An Efficient Novel TANAN's Algorithm for Solving Economic Load Dispatch Problems

R.Subramanian, K.Thanushkodi

Abstract - The Economic Load Dispatch (ELD) problems 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 transmission losses and including valve point loading effects. The NTA is a simple numerical approach based on a parabolic TANAN function. This paper presents an application of NTA to ELD for different IEEE standard test systems. ELD is applied and compared with various optimization techniques. The simulation results show that the proposed algorithm outperforms previous optimization methods.

Keywords: Economic Load dispatch, Evolutionary Programming (EP), Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Taguchi Method(TM).

Nomenclature

a_i, b_i, c_i : fuel cost coefficient of i^{th} generator ($\$/MW^2 h$, \$/MWh, \$/h)
F_i : fuel cost of i^{th} generator, \$/h
Ft : total fuel cost, \$/h
N : number of generators
Pi : output of i^{th} generator, MW
Pimax : maximum generation limit of i^{th} generator, MW
Pimin : minimum generation limit of i^{th} generator, MW
P_l : total system transmission loss, MW
P_d : system power demand, MW
B : transmission loss coefficient matrix
T_i : TANAN Function
r_i ,s_i ,t_i : coefficients of TANAN function
x : TANAN function Variable

I. INTRODUCTION

Electrical power industry restructuring has created highly vibrant and competitive market that altered many aspects of the power industry. In this changed scenario, scarcity of energy resources, increasing power generation cost, environment concern, ever growing demand for electrical energy necessitate optimal dispatch. Economic Load Dispatch (ELD) is one of the important optimization problems in power systems that have the objective of dividing the power demand among the online generators economically while satisfying various constraints. Since the cost of the power generation is exorbitant, an optimum dispatch saves a considerable amount of money. Optimal generation dispatch is one of the most important problems in power system engineering, being a technique commonly used by operators in every day system operation.

Optimal generation seeks to allocate the real and reactive power throughout power system obtaining optimal operating state that reduces cost and improves overall system efficiency. The economic dispatch problem reduces the system cost by allocating the real power among online generating units. In the economic dispatch problem the classical formulation presents deficiencies due to simplicity of models. Here, the power system modelled through the power balance equation and generators are modelled with smooth quadratic cost functions and generator output constraints.

To improve power system studies, new models are continuously being developed that result in a more efficient system operation. Cost functions that consider valve point loadings, fuel switching, and prohibited operating zones as well as constraints that provide more accurate representation of system such as: emission, ramp rate limits, line flow limits, spinning reserve requirement and system voltage profile. The improved models generally increase the level of complexity of the optimization problem due to the non-linearity associated with them.

Traditional algorithms like lambda iteration, base point participation factor, gradient method, and Newton method can solve the ELD problems effectively if and only if the fuel-cost curves of the generating units are piece-wise linear and monotonically increasing. The basic ELD considers the power balance constraint apart from the generating capacity limits. However, a practical ELD must take ramp rate limits, prohibited operating zones, valve point effects, and multi fuel options into consideration to provide the completeness for the ELD formulation. The resulting ELD is a non-convex optimization problem, which is a challenging one and cannot be solved by the traditional methods.

Practical ELD problems have nonlinear, non-convex type objective function with intense equality and inequality constraints. Recent advances in computation and the search for better results of complex optimization problems have fomented the development of techniques known as Evolutionary Algorithms. These algorithms provide an alternative for obtaining global optimal solutions, especially in the presence of non-continuous, non-convex, highly solution spaces. These algorithms are population based techniques which explore the solution space randomly by using several candidate solutions instead of the single solution estimate used by many classical techniques. The success of evolutionary algorithms lies in the capability of finding solutions with random exploration of the feasible region rather than exploring the complete region. This results in a faster optimization process with lesser computational resources while maintaining the capability of finding global optima. The conventional optimization methods are not able to solve such problems due to local optimum solution convergence.

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R.Subramanian, Associate Professor/EEE, Akshaya College of Engineering and Technology, Coimbatore, INDIA.
Dr.K.Thanushkodi , Director, Akshaya College of Engineering and Technology, Coimbatore, INDIA.

Meta-heuristic optimization techniques especially Genetic Algorithms (GA) [1], Particle Swarm Optimization (PSO) [12] and Differential Evaluation (DE) [7] gained an incredible recognition as the solution algorithm for such type of ELD problems in last decade.

II. PROBLEM FORMULATION

The objective of the classical ELD is to minimize the total fuel cost by adjusting the power output of each of the generators connected to the grid. The total fuel cost is modelled as the sum of the cost function of each generator.
The basic economic dispatch problem can be described mathematically as a minimization of problem.

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

Where $F_i(P_i)$ is the fuel cost equation of the 'i'th plant. It is the variation of fuel cost in $ with generated Power (MW).

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i \quad \text{.... (2)}$$

The total fuel cost to be minimized is subject to the following constraints and equation (6) represents fuel cost including valve point loading.

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

$$P_l = \sum_{i}^{n} \sum_{j}^{n} P_i B_{ij} P_j \quad \text{.... (4)}$$

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

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i + |e_i \sin(f_i(P_{i\,min} - P_i))| \quad \text{--- (6)}$$

III. ECONOMIC LOAD DISPATCH WITH VALVE POINT LOADING

Economic load dispatch (ELD) is considered one of the key functions in electric power system operation. The economic load dispatch problem is commonly formulated as an optimization problem, with the aim of minimizing the total generation cost of power system but still satisfying specified constrains. 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.

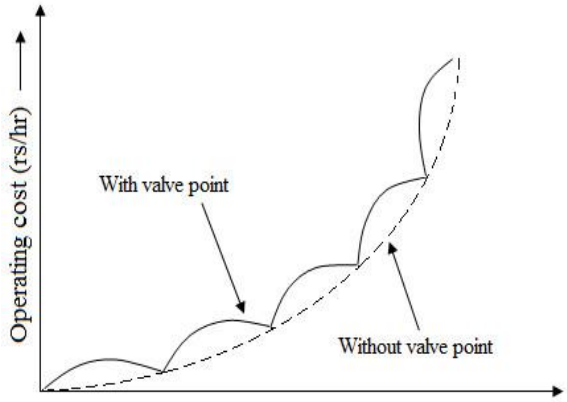


Fig.1 operating cost characteristics with valve point loading

The NTA for ELD problem have implemented in MATLAB and it was run on a computer with Intel Core2 Duo 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.

IV. NOVEL TANAN's ALGORITHM

The 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

$$T_i = r_i + s_i * x + t_i * x^2 \quad \text{---- (7)}$$

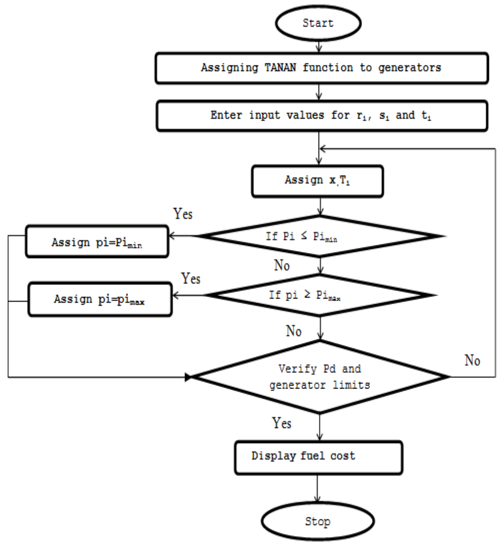
Where
Ti - TANAN function
r_i, s_i & t_i - coefficients of TANAN function
x - TANAN function variable

The coefficients r_i, s_i and t_i has been selected by taking the minimum limits of i^{th} generator respectively. The TANAN's variable x is a random variable and it ranges from 0 to 2.The value of 'x' has been selected by twenty random trial runs between 0 to 2 (tested for all IEEE standard test systems) with an increment of 0.1 and the value corresponds to minimum fuel cost has been taken from the twenty random trials and its value is again fine-tuned by several trial runs to get optimum fuel cost. Each generator is assigned by individual TANAN function and the value obtained from each TANAN function is considered as the power output of that particular generator ($T_i = P_i$).Since the TANAN function is a parabolic function and it has an extreme lowest point that corresponds to optimum value of fuel cost.

A. Algorithm:

Step1:Assign TANAN function to each generator
Step2:Initialize r_i, s_i and t_i values
Step3:Assign the value of x by several trial runs
Step4:Assign $T_i = P_i$
Step5:If $P_i \leq$ Pimin then fix Pi = Pimin and if Pi $\geq$ Pimax then fix Pi = Pimax
Step6:Verify all the generator output values lie within the range, if not adjust the value of x to meet the requirements.
Step7:Notify the fuel cost values and stop the process

B. Flowchart



V.SIMULATION RESULTS

The NTA for ELD problem have implemented in MATLAB and it was run on a computer with Intel Core2 Duo 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- Results of IEEE- 3 unit (Pd= 850 MW) test system without considering the power loss for different 'x' values by NTA.

S.No	x	Fuel Cost ($/MW/h)
1	0.1	8463.068919
2	0.2	8417.590792
3	0.3	8370.357420
4	0.4	8323.615112
5	0.5	8279.909688
6	0.6	8242.086472
7	0.7	8213.290299
8	0.8	8196.965512
9	0.9	8196.855959
10	1.0	8217.005000

From the table 1, the value of' x' lies in the range of 0.8 to 0.9 for the minimum fuel cost and to meet the power demand and the optimum value of x is again fine tuned by several random trials and the optimum value for minimum fuel cost obtained at x=0.8515 as shown in table 2.

Table 2- Best result from IEEE- 3 unit test system (Pd = 850 MW) without considering the Power loss (x = 0.8515)

Description	NTA
P_1(MW)	386.483
P_2(MW)	334.689
P_3(MW)	128.828
Total power(MW)	850.000
Total fuel cost($/MW/h)	**8194.636**
Execution time(sec)	0.014

Table 3-Results of IEEE- 3 unit (Pd=850MW) test system including valve point loading effect for different 'x' values by NTA.

S.No	x	Total cost ($/MW/h)
1	0.0	8626.212
2	0.1	8812.339
4	0.3	8957.678
5	0.4	8851.502
6	0.5	8844.216
7	0.6	8453.634
8	0.7	8692.171
9	0.8	8698.541
10	0.9	8706.624
11	1.0	8232.539
12	1.1	8691.328

From the table 3, the value of' x' lies in the range of 0.8 to 0.9 for the minimum fuel cost and to meet the power balance and the optimum value of x is again fine tuned by and the optimum value for minimum fuel cost obtained at x=1.001 as shown in table 4.

Table 4- Best result from IEEE- 3 unit test system (Pd = 850 MW) including valve point loading effect.

Description	NTA
P_1(MW)	300.300
P_2(MW)	399.550
P_3(MW)	150.150
Total power(MW)	850.00
Total fuel cost($/MW/h)	8231.906
Execution time(sec)	0.011

Table5-Results from IEEE-6 unit (Pd=1263MW) test system including power loss for different 'x' values by NTA.

S.No	x	Total cost ($/MW/h)
1	0.1	17663.633868
2	0.2	17345.105985
3	0.3	17006.852142
4	0.4	16661.403537
5	0.5	16322.951103
6	0.6	16007.341338
7	0.7	15732.071669
8	0.8	15518.936844
9	0.9	15384.724833
10	1.0	15321.137612
11	1.1	15324.437566

From the table 5, the value of' x' lies in the range of 1.0 to 1.1 for the minimum fuel cost and to meet the power balance and the optimum value of x is again fine tuned and the optimum value of fuel cost obtained at x=1.05 as shown in table 6.

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Table 6- Best result from IEEE- 6 unit test system (Pd = 1263 MW) including valve point loading effect.

Description	NTA
P_1(MW)	426.753
P_2(MW)	157.625
P_3(MW)	252.200
P_4(MW)	150.000
P_5(MW)	157.625
P_6(MW)	120.000
Total power (MW)	1264.203
Total fuel cost ($/MW/h)	**15314.858**
Power loss (MW)	1.203
CPU time (sec)	0.003

Table 7 - Comparison Table Showing Simulation Result of NTA for IEEE 3-unit test system (Pd=850 MW) with valve point loading effect along with GA [10], MPSO [10], EP [10], IEP [10], TM [11] and ABC [10] Algorithms.

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

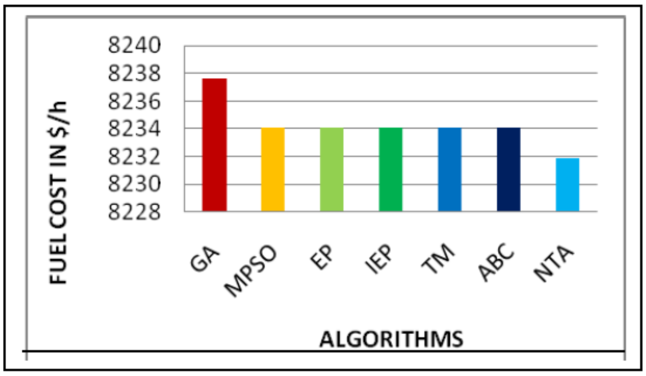

Fig-2 Comparison chart for fuel cost for IEEE-3 machine test system (Pd=850MW) with valve point loading.

VI. CONCLUSION

The proposed NTA to solve ELD problem with the practical constraints has been presented in this paper. From the comparison table it is observed that the proposed algorithm exhibits a comparative performance with respect to other population based techniques. 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 of minimized fuel cost, reduced power loss and very less computational time compared to all other optimization methods. 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.

APPENDIX

IEEE standard test system data and the loss co-efficient matrix for the ELD problems are given in table I to II.

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	Pimin (MW)	Pimax (MW)
1	0.001562	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

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

Table II - Generating unit capacity and Fuel cost Co-efficient for IEEE 6- machine test system with B-matrix loss co-efficient (Pd=283.4MW)

Unit	a_i	b_i	c_i	e_i	f_i	Pimin (MW)	Pimax (MW)
1	0.00375	2	0	15	0.06283	50	250
2	0.0175	1.75	0	10	0.08976	20	160
3	0.0625	1	0	10	0.14784	15	100
4	0.00834	3.25	0	5	0.20944	10	70
5	0.025	3	0	5	0.25133	10	60
6	0.025	3	0	5	0.1848	12	80

$$\mathbf{B = 10^{\wedge}\text{-} 3} \begin{pmatrix} 1.4 & 1.7 & 1.5 & 1.9 & 2.6 & 2.2 \\ 0.17 & 6.0 & 13 & 16 & 15 & 2.0 \\ 0.15 & 13 & 6.5 & 1.7 & 2.4 & 1.9 \\ 0.19 & 1.6 & 1.7 & 7.1 & 3.0 & 2.5 \\ 0.26 & 1.5 & 2.4 & 3.0 & 6.9 & 3.2 \\ 0.22 & 2.0 & 1.9 & 2.5 & 3.2 & 8.5 \end{pmatrix}$$

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AUTHORS PROFILE

R. Subramanian received the B.E degree in Electrical and Electronics Engineering from Coimbatore Institute of Technology in the year 2005 and M.E degree in Power Systems Engineering from Government College of Technology, Coimbatore in the year 2007. He is currently doing PhD in the area of Power system control and operation under Anna University. Presently he is working as an Associate professor in the Department of Electrical and Electronics Engineering at Akshaya College of Engineering and Technology, Coimbatore. His research interests are power system analysis, power system control and operation, mathematical computations, optimization and Soft Computing Techniques.

K. Thanushkodi received his B.E. degree in Electrical and Electronics Engineering from College of Engineering, Guindy in the year1972. He has received M.Sc. (Engg.) degree from PSG College of Technology, Coimbatore in the year1974. He has received PhD degree in Power Electronics from Bharathiyar University in the year 1991. Presently he is the Director of Akshaya College of Engineering and Technology, Coimbatore and he is a former Syndicate Member, Anna University of Technology, Coimbatore. His research interests are Power Electronics Drives, Electrical Machines, Power Systems, and Soft Computing techniques, Computer Networks, Image Processing and Virtual Instrumentation.