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A Numerical Random Search Algorithm to Solve Economic Load Dispatch Problems with Valve-Point Effect

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ABSTRACT

Background: The Economic Load Dispatch (ELD) problem in power generation systems is to reduce the fuel cost by reducing the total cost for the generation of electric power. This paper presents an efficient Novel TANAN's Algorithm (NTA), for solving ELD Problem. The main objective is to minimize the total fuel cost of the generating units having quadratic cost characteristics subjected to limits on generator true power output and including valve point loading effects. The NTA is a simple numerical random search approach based on a parabolic TANAN function. This paper presents an application of NTA to ELD for different IEEE standard test systems.

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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 Y 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 KS, 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.

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Economic Load Dispatch With Valve Point Loading:

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

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

where F_t is total fuel cost in \$/h and $F_i(P_i)$ is the fuel cost equation of the 'i'th plant expressed as follows.

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

where a_i , b_i and c_i are the fuel cost coefficients of i^{th} Generator in \$/MW²h, \$/MWh, and \$/h respectively. The total fuel cost to be minimized is subject to the following constraints.

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

where P_i is the output power of i^{th} Generator in MW, P_d and P_l are the system power demand and power loss in MW respectively.

The system power loss is given by the relation

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

where B and B_o are the loss coefficient matrices and B_{00} is the loss coefficient constant.

The inequality constraint is given by

$$P_i^{\min} \leq P_i \leq P_i^{\max} \quad (5)$$

where P_i is the power output of i^{th} Generator in MW, P_i^{\min} and P_i^{\max} are the minimum and maximum generation limit of i^{th} Generator in MW respectively.

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.

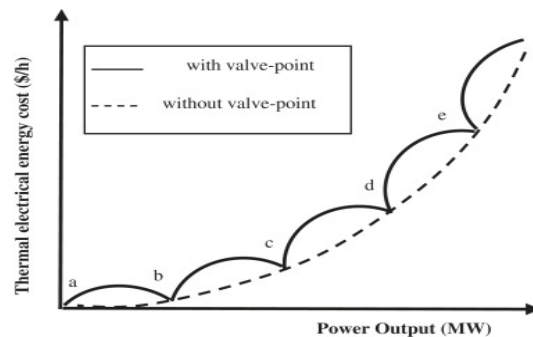


Fig. 1: Operating cost characteristics with valve point loading effect.

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

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

$$T_i = r_i + s_i x + t_i x^2 \quad (7)$$

where

T_i : TANAN Function for i^{th} Generator

r_i, s_i, t_i : coefficients of TANAN function for i^{th} Generator

x : TANAN function Variable with a power balance constraint

$$T_m = P_d + P_l - \sum_{\substack{i=1 \\ i \neq m}}^n T_i \quad (8)$$

The coefficients r_i , s_i and t_i have been assumed to be the minimum generation limit of the 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 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 ELD Problems:

Step1: Assign TANAN function to each Generator.

Step2: Enter input parameters, loss coefficient 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 $P_i \leq P_i^{\min}$ then fix $P_i = P_i^{\min}$ and if $P_i \geq P_i^{\max}$ 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 ELD problems, Prohibited Operating Zone limits, ramp rate limits and valve point coefficients are included in step 2 of the NTA algorithm

Simulation Results:

The NTA for ELD problems valve-point loading effects 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 depends on input parameters, they should be carefully chosen. After several runs, the following results were obtained and are tabulated from table I to table 10.

Table 1: Best result for IEEE- 3 machine test system with $p_d = 850$ MW.

Description	NTA method
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 (\$/MW/h)	8231.906
Avg.execution time (sec)	0.19

From the table 1, the optimum value of fuel cost to meet the necessary and sufficient conditions when the TANAN's variable at $x=1.001$.

Table 2: Individual fuel cost, power output and generator limits for IEEE- 3 machine test system with valve-point effect ($P_d = 850$ mw).

Power balance constraint	x	Fuel cost (\$/hr)
T1	1.300	8371.430
T2	1.001	8231.906
T3	1.301	8233.709

Table 2 shows the minimum and maximum generation limits and individual fuel cost for each machine for the IEEE standard test system with $P_d=850$ MW.

Table 3: 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).

Unit	P_i^{\min} (MW)	P_i^{\max} (MW)	Generation (MW)	Fuel Cost (\$/hr)
1	100	600	300.300	3088.118
2	100	400	399.550	3759.113
3	50	200	150.150	1384.676
Total Generation & Total Cost			850.000	8231.906

Table 3 represent best fuel cost for each x values and the generators considered to meet the required power balance and the optimum cost obtained when T2 as a power balance machine.

Table 4: Best result for IEEE- 5 machine test system with valve-point effect ($P_d=259\text{MW}$).

Description	NTA Method
x	0.068
$P_1(\text{MW})$	200.006
$P_2(\text{MW})$	21.452
$P_3(\text{MW})$	16.089
$P_4(\text{MW})$	10.726
$P_5(\text{MW})$	10.726
Total power (MW)	259
Total fuel cost (\$/MW/h)	703.32
Avg.execution time (sec)	0.29

From Table 4 the optimum fuel cost for IEEE 5 machine standard test system by NTA method when the value of x at 0.068.

Table 5: Individual fuel cost, power output and generator limits for IEEE- 5 machine test system with valve-point effect ($p_d = 259 \text{ MW}$).

Unit	P_i^{\min} (MW)	P_i^{\max} (MW)	Generation (MW)	Fuel Cost (\$/hr)
1	50	250	200.006	550.01
2	20	80	21.452	46.90
3	15	50	16.089	33.87
4	10	35	10.726	36.58
5	10	30	10.726	35.96
Total Generation & Total Cost			259	703.32

Table 5 shows the minimum and maximum generation limits and individual fuel cost for each machine for the IEEE 5 machine standard test system with $P_d=259 \text{ MW}$.

Table 6: Best result for IEEE- 5 machine test system including valve- point effect and power loss ($P_d=259\text{MW}$).

Description	NTA Method
x	0.0
$P_1(\text{MW})$	217.87
$P_2(\text{MW})$	20.00
$P_3(\text{MW})$	15.00
$P_4(\text{MW})$	10.00
$P_5(\text{MW})$	10.00
Total power (MW)	286.74
Total fuel cost (\$/MW/h)	881.244
Power loss (MW)	13.87
Avg.execution time (sec)	0.34

From table 6 the optimum fuel cost for IEEE 5 machine standard test system with valve point loading effect and power loss by NTA method when the value of x= 0.

Table 7: Individual fuel cost, power output and generator limits for IEEE- 5 machine test system including valve-point effect and power loss ($p_d = 259 \text{ MW}$).

Unit	P_i^{\min} (MW)	P_i^{\max} (MW)	Generation (MW)	Fuel Cost (\$/hr)
1	50	250	217.870	707.35
2	20	80	20.000	79.00
3	15	50	15.000	29.06
4	10	35	10.000	33.33
5	10	30	10.000	32.50
Generation & Cost			286.74	881.244

Table 7 shows the minimum and maximum generation limits and individual fuel cost for each machine for the IEEE 5 machine standard test system including valve point effect and power loss.

Table 8: Best result for IEEE- 13 machine test system with valve-point effect ($P_d=2520\text{MW}$).

Description	NTA Method
x	0.894
$P_1(\text{MW})$	448.602
$P_2(\text{MW})$	323.188
$P_3(\text{MW})$	323.188
$P_4(\text{MW})$	161.594
$P_5(\text{MW})$	161.594
$P_6(\text{MW})$	161.594
$P_7(\text{MW})$	161.594

P_8 (MW)	161.594
P_9 (MW)	161.594
P_{10} (MW)	107.729
P_{11} (MW)	107.729
P_{12} (MW)	120.000
P_{13} (MW)	120.000
Total power (MW)	2520
Total fuel cost (\$/MW/h)	24867.48
Avg.execution time (sec)	0.45

From table 8 the optimum fuel cost for IEEE 13 machine standard test system with valve point loading effect by NTA method when the value of $x = 0.894$.

Table 9: Individual fuel cost, power output and generator limits for IEEE- 13 machine test system with valve-point effect ($p_d = 2520$ MW).

Unit	P_i^{\min} (MW)	P_i^{\max} (MW)	Generation (MW)	Fuel Cost (\$/hr)
1	0	680	448.602	4242.098
2	0	360	323.188	3140.841
3	0	360	323.188	3099.960
4	60	180	161.594	1592.891
5	60	180	161.594	1592.891
6	60	180	161.594	1592.891
7	60	180	161.594	1592.891
8	60	180	161.594	1592.891
9	60	180	161.594	1592.891
10	40	120	107.729	1141.394
11	40	120	107.729	1141.394
12	55	120	120.000	1272.228
13	55	120	120.000	1272.228
Generation & Cost			2520	24867.48

Table 9 shows the minimum and maximum generation limits and individual fuel cost for each machine for the IEEE 13 machine standard test system including valve point loading effect with $P_d = 2520$ MW.

Table 10: Comparison table showing simulation result of NTA for IEEE 3-unit test system ($P_d = 850$ MW) with valve point loading effect.

S.No	Algo- rithms	P_1 (MW)	P_2 (MW)	P_3 (MW)	Power (MW)	Fuel cost (\$/hr)
1	GA [12]	300	400	150	850	8237.6
2	MPSO [6]	300.27	400	149.73	850	8234.07
3	EP [6]	300.26	400	149.74	850	8234.07
4	IEP [6]	300.23	400	149.77	850	8234.07
5	TM [6]	300.27	400	149.73	850	8234.07
6	ABC [7]	300.26	400	149.74	850	8234.07
7	NTA	300.30	399.55	150.15	850	8231.91

From table 10, the proposed algorithm shows a better performance than the existing method.

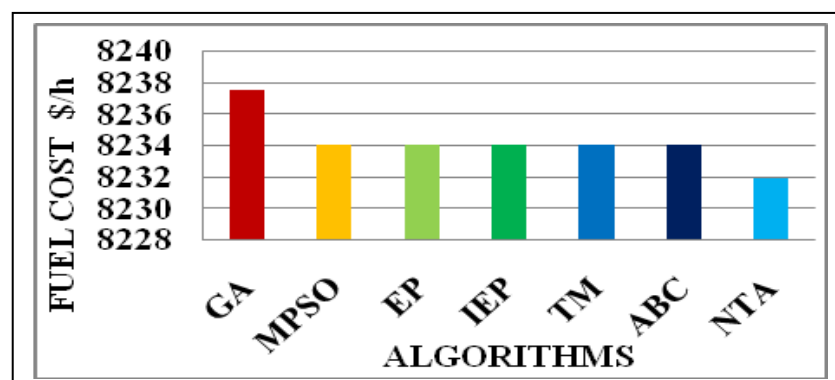


Fig. 2: Comparison chart for fuel cost with various optimization algorithms for IEEE-3 machine test system ($P_d = 850$ MW) with valve point loading effects.

Conclusion:

The proposed NTA to solve ELD problem with the valve point effect 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 NTA gave the best result very less computational time. In future, the proposed NTA can be used to solve ELD considering ramp rate limits and prohibited operating zones and also for finding the optimal value of the NTA variable 'x' by developing standard search techniques.

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