International Journal of Trend in Scientific Research and Development (IJTSRD)
International Open Access Journal | www.ijtsrd.com
ISSN No: 2456 - 6470 | Volume - 2 | Issue – 6 | Sep – Oct 2018

Applications of Energy Storage Systems in Wind Based Power System

Mohd Azrul
M.Tech Scholar, Electrical Engineering Department YIET,
Gadhauli, Yamunanagar, Haryana, India

ABSTRACT
Due to the global environmental concerns, increasing energy demands and developments in renewable energy technologies present a new opportunity to implement renewable energy sources. Wind energy is the most prominent among renewable sources, as it is an inexhaustible resource and its exploitation has thus far been ecologically friendly. The potential amount of wind energy is considerably greater than current worldwide energy demands. Wind energy has been developing more rapidly than the other renewable energy sources for the last few decades. The best way to harvest the wind energy is wind turbines. This paper presents a study on wind energy in the form of a stand-alone and hybrid power generation system used to electrify off-grid locations. The stand-alone wind-diesel system developed here is intended to be used to power a single house or a small community and it also functions as a mini-grid, generating power in places where adequate wind speed is available throughout the year. However, many places throughout the world experience unsteady amounts of wind speed and in those places, a hybrid wind-diesel system is the most efficient solution for electrification. The main benefit of the hybrid system is that the weakness of one source is covered by the other source. This paper also presents some comparative case studies, project examples and demonstrations of stand-alone wind diesel hybrid systems implemented at various locations throughout the world over the last twelve years.

Keyword: *Battery energy storage system, Micro grid, Frequency control, Single-phase inverter*

I. INTRODUCTION
Wind energy has achieved rapid development and growth. According to the estimation of International Energy Agency (IEA), the annual wind-generated electricity of the world will reach 1282 TW h by 2020, nearly 371% increase from 2009. By 2030, that figure will reach 2182 TW h almost doubling the year 2020 production [1]. Due to the intermittent nature of wind power, the wind power integration into power systems brings inherent variability and uncertainty. The impact of wind power integration on the system stability and reliability is dependent on the penetration level [2]. From the reliability perspective, at a relative low penetration level, the net-load fluctuations are comparable to existing load fluctuations [3], and the Conventional Generators (CGs), such as thermal or hydro units, have sufficient load tracking capability without requiring additional operating reserve. As the wind penetration level increases, the response time of committed CGs should be short enough during sudden and large changes of wind power production and load due to random failures and wind gusts, and more operating reserves will be required. From the stability perspective, different from synchronous generators, Wind Turbine Generators (WTGs) provide only small or even no contribution to frequency stability [4]. The wind power variation can also degrade the grid voltage stability due to the surplus or shortage of power [5]. An Energy Storage System (ESS) has the ability of flexible charging and discharging. Recent development and advances in the ESS and power electronic technologies have made the application of energy storage technologies a viable solution for modern power application [6]. The potential applications mainly cover the following aspects. Through time-shifting, the power generation can be regulated to match the loads. The ESS can also be used to balance the entire grid through ancillary services, load following and load leveling [7]. Moreover, it can meet the increasing requirement of reserves to manage the uncertainty of wind generation [8] which can increase the system operation efficiency, enhance power absorption, achieve fuel cost savings and reduce CO2 emissions. Additionally,

the ESS is a potential solution to smooth out the fluctuations, and improve supply continuity and power quality [9]. For a specific application, the first task of an ESS project is planning. It generally includes the type selection and size determination. Sometimes, the ESS siting also needs to be considered. Several factors, such as technical features, economical cost and local wind power characteristics, can influence the ESS selection [10]. Once a specific ESS type is chosen, the optimal sizing needs to be done by balancing the benefits and cost. If there are no geographical constraints, the ESS could be optimally installed to achieve the maximum benefit, mainly in the reduction of transmission system upgrade cost. The operation and control strategies of the ESS are designed for different application purposes. The recent studies mainly focus on the coordinated control of wind farms and on-site ESSs. The shortterm (daily or hourly) dispatch scheme of an ESS and fluctuation smoothing by a wash-out filter are the two attractive areas. It is also proposed to combine many dispersed ESSs as a virtual storage unit and control centrally [10]. Since the ESS is an expensive solution, it is not economically viable for the ESS to work for a single application service. It can also contribute to the system wide control.

II. ENERGY STORAGE TECHNOLOGIES

The electrical energy can be stored in different energy forms: mechanical, electro-chemical, chemical, electromagnetic, thermal, etc. [3,7]. The classification of energy storage technologies according to the stored energy form is illustrated in Fig. 1.There are various characteristics of the ESS required to be taken into consideration for different applications, including capital cost, power and energy rating, power and energy density, ramp rate, efficiency, response time, self-discharge losses, and life and cycle time [11,12]. The overview of the capital cost and the technical features of the ESS is listed in Tables 1 and 2, respectively. The technical details of the ESS have been described in many literatures [10,11,13,14]. A short description of the principles and potential capability of several commonly used ESSs for wind power integration support is presented in this section.

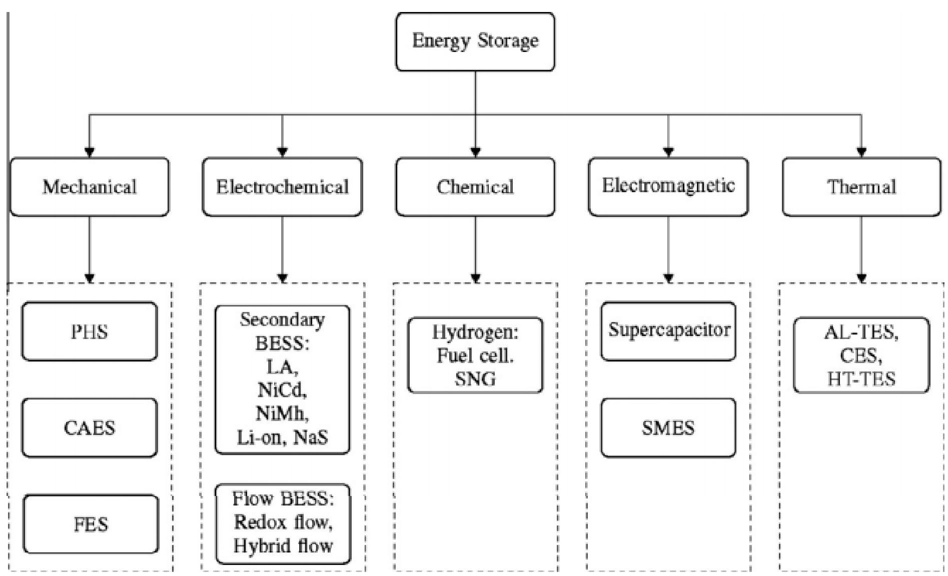

Fig.1. Energy storage classification

A. Pumped storage

Pumped Hydro Storage (PHS) The PHS is the largest and most mature energy storage technology available [15]. It represents nearly 99% of the worldwide installed electrical storage capacity with over 120 GW [10, 16]. The conventional PHS consists of two water reservoirs. The water body at the relatively high elevation represents the potential or stored energy. During off-peak hours, it pumps water from the lower reservoir to the upper one, considered as a charging process. In the discharging process, water from the upper reservoir is released and flows through hydro turbines which are connected to generators, producing electrical energy [14]. As illustrated in Table 2, the PHS has the largest power and energy rating, long lifetime, high efficiency and very small discharge losses. The main applications of the PHS for wind power integration are energy management via time-shifting, frequency control and non-spinning reserve supply. Due to the slow response, the PHS is not suitable for suppressing wind fluctuations. The installation of the PHS is dependent on geographical conditions and has an impact on the nature environment. Therefore, the flexibility of its application is low. The economic benefits of the PHS combined with Wind Farms (WFs) are described and analyzed in [17, 18] shows that the hybrid PHS-WF system can meet the hourly energy demand.

B. Compressed Air Energy Storage (CAES)

The CAES is a technology known and used since the 19th century for different industrial applications [10]. Electrical compressors are used to compress air and store it in either an underground structure (salt cavern, abandon mines, rock structures) or an above-ground system of vessels or pipes. When needed, the compressed air is released and mixed with natural gas, burned and expanded in a modified gas turbine. Current research on the CAES is focused on the development of systems with fabricated storage tanks which will remove the geological dependency and the compressed air will be stored with higher pressure. So far, there are only two CAES units in operation. They are located in Huntorf, Germany and MacIntosh in Alabama, USA [19]. There are several CAES units which are either planned or under construction [20]. From Table 2, it is shown that the high power and energy capacity rating makes the CAES another choice for wind farms for the energy management purposes, similarly to the PHS. The storage period can be over a year due to very small self-charge losses [11]. However, the CAES installation is also limited by topographical conditions.

C. Flywheel Energy Storage (FES)

The first generation of the FES has been available since 1970s which uses a large steel rotating body on mechanical bearings. In the FES, the rotational energy is stored in an accelerated rotor, a massive rotating cylinder [10]. The main components are a rotating cylinder (comprised of a rim attached to a shaft) in a compartment, bearings and a shaft. The whole structure is placed in a vacuum enclosure to reduce wind age losses. During the charging process, the rotor is accelerated to a very high speed which can reach from 20,000 to over 50,000 rpm. The energy is stored in the flywheel by keeping the rotating body at a constant speed. During the discharging process, the flywheel releases energy and drives the machine as a generator. The main advantages of flywheels are the excellent cycle stability, a long life of providing full charge–discharge cycles, little maintenance cost, high power density and high efficiency. The FES is mainly applied as a power quality device to suppress fast wind power fluctuation, provide ride-through of interruptions of several seconds or bridge the shift between two sources [11]. Besides, it is also designed to provide damping enhancement [21]. The main drawbacks are the short operation duration and high self-discharge losses. They are considered as a support for wind turbines in combination with other ESSs rather than standing alone [13].

Table 1. Capital cost of ESS

System	Capital cost		
	\$ (kW)	\$ (kW h)	\$ (kW h-per cycle)
PHS	600–2000	5–100	0.1–1.4
CAES	400–8000	2–50	2–4
FES	250–350	1000–5000	3–25
LA	300–600	200–400	20–100
NiCd	500–1500	800–1500	20–100
Li-on	1200–4000	600–2500	15–100
NaS	1000–3000	300–500	8–20
VRB	600–1500	150–1000	5–80
ZnBr	700–2500	150–1000	5–80
FC	10,000+	–	6000–20,000
SC	100–300	300–2000	2–20
SMES	200–300	1000–10,000	–

D. Battery Energy Storage System (BESS)

The BESS stores electricity in the form of chemical energy [22]. A conventional secondary battery consists of a set of low-voltage/ power battery cells connected in parallel and series to achieve a desired electrical characteristic. Each cell is made up of a liquid, paste or solid electrolyte together with anode and cathode [11]. A battery is charged by an internal chemical reaction under a potential applied to both electrodes. The reaction is reversible and let the battery deliver the absorbed energy for discharging. So far, various types of second batteries have been developed for commercial use, including Lead Acid (LA) battery, Nickel Cadmium (NiCd) battery, Nickel Metal Hybrid (NiMH) battery, Lithium Ion (Li-ion) battery and Sodium Sulphur (NaS) battery. As illustrated in Table 2, as a whole, secondary batteries have very rapid response time.

E. Superconducting Magnetic Energy Storage (SMES)

The SMES consists of superconductive coil, power conditioning system, refrigerator and vacuum [15]. The energy is stored in the magnetic field created by DC current circulating through a superconducting coil [10]. In order to avoid the losses caused by the current flow, the coil is kept in the superconducting state. The SMES has very rapid response. The power requested is available almost instantaneously [10]. The SMES is very promising as a power storage system for load leveling or a power stabilizer [24,25]. The SMES can be incorporated into a back to back DC link [25]. In this case, a back-to-back system is used as a power conditioning system for the SMES coils. It is also utilized by the coordination with wind farms for power quality improvement [24,26–28] and dynamic stability enhancement [21,29]. However, the superconductive coil is very sensitive to temperature changes. The operational reliability is crucially dependent on the refrigeration system. Up to now, only a few SMES with small capacity are available for commercial use.

F. Super-Capacitor (SC)

Great progress has been achieved in the capacitor storage technologies. Instead of the common arrangement of a solid dielectric between the electrodes, an electrolyte solution is placed between two solid conductors for the SC. Compared with conventional capacitors, it has much larger capacitance and energy density, thus enabling a compact design [10,11]. The SC has nearly unlimited cycle stability as well as extremely high power density, and fast charging and discharging due to extraordinarily low inner resistance. Other advantages are durability, high reliability, no maintenance, long lifetime, and operation over a wide temperature range and in diverse environments. They are environmentally friendly and easily recycled or neutralized. The efficiency is typically around 90% and the discharge time is in the range of seconds to hours. The current research for wind power integration support focuses on the power leveling of wind farms [30], coordination with batteries for smoothing fast fluctuations [31]. Other ESS technologies, including Fuel Cell (FC), Metal–Air (MA) battery, Solar Fuel, Cryogenic Energy Storage (CES), Synthetic Natural Gas (SNG) and Thermal Energy Storage (TES) are either still under development or technically developed, but still not widely used. The technical maturity of different types of ESSs is shown in Fig. 2. Different applications require different technical features of the ESS. Among them, energy and power ratings are the two main factors. In [10], a comparison of several storage technologies based on these factors is illustrated in a double-logarithmic chart (Fig. 3).

III. ESS APPLICATIONS FOR WIND POWER INTEGRATION SUPPORT

The ESS applications related to wind power integration can be summarized and categorized in terms of roles it plays for different stakeholders: the wind farm owner, the grid operator and the energy consumer.

A. Generation-side roles of ESS

The main challenges with wind power integration are power intermittency, ramp rate and limiting wind farm output [32]. The generation-side role of the ESS aims to improve the grid-friendliness of the wind farm to dispatch wind energy such that they can be controlled like conventional power plants. Additionally, it shall be controlled to effectively utilize limited transmission capacity.

1. Time shifting

Due to the stochastic characteristic of wind, wind power production is considered as a non-dispatchable resource and sometimes it demonstrates an anti-peak feature, e.g. high wind power during off-peak demand or low wind power during peak demand. The time shifting is to store extra wind energy during periods of low demand and stands ready to dispatch energy to the grid during periods of high demand [7]. The benefit of storing electricity is expected to be larger with the large gap of demand between peak and off-peak. To fulfill the time shifting function, large quantities of energy for significant periods of time (from hours to days) are required for the ESS facility. Besides, the storage efficiency is another key factor to be considered for the economical operation of time shifting, as significant losses occur for an inefficient storage system.

2. Output smoothing

The inherently variable nature of wind power can cause fluctuations in frequency and voltage [7]. The ESS can be used to smooth out these fluctuations to keep the system stable. Accordingly, the output power of the ESS needs to be rapidly regulated for absorbing the excess energy during output spikes and releasing energy during output drops. Therefore, the ramping capability is very important for the smoothing function. The output smoothing atthe plant level reduces the need for power quality and ancillary services at the system level [33].

3. Transmission utilization efficiency

Rich wind resources are often located in rural areas far from existing high capacity transmission lines [34]. Due to the transmission constraints, the energy produced may not be transferred to the load.

Additional ESS can mitigate transmission congestion, defer or avoid transmission and distribution upgrades.

B. Grid-side roles of ESS

Currently, the ESS is required by the grid operator to provide ancillary services to mitigate the variability and uncertainty of the entire grid, rather than specific loads or wind farms. These applications are listed in Table 3. Due to the geographical distribution of wind resources, the net variability and uncertainty are less. Therefore, the need of the overall service is reduced [7].

1. Energy arbitrage/load leveling

In the electricity market, the electricity price varies from time to time, normally hourly [14]. The ESS can be used to store low-cost off-peak energy and releases when the price is higher. It can reduce market risk exposure to volatile on-peak prices and manage high cost energy imbalance charges [35].

2. Frequency regulation

Modern wind farms are required to provide frequency regulation by the grid operator. With high wind penetration level, providing frequency response from a wind farm is technically feasible by utilizing additional droop control. However, it may cause fatigue of wind turbines and instability problem [36,37]. An effective solution is the use of the ESS. For the primary frequency control, a local droop control loop can be added to the active power controller of the ESS. The droop control aims to produce an active power output change which is proportional to the frequency deviation [38]. For the secondary frequency control, the active power command is generated by the centralized Automatic Generation Control (AGC).

3. Inertia emulation

The grid inertia reduces frequency variability and makes the grid less sensitive to sudden generation changes. The instantaneous inertial response determines the Rate of Change of Frequency (ROCOF) [4]. The addition of the ESS could significantly increase the apparent inertia of a grid. The supplementary loop can be added to the active power control of the ESS.

4. Oscillation damping

In an interconnected system, sudden changes of power in tie line might cause oscillations with frequency range between 0.5 and 1 Hz [14]. It may further result in synchronism loss of several machines. Application of a damping controller is an effective control scheme to simultaneously handle the inherent power fluctuations and enhance system stability for a large wind farm [26]. The SMES and FES are utilized in [21,29] to damp the system oscillation. The tie-line power deviation is used as a feedback signal to generate the phase component of the converter control.

5. Voltage control support

The wind power variability can degrade the grid voltage stability [5]. The installed ESS can provide adequate reactive power to maintain the local voltage level. This service can be obtained by the full scale converter connected to the grid [13].

6. Low Voltage Ride Through (LVRT) support

WTGs should have LVRT capability to remain connected during severe grid faults specified by grid codes [36]. Furthermore, some gird codes require that WTGs supply up to the maximum reactive current during such faults. The converter should draw real power to compensate for the switching losses associated with provision of the reactive power. During severe faults, no power can be drawn from the grid. As a result, the DC voltage falls and the converter switches are blocked. For such cases, the ESS can support the DC voltage during the faults.

7. Reserve application

Due to the forecast error of wind power, additional reserves are required for emergency support. Based on the response time, the reserves can be generally classified into primary, secondary and tertiary reserves [14].

8. Emergency power supply/black start

The ESS may be used to restart from a shut-down condition without the assistance from the electrical grid and energize the power system in the event of a catastrophic failure [7,14].

9. Transmission utilization efficiency

The ESS can help grid operators efficiently use the transmission system capacity, defer transmission system upgrades to reduce transmission costs and mitigate local dependency challenges of wind power.

C. Demand-side roles of ESS

Most existing ESS applications for energy consumers are more related to meet the energy needs rather than solving particular challenges related to the integration of large-scale RES [39]. Only one application has a significant support for the wind power integration support: Vehicle-To-Grid (V2G) [7,40]. Due to the aggregation effect of many Electrical Vehicles (EVs) plugged into the grid, these EVs can be considered as a Virtual Power Plant (VPP) with relatively large capacity. This EV VPP (EVPP) has to fulfill the requirements of both vehicle owners and grid operators. Since all the EVs are controlled as a whole, individual vehicles will not be locked in the charging station and its owner has the full convenience. The grid operator can treat this VPP as a provider of ancillary services [41], such as time-shifting, operation reserve, and frequency regulation. So far, many efforts have been made to investigate the EVPP feasibility and possible architecture [42]. One finished project is the EDISON project financed by the Danish TSO – Energinet, DK. The Danish island, Bornholm, was used as a test site. It aims to coordinate charging and discharging of EVs in order to optimize the utilization of wind energy in the island grid. Since the ESS is an expensive solution, it is not economically viable for the ESS to work for single application service. In [43], the installed ESS is mainly used for output smoothing. It can also contribute to system wide control such as frequency regulation or oscillation damping. In [36], the applied BESS has the ability to provide both frequency response service and energy time shifting.

IV. CONCLUSIONS

The ESS is considered as an effective solution to handle the reliability and stability challenges of future power systems with large scale wind power integration. Various ESSs with different technical features are available in the market. The ESSs can be used for different applications required by specific wind farms, grid operators or consumers. For the generation side, it can aim to improve the grid-friendliness of wind farms to dispatch wind energy such that they could be controlled like conventional power plants. For the grid-side roles of the ESS, it can provide ancillary services to mitigate variability and uncertainty of the entire grid. For the demand-side roles, the aggregated EVPP can fulfill the requirements of both vehicle owners and grid operators. For the ESS planning, it is important to properly select the ESS type, and determine the size and site of the ESS. The size of the ESS, including both power and energy capacity, can be determined by several methodologies, including the method of using historical wind profiles, the probabilistic method based on wind power forecast error, etc. The sizing problem can be formulated as an optimization problem with different cost functions. The siting of the ESS without topographical limitation can be installed either on-site or other locations to achieve high controllability. It shows the nodes at the end or the middle of crucial transmission lines have higher impact on the congestion management.

References

1. IEA. In: World energy outlook 2011. Paris: IEA Publications; 2011.
2. Wang P, Gao Z, Bertling L. Operational adequacy studies of power systems with wind farms and energy storages. IEEE Trans Power Syst 2012;27(4):2377–84.
3. Backhaus S N, Chertkov M, Dvijotham K. Operations-based planning for placement and sizing of energy storage in a grid with a high penetration of renewable. Report no. LA-UR-11-03619. Los Alamos National Laboratory; 2011.
4. Sun Y Z, Zhang Z S, Li G J, Lin J. Review on frequency control of power systems with wind power penetration. In: International conference on power system technology; 2010.
5. Le H T, Santoso S, Nguyen T Q. Augmenting wind power penetration and grid voltage stability limits using ESS: application design, sizing, and a case study. IEEE Trans Power Syst 2012;27(1):161–71.
6. Kondoh J, Ishii I, Yamaguchi H, et al. Electrical energy storage systems for energy network. Energy Convers Manage 2000;41(17):863–1874.
7. IEC. Grid integration of large-capacity renewable energy sources and use of large-capacity electrical energy storage, Tech report; 2012.
8. Boutsika T, Santoso S. Sizing an energy storage system to minimize wind power imbalances from the hourly average. In: IEEE PES general meeting, San Diego, California, USA, July 22–26, 2012
9. Billinton R, Karki R, Gao Y, et al. Adequacy assessment considerations in wind integrated power systems. IEEE Trans Power Syst 2012;27(4):2297–305. 989.
10. EC. Electrical energy storage white paper. Tech report; 2011.
11. Chen H, Cong T N, Yang W, et al. Progress in electrical energy storage system: a critical review. Progr Nat Sci 2009;19(3):291–312.
12. Wang D, Ren C, Sivasubramaniam A, et al. Energy storage in datacenters: what, where, and how much? ACM SIGMETRICS Perform Eval Rev 2012;40(1):187–98.
13. Swierczynski M, Teodorescu R, Rasmussen C N, et al. Overview of the energy storage systems for

wind power integration enhancement. In: Proceedings of IEEE international symposium on industrial electronics, Bari, Italy, July 4–7, 2010.

14. Energy storage for grid connected wind generation applications. EPRI-DOE handbook supplement; 2004.
15. Connolly D. An Investigation into the energy storage technologies available for the integration of alternative generation techniques. Tech report; 2007.
16. Zafirakis D, Chalvatzis K J, Baiocchi G, et al. Modeling of financial incentives for investments in energy storage systems that promote the large-scale integration of wind energy. Appl Energy 2013;105:138–54.
17. Castronuovo E D, Lopes JAP, Member S. On the optimization of the daily operation of a wind-hydro power plant. IEEE Trans Power Syst 2004;19(3):1599–606.
18. Dagdougui H, Minciardi R, Ouammi A, et al. A dynamic decision model for the real-time control of hybrid renewable energy production systems. IEEE Syst J 2010;4(3):323–33.
19. Madlener R, Latz J. Economics of centralized and decentralized compressed air energy storage for enhanced grid integration of wind power. Appl Energy 2013;101:299–309.
20. Van der Linden S. The commercial world of energy storage: a review of operating facilities. In: 1st Annual conference of the energy storage council, Houston, USA; 2003.
21. Wang L, Yu J Y, Chen Y T. Dynamic stability improvement of an integrated offshore wind and marine-current farm using a flywheel energy-storage system. IET Renew Power Gener 2011;5(5):387–96.
22. Ribeiro P F, Johnson B K, Crow M L, et al. Energy storage systems for advanced power applications. Proc IEEE 2001;89(12):1744–56.
23. Yoshimoto K, Nanahara T, Koshimizu G. New control method for regulating state-of-charge of a battery in hybrid wind power/battery energy storage system. In: Power systems conference and exposition; 2006. p. 1244–51.
24. Nomura S, Ohata Y, Hagita T, et al. Wind farms linked by SMES systems. IEEE Trans Appl Supercond 2005;15(2):1951–4.
25. Tam K S, Kumar P. Application of superconductive magnetic energy storage in an asynchronous link between power systems. IEEE Trans Energy Convers 1990;5(3):436–44.
26. Chen S S, Wang L, Lee W J, et al. Power flow control and damping enhancement of a large wind farm using a superconducting magnetic energy storage unit. IET Renew Power Gener 2009;3(1):23–38
27. Wang Z, Yuwen B, Cheng M. Improvement of operating performance for the wind farm with a novel CSC type wind turbine-SMES hybrid system. In: IEEE international symposium on industrial electronics, Hangzhou, China; 2012.
28. Liang L, Jianlin L, Dong H. An optimal energy storage capacity calculation method for 100 MW wind farm. In: International conference on power system technology, Hangzhou, China; 2010.
29. Wang L, Chen S S, Lee W J, et al. Dynamic stability enhancement and power flow control of a hybrid wind and marine-current farm using SMES. IEEE Trans Energy Convers 2009;24(3):626–39.
30. Qu L, Qiao W. Constant power control of DFIG wind turbines with supercapacitor energy storage. IEEE Trans Ind Appl 2011;47(1):359–67.
31. Li W, Joós G, Bélanger J. Real-time simulation of a wind turbine generator coupled with a battery supercapacitor energy storage system. IEEE Trans Ind Electron 2010;57(4):1137–45.
32. Teleke S, Baran M E, Huang A Q, et al. Control strategies for battery energy storage for wind farm dispatching. IEEE Trans Energy Convers 2009;24(3):725–32.
33. Tewari S, Mohan N. Value of NAS energy storage toward integrating wind: results from the wind to battery project. IEEE Trans Power Syst 2012;28(1):532–41.
34. Korpas M. Distributed energy systems with wind power and energy storage. PhD thesis; 2004.
35. Celli G, Mocci S, Pilo F, et al. Optimal integration of energy storage in distribution networks. In: IEEE PowerTech, Bucharest; 2009.
36. Banham-Hall D D, Taylor G A, Smith C A, et al. Flow batteries for enhancing wind power integration. IEEE Trans Power Syst 2012;27(3):1690–7.

37. Carrillo C, Feijoo A E, Cidras J, et al. Power fluctuations in an isolated wind plant. IEEE Trans Energy Convers 2004;19(1):217–21.
38. Morren J, de Haan S W H, Kling W L, et al. Wind turbines emulating inertia and supporting primary frequency control. IEEE Trans Power Syst 2006;21(1):2005–6.
39. Moura P S, De Almeida A T. The role of demand-side management in the grid integration of wind power. Appl Energy 2010;87(8):2581–8.
40. Liu W, Hu W, Lund H, et al. Electric vehicles and large-scale integration of wind power – the case of Inner Mongolia in China. Appl Energy 2013;104:445–56.
41. Quinn C, Zimmerle D, Bradley T H. The effect of communication architecture on the availability, reliability, and economics of plug-in hybrid electric vehicle-togrid ancillary services. J Power Sources 2010;195(5):1500–9.
42. Binding C, Gantenbein D, Jansen B, et al. Electric vehicle fleet integration in the Danish EDISON project – a virtual power plant on the island of Bornholm. In: IEEE PES general meeting, Minneapolis, Minnesota, USA; 2010.
43. Lubosny Z, Bialek J W. Supervisory control of a wind farm. IEEE Trans Power Syst 2007;22(3):985–94.
44. Jiang Q, Wang H. Two-time-scale coordination control for a battery energy storage system to mitigate wind power fluctuations. IEEE Trans Energy Convers 2013;28(1):52–61
45. Barton J P, Infield D G. Energy storage and its use with intermittent renewable energy. IEEE Trans Energy Convers 2004;9(2):441–8.
46. Li Q, Choi S S, Yuan Y, et al. On the determination of battery energy storage capacity and short-term power dispatch of a wind farm. IEEE Trans Sustain Energy 2011;2(2):148–58