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Flexible reactive power controller design for wind farm structure under wake effect

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Abstract

BACKGROUND/OBJECTIVES: Compact wind farms are vulnerable to wake effects and have demanded a general contrast solution for them. Recently interconnected wind power plants are equipped with conversion device, and not only a detailed switching model but also a phasor locked loop that can extract grid information for control should be developed.

METHODS/STATISTICAL ANALYSIS: It is important to determine reasonable reactive power references based on practical reserve because each power conversion system would be on different power extracting condition according to the real-time wind fluctuation. A flexible control module for this process has been composed in this paper.

FINDINGS: The wake effect induces real power fluctuations, which can affect reactive power reserve classified as grid interconnection conditions. For developing a stable reactive power controller, an appropriate reference assignment plan must be configured to reflect the internal network structure. In this paper, we propose a flexible control plan in terms of reactive power when the output fluctuation of wind power generation occurs due to the wake effect.

IMPROVEMENTS/APPLICATIONS: The designed fluctuating condition is utilized in a case study to verify control robustness. The simulation was performed with the aim of finding efficient allocation points on the use of the reactive power reserve according to the fluctuations.

Keywords: PCS application, curtailment, reactive power reserve, reserve calculation, wake effect

1. INTRODUCTION

Based on the expanding interconnection trends about large-capacity renewable energy resources, offshore wind farms are being built in each region, and a novel proposal for an efficient interconnection and composition of renewable energy is being investigated. Research on reactive power/voltage control has been continuously carried out because of its highest priority of voltage stability when these distributed generators are connected to the grid [1]. To handle this objective, an accurate control system regarding environmental-related resources have been developed by reducing the error between real extraction and imposed reference. Most of all, to improve the performance of the distributed generation system, real-time control applications for the large-scaled farm have been utilized in various directions. In order to extract renewable energy appropriately and efficiently, not only a technical approach but also a comprehensive scheme of prediction topology is being studied [2, 3]. With the voltage-sourced converter, which has fast characteristics of reactive current changes, currently composed large-scale wind farm can compensate required reactive power for connected power system [4-6]. However, in most existing small-scale power generation systems, reactive power supply capability is ignored, and the scope of the research has been formed to satisfy grid code s by focusing on point of common coupling (PCC). Yet, with the expansion of voltage source converters, including recent large-scale wind turbines, the view has grown that renewable energy sources should also participate in reactive power supply processes.

In the case of wind farm networks, the advanced control logic is required for each wind turbine structure because the expected reactive power reserve and caused impact are not the same. In each state, wind turbines have a different reactive power reserve, since the utilization of a power conversion system (PCS) is differed according to the extracted power from each turbine [7]. Recently, due to the lack of a construction site along with the increased capacity of the turbine, a wind farm installation frequently progresses within a limited area. In these conditions, the influence of the wake effect can be increased due to the variation of wind direction. It is necessary to use the reactive power reserve reflecting this state and, with this, an improvement in the reactive power supply process can be derived [8].

In the case of real power control of the wind system, a pitch control in order to respond to curtailment signal has been used as a basic option in a separated management system. Through developing a wind farm management system (WFMS) as in [9], for operation response, a system operator can determine a reduction signal that is for grid stability in terms of system frequency. In [10], an advanced curtailment control used to match grid balance regarding real power.

In this paper, we confirmed the fluctuation of the real power output according to the fluctuation of the wind speed and presented a method of assigning the reactive power references in consideration of each reserve quantity. In a hierarchical structure, a PSCAD simulation is designed in order to verify if the assigned reactive power references are acceptable. In the composition of the wind farm, to simulate the situation of high wake effect, a design is considered which placing 4 wind turbines at a relatively short distance. Fluctuation of the reactive power command was simulated with a limited power plant configuration. Thus, the significance of the assignment effect could be derived as a result.

2. THEORETICAL SET-UP

2.1. TARGET SYSTEM CONFIGURATION:

Various distributed generator systems were a planned system to reduce construction costs and efficiently use a single subsystem by building a series of generators on one platform [11]. Currently, a generating system of more than 10 MW is being formed. A permanent magnet synchronous generator (PMSG) are the main devices of these systems and the power generator would be transferred to the grid through the internal transfer system. Since the capacity of these generators is relatively greater than that of the previous system, it must follow the order of the transmission system operator (TSO) and the output power of each generator is designated according to the reference signal. Unlike the current power flow formulation that does not include the reactive power reserve of the connected turbine, the proposed control method tries to include an algorithm to maximize the utilization of the reserve that is useful for TSO.

2.2. REAL POWER PRODUCTION CHARACTERISTICS:

In the case of a wind farm with a wake effect, a wind speed at the back array is able to decrease. Along with this state, the real power output of wind turbines is hard to be considered. These states could generate variations of reactive power reserve. In particular, since the reactive power supply is focused on PCC, a solution for reducing apparent current flow in the internal cable could be a positive effect in terms of electrical loss. Therefore, the designed proportional dispatch algorithm has been formed an inverse proportion method by following measured real power extraction in real-time. Fig. 1 illustrates the power control process by focusing on real power extraction from the wind system. Both TSO orders for real and reactive power can be imposed in the whole control process.

Reactive power compensation must be used in accordance with the imposed TSO order. Added a PI controller in the power controller to match the amount required by TSO. To perform reactive power control to handle the voltage level that varies in real-time, the amount of extracted real and reactive power must be continuously reflected and included in the control process.

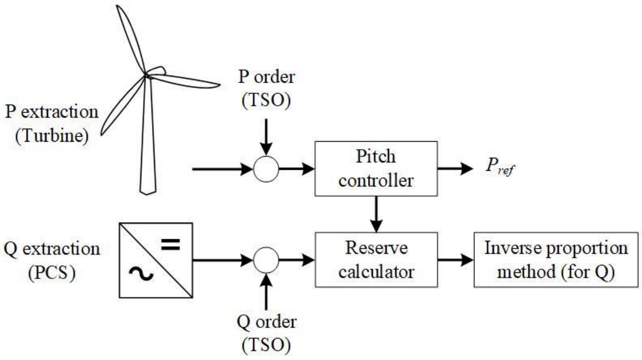

Figure 1. Utilized reactive power control concept for PCS reserve consideration

2.3. PCS CONTROLLER DESIGN:

The control model of the PCS includes active and reactive power references that are transferred to the system. The generated active power and reactive power references are sent to the generator model to handle the switching process, including a PI controller. Fig. 2 shows a reactive power control model of a used PCS device. In this paper, we propose to execute the reactive power control using the hierarchical structure and present a method to assign the reference signals derived by a comparison process about the reactive power reserve.

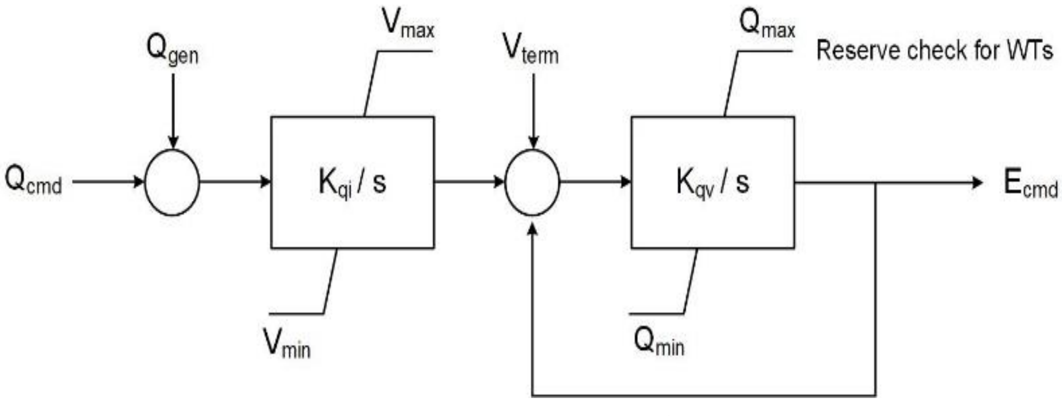

Figure 2. Designed reactive power controller for reserve utilization

3. REACTIVE CONTROL ALGORITHM

3.1. GRID COMPONENTS:

In the case of wind farms, since the internal network is made up of a medium voltage cable, the reactive power of the cable must be considered in the power control process. Reactive power flow is formed along the cable according to the magnitude of the voltage and the phase angle of each connection point. To consider this in the operation of the network, it is necessary to integrate the passive compensation device. This paper assumes that the reactive power of the cable is distributed equally across the cable. The reactive power produced by the cable can be calculated with Eq. (1).

$$Q_{cable} = \sqrt{3}V_{cable} \cdot 2\pi f_{grid} \cdot \frac{V_{cable}}{\sqrt{3}} \cdot C_{cable} \cdot L \qquad (1)$$

Here, C_{cable} is the line capacitance of cable (0.17 μF/km]), V_{cable} is the rated voltage level of cable, and f is the system frequency (60 Hz).

3.2. MAIN ALGORITHM:

The proposed control method pursues flexible power control based on the amount of reactive power reserve to minimize apparent current flow when there is a demand for reactive power from the network. The method is progressed generally based on the proportional expression. However, an additional power distribution algorithm is shown in Fig. 3 should be included in preparation for the unexpected reserve shortage.

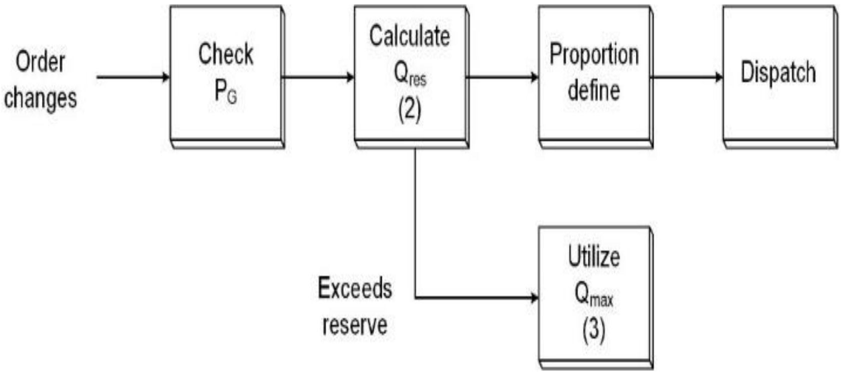

Figure 3. Main controller diagram

If the TSO requests reactive power compensation, the algorithm calculates the reserve focusing on real power supplied quantity with Eq. (2). After finding the available value, the algorithm determines the references of each generator and assigns the signal for system operation. Basically, the system mainly considers TSO's order to respond to grid requirement and the time interval between updating signals might be longer than electrical operation. Therefore, the algorithm should check the difference quickly from the previous phase and proceed to the next sequence by minimizing signal values. In general, the system primarily considers the TSO order to respond to grid requirements and the time interval between signal updates can be longer than real operation.

$$|Q_{res}| = P_G \tan(\cos^{-1} 0.95) \qquad (2)$$

Here, P_G is the real power supply amount.

$$|Q_{max}| = \sqrt{S_{PCS}^2 + P_G^2} \qquad (3)$$

Here, Q_{max} is the maximum reactive power reserve capacity of PCS, and S_{PCS} is the power conversion capacity.

4. CASE STUDY

A PSCAD simulation with 4 selected wind power generators was designed for the allocation processes. The structure of the wind system is as shown in Fig. 4, and the cables used are as shown in Table 1. Each wind turbine has a 3 MW (3.5 MVA) rated capacity [12]. With compact composition, the imposed wind condition shows severe wake effect is illustrated as Fig. 5. Under this condition, a 2,500 milliseconds simulation was progressed to verify the proposed reactive power allocation method. Fig. 6 describes the simulation of the real power extracted under the effect of wake from an adjacent position. Due to the generated wake effect, WT 2 and 4 show a minor supply portion regarding real power. According to the proposed method, these wind turbine should take charge of great proportion in terms of reactive power to reduce current flow. In this paper, constant reactive power order (1 MVAR) was imposed on the generation system. Therefore, composing generators should extract according to the order considering real power variation and own reserve.

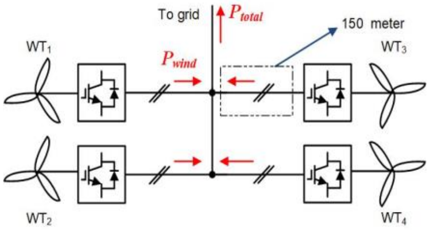

Figure 4. Wind system design for case study

Table 1: Cable information used in wind system design

Voltage level (kV)	Square meter (mm^2)	Allowance (A)	R (ohm/km)	L (mH/km)	C (uF/km)
22.9	95	291	0.193	0.42	0.17
	120	330	0.153	0.41	0.18

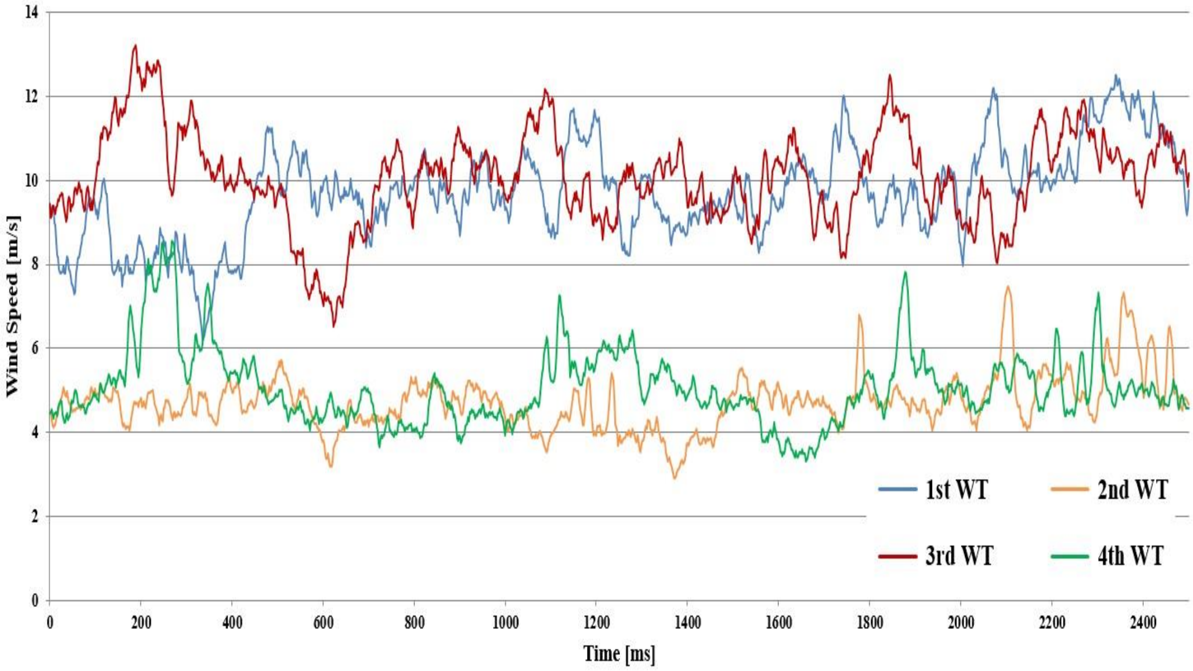

Figure 5. Simulated wake considered wind speed in the simulation

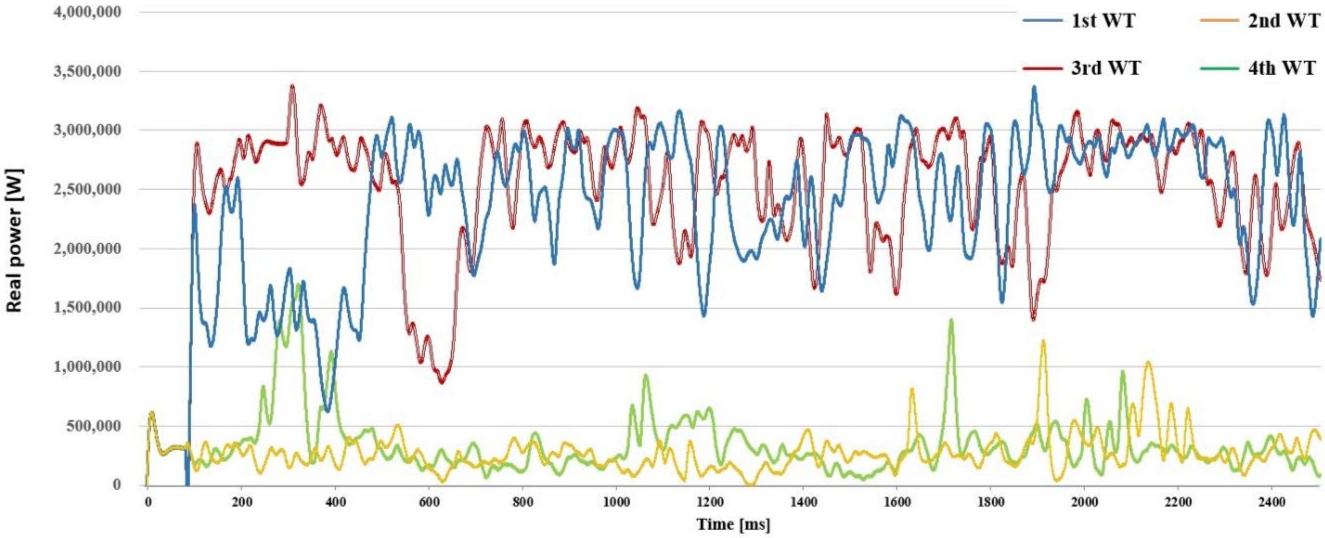

Figure 6. The real power output of case study

Fig. 7 shows the reactive power allocation in the wind system using the inverse proportional method. It can be confirmed that the reactive power output is smoothly performed based on the configured controller. Even if the reactive power algorithm is introduced, the real power output of each system is not affected, and it can be confirmed that stability control is possible. Based on the real power output value, the assigned reactive power value is stably changed through the algorithm. The amount of reactive power supplied to the grid is displayed in the same way as a general assignment condition.

Table 2 shows the comparison of loss with the general PD controller. The average loss is measured from 300 to 2,500 milliseconds. While the loss by power extraction of PD is about 1.012 kW, it shows a loss of 0.947 kW when the algorithm developed in this paper is inserted. This is categorized as an effect due to the reduction of apparent power flow.

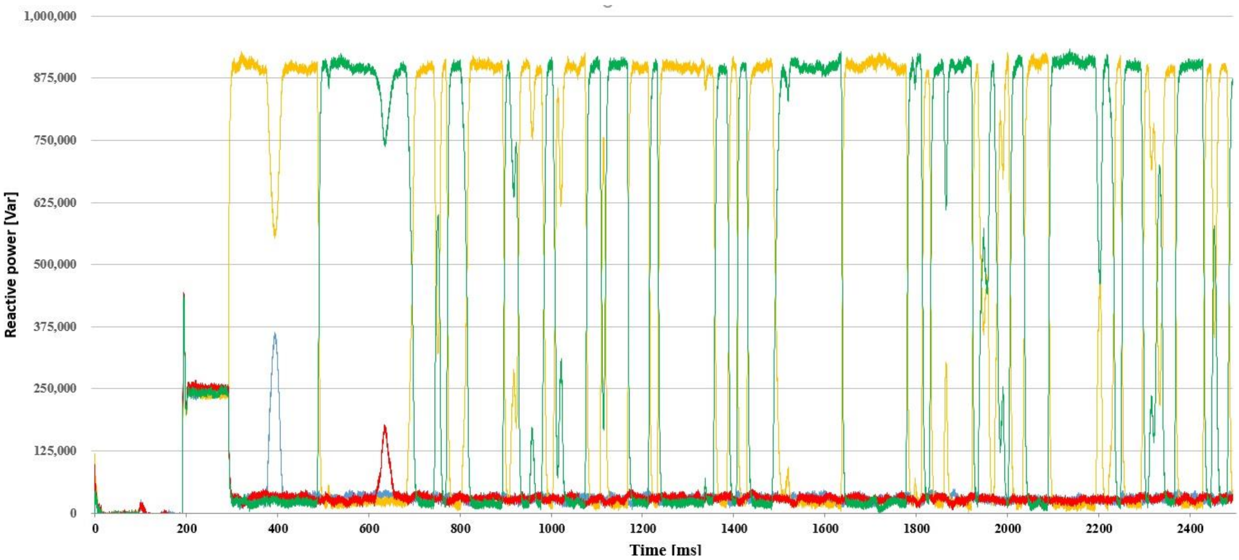

Figure 7. Reactive power extraction from designed simulation

Table 2: Numerical result of simulation

	PD	Proposed method	Improvement
Loss	1.012 kW	0.947 kW	6.43 %

5. CONCLUSION

This paper suggests the method of allocating reactive power to the wind power system based on a real-time reserve of each unit. Since apparent power has a direct effect on loss, we tried to induce loss reduction by applying a reactive power allocation method that is inversely proportional to active power. Assuming a wind farm with frequent wake effects, we applied severe wind speed reductions and imposed differences in active power supply. Through case studies, it is verified that the proposed algorithm contributes to the reduction of the apparent current flow. As a variation of the references, the PCS receives the modified signal when considering the reactive power reserve. The impact of the algorithm would increase with the high capacity of wind power plants. Small-scale reactive power compensation could also be useful for a distributed system.

6. ACKNOWLEDGEMENT

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