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Development of Modular Control System Based on Closed-Loop Control for Wind Farms☆

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ABSTRACT

The use of renewable energy sources for power generation has been steadily increasing. Power generation using renewable energy has the advantage of not generating carbon but has the disadvantage of high volatility depending on the weather. This volatility makes stable power supply difficult. Curtailment is occurring to address volatility. Various facilities are operated together to solve the loss caused by the curtailment. The existing SCADA must be modified for turbine control reflecting the conditions of various facilities. However, since it is difficult to modify SCADA, a modular control system is required. In this study, we propose Modular Control System Based on Closed-Loop Control for Wind Farms. Since the control logic can be changed without modifying SCADA, it is easy to respond to changes. The developed modular control system was evaluated as a lab test and confirmed to operate smoothly. Through future research, the experiment will be conducted by applying a modular control system to the actual wind farm.

☞ keyword : modular control system, wind farm, active power control, closed loop control

1. Introduction

The effort to reduce carbon emissions is increasing worldwide. With these efforts, the proportion of power generation using new and renewable energy is increasing every year. For this reason, solar power generation complexes using solar energy as energy sources and wind power generation complexes using wind as energy sources are also increasing. Power generation using renewable energy has the advantage of not generating carbon. However, renewable energy has the disadvantage of high volatility. This volatility makes it difficult to supply power stably. Since it is difficult to predict the amount of power generation depending on weather conditions, if the amount of power generation is reduced than the predicted value, it may be in danger of blackout. In addition, when the amount of power generation increases than the predicted value, curtailment occurs[1,2].

The curtailment in the wind farm arbitrarily lowers the power generation of wind turbines. In this process, power generation losses occur. In order to use such discarded electricity, various facilities, such as ESS and water electrolysis facilities, are combined and configured in the wind farm. In order to operate a power generation complex composed of multiple types, it is necessary to control the wind turbine reflecting the condition of all facilities[3,4].

Wind power generation complexes are generally controlled using SCADA(Supervisory Control and Data Acquisition) provided by turbine manufacturers. This control focuses on controlling the amount of power generated by the wind turbine. SCADA needs to be modified to control various facilities constituting Wind Farm. It is difficult to modify the existing SCADA according to the configuration of the wind farm. Therefore, there is a need for a control method that considers the configuration of the wind farm without changing SCADA. This study proposes a closed loop-based modular control system. Since it is modular, it is possible to control the power generation complex by connecting it with SCADA.

In Section 2, we describe the existing control system, and Section 3 describes the modular control system. Section 4

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evaluates the modular control system, and Section 5 discusses conclusions.

2. The Existing Control System

2.1 Curtailment

Power generation using renewable energy has the advantage of being clean energy using natural energy but has a problem of having great variability depending on weather conditions. If the power system fails to properly accommodate the instantaneous output volatility, it can undermine the stability of the system. This influence can directly lead to a decrease in power quality by affecting frequency and voltage. Therefore, this large volatility can also be taken as a serious problem from the perspective of the TSO(Transmission System Operator). In addition, the instantaneous excessive output can create instability in the power system. Due to the overload of the system, serious problems such as blackout may occur, and power supply stability may be greatly impaired.

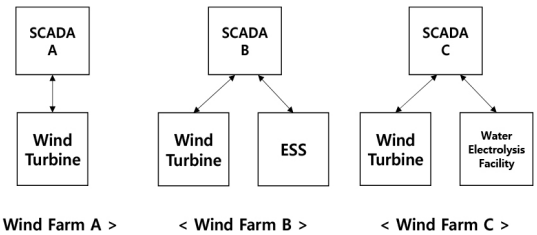
In order to maintain the stability of the system, a method of controlling the output amount of active and reactive power generated in the power generation complex may be used. In South Korea, there is also a situation in which output is restricted to ensure stability of the system when excessive output is expected momentarily[5,6]. As renewable energy generation facilities increase, the curtailment is expected to continue to increase.

2.2 The Existing Wind Farm Control System

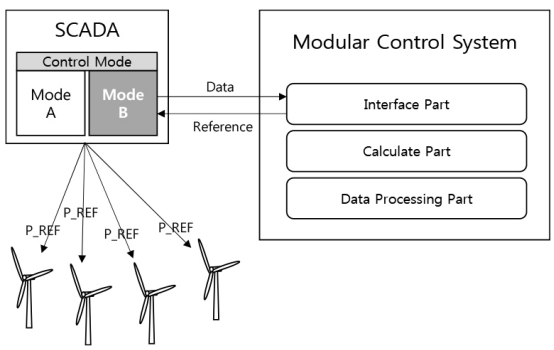
When a curtailment occurs, the power generation of the wind turbine is reduced using the existing SCADA. However, SCADA in a typical wind farm was created only to control wind turbines.

Therefore, the existing control system must create a new SCADA to operate heterogeneous facilities together.

Depending on the facilities configured as shown in Figure 1, all different types of SCADA are required. Whenever new facilities are added to the wind farm, SCADA needs to be newly built, so it takes additional time and money.



(Figure 1) The existing type of SCADA for wind farms



(Figure 2) Structure of Modular Control System

SCADA of wind farms is generally provided by wind turbine manufacturers, and it is difficult to manufacture SCADA in accordance with the configuration of each wind farms. Due to these difficulties, there is a need for a method for operating wind farms without modifying SCADA.

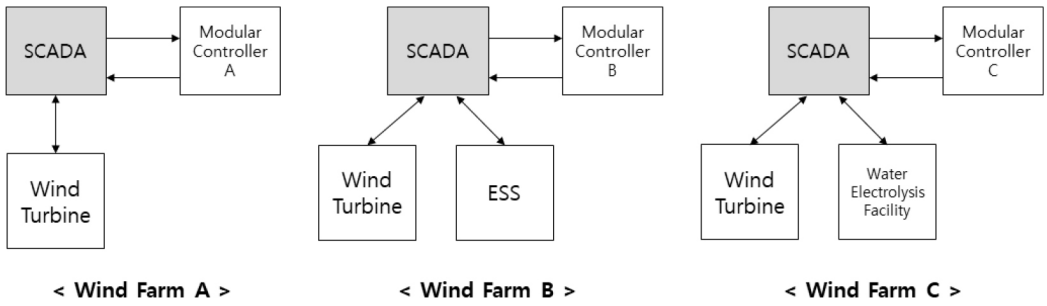
3. Modular Control System

3.1 Structure of Modular Control System

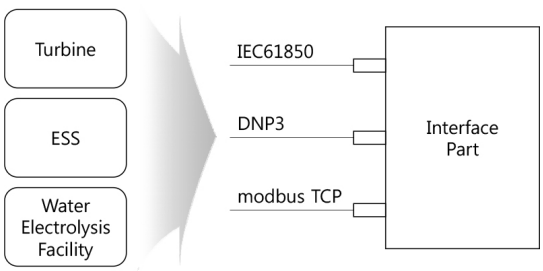
3.1.1 Overall Structure

The modular control system consists of an interface part, a calculate part and a data processing part as shown in Figure 2. This system is connected to SCADA and allocates the reference of the wind turbine by reflecting the conditions of other facilities.

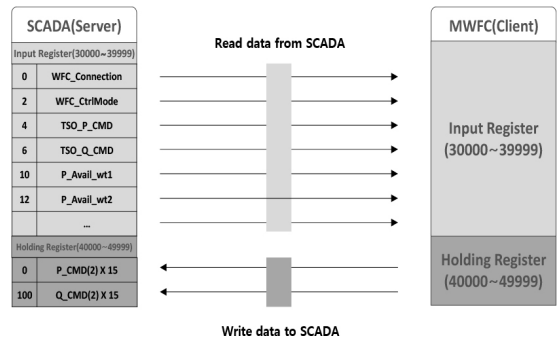
As shown in Figure 3, the control system configured in this form enables the operation of the wind farm using the modular control system without modifying SCADA.



(Figure 3) Propsed type of SCADA for wind farms



(Figure 4) Interface Part



(Figure 5) Modbus Map for Connection of System

3.1.2 Interface Part

The interface part transmits data between an existing SCADA and a modular control system in the wind farm. Since the modular control system exists outside the existing SCADA, data transmission through the interface is very important.

The interface between SCADA and modular controllers supports IEC61850, DNP3, and Modbus TCP protocols commonly used in the field as shown in Figure 4 to have a general purpose[7]. Since most SCADA uses one of these protocols, it makes modular control systems universally applicable. There is another advantage in using these protocols. If SCADA does not provide status data of heterogeneous facilities (ESS, Water Electrolysis Facility, etc.) operating together in the wind farm, it can be collected through the interface part.

In this study, SCADA and a modular control system were connected using Modbus TCP for experiments. It was implemented to exchange data between SCADA and the modular control system using Modbus TCP's Input Register and Holding Register. Figure 5 shows the Modbus Map for data transmission of SCADA and the proposed system.

3.1.3 Closed-Loop based Calculation Part

The calculation part allocates the power generation of individual wind turbines according to the configuration and operation conditions of the relevant wind farm under the curtailment situation. There is an increasing number of cases in which various facilities are operated together in wind farms. Therefore, it should be possible to allocate power generation by reflecting the state information of each facility. The control system configured in this way monitors the state of other connected facilities and the state of power supply and demand to allocate the power generation of individual wind turbines.

In the curtailment, the state of other facilities and the state of supply and demand are monitored to determine the amount of power to be generated in the actual wind farm. The power generation of individual turbines is allocated to follow the

power generation. There are various algorithms for allocating power generation. In this experiment, a closed-loop based control system was configured using a Proportional Distribution(PD) Algorithm. PD control allocates the power generation of individual turbines using the ratio of available power generation.

3.1.4 Data Processing Part

The data processing part stores and manages data transmitted through the interface part and data calculated through the calculation part. The collection cycle for data collection is the same as the data collection cycle collected by SCADA, enabling synchronized data management.

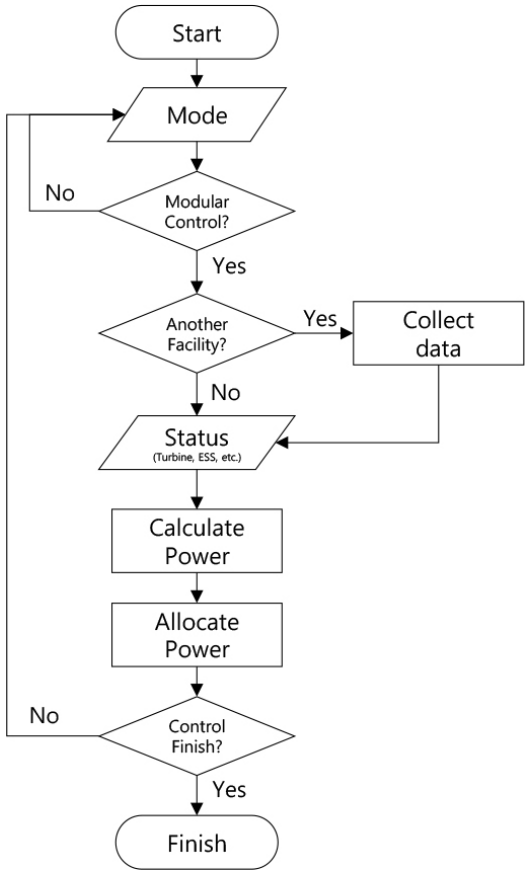
Various databases can be used for data collection, but in this study, it was implemented using Maria DB, a typical RDBMS. Since relational databases are used, it is advantageous to immediately evaluate the effectiveness of control.

3.2 Method of Operating Modular Control System

The procedure shown in Figure 6 is performed to control the power generation amount in the wind power generation complex using a modular controller. When the modular control system starts, the control mode is first checked. If the control mode is changed to a modular control system, data is collected through the interface part. The collected data includes a reference on wind farm and status information on turbines and other facilities. Through the collected data, commands for generating active and reactive power for each turbine are calculated. The calculated power generation references for each turbine are transferred to SCADA. The delivered references are applied to individual turbines to control the turbines. The wind farm is controlled by repeatedly performing.

3.2.1 Control Mode Selection

In order to allocate power generation references for individual turbines through a modular controller in the wind farm, the control mode is changed from SCADA to module



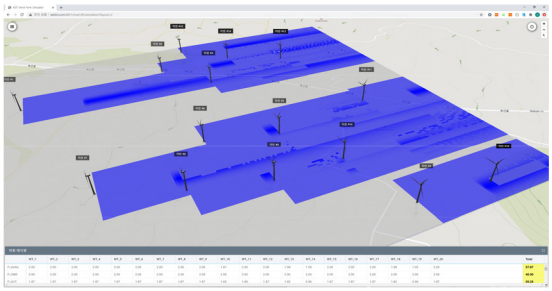
(Figure 6) Flow of Modular Control System

control. By changing the control mode, power generation allocation is performed through the calculation of the calculation part rather than general power generation through SCADA.

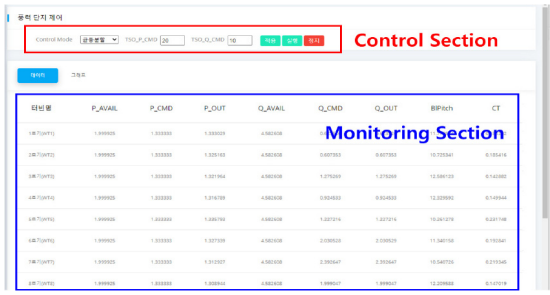
The control mode may be selected by the wind farm operator. Since the mode can be selected, the mode can be changed and applied immediately when the existing SCADA function is required.

3.2.2 Assignment of power generation commands for individual turbines

When the control mode is changed, data is transferred to the modular controller through the protocol provided by SCADA. The transmitted data has power generation commands that need to be currently generated in the wind farm, and various information on facilities.



(Figure 7) Wind Farm Simulator



(Figure 8) HMI of Modular Wind Farm Controller

The power generation command received from SCADA is calculated as the power generation command of individual turbines using the corresponding algorithm. The sum of the power generation commands of individual turbines follows the wind power generation command value. The assigned individual turbine power generation instructions are delivered to SCADA in the same way as when received.

3.2.3 Apply the calculated power generation command to individual turbines

SCADA applies the dielectric and reactive power generation instructions of individual turbines calculated using a modular controller to individual turbines. Therefore, the operation of the wind power generation complex is carried out through the calculation of the modular controller.

4. Verification

For the experiment, the self-developed Wind Farm Simulator(WFS) and MWFC(Modular Wind Farm Controller) were linked. The connection between the verified MWFC and the dummy SCADA of the actual wind farm is tested.

4.1 Wind Farm Simulator

WFS is a model-based simulator that accurately simulates the target wind power generation complex. As it is composed of a wind turbine model and a wind model including a rear stream, it is possible to accurately simulate a wind power plant by securing each model[8]. As shown in Figure 7, changes in the rear flow area of the turbine and the rear flow according to the wind speed are visualized and simulated. Each model can be secured to configure and simulate various wind power plants, so the wind power plant desired by the user can be configured.

Turbine modeling creates a MATLAB model through the project file of the commercial program GH Bladed, and C-codes the created MATLAB model to create and utilize an execution model available in real-time simulators. In the case of the turbine model made in this way, 99% accuracy was secured. The posterior modeling was applied by making the Ainslie eddy vision posterior model implemented with MATLAB as a C code execution model.

In this paper, a simulator was constructed by modeling wind turbines and wind at Dongbok and Bukchon wind power generation complexes in Jeju. Dongbok-Bukchon Wind Power Complexes are power generation complexes consisting of 15 2MW turbines of Hanjin Industrial Co., Ltd., and are connected to the Jeju electricity system through the Bukchon substation.

4.2 Modular Wind Farm Controller

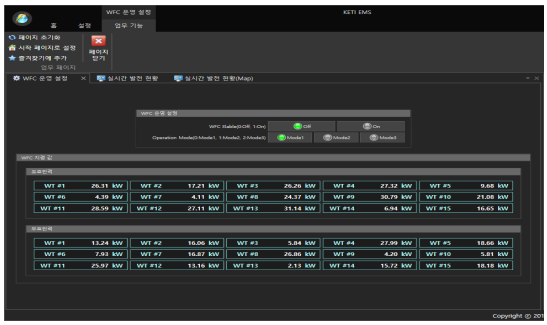
The MWFC is a control system for operating a wind power complex and can control the output of active and reactive power as desired within the range of available power generation[9]. MWFC can control the power generation by allocating the effective power generation and reactive power generation to the wind power complex using the MWFC UI as shown in Figure 8, and can continuously monitor the power generation by receiving the results through control again.

In the case of MWFC, various power generation allocation policies are provided to control the effective power generation

of the power generation complex. Since power generation allocation of turbines is artificially controlling power generation, most of them are used when output restrictions occur. Provided are a method of allocating 1/n of the total amount to each turbine according to the amount of output limit, an allocation method in which PID control is performed in the form of a proportional distribution, and a closed loop.

4.3 SCADA Connection Experiment

Through interworking with WFS and MWFC, it was confirmed that the Modular Control System was operating normally. It was confirmed whether the MWFC verified through simulation was normally connected to the actual wind power plant. This connection was carried out at the wind power plant SCADA, which was configured not to perform actual control. Figure 9 shows that the amount of power generated by using MWFC in SCADA is normally confirmed. Future research will confirm that the amount of power generated through MWFC is operating normally in the actual wind power complex.



(Figure 9) Connection Test between SCADA and Modular Control System

5. Conclusion

In this study, a modular wind farm control system was developed. This control system collects data from various facilities constituting the wind farm and enables control without modifying SCADA to allocate the amount of active and reactive power generation of the wind turbines.

Lab test was conducted because it was difficult to actually apply it to wind farm due to cost and technical problems. It was confirmed that the allocation of power generation of wind turbines was smoothly performed through the modular control system.

Through future study, this modular control system will be applied to actual wind farm to evaluate their effectiveness. In order to test at the actual wind farm, it will be conducted on the wind farm in Dongbok·bukchon in Jeju island, South Korea. Based on successful actual experiments, it will be expanded to a system that can allocate power generation of wind turbines by applying the configurations of various facilities.

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