International Journal of Engineering & Technology, 7 (2.33) (2018) 368-372

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

An economic ESS design method based on wind system capacity factor for island power grid

Minhan Yoon [1], Seungmin Jung [2] *

[1] Department of Electrical Engineering, Tongmyong University, Busan 48520, Korea
[2] Department of Electrical Engineering, Hanbat National University, Daejeon 305-719, Korea
**Corresponding author E-mail: seungminj@hanbat.ac.kr*

Abstract

Background/Objectives: Energy storage device is being considered in many fields but many system owners do not actively apply this compensation device because of the uncertainty of its criteria.
Methods/Statistical analysis: In this paper, an energy capacity calculation method based on the specific capacity factor of a wind farm is introduced. The calculation method has focused on the generated surplus power, which is the difference between the generated and consumed electric power quantities.
Findings: The capacity calculating method when integrating wind system has not yet been formulated steadily even though its remarkable supplementation, and previous algorithms are not considered as clear solution for various wind characteristics. In order to calculate the capacity in advance, capacity factor based pre-estimating method has been considered. Including surplus power conditions, the case studies are based on independent power-system for handling realistic environmental option and network information of an island power grid.
Improvements/Applications: The surplus power was compensated during simulated conditions. In the real power-system, a minimum load could be existed for short section, and the operation would be performed more appropriately.

Keywords: *ESS Capacity; Sizing Method; Reserve Power; Surplus Power; Wind Penetration.*

1. Introduction

Because of the variability of wind power systems, the development of wind power system management technologies and compensation devices has received attention. Large-scale wind power systems are being continuously integrated, and wind power penetration has been gradually expanded. In the power system industry, those statuses could raise several reliability issues in the entire network because of its dependence on environmental factors. Most of all, a large amount of wind power penetration can greatly affect the utility power grid because a wind turbine exhibits output fluctuation characteristics according to the wind energy environment. In addition, various problems such as reactive power issues and maximum wind-speed limitations under turbulent conditions have to be handled on imposed management plan. To solve these issues, an accurate prediction system regarding wind resources has been developed to reduce the error between the real output power and the predicted power [1]. Furthermore, since the entire cost issue has been reduced with developments in electronic device technology, several compensation devices are receiving attention from the wind power system sector. Basically, to improve the performance of wind power systems, application methods for the ESS have been developed by focused on demanding response process. In this regard, not only the technical grid code of the wind-combined system but also a comprehensive scheme for integrating the ESS has been studied [2], [3]. In the previous studies, through integration with an ESS which has fast charging and discharging characteristics, large-scale wind farm seems to supply reactive or active power more flexibly compared with general single wind power profile [4], [5]. A difference between the forecasted and the real output was expected to reduced, and an efficient reaction for accurate profile of wind system could be implemented. Based on these studies, a possibility of power system that manage integrated wind farm profile stably using an ESS have been checked, and an availability about demand response process was confirmed even if a network has to include certain environmental factors [6], [7].
Nonetheless, the cost issues about ESS are still the greatest factor when considering the device in a real system. Entire size and power capacity of ESS significantly affects the application both construction and application. Owing to the complexity of each power system characteristic, a strict standard configuration was not being progressed until recently. By focusing on this, this present study focuses on the ESS capacity calculation for island power system, which has a relatively large penetration of wind farm to reduce the output fluctuation, which occurs because of wind speed uncertainty. It is important to determine the appropriate capacity by considering the wind farm scale and the condition of the power grid because the cost and reliability of the ESS are closely related. Since there are many controversies between the wind turbine owner and the power system operator, development calculation method and simulating case study could be notable analysis in electrical section.
In this paper, a pre-calculation process for the ESS capacity is introduced by considering the surplus power, which is related to the capacity factor of a wind farm. The proposed system allocates a suitable proportion of the energy capacity of ESS as reserve power by focusing on an island power system. Using this proposed calculation process, a renewable based island network, which is expected to integrate large-scale wind farms with relatively small power consumption, can calculate ESS capacity in advance, and the entire system design can be developed preferentially.

Copyright © 2018 Minhan Yoon, Seungmin Jung. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

2. System description

Wind turbines have been connected to the utility grid in various ways, but a specific wind farm was usually designed using one connection topology and the same type of turbine generators [8]. As the cost and weight of permanent-magnet materials decrease, PMSGs have become attractive and have drawn attention because of their suitability for application in large-scale wind farms [9], [10]. In case of this device, a steady ac frequency can be strictly distributed to the utility grid using a full-rated converter. Therefore, independent configuration with entire storage system is available at an AC-side network. Figure 1 shows a configured wind-ESS integrated model in this paper. The wind system is composed with PMSG topologies, and the output electrical power is denoted by PWT. By focusing on this profile, the ESS operation plan has to be composed. A state management and regarded capacity calculation will be described after next section.

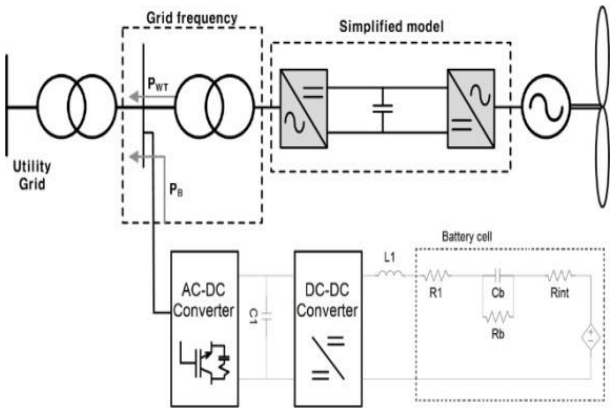


Fig. 1: Design of an Integrated Model and Controller.

2.1. ESS description

An ESS is normally operated according to local network conditions, i.e., whether it can absorb the released energy from storage. In this study, the simulation consists of storing the surplus output power of the integrated system, and a bidirectional power conversion system is integrated into the ESS to control the output power of the entire system. To consider the battery condition, the state of charge (SOC) of the ESS should be updated every second by following the integral of profile. The ESS operation has to be stopped when the SOC is reached to the constraint value. In addition, the SOC of the ESS cannot exceed a certain operational range due to its life cycle. This study is focusing on the entire output profile measured at the connection point (PCC); the relationship is defined as equation (1).

$$P_{PCC} = P_{WF} + P_{ESS} \tag{1}$$

Where, P_{PCC} is the entire profile, P_{WF} and P_{ESS} are the individual profile of wind generators and ESS. Each network has grid characteristics and this can be reflected with connected load and the 'must run' capacity. The 'must run' means a minimum quantity that certain local generator that has to generate for maintaining its operating states.

When described these equations as time functions, the ESS profile can be rewritten from the relationship of the profile of wind system as follows:

$$P_{ESS}(\mathrm{t}) = P_{PCC}(t) - P_{WF}(t) \tag{2}$$

$$P_{ESS}(\mathrm{t}+1) = \begin{cases} P_{load}(t) - P_{min} - P_{WF}(t) & (P_{load} \geq P_{PCC}) \\ P_{min} + P_{WF}(t) - P_{load}(t) & (P_{load} < P_{PCC}) \end{cases} \tag{3}$$

Where, P_{load} is a load capacity, and P_{min} is a minimum generated power. Each network has reserve characteristics and to reflect this, the minimum generation capacity is included in the equation.

2.2. ESS operation strategy

Figure 2 shows the concept of the ESS control scheme with pre-calculated ESS by considering the surplus power of the entire system. Basically, each wind turbine is operated using the MPPT control scheme, and the ESS focuses on the active power of the entire integrated system. Each turbine has different operating conditions relative to the tip speed ratio according to various wind speeds. Composing several groups operating in approximately similar environments can perform an estimated simulation.

The ESS mainly responds to the active power gap between the generated power and the local demand. Because the current system does not require a supervisory control scheme, the wind turbines usually follow the MPPT. However, in the case of excess active power in comparison with the load demand, active pitch control is used for sufficient wind velocity to shed off the aerodynamic energy by turning off the blades. In this study, the pitch angle is maintained at zero during normal operation. However, several wind turbines can be controlled using pitch angle control, and the amount is estimated to verify if additional control is required because of the presence of excess power over the pre-calculated ESS capacity.

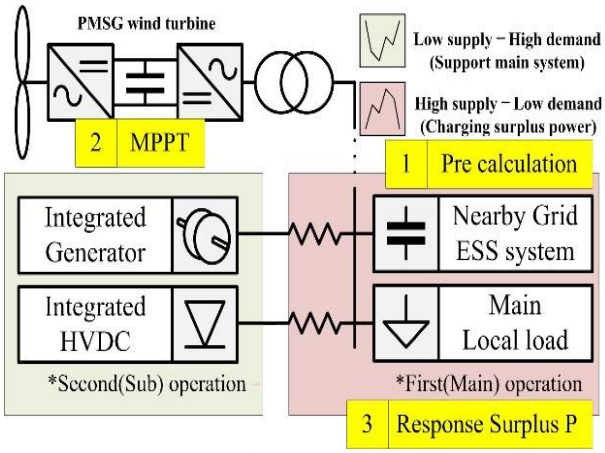


Fig. 2:.Three Stage ESS Configuration Plan with a Pre-Calculated ESS.

To confirm the excess power, the SOC of the ESS should be checked during operation. The pre-phase SOC should be considered at every second. The SOC of the ESS is described as follows:

$$SOC(\mathrm{t}+1) = \begin{cases} SOC(t) - \frac{E_{ESS}(t)}{\eta E_{max}} & (P_{ESS}(t) \geq 0) \\ SOC(t) + \frac{\eta E_{ESS}(t)}{E_{max}} & (P_{ESS}(t) < 0) \end{cases} \tag{4}$$

Where E_{ESS} is the electrical energy calculated by $P_{ESS}(t)$, and E_{max} is the maximum electrical energy of the ESS.

2.3. ESS capacity expectation

The capacity factor (CF) is an important parameter used to determine the annual energy output of a wind power system [11]. Usually, CF indicates the fraction of the entire energy delivered over a year. Therefore, the total output power is divided by the maximum energy, which means that the entire wind system operates at the maximum capacity throughout the entire year. CF is defined as:

$$CF = \frac{E_{total}}{E_{rate}} = \frac{E_{total}(MWh)}{P_{rate}(MW) \times t(h)} \tag{5}$$

Where E_{load} is the total output energy of the wind system, E_{rate} is the maximum output energy of the wind system, and P_{rate} is the maximum output power of the wind system.

Because the ESS is integrated to mitigate power fluctuation, a realistic output power consideration is required. CF is closely related to the realistic wind system operation because this factor is calculated using a realistic output power. However, this factor does not consider the intensity of the wind speed, which is closely related to a

specific season. Because the proposed calculation formula focuses on severe environmental conditions under a minimum load condition, the utilization process regarding the capacity factor should consider divided wind speed penetration. To appropriately utilize this factor in the calculation process, a classification process in a specific period relative to the intensity of the wind power fluctuation is required. In this study, CF is classified by considering the intensity of the wind speed. The process includes several wind environment characteristics such as the continuity of the wind stream during a specific period and the variability according to seasonal differences. The basic equation about ESS capacity is defined as follows:

$$C_T = \frac{E_{over}}{E_{rate}} = \frac{P_{rate} \times CF + P_{min} - P_{load}}{P_{rate}} \quad (6)$$

Where C_T is the ESS capacity percentage about target wind farm. The capacity is focused on the exceed energy and it is differed according to the capacity factor about certain period (the load capacity also considers minimum value). By using above equation, we can designate the capacity with focusing on the target section.
The high capacity factor (HCF) section is defined by using the highest CF section considering specific period. This factor is mainly used for limiting the capacity by considering the minimum output power of the local generator and the minimum load power.

$$C_{lim} = \frac{P_{HCF} + P_{min} - P_{load}}{P_{rate}} \quad (7)$$

Where C_{lim} is the ESS capacity percentage of the wind farm, and P_{HCF} is the wind output power with HCF.
The low capacity factor (LCF) is estimated using the same linked duration as that of the HCF; however, it defines the lowest CF. This value is used to determine whether ESS is required or not. If the value is lower than zero, the system is not required to compensate by ESS. The factor formulas are utilized like as follow:

$$STD = 1, C_T(LCF) > 0 \quad (8)$$

$$STD = 0, C_T(LCF) \leq 0 \quad (9)$$

Where STD is a criterion for deciding adaptation of ESS at certain system.

3. Simulation

3.1. Target system

The proposed calculation focuses on the surplus power generated during the midnight power service period, which has a significant probability of minimum load. This paper introduces the ESS calculation process to the Jeju Island power system operating in South Korea. The system has a local generator as a controllable reserve power and relies on large-scale wind power constructed at a nearby place. The system characteristics are applied using the information referred to in the five-step basic plan for electric power supply and demand (2010-2024).
The Jeju Island power system is integrated into the main power grid of South Korea by HVDC. Although the island system can be supplied with electricity through transmission lines, the capacity of the transmission lines is limited, and it is usually operated in a power supply mode. Table 1 presents information regarding the Jeju Island power system between 2016 and 2020, which is considered in the simulation process.

Table 1: Power System Information for Jeju Island

Year	HVD Capacity (MW)	Minimum supply (MW)	Maximum supply (MW)	Minimum demand (MW)	Maximum demand (MW)
2016	400	210	975	410	829
2017	600	210	1,175	428	866
2018	600	210	1,175	447	905
2019	600	170	1,175	466	942
2020	600	170	1,175	484	980

The wind power environment is applied separately by dividing the wind resources into two different areas. This divided information is used for each wind farm system to consider real wind farm system operation. The wind power capacity is assumed on the basis of the prediction reports of the local government of Jeju Island. The constructed wind power capacity is presented in Table 2.

Table 2: Wind Capacity Growth Prediction for Jeju Island

Year	Reserve power (MW)	Controllable power (MW)	Wind capacity prediction (MW)
2016	805	975	564
2017	1,005	1,175	680
2018	1,005	1,175	890
2019	1,005	1,175	1,300
2020	1,005	1,175	1,300

3.2. Case study design

Normally, the Jeju Island's CF is measured as 29.95% when considering an entire year. In this paper, we designate the high capacity section as one and half month during between January and February and the calculated high CF is 35.17%. The low CF also calculated for using determination process whether the ESS would be integrated or not. The calculated low CF is 26.7%. By considering the information of the Jeju Island wind farm, a simulation was configured using PSCAD. The location data was used for calculating wind prediction and system operation. Two different regions, Goo-Jwa and Woo-do, were considered to reflect the different distance characteristics of the wind. Each wind speed was input as a signal in the simulation. Such an application of wind information can reflect the geographic characteristics as well as an arbitrary situation. Figure 3 represents reallocation of present power system of Jeju Island. The location data was used for calculating wind prediction and system operation. Table 3 summarizes the calculated ESS capacity data by selecting an appropriate percentage for the targeted wind power system capacity.
Table 4 presents the wind prediction data, which are divided into monthly intervals. Considering the intensity of the wind velocity chose each case.
Figure 4 and 5 show the wind speed fluctuation data about each simulation case by applying wind prediction process to measured data of Jeju. If excess wind power occurs during the simulation, mechanical control of several wind turbines would continue using the pitch control scheme for system stability. The entire simulation time is 6 minutes at night between 3:50 a.m. and 3:56 a.m., considering the minimum power demand.

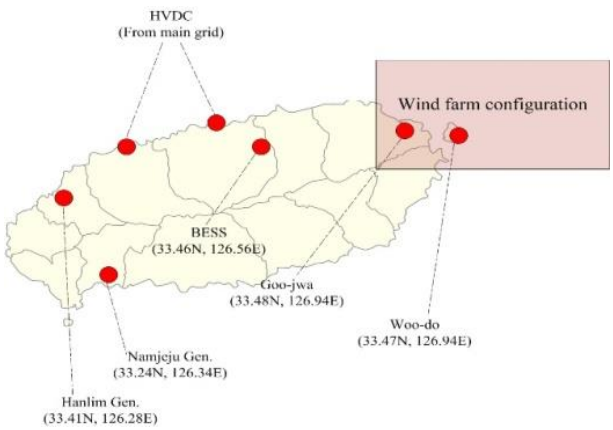


Fig. 3: Main System Location in the Simulation.

Table 3: Designated ESS Capacity for Each Year

Year	2016	2017	2018	2019	2020
C_{lim} (%)	-	-	2.77	12.4	11.016
C_{ESS} (%)	-	-	3.32	7.181	5.796
STD	Under	Under	Over	Over	Over
MW·h	None	None	24.653	93.35	75.35

Table 4: JejuIsland Wind Speed Data for the Case Study

Month	Goo-Jwa (m/s)			Woo-do (m/s)			Case
	Min.	Max.	Ave.	Min.	Max.	Ave.	
Jan.	0.87	20.56	7.29	0.26	22.27	6.83	1
Nov.	0.28	14.89	5.25	0.77	26.28	8.77	2

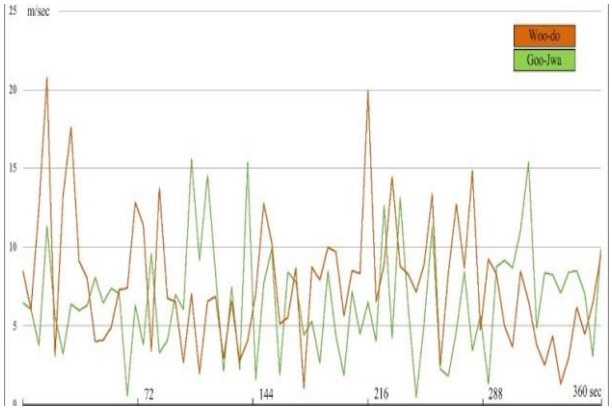


Fig. 4: Case 1 Wind Speed Data (January).

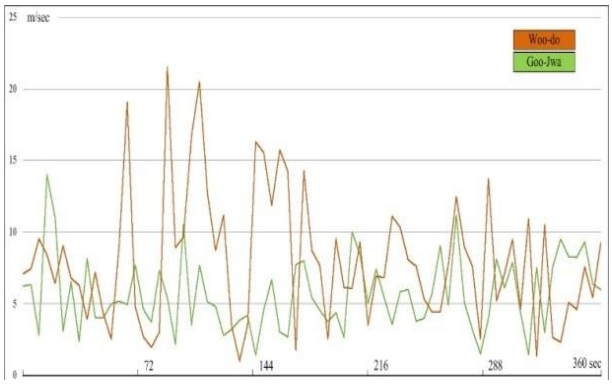


Fig. 5: Case 2 Wind Speed Data (November).

3.3. Results

Figures 6–9 show the power fluctuation curves of the simulated wind farm system integrated with the ESS. In the figures, the black curve represents the total power of the system (wind turbine, minimum generated power, and minimum demand power). The power capacity of each case ESS is assumed to 200 MW because too high-power capacity is not suitable due to realistic issue. The blue section represents the charged power due to the surplus power. The above power to blue section is required to limited by pitch control.

The SOC variation patterns for above studies are shown in Figure 10 and 11. As shown by the SOC curve, the battery capacity demands gradually increased because of the wind power capacity. In the simulation results, calculated ESS capacity is not reached to the compensation limit when we set the first SOC as 60%.

As the basic ESS capacity was designated to relatively low in 2018, the SOC reduction due to the compensation was dropped almost 40% (case 2). These systems should consider the SOC valancing plan because the range for the SOC is usually designated within 30–80% to protect the battery life.

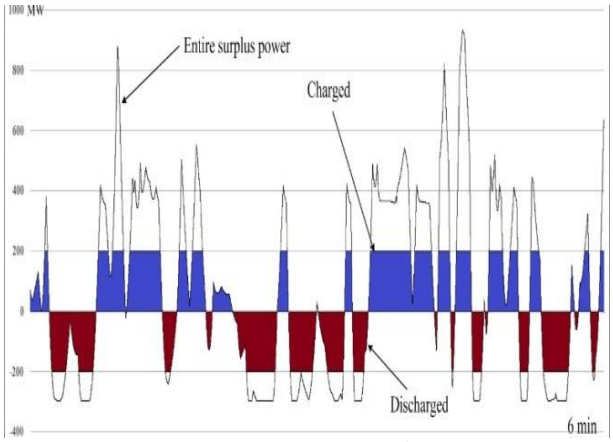


Fig. 6: Power Curve and Control Value for Case 1 (2018).

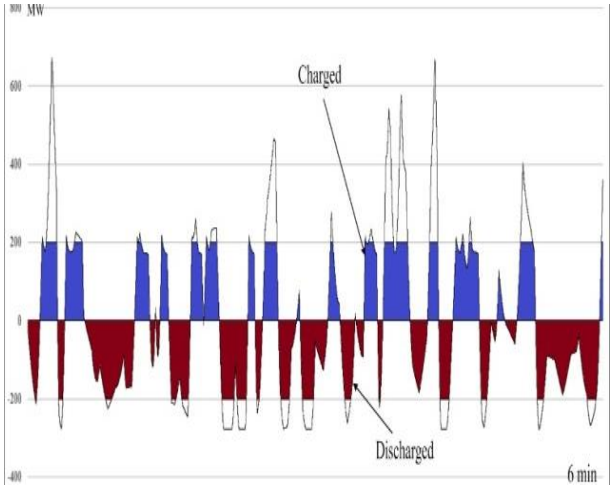


Fig. 7: Power Curve and Control Value for Case 1 (2020).

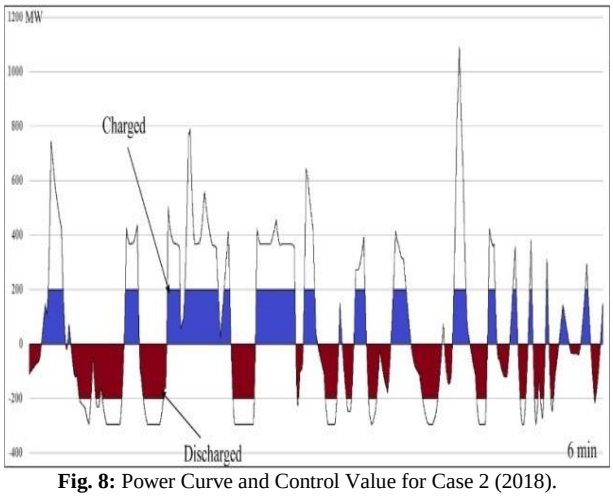


Fig. 8: Power Curve and Control Value for Case 2 (2018).

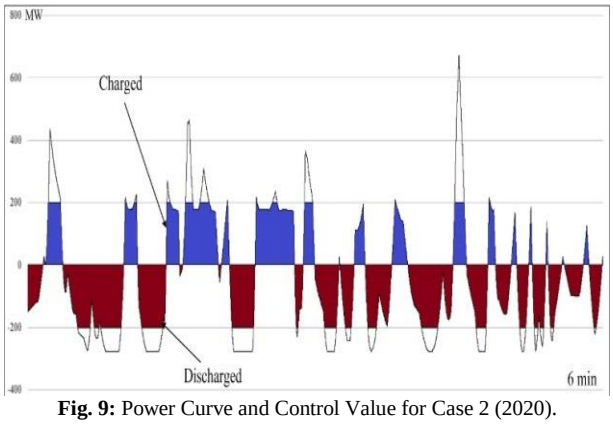


Fig. 9: Power Curve and Control Value for Case 2 (2020).



Fig. 10: SOC Fluctuation for Case 1.

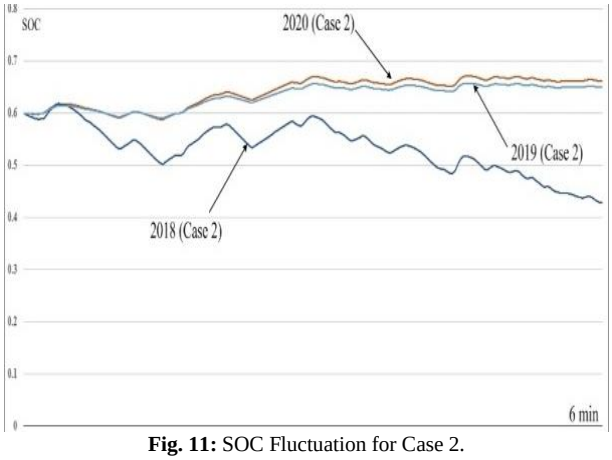


Fig. 11: SOC Fluctuation for Case 2.

4. Conclusion

This paper introduced an ESS capacity calculation plan for wind power systems to compensate for the generated surplus power. Considering the load power condition, which is related to the surplus power, derived the calculation formulas. An application was performed by considering a real power system in Korea. For severe surplus power situations, the estimated minimum load obtained from government data were used during the simulation process. In the simulation, the surplus power was successfully compensated during normal wind potential conditions. In the real power-system, the minimum load existed for short time duration, and the compensation process would be performed more appropriately.

Acknowledgment

This work was supported by Korea Electric Power Corporation Grant (18B-016), and National Research Foundation Grant (No. 2018R1C1B5030524) funded by the Korean government.

References

[1] Kusiak, A., Zheng, H., Song, Z., (2009). Short-Term Prediction of Wind Farm Power: A Data Mining Approach. *IEEE Trans. Energy Conversion*, 24(1), 125-136.

[2] Li, W., Joos, G., Belanger, J., (2010). Real-Time Simulation of a Wind Turbine Generator Coupled With a Battery Supercapacitor Energy Storage System. *IEEE Trans. Industrial Electronics*, 57(4), 1137-1145.

[3] M. Gökçek, A. Bayűlken, S. Bekdemir, (2007). Investigation of wind characteristics and wind energy potential in Kirklareli, Turkey. *Renew Energy*, 32, 1739-1752.

[4] Goel, P. K., Singh, B., Murthy, S. S., Kishore, N., (2011). Isolated Wind–Hydro Hybrid System Using Cage Generators and Battery Storage. *IEEE Trans. Industrial Electronics*, 58(4), 1141-1153.

[5] N. Eskin, H. Artar, S. Tolun, (2008). Wind energy potential of Gökçeada Island in Turkey. *Renew Sustain Energy Review*, 12, 839-851.

[6] Muyeen, S. M., Takahashi, R., Murata, T., Tamura, J., (2009). Integration of an Energy Capacitor System with a Variable-Speed Wind Generator. *IEEE Trans. Energy Conversion*, 24(3), 740-749.

[7] Quanyuan, J., Haijiao, W., (2013). Two-Time-Scale Coordination Control for a Battery Energy Storage System to Mitigate Wind Power Fluctuations. *IEEE Trans. Energy Conversion*, 28(1), 52-61.

[8] Carrasco, J. M., Franquelo, L. G., Bialasiewicz, J. T., Galvan, E., Guisado, R. C. P., Prats, Ma. A. M., Leon, J. I., Moreno-Alfonso, N., (2006). Power-Electronic Systems for the Grid Integration of Renewable Energy Sources: A Survey. *IEEE Transactions on Industrial electronics*, 53(1), 418-426.

[9] Inaba, N., Thkahashi, R., Tamura, J., Kimura, M., Komura, A., Takeda, K., (2009). Review of the wind energy generating system. *Advances in Power System Control, 8th International Conference*.

[10] Mihai, A. M., Benelghali, S., Livadaru, L., Simion, A., Outbib, R., (1999). An axial-flux permanent-magnet generator for a gearless wind energy system. *IEEE Trans. Energy Conversion*, 14(2), 251-257.

[11] A. S. Ahmed Shata, R. Hanitsch, (2006). The potential of electricity generation on the east coast of Red Sea in Egypt. *Renew energy*, 31, 1597-1625.