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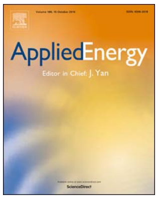

Utilizing distributed energy resources to support frequency regulation services

S. Zhang[a], Y. Mishra[b,*], M. Shahidehpour[c]

[a] *Southeast University, Nanjing, Jiangsu, China*
[b] *School of Electrical Engineering and Computer Science, QUT, Brisbane 4000, Australia*
[c] *Illinois Institute of Technology, Chicago, IL, USA*

HIGHLIGHTS

- Utilizing distributed small scale renewable generators in modern power systems requires new framework.
- Conceptual framework for new Renewable energy aggregators (REA) is proposed.
- The dynamic schedule and control strategies for REAs utilizing variable solar insolation and wind speed is employed.
- Participation of REAs in current electricity market to provide frequency regulation services.

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ABSTRACT

Increasing penetration of small-scale intermittent distributed energy resources (DER) such as solar/wind in the power system poses frequency regulation problems due to the reduced system inertia. This paper proposes a new entity, namely, renewable energy aggregators (REA), which enables several small-scale renewable energy generators (SREG) and energy storage systems (ESS) to enhance the frequency stability in low-inertia systems. REA participates in the electricity market and provides frequency regulation services by employing dynamic schedule and control strategies (DSCS). The proposed DSCS consists of forecasting and frequency regulation blocks to schedule appropriate amount of renewable energy in real-time. It utilizes individual weather conditions such as solar insolation and wind speeds for SREG and determines variable de-loaded coefficients to energy spilling or wastage. The efficacy of DSCS based REA under both open-loop and closed-loop simulation studies indicate improved frequency regulation performance under varying weather conditions and load fluctuations.

1. Introduction

System frequency regulation aims to maintain the frequency of synchronous power system as close as the nominated value after small load disturbances. Traditionally, conventional generators such as thermal generators are able to regulate the system frequency because of their high inertia and automatic generation control (AGC) [1]. However, modern power systems with increasing number of distributed energy resources (DER) primarily consisting of renewable energy generators (REG) such as solar and wind are making it difficult to maintain the frequency regulation.

Recently, researchers across the world are aiming to reign in the intermittency of the REG with or without energy storage systems (ESS) using several advanced control schemes [2–16]. For example, smoothening of power supply from PV system by tuning maximum power point tracking (MPPT) control is proposed in [2]. De-loaded operation wind turbines can be used in primary frequency control as proposed in [3]. ESS can be used to augment PV plants [4] and wind generators [5] to support the dynamic frequency response [6,7]. Moreover, authors in [8,9] use the active power from both REG and ESS to mitigate the generation-load imbalance. REG can perform as conventional generators by using de-loaded operation through MPPT and effective utilization of ESS to support the large-frequency response [10]. More generation participants e.g. PV, wind and BESS can be involved in the coordinated control for frequency response and the dynamic model of a stand-alone hybrid power system considering WG, PV and BESS is presented in [11,12].

For under-frequency response, which requires contribution to system inertia, the transmission system operator (TSO) should rely on large-scale generators as small generators are unable to respond to large

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[*] Corresponding author.
E-mail address: yateendra.mishra@qut.edu.au (Y. Mishra).

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frequency events. Whereas, the ability of small-scale REG (SREG) to response to large-frequency response is restricted due to limited available head-room, dispersed and distributed nature of SREG.

Owing to the distributed nature, weather fluctuations (wind speed and cloud cover) and size limitations of SREG, current interconnection agreements for SREG may not necessitate voltage and/or frequency regulation capability. This paper proposes a new framework of renewable energy aggregators (REA) to entice SREG and ESS to participate in frequency regulation market.

Recent uptake of ESS in distributed as well as at bulk level and the entrance of new market participants namely aggregators is changing the traditional way of power system operation [13–15]. Particularly, the demand aggregator has gotten wider attention where individual customers are encouraged to participate in demand response via some kind of rebate scheme offered by third party demand aggregators [16–18].

In this paper, the concept of renewable energy aggregator (REA) is proposed, which aims to manage SREG and ESS to provide frequency regulation services using dynamic schedule and control strategies (DSCS). The proposed REA acts as mediator/brokers between TSO and end-users equipped with SREG and ESS. The proposed scheme offers several advantages such as:

- It provides a possible way for SREG to participate in frequency regulation, which improves the overall system frequency performance.
- The variable de-loaded coefficients are used for SREG under different weather conditions, allowing REA to utilize the renewable energy for adequate frequency regulation and avoid energy spilling or wastage due to constant de-loading coefficients.
- DSCS employs forecasting block to take care of the real-time conditions such as solar insolation and wind speeds, which helps to schedule appropriate frequency regulation on distributed level.
- DSCS ensures that the overall utilization of ESS for a given area is better than several individual distributed uncontrolled ESS
- It allows for higher penetration of the SREG and gives end-users flexibility to manage their own generation providing yet another revenue stream from REA.

The paper is organized as follows: the role of the proposed REA in the current electricity market is introduced in Section 2 followed by their operating framework in Section 3. The details of the associated controllers in REA are presented in Section 4. The efficacy of REA in responding to the frequency regulation services under different operating conditions and contingencies is shown in Section 5, followed by conclusions.

2. Role of REA in current ancillary services market

Currently, TSO operates the energy market and the ancillary services market. In every coming dispatch period, generators bid a certain amount of power, and TSO commits generators in the most cost-efficient way through the real-time energy market. The frequency control ancillary services (FCAS), whereas, consists of frequency regulation and contingency frequency control [19–20]. Recently, aggregators, as a market participant can sell FCAS and are anticipated to play a critical role in the future [21–23]. Authors in [24–25] proposes the demand response aggregators (DRA) which gathers inelastic demand and act as mediator/brokers between end-users and grid operators.

The proposed REA, as shown in Fig. 1, acts as a third party and bridges the gap between individual SREG and TSO. Communities, business centers and/or universities with many SREG (e.g. roof-top PVs, community based wind turbines) and ESS (e.g. BESS) may join REA to produce, consume and store electricity. Moreover, BESS can be owned by REA or some SREG who would like to join the centralized control and share their battery banks. As the market participant, REA makes profit by buying energy from say SREG in a predetermined price and selling in the spot market and provides frequency regulation services by managing SREG and BESS. REA, as local aggregator, utilizes the complementary nature of solar/wind resources (because high insolation is usually available during sunny day time with lower wind speeds, and vice versa) and has improved forecasting ability and uses relatively smaller BESS size to obtain error-tolerant ability. Moreover, using reserve power from several SREG, the size of required storage is decreased. REA enables SREG to also participate in the ancillary services market and provide frequency regulation services.

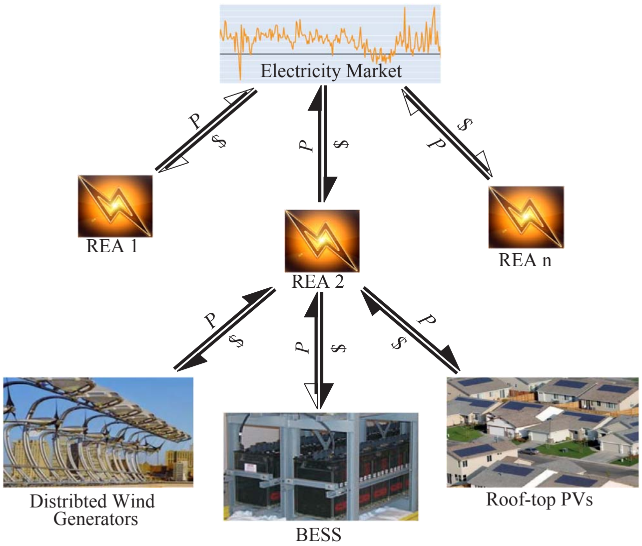

Fig. 1. Interaction between TSO and various REAs in the system.

3. Framework of DSCS for REA including frequency regulation

The operating framework of REA for frequency regulation services in the ancillary services market is introduced in this section. TSO monitors and controls each REA, who in turn controls SREG/BESS and provides frequency regulation to TSO. Moreover, DSCS is introduced, including the ‘forecasting block’ and the ‘frequency regulation block’.

Shorter bidding period for REA helps reduce the forecasting error in bidding caused to intermittency. It is clear from Fig. 2 (a typical insolation data for PVs from Australian Bureau of Meteorology) that for the same amount of de-loaded operation (say 10%), 15 min bidding interval reduces forecasting error. REA participates in the energy spot market ($P_{SREG}(T)$) every $T = 15$ min, and is also available to provide regulation services on a 4 s interval (225 times in 15 min) during each bidding period.

The operating scheme for REA can be summarized using Fig. 3. The given REA consists of I number of roof-top PVs (PV), J number of community based wind turbines (WG) and K number of BESS (S). Other types of SREG (e.g. bioenergy, geothermal, hydro, etc.) and ESS (e.g. flywheel, ultra-capacitor, compressed air, etc.) can be included in the proposed REA framework.

3.1. Forecasting block

Towards the end of the operation time interval, say $T-1$, the ‘Forecasting block’ determines the $P_{SREG}(T)$ and $P_S(T)$ for the next time interval, say T, using the information such as past insolation performance (In_i^μ and In_i^σ), wind speed performance (Ws_j^μ and Ws_j^σ) and frequency fluctuations (Δf^μ). In this case, ‘Forecasting block’ at T interval starts 1 min prior using past 15 min data say ($T-2,t_{210}$) to ($T-1,t_{210}$) for forecasting variables for the next interval. All the associated variables are determined using (1)-(12), in which $In_i(T,t_n)$,