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Environmental/economic power dispatch problem using multi-objective Hybrid Tabu Search and Algorithm Genetic

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***Abstract*— An efficient and optimum economic operation of electric power generation systems has always occupied an important position in the electric power industry. This involves allocation of the total load between the available generating units in such a way that the total cost of operation is kept at a minimum. In recent years this problem has taken a suitable twist as the public has become increasingly concerned with environmental matters, so that economic dispatch now includes the dispatch of systems to minimize pollutants, as well as to achieve minimum cost. This paper proposes a lambda based approach for solving the Combined Economic and Emission Dispatch (CEED) problem using Genetic Algorithm (GA) and Tabu search (TS) methodologies considering the power limits of the generator. The purpose of Combined Economic and Emission Dispatch (CEED) is to minimize both the operating fuel cost and emission level simultaneously while satisfying load demand and operational constraints. This multi-objective CEED problem is converted into a single objective function using a modified price penalty factor approach.**

***Keywords*— combined economic and emission dispatch, CEED, genetic algorithm, population, Tabu search.**

I. INTRODUCTION

In recent years the economic dispatch problem has taken a suitable twist as the public has become increasingly concerned with environmental matters. The absolute minimum cost is not any more the only criterion to be met in the electric power generation and dispatching problems. The generation of electricity from the fossil fuel releases several contaminants, such as sulfur oxides (SO_2), and oxides of nitrogen (NO_X) into the atmosphere.

These gaseous pollutants cause harmful effects on human beings as well as on plants and animals. The Clean Air Act Amendments of 1990 (CAAA) mandates that the electric utility industry should reduce its SO_2 emission by 10 million ton/year and the NO_X by 2 million ton/year from the 1980 level [1].

The limiting levels of emissions over a schedule horizon represent additional operational constraints that are to be satisfied when finding the optimal solution for the economic dispatch problem. The characteristics of emissions of different pollutants are different and are usually highly non-linear. This increases the complexity and non-monotonycity of the emission constrained economic dispatch problem. This work focuses on emission of nitrogen oxides (NOx) only, because its control is a significant issue at the global level.

II. PROBLEM FORMULATION

The traditional economic dispatch problem has been defined as minimizing factor of an objective function i.e. [2, 3] the generation cost function subject to equality constraints (total power generated should be equal to total system load plus losses for all solutions) and inequality constraints (generations should lie between their respective maximum and minimum specified values).

Minimize

$$\Phi(X,P) \quad \Phi_t(P_i) = \sum_{i=1}^{n} \Phi_i(P_i) \qquad (1)$$

Objective function Subject to g(x, P)

$$\sum_{i=1}^{n} P_i - P_L - P_D = 0 \qquad (2)$$

Equality constraints can be summarized as:

$$H(X,P) \le 0 \quad P_{i\min} \le P_i \le P_{i\max} \qquad (3)$$

Inequality constraint

Where x is a state variable, Pi is the control variable, i.e., real power setting of i the generator and n is the number of units or generators

Expression of transmission loss as a function of the generated power is given by:

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

Where Bij is the constant called the losses coefficient.

There are several ways to include emission into the problem of economic dispatch. Reference [4, 5] summarizes the various algorithms for solving environmental dispatch problem with different constraints. One approach is to include the reduction of emission as an objective. In this work, only NOx reduction is considered because it is a significant issue at the global level. A price penalty factor (h) is used in the objective function to combine the fuel cost, Rs/hr and emission functions, kg/hr of quadric form.

$$\varphi_t = \sum_{i=1}^{n} F_i(P_i) + h\sum_{i=0}^{n} E_i(P_i)\frac{Rs}{h} \qquad (5)$$

$$\varphi_t = \sum_{i=1}^{n}(a_iP_i^2 + b_iP_i + c_i) + h\sum_{i=1}^{n}(d_iP_i^2 + e_iP_i + f_i) \quad Rs/h \qquad (6)$$

Subject to equality and inequality constraint as defined by equations (2), (3). Once price penalty factor (h) is known, equation (5) can be rewritten as

$$\varphi_t = \sum_{i=1}^{n}\left\{(a_i + hd_i)P_i^2 + (b_i + he_i)P_i + (c_i + hf_i)\right\} \frac{Rs}{h} \qquad (7)$$

This has the resemblance of the familiar fuel cost equation, once h is determined. A practical way of determining h is discussed by Palanichamy and Srikrishan [6, 7]. Consider that the system is operating with a load of PD MW, it is necessary to evaluate the maximum cost of each generator at its maximum output, i.e.

Evaluate the maximum cost of each generator at its maximum output, ie,

$$F_i(P_{imax}) = \left(a_iP_{imax}^2 + b_iP_{imax} + c_i\right)Rs/hr \qquad (8)$$

Evaluate the maximum NOx emission of each generator at its maximum output, ie,

$$E_i(P_{imax}) = \left(d_iP_{imax}^2 + e_iP_{imax} + f_i\right)kg/hr \qquad (9)$$

Divide the maximum cost of each generator by its maximum NOx emission, i.e.

$$\frac{F_i(P_{imax})}{E_i(P_{imax})} = \frac{\left(a_iP_{imax}^2 + b_iP_{imax} + c_i\right)}{\left(d_iP_{imax}^2 + e_iP_{imax} + f_i\right)}\frac{Rs}{Kg} \qquad (10)$$

Recalling that

$$\frac{F_i(P_{imax})}{E_i(P_{imax})} = h_i \frac{Rs}{Kg} \qquad (11)$$

Arrange h_i (i =1,2,......,n) in ascending order.

(v) Add the maximum capacity of each unit,(P_{imax}) one at a time, starting from the smallest *hi* unit until total demand is met as shown below.

$$\sum_{i=1}^{n} P_{imax} \geq P_D \qquad (12)$$

At this stage, hi associated with the last unit in the process is the price penalty factor h Rs/Kg for the given load.

Arrange hi in ascending order. Let 'h' be a vector having 'h' values in ascending order.

$$h = [h_1; h_2; h_3..........h_n] \qquad (13)$$

For a load of PD starting from the lowest hi value unit, maximum capacity of unit is added one by one and when this total equals or exceeds the load, hi associated with the last unit in the process is the price penalty factor for the given PD. Then equation (6) can be solved to obtain environmental economic dispatch using Lambda iteration method [8].

III. The Genetic Algorithm

Genetic algorithm, which imitates the selection and biological evolutionary process, is a well-known structured random search method [9]. An important aspect of GA as stressed by Holland (1975) [10] was that, given certain conditions on the problem domain, GA would tend to converge on solutions that were globally optimal or nearly so even in a large and complicated search space. GA has been used in a wide range of research fields including design, scheduling, system configuration, financial portfolio management, adaptive control systems, and noisy data interpretation (Gen and Cheng 1997 [11], Holland 1975 [12], Goldberg 1989 [13], Hedberg 1994 [14], Reeves 1994 [15], Tam 1992 [16]). GA has the following features that distinguish itself from other heuristics: (a) a large number of feasible points in the solution space are searched and evaluated simultaneously, (b) the strings of characters which represent the parameter set are dealt with directly, and (c) the probabilistic theory, not a deterministic selection, is used to direct their search. Therefore, GA can decrease the possibility of being trapped into a local minimum and often produces high quality solutions in a shorter period of time. Despite of its effectiveness, several issues yet need to be explored in order to get good solutions:

The representation of chromosome.

- The generation of initial populations.

- The selection of fitness function.
- The selection and design of heuristic genetic operators: reproduction, crossover and mutation [17].

The determination of system parameters: population size, # of generations, crossover probability, mutation probability.

Selection is the process by which strings with better fitness values receive correspondingly better copies in the new generation. That is the more fitness string solutions should have more chances to be copied to the next generation population. The task of crossover is the creation of new individuals (children), out of two individuals (parents) of the current population. Mutation is a background operator, which produces spontaneous random changes in various chromosomes. A simple way to achieve mutation would be to alter one or more genes. In genetic algorithms, mutation serves the crucial role of either replacing the genes lost from the population during the selection process so that they can be tried in a new context or providing the genes that were not present in the initial population [18].

IV. Tabu Search

Tabu search is a metaheuristic that is used to manage a local method to search the solution space without entrapping into a local optimum by means of some strategies. The term “Tabu Search” first appeared in literatures in Glover’s paper (1986) [19]. Hansen (1986) [20] brought up a similar idea and called it “the steepest ascent/mildest descent heuristic”.

Tabu search is an iterative search method. It uses a local search algorithm at each iteration to search for the best solution in some subset of the neighborhood, which came from the best solution obtained at the last iteration. At each iteration, the local search algorithm looks for the best improving solution. If all solutions are not improving the objective function value, then it looks for the least deterioration solution. Tabu search keeps a list, which is called tabu list, of the moves it used to obtain the best solutions during each iteration and to restrict the local search algorithm in reusing those moves. A memory is used to keep track of this tabu list. Usually the tabu list has a pre-specified length. Therefore, this list varies from iterations to iterations.

There are mainly three strategies employed in tabu search: the forbidding strategy, the freeing strategy and the short-term strategy. The foebidding strategy what enters the tabu list. The freeing strategy decides what exits the tabu list and when the exit will occur. The shortterm strategy manages the interplay between the forbidding strategy and freeing strategy to generate and select trial solutions [21].

V. Hybrid TS /GA Algorithm

Hybridization is a trend in many works on metaheuristics past ten years. It takes advantage of the benefits accrued from different metaheuristics, so much so that the basic Metaheuristics are nothing more than canvas, starting points to begin to solve an optimization problem [22].

In the figures below, we propose an optimization method based on a hybrid approach.
The basic idea is to make a combination between the basic metaheuristics TS/AG on one hand

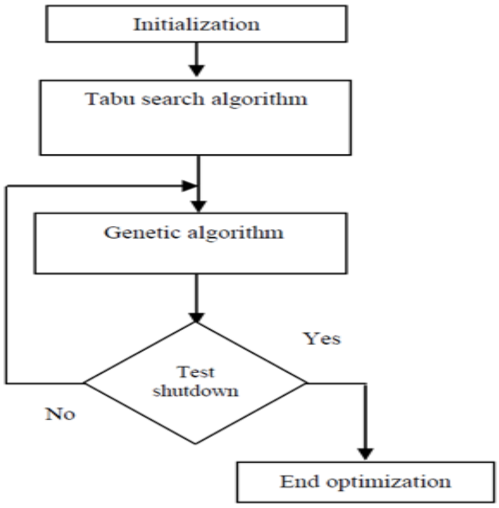

Fig1. TS/GA hybrid algorithm

VI. SIMULATION RESULTS

To assess the efficiency and performance of Hybrid GA/TS, it is applied to three standard test systems of three units, six units and fourteen unit systems. This algorithm is implemented using
MATLAB Software 7.10.0 and the system configuration is Intel. The simulation is performed for 20 repeated trials with 70 iterations per trial.

Test case 1: The system consists of three thermal units. The parameters of all thermal units are presented in table: 1 and table: 2.

Table 1
FUEL COST COEFFICIENT

unit	Fuel cost coefficient			P_{Gmin} (MW)	P_{Gmax} (MW)
	a_i	b_i	c_i		
G1	0.03546	38.30553	1243.53110	35	210
G2	0.02111	36.32782	1656.56960	130	325
G3	0.01799	38.27041	1356.65920	125	315

Table 2
NOX EMISSIN EQUATION IN Kg/h ARE GIVEN BELOW IN

unit	Emission coefficient			P_{Gmin} (MW)	P_{Gmax} (MW)
	d_i	e_i	fc_i		
G1	0.00683	-0.5455	40.26669	35	210
G2	0.00461	-0.5116	42.89553	130	325
G3	0.00461	-0.5116	42.89553	125	315

The Bmn loss coefficient matrix is

$$B_{mn} = \begin{bmatrix} 0.000070 & 0.000025 & 0.000030 \\ 0.000030 & 0.000069 & 0.000032 \\ 0.000025 & 0.000032 & 0.000080 \end{bmatrix}$$

Table 3
COMPARISON OF TEST RESULTS FOR THEREE GENERATING UNITS SYSTEM

PD (MW)	Performance	PSPSO [23]	RGA [24]	ABC [25]	Proposed GA/TS
400	**Fuel cost,RS/hr**	20837.6	20801.8	20838	20837.2961
	Emission ,Kg/hr	**200.230**	**201.21**	**200.2211**	**200.2075**
	PL,MW	7.412	7.39	7.5681	7.3490
	Total cost,Rs/hr	NR	29812	29804.2	29808,329
500	**Fuel cost,RS/hr**	NR	25491.6	25495	25496.204
	Emission ,Kg/hr	NR	**311.33**	**311.1553**	**311.0890**
	PL,MW	NR	11.70	11.1553	11.6071
	Total cost,Rs/hr	NR	39433	39428.3	39435,136
700	**Fuel cost,RS/hr**	35463.6	35471.4	35464	35464.724
	Emission ,Kg/hr	**651.585**	**651.60**	**651.5775**	**651.4647**
	PL,MW	23.638	23.28	23.366	23.2950
	Total cost,Rs/hr	NR	66631	66622.5	64654,824

NR means not reported in the referred literature.

Table: 3 shows the summarized result of CEED problem for load demand of 400MW, 500MW and 700MW are obtained by the proposed Hybrid GA/TS algorithm with stopping criteria based on maximum-generation=70.

Form Table: 3, it is clear that Hybrid GA/TS algorithm gives optimum result in terms of minimum fuel cost, emission level and the total operating cost.

Table: 4 gives the best optimum power output of generators for CEED problem using Hybrid GA/TS algorithm for load demand 400MW, 500MW and 700MW.

Table 4
OPTIMUM POWER DISPATCH RESULTS BY PROPOSED METHOD FOR THREE UNITS SYSTEM

Unit Power Output(MW)	Load Demand (MW)		
	400	500	700
P1	102,565123	130,131507	183,814504
P2	153,881829	192,480954	272,213313
P3	150,945308	189,043429	267,269009
Fuel cost ($/hr)	20837.29612	25496.2048	35464.72440
Emission (kg/hr)	200.207537	311.089004	651.464731
PL(MW)	7.34903	11.6071	23.2950046

The convergence tendency of proposed Hybrid GA/TS based strategy for power demand of 400MW, 550MW and 700 MW is plotted in figure. 2 figure. 3and figure 4. It shows that the technique converges in relatively fewer cycles thereby possessing good convergence property and resulting in low operating cost.

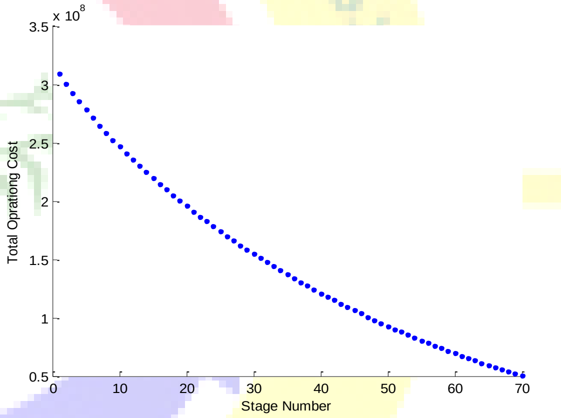

Fig.2. convergence of three generating units system for PD=400MW

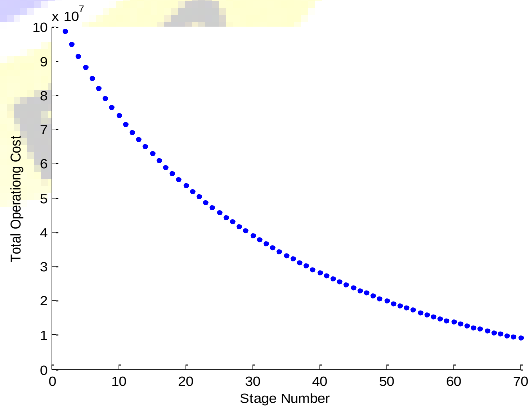

Fig.3. convergence of three generating units system for PD=550MW

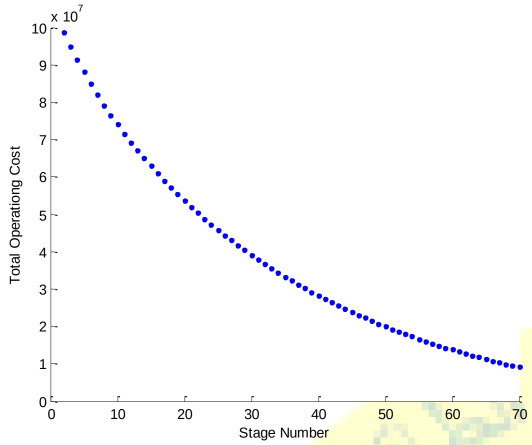

Fig.4. Convergence of three generating units system for PD=700MW

Test case II: The system consists of six thermal units. The parameters of all thermal units are presented in table: 5 and table: 6, the summarized result of CEED problem for load demand of 500MW and 900MW are obtained by the proposed Hybrid GA/TS algorithm with stopping criteria based on maximum generation= 70 is presented in Table: 7.

Table 5
FUEL COST COEFFICIENT

unit	Fuel cost coefficient			P_{Gmin}	P_{Gmax}
	ai	*bi*	*ci*	(MW)	(MW)
G1	0.1527	38.53973	756.7986	10	125
G2	0.1057	46.15916	451.3253	20	150
G3	0.0283	40.39655	1049.531	35	225
G4	0.0356	38.30552	1243.531	35	210
G5	0.0211	36.32782	1658.556	130	325
G6	0.0179	38.27041	1356.652	125	325

Table: 6
NOX EMISSIN EQUATION IN Kg/h ARE GIVEN IN

unit	Fuel cost coefficient			PGmin (MW)	PGmax (MW)
	di	ei	fi		
G1	0.00419	0.32767	13.85932	10	125
G2	0.00419	0.32767	13.85932	20	150
G3	0.00683	-0.54551	40.26690	35	225
G4	0.00683	-0.54551	40.26690	35	210
G5	0.00461	-0.51116	42.89553	130	325
G6	0.00461	-0.51116	42.89553	125	325

Bmn loss coefficient matrix in the order of 10-4 is given as:

$$B_{mn} = \begin{bmatrix} 1.40 & 0.17 & 0.15 & 0.19 & 0.26 & 0.22 \\ 0.17 & 0.60 & 0.13 & 0.16 & 0.15 & 0.20 \\ 0.15 & 0.13 & 0.65 & 0.17 & 0.24 & 0.19 \\ 0.19 & 0.16 & 0.17 & 0.71 & 0.30 & 0.25 \\ 0.26 & 0.15 & 0.24 & 0.30 & 0.69 & 0.32 \\ 0.22 & 0.20 & 0.19 & 0.25 & 0.32 & 0.85 \end{bmatrix}$$

Form Table: 7, it is clear that Hybrid GA/TS algorithm gives the optimum result in terms of minimum fuel cost, emission level and the total operating cost.

Table: 7
COMPARISON OF TEST RESULTS FOR SIX GENERATING UNIT SYSTEM

PD (MW)	Performance	Hybrid GA[26]	Hybrid GTA [27]	ABC [25]	Proposed Hybrid GA/TS
500	Fuel cost (RS/hr)	27695	27613.4	27613	27699.6081
	Emission (Kg/hr)	**263.37**	**263.000**	**263.012**	**263.764**
	PL(MW)	10.135	8.930	8.9343	8.8384
	Total cost(Rs/hr)	392567.5	39158.9	39156.9	39015,7915
900	Fuel cost(RS/hr)	48567.5	48360.9	47045.3	48829.8823
	Emission (Kg/hr)	**694.172**	**693.570**	**693.791**	**687.6865**
	PL(MW)	29.718	28.004	28.0087	27.9626
	Total cost(Rs/hr)	81764.4	81529.100	81527.6	78505,8286

Table .8
gives the best optimum power output of generators for CEED problem using Hybrid GA/TS algorithm for load demand 500MW and 900MW.

Unit Power Output (MW)	Load Demand (MW)	
	500	**900**
P1	24,6812282	104,887892
P2	30,8324615	109,588854
P3	97,1814723	137,588265
P4	90,2120478	139,806317
P5	131,133233	216,278759
P6	134,834462	219,816195
Fuel cost ($/hr)	27699.608	48829.882
Emission (kg/hr)	263.764	687.6865
PL(MW)	8.8384	27.9626

The convergence tendency of proposed Hybrid GA/TS based strategy for power demand of 500MW and 900 MW is plotted in figure: 5 and figure: 6. it shows that the technique converges in relatively fewer cycles thereby possessing good convergence property and resulting in low operating cost.

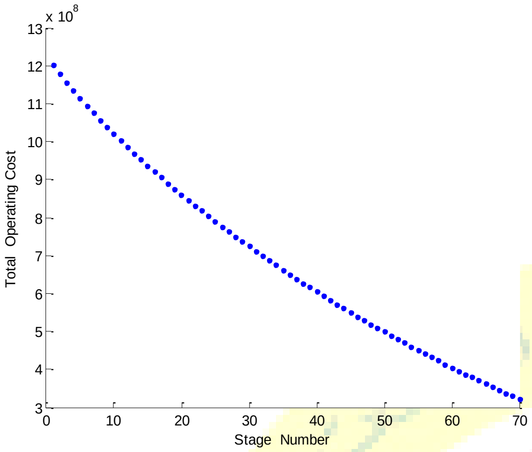

Fig.5. Convergence of six generating unit system for PD=500MW

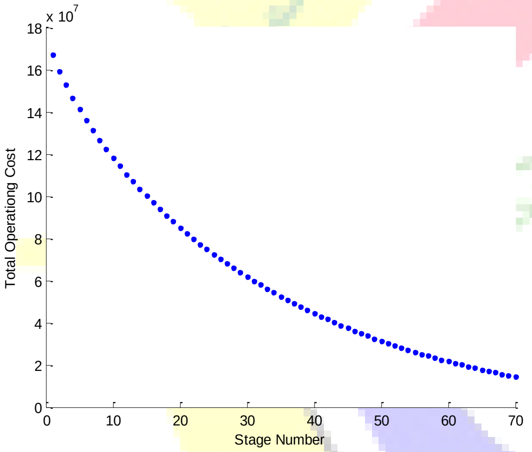

Fig.6. Convergence of six generating unit system for PD=900MW

VII. Conclusion

In conclusion this paper has formulated and implemented a hybridized GA and TS algorithm and has been shown to improve the optimization of the combined economic and emission dispatch problem. Though the proposed method shows efficiency than the algorithms it was compared with, its speed can be improved with the inclusion of mutation operators from other algorithms to improve its real time benefit.

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