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HSO based Dynamic Emission Dispatch

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ABSTRACT: This paper presents a harmony search optimization (HSO) strategy for dynamic emission dispatch (DED), which is a modification of static emission dispatch. It performs scheduling of generating units to meet the forecasted load demands over a scheduling horizon at minimum pollutions while considering the ramp rate limits. The HSO, inspired from the improvisation process of music by musician, explores for the global best solution. The proposed method partitions the DPD problem into as many as the number of sub-problems, and employs HSO in solving each sub-problem. The simulation results on standard test problem demonstrates that the proposed method is able to provide the global best solution.

KEYWORDS: dynamic emission dispatch; emission dispatch; harmony search optimization

NOMENCLATURE

$B\ B_o\ B_{oo}$	loss coefficients
DED	dynamic emission dispatch
DR_i	down-ramp limits of i^{th} generator
ED	emission dispatch
$E_i(P_{Gi})$	emission function of the i^{th} generator
nt	number of intervals
ng	number of generators
PM	proposed method
P_{Git}	real power generation at i^{th} generator at interval-t
$P_{Gi}^{\min}$ & $P_{Gi}^{\max}$	minimum and maximum generation limits of i^{th} generator respectively
P_{Dt}	total power demand at interval-t
P_{Lt}	net transmission loss at interval-t
UR_i	up-ramp limits of i^{th} generator in MW/h
$\Phi(P_G)$	objective function to be minimized
$\alpha_i, \beta_i, \gamma_i$, ξ_i and δ_i	emission coefficients of i^{th} generator

I. INTRODUCTION

Dynamic Economic Load Dispatch performs computation of the most economical generations so as to supply the forecasted power demand over a scheduling period at lowered operating cost, while satisfying several operational constraints that includes the ramp-rate limits of the generators. Operating at minimum fuel cost is not the only criterion for dispatching electric power, as the public are more concerned about environmental pollutions. Besides the enactment of the 'Clean Air Act Amendment of 1990' force the utilities to change their operating methodologies to meet environmental standards. The power plants using coal, oil and gas, releases pollutions such as sulphur oxides (SOx), nitrogen oxides (NOx) and carbon dioxide into the atmosphere. In the light of the fact that the economic load dispatch leads a large fuel cost savings, it causes large emissions. One of the simplest methodology in reducing the pollutions is the Dynamic Emission Dispatch (DED), which however results in higher operating cost. Several researchers have considered emissions either in the objective function or treated emissions as additional constraints. Emission function, which is similar to fuel cost function, is the sum of all types of emissions, whose characteristic is sometimes non linear and the slope of the curve is not always positive [1].

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Over the years, many methods were suggested in the literature for solving the DED problems. At earlier stages, mathematical or heuristically-based approaches, such as gradient projection method [2], linear programming [3], interior point methods [4], etc. were developed. Though they have several advantages such as mathematically proven, suitable for large-scale problems and not requiring any problem-specific parameters, they may land at sub-optimal traps, be sensitive to the initial guess, require functions to be differential, not handle non-convex objective function, etc. To overcome these drawbacks, methods involving artificial intelligence, such as neural networks, fuzzy logic, genetic algorithm, differential evolution and particle swarm optimization were employed for solving the DED problems [5-7]. Besides hybrid algorithms combining two or more approaches such as evolutionary programming with sequential quadratic programming [8], and Hopfield neural network with quadratic programming [9] were suggested for better results of DED problems.

Recently, a harmony search optimization (HSO), inspired from the improvisation process of music, has been suggested for solving optimization problems [10]. In this approach, problem solutions are denoted by harmony of music and the musician's improvisations are analogous to local and global search processes of optimization. This paper attempts to apply HSO in solving the DED problem by dividing the problem into several sub-problems for reducing the computational burden and improving the robustness.

II. Problem Formulation

The DED problem can be formulated as an optimization problem with an objective of lowering the total emissions of all ng generating units over the given dispatch period of nt intervals while satisfying several constraints.

$$\text{Minimize} \quad \Phi(P_G) = \sum_{t=1}^{nt} \sum_{i=1}^{ng} E_i(P_{Git}) \tag{1}$$

Subject to

$$\sum_{i=1}^{ng} P_{Git} - P_{Dt} - P_{Lt} = 0 \qquad t \in nt \tag{2}$$

$$P_{Gi}^{\min} \le P_{Git} \le P_{Gi}^{\max} \qquad i \in ng,\, t \in nt \tag{3}$$

$$\begin{aligned} &P_{Git} - P_{Git-1} \le UR_i \quad i \in ng \quad t = 2,\cdots,nt \\ &P_{Git-1} - P_{Git} \le DR_i \quad i \in ng \quad t = 2,\cdots,nt \end{aligned} \tag{4}$$

Where

$$E_i(P_{Git}) = \alpha_i P_{Git}^{\ 2} + \beta_i P_{Git} + \gamma_i + \xi_i \exp(\delta_i P_{Git}) \tag{5}$$

$$P_{Lt} = \sum_{i=1}^{ng} \sum_{j=1}^{ng} P_{Git} B_{ij} P_{Gjt} + \sum_{k=1}^{ng} B_{0k} P_{Gkt} + B_{00} \tag{6}$$

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III. PROPOSED METHOD

The number of decision variables in DED problem equals the product of the number of generating plants and the number of intervals over the scheduling horizon, thereby making the solution process very complex involving large computational burden. The proposed method (PM) divides the DED problem in to a number of sub-problems, each representing an emission dispatch (ED) of interval-t and then employs HSO for solving each sub-problem, while at the same time accounting the ramp-rate limits. Each harmony [10] in the DED is denoted to represent the real power generations of each sub-problem as

$$h_i = \left[P_{G1t}, P_{G2t}, \cdots, P_{Gngt}\right] \tag{7}$$

The fitness function is formed for the $t-th$ sub-problem as

$$\text{Maximize} \quad FF = \frac{1}{1+\sum_{i=1}^{ng} E_i(P_{Git}) + K_1 \sum_{i=1}^{ng} \left(P_{Git} - P_{Dt} - P_{Lt}\right)^2} \tag{8}$$

At a random initial interval $t = t^o$, the lower and upper bounds of the harmony is set as

$$\begin{aligned} h^{\min} &= \left[P_{G1}^{\min}, P_{G2}^{\min}, \cdots, P_{Gng}^{\min}\right] \\ h^{\max} &= \left[P_{G1}^{\max}, P_{G2}^{\max}, \cdots, P_{Gng}^{\max}\right] \end{aligned} \tag{9}$$

The HSO is then applied for solving the economic load dispatch (ELD) problem of the initial interval-t. Then the same solution process is continues for the subsequent intervals $t = t+1$, with the lower and upper limits for the harmony, set by accounting the ramp rate limits of Eq. (4) and solved using HSO.

$$\begin{aligned} h^{\min} &= \left[h_1^{\min}, h_2^{\min}, \cdots, h_{ng}^{\min}\right] \\ h^{\max} &= \left[h_1^{\max}, h_2^{\max}, \cdots, h_{ng}^{\max}\right] \end{aligned} \tag{10}$$

Where

$$\begin{aligned} h_j^{\min} &= \begin{cases} P_{Git-1} - DR_i & if \ \left(P_{Git-1} - DR_i\right) \geq P_{Gj}^{\min} \\ P_{Gj}^{\min} & else \end{cases} \\ h_j^{\max} &= \begin{cases} P_{Git-1} + UR_i & if \ \left(P_{Git-1} + UR_i\right) \leq P_{Gj}^{\max} \\ P_{Gj}^{\max} & else \end{cases} \end{aligned} \tag{11}$$

The above HSO based solution process is repeated by incrementing the interval -t till the last interval-nt of the scheduling horizon. Similarly the preceding sub-problems of the initial interval $t = t^o$ is obtained by decrementing the interval as $t = t-1$ and solved using the HSO till the solution for the first interval is obtained. The limits of the harmony during this phase are modified as

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$$h_j^{\min} = \begin{cases} P_{Git+1} - UR_i & if\ \left(P_{Git+1} - UR_i\right) \geq P_{Gj}^{\min} \\ P_{Gj}^{\min} & else \end{cases}$$
$$h_j^{\max} = \begin{cases} P_{Git+1} + DR_i & if\ \left(P_{Git+1} + DR_i\right) \leq P_{Gj}^{\max} \\ P_{Gj}^{\max} & else \end{cases} \tag{12}$$

The real power generations obtained for each interval over the scheduling horizon represent the optimal solution of the DED problem. The solution process, requiring HSO [10], of the PM is explained through the flow chart of Fig .1.

IV. SIMULATION RESULTS

The PM is applied on a test system possessing 10 generating units. The real power generations of DED, obtained by the PM, for the test system are furnished in Table 1. The net emissions of the PM is also included in the same table.

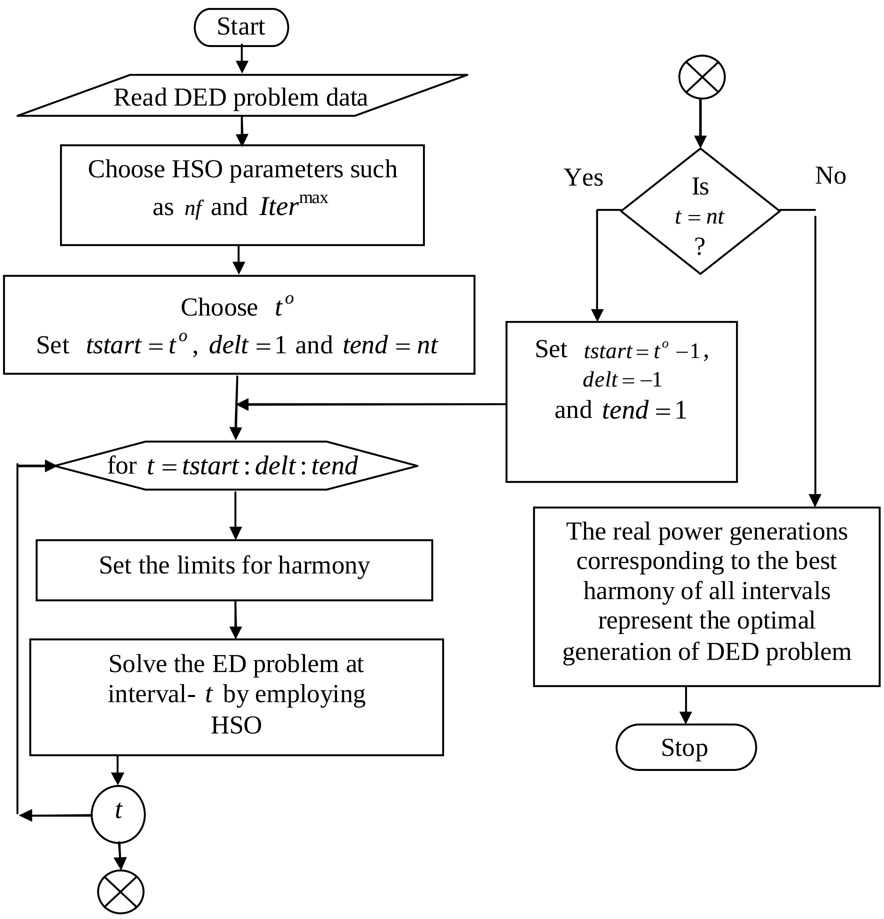

Fig 1 Outline of the PM

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Table 1 Real power generations of DED

Hour	P_D (MW)	Generations (MW)									
		P_{G1}	P_{G2}	P_{G3}	P_{G4}	P_{G5}	P_{G6}	P_{G7}	P_{G8}	P_{G9}	P_{G10}
1	1036	150	135.22	90.87	83.06	175.85	124.32	129.82	71.23	52.21	43.43
2	1110	150	135	137.62	62.72	178.39	158.81	129.71	87.41	49.40	43.47
3	1258	150	135	184.71	112.74	223.06	157.53	104.32	117.38	58.32	43.42
4	1406	209.40	135	241.04	150.23	238.25	159.85	108.36	104.43	52.12	43.40
5	1480	193.85	135	313.13	162.26	223.83	138.23	129.72	100.52	80	43.47
6	1628	219.14	194.73	337.22	201.25	204.95	147.11	129.74	120	80	43.42
7	1702	204.08	255.97	326.52	244.34	224.35	148.06	129.67	120	59.15	43.51
8	1776	215.07	299.38	303.63	266.92	234.53	143.73	129.75	120	79.16	43.42
9	1924	263.32	303.27	340	300	243	160	129.90	120	80	54.92
10	2022	336.72	336.86	340	300	243	160	130	120	80	55
11	2106	370.54	395.27	340	300	243	160	130	120	80	55
12	2150	369.75	444.77	340	300	243	160	130	120	80	55
13	2072	340.07	388.35	340	300	243	160	130	120	80	55
14	1924	279.69	345.32	308.88	273.49	242.79	160	129.92	120	80	54.93
15	1776	215.15	289.65	301.89	297.43	241.15	158.44	129.70	106.68	52.02	43.47
16	1554	150	214.27	240.99	248.43	223	148.38	129.88	120	79.90	43.49
17	1480	196.78	136.37	190.86	242.66	230.25	160	129.89	120	69.85	43.41
18	1628	234.07	216.11	211.81	254.31	227.64	160	129.86	120	80	43.47
19	1776	276.36	219.39	269.33	294.58	242.37	160	129.86	120	80	43.52
20	1972	331.09	293.76	334.38	299.87	242.92	160	129.96	120	80	55
21	1924	261.55	305.14	339.98	300	243	160	129.87	120	80	55
22	1628	208.87	225.13	261.13	288.37	224.85	123.51	129.89	120	52.21	43.52
23	1332	150	153.43	188.83	242.63	181.47	104.86	129.72	120	50.12	43.50
24	1184	150	135	129.66	239.23	157.22	122.94	99.65	91.59	40.64	43.48
Net Emissions over 24 hours, lb/day							284207.5892				

V. CONCLUSION AND FUTURE WORK

DED is a computational process of allocating generations to various generation plants so as to lower the release of emissions subject to load and operational constraints over a scheduling period. The HSO, inspired from the pollination process of plants, searches for optimal solution for multimodal optimization problems. A novel methodology using HSO was developed for solving DED problem, which is a complex non-linear optimization problem involving large number of decision variables and the ramp rate constraints. The problem is split into a number of sub-problems and each sub-problem is solved using HSO. The simulation results on a standard test system clearly exhibits the robustness and computational efficiency of the proposed method. The method can be extended to include both fuel cost and emissions in the solution process.

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