Prohibited Zone Dynamic Economic Dispatch Solution Using a Hybrid Artificial Neural Network

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Abstract—**This paper proposes a solution to the prohibited zone dynamic economic dispatch (DED) problem in power system using a hybrid artificial neural network (HANN), which is a continuous model named Hopfield model. The constrained DED must not only satisfy the system load demand and the spinning reserve capacity, but some practical operation constraints of generators, such as ramp rate limits and prohibited operating zone, are also considered in practical generator operation. The feasibility of the proposed HANN of Hopfield model method is demonstrated using two power systems, and it is compared with the other methods in terms of solution quality and computation efficiency.**

The experimental results showed that the proposed HANN method was indeed capable of obtaining higher quality solutions efficiently in constrained DED problems.

Index Terms—**dynamic economic dispatch, Hopfield Neural Network, dichotomy method, prohibited operating zone, ramping rate limits.**

I. Introduction

Dynamic economic dispatch (DED) is used to determine the optimal schedule of generating outputs on-line so as to meet the load demand at the minimum operating cost under various system and operating constraints over the entire dispatch periods. DED is an extension of the conventional ED problem that takes into consideration the limits on the ramp rate of generating units to maintain the life of generation equipment. The ramp rate constraints distinguish the DED problem from the traditional, static ED [1] [2]. In general, the DED is solved by discretization of the entire dispatch period into a number of small time periods. Therefore, the static ED in each dispatch period is solved subject to the power balance constraints and generator operating limits. Previous efforts on solving static ED problems have employed various mathematical programming methods and optimization techniques (lambda-iteration method, the base point and participation factors method, the gradient method and dynamic programming (DP)) [3]. Unfortunately, for generating units with non-linear characteristics, such as prohibited operating zones, ramp rate limits, and non-convex cost functions, the conventional methods can hardly to obtain the optimal solution. Furthermore, for a large-scale mixed-generating system, the conventional method often oscillates [4], which result in a longer solution time or a local minimum.

Previously, the genetic algorithms (GA), simulated annealing (SA), tabu search (TS), and evolutionary programming (EP), have been successfully used to overcome the non-convexity problems of the constrained ED [5] [6] [7] and [8]. In this category, due to its high potential for global optimization, the GA has received great attention in solving DED problems.

Yao proposed in [9] a fast evolutionary programming (FEP) which uses a Cauchy mutation and improved the EP. He proposed also in the same reference an improved fast evolutionary programming (IFEP) using mixed both Gaussian and Cauchy mutations for creation of offsprings from the same parent..

Employing different adaptation of strategy parameters may also affect the effectiveness of FEPs [10]. Therefore, Sinha [11] first compared the above variants of FEP using different adaptation of strategy parameters in terms of convergence rate, solution time, minimum cost, and probability of attaining better solutions in solving the static ED with valve-point effects taken into consideration. The results showed that the IFEP had the best performance in solving the large-scale static ED problem. Though the IFEP had better convergence rate than other FEP-based methods, the greater CPU time/iteration was its drawback.

Particle swarm optimization (PSO), is one of the heuristic algorithms. It was developed through simulation of a simplified social system, and has been found to be robust in solving continuous nonlinear optimization problems [12] [13]. The PSO seems to be sensitive to the tuning of some weights or parameters, many researches are still in progress for proving its potential in solving complex power system problems [14].

In order to make numerical methods more convenient in solving non-convex DED problems, artificial intelligent techniques, such as the gradient-type Hopfield neural networks, have also been employed to solve DED problems for units with ramping rate limit and spinning reserve constraint [15]. However, an unsuitable transfer function adopted in the Hopfield model may suffer from excessive numerical iterations, resulting in huge calculations [16].

To overcome these drawbacks, we have attempt to construct and implement a HANN, which employs a linear transfer function for the Hopfield neural network (HNN) model. The proposed method in this paper solves the constrained DED in power system. The feasibility of the proposed method was demonstrated for two power systems [17], respectively, as compared with the FEP, the IFEP and PSO in terms of solution quality and computation efficiency.

II. II. PROBLEM DESCRIPTION

The ED is one subproblem of the unit commitment (UC) problem. It is a nonlinear programming optimization one. Practically, while the scheduled combination units at each specific period of operation are listed, the ED planning must perform the optimal generation dispatch among the operating units to satisfy the system load demand, spinning reserve capacity, and practical operation constraints of generators that include the ramp rate limit and the prohibited operating zone [13].

A. *Practical Operation Constraints of Generator*

For convenience in solving the ED problem, the unit generation output is usually assumed to be adjusted smoothly and instantaneously. Practically, the operating range of all online units is restricted by their ramp rate limits for forcing the units operation continually between two adjacent specific operation periods [3], [4]. In addition, the prohibited operating zones in the input-output curve of generator are due to steam valve operation or vibration in a shaft bearing. Because it is difficult to determine the prohibited zone by actual performance testing or operating records, the best economy is achieved by avoiding operation in areas that are in actual operation. Hence, the two constraints of generator operation must be taken into account to achieve true economic operation.

1) Ramp Rate Limit: According to [5], [18], and [19], the inequality constraints due to ramp rate limits for unit generation changes are given as follow:

$$P_i^t - P_i^{t-1} \le R_i^{up}$$

(1)

$$P_i^{t-1} - P_i^t \le R_i^{down}$$

(2)

$i = 1,\ldots,N$ and $t = 1,\ldots,T$

Where P_i^t is output power at interval *t*, and P_i^{t-1} is the previous output power. R_i^{up} is the upramp limit of the i-th generator at period *t*, (MW/time-period); and R_i^{down} is the downramp limit of the i-th generator (MW/time period).

2) Prohibited Operating Zone: References [4], [13], and [18] have shown the input-output performance curve for a typical thermal unit with many valve points. These valve points generate many prohibited zones. In practical operation, adjusting the generation output P_i of a unit must avoid unit operation in the prohibited zones. Fig. 1 shows the input–output performance curve for a typical thermal unit with *Prohibited Zone*. The feasible operating zones of unit can be described as follows:

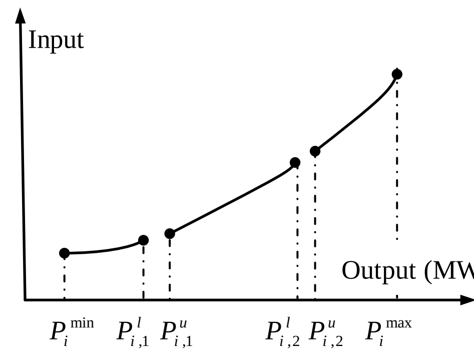

Fig. 1. shows the input– output performance curve for a typical thermal unit with *Prohibited Zone*.

$$P_i^t \in \begin{cases} P_i^{\min} \le P_i^t \le P_{i,1}^l \\ P_{i,j-1}^u \le P_i^t \le P_{i,j}^l \quad , j = 2,3,\ldots,n_i \\ P_{i,n_i}^u \le P_i^t \le P_i^{\max} \end{cases}$$

(3)

Where n_i is the number of prohibited zones of the ith generator. $P_{i,j}^l$, $P_{i,j}^u$ are the lower and upper power output of the prohibited zones *j* of the ith generator, respectively.

B. *Objective Function*

The objective of ED is to simultaneously minimize the generation cost rate and to meet the load demand of a power system over some appropriate period while satisfying various constraints. To combine the above two constraints into a ED problem, the constrained optimization problem at specific operating interval can be modified as

$$\min F_T = \sum_{t=1}^{T}\sum_{i=1}^{N} F_i^t(P_i^t) = \sum_{t=1}^{T}\sum_{i=1}^{N} a_i + b_i P_i^t + c_i (P_i^t)^2$$

(4)

where F_T is the total generation cost; $F_i^t(P_i^t)$ is the generation cost function of *i*th generator at period *t* , which is usually expressed as a quadratic polynomial; a_i, b_i, and c_i are the cost coefficients of the i-th generator; P_i^t is the power output of the *i*th generator and N is the number of generators committed to the operating system, *T* is the total periods of operation.

Subject to the following constraints

i) power balance

$$\sum_{i=1}^{N} P_i^t = D^t + L^t$$

(5)

where D^t is the load demand at period *t* and L^t is the total transmission losses of same period, which is a function of the unit power outputs that can be represented using the B-coefficients:

$$L^t = \sum_{i=1}^{N}\sum_{j=1}^{N} P_i^t B_{ij} P_j^t + \sum_{i=1}^{N} B_{0i} P_i^t + B_{00} \qquad (6)$$

where B, B_0 and B are the loss-coefficient matrix, the loss-coefficient vector and the loss constant, respectively.

(ii) System spinning reserve constraints

$$\sum_{i=1}^{N}\left[\min\left(P_i^{\max} - P_i^t, R_i^{up}\right)\right] \geq SR^t,\ t = 1,2,...,T$$

(7)

ii) generator operation constraints

$$\max(P_i^{\min}, P_i^{t-1} - R_i^{down}) \leq P_i^t \leq \min(P_i^{\max}, P_i^{t-1} + R_i^{up})$$

(8)

where P_i^{min} and P_i^{max} are the minimum and maximum outputs of the ith generator respectively.

The generation output P_i^t must fall in the feasible operating zones of unit *i by* satisfying the constraint described by Eq. 3.

III. An Enhanced HNN Applied to ED

The continuous model of the HNN is based on continuous output variables, and the transfer function is a continuous and monotonically increasing function of the input U_i. The model is a mutual coupling neural network and of non-hierarchical structure. The dynamic characteristic of each neuron can be described by the following differential equation:

$$\frac{dU_i}{dt'} = I_i + \sum_{j=1}^{N} T_{ij} V_j$$

(9)

where U_i is the total input of neuron i; V_i is the output of neuron i; T_{ij} is the interconnection conductance from the output of neuron j to the input of neuron i; T_{ii} is the self-connection conductance of neuron i and I_i is the external input to neuron i. It should be noted here that t' is not representing real time, it is a dimensionless variable.

To avoid the problems resulting from curve saturation, a linear model is used to describe the transfer function.

The energy function of the continuous Hopfield model can be defined as:

$$E = -\frac{1}{2}\sum_{i=1}^{N}\sum_{j=1}^{N} T_{ij} V_i V_j - \sum_{i=1}^{N} I_i V_i$$

(10)

In the computation process the model state always moves in such a way that energy function gradually reduces and converges to a minimum [20].

A. Mapping of ED into the Hopfield model

To solve the ED problem using the Hopfield method, energy function including both power mismatch, P_m and total fuel cost F is defined as follows:

$$E = \frac{A}{2}\left((D+L) - \sum_{i=1}^{N} P_i\right)^2 + \frac{B}{2}\sum_{i=1}^{N}\left(a_i + b_i P_i + c_i P_i^2\right)$$

$$. = \frac{A}{2} P_m^{\ 2} + \frac{B}{2} F_T$$

(11)

Where the positive weighting factors A and B introduce the relative importance of their respective associated terms.

We represent the power output value P_i using the output V_i of neuron i with a linear function described as follows:

$$P_i = \begin{cases} \dfrac{U_i - U_{\min}}{U_{\max} - U_{\min}}.(P_i^{\max} - P_i^{\min}) + P_i^{\min} & U_{\min} \leq U_i \leq U_{\max} \\ P_i^{\max} & U_i \geq U_{\max} \\ P_i^{\min} & U_i \leq U_{\min} \end{cases} \qquad (12)$$

where U_{min} and U_{max} are the minimum and maximum input of neurons.

Comparing the energy function Eq.11 with the Hopfield energy function Eq.10, we get

$T_{ii} = - A - B \,.\, c_i$ (13)

$T_{ij} = - A$

(14)

$I_i = A\ (D + L) - B\ (b_i\ /2)$

(15)

At this stage the transmission losses L can be neglected and reconsidered later in the next section.

Substituting Eq.13, Eq.14 and Eq.15 into Eq.8, the dynamic equation becomes,

$$dU_i / dt' = AP_m - (B/2)(dF_i / dP_i)$$

(16)

with $P_m = D - \sum_{i=1}^{N} P_i$

Substituting Eq.12 in Eq.16 the dynamic equation becomes:

$$dU_i / dt' = AP_m - (B/2)\left(b_i + 2c_i\left(K_{1i} U_i + K_{2i}\right)\right) \qquad (17)$$

with $K_{1i} = \left(P_i^{\max} - P_i^{\min}\right) / \left(U_{\max} - U_{\min}\right)$ and $K_{2i} = P_i^{\min} - K_{1i} U_{\min}$

Solving Eq.17 for the neuron's input function

$$U_i(t') = \left(U_i(0) + \left(K_{4i} / K_{3i}\right)\right) e^{K_{3i} t'} - \left(K_{4i} / K_{3i}\right)$$

(18)

with $K_{3i} = -Bc_i K_{1i}$ and $K_{4i} = AP_m - (B/2) b_i - Bc_i K_{2i}$

From Eq.12, the neuron's output function $P_i(t')$ is obtained as

$$P_i(t') = \left(2K_{AB}P_m - b_i\right)/2c_i + .+\left(K_{1i}U_i(0) + K_{2i} - \left(2K_{AB}P_m - b_i\right)/2c_i\right) e^{K_{3i}t'}$$
(19)

with $K_{AB} = A/B$

The second term in Eq.19 decays exponentially and finally becomes vanishingly small. Eventually setting $t' = \infty$ gives,

$$P_i(\infty) = \left(2K_{AB}P_m - b_i\right)/2c_i$$
(20)

Here $P_i(\infty)$ is the final output of neuron i and represents the optimal generation level of unit i, which is the required solution.

Back substituting of Eq.20 in Eq.19, give a more simple formula for the generation function:

$$P_i(t') = P_i(\infty) + \left(P_i(0) - P_i(\infty)\right) e^{K_{3i}t'}$$
(21)

where $P_i(0)$ is obtained from Eq.19 by letting $t' = 0$, to give:

$$P_i(0) = K_{2i} + K_{1i}U_i(0)$$
(22)

Using the power mismatch definition and Eq.20 we obtain:

$$P_m = \left(D + (1/2)\sum_{i=1}^{N}(b_i/c_i)\right) \Big/ \left(1 + K_{AB}\sum_{i=1}^{N}(1/c_i)\right)$$
(23)

Equations Eq.20 through Eq.23 constitute the Hopfield model for the ED problem. A non iterative direct computation process is, therefore, possible.

IV. Inclusion of Transmission Losses Using a Hybrid Artificial Neural Network

For each time period t, a dichotomy solution method for solving the ED including transmission losses combined to the HNN is proposed in the following steps:

Step 1: initialization of the interval search $[D_3 \;\; D_1]$, where D_3 is the power demand at period t and D_1 is a maximum forecast of power demand plus losses at the same period t.

ε : a pre-specified tolerance.

Initialize the iteration counter $k = 1$.

$D_3^{\,k} = D$;

$D_2^{\,k} = D_1^{\,k}$.

Step 2: Determine the optimal generators' power outputs $P_i, \;\; i = 1,...,N$ using the HNN algorithm, by neglecting losses and setting the power demand as $D^k = D_2^{\,k}$;

Step 3: Calculate the transmission losses L^k for the current iteration k using Eq.6;

Step 4: if $D_1^{\,k} - D_3^{\,k} < \varepsilon$, stop otherwise go to step 5;

Step 5: if $D_2^{\,k} - L^k < D$, update D_3 and D_2 for the next iteration as follows:

$D_3^{\,k+1} = D_2^{\,k}$

$D_2^{\,k+1} = D_2^{\,k} + (D_1^{\,k} - D_2^{\,k})/2$;

Replace k by $k+1$ and go to step 2;

Step 6: if $D_2^{\,k} - L^k > D$, update D_1 and D_2 for the next iteration as follows:

$D_1^{\,k+1} = D_2^{\,k}$, and $D_2^{\,k+1} = D_2^{\,k} - (D_2^{\,k} - D_3^{\,k})/2$;

Replace k by $k+1$ and go to step 2.

V. A Novel Strategy for Prohibited Zone Problem

To prevent the units with prohibited zones from falling in those zones during the dispatching process, we propose a novel strategy. In the strategy, we introduce an medium production point, $P^M_{i,j}$, for the jth prohibited zone of unit i. The corresponding incremental cost, $\lambda^M_{i,j}$, is defined by:

$$\lambda^M_{i,j} = \left[F_i(P^u_{i,j}) - F_i(P^l_{i,j})\right] \Big/ \left(P^u_{i,j} - P^l_{i,j}\right)$$
(24)

For each period t, a minimum and maximum outputs $P_i^{min,t}$ and $P_i^{max,t}$ of the ith generator is allowed due to the ramp rate limit, as follow:

$$P_i^{\min,t} = \max(P_i^{\min}, P_i^{t-1} - R_i^{down})$$
(25)

$$P_i^{\max,t} = \min(P_i^{\max}, P_i^{t-1} + R_i^{up})$$
(26)

The three possible cases of the prohibited cases with respect to the minimum and maximum allowed outputs are given in Fig. 2.

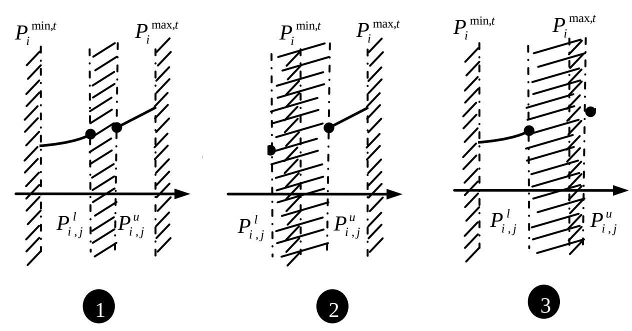

Fig. 2. The three possible cases of prohibited zones with respect to the minimum and maximum generator's outputs

For the quadratic fuel cost functions, the incremental cost $\lambda^M_{i,j}$ is actually equal to the average cost of the prohibited zone. The medium point divides the prohibited zone into a left and a right prohibited subzones.

Case 1: The prohibited zone is within the minimum and maximum generator's outputs of the period t.

Dispatch unit i with generation level at or above $P_{i,j}^{u}$ if the system incremental cost exceeds $\lambda_{i,j}^{M}$, by setting $P_i^{\min,t} = P_{i,j}^{u}$. Conversely, dispatch unit i with generation level at or below $P_{i,j}^{l}$, if the system incremental cost is less than $\lambda_{i,j}^{M}$, by setting $P_i^{\max,t} = P_{i,j}^{l}$.

Case 2: The minimum generator's outputs allowed of the period t exceeds the lower bound of the prohibited zone. Dispatch unit i by setting $P_i^{\min,t} = P_{i,j}^{u}$.

Case 3: The maximum generator's outputs allowed of the period t is less than the upper bound of the prohibited zone. Dispatch unit i by setting $P_i^{\max,t} = P_{i,j}^{l}$.

When a unit operates in one of its prohibited zones, the idea of this strategy is to force the unit either to escape from the left subzone and go toward the lower bound of that zone or to escape from the right subzone and go toward the upper bound of that zone.

VI. COMPUTATIONAL PROCEDURES

Based on the employment of the strategy mentioned above, the computational steps for the proposed approach for solving the constrained DED with 24-hour dispatch intervals (one day) are summarized as follows:

Step 0: Specify the generation for all units, at interval t-1.

Step 1: At interval t, specify the lower and upper bound generation power of each unit using Eq.25 and Eq.26, to satisfy the ramp rate limit. Pick the hourly power demand D^t. Apply the algorithm of section 3, based on HNN model to determine the optimal generation for all units without considering transmission losses and the prohibited zones.

Step 2: Apply the hybrid algorithm HANN of section 3, to adjust the optimal generation of step 1for all units, to include transmission losses.

Step 3: If no unit falls in the prohibited zone, the optimal generation obtained in Step 2 is the solution, go to Step 5; otherwise, go to Step 4.

Step 4: Apply the strategy of section 5 to escape from the prohibited zones, and redispatch the units having generation falling in the prohibited zone.

Step 5: Let $t=t+1$ and if $t \leqq 24$, then go to Step 1. Otherwise, Terminate the computation.

VII. NUMERICAL EXAMPLES AND RESULTS

To validate the efficiency of the proposed hybrid HANN method, a 6-thermal units power systems was tested. In this example, the ramp rate limits and prohibited zones of units were taken into account in practical application, so the proposed HANN method can be compared with other methods.

The results of the HANN algorithm method are compared with those obtained by the FEP and IFEP, and PSO algorithms in terms generation cost and average computational time for the 6-units test system as shown in Table VII. Obviously, all methods have succeeded in finding the near optimum solution presented in [13] with a high probability of satisfying the equality and inequality constraints. The software was written in Matlab language and executed on a Pentium IV 1.8 personal computer with 256MB RAM.

The 6-unit example: The system contains 6-thermal units, 26 buses, and 46 transmission lines [19]. The characteristics of the six thermal units are given in Table I and Table II. Total power capacities were committed to meet the 24-hour load demands from 930 MW to 1263 MW that was shown in Table III. In normal operation of the system, the loss coefficients B matrices with the 100 MVA base capacity are given in [13].

TABLE I
GENERATING UNIT CAPACITY AND COST COEFFICIENTS OF EXAMPLE 1

Unit	P_i^{max}	P_i^{min}	a_i (\$/h)	b_i (\$/MWh)	c_i (\$/MW^{2}h)
1	500	100	240	7.0	0.0070
2	200	50	200	10.0	0.0095
3	300	80	220	8.5	0.0090
4	150	50	200	11.0	0.0090
5	200	50	220	10.5	0.0080
6	120	50	190	12.0	0.0075

TABLE II
RAMP RATE LIMITS AND PROHIBITED ZONES OF GENERATING UNITS OF EXAMPLE 1

Unit	P_i^0	R_i^{up} (MW/h)	R_i^{down} (MW/h)	*Prohibited zone* (MW)
1	340	80	120	[210 240] [350 380]
2	134	50	90	[90 110] [140 160]
3	240	65	100	[150 170] [210 240]
4	90	50	90	[80 90] [110 120]
5	110	50	90	[90 110] [140 150]
6	52	50	90	[75 85] [100 105]

TABLE III
THE DAILY LOAD DEMAND (MW) OF EXAMPLE 1

Hour	1	2	3	4	5	6	7	8	9	10
Load	955	942	935	930	935	963	989	1023	1126	1150
Hour	11	12	13	14	15	16	17	18	19	20
Load	1201	1235	1190	1251	1263	1250	1221	1202	1159	1092
Hour	21	22	23	24						
Load	1023	984	975	960						

VIII. SIMULATION RESULTS

The proposed HANN method was employed to test a 6-units study systems in the 24-hour constrained DED problem. The spinning reserve was requested to be greater than 5% of the load demand at each dispatch interval. At each interval, the convergence criteria considered is the unit generation constraints must be not violated. The loss coefficients B matrices are given in [19].

The daily generation power that is generated by the proposed HANN method to meet the daily load demands was shown in Table (VI) for the 24-hours of a day. The generation cost is given in the last row of Table (VI).

Table (V) summarized both the daily generation cost and computation efficiency of the proposed methods applied to two test system (6-units and 15-units)..

TABLE IV
THE SOLUTION OF CASE 1 BY THE HANN METHOD OF CASE 1

Unit	P_i^0	1	2	3	4	5	6	7	8	9	10	11	12
1	340,00	384,08	380,00	380,00	380,00	380,00	386,47	395,97	393,86	420,08	425,93	436,33	442,67
2	134,00	125,11	122,30	120,12	118,90	120,12	126,87	133,87	132,32	160,00	160,00	163,61	168,28
3	240,00	210,00	210,00	210,00	208,84	210,00	210,00	210,00	240,00	243,39	247,95	256,03	260,96
4	90,00	76,50	73,54	71,24	69,95	71,24	78,36	80,00	90,00	104,50	109,06	120,00	122,07
5	110,00	117,32	113,98	111,39	110,00	111,39	119,41	127,72	125,87	150,00	153,94	163,04	168,58
6	52,00	50,00	50,00	50,00	50,00	50,00	50,00	50,00	50,00	58,74	64,21	73,91	85,00

Gen. Cost	8,004	7,827	7,745	7,679	7,745	8,114	8,558	9,047	10,716	11,091	11,920	12,569

Unit	13	14	15	16	17	18	19	20	21	22	23	24
1	433,73	446,58	449,28	446,33	441,65	436,57	428,23	419,61	393,86	394,02	390,51	385,57
2	161,70	171,16	173,15	170,98	167,53	163,78	160,00	140,00	132,32	132,43	129,85	126,21
3	254,01	264,01	266,10	263,82	260,17	256,22	249,73	240,00	240,00	210,00	210,00	210,00
4	120,00	125,12	127,21	124,93	121,28	120,00	110,00	104,14	90,00	80,00	80,00	77,67
5	160,77	172,01	174,37	171,79	167,69	163,24	155,95	140,00	125,87	126,01	122,94	118,62
6	71,48	85,00	85,99	85,00	75,00	74,13	66,34	58,30	50,00	50,00	50,00	50,00
Gen. Cost	11,696	12,873	13,103	12,854	12,336	11,940	11,252	10,047	9,047	8,466	8,301	8,072

TABLE V
THE SUMMARY OF THE DAILY GENERATION COST AND CPU TIME

Method	*Total Generation Cost ($)*		*CPU time/interval*	
	6-Units	*15-Units*	*6-Units*	*15-Units*
FEP	*315,634*	*796,642*	*357.58*	*362.63*
IFEP	*315,993*	*794,832*	*546.06*	*574.85*
PSO	*314,782*	*774,131*	*2.27*	*3.31*
Hybrid HNN	*313,579*	*759,796*	*1,52*	*2.22*

As can be seen, the simulation results given in Table IV and Table V showed that the proposed methods could obtain good solutions satisfying both the ramp rate limit, spinning reserve and the prohibited operating zones limit of generators. In a small-scale system as in the 6-units power system, though the advantage of HANN method was not very obvious, it could still have the fastest computation efficiency and the minimum daily total generation cost, as shown in Table V. The method was tested in a medium system of 15-units taken from [19], the advantage of the proposed HANN method was very obvious, and it could obtain both the fastest computation efficiency and the minimum daily total generation cost, as shown in Table V. Through the comparison simulations results, the FEP and IFEP [11] had almost the same solution qualities and total generation costs, and the PSO method [13] has a best solution quality compared to the FEP and IFEP methods .
However, the proposed HANN method always has the best solution quality with both the least total generation cost and the best efficiency.

IX. DISCUSSION AND CONCLUSION

The DED is a complex optimization problem, whose importance may increase as competition in power generation intensifies. The DED planning must perform the optimal generation dispatch at the minimum operating cost among the operating units to satisfy the system load demand, spinning reserve capacity, and practical operation constraints of generators that include the ramp rate limit and the prohibited operating zone. In this paper, we have successfully employed a HANN method to solve the constrained DED problem. The HANN algorithm has been demonstrated to have superior features, including high-quality solution and good computation efficiency. The results showed that the proposed HANN method was indeed capable of obtaining higher quality solution efficiently in constrained DED problems.

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