Applied Energy 161 (2016) 574–582

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Optimized reservoir operation model of regional wind and hydro power integration case study: Zambezi basin and South Africa

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HIGHLIGHTS

- The study introduced reliability assessment method of integrated wind–hydropower operation.
- The method identifies optimum target power operations that maximizes the firm generation.
- We test the proposed method on interconnected system of reservoirs in Southern Africa region.
- Results indicate that higher penetration of wind power can be achieved through the proposed frame work of operation.

ARTICLE INFO

Article history:
Received 4 June 2015
Received in revised form 16 September 2015
Accepted 21 September 2015
Available online 24 October 2015

Keywords:
Wind hydropower
Optimized operation
Zambezi
South Africa

ABSTRACT

The present study develops a reliability assessment method of wind resource using optimum reservoir target power operations that maximizes the firm generation of integrated wind and hydropower. A combination of water resources model for a system of reservoirs that implements a demand–priority based linear programing algorithm and a single node power grid system model is implemented on hourly time step. This model was accompanied by a global genetic algorithm solver to determine optimum operation targets for each storage reservoir aiming at maximizing the 90th percentile power generation produced by the integration of wind and hydro over the entire simulation period.

This model was applied on the reservoir storages and hydropower system in the Zambezi river basin to test if the storage reservoirs could be efficiently be used to offset wind power intermittence in South Africa subjected to the different physical and policy constraints. Based on the optimized target operation and hourly annual real data for the year 2010, the water resources system and power interconnection system were simulated together to assess the maximum firm generation of power as a result of the new wind and hydro combination target for storage hydropower plants.

The result obtained indicates that high regulation of wind and hydro can be achieved as a result of combined operation and showed 45% increase in the level of wind penetration in South Africa's power system over the reference scenario. The result also indicated a reduced level of coal power utilization and less cycling requirement. This will have a positive outcome in terms contributing to South Africa's goal toward reducing greenhouse gas emission and the efforts to build green energy supply and resilience to the impacts of climate change.

1. Introduction

Technologies utilizing wind energy have made considerable progress in recent years with notable improvement in efficiency of wind power harvesting as well as forecasting. Due to its clean and cost-effective renewable supply of energy, wind power has become an attractive investment and one of the world's fastest growing energy resources. Yet the penetration of this renewable resource remains low in most power grid systems due to the inherent intermittent nature of sufficient wind availability to power turbines. In addition to its variable characteristics it is also often difficult to control or easily adjust the power output, making it a highly non-dispatchable source of energy. Consequently utilization of this resource to its maximum potential remains one of the biggest challenges both for planning and operation. The use of

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http://dx.doi.org/10.1016/j.apenergy.2015.09.077
0306-2619/© 2015 Published by Elsevier Ltd.

complementary or other dispatchable energy resource in integration with wind has been found to be one effective way to make wind power more usable.

Hydropower is one of the least expensive and environmentally clean energy options; furthermore, hydropower stations with a storage reservoir are highly dispatchable, power generation can be scheduled in less than an hour, and even frequent startups and shutdowns can be executed without a significant damaging effect on the infrastructure service life. These qualities make it an excellent complement to intermittent power sources such as wind. Water reservoirs are suitable to be used as energy storage facilities, "batteries", to store water during high wind periods, and release this water to produce electricity when it is needed. This integrated operation of wind and hydro has been the topic of many studies and there is a growing interest in developing efficient ways of coordination in order to increase the over economic and environmental advantage of this intermittent energy source both at planning stage as well during operation. Generally, these studies have shown an increase in overall penetration of wind energy in the power system through integrated operation with hydropower. Proposed different operation strategies to get maximum benefit of the coordinated operation.

Methods employed in previous studies of wind–hydro integration can be viewed in two categories based on objectives: (1) Short term operational models utilize mathematical techniques to optimize or simulate the system for short term operational goals based on meeting some economic objectives, either in terms establishing optimum daily operational strategy that reduces total operating cost, or maximize the 24-h total economic gain [1–3] of wind and hydro operation; and (2) Long term reliability assessment models which look at longer time scale of operation and try to achieve overall increase of firm power available in the system [4–6]. Reliability assessment tools are mostly useful during planning or assessing the reliability of existing system and depend on either stochastic techniques of wind generation pattern or uses a perfect foresight wind generation pattern [6]. Operational models are mostly of high value for day-to-day operations of meeting management objective and make use of a short term, 24–48 h, forecast for wind power. We could further identify models based on scope of analysis and complexity of the components, whether the models are looking at single reservoir in isolation or over interconnected power grid systems [7].

The level of market penetration or extent of reliability of wind power that can be achieved through wind–hydro integration is dependent on several variety of factors. The capacity to which water storage dams are able to address the variability and unpredictability of wind energy is function of factors such as infrastructural capacity, policy and physical constraints in reservoir operation, characteristic of power demand and hydrological conditions. It is important to consider these parameters in reliability assessment models during planning as well as operation as their contribution to overall effectiveness of the integrated operation is highly variable and they are often system specific.

One of the key knowledge gap that exists in most previous wind–hydro studies is the lack to consider longer time scale regulation of wind variability by storage facilities. In addition to short time power balance, hydropower plants with large storage capacity are able to modulate longer time scale of variability such as weekly and seasonal, which is often present in power demand, hydrology and wind power generating potential [8]. In order to accommodate this seasonal variability reservoir rule curves should be adjusted to take the intermittency of wind power, longer time scale variability and variability in power demand into consideration. This is often complicated particularly for multi-purpose reservoirs with prior commitment to other water resources regulating functions, such as irrigation, flood control and downstream environmental flows as the operation strategy is often established to cater to the highest priority function. Most previous studies focused on establishing optimum daily operational strategy do not consider this since primarily the models employed only look at shorter time scale in the future. At present, there are few studies in reliability assessment methods of wind–hydro integration available in the scientific literature that consider longer time scale of regulating capacity. Efficient use of wind energy and 'battery' coordination can be achieved through looking at longer time of optimal coordination as longer scale variability is an essential element that needs to be taken into consideration when developing reservoir operation strategy of wind and hydro coordination.

When looking at infrastructural capacity, previous wind–hydro studies have addressed effect of storage capacity and flexibility of other energy sources that might be used in conjunction with hydropower such as cycling capacity of coal and gas. Interconnected system of reservoirs, as in the case of power pools, present additional opportunity that is crucial to effectiveness of wind–hydro integration. Hydrologic characteristics and thus availability of storage could potentially be different spatially. Operation of the reservoirs in coordination can create additional flexibility that could be utilized to modulate intermittent power source, distribute demand fluctuations and variability spatially. For example, if we consider two multi-purpose reservoirs with primary target for flood protection but having different flood season. They will have different pattern of rule curves for flood storage and thus different pattern of available storage. Adding an intermittent energy source to this system will have further advantage through choosing which reservoir to use for regulation depending on the storage availability in that particular season. This effect is which is often overlooked by many studies. No studies to date have considered this effect in reliability assessment of integrated operation of Wind and Hydropower reservoirs.

Policy constraints in reservoir operation such as downstream environmental flow requirements of dam release are often significant in limiting the capacity of the reservoir to modulate the intermittency of wind. Some system-based study on wind–hydro have realized this and have taken this into consideration [1,7] However as mentioned before, reservoirs with other function such as operation for irrigation demand downstream could narrow the range of operation to regulate wind–hydro integration. This is dependent on the priority assigned to each function of the reservoir. This aspect has not been adequately covered in studies available in scientific literature.

The above three key knowledge gaps are the motivation behind this work. This study represents an attempt to filling this gaps in wind–hydro assessment practice through the development of reliability assessment methods that address the knowledge gaps discussed. We are proposing a method for assessment of wind resource reliability using optimum reservoir target power operations that maximizes the firm generation of integrated wind and hydropower, a frame work that optimizes resource utilization both at a time step level for short time scale operation as well as over a longer period of simulation. The key contribution of the method presented here is in illustrating three level of optimization that capture (1) hourly allocation of power between different supplies, (2) long term seasonal variability of water resource for hydropower generation, (3) lateral distribution across demands and interconnected hydropower sources to considers optimal distribution of load for offsetting the gap in energy supply and storage.

A combination of demand-supply priority based linear programming hourly water resources model and Genetic Algorithm (GA) solvers are combined to determine operation strategies of multiple storage reservoirs linked in power pool simultaneously to yield maximum firm generation over one year of the simulation