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Genetic Algorithm for Solving Non-Convex Economic Dispatch Problem

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***Abstract*—**Economic dispatch (ED) is considered to be one of the key functions in electric power system operation. This paper presents a new hybrid approach based genetic algorithm (GA) to economic dispatch problems. GA is most commonly used optimizing algorithm predicated on principal of natural evolution. Utilization of chaotic queue with GA generates several neighborhoods of near optimal solutions to keep solution variation. It could avoid the search process from becoming pre-mature. For the objective of chaotic queue generation, utilization of tent equation as opposed to logistic equation results in improvement of iterative speed. The results of the proposed approach were compared in terms of fuel cost, with existing differential evolution and other methods in literature.

***Keywords*—**Economic Dispatch(ED), Optimization, Fuel Cost, Genetic Algorithm (GA).

I. Introduction

THE economic dispatch (ED) problem is one of the important optimization problems in a power system. Traditionally, in the ED problem, the cost function for each generator has been approximately represented by a single quadratic function [1]-[3].

Generally, the input–output characteristics of modern power generating units are inherently high nonlinear because of valve-point loading effects, multi-fuel effects, etc. [2]-[4]. To take these effects into consideration, the ED problem can be represented as a non-smooth optimization problem. These effects may lead to multiple local minimum points of the cost functions. This makes the problem of finding the global or near global optimum difficult. Over the past few years, a number of approaches have been developed for solving this problem using mathematical programming, i.e. lambda iteration method, gradient method, and linear programming, etc. However, these methods may not be able to provide an optimal solution because they usually get stuck at a local optimum [5].

This paper uses a chaotic queue based genetic algorithm (GA) for solving ED problem. The advantages of GA are simple structure; few control parameters and highly reliability [6]. Chaotic optimization directly utilizes chaotic variables to search the optimal solution. The argotic and regularity properties of chaos make chaotic optimization to obtain global optimal solution more possibly than the methods which have been adapted before [7].

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Here, a non-convex ED problem including various constraints, valve effect and transmission losses, has been efficiently solved using chaotic queue based genetic algorithm.

II. Problem Formulation

The main goal of Economic dispatch problem is to allocate the power to be generated from different units so that cost is minimized. Hence, the problem is to minimize the fuel cost of generators units under power balance constraints and power generating constraints. Mathematically, total fuel cost function is formulated as [8]:

$$C = \sum_i C_i = \sum_i (a_i + b_i P_i + c_i P_i^2) \tag{1}$$

where C is total fuel cost; a_i, b_i, c_i are the cost function coefficients of generator i ; Pi is power of generator of i .To minimize the fuel cost, following conditions must be satisfied:

A. Power Balance Constraint

The equality constraints should be satisfied for power balance. The generated power should be equal to load demand and total loss

$$\sum_i P_i = D + L \tag{2}$$

where, $\sum_i P_i$ is the total power generated by i units.

B. Transmission Loss

Transmission losses are calculated by power flow computation or the B coefficient method. If the B coefficient method is used then the relationship between transmission losses and the generation of units can be expressed as [9]:

$$P_S = P^T B_{GG} P + P^T B_{G0} + B_{00} \tag{3}$$

Here, P is the active power of n dimensions and B_{GG}, B_{G0}, B_{00} are B coefficients.

C. Power Output Constraint

Power generation of each generator should be laid between minimum and maximum value.

$$P_{i,\min} \le P_i \le P_{i,\max} \tag{4}$$

$P_{i,\min}$ and $P_{i,\max}$ are the minimum and maximum power generation of unit i.

D. Valve Point Effect

Mathematically, the valve point effect can be expressed as

$$E_i = \left| g_i \sin(h_i (P_i - P_{i,\min}) \right| \tag{5}$$

where g_i and h_i are constants. Hence, the actual characteristics of the unit's fuel consumption can be expressed as

$$FC = C + E_i \tag{6}$$

where FC is total fuel consumption. Hence, summarizing the above formulations, the economic dispatch problem taking various constraints into account can be expressed mathematically as:

$$Min\ \ FC = \sum_i C_i + E_i = \sum_i (a_i + b_i P_i + c_i P_i^2) + \left| g_i \sin(h_i (P_i - P_{i,\min}) \right| \tag{7}$$

Subject to $\sum_i P_i = D + L$.

III. Genetic Algorithm

Genetic Algorithms (GAs) were first introduced by John Holland in the early 1970s [8]. Nowadays, it has become an important tool in function optimization. Basically, GA is a stochastic method for global optimization based evolution theory. The algorithm of GA is based on evaluation of set of solutions, called population [9]-[11]. The population is initialized by randomly generated individuals. In this paper, initialization of the population has been done using a chaotic series and each individual's suitability is determined by value of objective function, called fitness function. Further, Roulette wheel selection algorithm is used in this work to select the fittest possible individuals in the population.

A. Operators of GA

Then new population is generated by different operations of GA.

1. Crossover

Crossover is primary operator of GA. The function of crossover is to combine the features of two parent's structure and to form offspring's. Crossover operator produce new chromosomes that is different from their parent's characteristics [6]. Two different strings share their good quality to produce better string. If the produced string is bad it will die off in the next generation. Strings are selected randomly but proportional to their fitness values in the mating pool. Different type of crossover methods are used like one point crossover, two point crossover etc [10]. The crossover operation occurs in proportion to its probability. Probability of crossover is high, nearly 0.9.

2. Mutation

Sometimes a desired bit misses in the string at a particular position and this bit may be critical to produce good solutions Crossover may not be able to produce that bit at that particular position. Mutation takes care of this problem [11]. The function of mutation is to take a bit from the string and alter it with some probability. But mutation probability is kept very low since mutation rate is very small in natural evolution.

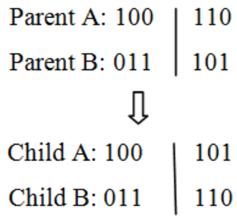

Fig. 1 Diagram of sample crossover

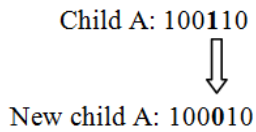

Fig. 2 Binary mutation

IV. Chaotic Queue Based GA

Chaos states disorder and irregularities within the system. The chaotic system has similar characteristics, such as pseudo-random, parameter sensitivity and the initial condition sensitivity [12].The hybrid algorithm used here uses a chaos search with genetic algorithm, thus preventing the pre-mature termination of the search process. The basic steps of the algorithm are as follows:

Step 1: Initialization: Optimal solution from the previous generation is reserved & a population of solutions is generated randomly as [2]. In the initial step, candidates are generated randomly in the feasible space as:

$$Initial\ \ solution = [L_{1,(t)}^{(0)}, L_{2,(t)}^{(0)}, \ldots, L_{i,(t)}^{(0)}] \tag{8}$$

$$PD_{i,(t)} = L_{1,(t)}^{(0)} + L_{2,(t)}^{(0)} + \ldots + L_{i,(t)}^{(0)} \tag{9}$$

$$L_{1,(t)}^{(0)}, L_{2,(t)}^{(0)}, \ldots, L_{i,(t)}^{(0)} \in [PS_{i,\min}, PS_{i,\max}] \tag{10}$$

where, i is the no. of parameters to be optimized. $L_{i,(t)}^{(0)} \in [PS_{i,\min}, PS_{i,\max}]$

$PS_{i,\min}$ is the minimum generation limit for i

$PS_{i,\max}$ is the maximum generation for i.

$PD_{i,(t)}$ is power demand for i

Step 2: Normalization: Transform the $L_{i(t)}$ to the interval of [0,1], i.e.

$$Z_{i(t)}^{(0)} = \frac{L_{i(t)}^{(0)} - PS_{i,\min}}{PS_{i,\max} - PS_{i,\min}} \quad (11)$$

Step 3: Generation of chaotic sequence satisfying the constraints: Tent equation is formula for approximating the evolution of animal population with time. Tent-Map-Based Chaotic sequences are used to generate variable Solution. It can be expressed mathematically as:

$$Z_{i+1} = \mu.(1 - 2|Z_i - 0.5|) \rightarrow where: 0 \le \mu \le 1 \quad (12)$$

It is iterated with respect to sub-generation and it can generate several neighborhoods of near optimal solutions.

Step 4: Perform the reverse transformation to produce the queue: Perform the reverse transformation to produce the non-normalized values chaotic queue [8].

$$G_{i,(t)}^{(0,a)} = PS_{i,\min} + (PS_{i,\max} - PS_{i,\min}) \times Z_{i(t)}^{(0,a)} \quad (13)$$

Step 5: Calculate the fitness value of each candidate: It includes the solution of the previous generation and the solutions generated by chaos search. Penalty factors have to be associated with violated constraints so that the solutions which do not satisfy the constraints will be rejected in the process of selection.

Step 6: To get optimal solution chaotic queue: Bubbling method is used to order fitness function values & local minima of these values is used as the initial population for the genetic algorithm.

Step 7: Evaluation process of GA: Give selected candidates to genetic algorithm as its initial population, and then evaluation process of GA starts by calculation of fitness function of each candidate.

Step 8: If we get optimal solution then go to step10 if not, then selection, crossover, mutation operators have to be used.

Step 9: Stopping criterion: GA search is stopped if the following condition is satisfied. "Change of fitness function of GA is less than a particular value for last few generations".

Step 10: If final stopping criterion is fulfilled (difference between maximum fit solution of current and previous iteration is less than a specified value) then stop the optimization process. if not, then extend the search space near optimal solution by performing normalization of optimal solution and generating chaotic series near optimal solution and going for next iteration from step1.

V. Simulation Results

The hybrid algorithm is used to determine the solution of economic load dispatch problem taking into account the transmission losses and valve point effect constraints. Parameters of problem have been given in Table I and Results have been shown in Table II. A comparison has been made between the results of used algorithm and a number of other search techniques as reported in the literature [3].

Distribute a total load of 500MW in a power system of three units and optimize the units' commitment. The *B* coefficients used for the power system are as follows:

$$B_{GG} = \begin{bmatrix} 0.676\times10^{-3} & 0.953\times10^{-3} & -0.507\times10^{-3} \\ 0.953\times10^{-4} & 0.521\times10^{-3} & 0.901\times10^{-4} \\ -0.507\times10^{-4} & 0.901\times10^{-4} & 0.294\times10^{-3} \end{bmatrix}$$

$$B_{G0} = \begin{bmatrix} -7.66\times10^{-2} \\ -0.342\times10^{-2} \\ 1.89\times10^{-2} \end{bmatrix}$$

$$B_{00} = 4.0357$$

TABLE I
PARAMETERS OF THE UNITS

Units	a_i	b_i	c_i	g_i	h_i	$P_{i,\min}$	$P_{i,\max}$
1.	0.00156	7.92	561	300	0.0315	600	100
2.	0.00194	7.85	310	200	0.0425	400	100
3.	0.00482	7.97	78	150	0.0635	200	50

TABLE II
FEASIBLE SOLUTIONS FOUND BY PROPOSED ALGORITHM

Algorithm	$P_1(MW)$	$P_2(MW)$	$P_3(MW)$	$\sum_i P_i$	Objective function value
MSCOA	299.4737	100.5674	181.1090	500.0007	5120.62
IMSCOA	200.2041	249.7814	50.0145	500.0000	5095.83
GA	**233.6312**	**180.1787**	**90.097**	**503.906**	**5085.81**
Hybrid algorithm used	**235.1817**	**181.1090**	**90.5545**	**506.98**	**5076.82**

In Table II, MSCOA stands for Mutative Scale Chaos Optimization Algorithm and IMSCOA is Improved Mutative Scale Chaos Optimization Algorithm [3]. From the results obtained, it is clear that the used hybrid algorithm gives the best results by minimizing the objective function value.

VI. Conclusion

A chaotic search based genetic algorithm is used for solving a non-convex ED problem including various constraints, valve effect and transmission losses. It has been observed that the used algorithm improves the global convergence. The hybrid algorithm can't fall in to local optimal solution trap as the chaotic queue generates several neighborhoods of near optimal solutions to maintain solution variation. It can prevent the search process from becoming pre-mature. Moreover for the purpose of chaos queue use of tent-map, instead of logistic function has further improved the results.

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