Economic Load Dispatch In Thermal Power Plant Taking Real Time Efficiency As An Additional Constraints

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Abstract—**This paper presents a particle swarm optimization (PSO) algorithm for solving economic load dispatch problem in thermal power plants. An additional inequality constraint, called real time efficiency of different generating units has been considered in order to calculate the economical generation shared by all the generating units. The effectiveness of the algorithm is validated by carrying out extensive test on a power system involving 6 and 8 thermal generating units. The results obtained are compared with the same system without taking efficiency in to consideration. The result shows that by taking efficiency as an additional operating constraint, a considerable reduction in total fuel cost is achieved. PSO approach is used as it is easy to implement and there are few parameters to adjust with high computational efficiency and high accuracy.**

Keywords- Economic Load Dispatch, Total Efficiency in generating units, Particle Swarm Optimization, real time Efficiency.

I. INTRODUCTION

The economic load dispatch (ELD) is one of the most important optimization problems in power system operation and planning to derive optimal economy. The main objective of economic load dispatch is to determine the optimal combination of all generating units so as to meet the required load demand at minimum cost while satisfying the various operating constraints like energy balance, max-min generation limits, transmission line constraints, running spare capacity and network security. A station has incremental operating costs for fuel and maintenance and fixed cost associated with the station itself that can be quite considerable for a typical thermal and nuclear power plant for example. Things get even more complicated when utilities try to account for transmission line losses and the seasonal changes associated with hydraulic power plants. Conventionally, the cost function for each unit for ELD problem has been approximately represented by a quadratic equation and is solved by using various mathematical techniques like lambda-iteration method, Lagrange method, Newton's method etc [1]-[4]. Unfortunately, the real-time cost characteristics of thermal generating units are highly non-linear because of prohibited operating zones, valve point loading and multi fuel insertion etc. Thus, practical ELD problem is represented as a non-linear optimization problem with various equality and inequality constraints, which directly cannot be solved by conventional mathematical techniques. Hence numerous intelligent techniques like Biogeography-Based Optimization (BBO) [5], genetic algorithm (GA) [6], Differential Evolution (DE) [7], Evolutionary Programming (EP) [8]-[10], neural network approaches [11]-[12], etc were introduced to solve complex nonlinear ELD problems over past few years.

In this paper, a new inequality constraint, called real time efficiency is introduced. The effectiveness of this constraint in solving ELD problem is easily evaluated as by considering it, the generation from units with poor efficiency got decreased and same with better efficiency got improved. The efficiency at any thermal power plant is regularly analyzed for various parameters like Total EFFIC, Hot water and ash contents etc before it is fed to furnace for combustion. Each parameter affects the whole generating unit efficiency i.e. Total EFFIC with heavy ash contents and poor EFFIC produces less useful heat per unit volume compared to same with maximum value of EFFIC and Total EFFIC. A better efficiency is desirable in order to get stable flame intensity in furnace which results in normal power generation with minimum of fuel consumption. In other case, poor efficiency is obtained which results in same power generation with increase of fuel consumption. Hence, generation from the unit is required to decrease with maximum insertion of efficiency which results in higher fuel cost. Therefore, it is desirable to operate the unit at near lower limits in order to maintain the fuel stock. The economical loading is decided by deriving the various parameter of efficiency of each operating unit of respective thermal power plant in to a suitable formulae which gives minimum fuel cost at any load demand.

II. FORMULATION OF ELD PROBLEM

A. Classical ELD problem

The ELD problem is to find the optimal combination of power generations that minimizes the total generation cost while satisfying an equality constraint and inequality constraints. The most simplified cost function of each generator can be represented as a quadratic function as given in (2).

$$FC_t = \sum_{i=1}^{n} FC_i(P_{Gi}) \quad \frac{Rs}{Hr}$$

….(1)

$$FC_i(P_{Gi}) = a_i P_{Gi}^2 + b_i P_{Gi} + c_i \quad \frac{Rs}{\square} Hr \qquad ….(2)$$

Where

FC_t is the total fuel cost.
FC_i is the cost function of generator i .
P_{Gi} is electrical output of generator i .
a_i, b_i, c_i are the cost coefficients of generator i .

While minimizing the total generation cost, the total generation should be equal to the total system demand plus the transmission network loss. However, the network loss is not considered in this paper as all the operating units of a power plant are on single bus. This gives the equality constraint

$$P_D = \sum_{i=1}^{n} P_{Gi} \qquad \text{….(3)}$$

Where P_D is the total power demand. The maximum active power generation of a source is limited again by thermal consideration and also minimum power generation is limited by the flame instability of a boiler. If the power output of a generator for optimum operation of the system is less than a pre-specified value P_{min}, the unit is not put on the bus bar because it is not possible to generate that low value of power from the unit. Hence the generator power P cannot be outside the range stated by the inequality

$$P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max} \qquad \text{…...(4)}$$

Where P_{Gi}^{min} , P_{Gi}^{max} is the minimum, maximum output of generator i .

B. ELD problem with efficiency as an additional inequality constraint

It is estimated that, if a whole generating Unit worked as running smoothly, then the whole units to calculate the turbine, boiler and generator efficiency. In a thermal power Plant, efficiencies are calculated every day from the bunkers of respective operating Units and are tested for various contents (like hot water, Total EFFIC, ash contents etc).

Suppose on a particular day, the EFFIC is as under

$$EFFICto_{i1} = [EFFIC_1\ EFFIC_2\ EFFIC_3\ \dots\dots\ EFFIC_n]$$

Similarly

$$Ash_{i1} = [Ash_1\ Ash_2\ Ash_3\ \dots\dots\dots\dots\ Ash_n]$$

$$HT_{i1} = [[HT]_1\ HT_2\ \ HT_3\ \dots\dots\dots\dots\dots\ HT_n]$$

Now

$$L_{i1}^{EFFIC} = \frac{EFFICto_{i1}}{EFFIC_{max}} \qquad \text{…..(5)}$$

$$L_{i1}^{Ash} = \frac{1}{Ash_{i1}/Ash_{max}} \qquad \text{…..(6)}$$

$$L_{i1}^{HT} = \frac{1}{HT_{i1}/HT_{min}} \qquad \text{…..(7)}$$

And

$$L_{i1} = L_{i1}^{Turbine} \times L_{i1}^{Boiler} \times L_{i1}^{Generator} \qquad \text{....(8)}$$

Where

$EFFICto_{i1}$ is the total efficiency for i_{th1} unit.

$EFFIC_{max}$ is the maximum value of efficiency of ‘n’ operating units.

Ash_{i1} is the %age ash contents for i_{th1} unit.

Ash_{max} is the maximum value of ash contents of ‘n’ operating units.

HT_{i1} is the %age of hot water for i_{th1} unit.

HT_{min} is the minimum value of hot water of ‘n’ operating units.

L_{i1}^{EFFIC} is the Penalty Factor associated with total efficiency for i_{th1} operating unit.

L_{i1}^{Ash} is the Penalty Factor associated with ash contents of efficiency for i_{th1} operating unit.

L_{i1}^{HT} is the Penalty Factor associated with hot water in efficiency for i_{th1} operating unit.

L_{i1} is the gross Penalty Factor for i_{th1} operating unit.

The generation from each unit obtained by applying PSO will be modified by multiplying the individual penalty factors with respective generating unit as given in eq. (9)

$$P_{Gi}^{new} = P_{Gi} \times L_{i1} \qquad \text{……(9)}$$

For a particular amount of load demand, after considering the effect of penalty factors, it is sometimes possible that the generation from any (or more than one) unit violate the maximum or minimum limits. In that case, it is recommended that the additional amount (after settling the maximum or minimum limits) will be proportionally distributed among the remaining units.

III. IMPLEMENTATION OF PSO AS ELD PROBLEM

A. Overview Of PSO

In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles. The system is initialized with a population of random solutions and searches for optima by updating generations.

PSO is initialized with a group of random particles (solutions) and then searches for optima by updating generations. In every iteration, each particle is updated by following two "best" values. The first one is the best solution (fitness) it has achieved so far. (The fitness value is also stored.) This value is called P^{best}. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the population. This best value is a global best and called G^{best}. When a particle takes part of the population as its topological neighbors, the best value is a local best and is called P^{best}. After finding the two best values, the particle updates its velocity and positions with following equation (10) and (11) as

$$V_i^{(u+1)} = w \times V_i^u + C_1 \times rand() \times \left(P^{best_i} - P_i^u\right) + C_2 \times rand() \times \left(G^{best_i} - P_i^u\right) \quad \ldots(10)$$

$$P_i^{(u+1)} = P_i^u + V_i^{(u+1)} \quad \ldots(11)$$

In the above equation,

- The term $rand() \times \left(P^{best_i} - P_i^u\right)$ is called particle memory influence
- The term $rand() \times \left(G^{best_i} - P_i^u\right)$ is called swarm influence.
- V_i^u is the velocity of i^{th} particle at iteration **'*u*'**
- C_1 and C_2 are constants which pulls each particle towards p*best* and ***gbest*** positions.
- w is the inertia weight provides a balance between global and local explorations, thus requiring less iteration on average to find a sufficiently optimal solution. It is set according to the following equation,

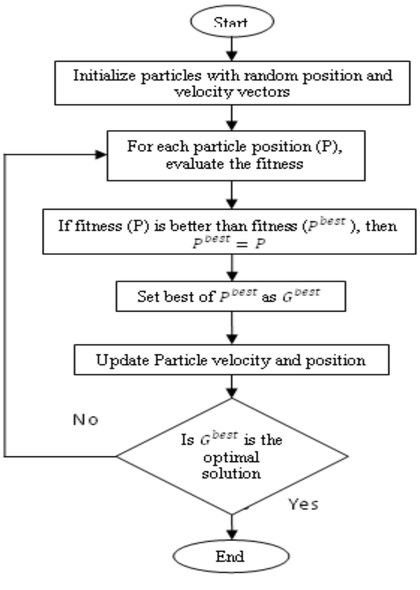
$$w = w_{max} - \left[\frac{w_{max} - w_{min}}{iter_{max}}\right] \times iter \quad \ldots.(12)$$

Where

w_{max} - maximum value of weighting factor.

w_{min} - minimum value of weighting factor.

A. *Flow chart*



B. *ELD using PSO*

When any optimization process is applied to the ELD problem, some constraints are considered. In this work three different constraints are considered. Among them the equality constraint is summation of all the generating power must be equal to the load demand and the inequality constraint is the powers generated must be within the limit of maximum and minimum active power of each unit. The additional constraint is the real time efficiency. The sequential steps of the proposed PSO method are given below.

Step 1) The individuals of the population are randomly initialized according to the limit of each unit including individual dimensions. The velocities of the different particles are also randomly generated keeping the velocity within the maximum and minimum value of the velocities. These initial individuals must be feasible candidate solutions that satisfy the practical operation constraints.

Step 2) Each set of solution in the space should satisfy the equality constraints. So equality constraints are checked. If any combination doesn't satisfy the constraints then they are set according to the power balance equation.

Step 3) The evaluation function of each individual P_i is calculated in the population using the evaluation function FC_i (2). The present value is set as the P^{best} value.

Step 4) Each P^{best} values are compared with the other P^{best} values in the population. The best evaluation value among the P^{best} is denoted as G^{best}.

Step 5) The member velocity v of each individual Pg is modified according to the velocity update equation (10).

Step 6) The velocity components constraint occurring in the limits from the following conditions are checked.

$$V_i^{min} = -0.5P_i^{min}$$
$$V_i^{max} = +0.5P_i^{max}$$

Step 7) The position of each individual P_i is modified according to the position update equation (11).

Step 8) If the evaluation value of each individual is better than previous P^{best}, the current value is set to be P^{best}. If the best P^{best} is better than G^{best}, the value is set to be G^{best}.

Step 9) If the number of iterations reaches the maximum, then go to step 10.Otherwise, go to step 2.

Step 10) The individual that generates the latest G^{best} is the optimal generation power of each unit with the minimum total generation cost.

IV. NUMERICAL STUDIES

The proposed method is used to solve two case studies involving 6 and 8 generating units. The initial particles are randomly generated within the feasible range. The parameters C_1, C_2 and inertia weight are selected for best convergence characteristic. Here C_1 = C_2 = 2.0 The maximum value of w is chosen 0.9 and minimum value is chosen 0.4. The velocity limits are selected as $V_i^{max} = +0.5P_i^{max}$ and the minimum velocity is selected as $V_i^{min} = -0.5P_i^{min}$. There are 10 no of particles selected in the population. The algorithm is implemented in MATLAB 7.10.0(R2010a).

A. *Case Study 1*

This test case comprise of 6 generating units [12] with quadratic cost functions and penalty factors as shown in Table I. The results obtained with load demand 1050 MW are compared in Table II for both approaches i.e. i) without taking efficiency ii) with taking efficiency

TABLE 1
GENERATION CHRACTISTICS OF 6-GENERATING UNIT SYSTEM

Unit	P^{min}	P^{max}	a_i	b_i	c_i	Penalty Factor
P1	**10**	**125**	**0.152**	**38.54**	**756.80**	**0.8806**
P2	**10**	**150**	**0.106**	**46.16**	**451.32**	**0.9431**
P3	**35**	**225**	**0.028**	**40.40**	**1050.00**	**1.9886**
P4	**35**	**210**	**0.035**	**38.21**	**1243.53**	**0.9438**
P5	**130**	**325**	**0.021**	**36.328**	**1658.57**	**1.9998**
P6	**125**	**315**	**0.018**	**38.27**	**1356.66**	**1.9413**

TABLE 2
COMPARISON OF FUEL COSTS FOR 6-GENERATOR SYSTEM WITH
PD = 1050MW

Li	**Units**	**Load Demand (1050MW)**	
		Output (W/o EFFIC)	**Output (With EFFIC)**
0.8806	**P1**	**73.20**	**76.03**
0.9431	**P2**	**175.75**	**175.30**
1.9886	**P3**	**170.09**	**188.47**
0.9438	**P4**	**172.51**	**170.07**
1.9998	**P5**	**182.16**	**221.72**
1.9413	**P6**	**259.24**	**329.45**
Fuel Cost (Rs)		**15598.557**	**15418.024**

B. *Case Study II*

This test case comprises of 8 generating units with quadratic cost functions and penalty factors as shown in Table III. The load demand in the system is taken as 1000 MW. The transmission loss is assumed to be zero. The output obtained is shown in Table IV.

TABLE 3
GENERATION CHRACTISTICS OF 8-GENERATING UNIT SYSTEM

Unit	P^{min}	P^{max}	a_i	b_i	c_i	Penalty Factor
P1	**62**	**101**	**0.3167**	**-10.94**	**102.8**	**0.1351**
P2	**55**	**85**	**0.3463**	**-7.586**	**100.6**	**1.0003**
P3	**53**	**78**	**0.6362**	**-23.52**	**104.6**	**0.0113**
P4	**52**	**82**	**0.5263**	**-16.15**	**109.6**	**1.0573**
P5	**115**	**183**	**0.08842**	**-2.344**	**63.7**	**0.0002**
P6	**110**	**182**	**0.08394**	**-4.138**	**77.77**	**1.0624**
P7	**168**	**240**	**0.08638**	**-5.496**	**98.7**	**1.000**
P8	**168**	**245**	**0.09525**	**-6.382**	**58.44**	**0.0165**

TABLE 4
COMPARISON OF FUEL COSTS FOR 8-GENERATOR SYSTEM
1000 MW

Li	**Units**	**Load Demand (1000MW)**	
		Output (W/o EFFIC)	**Output (With EFFIC)**
0.1351	**P1**	**69.99**	**68.54**
1.0003	**P2**	**71.76**	**72.50**
0.0115	**P3**	**66.97**	**66.26**
1.0573	**P4**	**68.76**	**71.38**
0.0002	**P5**	**153.00**	**152.66**
1.0624	**P6**	**150.23**	**150.51**
1.000	**P7**	**208.23**	**205.37**
0.0165	**P8**	**211.03**	**211.59**
Fuel Cost (in Thousand Rs)		**13877.947**	**13721.500**

V. CONCLUSION

This paper presents a new approach of considering real time efficiency as an inequality constraint to solve the economical load dispatch problem in thermal power plants. The efficiency of individual operating units is formulated as Penalty Factors (L_{i1}) of respective units. These penalty factors are utilized to economically distribute the total power demand (P_D) among individual operating units in order to achieve minimum fuel cost. A comparison analysis has been done on two different test systems comprises 6 and 8 generating units for two cases i.e. i) without taking efficiency and ii) with taking efficiency. Table II and IV shows the comparison between fuel costs obtained for above two cases. From the respective tables, it is seen that if efficiency is taken in to consideration, the power generation from individual operating units are improved proportional to penalty factors (which are calculated through turbine, boiler and generator efficiencies of respective operating units). From Table II and

IV, it is seen that taking efficiency in to consideration results in net saving (in terms of rupees) to the plant as a whole but it is not always possible. In some of the cases, by taking efficiency as an operating constraint, the total fuel cost may get increased by a small amount but this small increase in fuel cost is justified as at the same time the generation from various operating units are improved (i.e. if efficiency of any unit is poor, contribution from that unit is decreased accordingly and vice-versa). If a unit is operating at normal loading with poor efficiency, it results in high rejection from fuel, unstable flame condition, high amount of fly-ash particles in furnace and increase in loading on PA fans etc which causes sudden tripping and reduces the useful life an efficiency of various boiler auxiliaries and the plant as a whole. Therefore, it is desirable to operate the unit with poor efficiency at near lower limits in order to maintain the fuel stock and efficiency of the power plant.

VI. REFERENCES

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