# SCHEDULING OF WIND-PSP GENERATION UNDER DAY-AHEAD MARKET

**Ph.D. THESIS**

*by*

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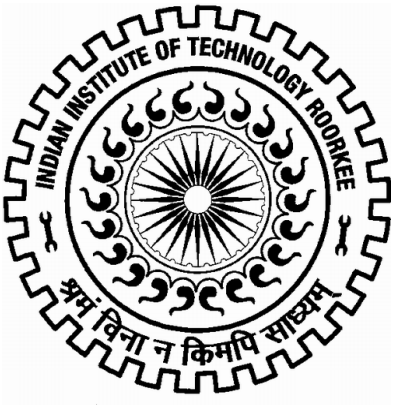


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# ABSTRACT

The world today is facing major environmental challenge in meeting energy needs. Rising fossil fuel prices, oil insecurity, concerns about climate change and erratic weather patterns cast a shadow over the future use of coal, oil and other conventional sources of energy. Such concerns and increasing energy prices encouraged the search for cost competitive alternate sources of energy. Energy obtained from inexhaustible renewable sources like wind, solar and hydro is reliable, clean and will have long term benefits. Various countries including India have taken policy initiation for speedy development of renewable sources. During 2009-10 in India, wind energy has been found the fastest growing renewable energy and added the highest installed capacity among renewable energy sources compared to the other top four wind energy developing countries viz USA, Germany, China and Spain.

Despite the apparent advantages of wind power, it faces major challenges being variable and intermittent in nature. To limit the impact of the intermittence of wind power, water storage ability of the pumped storage plant combined with a wind power plant is called the wind-pumped storage plant (Wind-PSP). The main advantage of a wind and pumped storage plant is to complement energy by optimizing the available local wind and hydropower resources to ensure high levels of quality, reliability and performance of power supply with cost effective installation and operation.

Literature review reveals that earlier studies in this area have not considered the efficient bidding strategy for operating wind and variable speed type pumped storage unit to increase the profit in day-ahead or spot market. Very few studies considered wind data uncertainty in short term scheduling of wind-PSP to reduce market imbalance. No study has been reported for the management of the risk associated with wind and market uncertainty to provide stable operation of wind-PSP system under uncertain condition.

The objective of the present study is to provide the scheduling of wind-PSP system to increase the day-ahead market profit as well as reducing the market imbalance with limiting the active power output variations of wind energy resources by considering the needs of grid and stored energy available in PSP. For this short term scheduling problem stochastic approach has been applied to consider the effect of wind data uncertainty. This study determined and managed the uncertainty risk for the stable operation of the wind-PSP system. A min-max approach also has been provided with the objective to minimize the effect of uncertainty risk of wind-PSP system under the worst conditions.

In order to achieve above objectives, a 24 hours time frame has been considered in this study for the hourly scheduling of wind and pumped storage plant under day-ahead market, where both wind and pumped storage system are operated as a single entity, but not necessarily installed at the same or adjacent location. PSP considered in the study, consists of reversible turbine unit which can either generate electricity or pump the water as per requirement. Both the systems (wind and PSP) are connected with the grid. An optimal strategy is developed to efficiently utilize the power generated by wind and PSP as per the demand or bid received from the electricity market.

In order to achieve the above objective, a mixed integer type problem has been formulated for providing the scheduling of wind-PSP system. The optimal solution has been obtained by considering four cases. In the first case (Case-I), only wind farm has been considered to supply the power under the day-ahead market and attempted to increase the overall profit. In the second case (Case-II), the combined operation of wind-PSP system has been used, where the PSP operated at fixed speed during pumping mode. In the third case (Case-III), pumping is done at two different speeds, whereas in the fourth case (Case-IV) variable speed operation has been provided, which further reduced the market imbalances created by wind system.

Uncertainties in the electricity market always affect scheduling operation of wind-PSP system. These uncertainties are in the form of price, demand and generation. For the power generation entities or the market operator, these uncertainties are mostly unknown

at the time of scheduling or bidding. In the present study, stochastic approach has been used to formulate the wind-PSP scheduling problem considering the wind system uncertainty as input data. Under this problem, an average sum of each individual solution set of uncertain input data weighted by their associated probability is considered in order to achieve a single solution. A probability based forecasting model has been used to forecast the uncertainty in the input data and computed the probability distribution function for the each set of input data. This solution has been found the best for all the individual solutions rather than solution from single set of input data. Three cases have been studied to check the optimality of the solution. In first two cases, wind-PSP system is considered to provide the scheduling under uncertain condition by operating the PSP in fixed and variable pumping modes, whereas third case provided the scheduling operation for grid connected wind-PSP to increase the overall profit under the deregulated environment.

As discussed above, probabilistic forecasting technique is used to predict the wind uncertainty, but in most of the cases, forecasting results were not very accurate and brought risks in the system. To manage these risks properly, an experimental design technique based on Taguchi method is employed to calculate and manage the uncertainty risk in this study. The proposed method utilized orthogonal array based structure, which is easy to implement and uses limited number of experiments thus demands less computational time. An adjustable speed type PSP unit has been considered, which effectively reduced the market imbalances occurred by uncertainties in wind generation and market demand.

Further, a game theory based Min-Max optimization method has been developed to reduce the effect of uncertainty during Wind-Pumped Storage System scheduling. The solution of this problem provided the best worst case performance of the system under uncertain condition. In the developed model, two feasible scenarios, the nominal scenario and the worst-case scenario were considered using the concepts of min-max optimization.

The uncertainty risk has been further reduced by providing the integrated operation with pumped storage plant (PSP).

The main aim of this research work was to provide the scheduling of wind-PSP system in order to increase the overall profit across wind-PSP system for day-ahead market. It has been found that in the wind and pumped storage scheduling, fixed speed type PSP units reduced the market imbalance by 60% and increased the overall profit by 19%. The profit was further improved to 31% by replacing the fixed pumped storage unit with a variable speed pumping unit. The operation of the pump unit in varying speed mode not only increased the total revenue but also decreased the market imbalance by 38% which otherwise would have caused the revenue loss during the combined operation. It is concluded that the utilization of wind energy has been increased from 1 to 4% by operating with grid system under uncertain condition. Thus grid connected wind-PSP system further improved the overall profit by 4%.

Taguchi method based model has been developed to optimize the wind-PSP operation under uncertain condition. This method reduced the operation risk of wind-PSP system under uncertain conditions by 64%. The major advantage of this approach is to design a wind-PSP system, which is able to withstand any level of risk and provide the stable performance under uncertain condition.

With min-max optimization technique, scheduling of the wind-PSP system was successful in reducing the uncertainty involved in risk by decreasing the imbalance costs under the selected scenarios. Scheduling is done in such a way that the risk involved in operating Wind-PSP system would remain same for all scenarios. By using this method risk was reduced by 20% for operating variable speed unit as compared to fixed speed PSP unit.

The developed Wind-PSP model can be considered as a significant tool in decision-making process for day-ahead market scheduling.