International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:10, No:4, 2016

Dynamic Modeling of Wind Farms in the Jeju Power System

Dae-Hee Son, Sang-Hee Kang, Soon-Ryul Nam

***Abstract*—**In this paper, we develop a dynamic modeling of wind farms in the Jeju power system. The dynamic model of wind farms is developed to study their dynamic effects on the Jeju power system. PSS/E is used to develop the dynamic model of a wind farm composed of 1.5-MW doubly fed induction generators. The output of a wind farm is regulated based on pitch angle control, in which the two controllable parameters are speed and power references. The simulation results confirm that the pitch angle is successfully controlled, regardless of the variation in wind speed and output regulation.

***Keywords*—**Dynamic model, Jeju power system, pitch angle control, PSS/E, wind farm.

I. Introduction

WIND power generation is one of the most attractive renewable energy resources in many countries due to its technical and economic feasibility. Many countries consider wind power generation to be an enabler of energy security, as well as a pathway to reducing greenhouse gas emissions.

Jeju Island has the highest average wind speed of wind power-generating sites in South Korea [1], [2]. Although Jeju Island is expected to accommodate additional wind power generation capacity due to its environmental advantages [3], some experts think that the installed wind power generation capacity is already sufficient to threaten its stable operation. Recently, revisions to the Korean grid code have been considered: i.e., requiring that the output power of wind farms be regulated according to the dispatching instructions from the EMS. Therefore, prior to applying this requirement, appropriate dynamic models and control schemes for wind farms should be developed, and their effects should be investigated.

In this paper, we develop a dynamic model of wind farms in the Jeju power system. The remainder of this paper is organized as follows. A dynamic model of wind farms in the Jeju power system is developed in Section II. Conclusions are drawn in Section III.

II. Dynamic Model of Wind Farms

In this paper, PSS/E was used to develop a dynamic model of wind farms in the Jeju power system. PSS/E includes a wind turbine package, which provides libraries for various wind generator manufacturers, including Acciona, Enercon, Fuhrlaender, GE, Mitsubishi, Siemens, and Vestas. Because doubly fed induction generators (DFIGs) are typically installed in the Jeju power system, the wind farms in this paper comprised GE 1.5 MW DFIGs, which provided detailed data and documentation on the DFIGs [4], [5]. With PSS/E, the multiple wind turbines in a wind farm are modeled as a single representative wind turbine with a common pitch angle. Therefore, for the Jeju power system shown in Fig. 1, we used a single 97.5-MW to describe the 65 1.5-MW turbines in the wind farm, which was connected to the Hallim and Seongsan substations.

As shown in Fig. 2 (a), the wind speed was initially maintained at a constant 10.5 m/s, and then at 150 s the wind speed decreased to 6.5 m/s over a period of 5 s. This resulted in a decrease in the output power of the Hallim wind farm from 84.8 MW to 21.8 MW. We also considered an increase in the wind speed, whereby the wind speed was initially maintained constant at 10.5 m/s, and at 150s was increased to 14.5 m/s over a period of 5 s. This resulted in an increase in the output power of the Hallim wind farm from 84.8 MW to 97.5 MW. We also considered wind speeds from 10.5 m/s to 8.5 m/s, 9.5 m/s, 11.5 m/s, and 12.5 m/s. As expected, the output power of the Hallim wind farm decreased with decreasing wind speed, and increased with increasing wind speed.

The results revealed that the output power of the Hallim wind farm did not reach its rated power, despite sufficient wind speed. The rated wind speed of the GE 1.5 MW DFIG is 11.5 m/s; therefore, with a wind speed of 11.5 m/s, the output power of the Hallim wind farm should be equal to the rated power of 97.5 MW. However, as shown in Fig. 2 (b), the output power was only 92.8 MW with a wind speed of 11.5 m/s. The pitch angle was 3.63º, which should be decreased to generate more output power. This is because the PSS/E library provides a simplified pitch angle control model for the GE 1.5 MW DFIG. For this reason, the simplified model of pitch angle control should be modified to improve the accuracy of simulations with variable wind speed.

As shown in Fig. 3, the pitch angle control model for the GE 1.5 MW DFIGs has two controllable parameters: speed and power references [4]. Because PSS/E does not provide a control model for the speed and power references, user-defined models were developed, using the model-writing functionality of PSS/E.

A. Pitch Angle Control Based on Speed Reference

Rotor speed control of a DFIG wind turbine is somewhat complex [6]. For modeling purposes, this can be approximated by closed loop control, with a speed reference that is proportional to the output power, as shown in Fig. 4.

Dae-Hee Son, Sang-Hee Kang, and Soon-Ryul Nam are with the Department of Electrical Engineering, Myongji University, Yongin 449-728, Republic of Korea (corresponding author: Soon-Ryul Nam, e-mail: ptsouth@mju.ac.kr).

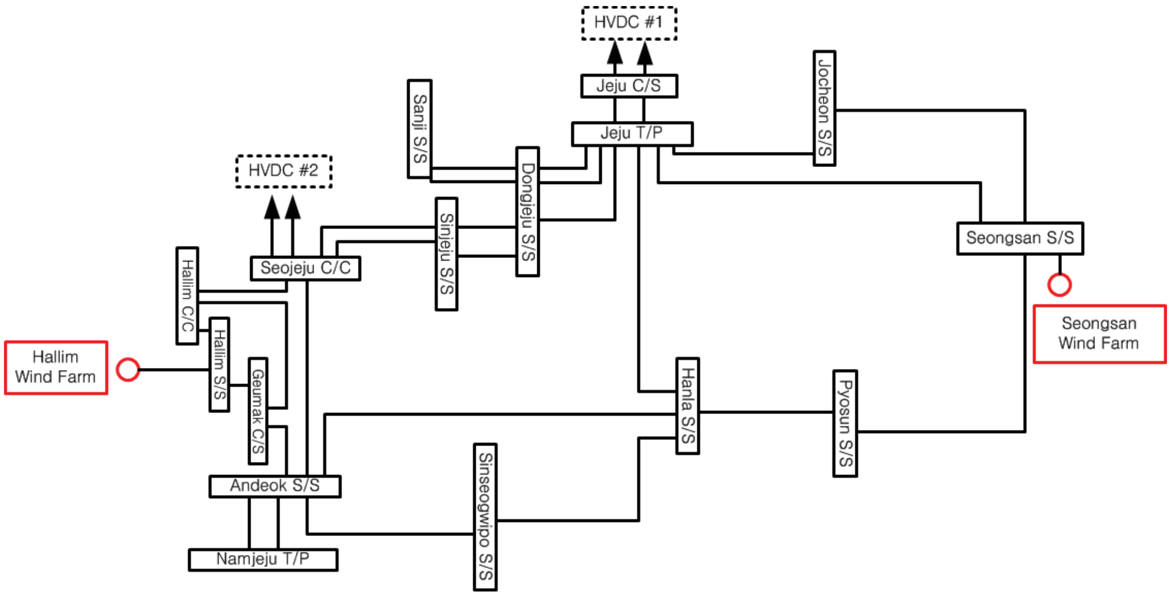
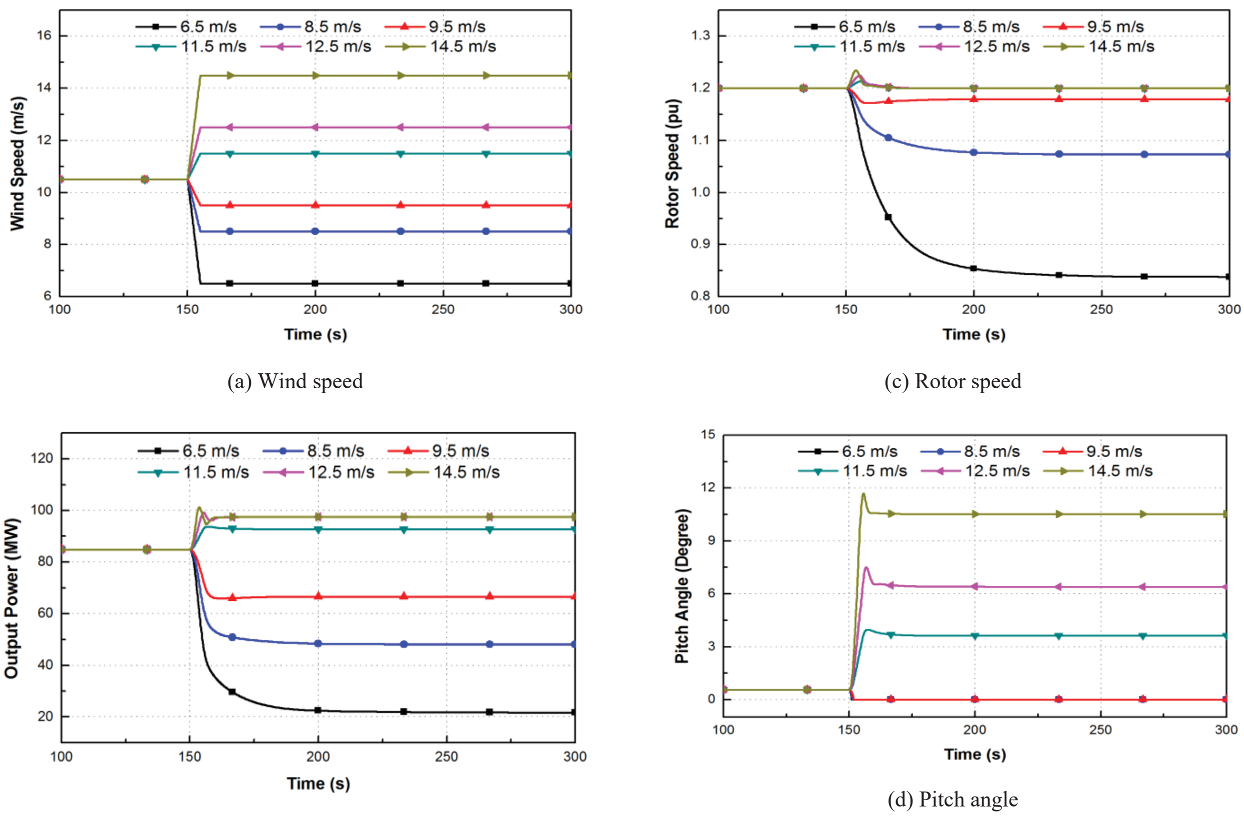


Fig. 1 The Jeju power system under study



(a) Wind speed

(c) Rotor speed

(b) Output power

(d) Pitch angle

Fig. 2 Simulation results for various wind speeds

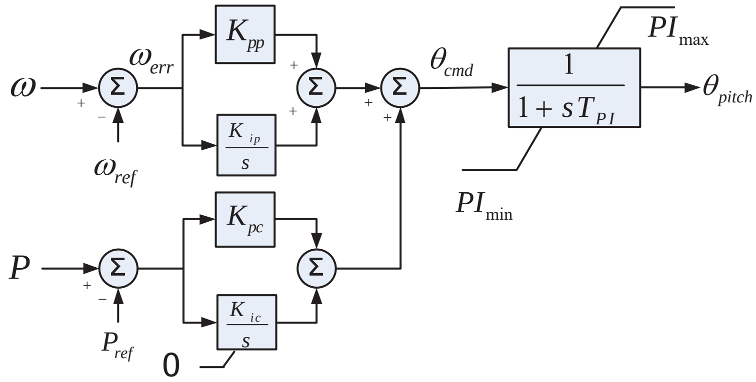


Fig. 3 Pitch angle control model of the GE 1.5 MW DFIG [4]

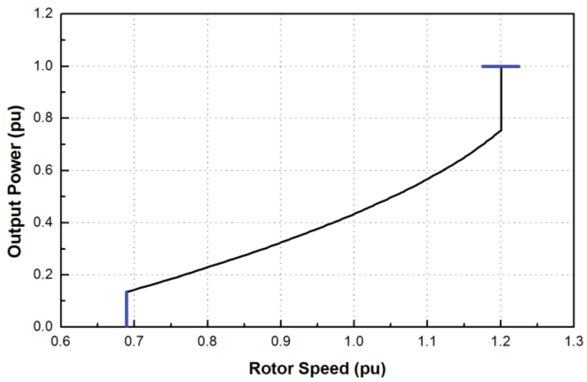


Fig. 4 Relationship between rotor speed and output power of the GE 1.5 MW DFIG

The speed reference is normally 1.2 pu; however, this was reduced for output powers below 0.76 pu. This behavior was described using the library model with the following relation, so that the speed reference is given by:

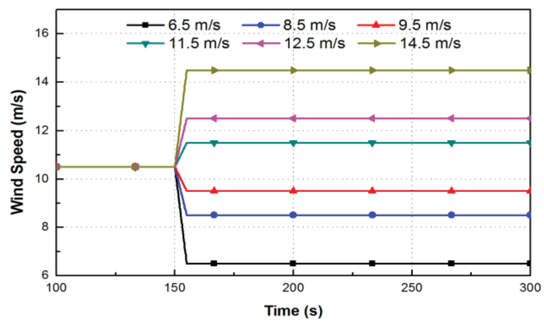
$$\omega_{ref} = -0.67P^2 + 1.42P + 0.51, \quad P \le 0.76 \tag{1}$$

The speed reference slowly tracks the changes in output power using a low-pass filter with a time constant of 5 s.

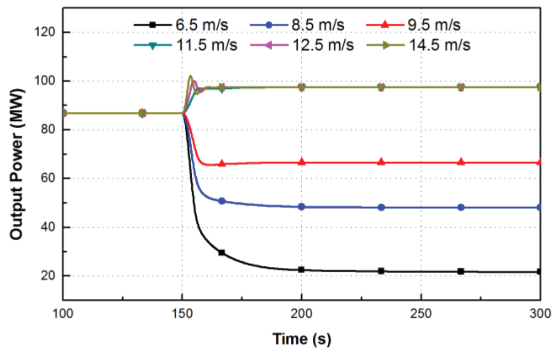
For output powers above the rated power (=1.0 pu), the rotor speed should be controlled to keep the output power equal to the rated power, with the speed allowed to rise above the reference transiently. This behavior was implemented using the user-defined model for the speed reference control as:

$$\omega_{ref} = \begin{cases} 0.00 & 0.00 \le P \le 0.14 \\ -0.67P^2 + 1.42P + 0.51 & 0.14 < P \le 0.76 \\ 1.20 & 0.76 < P \le 1.00 \\ 1.20 + (1.00 - P)\cdot\theta_{pitch} & 1.00 < P \end{cases} \tag{2}$$

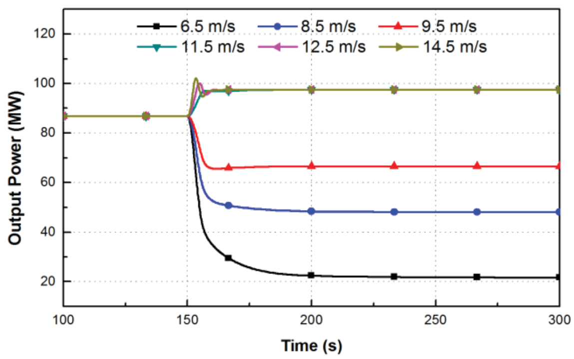
where θ_{pitch} is the pitch angle of the wind turbine. Fig. 5 shows the simulation results with speed reference control. As expected, the output power of the Hallim wind farm was equal to the rated power of 97.5 MW when the wind speed was 11.5 m/s or more.



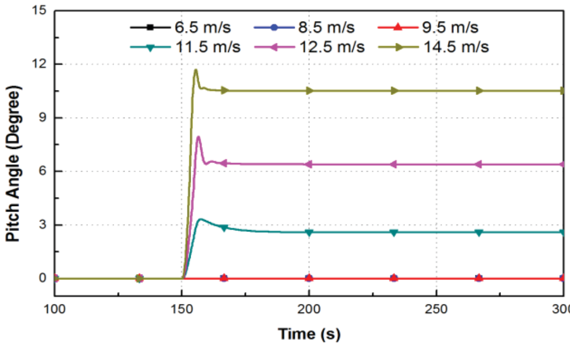
(a) Wind speed



(b) Output power



(c) Rotor speed



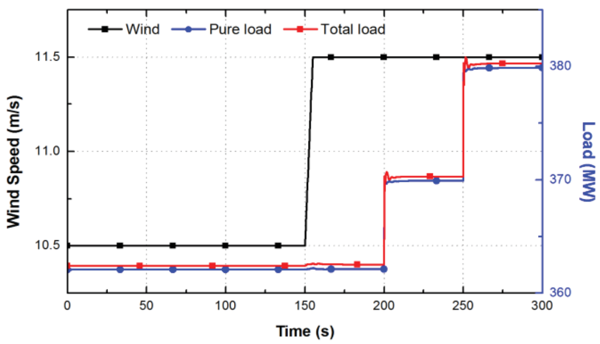
(d) Pitch angle

Fig. 5 Simulation results with speed reference control

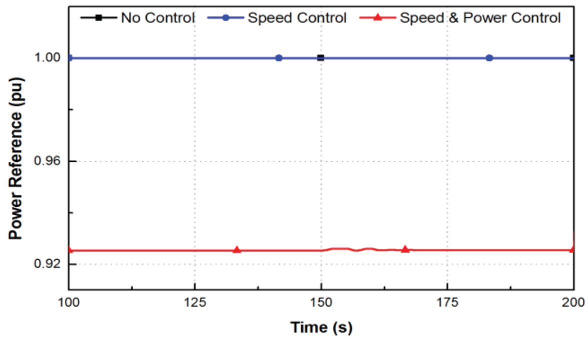
B. Pitch Angle Control Based on Power Reference

In order to comply with the Korean grid code, the output power of a wind farm should be regulated. This regulation can be implemented using pitch angle control based on power reference. As shown in Fig. 3, the pitch angle of a wind turbine was controlled based on both power reference and speed reference. Fig. 6 shows the simulation results with power reference control in addition to speed reference control.

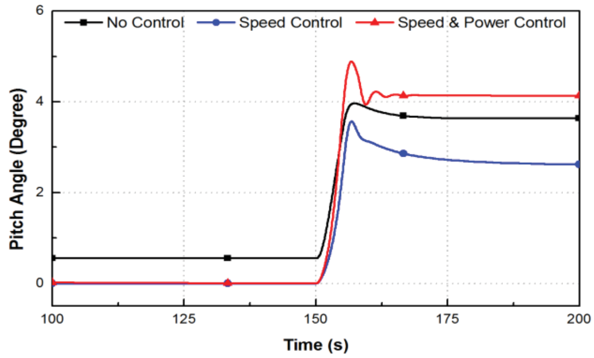
When the total load was 362.42 MW (i.e., a pure load of 362.07 MW and losses of 0.35 MW), the limitation of the Jeju power system was 180.42 MW, which was calculated based on the output regulation of Jeju power system [7]. Because there were two wind farms with the same rated power of 97.5 MW, the output regulation of the Hallim wind farm was 90.21 MW and the power reference was set to 0.9252 pu (i.e., 90.21 MW / 97.5 MW). The wind speed was initially maintained at a constant 10.5 m/s, and at 150s was increased to 11.5 m/s over a period of 5 s. The output power of a wind farm should not exceed the output regulation, even though the wind speed was sufficient to generate more output power. Therefore, the output power of the Hallim wind farm was limited to 90.21 MW, as shown in Fig. 6 (d).



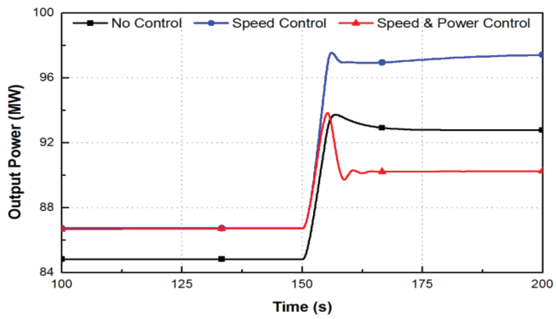
(a) Wind speed and total load



(b) Power reference



(c) Pitch angle



(d) Output power

Fig. 6 Simulation results with power reference control in addition to speed reference control

III. Conclusions

We developed a dynamic model of wind farms in the Jeju power system. PSS/E was used to develop the dynamic model of a wind farm composed of GE 1.5 MW DFIGs. The output of a wind farm was regulated based on the pitch angle control, in which the two controllable parameters were the speed and power references. Because PSS/E does not provide a control model for the speed and power references, user-defined models were developed for the speed and power references. Speed reference control was used to provide accurate simulations in which the wind speed was varied and power reference control was used to implement the output regulation. The simulation results demonstrated that the pitch angle was well-controlled in response to variations in the wind speed and the output regulation. Therefore, the dynamic model of wind farms is considered useful for studying the dynamic effects of wind farms on island power systems including the Jeju power system.

Acknowledgment

This research was supported in part by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (No. NRF-2013R1A1A2062924). This research was also supported in part by the Human Resources Program in Energy Technology of the Korea Institute of Energy Technology Evaluation and Planning (KETEP), granted financial resource from the Ministry of Trade, Industry & Energy, Republic of Korea (No. 20154030200770).

References

[1] Kim, E.-H.; Kim, J.-H.; Kim, S.-H.; Choi, J.-H.; Lee, K.-Y.; Kim, H.-C. Impact Analysis of Wind Farms in the Jeju Island Power System, IEEE Systems Journal, 2015, 6, 134-139.

[2] Lee, K.-Y.; Kim, S.-H. Progress in distributed generation in Korea, In Proceedings of 2007 IEEE Power Engineering Society General Meeting, Florida, USA, 24-28 June 2007; pp. 1–6.

[3] Kim, H.-T.; Baek, S.-I.; Park, E.-I.; Chang, H.-J. Optimal green energy management in Jeju, South Korea e On-grid and off-grid electrification. Renew. Energy 2014, 69, 123-133.

[4] Clark, K.; Miller, N.W.; Sanchez-Gasca, J.J. Modeling of GE wind Turbine-Generators for Grid Studies: version 4.5, GE, 16 April 2009.

[5] Kazachkov, Y.; Keung, P.-K.; Patil, K. PSS/E Wind Modeling Package for GE 1.5/3.6/2.5 MW Wind Turbines, SIEMENS, June, 2009.

[6] Miller, N.W.; Sanchez-Gasca, J.J.; Price, W.W.; Delmerico, R.W. Dynamic modeling of GE 1.5 and 3.6 MW wind turbine-generators for stability simulations: version 3.0, GE, 27 October 2003.

[7] Son, D.-H.; Kang, S.-H.; Kang, S.-H.; Nam, S.-R. Power Reference Control of Wind Farms Based On the Operational Limit, In Proceedings of 2014 International Conference on Electrical Power and Energy Systems, Thailand, 6-7 Feb. 2014; pp. 1–4.