The application of saturation memetic algorithm in economic load dispatch

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Abstract

To solve a nonlinear constrained economic load dispatch (ELD) problem in which the minimized generation cost is taken as objective and valve point effect of thermal units and operation constraints of power grid are taken into account. A saturation memetic algorithm was presented. To avoid the blindness in the search by the proposed using saturation increase efficiency and using adaptive penalty function to deal constraints. Calculation results of 3-machine system verify the effectiveness of the proposed algorithm. Compared with the other existing techniques, the proposed algorithm has been found to perform better. This method seems to be a promising alternative approach for solving the ELD problems in practical power system.

Keywords: memetic algorithm, economic load dispatch, valve point, saturation

1 Introduction

Economic load dispatch (ELD) is an important optimization task in power system operation. The practical ELD problems with valve-point are represented as a non-smooth optimization problem with equality and inequality constraints, and this makes finding the global optimum difficult. Not only traditional mathematical methods are difficult to solve [1,2], but many intelligent optimization algorithms have their own limitations. Such as chaos optimization algorithm (COA) [3,4], the genetic algorithm (GA) [5] artificial immune algorithm (IA) [6], (PSO) [7], the free search algorithm [8], and the differential bee colony algorithm [9].

In this paper, an alternative approach is proposed to the ELD problem using a modified MA. In general, MA is a synergy of evolution and individual learning, which improving the capability of evolutionary algorithms like GA for finding optimal solutions in function optimization problems with accuracy and convergence speed. Genetic Algorithm due to its good exploration capability is used as main algorithm and simulated annealing are used as local searches. And use the variable scales penalty function to improve the performance of the algorithm.

2 Economic load dispatch mathematical model

The ELD problem is to find the optimal combination of power generation that minimizes the total cost while satisfying the total demand. The most simplified cost function of each generator can be represented quadratic function as given in Equation (1) whose solution can be obtained by the conventional mathematical methods 10]:

$$obj = \min \sum_{i=1}^{n} F_i \ , \quad (1)$$

$$F_i = a_i \cdot P_i^2 + b_i \cdot P_i + c_i \ , \quad (2)$$

where *obj* is total generation cost; *a*, *b*, *c* is cost coefficients of generator; *n* is number of generators in the system; P_i is output generation for unit *i*.

While minimizing the total generation cost, the total generation should be equal to the total system demand plus the transmission loss. This gives the equality constraint:

a) power balance constraints:

$$\sum_{i=1}^{n} P_i = P_{total} + P_s \ , \quad (3)$$

where P_{total} is the total system demand and P_s is the transmission loss.

b) the generation output of each unit should be between its minimum and maximum limits.

That is, the following inequality constraint for each generator should be satisfied generating capacity constraints:

$$P_{i,\min} \le P_i \le P_{i,\max} \ , \quad (4)$$

where $P_{i,min}$, $P_{i,max}$ is the minimum, maximum output of generator.

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In the actual operation, the turbine intake valve suddenly turned caramelized phenomenon consumption characteristics of the unit will generate valve point effect. To model the effects of valve-points, a recurring rectified sinusoid contribution was added to the input-output Equation [11,12]. The result is:

$$E_i = | e_i \sin(f_i (P_i - P_{i,\min})) | . \quad (5)$$

The fuel-cost function considering valve-point loadings of the generating units is given as:

$$F_i = a_i \cdot P_i^2 + b_i \cdot P_i + c_i + E_i , \quad (6)$$

Transmission losses are a function of the unit generations and are based on the system topology. Solving the ELD equations for a specified system load requires an iterative approach since all unit generation allocations are embedded in the equation for each unit.

In practice, the loss penalty factors can be calculated directly using the *B* matrix loss formula. *B* coefficients are used for this example. The relations between transmission losses and Generator active power:

$$P_s = P^T BP + P^T B_0 + B_{00} , \quad (7)$$

where *P* is the N-dimensional generator active power vector; *B* is loss coefficient; the B_0 dimensional symmetric matrix for N-dimensional vector, B_{00} is constant.

3 Memetic-based ELD

Memetic algorithm [15, 16] is a hybrid algorithm population-based global search and individual-based local search. Algorithm is a framework, using different search strategies can constitute different algorithms. For solving specific problems, use genetic algorithms as the global search method, use simulated annealing algorithm as the local search strategy.

The unique aspect of MA is that the chromosomes are facilitated to gain some experience with a local search process in between regular evolutionary process. Similar to the GA, MA also generates an initial population randomly and searches in the fitness landscape. Subsequently, the local search process leads solutions in the direction of local optima. These improvements are going to accumulate over all generations, resulting in a larger improvement in total performance.

In order to avoid the blindness of search, introduced the concept of saturation, do a selective mutation, crossover and selection. Saturation is a metric which set on the solution space. For minimum optimizing, the more smaller value and saturation, the more close to the optimal solution. On the contrary, far from the optimal solution. In searching process, through saturation adjusts populations. High saturation means small choice probability, so as to ensure the diversity of population. Always searching for the optimal solution from the global, ensures that focus on the local optimal solution, while maintaining the global optimal solution.

$$s(x) = \frac{1}{1 + q(x)} , \quad (8)$$

$$q(x) = \frac{f - f_{\min}}{f_{\max} - f_{\min}} , \quad (9)$$

where *s(x)* is saturation F_{max}, F_{min} is maximum and minium respectively, F_i is the objective *q(x)* is intermediate amount.

For every violated constraint a penalty term proportional to the amount of the constraint violation is added to the fitness function. The penalty factor is chosen sufficiently large to discourage the selection of solutions with violated constraints.

The penalty function *PF* is:

$$PF = MAX (0, | P_{Total} - \sum_{i=1}^{n} P_i | \times \lambda(t)) , \quad (10)$$

where *λ(t)* is penalty factor. In this paper using adaptive penalty function for constraints, according to the optimal solution meet the degree of constraints adjust the penalty function. Adaptive penalty function is constructed as follows:

$$\lambda(t+1) = \begin{cases} \lambda(t) / (2\beta_1 / (\beta_1 + \beta_2)), & case1 \\ \lambda(t) / (2\beta_2 / (\beta_1 + \beta_2)), & case2 \\ \lambda(t), & case3 \end{cases} , \quad (11)$$

where β_1 is a random number between (1,2), β_2 is a random number between (0,1); *case*1 reduce the penalty factor to increase Infeasible solution; *case*2 increase the penalty factor to increase the feasible solution; *case*3 the penalty factor remain unchanged. Fitness function becomes:

$$\min F = \min(\sum_{i=1}^{n} F_i + PF) , \quad (12)$$

The hyper-heuristic search mechanism in the memetic algorithms offers the speed and quality of convergence. This paper uses Genetic Algorithm as main algorithm and the SA are used as the local search, where both the local search algorithms are heuristic algorithms. The algorithm steps are as follows:

Step1: encoding.

For the application of MA to the ELD problem, a float encoding was chosen to encode a solution. Individual's position at iteration 0 can be represented as real power outputs. Initialization of a group at random while satisfying constraints.

Step2: fitness functions.

Evaluation of the chromosome string is calculating the objective function for the problem.

Step3: genetic operators.

a) *select*. This operator use roulette, individuals which high fitness value have a greater chance to be selected to the next round of operations.

b) *crossover*. This operator is applied with a certain probability. When applied, the parent genotypes are combined (exchange bits) to form two new genotypes that inherit solution characteristics from both parents. In the opposite case the off-springs are identical replications of their parents.

$$\begin{cases} P_1^{new} = \omega_1 P_1 + (1-\omega_1)\cdot P_2 \\ P_2^{new} = \omega_2 P_2 + (1-\omega_2)\cdot P_1 \end{cases}. \quad (13)$$

c) *mutation*. With a small probability, randomly chosen bits of the offspring genotypes change.

$$P = P + (b_{sub} - P)\cdot\left[r\cdot(1-t)\right]^2, \quad (14)$$

Variable step size crossover and mutation probability

$$\begin{cases} P_c^{\,j} = P_c^{\,j-1} - (P_c^{\,o} - 0.6)/\max iter \\ P_m^{\,j} = P_m^{\,j-1} + (0.1 - P_m^{\,0})/\max iter \end{cases}, \quad (15)$$

d) *elitism*. The best solution of every generation is copied to the next so that the possibility of its destruction through a genetic operator is eliminated.

If any element of an individual violates its inequality constraint then the position of the individual is fixed to its maximum/ minimum operating point.

Step4: local search strategy

Local search strategy based on simulated annealing.

Step5: stopping criteria:

The MA is terminated if the iteration approaches to the predefined maximum iteration.

4 Examples and results

Proposed MA algorithm has been applied to ELD problems in three different test cases which the objective functions can be either smooth or non-smooth. The results obtained from the MA are compared with those of other methods: chaos optimization algorithm (COA) [3], the genetic algorithm (GA) [5], artificial immune algorithm (IA) [6], (PSO) [7], the free search algorithm [8].

Three separate runs were made to demonstrate the ability of the program using different initial random seed numbers. The cases considered were:

1) Input-output curves neglecting Valve-point effect and transmission losses.

2) Input-output curves considering Valve-point effect neglecting transmission losses.

3) Input-output curves considering Valve-point effect and transmission losses.

TABLE 1 Units data for test case

No.	*a*	*b*	*c*	*e*	*F*	P_{min}	P_{max}
1	0.00156	7.92	561	300	0.0315	100	600
2	0.00194	7.85	310	200	0.0420	100	400
3	0.00482	7.97	78	150	0.0630	50	200

The transmission loss coefficients (*B* coefficients) used for the power system follow:

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

$$B_0 = \left[-7.66\times10^{-2} \quad -0.342\times10^{-2} \quad 1.89\times10^{-2}\right]^T,$$

$$B_{00} = 4.0357.$$

To compare the results between MA and various methods in a statistical manner, every case was calculated 50 times. All the programs were run on a 1.8 GHz, with 2GB RAM PC. The crossover and mutation rates for binary GA were chosen as 60% and 0.05%, respectively, following common literature. The optimal result is provided.

The input data of the system are given in [3], where the system demand considered is 500MW. Table 2 shows the comparison of the results from MA, COA [3], GA [5], IA [6] and IFS [8]; Table 3 shows the results of considering valve-point effect neglecting transmission losses; Table 4 shows the results of considering valve-point effect and transmission losses.

TABLE 2 Comparison among different methods neglecting valve-point effects (demand= 500 [MW])

Method	P_1	P_2	P_3	$\sum P$	Cost
GA	214.60	227.20	58.20	500	5084.31
IA	237.73	187.58	74.69	500	5083.04
COA	228.71	202.29	69.01	500	5082.33
IFS	228.93	202.15	68.92	500	5082.22
MA	229.00	202.13	68.87	500	5082.22

TABLE 3 The results of considering valve-point effect neglecting transmission losses (demand= 500 [MW])

Method	P_1	P_2	P_3	$\sum P$	Cost
GA	299.22	101.34	99.30	499.86	5131.74
IA	199.76	250.24	50.00	500.00	5121.47
COA	299.41	100.70	99.90	500.01	5095.47
IFS	199.74	250.25	50.01	500.00	5095.40
MA	199.73	250.27	50.00	500.00	5095.38

TABLE 4 The results of considering valve-point effect and transmission losses (demand= 500 [MW])

Method	P_1	P_2	P_3	$\sum P$	Ps	Cost
GA	295.09	173.43	101.71	570.23	70.23	5772.27
IA	299.41	172.00	98.84	570.30	70.24	5735.93
COA	299.46	171.95	98.82	571.23	71.23	5735.76
IFS	299.45	171.91	98.85	571.21	71.21	5735.74
CPSO	299.47	171.88	99.87	571.22	71.22	5735.89
MA	299.47	171.91	99.86	571.22	71.22	5735.72

As seen in Tables 2, 3 and 4, the MA has provided the global solution with a very high probability, exactly satisfying the equality and inequality constraints.

Whether to consider the effect of transmission losses and valve point, the result is difficult, in the actual should consider the valve point effect and transmission loss. The MA has provided the global solution satisfying the constraints with a very high probability for the ELD problems with smooth cost functions. For the ELD problems with non-smooth cost functions due to the valve-point effects, the MA has also provided the global solution with a high probability for 3-generator system which are better than other methods. The MA has shown superiority to the conventional numerical method.

5 Illustrations

This improved memetic algorithm has been successfully implemented to solve ELD problems with the generator constraints. Many nonlinear characteristics of the generator have been considered. The proposed MA method performs good convergence property and can avoid the premature convergence as compared to other numerical method and artificial intelligence algorithm to obtain better quality solution. This promises a great potential of the proposed method for real-time economic load dispatch.

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References

[1] Peng L 2008 *Southern Power System Technology* **2**(5) 43-6
[2] Shushan L, Gang L, Chuntian,C 2011 *Proceedings of the Csee* **31**(7) 41-7
[3] We T, Dianpu T 2000 *Proceedings of the Csee* **20**(10) 36-40
[4] Fang Shuangxin W, Hengjun H 2005 *Proceedings of the Csee* **25**(24) 90-5
[5] Walters D C, Sheble G B 1993 *IEEE Transactions on Power Systems* **18**(3) 1325-32
[6] Jiaju Wenchuan M, Xiaomeng Q B 2006 *Power System Technology* **30**(23) 41-4
[7] Wenchuan M, Jiaju Q 2007 *Proceedings of the Chinese Society of Universities for Electric Power System and Automation* **19**(2) 114-9
[8] Shu X, Jianhua Z, Wei Q 2010 *Power System and Clean Energy* **26**(3) 37-40
[9] Liwei X, Mai X, Baoguo X 2011 *Control and Decision* **26**(12) 1813-7
[10] Jianguo W, Rudong M 2012 T*hermal Power Generation* **41**(12) 70-3
[11] Xiaohui Y, Yanbin Y, Cheng W 2005 *Transactions Of China Electro Technical Society* **20**(6) 92-6
[12] Zhiqiang Y, Zhijian H, Chuanwen J 2002 *Proceedings Power Con, International Conference,IEEE, Kunming, China* 2313-7
[13] Yalin M, Guozhong Z, Bin Z 2005 *Proceedings of the CSEE* **25**(3) 65-70
[14] Yunhe H, Xingeng X, Yaowu W 2003 *Proceedings of the CSEE* **23**(3) 59-64
[15] Hongfeng W, Dingwei W, Min,H 2010 *Control Theory & Applications* **27**(8) 1060-8
[16] Zhihao W, Xiangwei Z, Hongwei M 2013 *Journal of Chinese Computer Systems* **34**(3) 617-20
[17] Zhuo L, Chun H, Zhenhua G 2011 *Power System Technology* **35**(2) 100-4
[18] Weiping D, Jiandong, W Weihua 2011 *Journal of Shandong University(Natural Science)* **46**(5) 97-102

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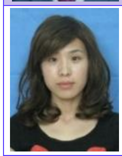

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