# Design of Simulator for 3MW Wind Turbine and Its Condition Monitoring System

Joon-Young Park, Jae-Kyung Lee, Ki-Yong Oh, Jun-Shin Lee and Beom-Joo Kim

***Abstract*—The condition monitoring system is essential for a large-scale wind turbine system to maximize its availability and reliability. In order to develop its effective condition monitoring algorithms, a wind turbine simulator is necessary for such a large-scale system. However, the existing simulators consisting of a motor and a generator are not suitable for this purpose, because they have not the general configuration of wind turbine systems. To solve this problem, we are now developing a novel wind turbine simulator that is composed of blades, a step-up gearbox and a generator. This paper presents a developed condition monitoring system and the design procedure of the wind turbine simulator.**

***Index Terms*—3MW, CMS, Simulator, Wind Turbine.**

## I. INTRODUCTION

According to the needs of the wind energy market for economic efficiency, the scale of wind turbines has increased over the last 2 decades. Especially, the growth in size from a 33.4m rotor diameter to over 126m has brought about the increase of the tower height and the load on the rotor blade. From the viewpoint of structural integrity, this means the increasing possibility of system failure. For this reason, the operation and maintenance technology for large-scale wind turbines is getting more importance. As a measure to maximize their availability and reliability, Korea Electric Power Corporation(KEPCO) is now developing a condition monitoring system(CMS) that will be applied to a near-shore wind turbine complex in Yeongheung-myeon in Korea.

In order to develop its effective algorithms for early fault detection and prevention, a wind turbine simulator is necessary for such a large-scale system. Traditionally, a Motor-Generator(M-G) set has been used as a wind turbine simulator. For example, an induction motor-induction generator set[1], a direct current motor(DCM)-doubly fed induction generator(DFIG) set[2], [3], a permanent magnet synchronous motor(PMSM)-DFIG set[4], a DCM-permanent magnet synchronous generator(PMSG) set[5]. POSTECH also developed a 20 kW small-scale simulator to study the control dynamics of the inverter for the 2 MW wind turbine[6]. Its rotor blades torque of the winds was simulated by a torque of a DCM, and a flywheel attached to the DCM implemented the rotational inertia of turbine blades as shown in Fig. 1. However, all the simulators described before are not suitable for developing the condition monitoring algorithms. This is because these systems have not the general configuration of a wind turbine system that consists of turbine blades, a step-up gearbox and a generator.


**Fig. 1 Simulator for 2MW wind turbine system**

As a solution to such a problem, we are now developing a novel wind turbine simulator that is specially designed for the purpose of developing the effective condition monitoring algorithms for early fault detection and prevention. The simulator was designed to have the characteristics equivalent to a 3MW wind turbine system. The overall structure of the wind turbine simulator with the developed CMS is shown in Fig. 2. This paper first presents a developed condition monitoring system, and then, the design procedure of the wind turbine simulator. Finally, the conclusions and the further work are presented.

Manuscript received December 4, 2009. This paper presents the results of “Technical Development for Design and Reliability of Near-shore Wind Turbine Complex” project supported by Renewable Energy Technology Development Projects performed by the Ministry of Knowledge Economy in Korea.

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ISBN: 978-988-18210-4-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

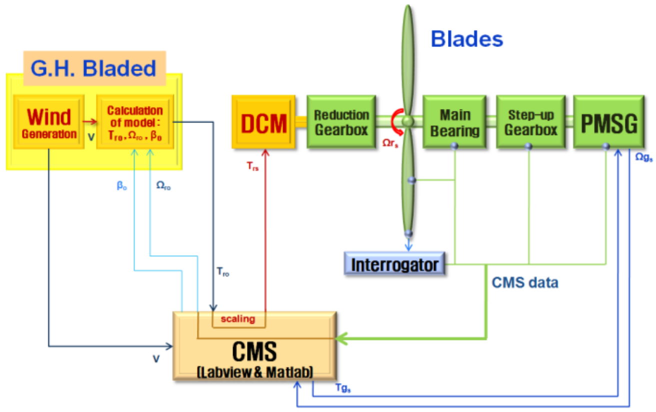



**Fig. 2 Overall structure of wind turbine simulator with CMS**

## II. Condition Monitoring System

### *A. Hardware*

The CMS for a wind turbine is specially developed to monitor its main components such as a main bearing, a gearbox and a generator, and its conditions such as wind speed, wind direction, generated power, the angular velocity of blades, and so on. Fig. 3 shows the developed CMS, and Table 1 gives its technical specifications. And its overall structure and connection with sensors are shown in Fig. 4.

**Fig. 3 Developed condition monitoring system**

**Table 1. Technical specifications of CMS**

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

The CMS consists of a main controller, a switching mode power supply, a data acquisition device. The main controller installed in the CMS of Fig. 3 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 with DC voltage, and protects its output from overvoltage and overcurrent. The data acquisition device is directly connected with sensors, and measures vibrations, temperature and various analog signals acquired from the sensors. Fig. 5 shows the sensors and their positions installed on the simulator.

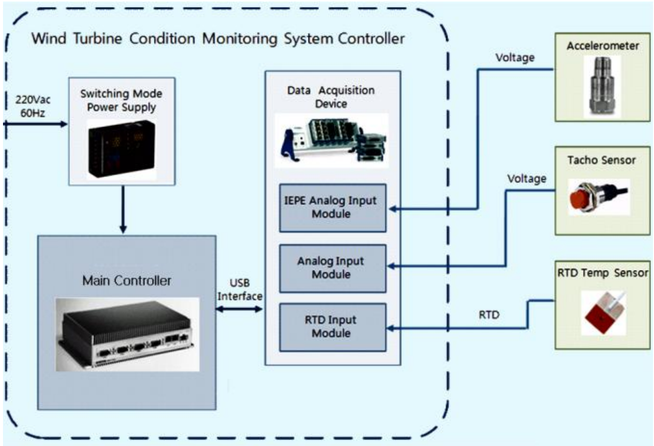



**Fig. 4 Overall structure of condition monitoring system**

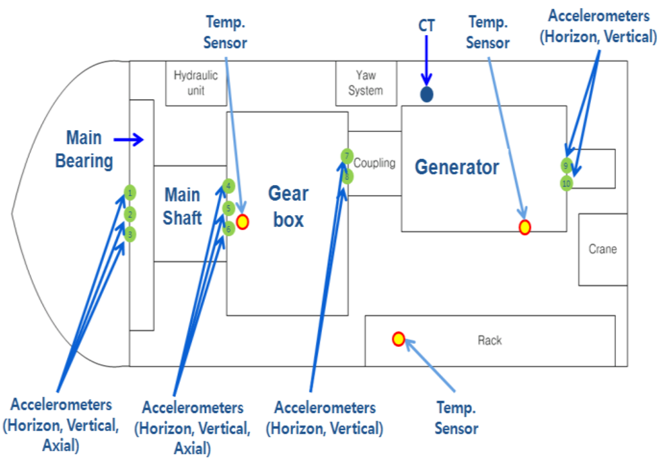



**Fig. 5 Sensors and their installation positions**

### *B. Software*

The overall software consists of the onsite monitoring system software for the CMS and the host system software for the CMS-Server PC. Fig. 6 shows the man-machine interface of the CMS-Server software. The CMS software is installed

**Fig. 6 Man-machine interface for CMS-Server software**


ISBN: 978-988-18210-4-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

on the main controller of Fig. 4. Directly connected with the sensors that measure the condition data of a wind power system, this software collects, stores, and sends the data. The CMS-Server software receives the data from the main controller, saves the data, and performs signal processing. The detailed structure of the overall software is presented in Fig. 7.

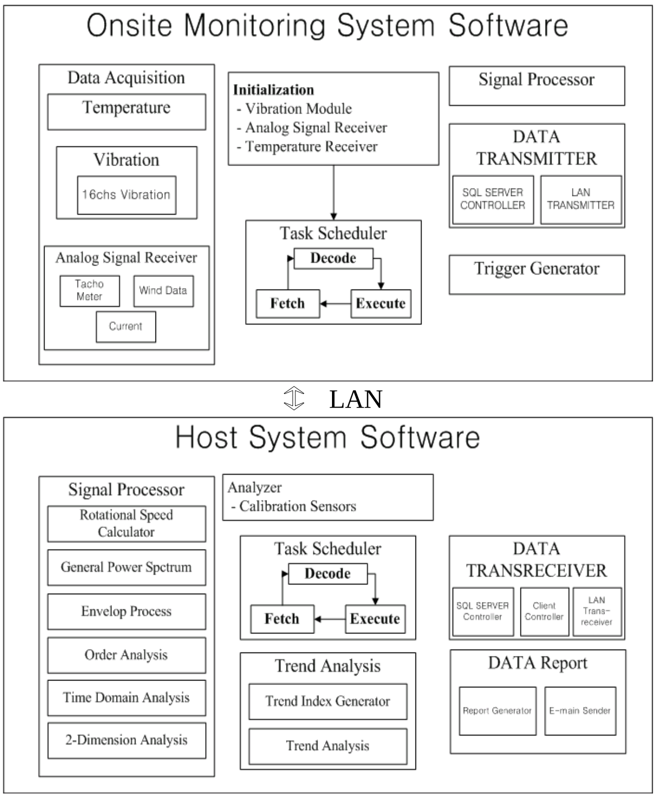



**Fig. 7 Overall structure of software**

## III. WIND TURBINE SIMULATOR

In this section, the wind turbine simulator is designed to have the characteristics equivalent to a 3MW wind turbine system whose specifications are given in Table 2.

**Table 2. Technical specifications of 3MW wind turbine system**

| | |
|---|---|
| **Power** | |
| Rated power, $P_a$ | 3,000 kW |
| Rated wind speed, $\upsilon_a$ | 13.0 m/s |
| Cut-in wind speed | 4.0 m/s |
| Cut-out wind speed | 25.0 m/s |
| **Rotor** | |
| Diameter, 2* $R_a$ | 91.3 m |
| Rated speed, $\omega_a$ | 15.7 rpm |
| Rotor moment of inertia, $J_a$ | $12.6 \times 10^6$ kgm$^2$ |
| **Nacelle** | |
| Gearbox / Type | 2 Planetary + 1 Parallel |
| - Ratio | 1:92.916 |
| Generator / Type | PM Synchronous Generator |
| - Poles, $p_a$ | 4 |
| - Speed, $\omega_{Ga}$ | 1,460 rpm |
| - Voltage | 690 V |
| - Electric frequency for inverter Input | 60Hz |
| - Generator moment of inertia | 239 kgm$^2$ |

Fig. 8 demonstrates the design procedure of the wind turbine simulator step by step, and Fig. 8(a) shows the 3MW wind turbine system roughly. First, we follow the design procedure proposed by POSTECH, and then, transform its resultant M-G set into the development environment for condition monitoring algorithms.

POSTECH's design criteria of the simulator are as follows[6]:

- Equal generator electric frequency $f$ for an inverter input
- Equal inertia time constant $H$ for a system dynamics
- Equal power coefficient $C_p$ for a tip speed ratio $\lambda$
- Scale down factor $s$ for an output power for a simulator

From the criteria above, the relationships between the actual system and the scale-down simulator can be expressed as follows:

$$\omega_{Ga}\, p_a = \omega_{Gs}\, p_s \tag{1}$$
$$J_a\, \omega_a^2 / P_a = J_s\, \omega_s^2 / P_s \tag{2}$$
$$\omega_a\, R_a / \upsilon_a = \omega_s\, R_s / \upsilon_s \tag{3}$$
$$\omega_a^3 R_a^5 = s\, \omega_s^3 R_s^5 \tag{4}$$

where $\omega_{G(\bullet)}$, $p_{(\bullet)}$, $J_{(\bullet)}$, $\omega_{(\bullet)}$, $P_{(\bullet)}$, $R_{(\bullet)}$, $\upsilon_{(\bullet)}$ denote the rated rotational speed of the generator, the number of generator poles, the moment of inertia, the rated rotational speed of the blade, rated power, the radius of the blade, and rated wind speed, respectively. Here, the subscripts $a$, $s$ indicate the actual system and the scale-down simulator, respectively.

First of all, we set the scale down factor $s$ to 150, and next, set the simulator blade speed $\omega_s$. In the case of POSTECH's 2MW simulator, a comparatively high value of 1172.98 rpm was chosen as the blade speed, because the blade was directly connected to a generator without a gearbox[7]. If we take such a high value of 1800 rpm as an example, it leads to Fig. 8(b). Comparing Fig. 8(a) with Fig. 8(b), however, clearly shows why this result is unsuitable for developing condition monitoring algorithms. For the simulator to have a similar rotational characteristic as that of the 3MW wind turbine system, we set the blade speed $\omega_s$ to 20rpm. Then, $R_s$ can be obtained from (4) as follows:

$$R_s = \left( (15.7)^3 \times (91.3/2)^5 / 150 / (20)^3 \right)^{0.2} = 14.5\text{m}.$$

And (3) gives $\upsilon_s$ as follows:

$$\upsilon_s = 20 \times 14.5 \times 13 / 15.7 / (91.3/2) = 5.26 \text{ m/s}.$$

Finally, the moment of inertia $J_s$ for the simulator is obtained from (2), and is realized by a flywheel with $J_s$.

$$J_s = 12{,}600{,}000 \times (15.7)^2 / 3{,}000 / (20)^2 \times 20 = 51{,}763 \text{ kgm}^2$$

To make the simulator have the general configuration of the 3MW wind turbine system and to satisfy (1), the following step-up gearbox and generator are introduced as shown in Fig. 8(c).

- Step-up Gearbox : Gear ratio = 1 : 90
- PMSG : $P_s$ = 20kW, $\omega_s$ = 1,800rpm, $p_s$ = 4, $f$ = 60Hz

However, the calculated $J_s$ and $R_s$ are too big to make such turbine blades in a laboratory, and the blade speed $\omega_s$ is too low to be achieved by a DC motor. This problem can be solved by introducing the configuration of "a flywheel – a reduction gear". Before determining the detailed specifications of the flywheel and the gear, we adopted the


ISBN: 978-988-18210-4-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

following motor as a DC motor to drive the turbine blades, which is based on that a motor to simulate the dynamics of turbine blades should be roughly twice the power of a generator[8].

- DCM : $P_{DCM}$ = 37kW, $\omega_{DCM}$ = 1,750rpm

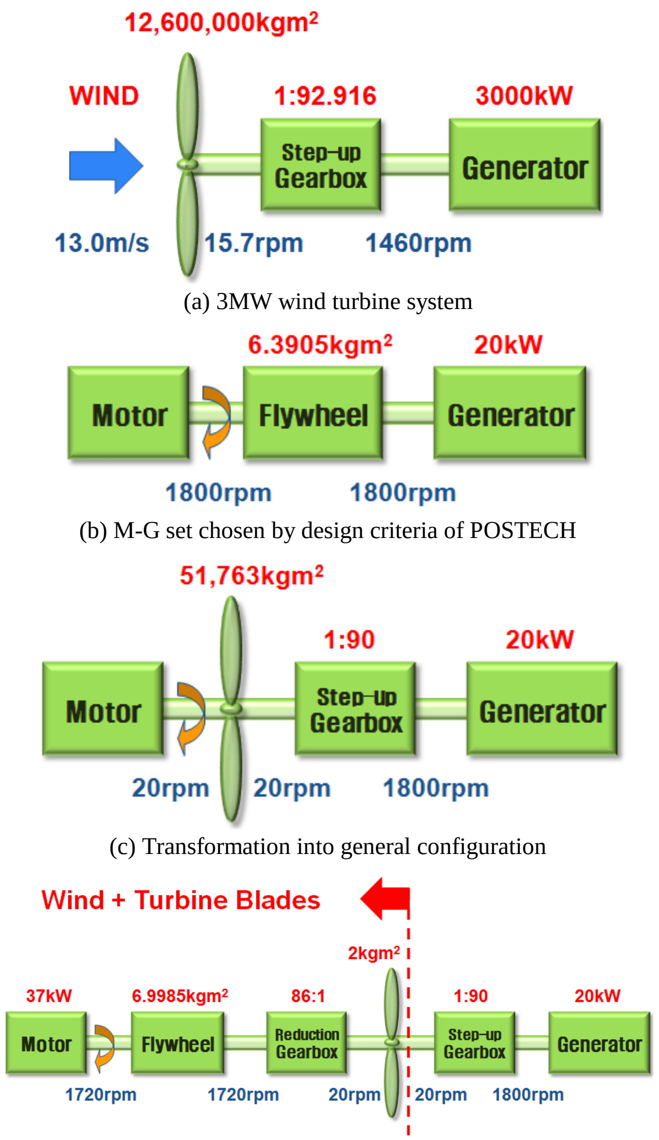
Therefore, the gear ratio of the reduction gear is chosen as follows:

$$n_{rg} = 1{,}750 / 20 \approx 86.$$

To enhance visual effects, we installed turbine blades with the radius of 1 m and the total moment of inertia $J_{blades}$ of 2kgm$^2$ next to the reduction gear. If we assume that stiffness and damping can be ignored to simplify the design problem, the moment of inertia of the flywheel can be obtained as

$$J_{flywheel} = (J_s - J_{blades}) / n_{rg}^{\,2} = (51{,}763 - 2) / 86^2 = 6.9985\text{kgm}^2.$$

And a cylinder flywheel is used for the flywheel. From the procedure above, the final configuration of the simulator is obtained as Fig. 8(d). The comparison of the scale-down simulator of Fig. 8(d) with the original system of Fig. 8(a) clearly shows the effectiveness of the designed wind turbine simulator for developing condition monitoring algorithms.




(a) 3MW wind turbine system

(b) M-G set chosen by design criteria of POSTECH

(c) Transformation into general configuration

(d) Final configuration of simulator

**Fig. 8 Proposed design procedure for wind turbine simulator**

## IV. Conclusions and Further Work

This paper presented the developed CMS and the new design procedure for the wind turbine simulator. Compared with the previous simulators generally consisting of an M-G set, the developed simulator is specially designed to be suitable for developing the effective condition monitoring algorithms and to have the characteristics equivalent to a 3MW wind turbine system. We are now manufacturing the designed wind turbine simulator, and are planning its application to the development of condition monitoring technologies. The developed wind turbine simulator with the CMS is expected to be very effective in the operation and maintenance field of large-scale wind turbine systems.

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ISBN: 978-988-18210-4-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)