Wind Turbine Simulator for Comparative Study of MPPT Controls

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Abstract

This paper proposed the wind turbine simulator for comparative study of the MPPT controls. The development of this wind turbine simulator is based on the torque controlled induction motor. The torque reference is obtained from a mathematical model of wind turbine whereas the inputs are rotor speed, wind speed and fixed-value of pitch angle. By using this wind turbine simulator, the real wind is not needed. Wind speed information can be stored and regenerated anytime. Hence it is possible to apply the same wind speed condition to different MPPT controls. With the same wind speed condition, it can fairly compare the advantages and disadvantages of the MPPT controls. The proposed wind turbine simulator is verified through PSIM simulation.

Keywords – wind turbine simulator, wind speed condition, induction motor, torque control

1. Introduction

Researches related to wind energy become more popular now. This kind of energy is cheap and has high availability in many countries. One of the popular researches is maximum power point tracking (MPPT) control. Several MPPT controls have been proposed recently. To find the best MPPT control, the MPPT controls must be compared fairly with the same wind speed condition. Unfortunately, nature impossibly provides the same wind speed condition at different time.

In this paper, the wind turbine model is proposed to overcome aforementioned problem. Real wind turbine is not used, it will be replaced by an induction motor which is torque controlled. This induction motor will follow the characteristic of wind turbine since the torque reference is obtained from mathematical model of wind turbine. By using this wind turbine model, wind speed data can be stored in a memory. Hence it can be regenerated anytime.

2. Wind Turbine Characteristic

The proposed wind turbine simulator must follow the characteristic of real wind turbine. As described in [1], the wind turbine characteristic is represented by wind turbine power coefficient, C_p In MPPT control, this value represents the ability of wind turbine to capture airflow power as stated in below equation,

$$P_{WT} = C_p P_{air} = C_p \times \frac{1}{2}\rho A v^3 \tag{1}$$

Whereas ρ is air density (kg/m^3), A is swept area and v is upwind free wind speed (m/s).

Then the wind turbine power coefficient, C_p, is obtained from this equation,

$$C_p(\lambda,\beta) = c_1\left(\frac{c_2}{\lambda_i} - c_3\beta - c_6\right)e^{\frac{-c_5}{\lambda_i}} + c_6\lambda \tag{2}$$

$$\lambda = \frac{\omega R}{v} \tag{3}$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \tag{4}$$

Whereas λ is tip speed ratio, c_1, c_2, c_3, c_4, c_5 and c_6 are wind turbine coefficients, β is pitch angle (*degree*), ω is rotor speed (*rad/s*) and R is radius to tip of the rotor (m).

For the wind turbine simulator, torque reference is needed. To determine the torque, wind turbine power must be divided by rotor speed as follow,

$$T_{WT} = \frac{P_{WT}}{\omega} \tag{5}$$

Then this torque will be used as torque reference for direct torque control (DTC) of induction motor.

3. Wind Turbine Simulator Design

Characteristic of wind turbine has been discussed in previous section. In this wind turbine simulator design, the induction motor is used to replace the wind turbine. The induction motor must follow the torque reference which is obtained from the wind turbine characteristic. The whole system of the wind turbine simulator is shown in fig. 1.

There are three main parts of wind turbine simulator design: wind data, mathematical model of wind turbine and induction motor with DTC. More details, each part will be discussed.

3.1 Wind data

Wind data is stored in a memory, so it can be generated anytime. To obtain the wind data, wind measurement can be conducted in area where the real turbine will be installed. For MPPT control verification, besides the real wind speed condition, usually the wind step test is needed. So the wind data can be a wind step condition as well.

3.2 Mathematical model of wind turbine

This mathematical represents wind turbine characteristic. It needs wind speed information, pitch angle and rotor speed. The rotor speed is the only one to be measured. Meanwhile the wind speed is from wind data and pitch angle is kept constant at 2^0. The output is the torque which will be the reference for DTC of induction motor.

3.3 Induction motor with direct torque control (DTC)

Wind turbine converts kinetic energy to mechanical energy. In this paper, induction motor replaces the use of wind turbine. It does not convert kinetic energy as like wind turbine. But, it produces mechanical energy for wind turbine generator based on wind data and wind turbine characteristic.

DTC is implemented to the induction motor. The torque reference is obtained from wind turbine mathematical model. Figure 2 shows the DTC scheme for induction motor.

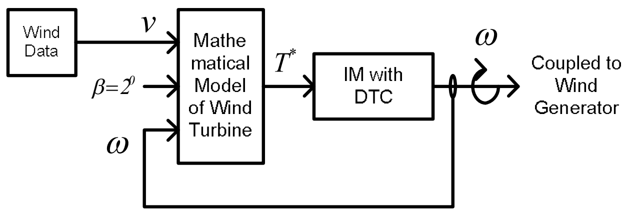

Figure 1 Wind turbine simulator system

To estimate the flux and torque, follow equations are used.

$$\psi_{ds}^{\ s} = \int \left(v_{ds}^{\ s} - R_s i_{ds}^{\ s} \right) dt \tag{6}$$

$$\psi_{qs}^{\ s} = \int \left(v_{qs}^{\ s} - R_s i_{qs}^{\ s} \right) dt \tag{7}$$

$$\psi_s = \sqrt{\psi_{ds}^{\ s2} + \psi_{qs}^{\ s2}} \tag{8}$$

$$T_e = \frac{3}{4} P \left(\psi_{ds} i_{qs} - \psi_{qs} i_{ds} \right) \tag{9}$$

From eq. (6) and (7), we can determine the position of stator flux as follow,

$$\theta_{\psi_s} = \arctan \left(\psi_{qs} / \psi_{ds} \right) \tag{10}$$

Then by using the divisions of stator flux which is shown in fig. 4, the sector number of flux can be estimated. DTC then can be implemented by having torque, stator flux and sector of stator flux. But, previously torque and stator flux should be transformed to H_ψ and H_{Te} by hysteresis equations as follow,

$H_{Te}=1,\ H_{Te}>+HB_{Te}$ (11)

$H_{Te}=-1,\ E_{Te}<-HB_{Te}$ (12)

$H_{Te}=0,\ \ -HB_{Te}< E_{Te}<+HB_{Te}$ (13)

$H_\psi=1,\ E_\psi>+HB_\psi$ (14)

$H_\psi=-1,\ \ E_\psi<-HB_\psi$ (15)

Table 1 shows the decision of switching scheme for inverter. '0' means upper leg is off and lower leg is on. Whereas '1' means vice versa. There are three values which each represents first leg, second leg and third leg of the inverter respectively.

4. Simulation Results

To verify the proposed method, simulations are conducted in PSIM. This wind turbine simulator is tested in small power PMSG system with two different fuzzy MPPT controls at low fluctuating wind speed. The results are shown in fig. 4, fig.5 and fig. 6.

5. Conclusions

Wind turbine simulator has been proposed and tested for two different fuzzy MPPT controls. By using this wind turbine simulator, real wind is not needed to fairly compare the different MPPT controls. Because wind information can be obtained from wind data block and it can be regenerated anytime. Another advantage of using wind turbine simulator is wind turbine power coefficient, C_p, can be evaluated.

Reference

[1] Bose, BK, "Modern Power Electronics and AC Drives," Prentice Hall PTR, 2002.

[2] Tafticht T. et. al, "Output Power Maximization of a Permanent Magnet Synchronous Generator Based Stand-alone Wind Turbine," in Industrial Electronics, IEEE International Symposium, pp. 2412-2416, 2006.

[3] Mirecki A. et. al, "Comparative Study of Maximum Power Strategy in Wind Turbines," in Industrial Electronics, IEEE International Symposium, pp. 993-998 vol. 2, 2004.

Table 1 Switching table for DTC

H_ψ	H_{Te}	S(1)	S(2)	S(3)	S(4)	S(5)	S(6)
1	1	110	010	011	001	101	100
	0	000	111	000	111	000	111
	-1	101	100	110	010	011	011
-1	1	010	011	001	101	100	110
	0	111	000	111	000	111	000
	-1	001	101	100	110	010	011

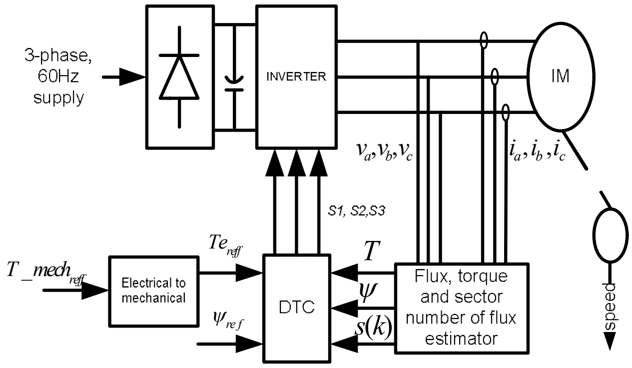

Figure 2 DTC scheme for induction motor

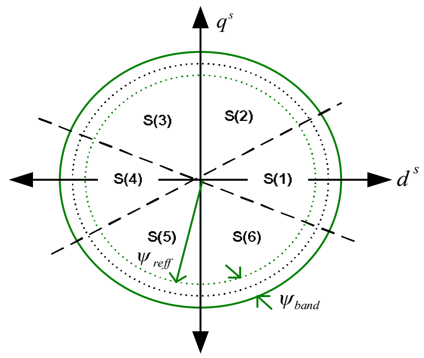

Figure 3 Divisions of stator flux

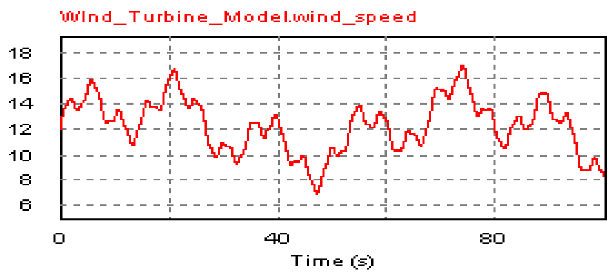

Figure 4 Fluctuating Wind Speed

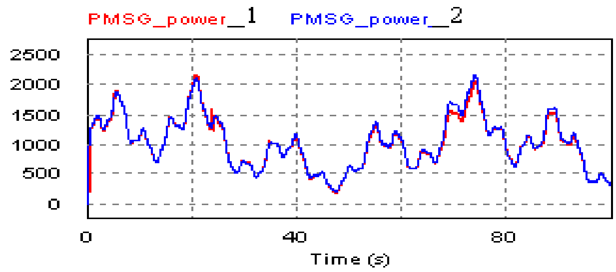

Figure 5 PMSG power

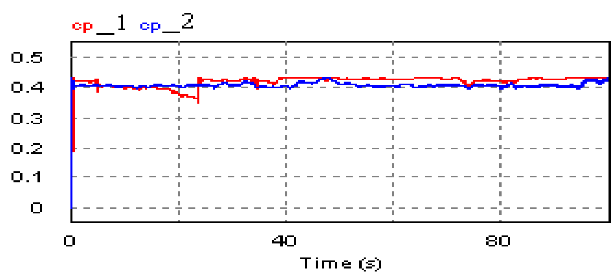

Figure 6 Wind turbine power coefficient