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Research Article

A NUMERICAL SOLUTION TO DIFFERENT TYPES OF ECONOMIC LOAD DISPATCH PROBLEMS

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ABSTRACT

This paper presents a newly proposed Novel TANAN's Algorithm (NTA) to solve different types of Economic Load Dispatch (ELD) problems. The main objective of ELD is to minimize the total fuel cost of the generating units, subjected to limits on generator power output, power loss and valve point loading effect. NTA is a numerical random search algorithm based on the concept called parabolic solutions. This paper presents an application of NTA to ELD problems for different types of IEEE standard test systems. The proposed method is compared with various optimization techniques and the simulation results show that the proposed algorithm outperforms previous optimization methods.

Keywords: Constrained Optimization, Economic Load dispatch, Numerical method, TANAN function.

INTRODUCTION

Electrical power systems are designed and operated to meet the continuous variation of power demand. In power system, minimization of the operation cost is very important. Economic load Dispatch (ELD) is a method to schedule the power generator outputs with respect to the load demands, and to operate the power system most economically, or in other words, we can say that main objective of economic load dispatch is to allocate the optimal power generation from different units at the lowest cost possible while meeting all system constraints.

Over the years, many efforts have been made to solve the ELD problem, incorporating different kinds of constraints or multiple objectives through various mathematical programming and optimization techniques. The conventional methods include Newton- Raphson method, Lambda Iteration method, Base Point and Participation Factor method, Gradient method, etc. However, these classical dispatch algorithms require the incremental cost curves to be monotonically increasing or piece-wise linear. The input/output characteristics of modern units are inherently highly nonlinear (with valve-point effect, rate limits etc) and having multiple local minimum points in the cost function. Their characteristics are approximated to meet the requirements of classical dispatch algorithms leading to suboptimal solutions and therefore, resulting in huge revenue loss over the time.

The conventional optimization methods are not able to solve such problems due to local optimum solution convergence. Meta-heuristic optimization techniques especially Genetic Algorithms (GA) (Walters and Sheble 1993, Bakirtzis et al., 1994), Differential Evaluation (DE) (Storn and Price 1995), Evolutionary programming (EP) (Sinha et al., 2003) , Particle Swarm Optimization (PSO) (Jong-Bae Park et al., 2005) and Biogeography-based optimization (BBO) (Simon 2008) and hybrid optimization techniques like Improved Coordinated Aggregation-Based PSO(ICA-PSO) (John Vlachogiannis and Kwang Lee 2009) , Improved Particle Swarm Optimization (IPSO) (Jong-Bae Park et al., 2010), Hybrid Interior Point Assisted Differential Evolution (IPM-DE) (Nagarjuna Duvvuru and Swarup 2011) , Hybrid Differential Evolution with Biogeography-Based Optimization (HDE-BBO) (Abbas Rabiee et al., 2012) , gained incredible recognition for such types of ELD problems in last decade.

PROBLEM FORMULATION

In this paper a novel algorithm named as Novel TANAN's Algorithm (NTA) is proposed to solve ELD problems. The following lists of problems are solved by using NTA.

ELD problems with and without considering power loss
ELD problems with valve-point effects
Economic Power Dispatch problems
Dynamic Economic Dispatch

Convex ELD Problems

The Economic dispatch problem is a fuel cost minimization of problem when several generators are operated to meet the required power demand. The objective function is given by

$$Minimize F_t = \sum_{i=1}^{n} F_i(P_i) \qquad (1)$$

where F_i (P_i) is the fuel cost equation of the 'i'th plant expressed as follows.

$$F_i(P_i) = \sum_{i=1}^{n} a_i P_i^2 + b_i P_i + c_i \qquad (2)$$

The total fuel cost to be minimized is subject to the following constraints.

$$\sum_{i=1}^{n} P_i = P_d + P_l \qquad (3)$$

$$P_L = \sum_{i=1}^{n}\sum_{j=1}^{n} P_i B_{ij} P_j + \sum_{i=1}^{n} B_{0i} P_i + B_{00} \qquad (4)$$

$$P_i^{\min} \le P_i \le P_i^{\max} \qquad (5)$$

Non-Convex ELD Problems

ELD With Valve Point Effects

The input-output characteristics (or cost functions) of a generator are approximated using quadratic or piecewise quadratic function, under the assumption that the incremental cost curves of the units are monotonically increasing piecewise-linear functions. However, real input-output characteristics display higher-order nonlinearities and discontinuities due to valve-point loading in fossil fuel burning plant. The valve-point loading effect has been modelled as a recurring rectified sinusoidal function, such as the one shown in Fig.1 and equation (6) represents fuel cost including valve point effects.

The practical ELD problem includes ramp rate limits, prohibited operating zones, valve point effects etc. into consideration resulting in a non-convex optimization problem.

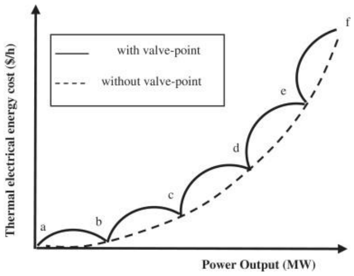

Fig.1: Operating cost characteristics with valve point loading

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i + \left| e_i \sin(f_i(P_i^{\min} - P_i)) \right| \quad (6)$$

Ramp Rate Limit Constraints

The operating ranges of all online units are restricted by their ramp rate limits, for forcing the units operation continually between two adjacent specific periods. The inequality constraints due to ramp rate limits are given by:
if generation increases,

$$P_i - P_i^0 \le UR_i \quad (7)$$

if generation decreases,

$$P_i^0 - P_i \le DR_i \quad (8)$$

Where P_i and P_i^0 are the current and previous power output of unit i, respectively. UR_i and DR_i are the up and down ramp rate limits of the ith generating unit respectively.

➢ *Prohibited Operating Zones (POZ)*

Prohibited operating zones (POZ) in the input-output curves of a generator are due to steam valve operation or vibration in shaft bearing. In actual operation, the best economy is achieved by avoiding operation in these areas. The feasible operation zone of unit i can be given as follows:

$$\left.\begin{aligned} P_i^{\min} &\le P_i \le P_{i,1}^L \\ P_{i,k-1}^U &\le P_i \le P_{i,k}^L \\ P_{i,nz}^U &\le P_i \le P_i^{\max} \end{aligned}\right\} \; k = 1 \ldots nz \quad (9)$$

where P_i^L and P_i^U are the lower and upper limits of prohibited operating zones of ith Generator in MW and nz is the total number of zones.

NOVEL TANAN'S ALGORITHM

The proposed 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

$$T_i = r_i + s_i x + t_i x^2 \quad (10)$$

with a power balance constraint

$$T_m = P_d + P_l - \sum_{\substack{i=1 \\ i \ne m}}^{n} T_i \quad (11)$$

The coefficients r_i, s_i and t_i have been assumed to be the minimum generation limit of the respective 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 to the power output of that particular Generator. Since the TANAN function is a parabolic function, it has an extreme lowest point that corresponds to the optimum value of fuel cost.

NTA Algorithm for convex ELD Problems

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Step1: Assign TANAN function to each Generator.
Step2: Enter input parameters, B-matrix and $r_i$, $s_i$ and $t_i$ values.
Step3: Initialize the value of x.
Step4: Calculate $T_i$ and assign $P_i = T_i$.
Step5: If $P_i \le P_i^{min}$ then fix $P_i = P_i^{min}$ and if $P_i \ge P_i^{max}$ then fix $P_i = P_i^{max}$.
Step6: Verify $P_d$ and generator constraints, if not adjust the value of
        x and go to step 4.
Step7: If satisfied, notify fuel cost, power output and power loss and
        stop the process.
```

For non convex problems POZ and ramp rate and valve point coefficients are included with the algorithm step 2.

SIMULATION RESULTS

The NTA for ELD problem has been implemented in MATLAB and it was run on a computer with Intel Core2 Duo processor of speed 2.0 GHz, 3GB RAM memory and Windows XP operating system. The simulation was done for IEEE standard test systems given in appendix (Table I and II) and the simulation results are tabulated from table 1 to table 9.

Table 1: Generating unit capacity and Fuel cost Co-efficient for IEEE 3- machine test system with P_D=850 MW

Description	Simulation output
x	1.198
P_1(MW)	386.686
P_2(MW)	334.419
P_3(MW)	128.895
Total power (MW)	850
Total fuel cost ($/h)	8194.636
Execution time (sec)	0.05

Table 2: Simulation result for IEEE- 3 machine test system (P_D = 850 MW) including power loss

Description	Simulation output
x	0.585
P_1(MW)	575.942
P_2(MW)	192.723
P_3(MW)	96.361
Total power (MW)	865.026
Power Loss(MW)	15.026
Total fuel cost ($/h)	8426.275
Execution time (sec)	0.08

Table 3: Simulation result for IEEE- 3 machine test system (P_D = 850 MW) with valve-point loading effects

Description	Simulation output
x	1.001
P_1(MW)	300.300
P_2(MW)	399.550
P_3(MW)	150.150
Total power (MW)	850
Total fuel cost ($/h)	8231.906
Execution time (sec)	0.09

Table 4: Power balance constraint and TANAN function variable for best fuel cost to IEEE- 3 machine test system with Valve-point effect (P_D = 850 MW)

Power Balance Constraint	x	Fuel cost ($/h)
T_1	1.300	8371.430
T_2	1.001	8231.906
T_3	1.301	8233.709

Table 5: Comparison table for power output and fuel cost of IEEE-3 machine test system with PD=850 MW

Description	Lambda Iteration method [Wood 1996]	Proposed Method
parameter	λ = 9.148	x =1.198
P_1(MW)	393.2	386.686
P_2(MW)	334.6	334.419
P_3(MW)	122.2	128.895
Total power (MW)	850	850
Total fuel cost ($/h)	8194.3561	8194.636
Average execution time (sec)	-	0.05

Table 6: Comparison Table Showing Simulation Result of NTA for IEEE 3-unit test system (Pd=850 MW) with valve point loading effect

S. No	Algorithms	P_1 (MW)	P_2 (MW)	P_3 (MW)	Power Output (MW)	Fuel cost ($/hr)
1	GA [6]	300	400	150	850	8237.6
2	EP [6]	300.26	400	149.74	850	8234.07
3	TM [6]	300.27	400	149.73	850	8234.07
5	Proposed NTA	300.3	399.55	150.15	850	8231.91

method

Table 7: Economic power dispatch results for 6-unit system

Unit power output (MW)	IDP Method [4]	PSO Method [4]	GA Method [4]	Proposed Method
P_1	450.9555	447.497	474.8066	424.039
P_2	173.0184	173.3221	178.6363	161.059
P_3	263.637	263.4745	262.2089	257.695
P_4	138.0655	139.0594	134.2826	150
P_5	164.9937	165.4761	151.9039	161.059
P_6	85.3094	87.128	74.1812	120
Total Power	1275.98	1276.01	1276.03	1273.848
Total Loss	12.9794	12.9584	13.0217	10.848
Total generation cost ($/h)	15450	15450	15459	15441

Table 8: Best scheduling of 6-unit system for DED problem using NTA method

Hour	P_d (MW)	x	P_1 (MW)	P_2 (MW)	P_3 (MW)	P_4 (MW)	P_5 (MW)	P_6 (MW)	Ploss (MW)	Fuel cost ($/h)
1	955	0.632	390.941	101.571	162.514	101.571	101.571	101.571	4.739	11464.61
2	942	0.616	387.846	99.773	159.636	99.773	99.773	99.773	4.573	11302.73
3	935	0.607	386.356	98.772	158.036	98.772	98.772	98.772	4.482	11215.78
4	930	0.601	385.006	98.11	156.976	98.11	98.11	98.11	4.422	11153.78
5	935	0.607	386.356	98.772	158.036	98.772	98.772	98.772	4.482	11215.78
6	963	0.642	392.68	102.708	164.333	102.708	102.708	102.708	4.846	11564.49
7	989	0.673	398.93	106.296	170.074	106.296	106.296	106.296	5.19	11890.54
8	1023	0.713	406.683	111.068	177.71	111.068	111.068	111.068	5.666	12320.18
9	1126	0.857	417.378	129.572	207.316	129.572	129.572	120	7.412	13634.53
10	1150	0.886	423.434	133.55	213.68	133.55	133.55	120	7.763	13943.78
11	1201	0.943	438.092	141.612	226.58	141.612	141.612	120	8.509	14608.32
12	1235	0.981	447.078	147.168	235.469	147.168	147.168	120	9.051	15056.93
13	1190	0.931	434.861	139.888	223.821	139.888	139.888	120	8.346	14464.13
14	1251	1.008	446.123	151.203	241.925	150	151.203	120	9.454	15269.41
15	1263	1.023	450.166	153.476	245.562	150	153.476	120	9.681	15428.68
16	1250	1.007	445.65	151.052	241.684	150	151.052	120	9.439	15256.17
17	1221	0.966	443.027	144.958	231.932	144.958	144.958	120	8.833	14871.67
18	1202	0.945	437.791	141.901	227.042	141.901	141.901	120	8.537	14621.45
19	1159	0.896	426.16	134.941	215.905	134.941	134.941	120	7.888	14060.32
20	1092	0.817	407.525	124.224	198.759	124.224	124.224	120	6.957	13200.22
21	1023	0.713	406.683	111.068	177.71	111.068	111.068	111.068	5.666	12320.18
22	984	0.667	397.793	105.594	168.951	105.594	105.594	105.594	5.122	11827.67
23	975	0.656	395.825	104.317	166.907	104.317	104.317	104.317	4.999	11714.71
24	960	0.638	392.191	102.252	163.604	102.252	102.252	102.252	4.803	11527.01

Table 9: Fuel cost comparison table for DED problem of IEEE 5 machine test system

S.No	Algorithms	Total cost($/h)
1	PSO [Chakrabarti et al , 2005]	50,124.00
2	MSL [Hemamalini & Simon, 2010]	49,216.81
3	Proposed method	48,654.47

CONCLUSION

The proposed NTA to solve ELD problems with practical constraints has been presented in this paper. From the comparison tables it is observed that the proposed algorithm exhibits a comparative performance with respect to other optimization techniques. From the simulations, it can be seen that NTA gave the best result of optimum fuel cost and very less computational time compared to all other optimization methods.

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APPENDIX

Table I: Generating unit capacity and Fuel cost Co-efficient for IEEE 3- machine test system with B-matrix loss co-efficient (Pd=850MW).

Unit	a_i	b_i	c_i	e_i	f_i	P_i^{min} (MW)	P_i^{max} (MW)
1	0.00156	7.92	561	300	0.0315	150	600
2	0.00194	7.85	310	200	0.042	100	400
3	0.00482	7.97	78	50	0.063	50	200

$$B = \begin{matrix} 0.0274 & 0.0002 & -0.0045 \\ 0.0002 & 0.0072 & -0.0034 \\ 0.0158 & -0.0034 & 0.0158 \end{matrix}$$

$B_o = [-0.0004469\ -0.0005744\ -0.0008301]$

$B_{oo} = [0.00031232]$

Table II: Generating unit capacity and Fuel cost Co-efficient for IEEE 6- machine test system with B-matrix loss co-efficient (Pd=1263MW)

Unit	P_i min	P_i max	a_i (\$/MW^2)	b_i (\$/MW)	c_i (\$)	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]

$$\mathbf{B = 10^{-3}} \begin{matrix} 1.7 & 1.2 & 0.7 & -0.1 & -0.5 & -0.2 \\ 1.2 & 1.4 & 0.9 & 0.1 & -0.6 & -0.1 \\ 0.7 & 0.9 & 3.1 & 0.0 & -1.0 & -0.6 \\ -0.1 & 0.1 & 0.0 & 2.4 & -0.6 & -0.8 \\ -0.5 & -0.6 & -1.0 & -0.6 & 12.9 & -0.2 \\ -0.2 & -0.1 & -0.6 & -0.8 & -0.2 & 15.0 \end{matrix}$$

$B_0 = 10^{-3}[-0.3908\ -0.1297\ 0.7047\ 0.0591\ 0.2161\ -0.6635]$

$B_{00} = 0.0056$