Search space reduction in optimal thermal dispatch and hydrothermal scheduling using heuristic search methods

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Abstract : This paper presents an accelerated search technique applied to optimal thermal dispatch and hydrothermal scheduling. The normal Genetic Algorithm search process, searches for maximum/minimum in the defined search space by continuously modifying the population using genetic operators. In this paper, along with the above, the search space is reduced in each cycle such that optimal solution is obtained in minimum number of trials. The technique can be easily applied to Particle Swarm Optimization as well. A normal search can be highly time consuming, but this technique reduces the search time drastically.

Index Terms — Genetic algorithm, search space reduction, optimal thermal dispatch, hydrothermal scheduling, heuristic search, particle swarm optimization

1 INTRODUCTION

In a simple GA search, first a population of 'N' random binary strings is formed to perform the search process. Fitness of each string is calculated and mating pool is formed by rejecting a few less fit individuals and making multiple copies of more fit individuals. Crossover and mutation are performed expecting higher fitness levels for individuals. Further, fitness of all the individuals is found again and the cycle is continued till the fit individual is selected.

Let there be a population of 'N' strings and x_{opt} be the optimum solution we are searching for. Length of the string can be suitably selected depending on the accuracy requirement. These strings are converted to their equivalent decimal values and then mapped between x_{max} and x_{min} i.e we are searching for x_{opt} between x_{max} and x_{min}. Fitness/error is calculated for all the 'N' values of x. Error will be of opposite sign for values of x above and below x_{opt} . Select the strings corresponding minimum positive error and minimum negative error. Out of the two values of x obtained as above, lower value is assigned to x_{min} and higher value is assigned to x_{max}. In case all the binary strings are mapped above x_{opt} or below x_{opt} , all the error values will be of the same sign. In such a case, another set of 'N' strings may be generated or may just proceed to reproduction, crossover and mutation. If new values of x_{max} and x_{min} are obtained, in the next cycle we will be searching for x_{opt} between new x_{max} and x_{min} which are xmax1 and $x_{min}1$ i.e in the next cycle the 'N' strings of the population will be mapped between xmax1 and xmin1 where $x_{max1}<x_{max}$ and $x_{min1} > x_{min}$, and hence the reduction in search space. The problem of 'all error values of the same sign' can also occur, if x_{maxn}/x_{minn} at some stage of iteration, becomes too close to x_{opt} such that no number is mapped into the narrow range between x_{maxn}/x_{minn} and x_{opt} . In this case x_{maxn}/x_{minn} can be reset to their corresponding initial values.

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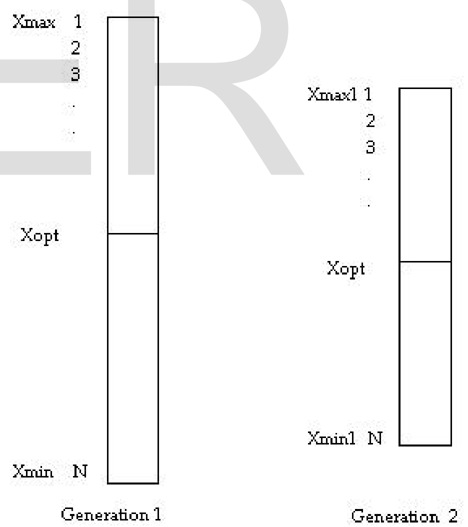

Fig1. Search space reduction

Hence this search method when applied to Thermal dispatch/ Hydrothermal scheduling simplifies the problem and accelerates the solution to a considerable extend.

2 PROBLEM FORMULATION

2.1 Notations

n - Number of thermal units
h- Number of hydro units
a_{1i} , b_{1i}, c_{1i} - cost coefficients of i_{th} unit
a_{2i} , b_{2i}, c_{2i} - NO_x emission coefficients of i_{th} unit
a_{3i} , b_{3i}, c_{3i} - SO_2 emission coefficients of i_{th} unit
a_{4i} , b_{4i}, c_{4i} - CO_2 emission coefficients of i_{th} unit
w- Weighing factor

P_D - Power Demand

P_L - Power Loss

P_i - Power output of i_{th} unit

P_{imax}, P_{imin} – Maximum/minimum power output of i_{th} unit

I – total number of sub-intervals

d_{jk} - Discharge of j_{th} hydro unit during k_{th} sub-interval (Duration of a sub-interval is taken as 1 hour in this study)

Va_i - Allocated volume of water for i_{th} hydro unit

λ, μ - Lagrange multipliers

λ_k –Lagrange multiplier for sub-interval k

α_j, β_j, γ_j - discharge coefficients of j_{th} hydro unit

ob – Number of objectives (in this study 4 objectives are considered)

2.2 Economic thermal dispatch

To solve the multi objective thermal power dispatch problem by weighing method, the objective function is

$$\text{Minimise } \sum_{m=1}^{ob} w_m F_m \tag{1}$$

$$\text{where } F_m = \sum_{k=1}^{I}\sum_{i=1}^{n}(a_{mi} P_{ik}^2 + b_{mi} P_{ik} + c_{mi})$$

Subject to the constraints

$$P_D + P_L - \sum_{i=1}^{n} P_i = 0$$

$$P_{i\,\min} \le P_i \le P_{i\,\max} \quad i=1,2,\ldots,n$$

$$\sum_{m=1}^{ob} w_m = 1 \quad (w_m \text{ is zero/+ive})$$

The objective function augmented by constraints is

$$L = \sum_{m=1}^{ob} w_m F_m + \lambda(P_D + P_L - \sum_{i=1}^{n} P_i \tag{2}$$

Partially differentiating L with respect to P_i and equating to zero yields the optimality conditions.

$$\partial P_i = \sum_{m=1}^{ob} w_m (\partial F_m / \partial P_i) + \lambda((\partial P_L / \partial P_i) - 1) = 0 \tag{3}$$

F_1, the cost function, is expressed in currency units/h and F_2,F_3,F_4 , the NO_x, SO_2 and CO_2 emission functions, are expressed in kg/h

Simplifying and rearranging terms

$$P_i = (\lambda - \sum_{m=1}^{ob} w_m b_{mi} - \lambda \sum_{j=1, j\ne i}^{n} 2B_{ij} P_j / \left(\sum_{m=1}^{ob} 2w_m a_{mi} + 2\lambda B_{ii})\right) \quad i=1,2,\ldots\ldots n \tag{4}$$

Losses can be computed as

$$L = \sum_{i=1}^{n}\sum_{j=1}^{n} P_i B_{ij} P_j \tag{5}$$

2.3 Solution Approach

First a weight combination is chosen. Initial value of λ can be computed by assuming losses=0 and hence total gen. equal to demand. Substituting the above conditions in (4) and rearranging.

$$\lambda = (P_D + \sum_{i=1}^{n}(t_2 / t_1)) / \sum_{i=1}^{n}(1/t_1) \tag{6}$$

$$\text{where } t_1 = 2w_1 a_{1i} + 2w_2 a_{2i} + \ldots\ldots\ldots\ldots + 2w_{ob} a_{obi}$$

$$t_2 = w_1 b_{1i} + w_2 b_{2i} + \ldots\ldots\ldots\ldots + w_{ob} b_{obi}$$

$$\lambda = (P_D + \sum_{i=1}^{n}(t_2 / t_1)) / \sum_{i=1}^{n}(1/t_1)$$

$$\text{where } t_1 = 2w_1 a_{1i} + 2w_2 a_{2i} + \ldots\ldots\ldots\ldots + 2w_{ob} a_{obi}$$

$$t_2 = w_1 b_{1i} + w_2 b_{2i} + \ldots\ldots\ldots\ldots + w_{ob} b_{obi}$$

Initial set of powers are given by

$$P_i = (\lambda - \sum_{m=1}^{ob} w_m b_{mi}) / \sum_{m=1}^{ob} 2 w_m a_{mi} \quad i=1,2,\ldots\ldots, n \tag{7}$$

Now the search space can be defined by fixing maximum and minimum values for λ. As variation in λ is within a small range the maximum and minimum values of λ can be fixed as λ_{max} = 1.5 λ and λ_{min} = 0.5 λ. The final value of λ may be anywhere near the λ obtained from (6). By fixing λ_{max} and λ_{min} as 1.5 times and 0.5 times λ respectively, a wide margin will be available above and below λ_{opt} , which makes the search process easier. Hence in the first trial, λ_{opt} will be searched in between the above maximum and mini-mum values. The 'N' randomly generated binary strings of length 'l' each are first converted to their equivalent decimal values and then mapped to a number between λ_{max} and λ_{min} . For each value of λ, P_i (i=1,2,….,n) and P_L are calculated using equations (4) and (5). Error in each case is found by

$$er = P_D + P_L - \sum_{i=1}^{n} P_i \tag{8}$$

which will be of opposite sign for values of λ above and below λ_{opt} . From the 'N' error values, find the minimum positive and minimum negative values of error. Locate the corresponding values of λ and the higher value is assigned to λ_{max} and lower value to λ_{min} . The new values of λ_{max} and λ_{min} are closer to λ_{opt}. Reproduction, crossover and mutation are performed to get the new generation. The decimal values of strings in the new generation are mapped between new values of λ_{max} and λ_{min}.

If error reduces within tolerance then optimal solution is reached. This may happen even with the first set of trial values. Each solution thus obtained can be called a non-inferior solution. The cycle is repeated for various weight combinations and F_1, F_2, F_3 and F_4 are evaluated in each case. From the table thus obtained, fuzzy membership value of each function for each weight combination is found. The

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best weight combination can be determined by fuzzy cardinal priority ranking.

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2.4 Hydrothermal Scheduling

The objective function is defined as

$$\text{Minimise } \sum_{m=1}^{ob} w_m F_m \tag{9}$$

$$\text{where } F_m=\sum_{k=1}^{I}\sum_{i=1}^{n}(a_{mi} P_{ik}^2 + b_{mi} P_{ik} + c_{mi})$$

Subject to the constraints

1. $P_{Dk} + P_{Lk} - \sum_{i=1}^{n+h} P_{ik} = 0$
2. $P_{ik\,\min} \le P_{ik} \le P_{ik\,\max}$ i=1,2,.....,n+h
3. $\sum_{m=1}^{ob} w_m = 1$ (w_m is zero/+ive)
4. $\sum_{k=1}^{I} d_{jk} = Va_j$, j=1,2,....,h

where d_{jk} is the water discharge of j_{th} hydro unit in k_{th} sub interval and expressed as a quadratic in terms of discharge coefficients

$$d_{jk} = \alpha_j P_{jk}^2 + \beta_j P_{jk} + \gamma_j \quad \mathrm{m}^3/h$$

The objective function augmented by constraints is

$$L = \sum_{m=1}^{ob} w_m F_m + \sum_{k=1}^{I} \lambda_k (P_{Dk} + P_{Lk} - \sum_{i=1}^{n+h} P_{ik})$$
$$+ \sum_{k=1}^{I}\sum_{j=1}^{h} \mu_j d_{jk} - \sum_{j=1}^{h} \mu_j Va_j \tag{10}$$

Differentiating with respect to thermal and hydro powers and equating to zero, results in the following equations

$$P_{ik}=\left(\lambda_k - \sum_{m=1}^{ob} w_m b_{mi} - \lambda_k \sum_{j=1, j\ne i}^{n+h} 2B_{ij} P_{jk}\right)$$
$$/(\sum_{m=1}^{ob} 2w_m a_{mi} + 2\lambda_k B_{ii}) \qquad i=1,2,...n \tag{11}$$

$$P_{ik}=(\lambda_k - \mu_i \beta_i - \lambda_k \sum_{j=1, j\ne i}^{n+h} 2B_{ij} P_{jk})$$
$$/(2\mu_i \alpha_i + 2\lambda_k B_{ii}) \quad i=n+1,n+2,...n+h \tag{12}$$

(11) and (12) are equations for thermal and hydro powers respectively.

Losses can be computed for each sub-interval as

$$P_{Lk}=\sum_{i=1}^{n+h}\sum_{j=1}^{n+h} P_{ik} B_{ij} P_{jk} \text{ MW} \tag{13}$$

2.5 Solution Approach

First a weight combination is chosen. Initial values of λ_k for all sub-intervals (k=1,2,….I) and μ_j (j=1,2…,h) can be computed by assuming losses equal to zero. Thermal and hydro powers are determined for all sub-intervals. Water consumption V_j (j=1,2,…h) are computed at the end of scheduling period and μ_j (j=1,2,…h) are modified as

$$\mu_j \leftarrow \mu_j + \Delta\mu_j \tag{14}$$
$$\text{where } \Delta\mu_j = \alpha\ \mu_j (V_j - Va_j)/Va_j$$

A suitable value of α, less than 1, may be chosen.
Final solution is reached, if constraint 4 of (9) is satisfied.

The above procedure is repeated for various weight combinations and the best solution is found as in the case of thermal dispatch.

3 TESTS AND RESULTS

3.1 Thermal dispatch

To test the efficiency of search space reduction technique, a test system with 6 thermal generators is tested for 161 combinations of weights ranging from 0 – 1.0, is tried to get values of λ in different ranges, and the best solution is found in each case.

The genetic algorithm used a population size 30, a string length 32, crossover probability 1 and a mutation probability 0.04. The program used Roulette wheel selection and a single site crossover. In a set of trials carried out, in the first case , for 113 weight combinations, solution was obtained in 5 or less number of attempts , for 37 weight combinations, solution was obtained in 6-10 attempts and for 11 weight combinations number of attempts was more than 10. Results for 4 trials are tabulated in Table 1.

The results of another test with the same system and power demand varying from 50% to 150% in equal increments of 30 MW is given in Table 2.

Table 1

TABLE RELATING NUMBER OF WEIGHT COMBINATIONS AND RANGE OF ATTEMPTS IN WHICH SOLUTION CONVERGED

Tri-al	Power Dema-nd(MW)	Atte-mpts 1-5	Atte-mpts 6-10	Atte-mpts 11-50	Attem-pts>50	Total
1	1800	113	37	11	Nil	161
2	1800	123	22	16	Nil	161
3	1800	108	33	20	Nil	161
4	1800	105	37	19	Nil	161

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Table 2
TABLE RELATING NUMBER OF WEIGHT COMBINATIONS AND RANGE OF ATTEMPTS IN WHICH SOLUTION CONVERGED WITH POWER DEMAND VARYING

Tri-al	Power Dema-nd(MW)	Atte-mpts 1-5	Atte-mpts 6-10	Atte-mpts 11-50	Atte-mpts> 50	Total
1	900	118	28	15	Nil	161
2	1200	116	29	16	Nil	161
3	1500	106	38	17	Nil	161
4	1800	105	38	18	Nil	161
5	2100	99	45	17	Nil	161
6	2400	105	43	13	Nil	161
7	2700	98	40	23	Nil	161

3.2 Hydrothermal scheduling

A test system with 2 thermal and 2 hydro units was tested for 11 weight combinations. Two objectives, cost and NO_x emission, were considered in the study. Scheduling period was 72 hours. For each weight combination, the total cost and NO_x emission were found for the entire scheduling period. Out of 11 weight combinations tested, membership values of cost and NOx emission were found for each weight combination, and the solution having highest cardinal priority ranking is selected. For 75% of sub-intervals, solution obtained in less than 10 attempts in various iteration cycles.

4. CONCLUSION

In a normal search process using GA, the number of attempts for obtaining solution for a particular problem varies significantly during repeated execution. It cannot be guaranteed that the local minimum [5] can be obtained within a definite number of attempts. But, by incorporating search space reduction technique, it can be guaranteed that at least in 60% of the cases the number of attempts will be within 5 and in 75 % of the cases the number of attempts will be within 10.

In thermal dispatch or hydrothermal scheduling the complexity in programming is totally eliminated as the co-ordination equations are solved directly in GA search method. The added advantage is the considerable reduction in number of attempts for obtaining a solution. Major disadvantage noted is the increase in time per iteration comparing with traditional methods. But this can be offset with the advantages of the method.

REFERENCES

[1] A George, DP Kothari, "A simple algorithm for multi-objective, short-term hydrothermal scheduling", Australian Journal of Electrical & Electronics Engineering, Vol 9 No 4, 2012.

[2] G A Bakare, U O Aliyu, G K Venayagamoorthy, Y K Shu'aibu, "*Genetic Algorithm based economic dispatch with application to coordination of Nigerian thermal power plants*", International Journal of Pure and Applied Mathematics, Volume 114, No.8, 2017.

[3] Julius Odili, Mohd Nizam Mohmad Kahar, A Noraziah, Syafiq F Kamarulzaman, "*A comparative evaluation of swarm intelligence techniques for solving combinatorial optimization problems*", International Journal of Advanced Robotic Systems, vol. 14, 3, First Published June 13, 2017.

[4] Vijay Kumar, Jagdev Singh, Yaduvir Singh, Sanjay Sood, " *Optimal Economic Dispatch using genetic algorithm*", World Academy of Science, Engineering and Technology International Journal of Electrical and Computer Engineering Vol:9, No:4, 2015.

[5] Aziz Ahmad, "*Economic dispatch using genetic algorithm*", International Journal of Advanced Research in Computer science, Volume 2, No.3, May-June 2011.

[6] Jarnail S Dhillon, J.S Dhillon and D.P Kothari, "Multi-Objective Short- Term Hydrothermal Scheduling Based on Heuristic Search Technique", *Asian Journal of Information Technology*, 6(4):447- 454, 2007.

[7] D.P Kothari and J.S Dhillon, *Power system Optimization*, New Delhi, Prentice-Hall of India, 2004.

[8] Singeresu S. Rao, *Engineering Optimization*, New Delhi, New Age International (P) Limited, 2003.

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