Electrical Power and Energy Systems 74 (2016) 310–321

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Hybrid wind power balance control strategy using thermal power, hydro power and flow batteries

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ARTICLE INFO

Article history:
Received 22 March 2015
Received in revised form 18 June 2015
Accepted 7 August 2015

Keywords:
Flow battery
Power system balance
Wind farms
Wind power generation

ABSTRACT

The increased number of renewable power plants pose threat to power system balance. Their intermittent nature makes it very difficult to predict power output, thus either additional reserve power plants or new storage and control technologies are required. Traditional spinning reserve cannot fully compensate sudden changes in renewable energy power generation. Using new storage technologies such as flow batteries, it is feasible to balance the variations in power and voltage within very short period of time. This paper summarises the controlled use of hybrid flow battery, thermal and hydro power plant system, to support wind power plants to reach near perfect balance, i.e. make the total power output as close as possible to the predicted value. It also investigates the possibility of such technology to take part in the balance of the Lithuanian power system. A dynamic model of flow battery is demonstrated where it evaluates the main parameters such as power, energy, reaction time and efficiency. The required battery size is tested based on range of thermal and hydro power plant reaction times. This work suggests that power and energy of a reasonable size flow battery is sufficient to correct the load and wind power imbalance.

Introduction

During the past decade, the number of renewable energy sources has increased dramatically. It is forecasted that the growth of green energy generation will increase even further. Policy makers in developed countries create many incentives in favour of the development of low-carbon technologies and subsidise green energy generation. This should help to reduce carbon footprint and climate change. On the other hand, most of renewable energy comes from generators that are inherently very hard to control [1], thus it introduces further complexity in system balancing task.

Up to now in many cases wind turbines or solar panels are being connected to the grid with minimal control. Due to hardly predictable natural resources, like wind or solar irradiation, the errors between actual energy output and forecasted generation are relatively large. This increases the difficulty of the energy balance problem: corresponding operators need either more tools or new technologies to come in hand [2]. Increasing advanced spinning reserve to back up intermittent generation would require inadequate level of investment considering exponential growth of power generation using green technologies. Also, this type of reserve has limited power variation capabilities (in the order of minutes) whereas solar power output can drop nearly instantly. The alternative is to use new highly responsive storage technologies [3,4] that could be incorporated into the system and shave over-generation as well as generate energy when demand overtakes supply.

Lithuanian Power System (PS) and other Baltic States currently operate synchronously with IPS/UPS synchronous zone and are connected to BRELL power ring, which consists of Belarus, Russian, Estonian, Latvian, and Lithuanian power systems. According to BRELL regulations Baltic States are not required to have automatic secondary power control, however Baltic States are planning to synchronically connect to the power grid of Continental Europe in 2020. This means decentralisation of power system control and responsibility to maintain power and energy balance within strict boundaries [5]. Therefore, it is important to investigate the feasibility of Lithuanian PS to automatically maintain power balance.

National Renewable Energy Laboratory in USA focuses on researching economic feasibility of energy storage and clearly

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http://dx.doi.org/10.1016/j.ijepes.2015.08.002
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states that high penetration of variable generation increases the need for all flexibility options including storage [6]. They also note that the economic value of energy storage devices is at its best when selling to the entire grid, instead of any single source. However the role of storage for wind generation requires continuous analysis and additional studies including new techniques to evaluate more dynamic grid operation.

Droste-Franke et al. analysed German power system balancing options and concluded that technological progress is needed in the following areas. Firstly, grid expansion and inter-regional connectivity compensating regional shortages of supply from renewable sources in Europe. Secondly, load management could become feasible through technologies such as smart metering, and finally, storage capacities need to be extended [7]. They also conclude that interrupted renewable power smoothing using battery storage system [4,8] is the cheapest option at present.

Söder and Hamon investigate wind power capabilities to participate in balancing services. They conclude that wind power plants do not usually participate in balancing services because they must be set to produce less than they are capable in order to be used for up regulation [9]. Margins are kept by spilling the wind, which cannot be stored. A method is proposed to select a certain tertiary reserve control in order to minimise the total cost of the system and maintain stability of the power system with larger portions of wind power. This means that they deal with emergency power system operation modes while our proposed method covers secondary control reserve and optimal share of reserve power between different kinds of generation sources.

Lubosny and Bialek proposed wind farm supervisory control scheme which is suitable to control individual wind mill or separate wind farm in two different ways – using additional storage device or power reserve achieved through part-loading one or more turbines in a wind farm. Authors suggest using wind power filter in order to separate the variability of wind power. They also concluded that elimination of larger power variations can be done more effectively using a central or single energy storage [10]. Therefore our proposed control strategy differs due to the fact that it deals with central control of all wind farms instead of individual ones.

Jiang and Wang similarly to [10] suggest to control wind power plant using power filter. Additionally, they proposed the optimisation model of corresponding filter parameters. However, due to the uncertainty inherent in wind power generation, optimal control during long time periods has difficulties predicting wind power and is unpractical in actual real-time operation [11]. Besides it requires additional computational resources and time. Active power losses and state of charge of storage devices depend on wind power generation, therefore it is hard to maintain the proper charge level and mitigate wind power fluctuation. Authors conclude that two-time-scale coordination control method gives controversial results because the required battery power reaches 33% of installed wind power (in our case it reaches 5–25% depending on power system operation mode, discussed later in the paper) while the power fluctuation allowance is up to 10%. Finally, the capacity component of the battery dominates (comparing to power) which means that storage devices are controlled according to wind power trends. The control strategy proposed in this paper controls storage devices according to high frequency component of wind power imbalance and it allows reaching 100% power balance with reasonably lower ratings of storage device.

Abbey et al. suggests using filters and neural networks to control two different types or multiple storage devises [12]. It is novel and interesting method but too complex for wind power balancing purposes on real-time operation. In principle, multiple levels of storage is needed only in new areas such as island household networks with renewable sources or micro-grids while wind power integration to conventional power systems usually require only short-term storage because the trends of wind power imbalance could be compensated by thermal or hydro power plants in more economical way. Our proposed hybrid wind power balance control strategy composes of conventional generation and energy storage control from power system operator point of view, which means central control in more efficient manner.

Wang et al. studied operational reliability of power system with high wind power penetration [13]. They have concluded that energy storage systems dramatically increase reliability of systems with wind farms. Authors also analyse and show the required battery sizing for certain reliability index.

Khalid and Savkin proposed new semi-distributed storage configuration [14] and using model predictive control [15] identified the optimal capacity of battery energy storage system. However the purpose was to identify the optimal capacity only taking into account the system ramp rates while our paper also deals with installed power of energy storage, conventional power plants optimal control and active power reserve optimisation. In addition we have used actual wind data of 10 days with a time step of one second instead of 1 day and 10 min time step. Yuan et al. proposed dual-battery energy storage system [16] which consist of two separate battery storage systems. One of them is suitable for positive error compensation where the other one is suitable for negative ones. They also proposed three indices for the assessment of the performance on wind power dispatchability which could be identified by using sequential Monte Carlo simulation. However the time step is one hour which means that little dynamic behaviour could be represented. The authors also do not introduce any optimisation task.

Ansari and Velusami have been investigating the dynamic stability of hybrid autonomous wind – diesel with battery energy storage system. They proposed dual mode linguistic hedge fuzzy logic controller [17] and have shown its advantages comparing to traditional fuzzy logic and PI controllers. Kalantar and Mousavi G. replaces less effective and high pollution diesel generator to more flexible and reliable microturbine with the addition of solar array system to earlier investigated one. In order to maximise power outputs of wind and solar power plants they proposed a model reference adaptive Lyapunov controller [18] and improve the system behaviour comparing to fuzzy logic and PID controllers. Latter Mousavi G. have adapted the proposed method to offshore wind and tidal hybrid system with microturbine and BESS [19]. The authors provide an in depth investigation/review of the autonomous rural hybrid system in literature [17–19], however the proposed methods are not suitable for wind integration to large power systems with conventional generation, therefore our paper deals with this issue. In addition, our paper represents the optimal wind balancing power allocation between conventional power plants and energy storage devices.

A feasibility study of hybrid solar-wind-battery system for remote location can be found in [20]. Although it shows that it is possible to replace diesel generators by 100% renewable energy, about 48.6% of energy is dumped due to lack of storage and energy management.

Traditional Automatic Generation Control (AGC) system calculates error of the control area and allocates the required regulating power plants. Then they participate in the system balance according to participation factors [21] in order to keep power system in balance. The participation factors are usually determined according to power plant's parameters such as rate limits [22,23], available spinning reserve [24] or economic (cost) characteristics. There are many methods to determine them: major part of power is allocated to the cheapest power plant, the fastest response power plant [25] or combined [21] method. This paper describes energy management method for increasing the quality of wind