

Development of Wind Turbine Simulator for Generator Torque Control

Jae-Kyung Lee, Joon-Young Park, Ki-Yong Oh, Jun-Shin Park

Abstract—Wind turbine should be controlled to capture maximum wind energy and to prevent the turbine from being stalled. To achieve those two goals, wind turbine controller controls torque on generator and limits input torque from wind by pitching blade. Usually, torque on generator is controlled using inverter torque set point. However, verifying a control algorithm in actual wind turbine needs a lot of efforts to test and the actual wind turbine could be broken while testing a control algorithm. So, several software have developed and commercialized by Garrad Hassan, GH Bladed, and NREL, FAST. Even though, those programs can simulate control system modeling with subroutines or DLLs. However, those simulation programs are not able to emulate detailed generator or PMSG. In this paper, a small size wind turbine simulator is developed with induction motor and small size drive train. The developed system can simulate wind turbine control algorithm in the region before rated power.

Keywords—Wind turbine, simulator, wind turbine control, wind turbine torque control

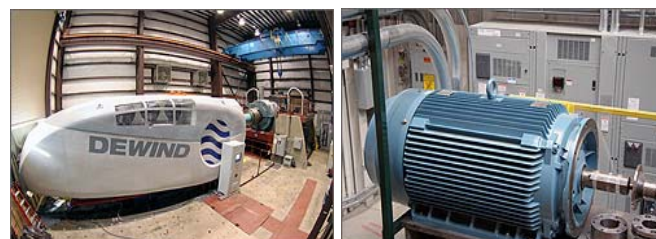
I. INTRODUCTION

ACCORDING to the needs of electric energy production, the importance of renewable energy is getting more greater, because of crisis on fossil fuel and power production cost. Especially, wind energy in renewable energy source has the best economic efficiency and low cost for power production. To make higher availability, the scale of wind turbines has increased over the last 2 decades. For example, the size of blade has grown from 33.4m to over 126m and tower, height are also increased to cope with the blade. Moreover, the control algorithm in wind turbine has also changed to capture maximum energy from wind. In order to test effective control algorithms for reliable wind turbine control, a wind turbine simulator is necessary for actual wind turbine developer. Already, some sorts of wind turbine simulation software has developed and commercialized by Garrad Hassan and NREL(National Renewable Energy Laboratory). Some control algorithm can be tested with those simulation software. But, those software are not fully support how to set up control strategies. Therefore, the control strategies are still depending on wind turbine developer.

Traditionally, a Motor-Generator(M-G) set has been used as a wind turbine simulator including DCM(Direct Current

Morot)-DFIG(Double Fed Induction Generator, PMSM(Permanent magnet Synchronous Motor)-DFIG, and DCM-PMSG(Permanent Magnet Synchronous Generator[1]-[5].

Concerning with wind turbine simulator, NREL-NWTC(National Wind Technology Center) has already developed 2.5MW Dynamometer to test long-term fatigue testing and short-term performance verification. NREL-NWTC also developed 225kW Dynamometer to test small size turbine components including subsystems, generators, and gear boxes[6]. POSTECH also developed 20kw simulator to study control dynamics of inverter for 2MW wind turbine[7]. Korea Electric Power Research Institute is also developing wind turbine simulator to verify condition monitoring algorithm on wind turbine components[8].



(a) 2.5MW Dynamometer(NREL) (b) 225KW Dynamometer(NREL)



(c) Wind turbine simulator(POSTECH)

Fig. 1 Developed wind turbine simulators

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This paper describes a small size wind turbine simulator to control torque on generator using induction motor and virtual generator with LabView. The developed system emulates wind profile with induction motor, and generator torque control algorithm is defined.

II. WIND TURBINE SIMULATOR

A. Wind Profile

Wind profile or distribution subjects dynamic effect, such as loading, durability, and operation, to wind turbine while operating. The wind profile or distribution into normal wind condition and extreme wind conditions. Normal wind condition generally generate regular loading on turbine, whereas the extreme wind condition stands for extreme wind condition which could cause maximum load on wind turbine irregularly. Those conditions should be reviewed on wind turbine design stage to secure wind turbine stability and regularity in turbine life time. Concerned with wind condition, wind turbine classes are defined with wind turbulence intensity and wind speed[9].

TABLE I
 WIND TURBINE CLASS

Wind turbine class	I	II	III	S
V_{ref} (m/s)	50	42.5	37.5	Values Specified by the designer
A $I_{ref}(-)$	0.16			
B $I_{ref}(-)$	0.14			
C $I_{ref}(-)$	0.12			

Table I shows wind turbine classes. Wind turbine classes are classified I, II, and III by 10 minute wind speed average. A, B, and C designate categories on wind turbulence intensity and values($I_{ref}(-)$) are wind turbulence intensity² at 15m/s. The wind profile which used on wind turbine simulator is applied NWP(Normal Wind Profile), Normal wind profile and turbulence models are defined as (1), (2).

$$P_g(V_{hub}) = 1 - e^{-\pi(V_{hub}/2V_{ave})^2}$$

$$V_{ave} = 0.2V_{ref}$$
(1)

$$V(z) = V_{hub}(z/z_{hub})^\alpha$$

$$\alpha = 0.2$$

$$\sigma_1 = I_{ref}(0.75V_{hub} + b); b = 5.6m/s$$
(2)

V_{ave} is defined as $0.2V_{ref}$ in wind turbine classes and wind profile is assumed to across all swept area of wind turbine blade. σ_1 represents wind turbulence standard deviation.

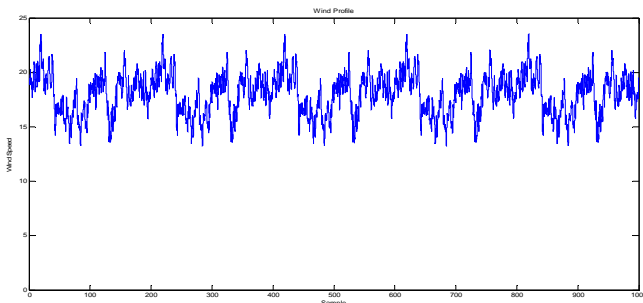
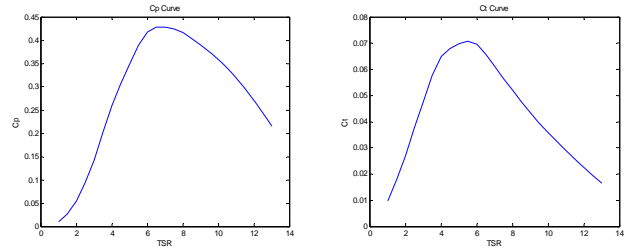


Fig. 2 Generated Wind Profile

B. Wind turbine blade

To simulate wind turbine, blade aerodynamics analysis should be performed to describe wind load behavior on blade.

In this paper, 1MW wind turbine blade is scaled down. The maximum power coefficient is approximately 0.43, TSR(Tip Speed Ratio) is 7 and air density is assumed as $1.225Kg/m^3$.



(a) Blade Power Coefficient (b) Blade Torque Coefficient

Fig. 3 Blade performance coefficients

Defining wind turbine torque curve to control wind turbine designates wind turbine control region. Moreover, torque control curve rules as a reference not to fall in stall region, when a wind turbine starts to generate electric power with wind and drive trains.

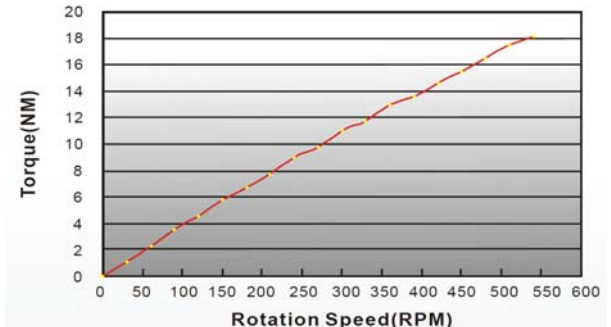


Fig. 4 General PMSG torque curve

Currently, most of wind turbines adapt PMSG(Permanent Magnet Synchronous Generator) because of its simple control mechanism, whereas DFIG(Double Fed Induction Generator) is not. Most of control algorithm and controls are performed on inverter which makes wind turbine designer free from designing and controlling. Fig. 4 shows general PMSG torque curve[10]. Wind turbine control region can be divided in three regions. Wind turbine torque controller increases torque on generator axis after cut in wind speed, Region I. Torque controller increases generator torque between Region I and rated power and prevents the blade from falling down stall region, Region II. Blade pitch controller adjust blade pitch to capture maximum torque from wind and torque controller sets torque reference on generator by varying RPM(Rotation Per Minute). Therefore, the torque on generator limited on torque curve reference. In region III, the torque flows into wind turbine is greater than maximum torque which can captured by generator, the pitch controller controls blade pitch to reduce maximum inflow torque by wind. PMSG could be considered as permanent magnet induction motor if the magnet is rotating in induction generator. Therefore, Torque which is working on generator can be modeled with (3)[11].

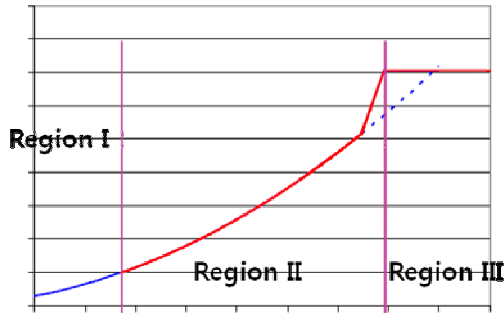


Fig. 5 Wind turbine control regions

$$Q_{gen} = k\Omega^2 \quad (3)$$

$$k = \frac{1}{2} \rho \pi R^5 \frac{Cp_{max}}{\lambda_{opt}^3} \quad (4)$$

where

ρ : Air Density

R : Rotor Radius

λ : Tip Speed Ratio

Cp_{max} : max Power Coefficient Corresponding

Virtual generator is used to configure wind turbine control profile. The virtual wind turbine generates 4 poles, 2 pole pairs, and 100RPM Rated. Rated torque is assumed 1964Nm. The torque coefficient k is about 2348, modeled torque curve on region II would be $Q_{gen}=2348\Omega^2$ in low speed region(Rotor side). The torque coefficient should be written in high speed region(Generator Side), $Q_{gen}=0.16458596\Omega^2$. If the generator is supposed as PMSG, the transient region between region II and region III would be very short region and the transient region can be neglected.

TABLE II

PARAMETERS TO DRIVE CONTROL TORQUE COEFFICIENT (K)

Variable	Value	Unit
Air density	1.02	Kg/m ³
rotor Radius	14.5	m
Optimal Lamda	6	
Cp Max	0.43	
Max Cp Blade Degree	-1	
Rated Torque	2000	Nm
Rated Speed	100	RPM
HSS K(Q Gen)	0.164585968	omega ² *N-m
VS_Rgn2K	0.164585968	Nm/rpm ²

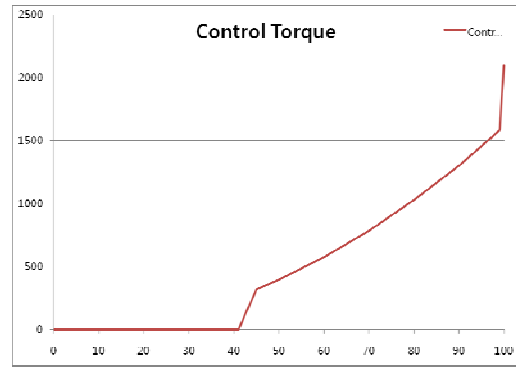
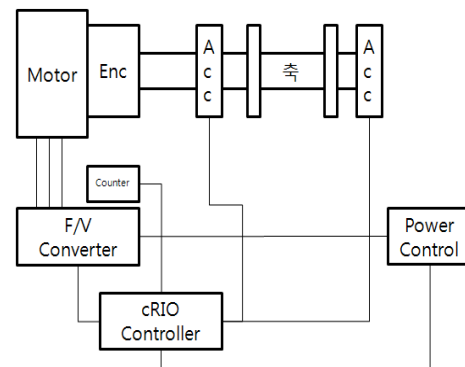


Fig. 6 Wind turbine control regions

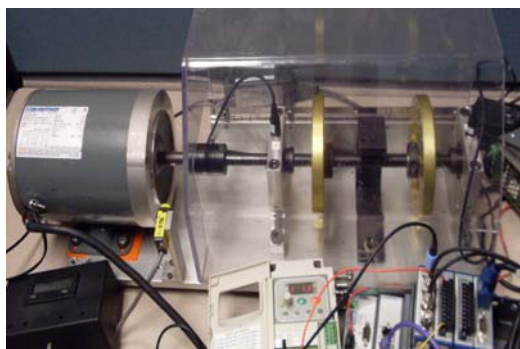
Fig. 6 shows generated wind turbine simulator torque control curve. The inverter on simulator should control 0 torque until the generator RPM reaches 42RPM. When RPM on generator exceeds 42RPM, the inverter increases torque reference value until RPM reaches 45RPM, Region I. When the RPM reaches 45, torque control region changes to Region II and torque on generator is controlled smoothly until the RPM reaches 98. The torque reference value increases rapidly between 98~100RPM. From 100RPM, torque reference on generator is fixed 2000 and the torque is controlled by blade pitch controller to regulate input torque from wind.

C. Wind turbine simulator hardware

A small wind turbine simulator is configured to verify control algorithm. Fig. 7 shows wind turbine simulator. 2KW induction motor, which emulates wind, rotates drive train. Also, two disks are attached on drive train to make inertia on rotating axis and to generate vibration using unbalanced mass. Two acceleration sensor are mounted on drive train to measure vibration while the simulator is operating. Laser reflection plate is attached on rotating axis and the signal of laser encoder is used to perform order analysis on vibration signals while the drive train is rotating. F/V(Frequency to Voltage) converter controls induction motor and receive RPM reference about wind profile. F/V converter connected with cRio main controller with analog signal. The voltage range of connected analog signal is 0~5V and the range is corresponded with 0~1800 RPM.



(a) Wind turbine simulator block diagram

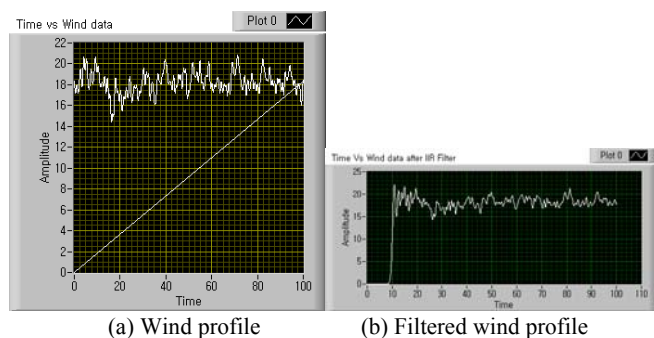


(b) Small size wind turbine simulator

Fig. 7 Wind turbine simulator

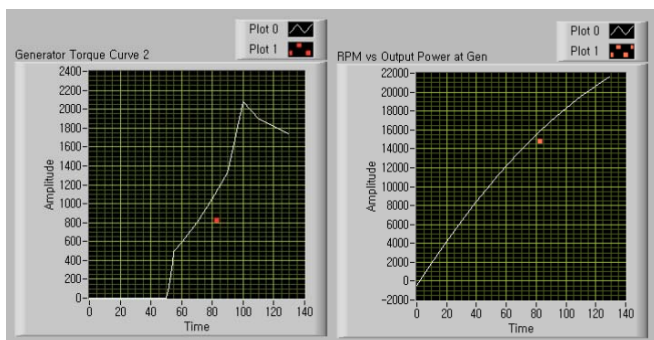
III. WIND TURBINE CONTROLLER SIMULATION RESULT

The simulator performs the control algorithm and entire program on every 200ms. PID controller is implemented to track wind profile on induction motor and torque control on simulation. Normal wind condition is used to test simulator and inertia and dynamics is emulated with IIR filter. The output power should be used Torque vs Output, however, to make control easier, RPM is used to match torque and output power. The references are modeled with 7th order approximate to Red point on result graph designates operating point of torque control and white line means torque control reference.



(a) Wind profile

(b) Filtered wind profile



(c) RPM vs Torque

(d) RPM vs Power

Fig. 8 Wind turbine controller simulation result

IV. CONCLUSION

In this paper, a small scale wind turbine simulator is configured and a torque control curve is defined to control the simulator. The control curve and algorithm is implemented on NI product. The simulation result show small error while the simulator is operating. The error is suspected due to not optimized PID gain on controller. Even though, the simulator controls torque on Region I, II, and III, it is not possible to control pitch on blade which regulates input torque on generator. KEPCO Research Center is also building another wind turbine simulator about 20KW. Therefore, actual pitch control, gain scheduling, yaw movement, and actual inverter control would be verified with the simulator.

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REFERENCES

- [1] H. Li, M. Steurer, K. L. Shi, S. Woodruff, and D. Zhang, “Development of a unified design, test, and research platform for wind energy systems based on hardware-in-the-loop real-time simulation,” *IEEE Trans. Industrial Electronics*, vol. 53, no. 4, 2006, pp. 1144-1151.
- [2] B. H. Chowdhury, and S. Chellapilla, “Double-fed induction generator control for variable speed wind power generation,” *Electric Power Systems Research*, vol. 76, iss. 9-10, 2006, pp. 786-800.
- [3] H. Camblong, I. M. de Alegria, M. Rodriguez, and G. Abad, “Experimental evaluation of wind turbines maximum power point tracking controllers,” *Energy Conversion and Management*, vol. 47, iss. 18-19, 2006, pp. 2846-2858.
- [4] J. R. Cardoso, V. Cecconi, A. O. Di Tommaso, D. La Cascia, R. Miceli, P. A. C. Rosas, and M. B. C. Salles, “Wind electrical energy generating systems EMC. A detailed experimental simulator for tests,” *Int. Conf. Electrical Machines*, 2008, pp. 1-6.
- [5] M. E. Mokadem, V. Courtecuisse, C. Saudemont, B. Robyns, and J. Deuse, “Experimental study of variable speed wind generator contribution to primary frequency control,” *Renewable Energy*, vol. 34, iss. 3, 2009, pp. 833-844.
- [6] <http://wind.nrel.gov/Dyno/>
- [7] S. J. Kwon, Y. G. Son, S. D. Jang, J. H. Suh, J. S. Oh, Ch. H. Chun, C. W. Chung, K. S. Han, D. H. Kim, and O. J. Kwon, “A simulator for the development of power conversion system for 2MW wind turbine,” *European Wind Energy Conference and Exhibition*, Athens, Greece, 2006.
- [8] J. Y. Park, J. K. Lee, K. Y. Oh, J. S. Lee, B. J. Kim, “Design of Simulator for 3MW Wind Turbine and Its Condition Monitoring System,” *Proceedings of the International MultiConference of Engineers and Computer Scientists*, Hong Kong, China, 2010.
- [9] IEC 61400-1
- [10] www.JinLong.com
- [11] A.D. Wright, L.J. Fingersh, “Advanced Control Design for Wind Turbines Part I: Control Design, Implementation, and Initial Tests,” *Technical Report*, NREL/TP-500-42437, March, 2008.