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Impact of load management on the energy management strategy of a wind-short hydro hybrid system in frequency based pricing

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ABSTRACT

In the post restructuring era of electrical power system, each of the generating farm or utility has its own business strategy in terms of generation planning, load management and for other decisions. The basic objective of the utility is to maximize the operational profit for a given period of time. Generation scheduling for a utility with wind farm largely depends on the accuracy of wind power prediction. Therefore, it is important to explore the suitability of load management approach in coordination with the use of energy storage facility to compensate the uncertainty in wind power generation. This paper focuses mainly the operating strategy of a grid connected small hybrid power system to maximize its profit by adopting coordination between load management technique and utilization of storage plant under frequency based pricing. The optimum load scheduling has been implemented to utilities own local load. An hourly-discretized optimization algorithm is proposed and solved using artificial bee colony algorithm. To verify the effectiveness of the proposed method, the optimization problem is solved for varied wind power scenarios with different demand expectations cases in a day ahead Indian electricity market. It is noted that the proposed load management approach results more profit for the hybrid system because of better power management compared to the case when load scheduling has not been incorporated. The solution of the proposed optimization algorithm gives the strategies to be followed by the hybrid system how to operate its pump storage unit and to serve its local load in next hours.

1. Introduction

Among the renewable energy source (RES) technologies, wind energy is world's fastest growing renewable energy source. There is a growing global demand of wind energy production and its integration into electrical power systems. Many large wind farms have already been installed till date across the world. Analysing the impact of integration of large scale wind farm in electrical power system network are priorities for many countries and perhaps because of this, wind power technology, uses, control and implementations are most researched topic in recent times.

The increase in large scale wind farm integration has intensified the problems associated with power system operation, control and management. Planning an optimal operation and generation scheduling with wind integrated power system is more complex and requires careful reserve management. To improve the controllability on wind power output, the use of energy storage devices in coordination with wind farm has gained attention. Among the energy storage devices, the pumped storage hydro plant is the oldest and most acceptable. The uses of pumped storage hydro unit in coordination with wind farm have already been reported in literature [1–3]. In wind-hydro coordinated operation, it is intended to operate the pumped storage hydro unit most optimally to maximize the operational economy of the utility. The optimization models describing the improvements in operational gains have been discussed in the above reported works. However, the benefit of such coordinated operation can only be maximized by selecting optimum dimension of pumped storage plant which can effectively recovers the rejected wind energy [4]. A properly designed pumped storage hydro unit can enhance the capacity factor of a plant and can make it economically viable [5]. Emphasis has been given on various economic perspective of operating wind farms in coordination with pumped storage hydro unit [6]. Moreover, the issues related to analyzing the generation rescheduling problems [7] for complex power system consisting of thermal power plants, wind farm and pumped storage hydro unit are gaining importance in recent times. An accurate wind power prediction is necessary by the utility for finding an operational strategy. Inaccuracy in prediction has impact on short term scheduling, market price, system stabilities, transmission congestions, load management etc. An adaptive and dynamic wind energy

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Nomenclature

B_{ij}	line susceptance between bus i and j
C	percentage of commercial load
c^k	hourly market price for schedule interchange in Rs/MW h
C_{SI}^k	hourly cost of schedule interchange in rupees
C_{PS}^k	hourly cost of extra power sold to the micro grid in rupees
C_{PPL}^k	hourly cost of extra power purchased from micro grid for supplying load in rupees
C_{PPP}^k	hourly cost of power purchased from micro grid for pumping in rupees
E^k	hourly reservoir energy level in MW h
E^U	maximum energy level of the reservoir in MW h
E^L	minimum reservoir energy level to maintain in MW h
G_{ij}	line conductance between bus i and j
I	percentage of industrial load
k	index of interval or hour
P_0	real power demand of local load at nominal voltage
P_S	actual real power demand of the local load
P_W^k	hourly available wind power generation in MW
P_h^k	hydro generation from pumped storage hydro unit in MW
P_{CG}^k	hourly real power from central generators in MW
$P_{CG}^{\min}$	minimum power of central generators in MW
$P_{CG}^{\max}$	maximum power of central generators in MW
P_P^k	power consumption during pumping hours in MW
P_D^k	hourly real power demand in MW
P_{HS}^k	hourly active power delivered by hybrid system to the grid in MW
P_L^k	hourly local load demand in MW
P_{LC}^k	hourly curtailed active load in MW
Q_0	reactive power demand of local load at nominal voltage
Q_S	actual reactive power demand of the local load
Q_D^k	hourly reactive power demand in MW
Q_{LC}^k	hourly curtailed reactive load in MW
Q_{HS}^k	hourly reactive power delivered to the micro grid in MW (if any)
R	percentage of residential load
$Rate^{UI}$	unscheduled interchange rate in Rs/MW h
S_{ij}^k	hourly line flow between bus i and bus j in MVA
S_{ij}^U	maximum line loading limit of line between bus i and bus j in MVA
UI^k	hourly unscheduled interchange in MW
UI_{PS}^k	hourly extra power sold to the grid as unscheduled interchange in MW
UI_{PPL}^k	hourly extra power purchased from grid for load balance in MW
UI_{PPP}^k	hourly extra power purchased from grid for pumping in MW
$\|V_i\|$	Voltage magnitude at ith bus
$\|V_i^{\min}\|$	minimum voltage magnitude of bus i
$\|V_i^{\max}\|$	maximum voltage magnitude of bus i
η_h	efficiency of pumped storage hydro unit during hydro generation
η_P	efficiency of pumped storage hydro unit during pumping
θ_i	voltage phase angle of ith bus
α, β	local load exponents

management plan based on short term wind power prediction has been reported in [8]. The impact on market price due to inaccuracy in wind power prediction has been addressed in [9] when a large scale wind farm is integrated into an electric power system. An optimal bidding strategy for pumped storage plant under market environment has been discussed in [10]. The formulation has been made to allow a pumped storage hydro unit to optimally reschedule its operation in a day ahead electricity market.

The Indian electricity market has been restructured and a new attribute has been added to the real time generation and dispatch in the form of frequency linked pricing; commonly termed as Availability Based Tariff (ABT) in 2002. The achievements with ABT mechanism ensure improved frequency condition of grid, accountability in power exchange, better utilization of resources etc. In real time power system operation, the actual power generation and dispatch may deviate from the schedule and that would result flow of unscheduled interchange (UI). The cost of UI flow is made frequency dependent in Indian power system operation [11]. The issues of frequency regulation under reformed system structure have been discussed in [12]. A day ahead unit commitment problem has been modeled and analyzed under frequency based pricing mechanism in [13]. The problem has been formulated as a mixed integer linear programming problem and tested on an Indian test system with the presence of pumped storage hydro unit. The work in [14] analyzes the issues related to pumped storage hydro plant operation in coordination with a grid connected wind farm in frequency based pricing environment. The frequency regulation is a key mechanism of controlling frequency by minimizing supply demand gap. Efforts have been taken to improve the frequency regulation of electrical power system network [15–17].

In the post restructuring era of electrical power system, each of the generating farms has its own business strategy in terms of generation planning, load management and for other decisions. The basic objective is to maximize the operational profit for a given period of time. Finding a generation scheduling strategy for a utility with wind generation largely depends on the accuracy of wind power prediction. Therefore, it is important to explore the suitability of load management approach that can compensate the uncertainty in wind power generation. Load management (LM) is an essential architecture to improve demand response which benefits both utility and customer [18,19]. An effective LM can limit the requirement of load curtailment and provides the strategy to maximize the use of RES for simultaneous financial savings of customer [18]. The impact of management and control on energy storages and loads enables the utility to meet the demand at all times in most economic manner [19].

This paper focuses mainly the business strategy of a grid connected small hybrid power system to maximize its profit by adopting an optimal load management technique under frequency based pricing. In this paper, the load management has been implemented to utilities own local load, in terms of load modeling and scheduling. Load modeling is an important aspect in power system operation. Impractical load modeling will give misleading results. Most of the loads in distribution side are sensitive to voltage and frequency [20]. The effect of load models in distribution system planning has been investigated in [21].

The present work, aims to maximize the profit of the hybrid system by the following operating strategies: (a) By operating the pumped storage hydro unit to minimize unscheduled interchange flow and to compensate the imbalances in wind power