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MHDE Algorithm for Hydrothermal Scheduling

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ABSTRACT: This paper presents a modified hybrid differential evolution (MHDE) algorithm, for short-term scheduling of fixed head hydrothermal systems. Hydrothermal scheduling involves the optimization of a nonlinear objective function with a set of operational and physical constraints. The performance of the proposed approach is validated by illustration with two test systems. From the numerical results it is found that the MHDE based approach is able to provide better solution at a relatively lesser computational effort.

KEYWORDS: Differential evolution; evolutionary algorithms; genetic algorithm; hydrothermal scheduling;

1. INTRODUCTION

Hydrothermal scheduling is an important aspect for the optimal utilization of the available hydro resources in order to achieve maximum economy and has attracted increasing attention of researchers in recent years. Several optimization techniques have been developed for solving the hydrothermal scheduling problems [1-3]. In hydrothermal scheduling, complicated constraints such as limited water discharge rate, hydraulic continuity and final reservoir volume restrictions are present. For hydrothermal scheduling dynamic programming is widely used as it provides accurate modeling of the majority of hydroelectric plant characteristics . The major disadvantage of the DP method is the growth of computational and dimensional requirements with increasing system size and planning horizon [4-5]. Lagrangian relaxation methods have also been prevalently applied, due to its flexibility in dealing with different types of constraints . The generation and load balance constraints are the coupling constraints that are relaxed using multipliers onto the cost to form lagrangian function. The conventional optimization techniques have been found to be inefficient in handling the hydrothermal scheduling problems. Recently evolutionary algorithms have been employed for the hydrothermal scheduling problems. They do not place any restrictions on the shape of the cost curves and other non-linearities in model representation. Genetic algorithm [5-8] and Evolutionary programming have been employed successfully for the scheduling of hydrothermal systems. Differential evolution (DE) is a numerical optimization approach that is simple, robust and significantly faster [9]. Modified differential evolution has been successfully employed for hydrothermal scheduling problems. In DE, a large population has to be employed to avoid premature convergence. Hybrid Differential Evolution (HDE) has overcome the usage of large population, which results in lesser computation time [10,11]. The modifications are incorporated in the HDE algorithm as the DE algorithm exhibits difficulties in handling the equality constraints, especially the reservoir end-volume constraints. The proposed algorithm has been implemented using VC++ on PIV-2.6 GHz 512MB RAM PC and the algorithm is illustrated on standard test systems.

II. HYDROTHERMAL SCHEDULING PROBLEM

The objective of the hydrothermal scheduling is to provide optimal utilization of hydro resources in order to minimize the thermal cost over a scheduling period T, as expressed by

Minimize $$F = \sum^{T}\sum^{N_s} f_i\,(P_s\,(i, t)) \qquad (1)$$

$t=1 \quad i=1$

where N_s is number of thermal units and P_s represents thermal generation in MW. It is subjected to a set of linear, non-linear and dynamic constraints. The load balance constraint is expressed as

$$\sum_{i=1}^{N_s} P_s(i,t) + \sum_{i=1}^{N_h} P_h(i,t) = P_D(t) + P_L(t) \qquad (2)$$

where N_h is the number of hydro units, P_h is the generation of hydro units in MW and P_D is the power demand in MW. P_L is the total transmission loss in MW, as given by

$$P_L = \sum_{i=1}^{(N_s+N_h)} \sum_{j=1}^{(N_s+N_h)} P_i B_{ij} P_j \qquad (3)$$

where B_{ij} represents the loss formula coefficients. The hydro generator power output is expressed as a function of water discharge rate, Q_h in m^3 and storage volume, V_h in m^3.

$$P_h(i,t) = f(Q_h(i,t), V_h(i,t)) \qquad (4)$$

The generator capacity constraints are expressed as

$$P_s(i)^{\min} \le P_s(i,t) \le P_s(i)^{\max} \text{ and } P_h(i)^{\min} \le P_h(i,t) \le P_h(i)^{\max} \qquad (5)$$

The continuity equation for the hydro reservoirs neglecting spillage and physical limitations on reservoir storage volumes and water discharge rate limits are given by is given by

$$V_h(i,t+1) = V_h(i,t) + I_h(i,t) - Q_h(i,t) \qquad (6)$$

$$V_h(i,t)^{min} \le V_h(i,t) \le V_h(i,t)^{max} \text{ and } Q_h(i,t)^{min} \le Q_h(i,t) \le Q_h(i,t)^{max} \qquad (7)$$

$$V_h(i,t)\Big|_{t=0} = V_h(i)^{begin} \text{ and } V_h(i,t)\Big|_{t=T} = V_h(i)^{end} \qquad (8)$$

where $V_h(i)^{begin}$ is the initial reservoir volume and $V_h(i)^{end}$ is the final reservoir volume.

III. MHDE ALGORITHM FOR HYDROTHERMAL SCHEDULING

In MHDE based approach, modifications are incorporated in the initialization and mutation steps of the HDE algorithm to efficiently deal with the final reservoir storage volume constraints [1-5].

3.1 Initialization

The following steps are carried out in the initialization process:

1. The initial population of Np individuals is randomly selected based on uniform probability distribution for all variables to cover the entire search space uniformly. The discharge of ith plant at time t is expressed as

$$Q_h(i, t) = Q_h(i)^{min} + \rho(Q_h(i)^{max} - Q_h(i)^{min}) \qquad (9)$$

where $\rho \in [0,1]$ is uniformly distributed random number. The initial population excluding the dependent hydro discharge is expressed as

$$Z^0_k = [Q_{(i,1)}, Q_{(i,2)}, \ldots, Q_{(i,d-1)}, Q_{(i,d+1)}, \ldots, Q_{(i,T)}],\ k = 1,2, \ldots, Np,\ i = 1,2,\ldots,Nh. \qquad (10)$$

2. A random element is chosen and the dependent hydro discharge $Q_h(i, d)$ is computed using

$$Q_h(i, d) = V_h(i)^{begin} - V_h(i)^{end} - \sum_{\substack{t=1 \\ t \neq d}}^{T} Q_h(i, t) + \sum_{t=1}^{T} I_h(i, t) + \sum_{m=1}^{R_u} \sum_{t=1}^{T} Q_h(m, t - \tau) \qquad (11)$$

3. The above steps are repeated until the element representing the dependent variable doesn’t violate the constraints.

3.2 Mutation

In mutation, a perturbed individual is generated on the basis of the parent individual by

$$\hat{Z}_i^{G+1} = Z_p^{G} + F \times (Z_j^{G} - Z_k^{G}) \qquad (12)$$

where F is a scaling factor and j and k are randomly selected. The scaling factor $F \in [0,1.2]$ ensures the fastest possible convergence. In order that the perturbed individuals satisfy final reservoir storage constraints the following steps are carried out for all the Np individuals:

1. A random element of the perturbed individual is chosen. Let *l* = 1.
2. The dependent hydro discharge is computed using (11). If the computed hydro discharge doesn’t violate the constraints then go to step 6; otherwise go to the next step.
3. The dependent discharge is fixed either to its maximum or minimum limit according to its limit violation, a new random element is chosen and *l* = *l* + 1.
4. If *l* < = T, then go to Step 2; otherwise go to next step.

5. Since all the elements of the individual are fixed either to their maximum or minimum limits, a dummy fitness of higher magnitude is assigned for the individual.

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6. The mutation process is terminated.

The new set of Np perturbed individuals thus obtained by the modification process will satisfy the final storage volume. While generating the random element it is ensured that it is not repeatedly selected [6-10].

3.3 Crossover

The gene of an individual at the next generation is produced from the perturbed individual and the present individual, where the crossover factor CR ∈ [0,1.0] is assigned by user.

$$\hat{Z}_i^{G+1} = \begin{cases} Z_{ji}^{G}, & \text{if a random number} > C_R \\ \hat{Z}_{ji}^{G+1}, & \text{otherwise} \end{cases} \qquad i = 1, \ldots, Np,\ j = 1, \ldots, n \tag{13}$$

3.4 Evaluation and Selection

The two steps involved are one-to-one competition and selection of best individual in the population as expressed by

$$Z_i^{G+1} = \arg\min\{\psi(Z_i^{G}), \psi(\hat{Z}_i^{G+1})\},\ i = 1, \ldots NP \tag{14}$$

$$Z_b^{G+1} = \arg\min\{\psi(Z_i^{G+1}),\ i = 1, \ldots N_P\} \tag{15}$$

3.5 Acceleration Operation

The acceleration phase with a step size α ∈ [0,1] is represented as

$$Z_b^{G+1} = \begin{cases} \hat{Z}_b^{G+1}, & \text{if } \psi(\hat{Z}_b^{G+1}) < \psi(Z_b^{G}) \\ \hat{Z}_b^{G+1} - \alpha\,\nabla\psi, & \text{otherwise} \end{cases} \tag{16}$$

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3.6 Migration Operation

Migration phase regenerates a newly diverse population of individuals and the h^th gene of the ith individual is regenerated as

$$Z_{hi}^{G+1} = \begin{cases} Z_{hb}^{G+1} + \delta_{hi}\left(Z_{h\min} - Z_{hb}^{G+1}\right), & \text{if } \tilde{\delta}_{hi} < \dfrac{Z_{hb}^{G+1} - Z_{h\min}}{Z_{h\max} - Z_{h\min}} \\ Z_{hb}^{G+1} + \delta_{hi}\left(Z_{h\max} - Z_{hb}^{G+1}\right), & \text{otherwise} \end{cases} \quad i = 1, \ldots, Np,\ h = 1, \ldots, n \tag{17}$$

where δ and δ denote uniformly distributed random numbers. The migration operation is performed only if

$$\rho = \frac{\left\{ \sum_{\substack{i=1 \\ i \neq b}}^{N_p} \left(\sum_{h=1}^{n} \eta_Z \right) \right\}}{n(N_p - 1)} < \varepsilon_1$$

where

$$\eta_Z = \begin{cases} 1, & \text{if } \left| \dfrac{Z_{hi} - Z_{hb}}{Z_{hb}} \right| > \varepsilon_2 \\ 0, & \text{otherwise} \end{cases} \tag{18}$$

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Parameter e2 expresses the gene diversity with respect to the best individual. η_Z is the scale index. With the members of the next generation thus selected, the cycle repeats until there is no improvement in the best individual. In this study, DE with random vector perturbation and binominal crossover is employed [11-15].

IV. SIMULATION RESULTS

4.1 Test System I

The first test system consists of two hydro and four thermal plants, as given in ref. [10]. The quadratic fuel cost function including the effect of valve point loading is expressed as

$$F=\sum_{i=1}^{N_s} a_{s_i}+b_{s_i}P_{s_i}+c_{s_i}P_{s_i}^{2}+\left| d_{s_i}\sin\{e_{s_i}(P_{s_i}^{min}-P_{si})\}\right| \qquad (19)$$

where a_s, b_s c_s represent the cost coefficients and d_s, e_s represent the coefficients corresponding to valve point loading. The water discharge constraint of the hydro plant is

$$\sum_{t=1}^{T} 12(a_h(i)+b_h(i)P_h(t,i)+c_h(i)P_h^{2}(t,i))-W_h(i)=0 \qquad i\in N_h \qquad (20)$$

where a_h, b_h and c_h represent the hydro coefficients and W_h represents the allowable volumes of water for the scheduling horizon [16-20]. Table 1 provides the comparison with EP and GA. The control parameters N_p, F and C_R are 16, 1.0 and 0.9 respectively and MHDE converges in 0.63s.

4.2 Test System II

The second system consists of two thermal and two hydro plants [11]. The water discharge as a segmented piecewise linear function of output power of each hydro unit is given by

$$\sum_{i=1}^{T}12\left(Q_h(P_h^{min})+\sum_{j=1}^{L}\delta_{hj}P_{hj}(i,t)\right)-W_h=0 \qquad (21)$$

Table 2 compares results of the proposed approach with those of EP and GA. The control parameters N_p, F and C_R are 13, 1.0 and 0.95 respectively and MHDE converges in 0.39s [21, 22].

Table 1: Comparison of schedules of MHDE with EP and GA for test system I

Technique	Interval number	P_1 MW	P_2 MW	P_3 MW	P_4 MW	P_5 MW	P_6 MW	Total cost $
MHDE	1	232.6270	371.3947	20.6284	30.2941	125.0089	139.8990	65350.04
	2	178.1177	380.7064	98.6645	30.1278	209.8565	229.5648	
	3	227.2190	391.0838	20.5137	30.4337	125.0565	229.6026	
	4	239.2884	447.1687	98.7062	113.2761	209.9360	229.5651	
EP	1	207.2518	408.0409	95.6819	32.5566	124.8094	51.8704	70721.91
	2	221.3968	495.4297	98.6571	30.3246	128.5601	155.3188	
	3	244.6772	185.9374	99.8981	48.9338	212.2857	229.4713	
	4	204.9537	467.1949	115.1891	111.4051	209.7435	229.4798	
GA	1	207.3346	408.2062	95.6819	32.5566	124.8094	51.8704	70773.86
	2	221.1269	495.1563	98.6571	30.3246	128.5601	155.3188	
	3	244.5616	186.0649	99.8981	48.9338	212.2857	229.4713	
	4	205.2702	467.2348	115.1891	111.4051	209.7435	229.4798	

Table 2: Comparison of schedules of MHDE with EP and GA for test system II

Method	Interval number	P1 MW	P2 MW	P3 MW	P4 MW	Total cost $
. MHDE	1	354.0986	288.0500	199.9991	390.0646	372625.50
	2	565.5165	384.6651	200.1617	399.9983	
	3	493.8455	349.8964	200.0007	400.0016	
	4	661.4623	426.1222	277.0639	399.9998	
EP	1	360.2849	258.8861	200.1733	400.0024	373369.88
	2	448.9986	463.8880	227.4372	390.2221	
	3	294.8204	529.6531	199.6915	399.0026	
	4	449.9879	637.3414	249.8646	400.5992	
GA	1	350.6644	268.2802	200.0472	400.1263	374153.91
	2	449.7204	464.3986	228.7785	387.7219	
	3	279.9608	543.5551	199.4901	399.8788	
	4	443.2979	643.8198	248.8126	401.6378	

V. CONCLUSION

A novel approach based on modified hybrid differential evolution algorithm for solving the short-term hydrothermal scheduling problem has been presented in this paper. The results confirm that the MHDE has a remarkable performance over other evolutionary programming techniques.

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