International Conference on Renewable Energies and Power Quality (ICREPQ'15)
La Coruña (Spain), 25th to 27th March, 2015
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, No.13, April 2015

A study on the voltage calculation method for ESS operation plan in Hybrid Generation System

S. Jung[1] and G. Jang[1]

[1] School of Electrical Engineering
Korea University
Anam-dong, Seongbuk-Gu, Seoul, 136-701 (Korea)
Phone number: +82-2-3290-3675, e-mail: muejuck@korea.ac.kr, gjang@korea.ac.kr

Abstract. The designed hybrid generation system (HGS) not only consider the voltage condition of connection point but also do limit output profile by following the transmission system operator's directions. Therefore, when developing large-scaled system including a number of HGS, appropriate compensation strategy based on the system components and impacts should be formulized with considering inner system's characteristics. The ESS operation plan in HGS should be supported by precise voltage expectation method because the system has large physical areas: it includes almost 150m DC section. Especially, since the previous system is not considering power limiting method at the DC section which is integrated with wave generators, an appropriate ESS compensation could provide a lots of solutions such as power control and quality issue. In this paper, an active power control algorithm with expected voltage based on the DC power flow is introduced, and imposed to the simulation process that is performed on EMTDC environment. Further, the comparison with the normal control process is carried out based on the composed layout in ongoing project.

Key words

Combined generator, ESS application, DC power flow, system dynamic, wave energy

1. Introduction

In the renewable energy sources, technical studies have been underway to be able to implement the output power control as well as the additional ancillary services such as power compensating with energy storage device and the voltage control by composing cluster mainly based on the wind generator [1]. Among them, offshore system to increase the entire system efficiency by installing generators with the floating structure has been continuously studied, and the efforts to try to improve the efficiency of electrical equipment for transferring generated electricity to the grid have been followed [2].

There has been a growing interest in not only doing research on the existing renewable sources but forming the combined generator system with several power sources which can reduce the construction cost regarding offshore platform. This concept is proposed for taking the advantages of formulating not only the transmission system but also power profile management [3]. Most of all, the wave power generator system is being considered as a promising resources for composing hybrid system with wind energy system in offshore region due to the effectiveness and commonness.

In case of the wave-offshore hybrid generation system (HGS), the total capacity is higher than previous renewable energy and advanced power limitation process for entire profile is demanded by transmission and system operator (TSO) for system stability. Therefore, the HGS firstly consider adopting the pitch control scheme in the wind system but other utilization is being discussed. By focusing on the DC section in the HGS, ESS application is also considered but the wave generators in the HGS transferring the output power through long DC section and it generating high voltage variation at the interconnection point of PCC. If a compensating device is utilized in this section, advanced technology should be imposed for system performance.

In this paper, the ESS compensation plan is proposed to do output determination of the entire combined generator system by paying attention to demand of utility grid. With the analysis of the controllable elements of the wind and wave power generator, DC power flow calculation method is introduced to the power control process. The designed voltage prediction process for ESS operation is confirmed through using the EMTDC. The entire simulation process was designed by adopting the active power control according to the reference signal of TSO.

2. System Description

Fig. 1 shows a conceptual image of the proposed system and the location of DC section is described. The HGS is introduced to reduce the electrical infrastructure cost and to maximizing the system efficiency by sharing both PCS and transformer. It can be achieved by constructing a number of wind turbines and wave generators in one platform [4]. Total power capacity is over 10 MW and the system is basically composed with doubly fed induction generator (DFIG) wind turbine and permanent

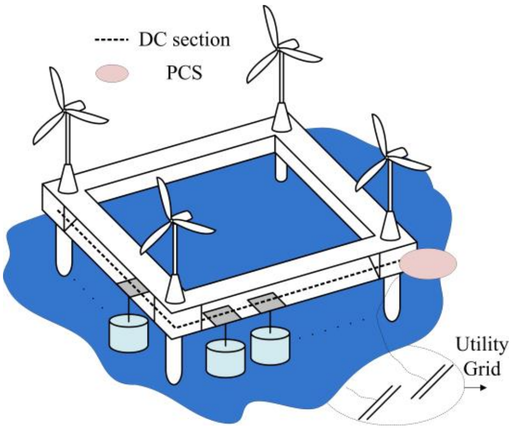

Fig. 1. Concept of the wave-offshore hybrid system

magnetic synchronous linear generator (PMSLG) wave generator. These main devices of the proposed system generate output power with each environmental factor and output profile would be transferred to the utility grid through the inner electrical transfer system. Because the proposed generation system has relatively higher capacity than the general renewable system, it is required for the HGS to follow the order of system operator.

A. ESS application

The fluctuation characteristics of the large-scale distribution system can make a short-term effect to the utility grid. Generally, the ESS application is being progressed with a similar system design, which is connected to a target system, where the ESS can directly supply power using conversion devices that convert the DC voltage of the storage device to the ac voltage of the utility.

The appropriate location of the ESS interconnection would be DC section in the HGS, which is integrating wave generators through common converter system [5]. To perform ESS in the designated section, an advanced control logic about considering DC section of voltage source converter. The device is integrated in DC section with DC/DC converter and the entire PCS transfer the total output power including the profile of ESS. Therefore, the ESS in the HGS should be operated according to system voltage condition which is one of the reference value in the ESS operation. In this study, the simulation consists of storing the surplus output power than reference signal, and a bidirectional power conversion system is integrated into the ESS to control the output power of the entire system.

Basically, the ESS follow the other generator signal and has limitation quantity by according to the PCS conversion capacity. The relation between output profiles of the each system is shown as Eq. (1) and (2).

$$P_{PCC} = \sum P_{WT} + \sum P_{wave} + P_{ESS} \tag{1}$$

Where P_{pcc} is the total output profile at the PCC, P_{WT} is the wind power output, P_{wave} is the wave power output, P_{ESS} is the ESS output profile.

$$\max P_{ESS} \le S_{pcs} - \sum P_{wave} \tag{2}$$

Where S_{pcs} is the power conversion capacity of the PCS.

B. DC power flow for ESS operation

In the proposed system, the ESS integrated with shared DC section and the wave generators in this section are totally designed adopting a central control topology [6]. The grid-side converter is continuously maintaining the designated voltage level. However, each section in this system has possibility about voltage fluctuation according to the wave system's generating profile. To consider this impact, further circuit analysis should be imposed in the ESS control system. It is possible to calculate the voltage condition at the each interconnection point by through DC circuit analysis. Fig. 2 shows the simplified model of the DC section of the HGS with ESS.

The output power control of ESS is performed by charging the generated surplus power that over the reference signal and discharging the quantity at the minimum power expected section thorough own prediction system. With the control method, the wind turbine can progress the maximum power point tracking (MPPT) control regardless the order of TSO. The charging/discharging profile of ESS can be formulated as Eq. (3).

$$P_{ESS}(t) = P_{PCC}(t) - \sum P_{WT}(t) + \sum P_{wave}(t) \tag{3}$$

At the surplus power generated section, the ESS charging the energy with the Eq. (4).

$$P_{ESS}(t+1) = P_{ref}(t) - \sum P_{WT}(t) + \sum P_{wave}(t) \quad (P_{\max} \ge P_{PCC}) \tag{4}$$

The operating system generate the discharging reference signal with the charged power by previous state and the ESS follow the signal as Eq. (5).

$$P_{ESS}(t+1) = \sum P_{WT}(t) + \sum P_{wave}(t) - P_{ref}(t) \quad (P_{\min} < P_{PCC}) \tag{5}$$

In the equation, the ESS profile is differed with the voltage condition of connection point. Fig. 3 represents the equivalent circuit of the Fig. 2. The voltage source in the Fig. 2 is alternated with the constant current source for circuit analysis. The connection point is expressed as a node in the equation for analysing the output power of each side wave generators, incorporated separately for a different array. From the represented network, the node equation can be derived as shown in Eq. (6):

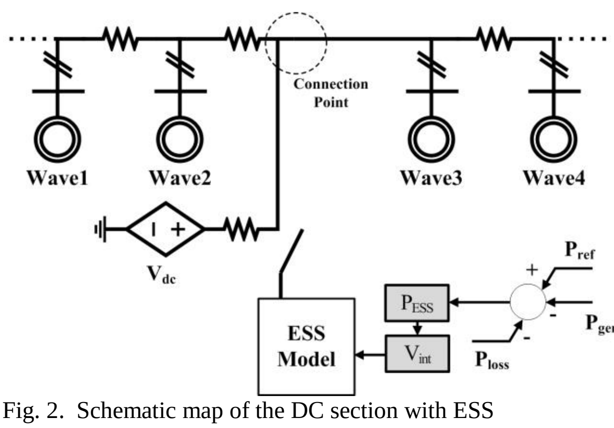

Fig. 2. Schematic map of the DC section with ESS

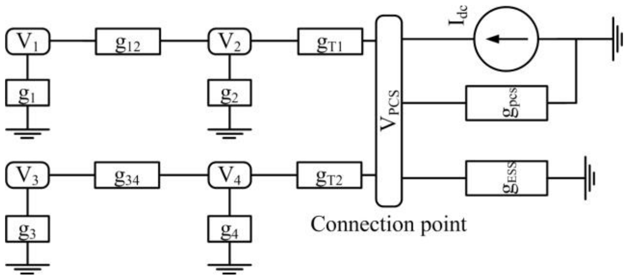

Fig. 3. Equivalent circuit of HGS with ESS

$$\begin{bmatrix} g_1+g_{12} & -g_{12} & 0 & 0 & 0 \\ -g_{12} & g_2+g_{12}+g_{T1} & 0 & 0 & -g_{T1} \\ 0 & 0 & g_3+g_{34} & -g_{34} & 0 \\ 0 & 0 & -g_{34} & g_4+g_{34}+g_{T2} & -g_{T2} \\ 0 & -g_{T1} & 0 & -g_{T2} & g_{T1}+g_{T2}+g_{pcs}+g_{ESS} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \\ V_{pcs} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ I_{dc} \end{bmatrix} \quad (6)$$

In the equivalent DC section, a number of admittance components are designated and they differ according to the voltage change. In order to reflect situation, an iterative calculation method is adopted with designated current value of source. The wave generators act as a negative resistance because the equivalent generator only generates power with the designated voltage. The relation between the voltage and equivalent admittances of each wave generator is defined in Eq. (7);

$$g = -\frac{P}{V^2} \quad (7)$$

Additionally, the ESS admittance is also developed with the above equation. With the designated reference signal, the iterative process predict voltage condition with the ESS profile and the ESS can control accurately with the expected voltage condition.
Since I_{dc} has been determined, the solution of the voltage at each node can be obtained using an iteration process. The equation used in the iteration is Eq. (4).

$$[V] = [g]^{-1} \times [I] \quad (4)$$

3. Simulation

A simulation was configured using PSCAD. The real system and location data of JEJU was used for calculating wind prediction and system operation. The prediction system uses the Weibull distribution formula, which is the most commonly used statistical distribution formula to describe wind speed data. The described data match well with the experimental data [7]. The Weibull distribution function is expressed as Eq. ()

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left\{-\left(\frac{v}{c}\right)^{k}\right\} \quad (10)$$

Where c is the Weibull scale parameter (m/s), k is the Weibull shape parameter, and v is the wind speed (m/s).

The simulation is composed to perform the limitation process according to the reference signal both upper and lower active power profile. The reference signal is changed every 5 seconds and the entire simulation time is 11 second including transient section for start-up. Two different reference signal is utilized in the simulation and related simulation information is represented in Table I.

Table I. – Simulation information of the HGS simulation

	Unit	Value
Simulation time	Sec.	11
First order section	Sec.	3-8
Second order section	Sec.	8-11
Rated voltage (AC)	kV	0.69
Rated voltage (DC)	kV	0.44
Rated capacity (wind)	MW	8
Rated capacity (wave)	MW	2.4
First P order (Max.)	MW	8
Second P order (Min.)	MW	3.6

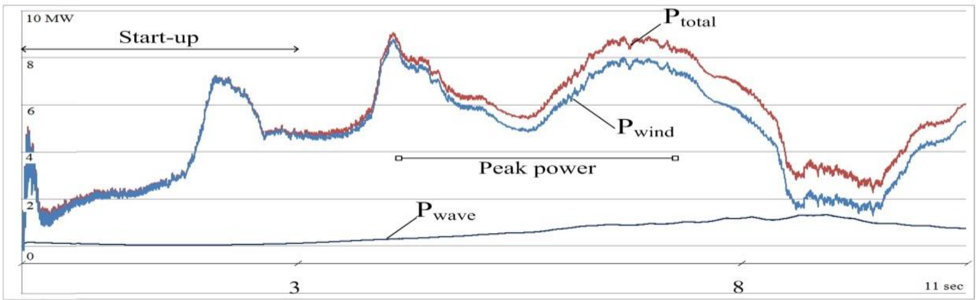

Fig. 4. Output power of HGS (without ESS)

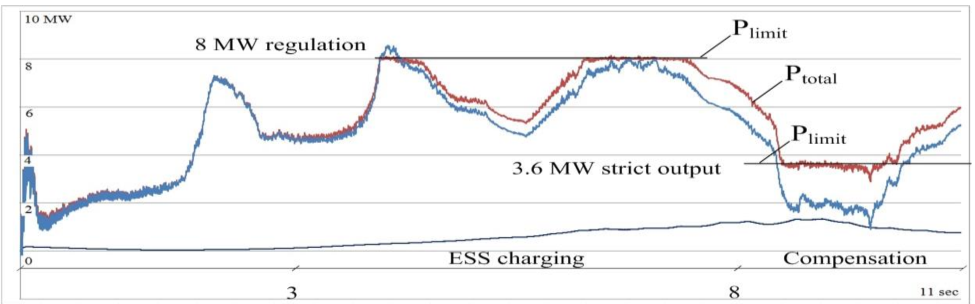

Fig. 5. Output power of HGS (with ESS)

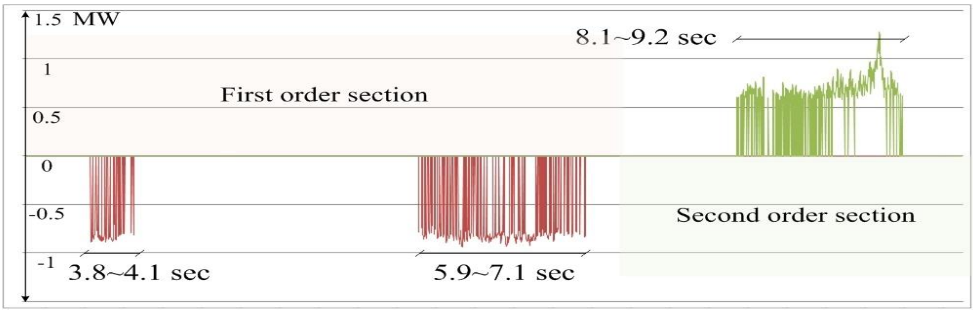

Fig. 6. ESS output within designated section (2.4 MVA)

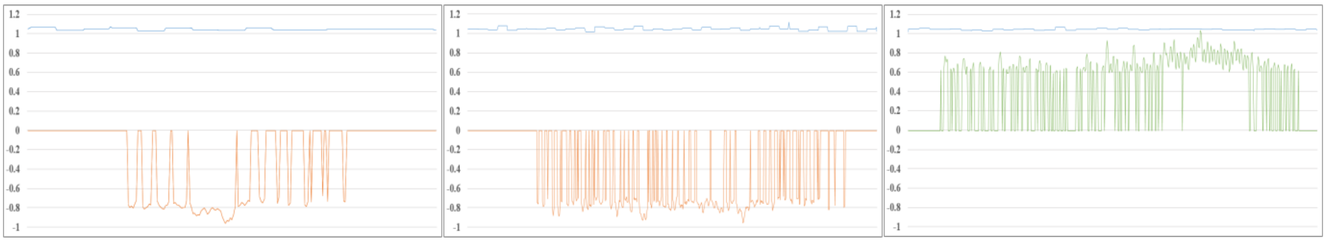

Fig. 7 (a) First operation section (V, P_{ess}) (b) Second operation section (V, P_{ess}) (c) Third operation section (V, P_{ess})

Fig. 4 shows the normal operation which is not utilizing the ESS as compensating method. The HGS could not follow the reference signal without further control method. The ongoing system consider adopting supervisory control such as pitch control system, but it is only available on wind turbine and the method can cause mechanical load to certain device. The ESS application with the mentioned voltage calculation method is progressed in this paper, and the output profile is represented in Fig. 5. According to the reference signal in the Table 1, ESS compensate the output profile of entire HGS. Since the PCS capacity is designated according to the wave generator, the power conversion quantity is limited according to the PCS operation. The ESS performance is shown in Fig. 6. The active power compensation consider the wave power output profile for matching the total power capacity of the PCS because the wave generator and ESS share the DC section.

Each control profile and voltage variations which are deal with this paper are shown in Fig. 7 individually. There are 3 operation section in this simulation process and each operation can utilize the pre-calculated voltage level directly.

With the voltage expectation, the power control for ESS can be progressed through lower voltage variation and the voltage is not exceeded at certain point.

4. Conclusion

To perform the ESS operation appropriately, the voltage calculation method is formulized and adopted in the designed system. Through case studies, it is verified that the performing process to the response of the TSO order. Due to the change of the TSO order, the system check the voltage condition by calculating the expected and reference active power profile. It is clear the HGS should adopt certain power control method for limiting output profile. The pitch control for wind turbine can be a solution but these kind of HGS is composed with diverse generator that is affected additional whether condition. Since the HGS is based on large-scale offshore platform, the ESS application can be a solution in terms of the construction site. Moreover, the low utilization of PCS in HGS can be improved with the ESS adaptation.

Acknowledgement

This work was supported by the MOF grant (Development of the design technologies for a 10MW class wave and offshore wind hybrid power generation system and establishment of the sea test infra-structure) and by Human Resources Development of KETEP grant (No. 20114010203010) funded by the Korea government Ministry of Knowledge Economy.

References

[1] A. Kusiak, H. Zheng, Z. Song, "Short-Term Prediction of Wind Farm Power: A Data Mining Approach", IEEE Transactions on Energy Conversion, Vol. 24 (1), pp. 125-136.

[2] M. J. Dvorak, C. L. Archer, M. Z. Jacobson, "California offshore wind energy potential", Renewable Energy, Vol. 35 (6), pp. 1244-1254.

[3] T. V. Cutsem, C. Vournas, Voltage stability of electric power systems, Kluwer Academic Publisher (2012).

[4] J. Beerens, "Offshore Hybrid Wind-Wave Energy Converter System".

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

[6] L. Zhang, K. Sun, Y. Xing, L. Feng, H. Ge, "A Modular Grid-Connected Photovoltaic Generation System Based on DC Bus", IEEE Transactions on Power Electronics, Vol. 26 (2), pp. 523-531.

[7] A. S. Ahmed Shata, R. Hanitsch, "The potential of electricity generation on the east coast of Red Sea in Egypt," Renew energy, vol. 31, pp. 1597-1625, 2006.

[8] Korea Meteorological Administration , www.kma.go.kr