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A Novel TANAN's Algorithm to solve Economic Power Dispatch with Generator Constraints and Transmission Losses

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Abstract – This paper presents a Novel TANAN's Algorithm (NTA) approach to solve the economic power dispatch problem including transmission losses in power systems. The transmission losses are augmented with the objective function using price factor. The generalized expression for optimal scheduling of thermal generating units derived in this article can be implemented for the solution of the economic power dispatch problem of a large-scale system. Six-unit, fifteen-unit, and forty- unit sample systems with non-linear characteristics of the generator, such as ramp-rate limits and prohibited operating zones are considered to illustrate the effectiveness of the proposed method. The proposed method results have been compared with the results of genetic algorithm and particle swarm optimization methods reported in the literature. Test results show that the proposed NTA approach can obtain a higher quality solution with better performance.

Keywords: Dynamic programming, Economic power dispatch, Optimization, Prohibited operating zones, Ramp-rate constraints.

1. Introduction

The main objective of the economic dispatch problem is to determine the optimal combination of power outputs for committed generating units, which minimizes the total fuel cost while satisfying load demand and operating constraints. This makes the economic power problem a large-scale non-linear constrained optimization problem. Traditional methods such as Lambda-iteration method, the base point and participation factors methods and the gradient method [1-4] are well known for the economic dispatch of generators. In these numerical methods, an essential assumption is that the whole of the generating unit operating range is available for operation. Conventional techniques offer good results but when the search space is non-linear and it has discontinuities they become very complicated with a slow convergence ratio and not always seeking the optimal solution.

In a practical system, the generating units have prohibited operating zones between their minimum and maximum generation limits and the operating range of online units are restricted by their ramp-rate limits due to physical operational limitations. Unit operation in prohibited operating zones may cause amplification of vibrations in shaft bearings, which should be avoided in practice. The prohibited operating zones of a unit divide the operating range between its minimum to maximum generation limits into several disjoint convex sub-regions. Hence, conventional methods cannot be directly applied to solve the economic dispatch problem with prohibited operating zones. Several methods have been reported for the solution of the economic power dispatch problem with prohibited operating zones. The dynamic programming approach [5, 6] is one of the most widely employed methods for the solution of the nonconvex economic power dispatch problem. Unlike the Lambda iteration approach, the dynamic programming method has no restrictions on generator cost function and performs a direct search of solution space. However, for a practical sized system, the fine step size and the large unit number often cause the 'curse of dimensionality' problem or local optimality in the dynamic programming solution process. Lee et al. [7] decomposed the nonconvex decision space into a small number of subsets such that each of the associated dispatch problems, if feasible, is solved through the conventional Lagrangian relaxation approach. This approach requires fairly extensive computational time when a system owns more units that have prohibited operating zones. Ref. [8] defined a small advantageous set of decision spaces with respect to the system demand and then utilized the iterative method to find the feasible optimal solution. This method may not be applicable if the problem contains too many nonlinear constraints for large scale nonconvex systems. The stochastic search algorithms such as genetic algorithm (GA) [9], evolutionary programming (EP) [10], [11], simulated annealing (SA) [12], tabu search algorithm (TSA) [13], and particle swarm optimization (PSO) [14, 15], may prove to be effective in solving nonlinear ED problems without any restriction on the shape of the cost curves. Although these heuristic methods do not always guarantee discovering the globally optimal solution in finite time, they often provide a reasonable solution. Further, the stochastic searching algorithms take a longer time for convergence. Neural network [16, 17] models were applied to the economic power dispatch problem. These methods also required tremendous amounts of time for training the network.

2. Problem Formulation

The economic power dispatch problem with ramp-rate limits and prohibited operating zones can be formulated as

$$Minimise Ft = \sum_{i=1}^{n} Fi(Pi) = \sum_{i=1}^{n} a_i P_i^2 + b_i P_i + c_i$$

\$/h (1)

Where i denotes index of units; F_i, Fuel cost function of unit i; a_i, b_i, and c_i are cost coefficients of generator i; n is the number of generators committed to the operating system; P_i is the power generated by the ith unit, subject to

(i) the power balance constraints:

$$\sum_{i=1}^{n} P_i = P_d + P_l \qquad (2)$$

Where P_D is the system load demand and P_L is the transmission loss which can be found through the use of B-matrix loss coefficients.

(ii) Generating capacity constraints:

$$P_i^{\min} \le P_i \le P_i^{\max} \quad i=1, 2, 3\ldots n \qquad (3)$$

Where P_i^{min} and P_i^{max} are the minimum and maximum power outputs of the ith unit. (iii) The additional constraints for units with prohibited operating zones are:

$$\left.\begin{array}{l} P_i^{\min} \le P_i \le P_{i,1}^{l} \\ P_{i,j-1}^{u} \le P_i \le P_{i,j}^{l} \\ P_{i,m_i}^{u} \le P_i \le P_{i,}^{\max} \end{array}\right\} \quad j=2, 3\ldots, m_i \qquad (4)$$

Where j is the number of prohibited zones of unit i. l and u denote the lower bound and upper bound of the prohibited zone of the generator.

(iv) ramp-rate constraints:

$$Max(P_i^{\min}, P_i^0 - DR_i) \le P_i \le Min(P_i^{\max}, P_i^0 + UR_i) \qquad (5)$$

Where P_i is the current output power, and ^0P_i is the previous output power. UR_i is the up-ramp limit of the ith generator (MW/time-period), and DR_i is the down-ramp-limit of the ith generator (MW/time-period). The transmission losses are represented by:

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

The modified form of the cost equation of the n-generator system is given by:

$$F_t = \sum_{i=1}^{n} a_i P_i^2 + b_i P_i + c_i + g_i (d_i P_i^2 + e_i P_i + f_i) \text{ \$/h} \qquad (7)$$

The analytical nature of the above problem formulation leads to the high possibility of an accurate solution for the economic power dispatch problem including transmission losses.

3. Novel TANAN's Algorithm

Novel TANAN's Algorithm (NTA) is specially defined for solving economic dispatch problems. The algorithm is stated as follows. The TANAN function is given by

$$T_i = r_i + s_i x + t_i x^2 \qquad (8)$$

With a power balance constraint

$$T_m = P_d + P_l - \sum_{\substack{i=1 \\ i \ne m}}^{n} T_i \qquad (9)$$

Where

Ti - TANAN function

r_i, s_i & t_i - coefficients of TANAN function

x - TANAN function variable

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The coefficients r_i, s_i and t_i have been assumed to be the minimum limit of i^{th} generator. The TANAN function variable 'x' is a random variable assumed to vary from 0 to 2.The value of each TANAN function is equivalent the power output of that particular generator. Since the TANAN function is a parabolic function, which has an extreme lowest point that corresponds to the optimum value of fuel cost.

3.1 Algorithm

Step1: Assign TANAN function to each generator.
Step2: Initialize r_i, s_i and t_i values.
Step3: Initialize the value of x
Step4: Assign $P_i = T_{i.}$
Step5: If $P_i \leq P_{imin}$ then fix $P_i = P_{imin}$ and if $P_i \geq P_{imax}$ then fix $P_i = P_{imax}$.
Step6: Verify P_d and generator constraints, if not adjust the value of x and go to step 3.
Step7: If satisfied, notify the fuel cost values and stop the process.

3.2 Flow chart

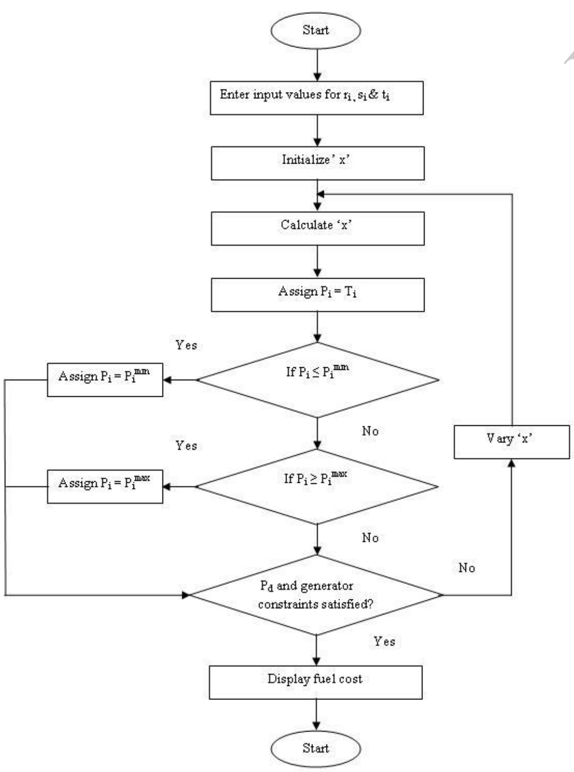

Fig1.flow chart for NTA method

4. Simulation Results

The NTA for ELD problems has been implemented in MATLAB and it was run on a computer with Intel Core2 Duo 2.0 GHz processor, 3GB RAM memory and Windows XP operating system. Since the performance of the proposed algorithm sometimes depends on input parameters, they should be carefully chosen. After several runs, the following results were obtained and are tabulated.

Table 1. Economic dispatch results for 6-unit system

Unit power output (MW)	IDP method	PSO method	GA method	**NTA Method** (x=1.072)
P1	450.9555	447.497	474.8066	**424.039**
P2	173.0184	173.3221	178.6363	**161.059**
P3	263.637	263.4745	262.2089	**257.695**
P4	138.0655	139.0594	134.2826	**150.000**
P5	164.9937	165.4761	151.9039	**161.059**
P6	85.3094	87.128	74.1812	**120.000**
Total Power (MW)	1275.98	1276.01	1276.03	**1273.848**
Total output Loss (MW)	12.9794	12.9584	13.0217	**10.848**
Total generation cost ($/h)	15450	15450	15459	**15441**

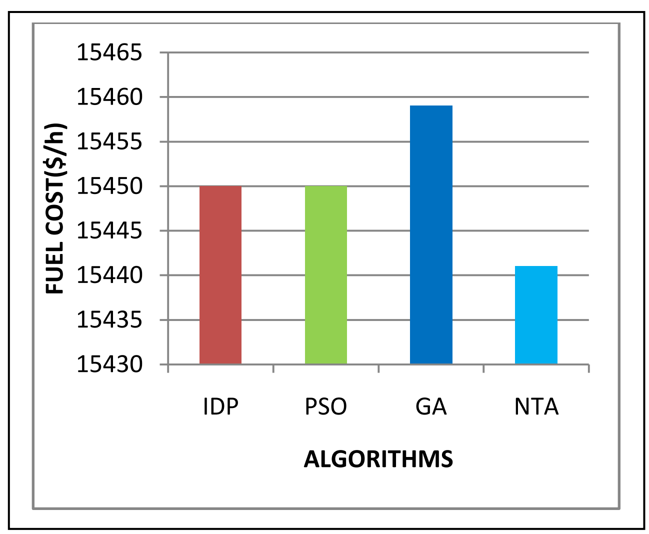

Fig2. Comparison chart for fuel cost

Table 2. Economic dispatch results for 15-unit system

Unit power output (MW)	IDP method	PSO method	GA method	Proposed NTA method
P1	455.000	439.1162	415.3108	405.241
P2	420.000	407.9727	359.7206	405.241
P3	130.000	119.6324	104.425	54.032
P4	130.000	129.9925	74.9853	54.032
P5	270.000	151.0681	380.2844	468.253
P6	460.000	459.9978	426.7902	364.717
P7	430.000	425.5601	341.3164	364.717
P8	60.000	98.5699	124.7867	162.097
P9	25.000	113.4936	133.1445	67.540
P10	63.0411	101.1142	89.2567	67.540
P11	80.000	33.9116	60.0572	54.032
P12	80.000	79.9583	49.9998	54.032
P13	25.000	25.0042	38.7713	67.540
P14	15.000	41.414	41.9425	40.524
P15	15.000	35.614	22.6445	40.524
Total output	2658.04	2662.4	2668.4	2670.064
Loss (MW)	27.9777	32.4306	38.2782	40.064
Total generation cost ($/h)	32590	32858	33113	33319

Table 3. Economic dispatch results for 40- unit system

Unit	Generation (MW) IDP	Generation (MW) NTA (X=0.346)	Fuel cost (NTA) ($)	Unit	Generation (MW) IDP	Generation (MW) NTA (X=0.346)	Fuel cost (NTA) ($)
P1	40.5439	52.766	469.03	P21	456.6654	372.292	3667.29
P2	60	52.766	469.03	P22	460	372.292	3667.29
P3	140.4525	87.943	1088.14	P23	460	372.292	3667.29
P4	24	117.257	1457.71	P24	460	372.292	3667.29
P5	26	68.889	571.54	P25	460	372.292	3828.52
P6	115	99.669	1138.11	P26	460	372.292	3828.52
P7	110	161.229	1542.59	P27	460	14.657	1215.89
P8	217	197.872	1967.74	P28	10	14.657	1215.89
P9	265	197.872	1986.06	P29	10	14.657	1215.89
P10	130	130.190	2504.80	P30	10	68.889	571.54
P11	205	137.777	2510.29	P31	20	87.943	800.77
P12	205	137.777	1937.25	P32	20	87.943	800.77
P13	125	183.214	3344.90	P33	20	87.943	800.77
P14	132.0895	183.214	3632.44	P34	20	131.914	1290.24
P15	125	183.214	3642.37	P35	18	131.914	1298.95
P16	125	183.214	3642.37	P36	18	131.914	1255.42
P17	125	322.458	3543.29	P37	20	36.643	544.53
P18	456.6654	322.458	3538.68	P38	25	36.643	544.53
P19	458.9178	354.703	3868.61	P39	25	36.643	544.53
P20	456.6654	354.703	3868.59	P40	25	354.703	3868.61
Total power generation and Total Cost					7000	7000	85018.74

5. CONCLUSION

The proposed NTA to solve PED problem with the practical constraints has been presented in this paper. It is clear that the NTA is a simple numerical random search technique for solving ELD problems. From the simulations, it can be seen that the optimum fuel cost can be obtained by varying the TANAN function variable from 0 to 2 and the proposed NTA gave the best results in very less computational time.

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APPENDIX

Table I. Generating unit capacity and coefficients for 6-unit system

Unit	Pi min	Pi max	ai ($/MW2)	bi ($/MW)	ci ($)	Pi^0	URi (MW/h)	DRi (MW/h)	Prohibited zones (MW)
1	100	500	0.007	7	240	440	80	120	[210-240][350 - 380]
2	50	200	0.0095	10	200	170	50	90	[90 - 110][140 - 160]
3	80	300	0.009	8.5	220	200	65	100	[150-170][210 - 240]
4	50	150	0.009	11	200	150	50	90	[80 - 90][110 - 120]
5	50	200	0.008	10.5	220	190	50	90	[90 - 110][140 - 150]
6	50	120	0.0075	12	190	110	50	90	[75 - 85][100 - 105]

Table II. Generating unit data for 15-unit system

Unit	Pi min	Pi max	ai	bi	ci	URi	DRi	Pi^0
1	150	455	0.000299	10.1	671	80	120	400
2	150	455	0.000183	10.2	574	80	120	360
3	20	130	0.001126	8.8	374	130	130	105
4	20	130	0.001126	8.8	374	130	130	100
5	150	470	0.000205	10.4	461	80	120	190
6	135	460	0.000301	10.1	630	80	120	400
7	135	465	0.000364	9.8	548	80	120	350
8	60	300	0.000338	11.2	227	65	100	95
9	25	162	0.000807	11.2	173	60	100	105
10	25	160	0.001203	10.7	175	60	100	110
11	20	80	0.003586	10.2	186	80	80	60
12	20	80	0.005513	9.9	230	80	80	40
13	25	85	0.000371	13.1	225	80	80	30
14	15	55	0.001929	12.1	309	55	55	20
15	15	55	0.004447	12.4	323	55	55	20

Table III. Prohibited zones of generating units for 15-unit system

Unit	Prohibited zones (MW)
2	[185 - 225][305 - 335][420 - 450]
5	[180 - 200][305 - 335][390 - 420]
6	[230 - 255][365 - 395][430 - 455]
12	[30 - 40][55 - 65]