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Energy Storage Design for Island Power System with High Wind Penetration Characteristics

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Abstract

Establishment and focus: To calculate the capacity of an energy storage device efficiently, it is necessary to realistically consider wind power generation and the size of the connected load. When considering wind power generation, since the utilization rate differs for each season, it is necessary to thoroughly examine the magnitude of the load and the utilization rate of the installation for each time unit. In the case of a separated island system, the sum of the amount of fossil power generation and the total amount of the HVDC link may exceed the entire load. Therefore, taking into account the capacity of connected HVDC, it is very important to examine the acceptable capacity of wind power generation, so it is necessary to review in advance the operating capacity limit of the energy system and establish an optimal distribution target for wind power.

This paper has attempted to calculate the capacity of the energy storage device based on the expected excess power in the high wind penetration system. Based on realistic HVDC connections of ROK, ESS storage estimates were progressed. Practical wind and power system conditions are utilized in simulation to reflect possible critical situation. The main case studies focus on the feasibility of ESS operation with applied capacity and control method.

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1. Introduction

Wind power generation depends entirely on wind speed as an intermittent energy resource, and the amount of power generation varies according to the intensity of irregular winds. Therefore, unlike fossil fuels, production is not constant. In current state, there will be no significant impact on systems where the participation of wind power generation facilities is not very high [1]. However, in case of high wind penetration power system, a serious power stability issues can be occurred according to the wind variation. In particular, in the case of wind power generation, which has recently been connected to the network with a large-scale capacity, it can cause not only voltage fluctuations in terms of power quality but also an inaccurate power supply. Therefore, it should be necessary to conduct more detailed research and analysis focusing on the point of interconnection [2], [3]. Above all, the ability of existing operating systems to accommodate renewable energy sources must be analyzed based on a multi-dimensional perspective before integration. This is because if renewable energy is introduced into the network to leave the capacity limit, the existing operating system must be improved or changed [4].

To address these issues, wind power generation systems generally should comply with the grid code. If this criterion is not met, a cooperative system with another compensator should be built, and there is a generalized type to work with the energy storage device [5]. When connecting an energy storage device with a wind power generation system, the general demand is that fulfilling grid codes which are related with the real/reactive power control capability, frequency characteristics, and power quality. The energy storage device has a faster response characteristic than other conventional compensators and is advantageous for charging and discharging due to output fluctuations [6]. Therefore, a hybrid system based on wind-energy storage system (ESS) can compensate for the lack of reliability and stability of the single wind power generation system. In addition, since the amount of power generation can be adjusted according to the fluctuation of the load, it is possible to provide an advantage to the wind system owner by improving the utilization rate of wind farm [7]. However, there are practical issues that should consider both the cost of installation and the life cycle of the ESS (due to charging / discharging). Therefore, the introduction of an energy storage device that can satisfy a grid code has been limited to a certain level determined by the operators [8].

This paper attempts to present a realistic capacity calculation method, focusing on the case where the output of wind power exceeds the expected load. In general plans about power supply / demand, the generation capacity exceeds the expected load, and the power generation amount by wind power system is able to be not consumed and to be treated as a surplus power [9]. In order to use this generated power efficiently, it is necessary to calculate the surplus power in consideration of the realistic output of the wind power generator, and to calculate the capacity of the base energy storage device [10]. The surplus power must be calculated in consideration of the power generation of the system, expected load, capacity factor, etc., and the position and output fluctuation of the wind power generation power should be taken into account. To do this, based on the Jeju area of ROK where this can be reflected, a realistic capacity calculation process has been performed.

2. Theoretical Set-Up

2.1. General descriptions

When renewable energy is linked to ESS, it is possible to operate the sources with compensatory options. It is possible to reduce the gap between the expected / actual output power, and deal with instantaneous uncertainty including variability. If it is able to reduce wind power errors and maintain a stable output condition, an energy supply plan that includes a wind power system could be achieved. In addition, the reserve capacity required for wind energy uncertainty can be reduced.

However, since the ESS has a relatively expensive installation cost, it is required to determine adequate capacity in consideration not only of the scale of the energy system but also of the environment of the target wind power generation system. In the case of the ESS, when cooperates with the wind power generation system, the charging/discharging controls are generally carried out considering the restrictions on the state of charge (SOC) [11]. The output amount and interval for ESS operations have to be remained within the allowed SOC range. Therefore, the required output capacity is determined depending on the size of the expected wind power uncertainty. According to the confidence level of wind power production with stochastic distribution, the forecast output range must be established [12]. Based on this, the ESS must be constructed to cover the predicted wind power output appropriately.

These stochastic analyses are closely related to the power system load, as shown in the conceptual diagram of limit capacity calculation of Figure 1. In the energy management process, the possible

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minimum load has a great influence. The limit capacity can be calculated by dividing into year, season, month, day, etc., so that more specified wind resources have to be considered. The concept of limited power capacity has to be based on operational limitation instead of equipment capability limit for improving system efficiency.

2.2. Must-run capacity

The Must-run capacity is specified amount of generation that is required to be maintained at specific levels in parts of the local electricity system to compensate for insufficient transmission limit relative to demand. The defined capacity is considered to ensure reliability during power system operation in certain local area. The Must-run capacity should be maintained to a criterion level by balancing other supplying capacity (high voltage DC (HVDC), ESS, wind farm). Wind energy fluctuation could first be handled by an integrated ESS, and if the capacity of the ESS cannot cover the amount, the curtailment option should be considered. This concept is shown in Figure 2 based on wind power supply (PWT). The remainder of this paper is composed with system analysis to derive an adequate ESS capability.

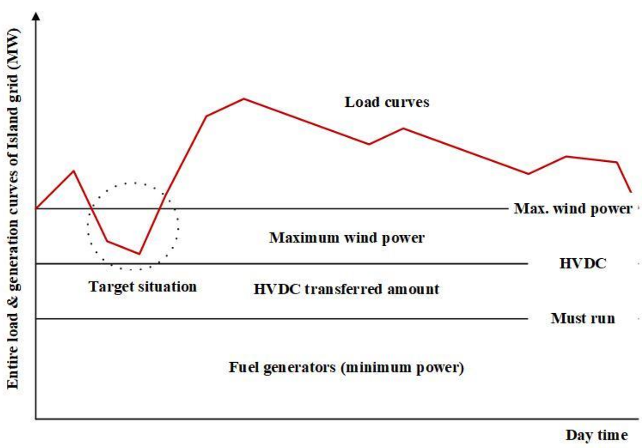

Figure 1. Daytime power fluctuation of island power system

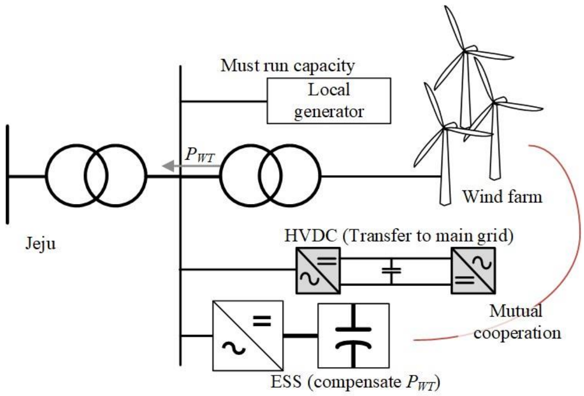

Figure 2. Conceptual description of ESS design for wind farm

3. Target System Analysis

3.1. Statistics of Jeju Island

In the case of the Jeju region, which is made up of relatively small loads, the uncertainty is high; an accurate analysis of the loads and energy sources is required. Above all, it is expected that the design of ESS should be progressed by considering the great penetration of wind power generation systems. In this paper, based on the information represented in the Korean Electric Power Supply and Demand Basic Plan, the load and power generation of the Jeju have been analyzed to derive a required storage capacity. A method of introducing an ESS in a stepwise manner according to the increasing ratio of the wind power generation system in consideration of the wind fluctuation characteristics is required to be reflected.

In case of a general power system, a high proportion of wind power generation capacity could be an issue for stability. However, the Jeju Island, through the transmission to the mainland by HVDC transmission system control, the system operator can mitigate the instantaneous power fluctuation. To reflect this momentary support in the calculation of capacity, the stability of the system should be addressed from the standpoint of reserve capacity.

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When HVDC capacities were calculated as a reserve, the total controllable power generation is larger than the expected load capacity in current state. Therefore, it is expected that there would be no problem with the load supply due to the sudden decrease of wind power generation. However, since the wind power generation has gradually increased, the sum of must-run and the wind power generation could exceed the load capacity. The surplus power is possible to be generated which have to be transmitted to the mainland system through HVDC which requires an additional conversion time. According to the basic plan, not only the wind capacity in 2017 exceed the total load capacity, but frequent transmissions will be required with given peak load. The Table 1 compares the amount of wind and HVDC capacity by focused on the expected surplus power.

In this paper, we try to calculate the amount of power generation that is exceeded based on the minimum load and reflect it in the calculation of the ESS capacity. The main objective of this criterion is to eliminate the situation to transfer surplus energy to the main power grid. Since a power transfer is required when the amount of total power generated from Jeju exceeds the amount of local load, it is necessary to calculate the ESS capacity taking into account both load fluctuations and wind power uncertainty.

Given that the curtailment about wind power is possible, we tried to consider the minimum load to create a severe situation in the analysis process. However, instead of considering the maximum wind energy production that has few possibilities, the stochastic wind energy production that takes into account the capacity factor is applied to the capacity calculation.

3.2. Stochastic approach for wind power

In the case of wind power generation, there is a problem that production fluctuations are severe due to wind fluctuations, and nominal production cannot always be maintained. Therefore, it is necessary to realistically calculate the amount of output and examine the cooperation of ESS. In wind power generation, the ratio of the amount of power generation compared to the nominal output is called the capacity factor. The capacity factor is an important index in the process of calculating the real capacity for energy acquisition. The calculation formula for the equipment utilization rate is as follows.

$$CF = \frac{E_{total}}{E_{rate}} = \frac{Total\ generated\ power}{P_{rate} \cdot t} \tag{1}$$

Where E_{total} is the total energy from wind system, E_{rate} is energy with rated power extraction of wind system, and $P_{rate}(t)$ is rated power of wind system.

Table 1 : Numerical power network data of JEJU Island

Year	Must run (MW)	Wind generation capacity (MW)	Minimum load (MW)	Maximum load (MW)	HVDC capacity (MW)	Transferable HVDC capacity (MW)
2018	170	564	410	829	400	250
2019	170	680	428	866	600	450
2020	170	980	447	905	600	450
2021	170	1300	466	942	600	450
2022	170	1300	484	980	600	450
2023	170	1300	503	1017	600	450
2024	170	1400	521	1054	600	450

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Since the ESS is integrated to mitigate power fluctuation, the realistic output power consideration is required. To derive a realistic extracting condition, a historical environmental data for Jeju is applied in the Weibull distribution function which is expressed as:

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} e^{-\frac{v^k}{c}} \qquad (2)$$

Where c is Weibull scale parameter (m/s), k is Weibull shape parameter, and v is wind speed. Based on wind speed information from automatic weather system in ROK, averaged high capacity factor for single month is derived as 36 percentage (for January). Based on this, ESS capacity estimation is progressed in Section 4. With full and half generating condition for wind power system, 30 and 36 percentage extraction of wind system are analyzed in capacity estimation.

4. Capacity estimation

4.1. Basic analysis (with full capacity of wind power)

This paper tries to analyze the monthly capacity factor of wind power generation system to derive adequate capacity. If the sum of wind power production and minimum power generation exceeds the load, there will be a surplus power. If excess energy is immediately transferred to main grid, it may be efficient, but an additional mode conversion control is required. In the case of Jeju Island, the total amount of fossil power generation and the total amount of HVDC connection often exceeds the amount of load capacity. Thus, the capacity of ESS should be calculated based on this phenomenon. Figure 3 is a graph that compares the size with the load, taking into account a target power generation. As described in the figure, in 2020, wind power capacity will exceed the maximum load. Therefore, there is a high possibility that an excess amount of energy will occur. However, if ESS capacity calculation is performed with rated capacity, excessive equipment input is expected. In this document, we calculate the capacity of ESS considering the capacity factor of Jeju Island.

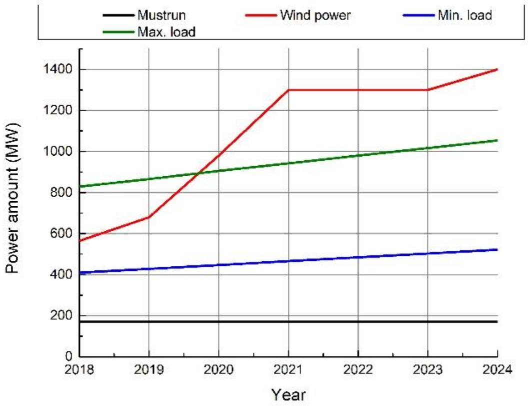
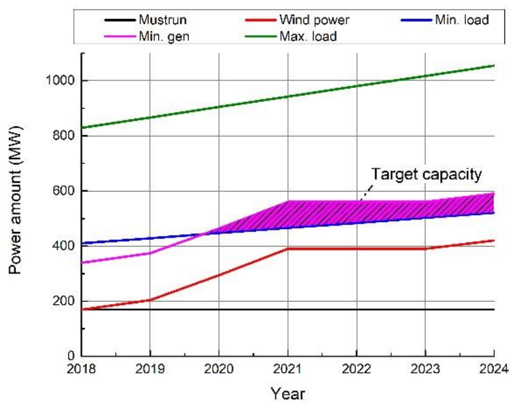


Figure 3. Generalized capacity for Jeju power system



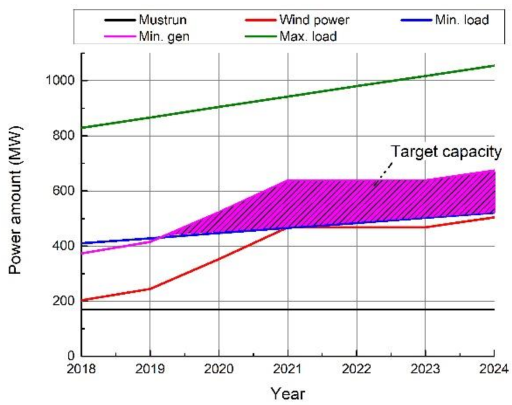


Figure 4. Estimated expected surplus power with determined capacity factor - Left: 30 percentage, Right: 36 percentage

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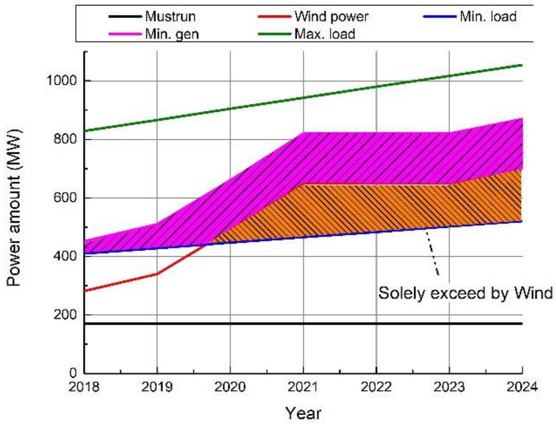

Figure 5. Expected surplus power with half generating condition of wind system

Table 2 : Power network data of JEJU Island

Year	30 Percentage case		36 Percentage case		50 Percentage case	
	Surplus power (MW)	Capacity to wind system ratio	Surplus power (MW)	Capacity to wind system ratio	Surplus power (MW)	Capacity to wind system ratio
2018	-	-	-	-	42	7%
2019	-	-	-	-	82	12%
2020	17	2%	75.8	8%	213	22%
2021	94	7%	172	13%	354	27%
2022	76	6%	154	12%	336	26%
2023	57	4%	135	10%	317	24%
2024	69	5%	153	11%	349	25%

4.2. Capacity factor based analysis

This paper pursues an ESS capacity that the instantaneous extra power can be absorbed without conversion control. In this paper, basically, we would like to proceed with the capacity analysis reflecting the monthly maximum capacity factor (36 percentage) that is analyzed above based on the Jeju Island. Figure 4 includes graphs that analyze the required ESS capacity with the maximum capacity factor (30 percentage) for three months (December to February). When the capacity factor is taken into account at 36 percentage, a year in which the minimum load quantity reaches to the wind power is existed.

Since the minimum load and the amount of wind power generation intersect on a 36 percentage capacity factor graph, reasonable installation of ESS could be achieved with this point. When the capacity factor is taken into account at 50 percentage, there are sections in which the production of wind power alone exceeds the load. In this case, it is shown that frequent curtailment cannot be avoided. Figure 5 displays the surplus power generated only by wind energy with 50 percentage of capacity factor. Table 2 represents the required capacity of ESS and the ratio based on each wind power capacity. In the case of the 36 percentage capacity factor, it shows a 10 percentage ratio comparing the wind capacity installation, which is similar to the capacity currently used on the island of Jeju.

Taking into account the characteristics shown in the graphs, as the year increases, the probability of an excess of existing load increases. However, according to the total wind power generations

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shown in the table, it can be seen that the excess power is maintained within a certain range when viewed in a relationship that takes into account the total wind power generation. When configuring an ESS, an efficient calculation can be performed if the fixed capacity ratio is established as criteria. Considering that the excess power shown in the table is selected based on the minimum load, it is able to optimize by configuring the load fluctuation more realistically.

4. Conclusion

In the case of Jeju Island, it is necessary to take into account fluctuations in small-scale loads and fluctuations of large-scale wind farms. Therefore, a momentary power control is required and the introduction of ESS needs to be considered. Nevertheless, the introduction of ESS for system stability requires the balance of the entire system based on an economically appropriate calculation process. The whole design should cooperate with the system operator as well.

In the calculation of capacity confirmed in this paper, the minimum load was used as a reference, so if more realistic load fluctuations were reflected, it would be possible to calculate the appropriate power capacity of the ESS. In addition, if the wind power company contributes obligatorily to the ESS, the proportion of the planned wind power capacity can be used as a criterion. The grid operator and the wind power operator can establish the required capacity in a balanced manner and use it to the ESS construction.

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