World Academy of Science, Engineering and Technology
International Journal of Energy and Power Engineering
Vol:8, No:2, 2014

Power Reference Control of Wind Farms Based On the Operational Limit

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

***Abstract*—**Wind farms usually produce power irregularly, due to unpredictable change of wind speed. Accordingly, we should determine the penetration limit of wind power to consider stability of power system and build a facility to control the wind power. The operational limit of wind power is determined as the minimum between the technical limit and the dynamic limit of wind power. The technical limit is calculated by the number of generators and the dynamic limit is calculated by the constraint of frequency variation when a wind farm is disconnected suddenly. According to the determined operational limit of wind power, pitch angles of wind generators are controlled. PSS/E simulation results show that the pitch angles were correctly controlled when wind speeds are changed in addition to loads.

***Keywords*—**Pitch Angle, Dynamic limit, Operational limit, Technical limit.

I. Introduction

RECENTLY, rapid increase of unsteady renewable generators has been concerned about stability of power system. In Korea, considering stability of power systems, new renewable generators more than 20MW should furnish communication equipment to monitor the state of operation and maintain the electrical quality more than certain level. Moreover, the amount of their generation should be controlled in an emergency.

If there were a standard to control the amount of wind generation, we can increase the acceptable penetration limit through the pitch angle control of wind generators. If the amount of wind generation can be limited depending on loads, we can use the concept of operational limit instead of the acceptable limit, which is determined conservatively by offline. When the operational limit is determined, the time to limit the amount of wind generation should be minimized to maximize economic profit. That is, the amount of wind generation is only limited when the available amount of wind generation is more than the operational limit corresponding to the total loads [1].

To determine the operational limit of wind generation, the technical limit depending on the minimum power of generators and the dynamic limit depending on the constraint of frequency variation should be considered together. After the operational limit is determined, the control of wind generation to increase the power system stability is essential when the wind speed and loads are changed [2].

In this paper, SAVNW example, which is a benchmark system of PSS/E, was used to simulate the pitch angle control based on the operational limit. GEWT 1.5MW wind generator model is used and wind generators of 375MW are initially connected to 21th bus and 32th bus, respectively. The operational limit is determined for the power system shown in Fig. 1 and the pitch angles of wind generators are controlled to satisfy the operational limit when the wind speed and loads are changed.

Dae-Hee Son, Seung-Hwa Kang, Sang-Hee Kang, and Soon-Ryul Nam are with the Department of Electrical Engineering, Myongji University, Yongin 449-728, Republic of Korea (e-mail: sonking18@nate.com).

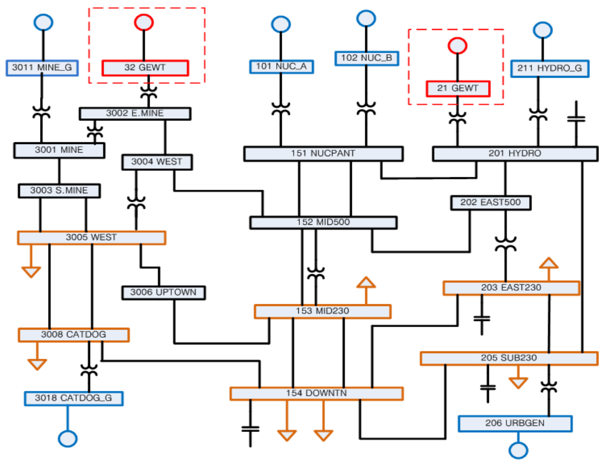


Fig. 1 Power system model under study

II. Determination of Operational Limit

Operational limit ($P^O_{\max}$) by change load is determined as minimum value of technical limit ($P^T_{\max}$) and dynamic limit ($P^D_{\max}$).

$$P^O_{\max} = \min(P^T_{\max},\ P^D_{\max}) \tag{1}$$

Technical limit ($P^T_{\max}$) is determined to depending on input of the wind generators and is calculated by considering minimum generation of wind generators in according with Loads [2], [3].

$$\begin{aligned} P^T_{\max} &= P_L - \sum_k c_k P_k = \sum_k P_k - \sum_k c_k P_k \\ &= \sum_k (1 - c_k) P_k \end{aligned} \tag{2}$$

P_L is amount of loads, P_k is maximum generation of the generators that are connected to power system, c_k is minimum generation rate of the each generator. Therefore, the minimum generation of the generators that are connected to power system is expressed as $\sum_k c_k P_k$ [2].

Dynamic limit ($P^D_{\max}$) can be set by measuring power system frequency through WAMS (Wide Area Measurement System). In this paper, the wind generators are unconnected from 21st bus. Then, the dynamic limit ($P^D_{\max}$) is set by the amount of wind generation to be not dropped below 59.5Hz frequency [1]-[3].

As a result, the graph of the technical limit ($P^T_{\max}$), the dynamic limit ($P^D_{\max}$) and the operational limit ($P^O_{\max}$) is as shown in Fig. 2. Like the graph, wind generators are controlled by the operational limit.

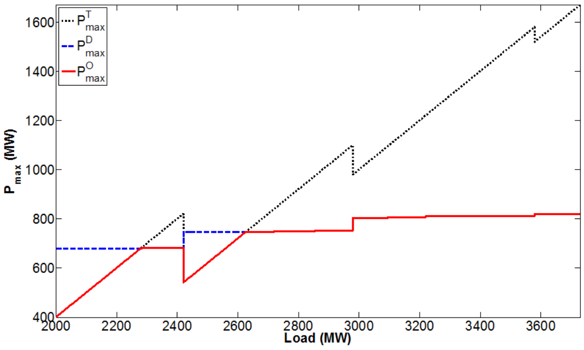
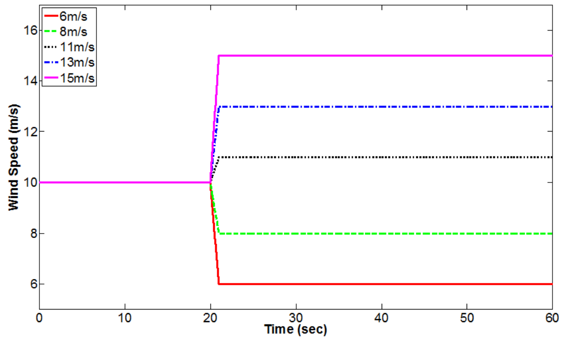


Fig. 2 Penetration limit of wind generation

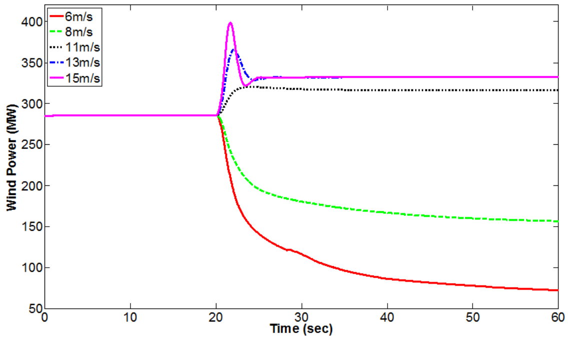
III. Modeling of DFIG Wind Farms

PSS/E has a sub-program called "Wind Turbine Package", which provides libraries for various wind power generator models, including Acciona, Enercon, Fuhrlaender, GE, Mitsubishi, Siemens, and Vestas. In this paper, wind farms are composed of GE 1.5MW DFIG model, since this model provides more detailed data than other models. In this power system, 375MW (1.5MW*250EA) wind farms were connected at 21bus and 32bus, respectively. PSS/E 32 and Wind Turbine Package 5.1.0 were used in the simulations.

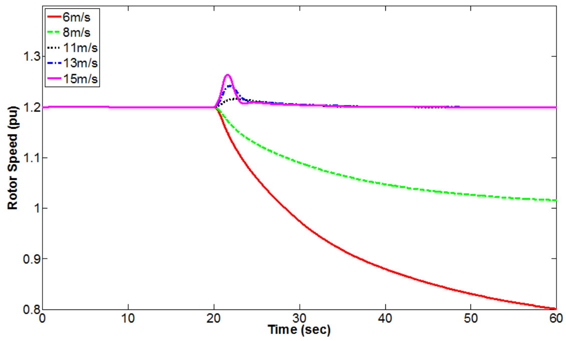
The initial wind speed was kept constant at 10 m/s and it was decreased to 6m/s for 1sec from 10sec. With the decrease in the wind speed, the active power of a wind farm decreased from 285 MW to 72 MW. To consider the increase in wind speed, the initial wind speed was kept constant at 10 m/s and it was increased to 15m/s for 1sec from 10sec. With the increase in the wind speed, the active power of a wind farm increased from 285 MW to 332 MW. For more analysis, the wind speed was varied to 8m/s, 11m/s, and 13m/s. As expected, the active power of the wind farm decreased with the decrease in the wind speed, and increased with the increase in the wind speed [4], [5].



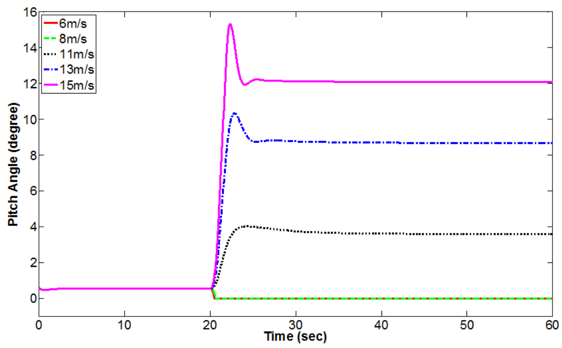
(a) Wind Speed



(b) Active power of wind farm



(c) Rotor Speed



(d) Pitch Angle

Fig. 3 Simulation result of a DFIG Wind farm with the variation of wind speed

IV. Pitch Angle Control Depending on the Operational Limit

To control output of GEWT 1.5MW model that is used to simulation in accordance with the operation limit, Pitch Angle control is required. At the Pitch Angle control, two factors are considered. The one is controlled by Speed Reference; the other is controlled by Power Reference.

In this research, Pitch Angle is controlled by only Power Reference. Power Reference control Pitch Angle following power of wind generators. Power limit is determined to the operational limit, the amount of wind generation is not over it when wind speed increase. For example, if Power Reference value is 1.00pu, the amount of wind generation is maximum 750MW.

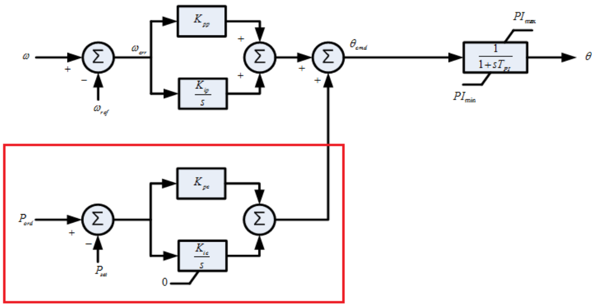


Fig. 4 Block diagram of pitch angle control [6]

To confirm the result, simulation is conducted. Wind generators that maximize 375MW (1.5MW*250) are connected to 21th bus and 32th bus, respectively. First of all, for progress in steady state, do the simulation for 10second at initial wind speed 10m/s, initial load 2500MW. Then initial power of wind generators is 285MW [6].

After 10second, wind speed is increased from 10m/s to 12m/s at the place of 21bus. Then, the technical limit is 620MW and the dynamic limit is 747MW.

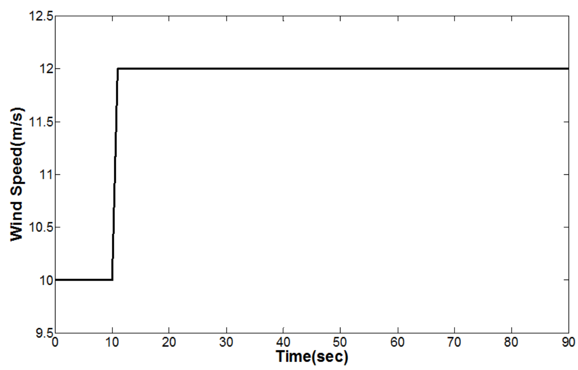


Fig. 5 Change of wind speed

So the operational limit is 620MW that is minimum value between both and Power Reference is 0.8240pu. However, actual Power Reference is 0.8860pu as shown in Fig. 5. It is the technical limit characteristic that is linearly increased depending on load increase. In fact, output of generators not only consider load but line loss. So output of generators more increases as loss. In this system, the line loss is about 81MW, as a result, Power Reference also increase.

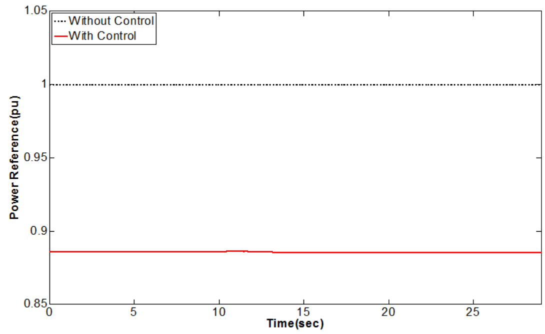


Fig. 6 Power reference

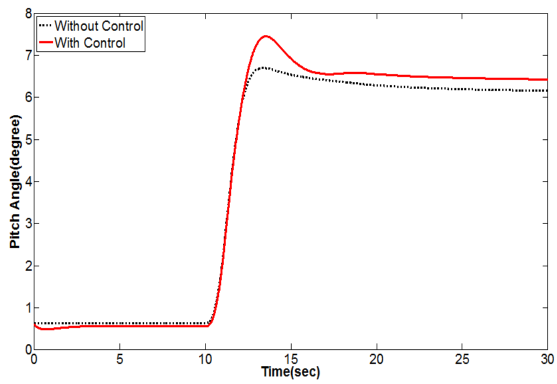


Fig. 7 Pitch angle

Pitch Angle increases depending on Power Reference in the case that wind speed increases. According to Pitch Angle control, output of wind generators is changed, so output 335MW as shown in Fig. 7.

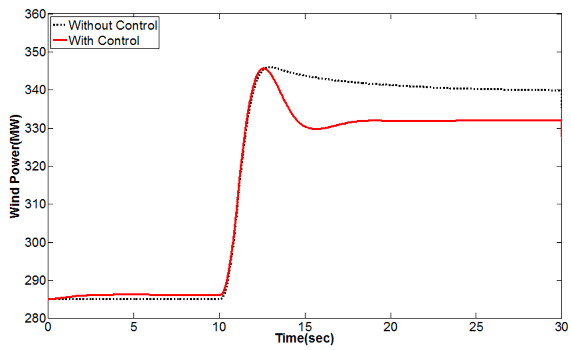


Fig. 8 Active power of the wind farm connected at 21bus

After 30second, load is increased from 2500MW to 2700MW. Then, the operational limit is 373.5MW applied for dynamic limit and Power Reference is 0.9960pu.

Unlike the previous, Power Reference is converged to 0.9960pu. Once the operational limit is applied for the dynamic limit, power of wind generator is constantly maintained because the dynamic limit characteristic is not increased despite of load increase.

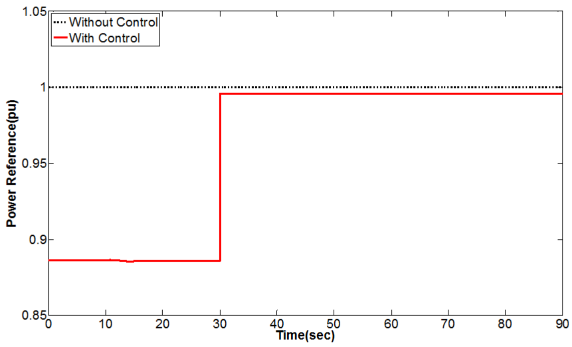


Fig. 9 Power reference

To increase the output, Pitch Angle is decreased. As shown in Fig. 10, output of wind generators is converged to about 343MW, not reach 373.5MW that is target. It is due to that Pitch Angle is controlled by only Power Reference without Speed Reference. To control output of wind generators exactly, Speed Reference is included to control Pitch Angle. Next, it should be going to be researched.

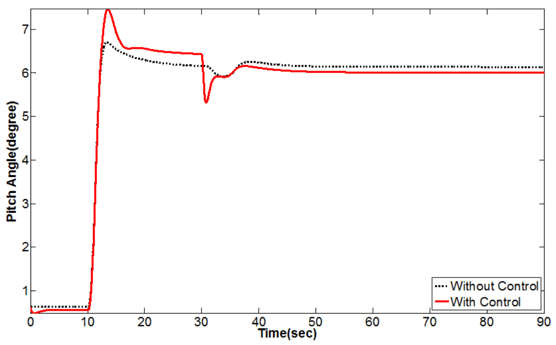


Fig. 10 Pitch angle

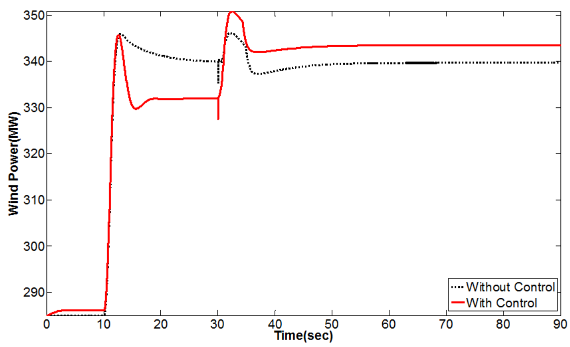


Fig. 11 Active power of the wind farm connected at 21bus

V. Conclusions

In this paper, example power system operational limit is determined and power of wind generators is controlled by Pitch Angle control in accordance with Speed and Power Reference to use PSS/E.

To determine the operational limit, consider the technical limit by minimal power of generators and the dynamic limit by the constraint of frequency variation. In the PSS/E simulation, power of wind generator is controlled following the operational limit when load and wind speed changes and confirm the result. By controlling Pitch Angle following the operational limit, more wind generators are connected to power system.

Acknowledgment

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (No. 2012-0001591).

References

[1] Jin-woo Park, Young-ho Park, Seung-il Moon “Instantaneous Wind Power Penetration in Jeju Island” Power and Energy Society General Meeting Pittsburgh, PA, July 20-24, 2008.
[2] Seung-il Moon, Gi-chan Pyo, Jin-woo Park “Study on development of Grid code and operation scheme of Juju Island with high wind penetration”, World Energy Council, 2010. 9.
[3] Stavros A. Papathanassiu, Nikos G. Boulaxis, “Power limitations and energy field evaluation for wind farms operating in island systems”, Revewable Energy, 2006. 4.
[4] Soon-ryul Nam, Sang-hee Kang, Hae-kon Nam, Joon-ho Choi “Development of Dynamic Models for DFIG wind Farms and HVDC in Jeju Power System Using PSS/E”, KIEE Volume 60, Issue 12, pp2183-2189, December. 2011.
[5] Biessler, “BOSL Controllers Package Standard-1”, Siemens PTI, 2008.5.
[6] Yuriy Kazachkov, Ping-Kwan Keung, Krishnat Patil, “PSS/E Wind Modeling Package for GE 1.5/3.6/2.5 MW Wind Turbines User Guide” Siemens PTI Issue 5.1.0 2009. June.