ADAPTIVE STRATEGY BASED BACTERIAL FORAGING FOR OPTIMIZATION TO MULTI CONSTRAINED ELD PROBLEM

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Abstract-*In this paper, an adaptive strategy based bacterial foraging optimization (ABFO) technique to solve non-convex economic load dispatch (NCELD) problem of thermal units. The presented methodology can take care of economic dispatch problems involving constraints such as transmission losses, valve point loading, ramp rate limits and prohibited operating zones. The idea of ABFO is motivated by the natural selection which tends to eliminate the animals with poor foraging strategies and favor those having successful foraging strategies. The ABFO method is tested with two power system cases consisting of 6 and 13 thermal units. Comparison with similar approaches including Genetic Algorithm (GA), particle swarm optimization (PSO) and other versions of differential evolution (DE) are given. The presented method outperforms other state-of-the-art algorithms in solving economic load dispatch problems with non convex cost function..*

Keywords-*Bacterial foraging, Economic load Dispatch, Non convex cost function, Valve-point effect.*

I. INTRODUCTION

The objective of the economic load problem (ELD) is to schedule the committed generating unit outputs so as to meet the required load demand at minimum operating cost while satisfying all unit and system equality and inequality constraints [2].

In traditional EDPs, the cost function of each generator is approximately represented by a simple quadratic function and is solved using mathematical programming[1] based on several optimization techniques, such as dynamic programming [3], linear programming[4], homogenous linear programming[5], and nonlinear programming technique[6], [7]. However, real input–output characteristics display higher-order nonlinearities and discontinuities. Power plants usually have multiple valves that are used to control the power output of the unit. When steam admission valves in thermal units are first opened, a sudden increase in losses is observed. This leads to ripples in the cost function, which is known as the valve-point loading. The ELD problem with valve-point effects is represented as a non-smooth optimization [11].

The traditional algorithms can solve the ELD problems effectively only if the incremental fuel-cost curves of the generating units are monotonically increasing piece-wise linear functions. But, a practical ELD must include ramp rate limits, prohibited operating zones, valve-point effects and multi-fuel options. The resultant ELD is a challenging nonconvex optimization problem, which is hard to solve by the traditional methods.

Recently, as an alternative to the conventional mathematical approaches, modern heuristic optimization techniques such as simulated annealing, evolutionary algorithms (EAs) (genetic algorithm, evolutionary programming, and evolution strategies) [8], particle swarm optimization, neural networks, and tabu search[9]-[12] have been given much attention by many researchers due to their ability to find an almost global optimal solution. These methods have drawbacks such as premature convergence and after some generations the population diversity would be greatly reduced.

Inspired from the mechanism of the survival of bacteria, e.g., E. coli, an optimization algorithm, called Bacterial Foraging Algorithm (BFA) [10], has been developed. A modification in traditional BFA is being adapted in this paper which controls the exploration of the whole search space and the exploitation of the promising areas. This strategy is used to analyze the run length parameter of the BFA. This improvement is achieved by enabling the bacterial foraging algorithm to adjust the run-length unit parameter dynamically during algorithm execution in order to balance the exploration/exploitation trade off.

This paper considers two types of non-convex ELD problems, namely, ELD with prohibited operating zones and ramp rate limits (ELDPOZRR), ELD with valve-point loading effects (ELDVPL). The performance of the proposed method in terms of solution quality and computational efficiency has been compared with NPSO-LRS, CDE-QP and other techniques with non convex cost function.

II. PROBLEM FORMULATION

The objective of the economic dispatch is to minimize the total generation cost of a power system over some appropriate period while satisfying various constraints.

The objective function can be formulated as,

$$F_T = \min \sum_{i\in\Psi} F_i(P_i) = \min \sum_{i\in\Psi} (a_i + b_i P_i + c_i P_i^2) \quad (1)$$

Where F_T is the total fuel cost of all generating units, i is the index of dispatchable units; $F_i(P_i)$ is the cost function of the unit *i*, P_i is the power output of the unit *i*, Ψ is the set of all dispatchable units and a_i, b_i, c_i are the fuel cost coefficients of the unit *i*. The general PED problem consists in minimizing F_T subject to following constraints,

Power Balance Constraint:

$$\sum_{i\in\Psi} P_i - P_D - P_L = 0 \quad (2)$$

The transmission Loss P_L may be expressed using B-coefficients as,

$$P_L = \sum_{i\in\Psi}\sum_{j\in\Psi} P_i B_{ij} P_j + \sum_{i\in\Psi} B_{0i} P_i + B_{00} \quad (3)$$

Where P_D the total is load demand; P_L is the power losses and B_{ij} is the power loss coefficient.

Generator Capacity Constraints:

The power generated by each unit lies within their lower limit $P_i^{\min}$ and upper limit $P_i^{\max}$. So that,

$$P_i^{\min} \le P_i \le P_i^{\max} \quad (4)$$

A. ELDVPL

To consider the valve-point effects in the cost model, the rectified sinusoidal function should be incorporated into the quadratic function and the objective function min (F_T) is represented by a more complex formula along with (2), (3) and (4) as,

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i + \left| e_i \sin(f_i (P_i^{\min} - P_i)) \right| \quad (5)$$

Where e_i and f_i are the fuel cost coefficients of generator i reflecting valve point effects.

B.ELDRRPOZ

The operating range of units is restricted by their ramp rate limits during each dispatch period. Consequently the power output of a practical generator cannot be varied instantaneously beyond the range along with (2), (3), (4) and (5) as it is shown in the following expression:

As generation increases,

$$P_i - P_{io} \le UR_i \quad (6)$$

As generation decreases,

$$P_{io} - P_i \le DR_i \quad (7)$$

and

$$\max(P_i^{\min}, P_{io} - DR_i) \le P_i$$
$$P_i \le \min(P_i^{\max}, P_{io} + UR_i) \quad (8)$$

Mathematically, the feasible operating zones of unit can be described as follows:

$$\begin{aligned} &P_{i\min} \le P_i \le P_{i,1}^l \ or \\ &P_{i,j-1}^u \le P_i \le P_{i,j}^l, j = 2,\ldots,n_i \ or \\ &P_{i,n_i}^u \le P_i \le P_{i\max}, \forall i \in \psi \end{aligned} \quad (9)$$

where $P_{i,j}^l$ is the lower bound of the prohibited zone j of unit i, $P_{i,j}^u$ is the upper bound of the prohibited zone j of unit i, n_i be the number of prohibited zones in unit i, $P_{i\min}$ is the minimum generation limit of unit i and $P_{i\max}$ is the maximum generation limit of unit i.

III. BACTERIAL FORAGING: REVIEW

BFA was invented by Kevin M. Passino motivated by the natural selection which tends to eliminate the animals with poor foraging strategies and favor those having successful foraging strategies. The foraging strategy are given as,

A. CHEMOTAXIS

Chemotaxis process is the characteristics of movement of bacteria in search of food and consists of two processes namely swimming and tumbling. A bacterium is said to be 'swimming' if it moves in a predefined direction, and 'tumbling' if moving in an altogether different direction. Suppose $\theta^i(j,k,l)$ represents i^{th} bacterium at j^{th} chemotactic, k^{th} reproductive and l^{th} elimination dispersal step. C (i) is the size of the step taken in the random direction specified by the tumble (run length unit). Then in computational chemotaxis the movement of the bacterium may be represented by

$$\theta^i(j+1,k,l) = \theta^i(j,k,l) + C(i)\frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}} \qquad (10)$$

Where Δ indicates a vector in the random direction whose elements lie in [–1, 1].

B. SWARMING

It is always desired that the bacterium which has searched optimum path of food search should try to attract other bacteria so that they reach the desired that the bacterium which has searched optimum path of food search should try to attract other bacteria so that they reach the desired place more rapidly. Swarming makes the bacteria congregate into groups and hence move a concentric pattern of groups with high bacterial density. Mathematically, swarming can be represented by

$$J_{CC}(\theta, P(j,k,l)) = \sum_{i=1}^{S}[-d_{attract}\exp(-\omega_{attract}\sum_{m=1}^{p}(\theta_m-\theta_m^i)^2)] + \sum_{i=1}^{S}[h_{repellant}\exp(-\omega_{repellant}\sum_{m=1}^{p}(\theta_m-\theta_m^i)^2)] \qquad (11)$$

Where, J_{CC} is the penalty added to the original cost function. J_{CC} is basically the relative distances of each bacterium from the fittest bacterium. S is the number of bacterium, ‘p’ represents number of parameters to be optimized, θ_m is the position of the fittest bacterium, $d_{attract}$, $h_{repellant}$, $\omega_{attract}$ and $\omega_{repellant}$ are different coefficients.

C. REPRODUCTION

In reproduction, population members who have had sufficient nutrients will reproduce and the least healthy bacteria will die. The healthier half of the population replaces with the other half of bacteria which gets eliminated, owing to their poorer foraging abilities. This makes the population of bacteria constant in the evolution process.

D. ELIMINATION AND DISPERSSAL

A sudden unforeseen event may drastically alter the evolution and may cause the elimination and/or dispersion to a new environment. They have the effect of possibly destroying the chemotactic progress, but they also have the effect of assisting in chemotaxis, since dispersal may place bacteria near good food sources. Elimination and dispersal helps in reducing the behavior of stagnation i.e. being trapped in a premature solution point or local optima.

IV. ADAPTIVE STRATEGY

A variation to the traditional BFA is being adapted in this paper which controls the exploration of the whole search space and the exploitation of the promising areas. This strategy is used to analyze the run length parameter of the BFA. This improvement is achieved by enabling the bacterial foraging algorithm to adjust the run-length unit parameter dynamically during algorithm execution in order to balance the exploration/exploitation trade off. Living in groups allows individuals to allocate foraging effort between two different roles, namely, the producer and the scrounger. The “producer” can be used to locate food patches (optimal solution) independently while the “scrounger” can be used to exploit the food (solution) discovered by other group members.

The bacterial producers explore the search space and have the responsibility to find the promising domains (solutions) and to leave the local optimal points that have been visited while the bacterial scroungers focus on the precision of the found solutions. Exploring and exploiting the solutions in each run process may reveals best solutions during iteration. This self tuning capability is one of the unique characters of this algorithm .The main advantage of this method is to find the best solution during the run progress of the algorithm.

A. PSEUDO CODE:

```
If (t mod n = 0) then
        If (f best < Є (t)) then
                C (t + 1) = C (t - n) / α
                Є (t + 1) = Є (t) / β
        ELSE
                C (t + 1) = C (t-n);
                Є (t + 1) = Є (t-n);
        END IF
ELSE
C (t + 1) =C (t)
Є (t + 1) = Є (t);
END IF
```

Where t is the current generation number, f_{best} is the best fitness value among all the bacteria in the colony, $\epsilon\ (t)$ is the required precision in the current generation, and n, α, and β are user-defined constants.

V. SIMULATION RESULT

To validate the effectiveness of the proposed method, two test cases such as 6 unit and 13 unit systems with non convex cost function are taken. The result obtained from proposed method has been compared with CDE-QP [13] for 13 generator system; with MPSO and other techniques for 6 generator system. The software has been written in MATLAB-R2009a language and executed on a 2.0-GHz Pentium Dual personal computer with 1400-MB RAM.

A. TEST CASE I

A system with six generators with ramp rate limit and prohibited operating zone is used here and has a total load of 1263 MW. The input data have been adopted from [13]. Results obtained from DE, ABFO, PSO and new coding-based modified PSO [12] and other methods have been presented here. Table I shows the frequency of convergence in 50 trial runs. It is clear from Table II shows that the proposed method produces a much better solution compared to the MPSO, NPSO-LRS, IDE and other methods.

Table I

FREQUENCY OF CONVERGENCE FOR 50 TRIALS (6-UNIT SYSTEM)

Methods	Range of Generation Cost ($/h)		
	15000-15350	15350-15400	15400-15500
ABFO	32	10	8

Table II

COMPARISON OF COST AMONG DIFFERENT METHODS FOR 50 TRIALS

Method	Generation Cost ($/h)		
	Maximum cost	Minimum cost	Average cost
GA	15,524	15,459	15,469
PSO	15,492	15,450	15,454
NPSO – LRS	15,452	15,450	15,450.5
MPSO	15,447	15,455	15,447
IDE	15,359	15,351	15,356
ABFO	15, 352	15,348	15,350

B. TEST CASE II

This test case is a NSELD of 13 units with valve point loading and has a load demand of 1800MW.The input data are given in [13]. The result obtained from presented method has been compared with CDE-QP [13] and other methods. Table III shows the frequency of convergence in 50 trial runs. It is clear from Table III and IV that the proposed method produces a much better solution with less computation time compared to the ICA-PSO, CDE-QP and other methods.

Table III

FREQUENCY OF CONVERGENCE FOR 50 TRIALS (13-UNIT SYSTEM)

Methods	Range of Generation Cost ($/h)		
	17800-17920	17920-17930	17930-17940
ABFO	28	12	10

Table IV

COMPARISON OF COST AMONG DIFFERENT METHODS FOR 50 TRIALS

Method	Generation Cost ($/h)		
	Maximum cost	Minimum cost	Average cost
PS	18404.04	18048.21	18190.32
STDE	18128.87	17963.89	18046.38
MDE	17969.09	17960.39	17967.19
ICA-PSO	17978.14	17960.37	17967.94
CDE-QP	17944.81	17938.95	17943.133
ABFO	17933.61	17918.73	17921.12

VI. CONCLUSION

This paper presents new combined approaches combining to solve the ELD problems of electric energy with the valve-point effect. The ABFO algorithm has the ability to find the better quality solution and has better convergence characteristics, computational efficiency, and robustness. It is clear from the results obtained by different trials that the proposed ABFO method has good convergence property and can avoid the shortcoming of premature convergence of other optimization techniques to obtain better quality solution. Two case studies have been used and the simulation results indicate that this optimization method is very accurate and converges very rapidly so that it can be used in the practical optimization problems. Due to these properties, the ABFO method in the future can be tried for solution of large unit systems and dynamic ELD problems in the search of better quality results.

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