International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Issue 05, Volume 7 (May 2020) https://www.ijirae.com/archives

SMOOTHING OF WIND POWER FLUCTUATIONS IN WIND TURBINE GENERATOR SYSTEM BASED ON LINEAR POWER REFERENCE STRATEGY

Iwan Setiawan*
Electrical Engineering Dept.
Universitas Diponegoro, Semarang, Indonesia
iwansetiawan@live.undip.ac.id

Trias Andromeda
Electrical Engineering Dept.
Universitas Diponegoro, Semarang, Indonesia
trias1972@gmail.com

Mochammad Facta
Electrical Engineering Dept.
Universitas Diponegoro, Semarang, Indonesia
mochfacta@gmail.com

Hermawan
Electrical Engineering Dept.
Universitas Diponegoro, Semarang, Indonesia
hermawan.60@gmail.com

Achmad Hidayatno
Electrical Engineering Dept.
Universitas Diponegoro, Semarang, Indonesia
achmad.hidayatno@gmail.com

Manuscript History
Number: **IJIRAE/RS/Vol.07/Issue05/MYAE10083**
Received: 02, May 2020
Final Correction: 11, May 2020
Final Accepted: 17, May 2020
Published: **May 2020**
DOI: https://doi.org/10.26562/ijirae.2020.v0705.001
Citation: Iwan, Trias, Mochammad, Hermawan, Achmad (2020). Smoothing off Wind power Fluctuations in wind Turbine Generator System Based on Linear Power Reference Strategy. International Journal of Innovative Research in Advanced Engineering (IJIRAE), Volume VII, 279-288.
Editor: Dr.A.Arul Lawrence Selvakumar, Chief Editor, IJIRAE, AM Publications, India

Abstract: It is well known, that to achieve the maximum power in wind power generation systems, the maximum power point tracking (MPPT) algorithm should be employed as the main strategy to extract the wind power. However, due to the intermittent and unpredictabe nature of the wind speed, then the usage of the MPPT without using any compensation, will practically generate severe power fluctuation. The high fluctuation of the wind power basically come from to the cubic curve relation between the extracted wind power and wind speed in the MPPT method. To minimize the high fluctuation of the extracted wind power, in this paper we propose a simple linear power or a constant torque reference strategy. Based on simulation result run at Matlab/Simulink, it is shown that the power extracted by using a linear power or a constant torque reference is smoother compared with the usage of the maximum power point tracking strategy. However, by using this strategy the power average is lower than the MPPT.

Keywords : Wind turbine; MPPT; smoothing; constant torque, wind fluctuation

I. INTRODUCTION

As electrical energy demand has been increasing rapidly, and due to the depletion of fossil fuels and also boosted by global warming issues, the utilization of green power generation systems such as wind power generation system is very demanding [1-2]. To achieve a high wind power efficiency, an algorithm that best known as Maximum Power Point Tracking (MPPT) is usually employed as the main strategy to extract the wind power. In this strategy, the rotor of the wind turbine generator (WTG) is varied to track the maximum of the wind power, either by controlling output power directly or by regulation of the rotor speed at the outer control loop of the rotor side-converter [3-6].

Although the MPPT is the best strategy in the sense of the maximum power generation, however the wind turbine power usually will fluctuate severely. The huge fluctuation of the wind turbine power is come from the fact that the relation of the wind power to the wind speed is a cubic function, while the wind speed is actually an uncertain turbulent variable that fluctuate rapidly and stochastically and very difficult to predict precisely [7]. In grid connected wind turbine systems, this fluctuating power could make serious problem mainly. In this case, the utility grid frequency could deviate from its nominal. Due to high expectations in the penetration of more wind turbine generation systems in the future time, the research of the wind power smoothing is very important and demanding to be done.

There are several methods found in literatures to cure the fluctuation in wind power harvesting. One of the solutions to smooth the output power is by employing an energy storage system, including supercapacitor [8-9], the superconducting magnetic energy storage-SMES [10-11], high speed flywheel [12-13] and battery energy storage system [14]. The operation principle of the energy storage systems in the wind turbine system are almost the same: the storage will be charged if there is an excess energy caused by a high wind speed, and the stored energy will be released if the wind power output is lower than desired. The other techniques to smooth the wind power fluctuation is by employing a pitch control of the turbine blade [15] and by a constant power reference strategy [16]. Although the pitch control technique can give a promising result in the wind power smoothing, however, as point out by [17] the pitch control will make the stress on the blades increased. While the later, to be work properly this strategy practically need a very accurate prediction system of the very-short term wind speed (in the second time scale)

The main objective of this work is to smooth wind power fluctuation of the generator system output without using energy storage devices and without an accurate wind speed prediction system. To fulfil this objective, we here propose a linear power or a constant torque reference strategy to mitigate power fluctuation of the wind turbine system output. For simulation purposes, the WTG used in this study is DFIG-double fed induction generator. The remainder of the paper is organized as follows. Section 2 describes the general model of the wind turbine generator based on DFIG model. In Section 3, the wind turbine aerodynamic and MPPT algorithm will be discussed, next, Section 4 present a linear power or a constant torque reference design. Next, the simulation result will be presented in Section 5. Finally, the conclusions are drawn at Section 6.

II. WIND TURBINE GENERATOR BASED ON DFIG MODEL

Compared to other wind turbine-based power generation systems, the control system of a DFIG-wind turbine is relatively more complex. The topology of a DFIG-based wind turbine system could be shown at Fig 1. As shown at Fig.1, the DFIG-based wind turbine system is composed by two independent converter control systems: Rotor side converter (RSC) and a Grid side converter (GSC) control systems. The main function of the RSC control system generally is to extract maximum wind power by means of a feedback control of the maximum stator power or the optimal rotor speed. Whereas the main role of the GSC control system is to inject DC bus power to the electrical grid by regulating the DC bus voltage at a certain level [18].

The converters' operation mode of the DFIG basically depend on the state of the rotor speed and they are always be inverse: if the rotor speed is at the sub-synchronous state, the power will flow from the DC bus capacitor to the rotor windings of the generator, so in this condition, the RSC have role as an inverter while the GSC have role as a rectifier that convert the AC grid power to the DC power of the DC bus capacitor. If the rotor speed is at the super-synchronous state, the power will flow from the rotor windings of the generator to the DC bus capacitor, so in this condition, the RSC have role as an converter while in the same time, the GSC have role as an inverter which convert the DC power of the DC bus capacitor to the AC grid power. Due to the inverse operation of these two converters, then the configuration of the converters of the DFIG is also well-known as back to back AC/DC/AC converters.

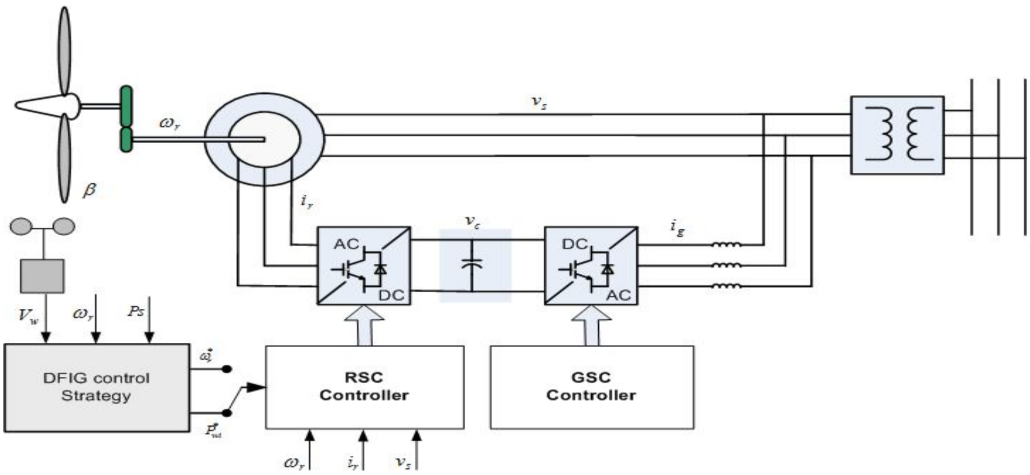

Fig. 1. DFIG-Wind Turbine control system model

The RSC system model basically composed from several functional blocks: the aerodynamic model, the drive train model, the electrical circuit of the wound rotor induction generator model and the RSC controller model. The integration of those models is shown at Fig. 2. The deep discussion of the DFIG dan drive train model could be referred to [19].

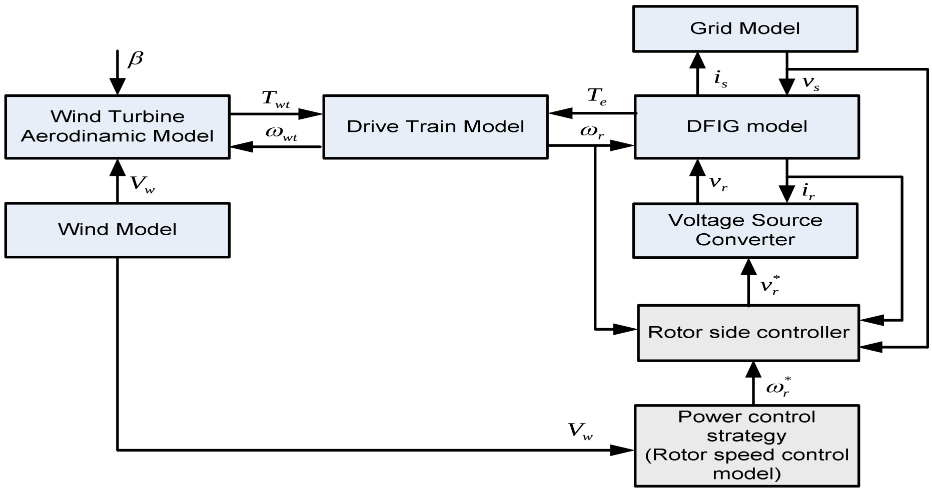

Fig. 2. DFIG- Wind Turbine control system model

III. WIND TURBINE AERODYNAMIC MODEL AND MPPT

Wind turbine power generation system is a energy conversion system which generating electrical energy by the conversion process of the wind energy into the mechanical rotation rotor and subsequently transform to electrical power via a generator. The power generated by wind mathematically could be represented as shown at (1):

$$P = \frac{1}{2}\rho A v^3 \quad (1)$$

Where P, ρ, A and v respectively are the power of the wind speed (W), the air density (kg/m3), the wind swept area of the turbine rotor blade (m2), and the wind speed (m/s). However the power absorption by a wind turbine practically depends on the turbine coefficient power factor which is affected by the turbine design as shown at (2).

$$P_m = \frac{1}{2}\rho\pi R^2 C_p(\lambda,\beta)v^3 \quad (2)$$

where Pm and Cp respectively are the mechanical power output of the turbine (W), and the power coefficient (wind turbine efficiency) that depend on the wind turbine tip speed ratio-TSR (λ) and the blade pitch angle (β).

Referring to [20], the power coefficient could be approximated by:

$$C_p(\lambda,\beta) = 0.73\left(\frac{151}{\lambda_i} - 0.58\beta - 0.002\beta^{2.14} - 13.2\right)e^{\frac{-18.4}{\lambda_i}} \quad (3)$$

Where

$$\lambda_i = \frac{1}{\frac{1}{\lambda - 0.02\beta} - \frac{0.003}{\beta^3 + 1}}$$

Fig. 3 and fig. 4 respectively show the relation between TSR vs the power coefficient and the block diagram of the wind turbine aerodynamic model.

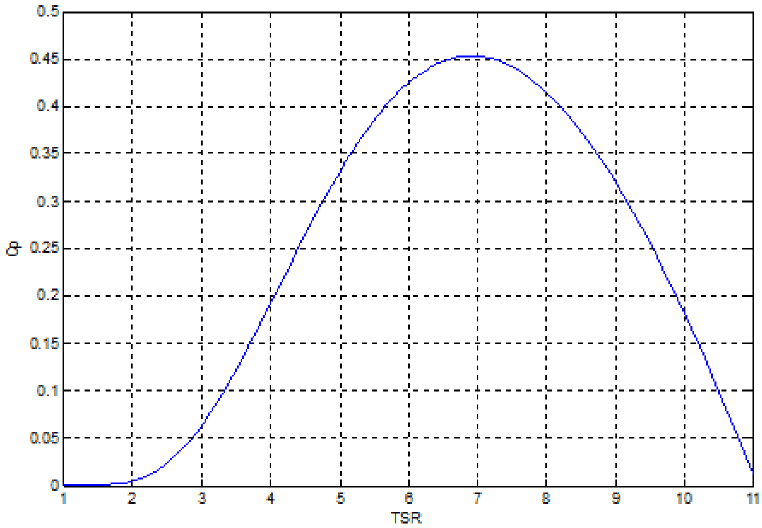

Fig.3. TSR versus power coefficient of the wind turbine

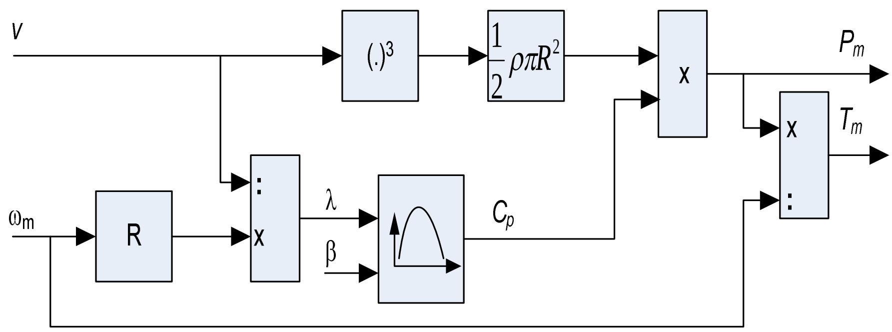

Fig. 4. The aerodinamic model of the wind turbine

Whereas Fig. 5 and fig. 6 respectively show the plot of the wind turbine power and wind turbine torque versus rotor speed for certain wind speed by using the aerodinamic wind turbine model. The dashed line in both pictures basically shows maximum power point and torque reference that should be tracked by the generator output. As seen in the both pictures, the use of MPPT reference will always result in a stable system. In this case, there should be always intersection point between aerodynamic power (torque) and power (torque) reference. However due the wind speed fluctuates rapidly, then the wind turbine generator power output also will be fluctuated by a cubic function of the wind speed.

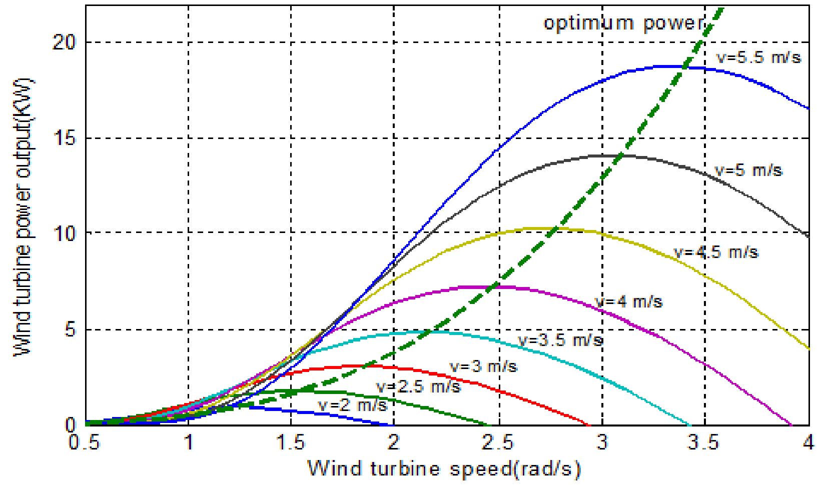

Fig.5. The dashed line show the power reference in the MPPT strategy

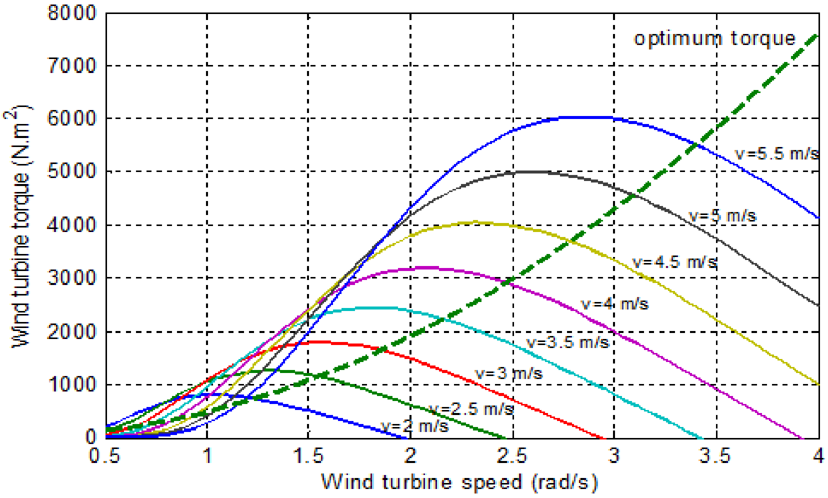

Fig. 6. The dashed line show the torque reference in the MPPT strategy

IV. DESIGN OF CONSTANT TORQUE REFERENCE

Fig. 7 shows the complete block diagram of the DFIG control system in the rotor side converter. In this research, we employ simple PI strategies for the inner current loop and the outer loop of the DIFG. The reader could refer to our previous work for the detail explanation of this control schema [19]. In this Section, we just will deliver the derivation of constant torque reference for this DFIG control system. For maximize the power extracted from the wind turbine generation system based on the DFIG, we should use MPPT algorithm as represented at (4) for the reference of the generator stator power (P_s^*).

$$P_s^* = \frac{K_{opt}}{1-s}\omega_{wt}{}^3 \quad (4)$$

Where $$K_{opt} = \left(\frac{1}{2}\frac{\rho A R^3 C_{p\_max}}{\lambda_{opt}{}^3}\right) \quad (5)$$

However, as shown at (4), the power generated by the generator will fluctuated severely due to the power output related cubically with wind speed. To minimize this power fluctuation, in this paper, we propose a linear power reference strategy or a constant torque strategy for the DFIG stator feedback control. Instead using MPPT method as shown at (4), to suppress power fluctuating, the linear power reference strategy as shown at (6) was employed in this paper.

$$P_s^* = \frac{K_{opt}}{1-s}\omega_{wt} \quad (6)$$

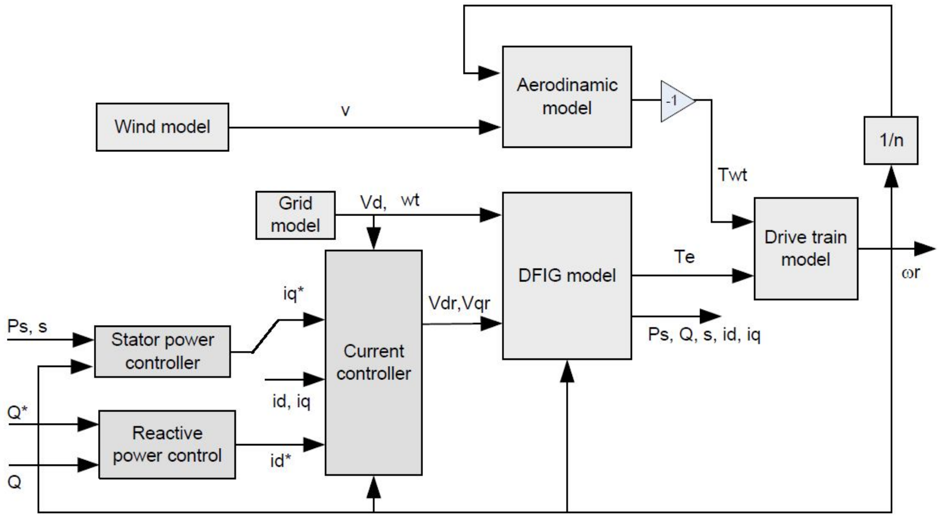

Fig. 7. DFIG control system in rotor side converter

V. SIMULATION RESULTS

To investigate the dynamic of the DFIG-wind turbine main variables under the proposed linear power/ constant torque control strategy, the complete simulation model which is run under Simulink/Matlab environment as shown at Fig.7. has been built based on component models of the DFIG-wind turbine control system. The parameters of the modeled wind turbine are presented in Appendix.

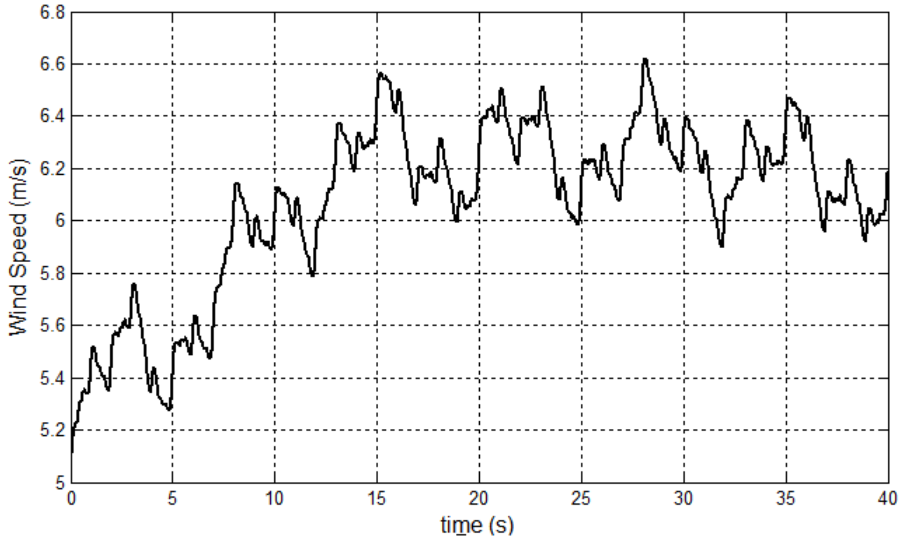

Fig. 8. Random wind profile (a) generated by simulation

Beside the linear power/ constant torque control strategy, for comparison purposes, in this work we also simulate the wind turbine model by using MPPT method. Fig. 8. till Fig. 10 Show the wind speed profile with difference magnitude that used to test the performance of the linear Power control strategy.

For all of the wind speed profile, the linear power reference or the constant torque reference which are used in this work are shown respectively at Fig.11 and Fig.12. By using the wind speed and the linear power reference in those plots, the response of the stator power that generated by the MPPT and linear power reference respectively are shown at Fig. 13, Fig.14, and Fig 15.

International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Issue 05, Volume 7 (May 2020) https://www.ijirae.com/archives

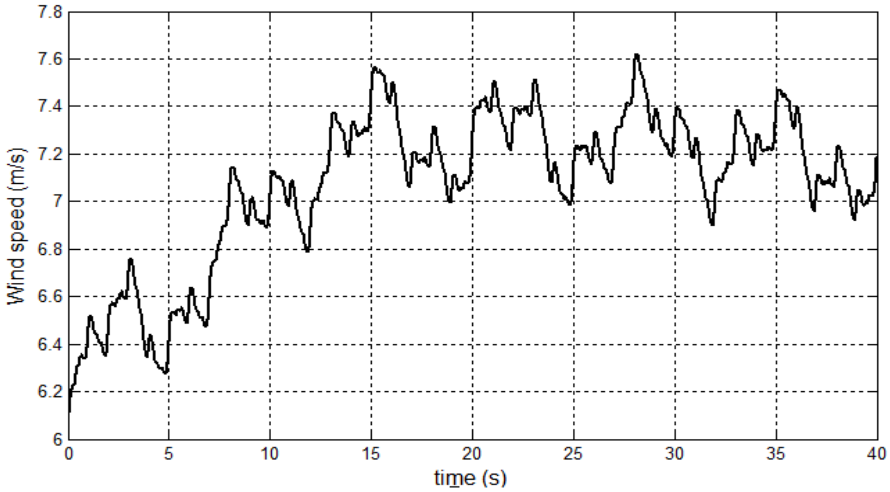

Fig.9. Random wind profile (b) generated by simulation

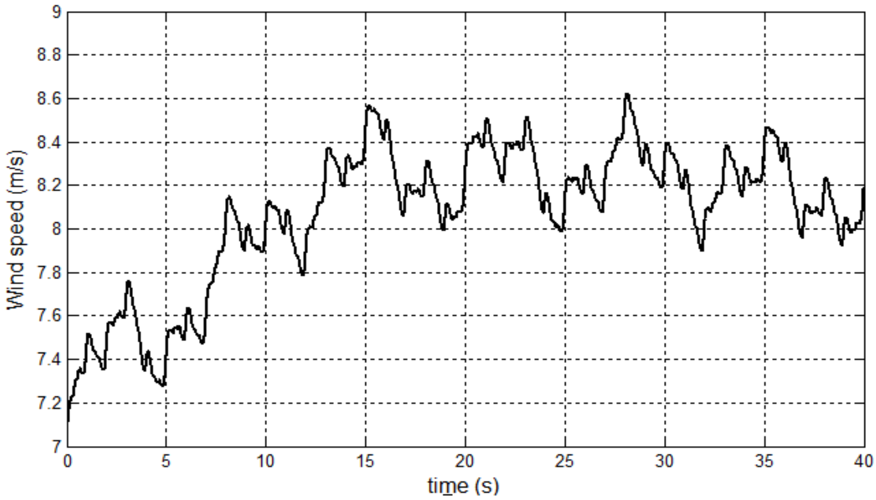

Fig. 10. Random wind profile (c) generated by simulation

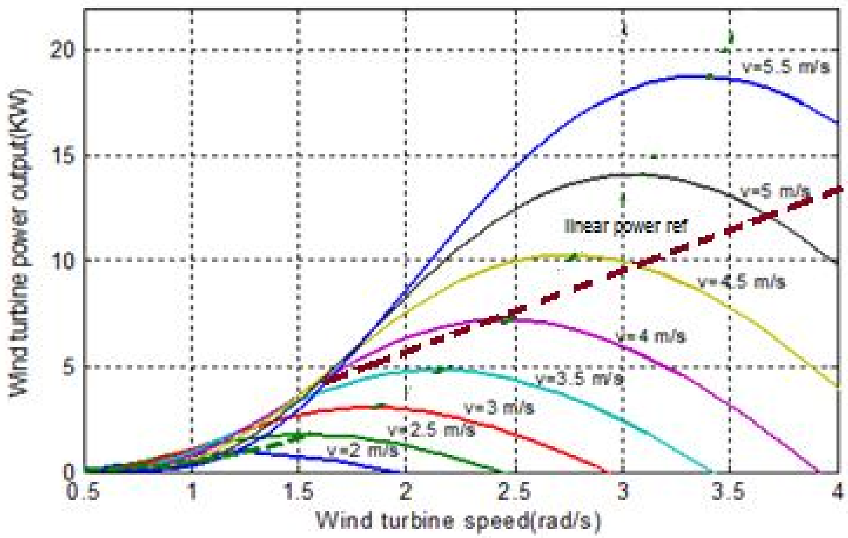

Fig. 11. The dashed line show power reference in the linear power/constant torque reference strategy

International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Issue 05, Volume 7 (May 2020) https://www.ijirae.com/archives

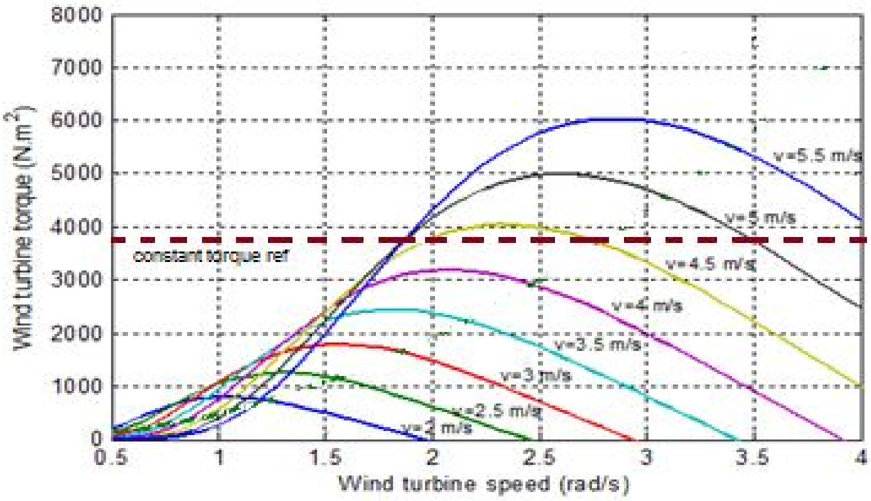

Fig. 12. The dashed line show torque reference in the linear power/constant torque reference strategy

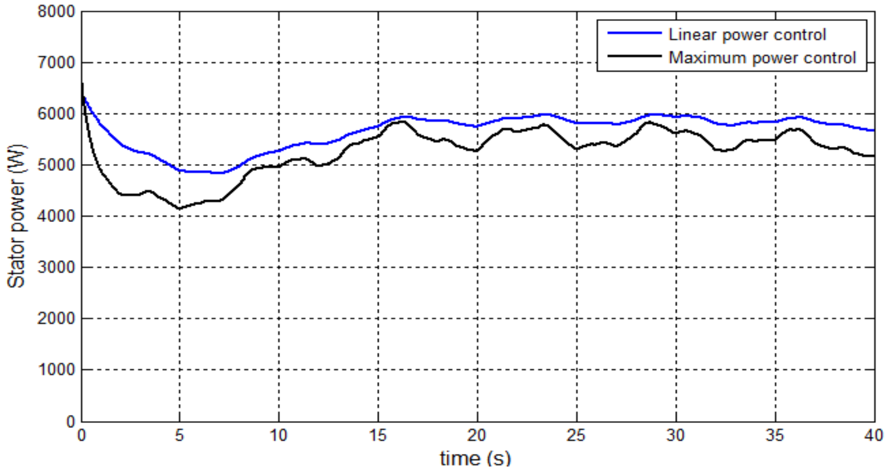

Fig. 13. Response of the total power under two different control strategies with the wind speed profile at Fig. 8

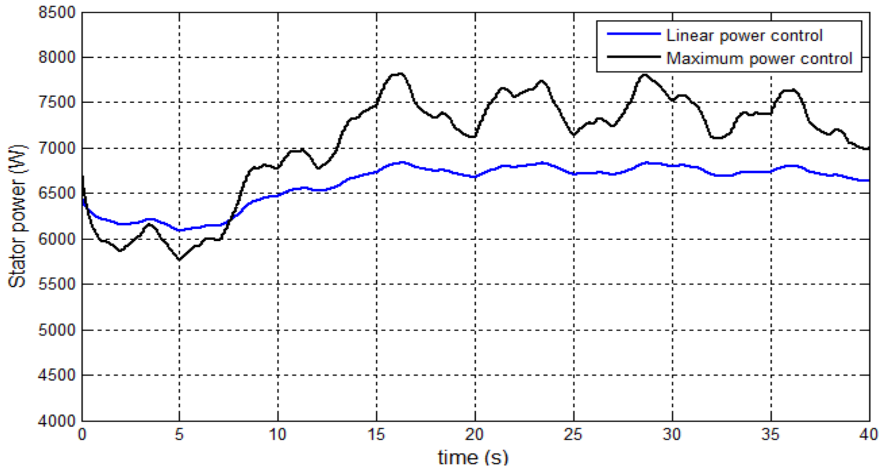

Fig. 14. Response of the total power under two different control strategies with the wind speed profile at Fig. 9

It is clear from the plots, that the stator power generated by the linear power control strategy or constant torque control strategy is less fluctuated compared to the stator power generated by maximum power control strategy.

However, compared to maximum power control strategy, the linear power control is less eficient in power extraction. For certain average wind speed, the efficiency of the linear power directly depends on the magnitude of the torque reference or the slope of the linear power reference which is used, or for certain magnitude of the torque reference, the average extracted power depend on the wind speed average.

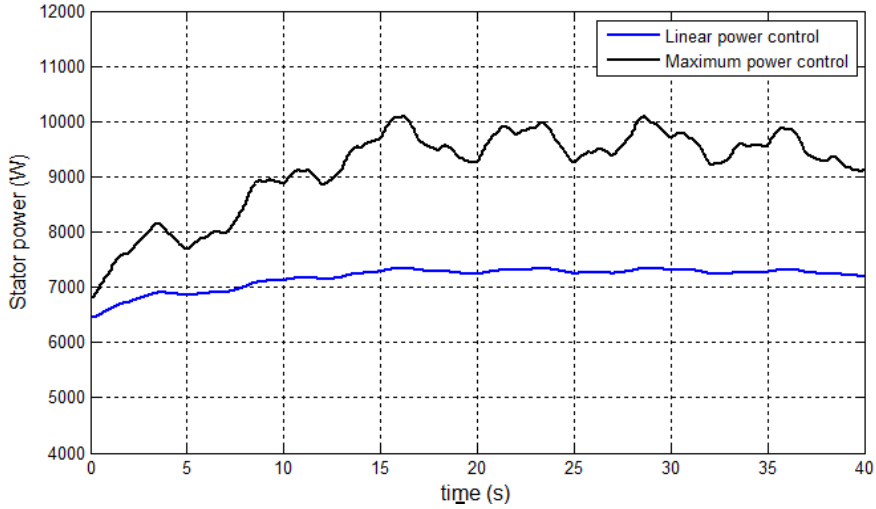

Fig. 15. Response of the total power under two different control strategies with the wind speed profile at Fig. 10

By comparing Fig. 13, Fig. 14 and 15, it could be seen that for relatively small average wind speed, the extracted wind power by the linear power is very efficient. However, as the average wind speed are higher, the extracted power by the linear power reference is less efficient compared with the MPPT power extraction.

VI. CONCLUSION

The minimize of the high fluctuation of the extracted wind power by using the linear power or constant torque reference strategy has been presented in this paper. Based on simulation resulted from Matlab/Simulink environment, it is shown that the power extracted by using the linear power or constant torque reference is smoother compared with the maximum power point tracking strategy. However, by using this strategy the power average is lower than the MPPT.

APPENDIX

DFIG parameter: R_r=0.65 ohm,L_r= 67.6e-3 (H), L_m= 63.9e-3 (H), R_s = 0.65 (Ohm), L_s =: 67.6e-3 (H), Pole=2, Ke=5.614, vs=311,wse=2*pi*50 rad/s Wind Turbine parameters: Blade radius =2.5 (m), Gear ratio=5, Jgen= 0.0203 (kgm2), JWT=17.4 (kgm2), J=0.717

ACKNOWLEDGMENT

This research was financially supported by The Faculty of Engineering, Diponegoro University, Indonesia through Strategic Research Grant 2020 with contract number **[2496/STE11/UN7.5.3.2/PP/2020].**

REFERENCES

1. Jha, Asu Ram. Wind turbine technology. CRC press, 2010.
2. Hansen, Anca D. "Wind turbine technologies." Wind Energy Engineering. Academic Press, 2017. 145-160.
3. Chen, Jian, et al. "Design of robust MPPT controller for grid-connected PMSG-Based wind turbine via perturbation observation based nonlinear adaptive control." Renewable energy 134 (2019): 478-495.
4. Kumar, Dipesh, and Kalyan Chatterjee. "A review of conventional and advanced MPPT algorithms for wind energy systems." Renewable and sustainable energy reviews 55 (2016): 957-970.
5. Tiwari, Ramji, and N. Ramesh Babu. "Fuzzy logic based MPPT for permanent magnet synchronous generator in wind energy conversion system." IFAC-PapersOnLine 49.1 (2016): 462-467.
6. Sitharthan, R., et al. "Adaptive hybrid intelligent MPPT controller to approximate effectual wind speed and optimal rotor speed of variable speed wind turbine." ISA transactions 96 (2020): 479-489.
7. C. Luo, H. Banakar,Sh. Baike,O Boon-Teck,"Strategies to Smooth Wind Power Fluctuations of Wind Turbine Generator",IEEE Transaction on Energy Conversion, Volume 22, Issue 2, Pages 341 - 349, June 2007

8. L. Qu, W. Qiao, Constant power control of DFIG wind turbines with supercapac-itor energy storage, IEEE Trans. Ind. Appl. 47 (2011) 359–367.

9. de Carvalho, Wilhiam C., et al. "Fuzzy-based approach for power smoothing of a full-converter wind turbine generator using a supercapacitor energy storage." Electric Power Systems Research 184 (2020): 106287.

10. M. Saejia, I. Ngamroo, Alleviation of power fluctuation in interconnected powersystems with wind farm by SMES with optimal coil size, IEEE Trans. Appl.Supercond. 22 (2012) 5701504.

11. Qais, Mohammed H., et al. "Output Power Smoothing of Grid-Tied PMSG-Based Variable Speed Wind Turbine Using Optimal Controlled SMES." 2019 54th International Universities Power Engineering Conference (UPEC). IEEE, 2019.

12. G. Suvire, P. Mercado, Active power control of a flywheel energy storage systemfor wind energy applications, IET Renew. Power Gener. 6 (2012) 9–16.

13. Iranmanesh, Shahrzad, and Roohollah Fadaeinedjad. "Using Flywheel Energy Storage System to mitigate voltage and power fluctuations due to aeroelastic aspects of wind turbines." 2016 24th Iranian Conference on Electrical Engineering (ICEE). IEEE, 2016.

14. X. Li, Fuzzy adaptive Kalman filter for wind power output smoothing withbattery energy storage system, IET Renew. Power Generation. 6 (2012) 340–347.

15. T. Senjyu, R. Sakamoto, T. Kaneko, A. Yona, T. Funabashi, Output power leveling of wind farm using pitch-angle control with fuzzy neural network, Electr. Power Compon. Syst. 36 (2008) 1048–1066.

16. Margo Pujiantara,et al. Output Power Smoothing of Doubly Fed Induction Generator Wind Turbine Using Very Short Term Wind Speed Prediction Based on Levenberg–Marquardt Neural Network, International Review on Modelling and Simulations (I.RE.MO.S.), Vol. 8, N. 5 ISSN 1974-9821 October 2015

17. Sadegh Ghani Varzaneh, G.B. Gharehpetian, Mehrdad Abedi, Output power smoothing of variable speed wind farms using rotor-inertia , Electric Power Systems Research 116 (2014) 208–217

18. Setiawan, Iwan, et al. "Investigation of symmetrical optimum PI controller based on plant and feedback liniearization in grid tie inverter systems." International Journal of Renewable Energy Research 7.3 (2017): 1228-1234.

19. Setiawan, I., Facta, M., Priyadi, A., Purnomo, M., Analysis and Comparison of Control Strategies for a DFIG-Small Wind Turbine System with High Fluctuating Wind Speed Conditions, (2017) International Review of Electrical Engineering (IREE), 12 (2), pp. 110-120.

20. Ling, Yu, Guoxiang Wu, and Xu Cai. "Comparison of wind turbine efficiency in maximum power extraction of wind turbines with doubly fed induction generator." Przegląd Elektrotechniczny Electrical Review 5 (2012).

