Development of Condition Monitoring System with Control Functions for Wind Turbines

Joon-Young Park, Beom-Joo Kim, and Jae-Kyung Lee

Abstract—As an effort to promote wind power industry in Korea, Korea South-East Power Corporation has been developing 22MW YeungHeung wind farm consisting of nine 2 to 3MW wind turbines supplied by three manufacturers. To maximize its availability and reliability and to solve the difficulty of operating three kinds of SCADA systems, Korea Electric Power Corporation has been developing a condition monitoring system integrated with control functions. This paper presents the developed condition monitoring system and its application to YeungHeung wind test bed, and the design of its control functions.

Keywords—condition monitoring, control function, reliability, wind turbine

I. INTRODUCTION

THE scale of a wind turbine has continuously increased over the last two decades due to technological advancement, which accordingly leads to the improvement of its economic efficiency and to the rapid growth of the wind energy market. As seen in Fig. 1, such a trend toward larger capacity has inevitably brought about the increase of the tower height and the blade length. Notably, Repower's latest 6.15 MW wind turbine has a rotor of 126 meter in diameter, and Clipper Windpower Plc is developing a 7.5MW wind turbine now.
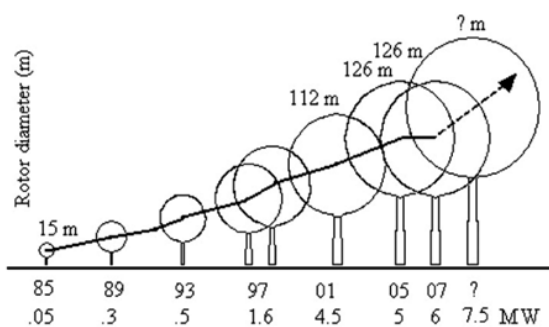

Fig. 1 Wind turbine size evolution[1]

However, a larger-scale turbine requires that more loads should be withstood by mechanical and electrical components in a wind turbine. This means the increasing possibility of system failure. Fig. 2 shows annual failure rate by rated power

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according to operational year. We can confirm that as the rated power of a wind turbine goes up, its failure rate becomes higher. For this reason, condition monitoring technology is essential for MW-class wind turbines to maximize their availability and reliability by early fault detection and prevention.
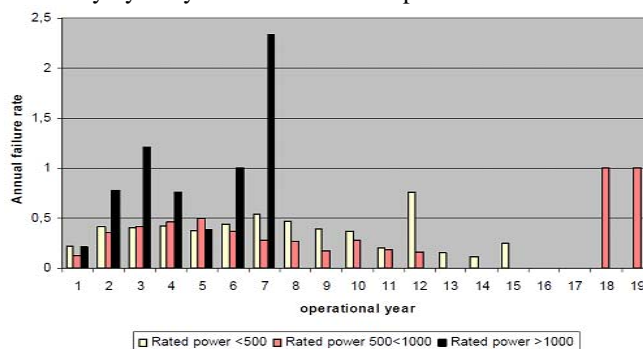

Fig. 2 Annual failure rate according to operational year[2]

The condition monitoring technology is mainly divided into three categories: vibration-based monitoring, oil debris-based monitoring and blade monitoring[3, 4]. The vibration-based monitoring estimates the current status or performance of wind turbine components by analyzing their measured vibrations. According to the frequency ranges of the vibrations, appropriate vibration sensors are chosen. Typically, position transducers, velocity sensors or accelerometers are used as vibration sensors.The oil debris-based monitoring observes whether a gear box or a bearing experiences excessive wear or not through oil sampling or its continuous measurement. Blade monitoring, especially fiber optic sensing has been generating much interest recently and has been actively studied, because the influence and cost of the blades on a wind turbine are growing according to the growth of wind turbine size as shown in Fig. 3.
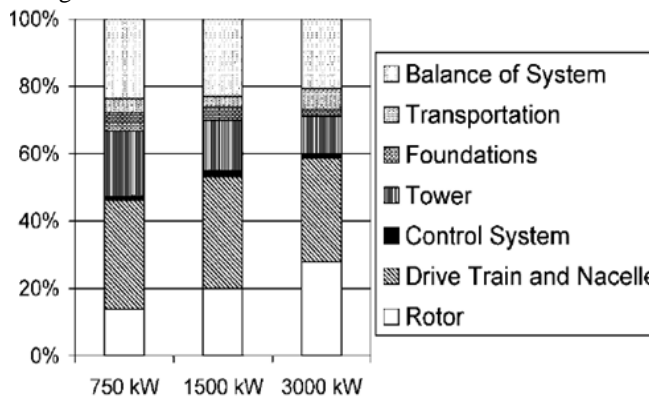

Fig. 3 Cost of wind turbine components[5]

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As mentioned before, with the rapid development of wind power technology, the global wind energy market has grown at about 20~30% annually since 2000. In Korea, as an effort to promote wind power industry, Korea South-East Power Corporation(KOSEP) has been developing YeungHeung wind farm in order to improve the reliability of domestic wind turbines and to secure operation and maintenance technology. YeungHeung wind farm is planned to be 22MW in total, consisting of nine 2 to 3MW wind turbines that will be supplied by three manufacturers. As the first stage, YeungHeung wind test bed comprising three 2 to 3MW wind turbines is being operated now as shown in Fig. 4. As a measure to maximize the availability and reliability of the wind farm, a Condition Monitoring System(CMS) was developed and has been successfully applied to the wind test bed by Korea Electric Power Corporation(KEPCO).

Fig. 4 YeungHeung wind test bed for domestic wind turbines.

However, due to different kinds of Supervisory Control and Data Acquisition(SCADA) systems supplied by the three turbine manufacturers, the operators of KOSEP had difficulty in monitoring and controlling the wind test bed. To solve this problem, KOSEP required KEPCO to integrate control functions into the developed CMS, and we are developing a novel CMS integrated with control functions now.

This paper presents the developed condition monitoring system and its successful application to YeungHeung wind test bed, and finally the design of its control functions.

II. OVERALL STRUCTURE

As mentioned before, three wind turbine manufacturers contracted to supply wind turbines, their controllers and SCADA systems, and KEPCO to develop a condition monitoring system for the wind farm. Fig. 5 shows the original overall structure of YeungHeung wind test bed on the contract basis.
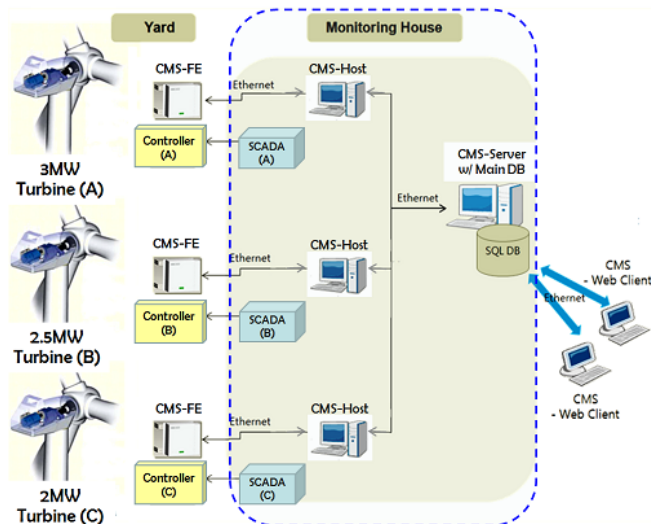

Fig. 5. Original overall structure for YeungHeung wind test bed.

That is to say, a SCADA system was provided for each wind turbine, and a CMS was given for monitoring all the turbines. There was no connection between these two systems. Here, the CMS comprises a CMS-Server, CMS-Hosts, CMS-FE(Front End)s and CMS-Clients, as will be described in later section.

However, after the commissioning of the wind test bed, the operators of KOSEP found the following problems in its operation: The operators are required to learn how to operate three different SCADA systems, which make it a difficult task for the operators to monitor and control different wind turbines. Especially, in the event of alarm activation, an emergency situation may not be recognized due to different user interface screens.

To solve this operational difficulty, KEPCO is now developing a novel condition monitoring system that is directly connected with SCADA systems and provides the operating condition and alarm reporting for different wind turbines as well as condition monitoring. Fig. 7 shows the final overall structure of YeungHeung wind test bed on the basis of the new concept.
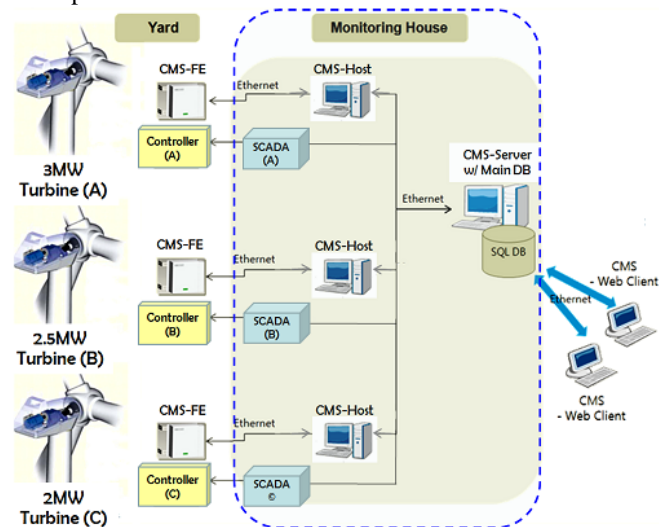

Fig. 6 Final overall structure for YeungHeung wind test bed

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III. CMS HARDWARE

As seen in Fig. 6, the developed CMS consists of a CMS-FE and a CMS-Host for each wind turbine, a CMS-Server with a main database, CMS-Clients for remote control and monitoring.

A. CMS-FE

The CMS-FE is installed at the inside of a nacelle, and consists of a main controller, a switching mode power supply, a data acquisition device as shown in Fig. 7. The main controller is connected with the data acquisition device through the USB interface, and plays a dedicated role in controlling the data acquisition device. The switching mode power supply provides the CMS-FE with DC voltage, and protects its output from overvoltage and over current. The data acquisition device is directly connected with sensors, and measures vibrations, temperature and various analog signals acquired from the sensors. The CMS-FE also performs signal processing on the measured data to reduce the amount of communication. The technical specification of the CMS-FE is listed in Table I.
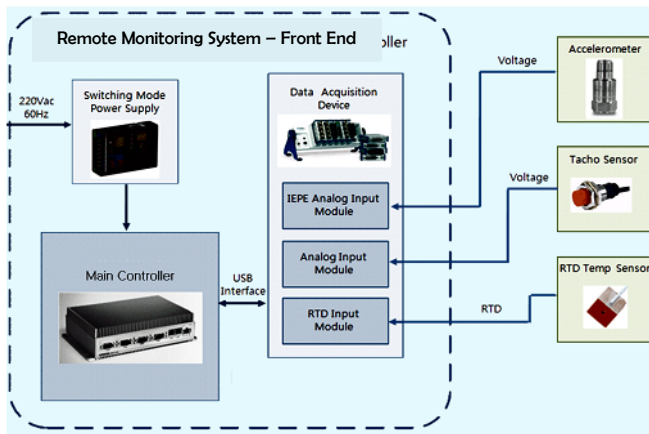

Fig. 7 Structure of CMS-FE

TABLE I
TECHNICAL SPECIFICATIONS OF CMS-FE

Monitoring Channels	• Accelerometers 12 CH • AI 8 CH, DIO 4 CH, RS-232 • TCP/IP
Shock & Vibration	• 30G Shock, 5g Sinusoidal and Random
Environmental	• Operation: -20 ~ 55 deg, 10 ~ 90% R.H. • CE Compliance
Individual Threatening Protection	• Electric & Communication Line Protection
Embedded H/W & S/W	• National Instruments CRIO & cDAQ • VXWorks OS
Watchdog H/W	• Remote Power Management by Watchdog H/W

B. CMS-HOST

A CMS-Host is installed for each turbine at a monitoring room within YeungHeung wind farm. The CMS-Host receives the real-time measured signals and their processed data from the CMS-FE and puts the data into a database. In addition, it sends the received data to the CMS-Server.

C. CMS-SERVER

The CMS-Server, also installed at the monitoring room, integrates all the sensor data from CMS-Hosts and all the turbine info including alarm messages from the SCADA systems into an integrated database. In order to protect the CMS-Server in the event of a power failure, an Uninterruptible Power Supply(UPS) was installed with it.

D. CMS-CLIENT

The CMS-Client enables an operator at a remote place to monitor the wind farm through the network connection to the CMS-Server. The CMS-Client software provides the trend review function that performs trend analysis by using various signal analysis techniques as follows:
- General power spectrum
- Envelope process
- Order analysis
- Time domain analysis
- Two-dimensional analysis

Because of its computational burden, the CMS-Server does not provide this function.

E. Sensors and Camera

The CMS was developed on the basis of vibration monitoring. The sensors including a camera and their installation positions are shown in Fig. 8.
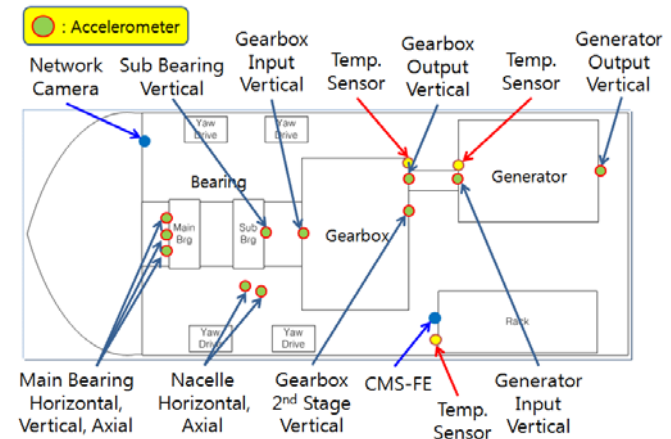

Fig. 8 Installation example of sensors and camera.

TABLE II
NECESSARY VIBRATION-MEASURING POINTS FOR WIND TURBINES[6]

Component of the wind turbine	Necessary number of sensors per component	Direction of measure-ment	Frequency range
Rotor bearing	1	radial	0.1 Hz… ≥ 10 kHz
Gearbox	3	radial	0.1 Hz… ≥ 10 kHz
Generator bearing	2	radial	10 Hz… ≥ 10 kHz
Tower with na-celle	2	a) axial [in wind direction] b) transversal [transversely to a)]	0.1 Hz… ≥ 100 Hz

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Accelerometers were chosen as vibration sensors. Their specifications and installation positions were determined in accordance with GL guideline[6], which is a guideline for the certification of a condition monitoring system for wind turbines. Table II shows the minimum requirements for the measuring points for the vibration monitoring of wind turbines with an indication of the accelerometers to be used[6].

As another important factor to be monitored, temperature can be considered. According to the International Association of Engineering Insurers(IMIA), overheated bearings are one of main reasons causing damage by fire in wind turbines[7]. Therefore, temperature monitoring of bearings should be performed. Especially, high-speed shaft bearings and generator bearings should be monitored carefully[8]. For this purpose, we installed temperature sensors on a high-speed shaft bearing and a generator input bearing as well as inside nacelle.

Besides, a tachometer was applied to the main shaft of a rotor to measure its rotational speed, and a network camera was mounted at the corner of nacelle to observe whether the wind turbine works well or not.

IV. CMS SOFTWARE

A. CMS-FE & CMS-HOST

The CMS-FE software initializes its sensors installed on the wind turbine components within nacelle, acquires their signals by generating triggers according to the respective methods for receiving the signals from the sensors, and performs signal processing on the measured data. In addition, it makes basic analyses on the collected signals through monitoring algorithms, thereby providing an alarm generation function by setting alarm limits. Moreover, it sends the data with their analysis results to its corresponding CMS-Host.

The CMS-Host software executes sensor calibration at the system startup. It receives the measured signals and their processed data from CMS-FEs, puts the data into a database, and sends them to the CMS-Server.

B. CMS-SERVER

The CMS-Server software is used for the operation and maintenance of a wind farm by integrating all the data from CMS-Hosts and SCADA systems, and provides the man-machine interface for wind farm operators. Fig. 9 shows its man-machine interface, which consists of wind farm info, wind turbine info, power info, alarm info, trend info and map info screens.

The wind farm info presents the overall operational status of a wind farm as shown in Fig. 9a, while the wind turbine info the operational status and sensor values of each wind turbine in Fig. 9b. In the event of alarm generation, the software turns on the red light located at the corresponding turbine number in the Alarm Information window of the wind farm info screen, and automatically sends generated alarm information to operators through SMS or E-mails.

The power info shows accumulated power production, current output power and wind information. Furthermore, as

(a) Wind farm info   (b) Wind turbine info

(c) Power info   (d) Alarm info
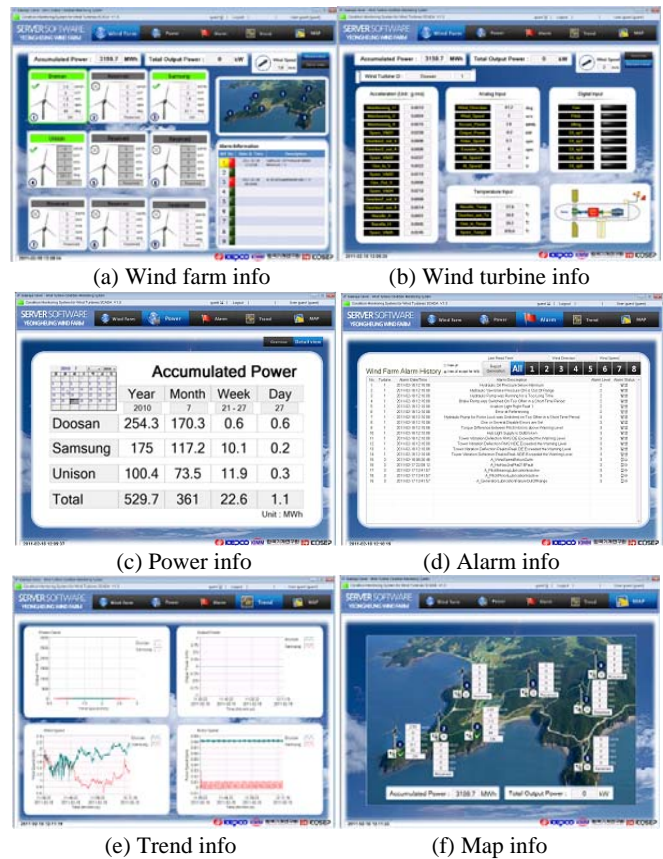
(e) Trend info   (f) Map info
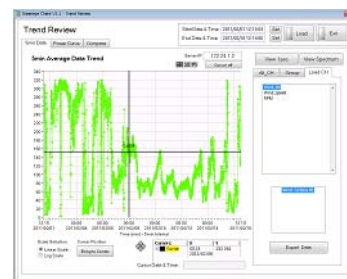
Fig. 9. CMS-Server software.

Fig. 10 Trend review function screen of CMS-Client software

seen in Fig. 9c, it gives yearly, monthly, weekly and daily power production for each turbine up to the date appointed through a calendar.The alarm info provides current alarm information and generated alarm history, and alarm reporting functions. The trend info shows a power curve, output power, wind speed and rotor speed graphs. The map info shows geographical information on YeungHeung wind farm in combination with the operational status of its constituent wind turbines.

C. CMS-CLIENT

The CMS-Client software is used to monitor a wind farm at a remote place from a monitoring room, and offers the same functions as those of the CMS-Server. In addition to that, it provides the trend review function that performs trend analysis by using various signal analysis techniques through the connection to the CMS-Server's database.

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V. FIELD TESTS

The developed CMS was installed at YeungHeung wind test bed on May, 2010, and has been successfully applied since its commissioning for two months. Fig. 11 shows the implemented overall system for YeungHeung wind test bed. As seen in this figure, the system largely consists of CMS-FEs installed at the inside of each nacelle, CMS-Hosts installed for each turbine at a monitoring room within YeungHeung wind farm, a CMS-Server also installed at the monitoring room to integrate all the data from the CMS-Hosts and SCADA systems, and CMS-Clients installed at the far-off offices of KOSEP.
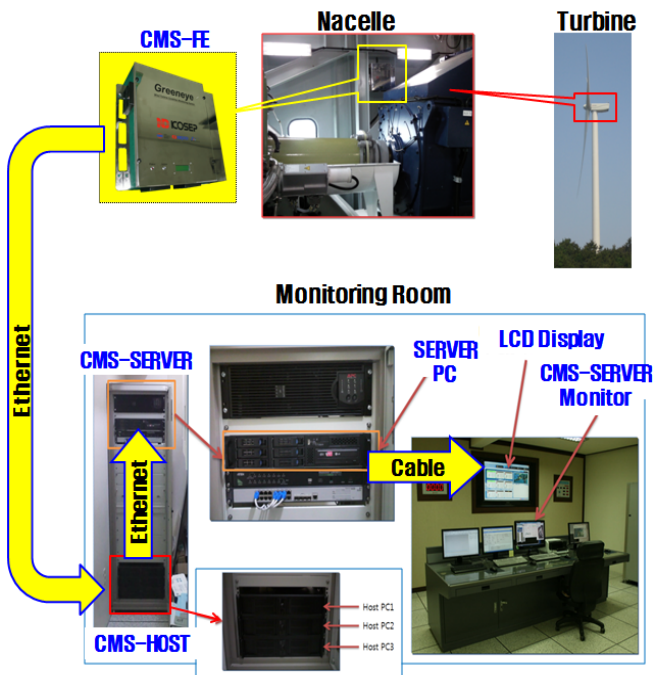

Fig. 11.Developed condition monitoring system

Fig. 12 shows the screenshots of trend review functions in the CMS-Client software, which resulted from the stored data in the CMS-Server's database. The real-time images of a network camera installed at each turbine are accessible by Internet Explorer as Fig. 13, and are stored at a Network Video Recorder (NVR) to review the past images that an operator wants to see. The advantage of such a camera system is that you can observe the inside of nacelle by the naked eye without visiting.
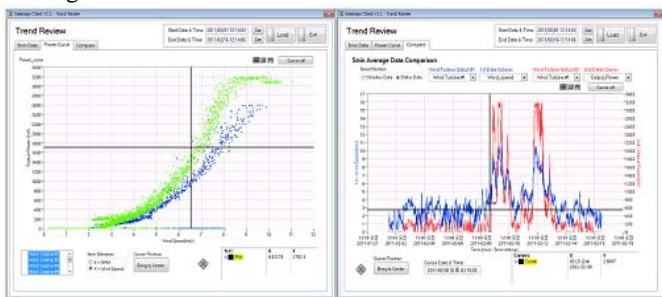

Fig. 12.Application of Trend Review functions in CMS-Client software to YeungHeung Wind Test Bed

Fig. 13 Network camera images
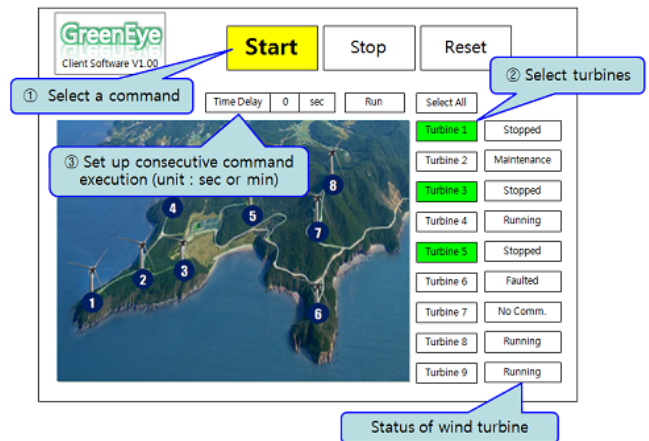
VI. DESIGN OF CONTROL FUNCTIONS

In order to solve the operational difficulty stemming from different SCADA systems, we are developing a novel CMS integrated with control functions now. In this paper, the conceptional design of control functions is introduced.

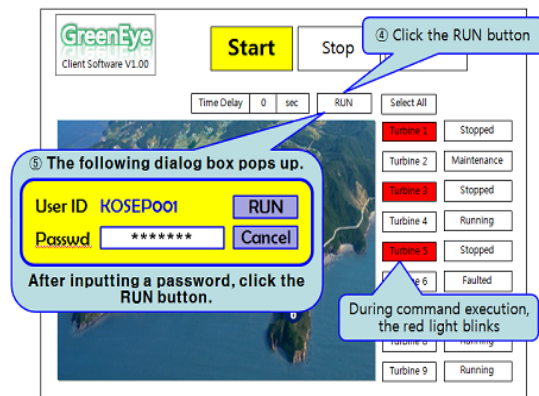In general, a SCADA system has two kinds of control functions as follows:

- Auto mode: Start, Stop, Reset
- Manual mode: yaw control, pitch control

Among these, the integrated CMS is determined to offer only the auto mode control for the sake of system safety.
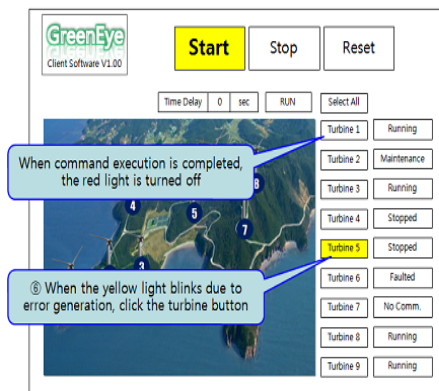
Fig. 14 shows the prescribed procedures for executing a control command in the CMS-Client software. In Fig. 14a,
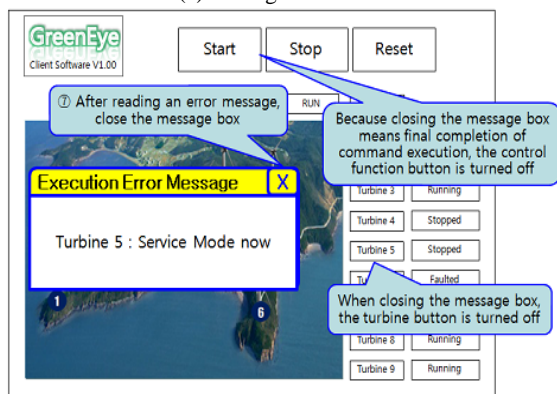

(a) Selection

(b) Execution

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(c) Error generation

(d) Error message box
Fig. 14 Prescribed procedures for executing a control command.

the consecutive command execution function makes the CMS-Server consecutively send a command to the relevant SCADA systems with a given time delay. The purpose of this function is to prevent all the turbines starting or stopping at the same time that may cause power quality problems on the power grid.

The CMS-Server checks the current status of each turbine related to command execution so as to enable CMS-Clients to send a command to only the turbines that are ready for command execution. In case the CMS-Server simultaneously receives different commands on the same turbine from multiple CMS-Clients, the CMS-Server gives a command decided from the following order of priority for system safety's sake.

- Stop >> Reset >> Start

The unselected CMS-Clients turn on the relevant turbine button with yellow, and explain why they cannot execute the given commands through an error message box.

VII. Conclusion

This paper presented a novel CMS for the 22MW YeungHeung wind farm to maximize its availability and reliability. The developed CMS has been successfully applied to YeungHeung wind test bed comprising three wind turbines. Its field test results showed that this system was quite suitable for monitoring wind turbines and giving early warning signals before their failures. We are now integrating control functions

into the developed CMS to solve operational difficulty due to different kinds of SCADA systems supplied by different turbine manufacturers. In this paper, the conceptional design of its control functions was given. The developed CMS with control functions is expected to contribute greatly to the operation and maintenance of offshore wind farms to be constructed in the near future in Korea as well as YeungHeung wind farm.

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