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A Novel TANAN's Algorithm for Solving Economic Load Dispatch Problems

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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 a Novel TANAN's Algorithm (NTA) for solving ELD Problems. The main objective of NTA is to minimize the total fuel cost of the generating units subjected to limits on generator true power output, power loss. The NTA is a simple numerical random search approach based on a parabolic TANAN function. This paper presents an application of NTA to ELD problems for different IEEE standard test systems. ELD is applied and compared with various optimization techniques and the simulation results show that the proposed algorithm outperforms previous optimization methods.

Index Terms- 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 coefficients of i^{th} generator ($/MW^{2}h, $/MWh, $/h)
F_i	: Fuel cost of i^{th} generator, $/h
F_t	; Total fuel cost, $/h
n	:Number of generators
P_i	: Output of i^{th} generator, MW
P_{imax}	: Maximum generation limit of i^{th} generator, MW
P_{imin}	: Minimum generation limit of i^{th} generator, MW
P_l	: Power loss, MW
P_d	: System power demand, MW
B	: Loss coefficient matrix
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

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. 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 classical ELD problem is an optimization problem that determines the power output of each online generator that will result in a least cost system operating state. The objective of the classical economic dispatch is to minimize the total system cost where the total system cost is a function composed by the sum of the cost functions of each generator. This power allocation is done considering system balance between generation and loads, and feasible regions of operation for each generating unit.

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.

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

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).

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i \qquad (2)$$

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

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

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

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

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

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

with a power balance constraint

$$T_1 = P_d + P_l - \sum_{2}^{n} T_i \qquad (8)$$

Where

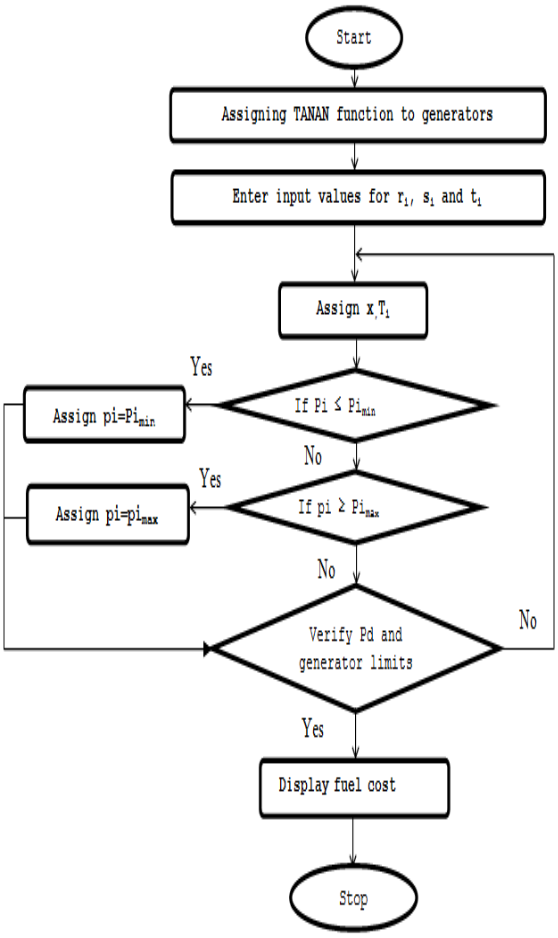
Ti	- TANAN function
r_i, s_i & t_i	- coefficients of TANAN function
x	- TANAN function variable

The coefficients r_i, s_i and t_i has been selected y taking the minimum limits of i^{th} generator respectively. The TANAN function variable 'x' is a random variable and it ranges from 0 to 2.The value of 'x' has been selected by maximum of 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 random trials and its value is again fine-tuned by several trial runs to get the optimum value of fuel cost. Each generator is assigned by individual TANAN function and the value of 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 , it has an extreme lowest point that corresponds to the optimum value of fuel cost.

A. Algorithm:

Step1:Assign TANAN function to each generators.
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 $P_i \le$ Pimin then fix Pi = Pimin and if Pi ≥ Pimax then fix Pi = Pimax.
Step6:Verify P_d and generator limits lie within the given range, if not adjust the value of x to meet the power balance.
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 machine (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 machine test system (Pd = 850 MW) without considering the Power loss
(x = 0.8515)

Description	NTA
P_1(MW)	386.482838
P_2(MW)	334.689550
P_3(MW)	128.827613
Total power(MW)	850.000000
Total fuel cost($/MW/h)	8194.636018
Execution time(sec)	0.001474

Table 3-Results from IEEE-6 machine (Pd=1263MW) test system including power loss for different 'x' values by NTA.

S.No	x	**Total cost** ($/MW/h)
1	0.1	17655.684680
2	0.2	17345.865169
3	0.3	17017.906250
4	0.4	16684.352690
5	0.5	16359.349516
6	0.6	16058.615066
7	0.7	15799.410956
8	0.8	15602.409125
9	0.9	15480.812974
10	**1.0**	**15430.182993**
11	1.1	15447.425273
12	1.2	15534.553158

From the table 3, 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 by several random trials and the optimum value for minimum fuel cost obtained at x=1.03 as shown in table 4.

Table 4 -Best result of IEEE- 6 machine (Pd=1263MW) test system including power loss (**x**=1.03)

Description	NTA
P_1(MW)	446.420479
P_2(MW)	154.545000
P_3(MW)	247.272000
P_4(MW)	150.000000
P_5(MW)	154.545000
P_6(MW)	120.000000
Total power (MW)	1272.782479
Total fuel cost ($/MW/h)	15428.730294
Power loss (MW)	9.782479
CPU time (sec)	0.254221

Table 5- Results from IEEE-6 machine (Pd=283.4MW) test system including power loss for different 'x' values by NTA.

S.No	x	**Total cost** ($/MW/h)
1	0.1	977.218838
2	0.2	975.744877

3	**0.3**	**976.117638**
4	0.4	979.222847
5	0.5	986.062392
6	0.6	997.753602
7	0.7	1015.528440
8	0.8	1040.732620
9	0.9	1074.824641
10	1.0	1119.374738

From the table 5, the value of' x' lies in the range of 0.2 to 0.3 for the minimum fuel cost and to meet the power balance 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=0.235 as shown in table 6.

Table 6-Best result of IEEE- 6 machine (Pd=283.4MW) test system including power loss (**x=0.235**)

Description	NTA
P_1(MW)	197.352501
P_2(MW)	25.804500
P_3(MW)	19.353375
P_4(MW)	12.902250
P_5(MW)	12.902250
P_6(MW)	15.482700
Total power (MW)	283.797576
Total fuel cost ($/MW/h)	975.622401
Power loss (MW)	0.397576
CPU time (sec)	0.003089

Table 7- Results from IEEE-15 machine (Pd=2640 MW) test system including power loss for different 'x' values by NTA.

S.No	x	Total cost ($/MW/h)
1	0.1	33386.921422
2	0.2	33333.759960
3	**0.3**	33284.089414
4	0.4	33242.851931
5	0.5	33215.609374
6	0.6	33208.528755
7	0.7	33228.366041
8	0.8	33282.448369
9	0.9	33378.654686
10	1.0	33525.394866

From the table 7, the value of' x' lies in the range of 0.7 to 0.8 for the minimum fuel cost and to meet the power balance 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=0.747 as shown in table 8.

Table 8 -Best result of IEEE- 15 machine (Pd=2640 MW) test system including power loss (**x=0.747**)

Description	NTA
P_1(MW)	448.431247
P_2(MW)	410.292150
P_3(MW)	54.705620
P_4(MW)	54.705620
P_5(MW)	410.292150
P_6(MW)	369.262935
P_7(MW)	369.262935
P_8(MW)	164.116860
P_9(MW)	68.382025
P_{10}(MW)	68.382025
P_{11}(MW)	54.705620
P_{12}(MW)	54.705620
P_{13}(MW)	68.382025
P_{14}(MW)	41.029215
P_{15}(MW)	41.029215
Total power (MW)	2677.685262
Total fuel cost ($/MW/h)	**33389.662792**
Power loss (MW)	37.685262
CPU time (sec)	0.007171

Table 9- Results from IEEE-20 machine (Pd=2500 MW) test system including power loss for different 'x' values by NTA.

S.No	x	Total cost ($/MW/h)
1	0.1	61355.381113
2	0.2	61295.578628
3	0.3	61271.142479
4	0.4	61300.750489
5	0.5	61405.293039
6	0.6	61607.772058
7	0.7	61933.190026
8	0.8	62408.429576
9	0.9	63062.124409
10	1.0	63906.958143

From the table 9, the value of' x' lies in the range of 0.7 to 0.8 for the minimum fuel cost and to meet the power balance 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=0.747 as shown in table 10.

Table 10-Best result of IEEE- 15 machine (Pd=2500 MW) test system including power loss (**x=0.747**)

Description	NTA
P_1(MW)	599.962597
P_2(MW)	115.250450
P_3(MW)	115.250450
P_4(MW)	115.250450
P_5(MW)	115.250450
P_6(MW)	46.100180
P_7(MW)	57.625225
P_8(MW)	115.250450
P_9(MW)	115.250450
P_{10}(MW)	69.150270
P_{11}(MW)	230.500900
P_{12}(MW)	345.751350
P_{13}(MW)	92.200360
P_{14}(MW)	46.100180
P_{15}(MW)	57.625225
P_{16}(MW)	46.100180
P_{17}(MW)	69.150270
P_{18}(MW)	69.150270
P_{19}(MW)	92.200360
P_{20}(MW)	69.150270
Total power (MW)	2582.270337
Total fuel cost ($/MW/h)	**62136.184169**

Power loss 798(MW)	82.270337
CPU time (sec)	0.009748

Table 11 - Comparison Table Showing Simulation Result of NTA for IEEE 3-unit test system (Pd=850 MW) with valve point loading effect along with GA [1], PSO [9],DE[9],NPSO-LRS[8],BFO[9]and BBO [9] Algorithms.

Sl. No	Description	GA	PSO	DE	NPSO-LRS	BFO	BBO	NTA
1.	P_1 (MW)	474.8066	447.8066	447.744	446.96	449.46	447.3997	**446.420479**
2.	P_2 (MW)	178.6363	178.6363	173.407	173.3944	172.88	173.2392	**154.545000**
3.	P_3 (MW)	262.2089	262.2089	263.411	262.3436	263.41	263.3163	**247.272000**
4.	P_4 (MW)	134.2826	134.2826	139.076	139.512	143.49	138.0006	**150.000000**
5.	P_5 (MW)	151.9039	151.9039	165.364	164.7089	164.91	165.4104	**154.545000**
6.	P_6 (MW)	74.1812	74.1812	86.944	89.0162	81.252	87.07979	**120.000000**
7.	Power Output (MW)	1276.0195	1276.0195	1275.947	1275.9351	1275.402	1275.446	**1272.782479**
8.	P_{loss} (MW)	13.0217	13.0217	12.957	12.9351	12.402	12.446	**15428.730294**
9.	Fuel cost ($/h)	15469	15459	15449.766	15450	15443.8497	15443.096	**9.782479**
10.	Execution time(sec.)	41.58	14.89	NA	NA	NA	0.03	**0.254221**

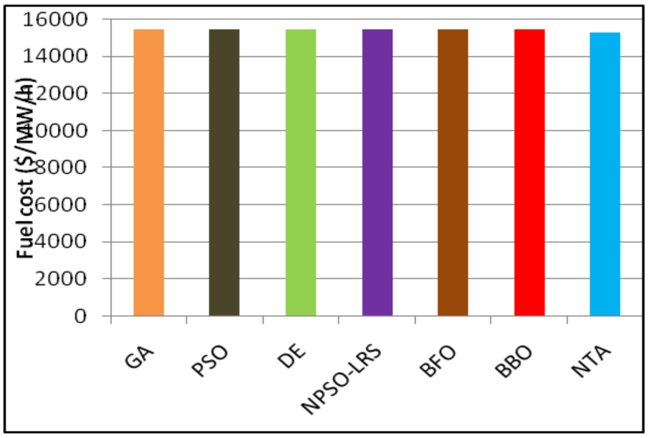


Fig-4 Comparison chart for IEEE-6 machine test system outputs (Pd=1263MW) with power loss.

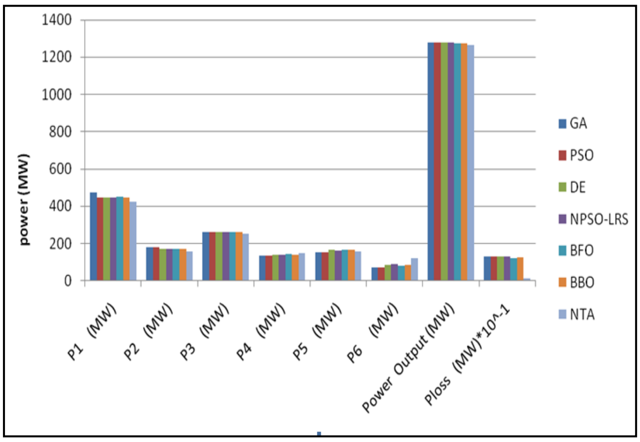


Fig-5 Comparison chart for fuel cost for IEEE-6 machine test system (Pd=1263MW) with power loss.

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.

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