real power loss by satisfying number of constraints like limits of bus voltages, tap settings of transformers, reactive and active power of power resources and transmission lines and controllable Variables [1], [2].At the beginning, a number of classical methods such as gradient based [3], interior point [4], linear programming [5] and quadratic programming [6] have been effectively used in order to solve the ORPD problem. However, these methods had some disadvantages in the method of solving the complex ORPD problem. Drawbacks of these algorithms can be confirmed by their insecure convergence properties, long execution time, and algorithmic complexity and can be trapped in local minima [1], [7]. In order to prevail over these disadvantages, researches had successfully applied evolutionary and heuristic algorithms such as Genetic Algorithm (GA) [2], Differential Evolution (DE) [8] and Particle Swarm Optimization (PSO) [9]. In [10] developed a hybrid optimization algorithm - combining bacterial foraging optimisation algorithm (BFA) with BBO, and referred to it as intellectual biogeography based optimization. In [11] introduced a hybrid description of BFA with differential evolution (DE) algorithm called chemotaxis differential evolution. In [12] introduced a hybrid algorithm BPSO-DE synergizing BFA, particle swarm optimization (PSO), and DE to solve dynamic economic dispatch problem with valve-points effect. Bacterial. This paper presents hybrid version [13]-[14] of bacterial foraging algorithm (BFA) chemotaxis strategy and spiral dynamics algorithm (SDA).The proposed Algorithm is tested on IEEE30-bus system for evolution of effectiveness of it. Results obtained from CSDBCA are powerful than other algorithms in solution of ORPD problem.

II. Formulation of ORPD Problem

The objective of the ORPD problem is to minimize the objective functions by satisfying a number of constraints such as load flow, generator bus voltages, load bus voltages, switchable reactive power compensations, reactive power generation, transformer tap setting and transmission line flow.

A. Minimization of Real Power Loss

Minimization of Real power loss (P_{loss}) in transmission lines is mathematically stated as follows.

$$P_{loss}=\sum_{\substack{k=1\\k=(i,j)}}^{n} g_{k}(V_i^2+V_j^2-2V_iV_j\cos\theta_{ij}) \quad (1)$$

where n is the number of transmission lines, g_k is the conductance of branch k, V_i and V_j are voltage magnitude at bus i and bus j, and θ_{ij} is the voltage angle difference between bus i and bus j.

B. Minimization of Voltage Deviation

Minimization of the Deviations in voltage magnitudes (VD) at load buses is mathematically stated as follows.

$$\text{Minimize VD} = \sum_{k=1}^{nl}|V_k-1.0| \quad (2)$$

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where n_l is the number of load busses and V_k is the voltage magnitude at bus k.

C. System Constraints

In the minimization process of objective functions, some problem constraints which one is equality and others are inequality had to be met. Objective functions are subjected to these constraints shown below.
Load flow equality constraints:

$$P_{Gi} - P_{Di} - V_{i\sum_{j=1}^{nb} V_j} \begin{bmatrix} G_{ij} & \cos\theta_{ij} \\ +B_{ij} & \sin\theta_{ij} \end{bmatrix} = 0, \quad i = 1,2 \ldots., nb \tag{3}$$

$$Q_{Gi} - Q_{Di} V_{i\sum_{j=1}^{nb} V_j} \begin{bmatrix} G_{ij} & \cos\theta_{ij} \\ +B_{ij} & \sin\theta_{ij} \end{bmatrix} = 0, i = 1,2 \ldots., nb \tag{4}$$

where, nb is the number of buses, P_G and Q_G are the real and reactive power of the generator, P_D and Q_D are the real and reactive load of the generator, and G_{ij} and B_{ij} are the mutual conductance and susceptance between bus I and bus *j*.

Generator bus voltage (V_{Gi}) inequality constraint:

$$V_{Gi}^{min} \leq V_{Gi} \leq V_{Gi}^{max}, i \in ng \tag{18}$$

Load bus voltage (V_{Li}) inequality constraint:

$$V_{Li}^{min} \leq V_{Li} \leq V_{Li}^{max}, i \in nl \tag{19}$$

Switchable reactive power compensations (Q_{Ci}) inequality constraint:

$$Q_{Ci}^{min} \leq Q_{Ci} \leq Q_{Ci}^{max}, i \in nc \tag{20}$$

Reactive power generation (Q_{Gi}) inequality constraint:

$$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max}, i \in ng \tag{21}$$

Transformers tap setting (T_i) inequality constraint:

$$T_i^{min} \leq T_i \leq T_i^{max}, i \in nt \tag{22}$$

Transmission line flow (S_{Li}) inequality constraint:

$$S_{Li}^{min} \leq S_{Li}^{max}, i \in nl \tag{23}$$

where, nc, ng and nt are numbers of the switchable reactive power sources, generators and transformers.

III. Bacterial Foraging Optimization Algorithm

The BFA is a biologically inspired algorithm introduced in [15]. It is based on adaptation technique of Escherichia Coli (E. Coli) bacteria to find out nutrient or food source throughout their lifetime and the method is called bacterial foraging strategy. One of the outstanding characteristics of E. Coli is that it has very high augmentation rate, which is normally exponential. Bacterial foraging strategy consists of three fundamental sequences namely chemotaxis, reproduction and elimination & dispersal. These sequences are rolling processes and are effective for optimization purposes [16].When searching for food or nutrient, plummeting and swimming will take place. Plummeting is similar to sail and it happens when the E. Coli navigates in the search area and once the food source is found, and it swims like ambushing a objective area with enormous speed, up to 20μm/s or faster in a rich nutrient medium. This exclusive movement is called chemotaxis. Reproduction, elimination and dispersal events then happen to bacteria with high fitness that has capability to reach food source precisely and rapidly. The details of the original algorithm and pseudo code of BFA can be found in [20]. In this paper, number of bacteria, number of chemotaxis, chemotactic step size, number of swims, number of reproduction, number of elimination & dispersal are represented as *S, Nc, C, Ns, Nre* and *Ned* respectively. The probability that each bacterium will be eliminated and dispersed is defined as *ped* and its value 0.25 for our problem.

IV. Spiral Dynamics Inspired Optimization Algorithm

The SDA is a different metaheuristic algorithm adopted from spiral phenomena in nature [13].Furthermore; comparisons with other optimization algorithms [13] such as PSO and DE have shown that SDA performance is better. This simple and effectual approach retains the diversification and amplification at the early phase and later phase of the trajectory as diversification and amplification are important characteristics of the optimization algorithm. At the initial stage, the spiral trajectory explores a wider search space and it incessantly converges with a smaller radius providing dynamics step size when close to the final point, which is the best solution, situated at the centre. The distance between a point in a path trajectory and the centre point is varied regularly. The radius of the trajectory is altering at steady rate thus making the radius an important converging parameter for the algorithm. The strength of SDA lies in its spiral dynamics model. An n-dimensional spiral mathematical model that is derived using composition of rotational matrix based on combination of all 2 axes is given as:

$$x(k+1) = S_n(r,\theta)x(k) - (S_n(r,\theta) - I_n)x' \tag{24}$$

where

$$S_n(r,\theta)x(k) = rR^n(\theta_{21,}, \theta_{1,3}, \ldots, \theta_{n-1,n})x(k)$$

and $R_{i,j}^n(\theta_{ij}) :=$

$$\begin{bmatrix} 1 & & \cdots & & 1 \\ \vdots & \begin{bmatrix} cos\theta_{ij} \\ \vdots \\ sin\theta_{ij} \end{bmatrix} & \begin{matrix} \cdots \\ \ddots \\ \cdots \end{matrix} & \begin{bmatrix} -sin\theta_{ij} \\ \vdots \\ cos\theta_{ij} \end{bmatrix} & \vdots \\ 1 & & \cdots & & 1 \end{bmatrix}$$

where

θ_{ij} - Bacteria angular displacement on$x_i - x_j$plane around the origin.

r - Spiral radius

V. Crossbreed Spiral Dynamics Bacterial Chemotaxis Algorithm

The CSDBCA is a mixture of bacterial chemotaxis approach used in BFA and SDA. BFA has quicker convergence speed due to the chemotaxis approach, but suffers from fluctuation problem towards the end of its search method. On the other hand, SDA provides superior stability when approaching optimum point due to dynamic spiral pace in its trajectory motion but has sluggish convergence speed. CSDBCA algorithm conserves the strengths possessed by both BFA and SDA.

CSDBCA for solving optimal reactive power problem.

Step 1: Training

choose the number of search points (bacteria) $m \geq 2$, parameters$0 \leq \theta < 2\pi$, $0 < r < 1$ of $S_n(r,\theta)$, maximum iteration number,$k_{\max}$ and maximum number of swim, $N_s$for bacteria chemotaxis.

Set $k = 0$, $s = 0$.

Step 2: Initialization

Set preliminary points $x_i(0) \in R^n$, i=1, 2,..,m in the feasible regionat random and centerx^* as $x^* = x_{ig}(0)$,i_g= arg $\min_i f(x_i(0))$, i=1, 2,...,m .

Step 3: Apply bacteria chemotaxis

(i) Renew x_i

$x_i(k+1) = S_n(r,\theta)x_i(k) - (Sn(r,\theta) - In)x^*$

i=1, 2,...,m.

(ii) Bacteria swim

(a) Verify number swim for bacteria i.

If $s < N_s$, then check fitness,

Otherwise set $i = i+1$, and return to step (i).

(b) Verify fitness

If $f(x_i(k+1)) < f(x_i(k))$, then update x_i ,

Otherwise set $s = N_s$, and return to step (i).

(c) renewx_i

$x_i(k+1) = S_n(r,\theta)x_i(k) - (S_n(r,\theta) - In)x^*$

i=1, 2,...,m.

Step 4: update x^*

$x^* = x_{ig}(k+1)$,

i_g= arg $\min_i f(x_i(k+1))$, i=1, 2,...,m .

Step 5: Examination of termination criterion

If $k = k_{\max}$ then terminate. Otherwise set $k = k+1$, and return to step 2.

where

- θ_{ij} - Bacteria angular displacement on $x_i - x_j$plane around the origin.
- r - Spiral radius
- k_{max} -Maximum iteration number
- m – Number of search points
- N_s - Maximum number of swim
- $x_i(k)$- Bacteria position
- R^n - n x n matrix

In this planned approach, bacterial chemotaxis strategy is employed in step 3 to balance and augment exploration and exploitation of the search space. The bacteria move from low nutrient location in the direction of higher nutrient location, located at the centre of a spiral. The most significant feature of CSDBCA algorithm is the particular diversification and amplification at the early phase and later phase of the spiral motion. In the diversification phase, bacteria are located at low nutrient location and move about with larger step size thus producing quicker convergence. On the other hand, in the amplification phase, bacteria are approaching rich nutrient location and move about with smaller step size hence avoiding fluctuation around the optimum point. Another factor contributing to superior performance of the algorithm is the swimming action in bacterial chemotaxis. Bacteria continuously swim towards optimum point if the next location has superior nutrient value compared to previous location until the maximum number of swim is reached.

TABLE I. BEST CONTROL VARIABLES SETTINGS FOR DIFFERENT TEST CASES OF PROPOSED APPROACH

Control Variables setting	Case 1: Power Loss	Case 2: Voltage Deviations
VG1	1.02	0.98
VG2	1.03	0.91
VG5	1.03	1.02
VG8	1.01	1.03
VG11	1.02	1.02
VG13	0.91	1.04
VG6-9	1.00	0.90
VG6-10	1.02	1.01
VG4-12	1.01	1.03
VG27-28	1.02	0.90
Power Loss (Mw)	4.5045	3.673
Voltage deviations	0.6978	0.1863

TABLE II. COMPARISON OF REAL POWER LOSS AND VOLTAGE DEVIATIONS

Control Variables Setting	CSDBCA	GSA [17]	Individual Optimizations [1]	Multi Objective Ea [1]	As Single Objective [1]
VG1	1.02	1.049998	1.050	1.050	1.045
VG2	1.03	1.024637	1.041	1.045	1.042
VG5	1.03	1.025120	1.018	1.024	1.020
VG8	1.01	1.026482	1.017	1.025	1.022
VG11	1.02	1.037116	1.084	1.073	1.057
VG13	0.91	0.985646	1.079	1.088	1.061
T6-9	1.00	1.063478	1.002	1.053	1.074
T6-10	1.02	1.083046	0.951	0.921	0.931
T4-12	1.01	1.100000	0.990	1.014	1.019
T27-28	1.02	1.039730	0.940	0.964	0.966
Power Loss (Mw)	4.5045	4.616657	5.1167	5.1168	5.1630
Voltage Deviations	0.6978	0.836338	0.7438	0.6291	0.3142

VI. Simulation Results

Planned approach has been applied to solve ORPD problem. In order to demonstrate the efficiency and robustness of proposedCSDBCA approach it has been tested on standard IEEE30-bus test system .The test system has six generators at the buses 1, 2, 5, 8, 11and 13 and four transformers with off-nominal tap ratio at lines6-9, 6-10, 4-12, and 28-27 and, hence, the number of the optimized control variables is 10 in this problem. Table I and Table II shows the simulation output of the proposed algorithm.

VII. Conclusion

In this paper, one of the newly developed stochastic algorithm CSDBCA has-been applied to solve optimal reactive power dispatch problem. The problem has been formulated as a constrained optimization problem and the Objective function considered here is to minimize real power loss and to keep the voltages within the limits .The proposed approach is tested on IEEE 30-bus power system. The simulation results indicate the effectiveness and robustness of the proposed algorithm to solve optimal reactive power dispatch problem in test system.

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