Advanced Research in Electrical and Electronic Engineering
Print ISSN: 2349-5804; Online ISSN: 2349-5812 Volume 1, Number 4 (2014) pp. 1-5

http://www.krishisanskriti.org/areee.html

Determination of Market Clearing Price and Optimization of Generation Scheduling in a Wind-Hydro-Thermal Electricity System

Navdeep Batish[1], Sunny Vig[2], Yajvender Pal Verma[3]

[1]*ME-EE Scholar, UIE, Chandigarh University, Gharuan*
[2]*Assistant Professor, UIE, Chandigarh University, Gharuan*
[3]*Assistant Professor, UIET, Panjab University, Chandigarh*

Abstract: **Generation scheduling (GS) is an important but a challenging optimization problem that involves the allocation of efficient generation among the interconnected systems which not only satisfies the load demand but also provides economical operation of the system. A Mixed Integer Non Linear Programming based GS optimization model has been developed using GAMS modeling. The paper proposes an approach to hybrid generation scheduling of the system comprising of wind, thermal and hydro generating units. The main objective is to minimize the total overall cost comprising of unit commitment of the units. Another important factor in the electricity market is determination of Market Clearing Price (MCP). It is the prime operating function for a pool operator in energy trading scenario. Its main objective is to maximize the social welfare function where both the generating companies and the consumer are at advantages. The proposed approach has been extended to calculate the MCP for the units participating in electricity market. IEEE 24 bus test system having 10 generating unit systems has been modified to carry out the simulation studies. The results obtained can help various power producers to plan their operating strategies in a hybrid system with emission constraints to maximize the profit and reduce the fuel and emission cost.**

1. INTRODUCTION

The optimization of short-term generation scheduling is presently an area of depth concentrated research; mainly with the tendency towards privatization and deregulation of the power industry. It is a challenging optimization problem because of the complex interplay amongst many variables [1]. The generation scheduling is the determination of the generating unit such that the total system generation cost is minimum while satisfying the system constraints. The total cost of generation depends on the operating, start up and shut down cost of the generating units. As for the renewable energy resources, especially wind energy penetration is comparatively more than the other renewable energy and in future it is one of the most preformed available alternative energy sources. In a statistics report given by the Global Wind Energy Council (GWEC), China have the highest installed capacity of wind energy of about 63 GW followed by USA, Germany, Spain and India. For the interconnection of wind energy with other source of generating electricity by 3-4% penetration India is on top, while by approximately 3% and 2% USA and China are having second and third positions respectively [2-3]. The vertically merged syndicate power industries in the past were influenced to most of the electricity power generation, transmission and distribution of the power sector companies. For the period during nineties, deregulation occurred among many power network companies and electric utilities globally. Deregulation involves up selling the responsibilities of syndicate power industries into generation companies (Gencos), transmission companies (Transcos) and distribution companies (Discos), with a central administrator called Independent System operator (ISO) to balance the supply, maintaining system reliability and security[4]. As we all know the nature of electricity, it is difficult to store and is available only when is in demand. Consequently, under normal operating conditions it is not possible to keep it in stock unlike other products. Therefore a separate self-reliant system is needed to sport the rapidity of the expected demands and electricity generating units of the power systems. In terms of economic values, electricity that is both power and energy is an asset or a product actually having the ability of being selling, buying and trading. Electricity, in a market is a system for executing purchases, through offers to sell, bids to buy and short-term trading in field market companies. Price is being set by using the demand principles and supply by the offers and bidding policies. There are trades such as long terms considering bi-lateral transactions, power purchasing agreements and are generally considered private between corresponding parties. An electricity market is a system where wholesale transactions are consistently settled, cleared by a special purpose autonomous organization or sometime by the market operator. They do not clear merchandising tariffs but usually needs awareness to maintain generation and load balance in prescribed manner for trades. Market clearing price has been the prime operating function for a pool operator in energy trading scenario [5]. In restructured power system, different market players participate in electricity market and many generations, distribution and transmission companies come in a bi-lateral agreement to supply or purchase power among themselves. The main objective of MCP is to maximize the social welfare function where, both the generating companies and the consumers in a society are benefited and getting neutral. The generators/generating companies indicate the bidding supplied for the power quantity in terms of certain price function and by supply being given by the bidding operators. For several decades, the generation scheduling problem of hydrothermal systems and calculating MCP has been the subject of intensive research such as Mixed-integer programming [6], Genetic Algorithm (GA) [7], Simulated Annealing [8], Evolutionary Programming [9], Particle Swarm Optimization (PSO) [10] and for MCP determination researcher uses ANN and probability theory but these methods are not found helping in maximize the social benefit and biasing the social cause [11-12]. Here, in this research paper a Mixed Integer Non Linear Programming based GS optimization model has been developed using GAMS modeling [13]. The paper proposes an approach to hybrid generation scheduling of the system comprising of wind, thermal and hydro generating units and also a proposed method for determining the MCP by solving the non-linear equations using gradient method [14]. The proposed method considers the bids of consumers and is analyzed without considering losses.

2. PROBLEM FORMULATION AND METHODOLOGY

2.1 Hybrid Generation Scheduling Model

The Generation Scheduling problem is a short-term scheduling problem, with a scheduling period of 24 hours in which optimal start-up and shut-down schedules need to be determined over a given time horizon for a group of power generators such that the total system generation cost is minimum. For a given hybrid system, the problem may be described as optimization (minimization) of total cost as defined by 1 under a set of operating constraints.

$$\text{Minimize Total Cost } C_i = \sum_{i=1}^{n} \sum_{t=1}^{n} \left[FC_{i,t} + CC_{i,t} \right] \quad (1)$$

where, $FC_{i,t}$, is the fuel cost of unit *i* at time t, and $CC_{i,t}$ is the carbon cost of unit i at time t, C_i is the total cost.

$$FC_{i,t} = F_i \times (a_i + b_i P_{i,t} + c_i P^2{}_{i,t}) \quad (2)$$

where, F_i is the fuel cost of i^{th} generating unit, $P_{i,t}$ is the power generation of the i^{th} thermal generating unit at time *t*, and a_i, b_i, c_i is the fuel coefficients of the i^{th} thermal generating unit.

$$CC_{i,t} = E_c + \alpha_i \times (SC - E_c) \times (\beta_i \times P_{i,t} + \gamma_i) \quad (3)$$

where, E_c is the emission cost of the thermal generating unit, SC is the sequestration cost of the i^{th} thermal generating unit, and α_i, β_i, γ_i is the emission cost coefficients of the i^{th} thermal generating unit.

The total power generation must balance the power demand plus total transmission losses at each time interval over the entire scheduling period. Thus

$$\sum_{i=1}^{n} P_{i,t} + P_{wt} + P_{ht} = P_{dt} + P_{lt} \quad (4)$$

where, $P_{i,t}$ is the power generation of the i^{th} thermal generating unit at time t, P_{wt} is the wind power at time t, P_{ht} is the power generation of the hydro generating unit at time t, P_{dt} is the power demand at time t and P_{lt} is the total transmission loss at time t.

The hydro and wind power equality constraints are:
(a)The hydropower generation is a function of reservoir storage volume and water discharge rate, which can be described as

$$P_{ht} = C_1 V_{ht}{}^2 + C_2 Q_{ht}{}^2 + C_3 V_{ht} + C_4 V_{ht} + C_5 Q_{ht} + C_6 \quad (5)$$

where, P_{ht} is the power generation of the hydro generating unit at time t, C_1, C_2, C_3, C_4, C_5, C_6 are the power generation coefficients of the hydro generating unit, V_{ht} is the storage volume of the reservoir at time t, and Q_{ht} is the water discharge rate of the reservoir at time t.

(b)The wind power depends upon the speed and density of the air at the corresponding time interval and is given as

$$P_{wt} = \frac{1}{2} \rho A V^3 \quad (6)$$

where, P_{wt} is the wind power at time *t*, ρ is the air density, A is the area of the wind blade, and *V* is the wind speed in m/sec.

2.2 Methodology for MCP

MCP is defined as the operating function that maximizes the social welfare function where both the generating companies and the consumers are at advantages. The proposed method has been derived using fixed demand and only considering the generator bid functions. Here, calculation of MCP has been explained by considering the N generators and M consumer bid functions and is explained by taking various constraints.

$$A = \sum_{i=1}^{N} \left(\frac{1}{ai} \right) \quad (7)$$

$$B = \sum_{i=1}^{N}\left(\frac{ai}{bi}\right) \quad (8)$$

$$Ad = \sum_{i=1}^{M}\left(\frac{1}{\alpha i}\right) \quad (9)$$

$$Bd = \sum_{i=1}^{M}\left(\frac{\beta i}{\alpha i}\right) \quad (10)$$

where, A, B, A_d and B_d are the defined parameters of N generators and M consumers

$$PR = \frac{ABd - AdB}{2\left(Ad - A\right)} \quad (11)$$

where, P_R is the total demand that can be supplied

$$\lambda = \frac{2PR + B}{Ad} \quad (12)$$

$$\lambda = \frac{2PR + Bd}{Ad} \quad (13)$$

where, λ is the Market clearing Price

3. CASE STUDY AND RESULTS

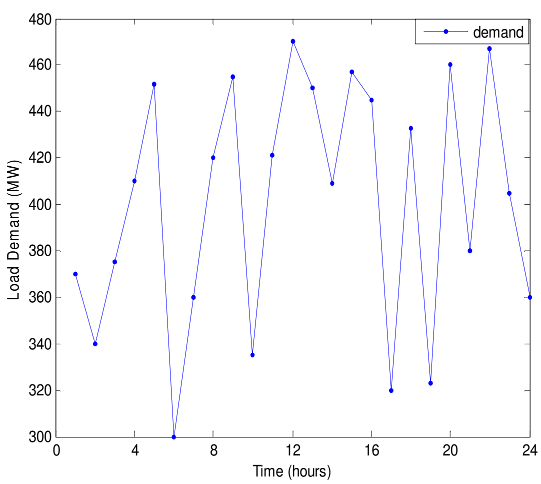

Fig.1 Load demand for operating intervals

Short-term generation scheduling problem is a crucial task in the economic operation of the power system. A good generation scheduling reduces the production cost, increases the system reliability, and maximizes the profit. The primary objective of the hybrid short-term generation scheduling problem is to minimize the total thermal cost while satisfying all the equality and inequality constraints. The data that is used to develop the model has been taken from IEEE 24 bus system.

The hybrid systems studied here incorporates the wind uncertainties and has water availability in hydro units to generate power. In fig.1, the total load demand has been shown for each hour during generation scheduling of thermal, hydro and wind generating units. The generation is maximum by considering wind and hydro units having less operational and emission cost. Different cases have been studied and carried out which are given as follows.

3.1 Generation Scheduling of Hybrid System

In this case, a combination of wind, thermal and hydro units has been used to feed the modified load of IEEE 24 bus system. The thermal unit's experiences increased number of startups and shutdowns, and periods of operation at low load and at high load levels. The fuel cost of generation is generally taken to be a linear, piecewise-linear, or a quadratic function of dispatched generation, out of which quadratic function curve has been taken as described in equation (2). The operating cost of thermal plant is very high, though their capital cost is low. On the other hand, the operating cost of hydroelectric plant is low, though their capital cost is high. Wind power is a green power. Moreover, the uncertainty and variability in wind power can result in the reduction of efficiency and affecting generator starting. Thus, the scheduling study forms to be an efficient process to generate power in a hybrid generation system.

In Fig. 2, upper part shows the power generation of the 10 thermal generating units and lower part gives the power generation by hydro and wind units for the time span of 24 hours. It can be seen from the figure that the generating units 7, 8 and 10 are generating maximum power. It is due to their low operational cost that these units tend to generate more. This reduces overall cost corresponding to the total load demand for the 24 hours as shown in the figure 1.The effect of hydro power generation and wind power can also be seen in the scheduling of thermal generating units. During operating hours 1 and 2, the hydro unit generates the power to meet the load demand by interconnection with the thermal unit and a small power is also being provided by the wind unit. The water discharge rate during these operating hours is very low such as the water is utilize to generate power in the absence of wind that happens in minimizing the operational cost as shown in figure 3. As wind power increase from 3h onwards and the hydro unit tend to store water for the future use as shown in lower part of figure 2. During the peak operating hours from 8 to 18 the wind availability is less, during this period the hydro units tends to generate power with respect to the thermal unit. It can be seen from the load demand that load is increasing during 8, 9, 12, 15, 16 and 18h and reaches above 450 MW. At operating hour 19, the hydro unit remains closed as wind power generation is increasing and it shares the larger load. This shows that when there is no availability of water the interconnected hybrid plant does not generate power. This helps in reducing maintenance cost as well as the operating cost.

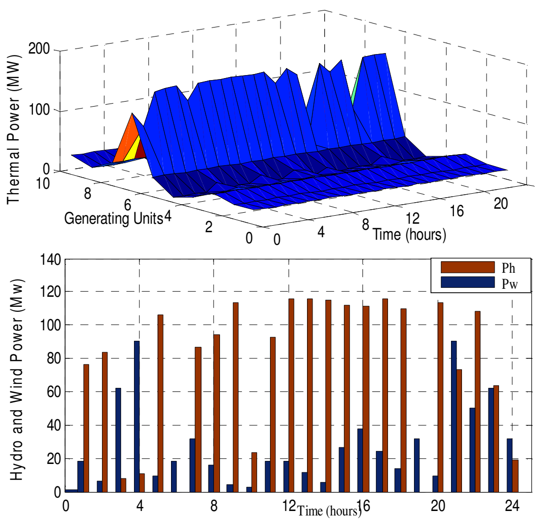

Fig.2 Power generation during hybrid operation

As wind power increases from 21 to 24 hour, during this operational time period wind power is used to generate power as for the hydro unit is considered to be less corresponding to the thermal generating units and less emission cost. The total emission cost during hybrid generation is 1985.112 $/day.

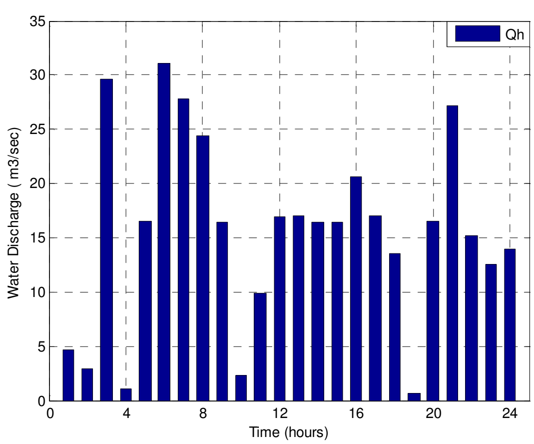

Fig.3 Total Water Discharge

The total water discharge during hybrid generation is as shown in the figure 3. It can be seen from the figure 3, that water discharge rate is maximum for the 3, 6, 7, and 21 operating hour and is minimum for the 4, 9, and 19h for which the hydro unit seem to be closed.

3.2 Determination of MCP

The determination of MCP is based on the bids received from the generators and the consumers. The quadratic bid function offered by the generators and consumers are more realistic and have more information. In this Case study, three generating units 1, 5, 7 and two consumers have been assumed to be participating in electricity market and have offered their bids in the form of quadratic cost curve as described by the following equations.

The generator cost function of three generating units are given as

$$C_1 = 0.35P^2_{i,t} + 2.17P_{i.t} + 108 \quad \text{Rs/h}$$

$$C_2 = 0.019P^2_{i,t} + 1.91P_{i.t} + 63.08 \quad \text{Rs/h}$$

$$C_3 = 0.014P^2_{i,t} + 0.86P_{i.t} + 440 \quad \text{Rs/h}$$

The offer functions of two consumers are

$$B_{f1} = -0.003Pd^2{}_1 + 5Pd_1 + 150 \quad \text{Rs/h}$$

$$B_{f2} = -0.002Pd^2{}_2 + 6Pd_2 + 200 \quad \text{Rs/h}$$

Thus, the values of A, B, A_d and B_d are calculated by using equations (7), (8), (9) and (10)

Thus, the values obtained are

A = 153, B = 224, A_d = -833, B_d = -4666.67

Now, the total demand P_R that can be supplied is obtained using equation (11) as

$$P_R = \frac{(153 \times -4666.67)\text{- }(-833 \times 224)}{2(-833-153)} = 267.44$$

Thus, P_R = 267.44 MW
The value of MCP is obtained by using equation (12) and (13) as

$$\lambda = \frac{2 \times 267.44+224}{153} = 4.96 \text{ Rs/MW}$$

$$\lambda = \frac{2 \times 267.44\text{-}4666.67}{-833} = 4.96 \text{ Rs/MW}$$

Thus the value of λ (MCP) is = 4.96 Rs/MW

The value above found for the MCP is based on the criteria when there are no limit constraints being imposed either on the generators or the consumers. The further analysis of MCP can be done for all the generating units based on their offer bids using above mentioned procedure.

4. CONCLUSIONS

The paper work proposes and formulates an algorithm that optimize the generation schedule of the thermal generating units on modified IEEE 24 bus system data for a predicted load demand with a motive to minimize the overall operating cost of the hybrid system. The operating cost includes the fuel cost of the thermal power plant, as the operating costs of the hydro and wind plants are insignificant. The effectiveness of the developed model has been tested on the system having 10 thermal units, 1 hydro and 1 wind units respectively. The paper also determines the MCP for the generating units which participate in the electricity market and offer their bids in the form of quadratic cost curves. This model helps in scheduling of conventional generators in the presence of renewable like wind and hydro units. The proposed work for MCP has yielded satisfactory results for market clearing price determination under different market conditions including emission constraints. The algorithm used for determining is modest and easy which will provide optimal solutions for a hybrid system. The work can be further extended by using real time variations in load and wind power that can be incorporated through stochastic modeling in GAMS.

5. ACKNOWLEDGMENT

The authors thank the Management of Chandigarh University, Gharuan, Punjab, India for providing an ambient environment for research work and kind support during the research time period.

REFERENCES

[1] Wood, A.J., and Wollenberg B.F., "Power Generation Operation and Control"*, 2nd edition, John Willey & Sons, Inc,* 1996, New York, USA.

[2] CWET. In:, "*13th National training course on wind energy technology*", , 2012, Chennai, India.

[3] Pappala, V.S., Erlich, I., Rohrig, K., and Dobschinski, J., "A stochastic model for the operation of wind-thermal power system", *IEEE Transactions on Power Systems,* 2009, vol. 24, no 2, pp. 940-950.

[4] Lakshmi, K., and Vasantharathna, S., "Gencos wind-thermal scheduling problem using artificial immune system algorithm", *Electric Power and Energy Systems*, 2014, vol. 54, pp 112-122

[5] Rao, P.S.N., "Direct method of determining optimum generation schedules, "*Institution of Engineers (India) Journal – Electrical*, June 1987, vol 67, PP 251-253.

[6] Yu, Z., Sparrow, F.T., Bowen, B., Smardo, F.J., "On convexity issues of short-term hydrothermal scheduling", *International Journal of Electric Power & Energy Systems*, 2000, 22, pp 451-457.

[7] Gil, E., Bustos, J., and Rudnick, H., "Short-term hydrothermal generation scheduling model using a genetic algorithm", *IEEE Transaction on Power Systems*, 2003, vol. 18, pp 1256-1264.

[8] Simopoulos, D.N., Kavatza, S.D., and Vournas, C.D., "Unit commitment by an enhanced simulated annealing algorithm", *IEEE Transaction on Power Systems*, 2006 vol. 21, issue 1, pp 68-76.

[9] Troncoso, A., Riquelme, J.C., Asuilar-Ruiz, J.S, and Santos, J.M.R, "Evolutionary techniques applied to the optimal short-term scheduling of the electrical energy production", *European Journal of Operational Research*, 2008, vol. 185, pp 1114-1127.

[10] Umayal, S.P., and Kamaraj, N., "Stochastic multi objective short term hydrothermal scheduling using particle swarm optimization", *INDICON 2005 Annual IEEE*, pp. 497-501.

[11] Ni, E., and Luh, P.B., "Experience in day-ahead market price forecasting", *in IEEE Power engineering society Winter Meeting*, vol 3 2001, pp 1518-1523.

[12] Hsiao, C.Y., and Hong, Y.Y., " Locational marginal price forecasting in deregulated electricity markets using artificial intelligence" *IEE Procedings-Generation Transmission & Distribution*, 2002, vol. 149 no 5 pp621-626 .

[13] A. Brooke, D. Kendrick, A. Meeraus, R. Raman and R.E. Rosenthal, "GAMS: A user's guide", *GAMS Development Corporation*, 1998 Washington, DC.

[14] Kunju, B., and Rao, P.S.N., "Determination of market clearing price in pool markets with elastic demand", *Fifteenth National Power Systems Conference (NPSC)*, 2008, IIT Bombay.