A New Model for Short-Term Hydrothermal Scheduling of a GENCO in the Competitive Electricity Market

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Abstract

A new mathematical model has been proposed for a hydrothermal Generating Company (GENCO) considering profit maximization as objective function is presented initially. Followed by this, bi-objective problem of profit maximization with simultaneous emission minimization has been formulated. Further, the different bidding strategies adopted for maximizing the social profit has been discussed. Methods/Statistical Analysis: IEEE 30-bus system has been chosen as the test case here. All the above mentioned problem formulations are simulated using a hybrid algorithm of LR-PSO (Lagrangian Relaxation - Particle Swarm Optimization). Findings: In Short-Term HydroThermal Scheduling (STHTS), the problem of fuel cost minimization has been attempted for several decades. In the competitive electricity market there is a need for maximization of profit rather than thermal plants fuel cost minimization subjected to hydro-thermal constraints. This necessitates a suitable mathematical model. In this paper the required model has been arrived at for the IEEE test case. The findings obtained prove effectiveness of the LR-PSO algorithm in arriving at the optimal scheduling much suitable for the GENCO in the deregulated environment. Applications: The various strategies followed will definitely enable the GENCO in the optimal allocation of selling the power that is generated as well as the reserve power generated in the deregulated market. This will also provide an opportunity for the ISO to maximize the social profit.

Keywords: Competitive Electricity Market, GENCO, LR-PSO STHTS

The scheduling problem of the hydro-thermal system aims at maximum utilization of power from hydro power plants so that the fuel cost associated with thermal power plants gets substantially reduced while subjected to constraints of thermal and hydel power plants. As the power system moves towards deregulation, the objective of fuel cost minimization has been reframed to profit maximization of the GENCO.

Several conventional techniques have been for decades for solving the STHTS problem such as Lagrangian Relaxation, Dynamic Programming etc. However they are computationally rigorous. They involve longer computation time and are not effective in solving large scale STHTS problems.

The recent advancement of power industries moving towards deregulation and the arrival of several soft computing techniques are the basic reasons motivated for solving STHTS in a competitive electricity market employing intelligent algorithms. The main merits in the use of these evolutionary algorithms for power system problems are that they are derivative free methods which can yield a global optimum solution with lesser computational effort.

Zoumas, et al, attempted a STHTS problem employing Genetic Algorithm (GA) where the hydro sub-problem and thermal sub-problem has been formulated and solved separately. Rajan C.C.A, et al, proposed a UC problem adopting a hybrid algorithm. Wong K.P, et al. presented the STHTS problem using Simulated Annealing (SA) technique in paper for a one hydro and one thermal plant and the results obtained were reasonably good, but the main weakness was its high computation time. Naresh

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R, et al. applied a two-phase neural network for solving the STHTS problem in paper4. Padhy N. P, conducted a literature survey of various optimization techniques that could be applied for unit commitment in both regulated and deregulated energy markets5.

Attaviriyanupap P. proposed a hybrid method combining LR method and Evolutionary Programming (EP) technique for solving UC in a deregulated market6. Mandal K.K. et al. applied Particle Swarm Optimization (PSO) algorithm considering valve point effects7. Basu M. presented a multi-objective STHTS problem using EP technique8. S. Subramanian proposed a mathematical Economic Load Dispatch (ELD) of a power system9. Abido M. A. developed a new multi-objective evolutionary technique based ELD10. Jacob Raglend L, et al. presented the profit maximization of a GENCO employing PSO11. Singh H, et al. discussed the framework of an auction market that formed the basis for the California Independent System Operator (ISO) Ancillary Services market12. Haili Song, et al. proposed a probabilistic model for a bidding in a power system13. David A. K, et al. conducted a literature survey on various bidding models considered in a deregulated market14. Janghorbanrchi M, et al. presented a GENCO with the incorporation of managing the risk parameters. B. Luh, et al. proposed an optimization bidding model for an ISO in a deregulated market15. Huang H, et al. explained the bidding model for a wind GENCO16.

2. Problem Formulation

2.1 Single Objective Problem Formulation

The objective function of profit maximization of a GENCO can be expressed as below:

Maximizing Profit = Revenue - Total Cost

subject to

- Power demand constraint:
  \[ \sum_{n=1}^{N} P_{in} X_{in} \leq D^{n} ; \quad n = 1,...,T \]  

- Reserve power constraint:
  \[ \sum_{n=1}^{N} R_{in} X_{in} \leq SR^{n} ; \quad n = 1,...,T \]  

- Power and Reserve generation limits:
  \[ 0 \leq R_{in} \leq (P_{in}^{max} - P_{in}^{min}) \]  

(2)  

(3)  

(4)

2.2 Multi Objective Problem Formulation

In the interconnected hydrothermal system, the main disadvantage of thermal power scheme is the gaseous emission of pollutants. Thus the STHTS problem has been extended as a bi-objective problem of profit maximization and emission minimization and is given by:

\[ f_1 = \max (RV - TC) \]  

\[ f_2 = \min \left( \sum_{i=1}^{N} \sum_{n=1}^{T} \left( a_i + \beta P_{in} + Y P_{in}^2 \right) \right) \]  

(10)  

(11)

2.3 Bidding Strategy in Deregulated Markets

It is more reasonable to determine the economic power generations in a restructured electricity market to achieve maximum social profit. Generally the customers and the GENCO submit their bids with the idea of obtaining individual higher profits without considering the social profit. To overcome this problem another agency called Independent System Operator (ISO) is introduced. Here, the ISO acts as a regulatory bond between the needs of customers and the resources of the GENCO. ISO matches the electricity transaction bids and arrive at the one for which maximum social profit is obtained.

Thus, the objective function is formulated as given below:

\[ \text{Maximize Profit} = \sum_{i=1}^{m} \sum_{j=1}^{n_{ij}} C_j(d_i') - \sum_{j=1}^{n_{ij}} G_j(P_i') \]  

(12)

Where \( d_i' \) is the bid quantity of the \( i \)th generator at period \( t \) and \( P_i' \) is the bid quantity of the customer \( j \) at period \( t \).
3. Lagrangian Relaxation - Particle Swarm Optimization Method

This hybrid method employs the suitable updation of Lagrange multipliers using PSO for obtaining better solution. The algorithm for solving STHTS problem using LR-PSO method is furnished below.

- Commit all hydro units. Assume discharge rates within the limits; calculate the volume of water to be used in each hydro unit.
- Calculate the corresponding powers that can be produced in each hydro unit. The power demands on thermal units for each period are then calculated.
- Thermal UC is then performed.
- The populations are created randomly for the Lagrange multipliers namely $\lambda$ and $\mu$ respectively around the search space.

$$\lambda = [\lambda_1, \lambda_2, ..., \lambda_n] \quad (13)$$

$$\mu = [\mu_1, \mu_2, ..., \mu_n] \quad (14)$$

- $P_{in}$ and $R_{in}$ are calculated from Equations 15 and 16 respectively. Values of $\lambda_1$ and $\mu_1$ are computed as suggested in paper7.

$$P_{in} = (\frac{1}{1-r}) \times (A_{in} - B_{in}) \quad (15)$$

$$R_{in} = (\frac{1}{1-r}) \times (-A_{in} + B_{in}) \quad (16)$$

- Lagrangian function is then evaluated from Equation 17.

$$LF = TC - RV - \sum_{i=1}^{N} \lambda_i \left( D_i - \sum_{j=1}^{T} P_{in} \cdot X_m \right)$$

$$- \sum_{i=1}^{T} \mu_i \left( SR_i - \sum_{j=1}^{T} R_{in} \cdot X_m \right) \quad (17)$$

- The dual value $q$ is then calculated as:

$$q = \sum_{i=1}^{N} \sum_{j=1}^{T} \left[ (1-r)F(P_{in}) + rF(P_{in} + R_{in}) + ST_i - (P_{in} \cdot SP_i) - (r \cdot RP_i + \lambda_i P_{in} + \mu_i R_{in}) \cdot X_m \right]$$

$$-(r \cdot RP_i + \lambda_i P_{in} + \mu_i R_{in}) \cdot X_m \quad (18)$$

- The velocity and position update Equations are shown in (19) and (20) respectively.

$$\text{Velocity Update:} \quad \text{Taking } \lambda_{best} = \lambda \quad (19)$$

$$\text{Position Update:} \quad \text{Taking } \mu_{best} = \mu \quad (20)$$

- Knowing the unit status, compute the primal value $J$. Here $J$ is the difference between revenue and total cost obtained.

- Compute the value of $\texttt{IF}$ if it is less than the specified tolerance value terminate; else proceed from step 5.

4. Simulation Discussion

The test case considered here has been adopted from $[10, 12]$. The test system comprises of 4-hydro and 6-thermal generating units. Three different objective functions are considered.

4.1 Objective I: Single Objective Hydrothermal Scheduling in the Competitive Electricity Market

Simulation studies are carried out using MATLAB 7.0 and the results obtained are shown in Table 1.

The parameters adopted for solving the LR-PSO technique are given below:
- Both the Lagrange multipliers particles are taken as 50. Here $C_i$ and $C_2$ are acceleration constants; $C_i = C_2 = 2$.
- $w_{max}$ and $w_{min} = 0.4$.

![Figure 1. Comparison between output power dispatched and forecasted power demand using LR-PSO.](image)

Thus GENCO need not constrained to meet the power demand exactly. Graphical representation is given in Figure 1. The GENCO can produce power less than the forecasted demand and forecasted reserve in certain scheduling hours in order to yield more profit since the pricing depends on the forecasted price of that hour.
4.2 Objective II: Multi-objective Hydrothermal Scheduling in the Competitive Electricity Market

The goal of hydrothermal scheduling problem now becomes multi-objective which not only maximizes the profit, but also minimizes the quantity of gaseous pollutants emitted by the thermal units. The results obtained are furnished in Table 2 and are shown in Figure 2 respectively.
4.3 Objective III: Bidding Strategies for Social Profit Maximization
The results for the three bidding model in a deregulated energy market are shown in Table 3. These results are shown graphically in Figure 3.

Table 3. Comparison of social profit for the three bidding strategies

| Social Profit ($) Under LR-PSO |        |
|-------------------------------|--------|
| Low bidding                   | 10196.92|
| Medium bidding                | 14685.17|
| High bidding                  | 15847.01|

Figure 3. Comparison of bidding strategies.

Thus, from the results obtained from Table 3, high bidding strategy can be adopted by ISO in competitive electricity market since it results in largest social profit when compared with both low and medium bidding trading mechanism.

5. Conclusion
Recognizing the importance of STHTS in a deregulated energy market, a new model for hydrothermal scheduling as applied to GENCO has been proposed considering profit maximization as single objective function. Followed by this, multi-objective problem formulation of maximizing the profit and minimizing the emission has been carried out. Further the different bidding strategies adopted for maximizing the social profit has been discussed. The various strategies followed in this research work will give a full picture of optimal operation of hydrothermal system and will definitely help the GENCO in maximizing the profit. This will also provide an opportunity for the ISO to maximize the social profit.

6. References

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Nomenclature:

\[
\begin{align*}
\text{\(P_{in}\)} & \quad \text{Thermal power generation of \(i\)th generator at \(n\)th hour;} \\
\text{\(R_{in}\)} & \quad \text{Reserve power generation of \(i\)th generator at \(n\)th hour;} \\
\text{\(X_{in}\)} & \quad \text{Unit status of \(i\)th generator at \(n\)th hour;} \\
\text{\(D'_n\)} & \quad \text{Demand in MW of \(i\)th generator at \(n\)th hour;} \\
\text{\(V_{jn}\)} & \quad \text{Volume of the water in the \(j\)th hydro reservoir at time \(n\);} \\
\text{\(N_h\)} & \quad \text{Hydro power generation units;} \\
\text{\(V_{jn}\)} & \quad \text{Volume of the water in the \(j\)th hydro reservoir at time \(n\);} \\
\text{\(P_{jn}\)} & \quad \text{Output power of \(j\)th hydro unit at time \(n\);} \\
\text{\(P_{i,\text{max}}\)} & \quad \text{Thermal power generation maximum limit of \(i\)th thermal generator;} \\
\text{\(P_{i,\text{min}}\)} & \quad \text{Thermal power generation minimum limit of \(i\)th thermal generator;} \\
\text{\(N\)} & \quad \text{Thermal power generation units;} \\
\text{\(F_i\)} & \quad \text{Fuel cost for \(i\)th thermal power generation;} \\
\text{\(SR'n\)} & \quad \text{Forecasted reserve at hour \(n\);} \\
\text{\(ST_i\)} & \quad \text{Startup cost function for \(i\)th thermal power generation;} \\
\text{\(PF\)} & \quad \text{Profit for the GENCO;} \\
\text{\(RV\)} & \quad \text{Revenue for the GENCO;} \\
\text{\(TC\)} & \quad \text{Total cost of generation for the GENCO;} \\
\text{\(D'_n\)} & \quad \text{Demand in MW of \(i\)th generator at \(n\)th hour;} \\
\text{\(SP_n\)} & \quad \text{Spot price that is forecasted at \(n\)th hour;} \\
\text{\(RP_n\)} & \quad \text{Reserve price that is forecasted at \(n\)th hour;} \\
\text{\(r\)} & \quad \text{Probable value of reserve power generation called and generated;} 
\end{align*}
\]