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Maximum power point tracking controller using Lyapunov theorem of wind turbine under varying wind conditions

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ABSTRACT

Due to the instantaneous variation in wind speed, it is necessary to identify the optimal rotational speed that ensures maximum energy efficiency and system stability. We proposed a controller based on the Lyapunov theorem to extract the maximum power from wind speed and to ensure the overall stability of the controlled system under random operating conditions imposed by wind speed and parameter variations. The control of the Tip speed ratio is based on the Lyapunov theorem (TSR_LT), which is a controller based on Lyapunov's theory and the definition of a positive, energetic function, to ensure the stability of the system being controlled, the dynamics of this function must be negative. The viability of this work is demonstrated by MATLAB-based mathematical and simulation models and a comparison with the results obtained using proportional integral (PI) controller-based tip speed ratio control (TSR_PI controller). The simulation results demonstrate the controller's effectiveness.

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1. INTRODUCTION

Renewable energy has become one of the most promising energy sources as a result of the advancements made in semiconductor technology and modern control techniques over the past few decades. Wind energy is one of the best renewable energy sources. As renewable energy becomes more prevalent, there is a growing interest in intelligently controlling wind turbines or wind plants to reduce the cost of wind energy. This can be accomplished by positioning the wind turbines to extract more wind energy, which is the focus of ongoing research.

In order to maintain the optimal blade tip speed ratio in order to achieve the maximum wind energy under both low and high wind speeds, a number of control strategies have been proposed over the past decade, the wind turbine Zhang *et al.* [1] proposed the fuzzy logic controller to control the wind wheel's rotation moment and the generator's reverse moment, Zhang *et al.* [2] Utilized the fuzzy logic controller to control the individual pitch angle of the turbine in order to guarantee a higher value for the power coefficient Cp, and thus the high aerodynamic torque. A new pitch controller based on the theory of generalized predictive control is proposed in Zhang *et al.* [3] to improve the quality of variable speed constant frequency power output in wind turbines. For maximum energy extraction from variable speed wind turbines, Calderaro *et al.* [4] proposed a data-driven design methodology able to generate a Takagi–Sugeno–Kang (TSK) fuzzy model, combined with genetic algorithms (GA) and recursive least-squares (LS) optimization methods for model parameter adaptation. Matthew and Saravanakumar [5] proposed a nonlinear controller, namely double integral sliding mode controller (DISMC), for the single mass model of a wind turbine at partial load region (below rated wind speed) to address the issue of optimal power extraction for variable-speed wind energy conversion systems (VSWECS) at partial load. Ullah *et al.* [6] proposed the linear active disturbance rejection control to control the output power and rotor speed of the wind turbine for variable pitch and variable speed wind turbine. Arya and Dewan [7] applied the H-infinity controller for speed control of variable speed wind turbine to solve the issue of the variation in rotor speed caused by the load charge. To achieve precise pitch control, the adaptive backstepping pitch angle control for wind turbines based on a servo-valve-controlled hydraulic motor was proposed in Yin *et al.* [8].

The proposed controller that is based on a Lyapunov theorem (the TSR_ LT controller) has as its goal the extraction of the maximum amount of power available from the wind. The proposed controller is primarily based on the definition of error speed, which is the difference between the optimal speed and the generator speed. This is done to ensure that the error will converge toward zero and that the system will be stable as a whole. It is essential to make certain that the Lyapunov energy function has a negative value by performing an action on the electromagnetic torque, which acts as a substitute for a command virtually.

The remaining sections are organized as: The modelling of the system is presented in section 2. The theory of turbine control and the proposed controller applied to our system were presented in section 3. The simulation results obtained and the discussion of these results were presented in section 4, and we concluded this work in section 5.

2. MODELING OF SYSTEM

2.1. Mathematical model for wind turbine

The wind power is converted into aerodynamic power and aerodynamic torque according to the Betz's law [9]–[11]. The aerodynamic power is given by (1).

$$P_{aer} = \frac{1}{2} C_p(\lambda, \beta) \rho \pi R^2 V^3 \tag{1}$$

where V is the wind speed, ρair density, tip speed ratio area of the turbine blades in m^2, wind turbine radius, and power coefficient.

The power coefficient $C_p(\lambda, \beta)$ can be represented by (2) [12].

$$\begin{cases} C_p(\lambda, \beta) = c_1 \left(\frac{c_2}{\lambda_i} - c_3\beta - c_4 \right) e^{\frac{c_5}{\lambda_i}} + c_6\lambda \\ \frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \end{cases} \tag{2}$$

The tip speed ratio λ. It is given by (3) [13], [14].

$$\lambda = \frac{R\Omega_t}{V} \tag{3}$$

where Ω_t is the turbine shaft speed.

The turbine torque is the ratio of the aerodynamic power to the turbine shaft speed:

$$T_{ear} = \frac{P_{aer}}{\Omega_t} = \frac{1}{2\lambda} C_p(\lambda, \beta) \rho \pi R^3 V^2 \tag{4}$$

The mechanical equation of the generator is given as (5) [15]:

$$j \frac{d\Omega_g}{dt} = T_g - T_{em} - f_c \Omega_g \tag{5}$$

where T_{em} is the electromagnetic torque, j is the total moment of inertia and f_c is the coefficient of viscous friction, Ω_g is the generator shaft speed, and T_g is the generator torque. Where the shaft speed and torque of the generator are given by (6).

$$T_g = \frac{T_{aer}}{G}$$
$$\Omega_g = G\Omega_t \quad (6)$$

From (4), it is observed that the aerodynamic torque mainly depends on the value of the power coefficient C_P and the wind speed V So for each wind speed there is only one maximum torque and consequently only one maximum power point this point is configured by the C_P^{max} and optimal λ_{opt}; this can be seen in the nonlinear torque-speed characteristic curve of a turbine shown in Figures 1 and 2. From Figure 1, we can see that for each wind speed, there is a maximum point. Two quantities define this ultimate point *C_P^max* and *λ_opt*, this can be seen that in the Figure 2, the objective of the control to reach these points is to extract the total amount of power available from the wind.

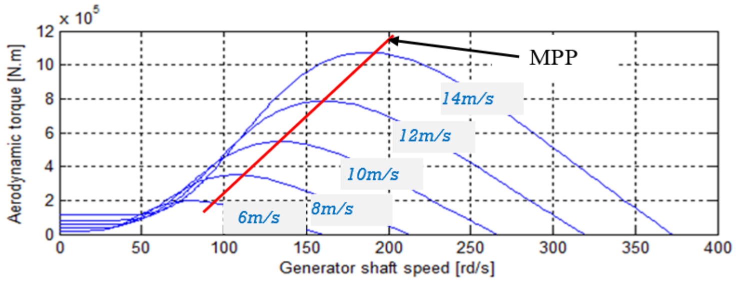

Figure 1. Torque-speed characteristic for different wind speeds

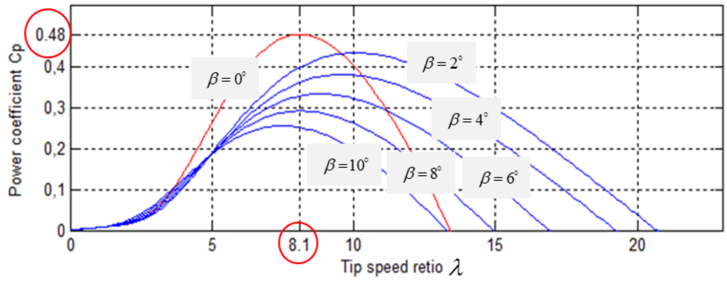

Figure 2. Power coefficient versus tip speed ratio

3. TURBINE CONTROL

There are numerous control techniques utilized to reach the maximum power point (MPPT). These control techniques include: tip speed ratio and optimal torque control. In this field, there are several literature searches done [10], [16]–[18].

3.1. Tip speed ratio control

The tip speed ratio (TSR) control method requires maintaining the TSR at an optimal value, to extract the maximum power in the wind speed [15], [19]–[21]. This method relies on the knowledge of wind speed and turbine is required, in order to keep the turbine operating in the maximum power point, Figure 3 represent the Tip speed ratio control method.

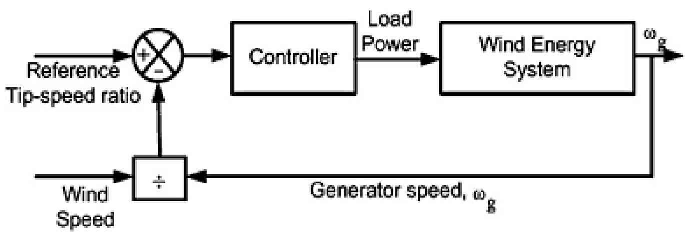

Figure 3. Tip speed ratio control [22]

3.2. Optimal torque control

This control is based on the calculation of an optimal reference torque T_{opt}. According to the optimal λ_{opt} and the C_P^{max}, the only variable in the reference torque is the wind speed. The error between this torque T_{opt} and the generator torque T_g is regulated via a regulator Figure 4. Several regulators are used in the literature [19], [22]–[26].

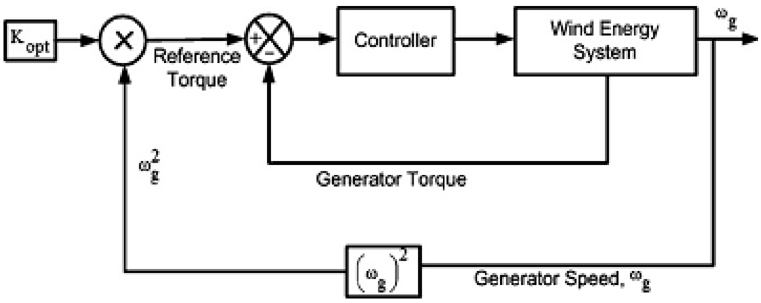

Figure 4. Optimal torque control [22]

3.3. Proposed controller design

The speed error can be defined as (7):

$$e = \Omega_{gref} - \Omega_g \tag{7}$$

where the reference speed is given by (8):

$$\Omega_{gref} = \frac{\lambda_{opt}V}{R} \tag{8}$$

From (5) and (8), the dynamic speed error is defined as (9).

$$e = \frac{\lambda_{opt}V}{R} - \frac{1}{j}\left(T_g - T_{em} - f_c\Omega\right) \tag{9}$$

The proposed Lyapunov function is defined as (10).

$$V = \frac{1}{2}e^2 \tag{10}$$

The Lyapunov function's derivative can be calculated using (9):

$$V = e\left[\frac{\lambda_{opt}V}{R} - \frac{1}{j}\left(T_g - T_{em} - f_c\Omega\right)\right] \tag{11}$$

To ensure the system's stability, the proposed Lyapunov function is defined as positive; it is necessary to ensure the function's negativity by selecting the optimal virtual control [27].

In this case, the virtual control is electromagnetic torque:

$$T_{em} = \frac{-j\lambda_{opt}V}{R} + T_g - f_c\Omega - jke \tag{12}$$

where k is the constant positive gain. To justify the system's stability according to the Lyapunov theorem, the dynamic of the Lyapunov function must be negative.

If we replaced the (12) into (11), we have:

$$V = -ke^2 \leq 0 \tag{13}$$

From (13), we can say that the system is stable. Figure 5 represents the proposed controller.

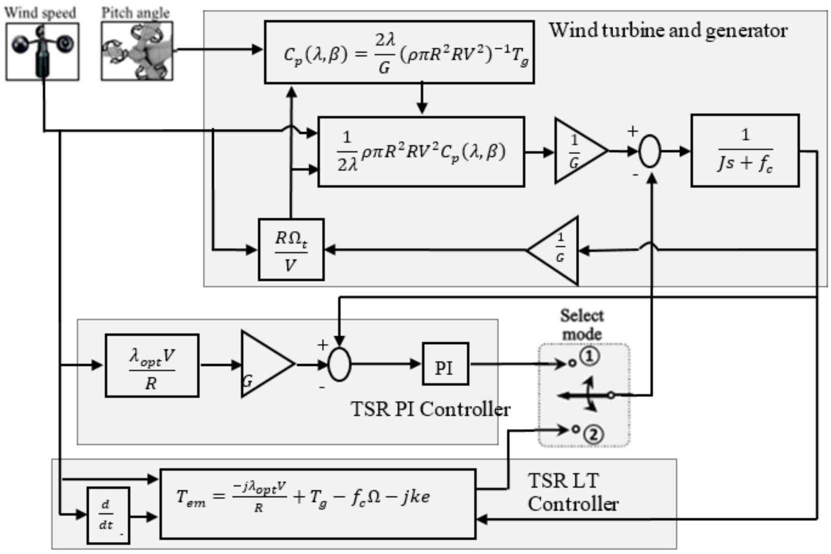

Figure 5. WFSG model and control structure with select mode

4. SIMULATION RESULTS

The proposed controller's simulation was carried out in the MATLAB Simulink environment. The proposed TSR LT controller's speed regulation performance will be compared to the TSR PI controller in this section. The goal of this regulation is to extract as much wind energy as possible in order to generate as much electricity as possible. In this regard, the wind turbine speed must be continuously adjusted in response to wind speed variations. The wind speed profile is represented in Figure 6 with 14% and 16% density. Table 1 lists the wind energy conversion systems (WECS's) parameters.

Table 1. Parameters of turbine and permanent magnet synchronous generator (PMSG)

Turbine	PMSG
$\rho = 1.22Kg/m^3$	$P_{sn} = 1.5\ MW$
$R = 35.35m$	$2P = 80$
$\beta = 0°$	$R_s = 3.17m\Omega$
$G = 70$	$L_s = 3.7mH$
	$\phi_f = 7.0172Wb$

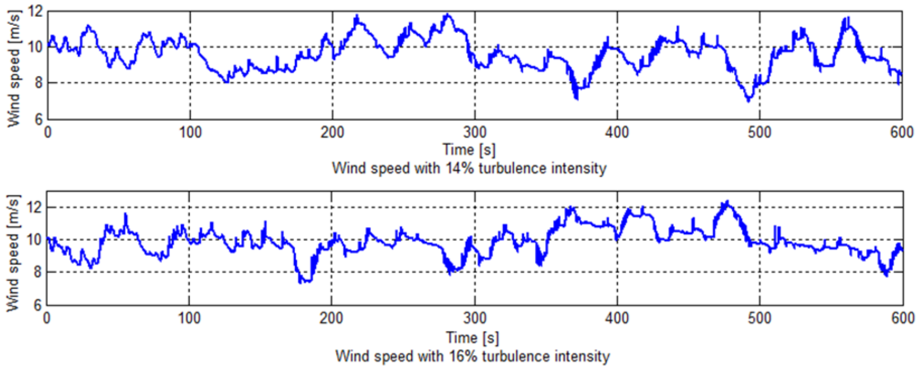

Figure 6. windspeed profile with the 14% and 16% turbulence intensity

4.1. Test I

Figures 7(a), 7(b) and 8(a), 8(b) show the simulation results for the TSR PI and TSR LT controllers for the 14 percent density wind speed profile, and Figures 9(a), 9(b) and 10(a), 10(b) show the simulation results for the 16 percent density wind speed profile. Figures 7(a), 8(a), 9(a), 10(a), 7(b), 8(b), 9(b), and 10(b) represent the power coefficient and tip speed ratio, respectively. We can see from these figures that the commands TSR PI and TSR LT keep the system running at maximum power with different time responses between the controls.

The generator speed is shown in Figures 7(c), 8(c), 9(c), and 10(c). In the two proposed controllers, TSR PI and TSR LT, the generator speed takes the same form as the optimum speed, with excellent tracking of optimum speed in the TSR LT controller. Figures 7(d), 8(d), 9(d), and 10(d) depict generator torque and aerodynamic torque for wind speeds of 14 percent density, 16 percent density, and 18 percent density, respectively. The generator torque and aerodynamic torque are shown in Figures 7(e), 8(e), 9(e), and 10(e). The generator torque is adapted to the aerodynamic torque variation, as shown in the figures. Figures 7(f), 8(f), 9(f), and 10(f) show how the generator torque is proportional to the aerodynamic power, which converts to an aerodynamic torque Figure 10(f).

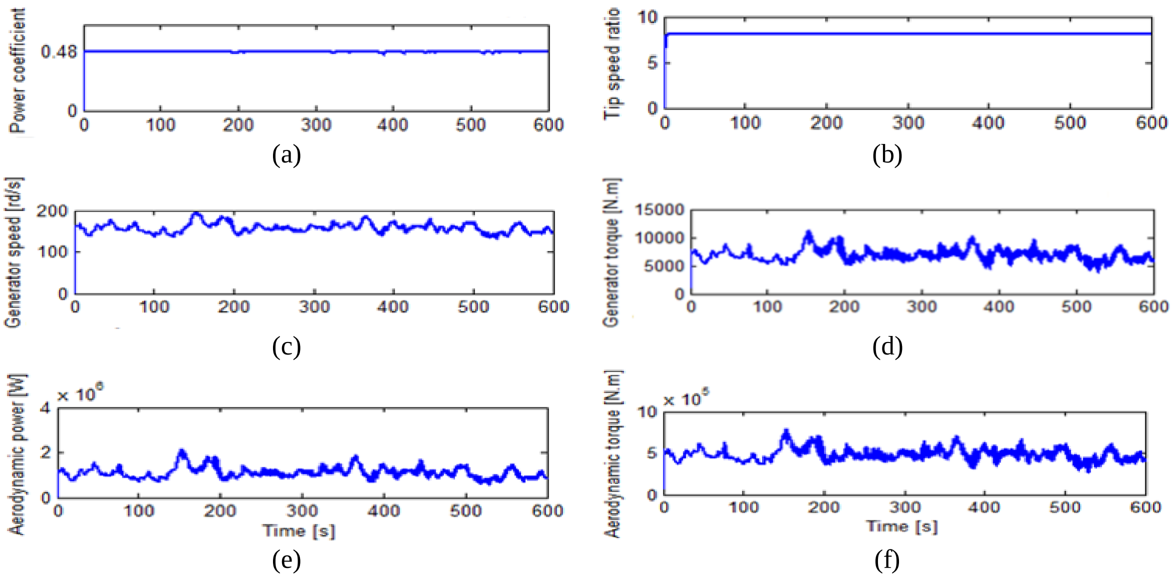

Figure 7. Wind turbine generator system (WTGS) performance based on 14% turbulence intensity wind speed in TSR_LT controller; (a) power coefficient, (b) tip speed ratio, (c) generator speed, (d) generator torque, (e) aerodynamic torque, and (f) aerodynamic power

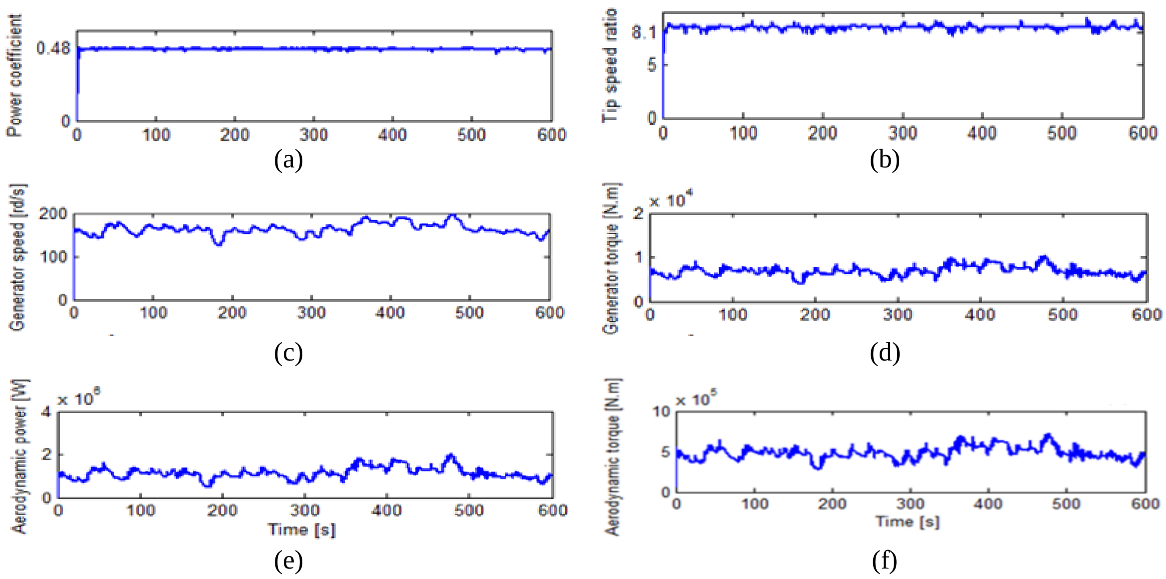

Figure 8. WTGS performance based on 14% turbulence intensity wind speed in TSR_PI controller; (a) power coefficient, (b) tip speed ratio, (c) generator speed, (d) generator torque, (e) aerodynamic torque, and (f) aerodynamic power

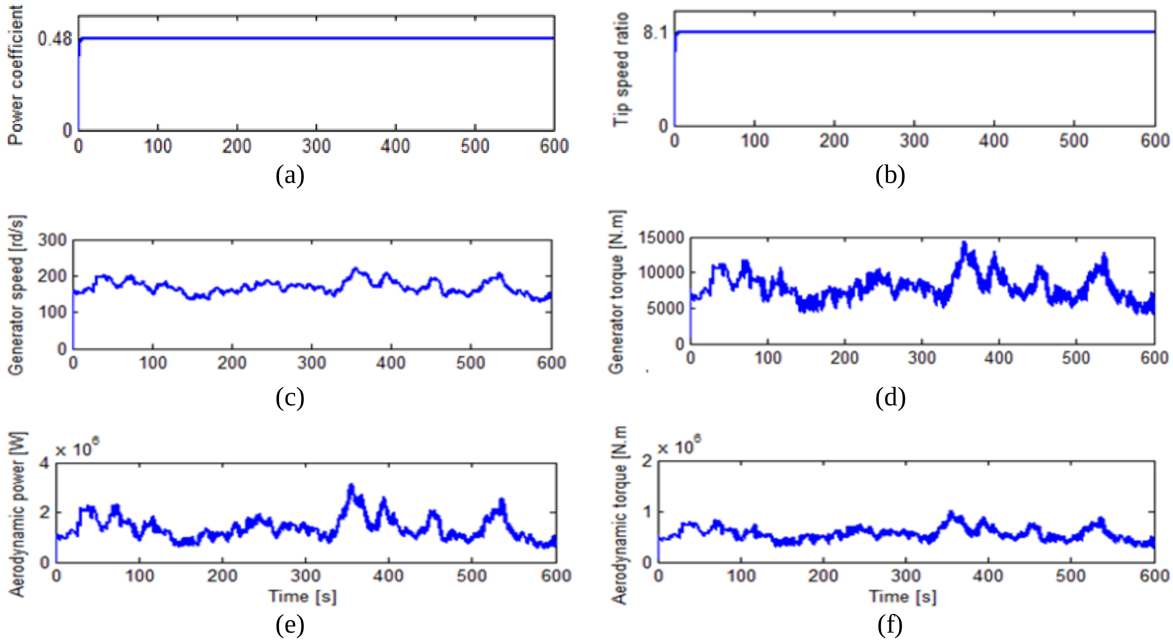

Figure 9. WTGS performance based on 16% turbulence intensity wind speed in TSR_LT controller; (a) power coefficient, (b) tip speed ratio, (c) generator speed, (d) generator torque, (e) aerodynamic torque, and (f) aerodynamic power

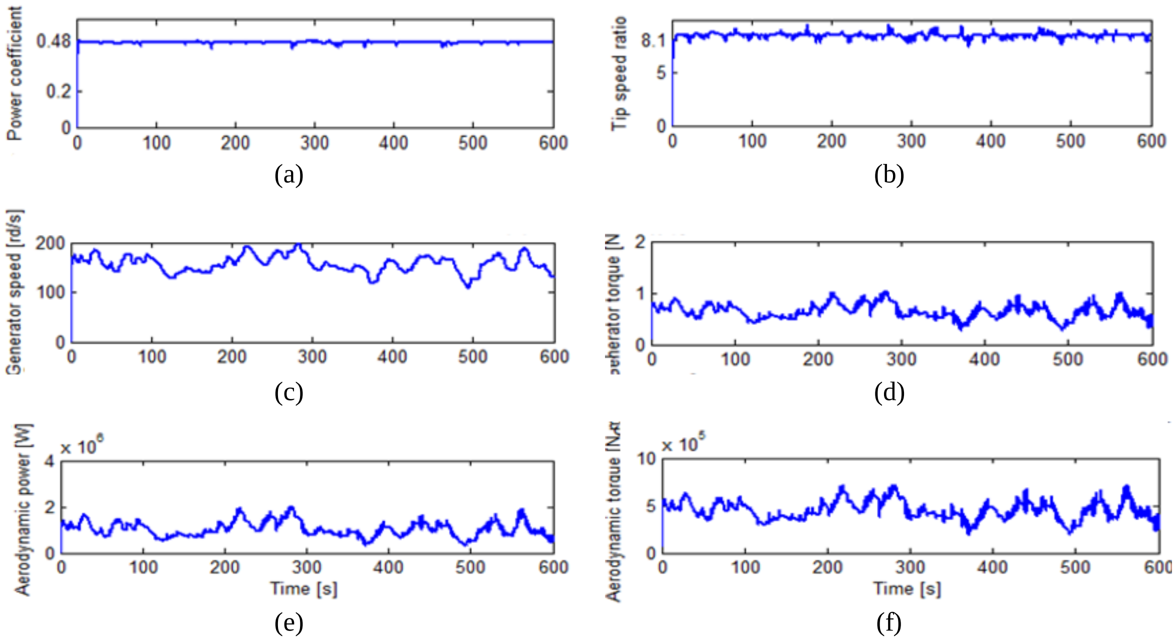

Figure 10. WTGS performance based on 16% turbulence intensity wind speed in TSR_PI controller; (a) power coefficient, (b) tip speed ratio, (c) generator speed, (d) generator torque, (e) aerodynamic torque, and (f) aerodynamic power

From Figures 11 and 12, we compare the critical point C_P^{max} and λ for the two winds speed profiles, 16% and 14%, in the two controllers, tip speed ratio-proportional integral (TSR_PI) and tip speed ratio-Lyapunov theorem (TSR_LT). From the results obtained, we notice that the TSR_LT controller gives good performance in maximum power point tracking, which justifies good maintenance and stability of C_P its value of $C_P^{max} = 0.48$ and $\lambda = 8.1$ for any wind speed.

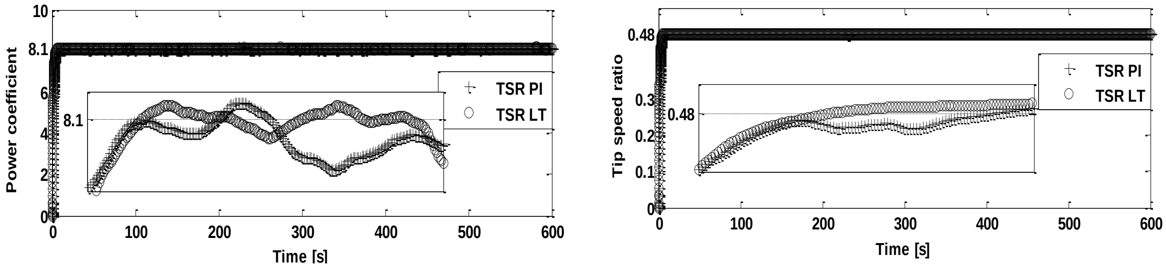

Figure 11. WTGS performance based on 14% turbulence intensity wind speed

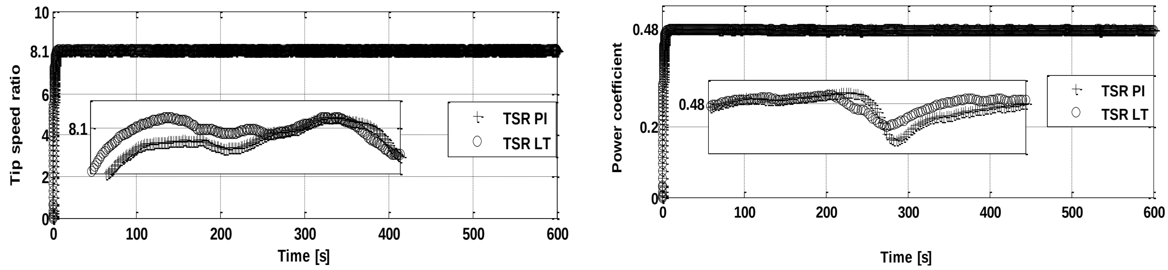

Figure 12. WTGS performance based on 16% turbulence intensity wind speed

5. CONCLUSION

To operate the wind energy conversion system based on the Lyapunov theorem, we proposed a tip speed ratio control based on a permanent synchronous generator at the maximum power point and ensure the system's overall stability under all operating conditions. In comparison to a traditional PI controller, the TSR LT controller reached the maximum power point quickly and has good stability for a wide range of wind speed densities. Based on the simulation results and a comparison with the PI controller-based tip speed ratio control, we concluded that the Lyapunov theorem-based tip speed ratio control is very efficient, and we recommend using artificial intelligence in future work.

REFERENCES

[1] X. Zhang, W. Wang, Y. Liu, and J. Cheng, "Fuzzy control of variable speed wind turbine," in *2006 6th World Congress on Intelligent Control and Automation*, 2006, pp. 3872–3876, doi: 10.1109/WCICA.2006.1713097.

[2] X. Zhang, W. Wang, F. Li, and Y. Dai, "Individual pitch control based on fuzzy PI used in variable speed wind turbine," in *2012 12th International Conference on Control Automation Robotics and Vision (ICARCV)*, Dec. 2012, pp. 1205–1208, doi: 10.1109/ICARCV.2012.6485358.

[3] J. Zhang, H. Wang, G. Hou, and J. Zhang, "Generalized predictive control for wind turbine systems," in *2010 5th IEEE Conference on Industrial Electronics and Applications*, Jun. 2010, pp. 679–683, doi: 10.1109/ICIEA.2010.5516988.

[4] V. Calderaro, V. Galdi, A. Piccolo, and P. Siano, "A fuzzy controller for maximum energy extraction from variable speed wind power generation systems," *Electric Power Systems Research*, vol. 78, no. 6, pp. 1109–1118, Jun. 2008, doi: 10.1016/j.epsr.2007.09.004.

[5] K. Matthew and R. Saravanakumar, "Design of double integral sliding mode control for variable speed wind turbine at partial load region," in *2017 IEEE International Conference on Computational Intelligence and Computing Research (ICCIC)*, Dec. 2017, pp. 1–5, doi: 10.1109/ICCIC.2017.8524196.

[6] F. Ullah, S. Ali, D. Ying, and A. Saeed, "Linear active disturbance rejection control approach base pitch angle control of variable speed wind turbine," in *2019 IEEE 2nd International Conference on Electronics Technology (ICET)*, May 2019, pp. 614–618, doi: 10.1109/ELTECH.2019.8839443.

[7] D. K. Arya and L. Dewan, "Speed control of variable speed wind turbine system," in *2015 International Conference on Energy, Power and Environment: Towards Sustainable Growth (ICEPE)*, Jun. 2015, pp. 1–5, doi: 10.1109/EPETSG.2015.7510078.

[8] X. Yin, Y. Lin, W. Li, Y. Gu, P. Lei, and H. Liu, "Adaptive back-stepping pitch angle control for wind turbine based on a new electro-hydraulic pitch system," *International Journal of Control*, vol. 88, no. 11, pp. 2316–2326, Nov. 2015, doi: 10.1080/00207179.2015.1041554.

[9] Y. Errami, A. Obbadi, and S. Sahnoun, "MPPT control for grid connected wind energy conversion system based permanent magnet synchronous generator (PMSG) and five-level neutral point clamped converter," *IOP Conference Series: Materials Science and Engineering*, vol. 765, no. 1, Mar. 2020, doi: 10.1088/1757-899X/765/1/012042.

[10] K. D. E. Kerrouche, A. Mezouar, L. Boumediene, and A. Van Den Bossche, "Modeling and lyapunov-designed based on adaptive gain sliding mode control for wind turbines," *Journal of Power Technologies*, vol. 96, no. 2, pp. 124–136, 2016.

[11] K. D.-E. Kerrouche, A. Mezouar, L. Boumediene, and K. Belgacem, "Modeling and optimum power control based DFIG wind energy conversion system," *International Review of Electrical Engineering (IREE)*, vol. 9, no. 1, pp. 174–185, Feb. 2014, doi: 10.15866/iree.v9i1.118.

[12] E. M. Youness *et al.*, “Implementation and validation of backstepping control for PMSG wind turbine using dSPACE controller board,” *Energy Reports*, vol. 5, pp. 807–821, Nov. 2019, doi: 10.1016/j.egyr.2019.06.015.
[13] A. Mechter, K. Kemih, and M. Ghanes, “Backstepping control of a wind turbine for low wind speeds,” *Nonlinear Dynamics*, vol. 84, no. 4, pp. 2435–2445, Jun. 2016, doi: 10.1007/s11071-016-2655-y.
[14] N. Abu-Tabak, “Dynamic stability of multi-machine electrical systems: modelling, control, observation and simulation,” (In French) Ecole Centrale de Lyon, 2008.
[15] Y. Saidi, A. Mezouar, Y. Miloud, K. D. E. Kerrouche, B. Brahmi, and M. A. Benmahdjoub, “Advanced non-linear backstepping control design for variable speed wind turbine power maximization based on tip-speed-ratio approach during partial load operation,” *International Journal of Dynamics and Control*, vol. 8, no. 2, pp. 615–628, Jun. 2020, doi: 10.1007/s40435-019-00564-3.
[16] A. Mesemanolis, C. Mademlis, and I. Kioskeridis, “High-efficiency control for a wind energy conversion system with induction generator,” *IEEE Transactions on Energy Conversion*, vol. 27, no. 4, pp. 958–967, Dec. 2012, doi: 10.1109/TEC.2012.2213602.
[17] E. S. Abdin and W. Xu, “Control design and dynamic performance analysis of a wind turbine-induction generator unit,” *IEEE Transactions on Energy Conversion*, vol. 15, no. 1, pp. 91–96, Mar. 2000, doi: 10.1109/60.849122.
[18] R. A. Gupta, B. Singh, and B. B. Jain, “Wind energy conversion system using PMSG,” in *2015 International Conference on Recent Developments in Control, Automation and Power Engineering (RDCAPE)*, Mar. 2015, pp. 199–203, doi: 10.1109/RDCAPE.2015.7281395.
[19] S. Lalouni, D. Rekioua, K. Idjdarene, and A. Tounzi, “Maximum power point tracking based hybrid hill-climb search method applied to wind energy conversion system,” *Electric Power Components and Systems*, vol. 43, no. 8–10, pp. 1028–1038, Jun. 2015, doi: 10.1080/15325008.2014.999143.
[20] K. N. Yu and C. K. Liao, “Applying novel fractional order incremental conductance algorithm to design and study the maximum power tracking of small wind power systems,” *Journal of Applied Research and Technology*, vol. 13, no. 2, pp. 238–244, Apr. 2015, doi: 10.1016/j.jart.2015.06.002.
[21] D. Zouheyr, B. Lotfi, and B. Abdelmadjid, “Improved hardware implementation of a TSR based MPPT algorithm for a low cost connected wind turbine emulator under unbalanced wind speeds,” *Energy*, vol. 232, Oct. 2021, doi: 10.1016/j.energy.2021.121039.
[22] M. A. Abdullah, A. H. M. Yatim, C. W. Tan, and R. Saidur, “A review of maximum power point tracking algorithms for wind energy systems,” *Renewable and Sustainable Energy Reviews*, vol. 16, no. 5, pp. 3220–3227, Jun. 2012, doi: 10.1016/j.rser.2012.02.016.
[23] M. Hannachi, O. Elbeji, M. Benhamed, and L. Sbita, “Optimal torque maximum power point technique for wind turbine: Proportional–integral controller tuning based on particle swarm optimization,” *Wind Engineering*, vol. 45, no. 2, pp. 337–350, Apr. 2021, doi: 10.1177/0309524X19892903.
[24] M. Jingfeng, W. Aihua, W. Guoqing, and Z. Xudong, “Maximum power point tracking in variable speed wind turbine system via optimal torque sliding mode control strategy,” in *2015 34th Chinese Control Conference (CCC)*, Jul. 2015, pp. 7967–7971, doi: 10.1109/ChiCC.2015.7260906.
[25] M. Shirazi, A. H. Viki, and O. Babayi, “A comparative study of maximum power extraction strategies in PMSG wind turbine system,” in *2009 IEEE Electrical Power & Energy Conference (EPEC)*, Oct. 2009, pp. 1–6, doi: 10.1109/EPEC.2009.5420931.
[26] M. Yin, W. Li, C. Y. Chung, L. Zhou, Z. Chen, and Y. Zou, “Optimal torque control based on effective tracking range for maximum power point tracking of wind turbines under varying wind conditions,” *IET Renewable Power Generation*, vol. 11, no. 4, pp. 501–510, Mar. 2017, doi: 10.1049/iet-rpg.2016.0635.
[27] F. Wang, W. Chen, H. Dai, J. Li, and J. Jia, “Backstepping control of a quadrotor unmanned aerial vehicle based on multi-rate sampling,” *Science China Information Sciences*, vol. 62, no. 1, Jan. 2019, doi: 10.1007/s11432-018-9542-3.

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