Modelling And Control of 6MG Siemens Wind Turbine Blades Angle and Rotor Speed

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Abstract: In this article, dynamic modelling of governed on various parts of the Siemens SWT-6.0 6 MW wind turbine, for critical work point, rotor output speed operation, and bade step angle in the presence of tracking aim various profiles with oscillation and constant speed profile are investigated. Also, the classic controller with frequency instability impact elimination time filter of synchronous generator against wind immediate changes to the model has been used. Choosing classic controller coefficients causes both turbine rotor speeds control to reduce rotor speed excessive effect in low frequency and to converge with control aim signal and output frequency regulation in PMSG generator also provides necessary changes for blade step angle in authorized and unauthorized wind various speeds for pitch driver. Simulation results show fairly accurate control of rotor speed output behaviour and necessary changes to drive blade step angle with a small percentage of RMS fault and mean squared error of plant output signals for model uncertainty.

Keywords: Turbine Rotor Speed Control; PMSG Synchronous Generator; Controller; 6 MW Turbine of Siemens Company.

1. Introduction

Today, needing to renewable energy is essential and forecasts show that global demand to clean energy will have been triple by 2050[1]. By the end of 2015, installed wind energy capacity based on World Wind Energy Association (WWEA) statistics will have been more than 420MW and will have been at least 1500MW by 2020 [2,3,4]. SFIGURE and DFIGURE are two wind turbines that control operation can be implemented on them [5]. triple re of structure roller-tower and wind turbine blades in this article isSWT-6.0 model of Siemens company which follows Direct Drive technology of Permanent Magnet Synchronous Generator (PMSG), three horizontal-axis blades and Offshore structure [4,6,7]. Using Permanent Magnet Synchronous Generator (PMSG) in an offshore wind turbine causes 50% reduction in mechanical stimulation equipment due to removing slider loop, brush, rotor winding, and gear box. Also, reduce tower mass to less than 350 tons compared to synchronous generator Nassel tower of SG type generator [7].

In recent years, Matlab, Simulink, and Wind-pro software have become powerful tools for dynamic modelling and simulation in real wind turbine systems [8]. Due to parametric data effects governing on wind turbine of SWT 6.0MW model of Siemens company, for authorized, unauthorized and critical speed from 3m/s to 70m/s and height 156, both tower and turbine blades to direct effectiveness of wind speed to turbine elastic blades placed in the sea (offshore), have control ability and control aim tracing to set generator rotor constant speed and acceptable changes for pitch angle [9, 10]. Therefore, avoiding exhaustion and mechanical drives fluctuations (rotor and blade) is an essential work. To solve this problem, control various algorithms such as LQG [11,12], fuzzy gain controllers [13,14],adaptive controllers [15], and classical controllers are limited to the most ideal control state for a dynamic section of wind turbine with PI controller [16,17,18] is designed that all above methods are valid for a finite work

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point. In researches limited to control turbine rotor speed, blade step angles, and output frequency dependent on generator rotor speed, are presented based on the most critical work point of Drivetrain turbine dynamic with permanent magnet synchronous generator (PMSG). In this article, in addition to turbine aerodynamic sections modelling, two classical methods based on PID controller improved coefficients with instability effect remove the filter of the derivative term in rotor output frequency behaviour in various wind speed has been used to apply tracing aim real RMS fault and control output for Siemens 6MW turbine.

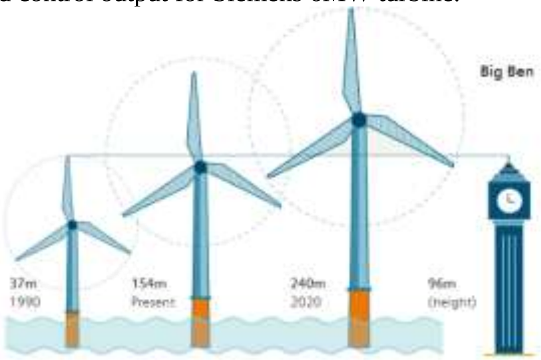


Figure 1. Structural design scale of 6mw to 350mw turbines from 1990 to 2016.

2. Control block diagram model structure and PMSG generator of SWT-6.0 wind turbine

In wind turbine control modelling structure, various sections have been used for wind swinging speed to control and required changing of rotor speed and blade step angle to control modern and classic methods (Figure.2) [3]. Also, Permanent Magnet Synchronous Generator (PMSG) consisting of a DC to AC rectifier and a communicational DC Link to stimulate generator-side output with a stimulation permanent magnet are shown in Figure.3.

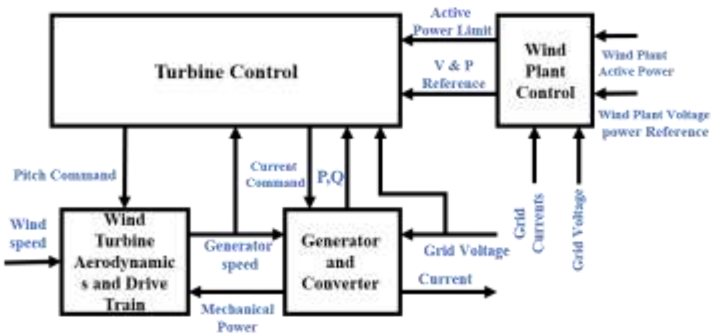


Figure 2. Wind model transformation system to output voltage generation in the electric network of SWT6.0MW wind turbine.

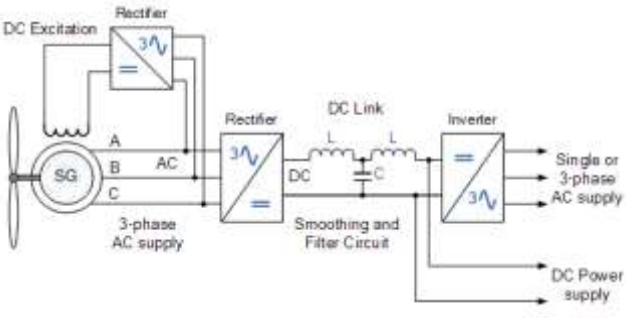


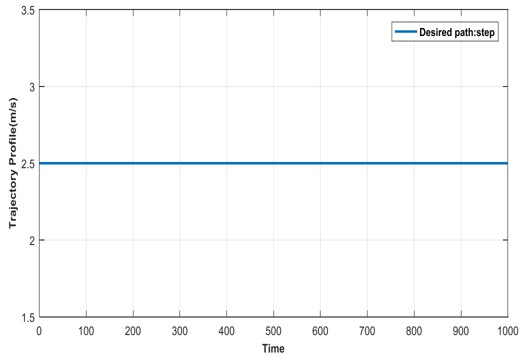
Figure 3. Permanent Magnet Synchronous Generator (PMSG) structure.

Table 1 shows the nominal values and technical specifications of the 6.0mw wind turbine of Siemens Company.

Table 1. Nominal specification values with parametric uncertainty governing on SWT6.0mw

UNCERTAINTY VALUE		NOMINAL VALUE	
V_W	0 □ 12 m/s	R	19 m
C_p	$0.24 < C_p < 0.5$	ω_r	2 rad/s
R_{f_t}	$0.24 < R_{f_t} < 0.5$	P_0	100 kw
J_t	16 kg < J_t < 18 kg	P	1.31Kg/m^3
B_t	$52 < B_t < 54$	λ	37.5
K_t	$52 < K_t < 54$	L	0.001
K_{Q_t}	$1.7 < K_{Q_t} < 1.9$	R_f	0.02
ns_r	700rpm	T_g	50kN.n
B	50	J	16kg.m^2
K	50	Kw	10

3. Modelling control target signal and wind speed



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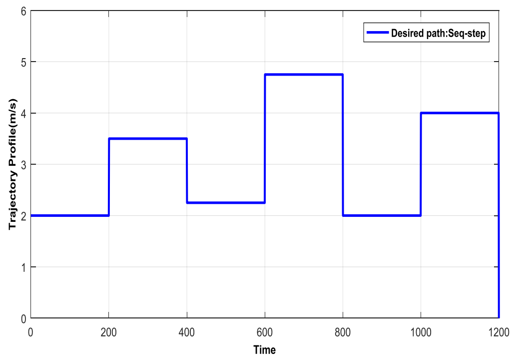

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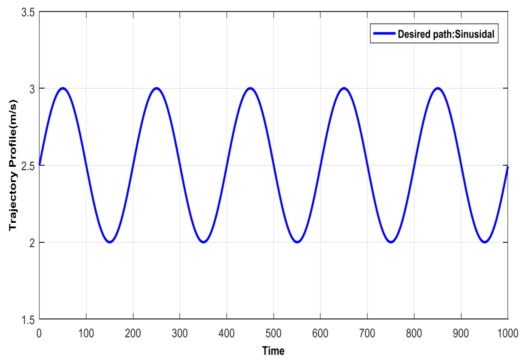
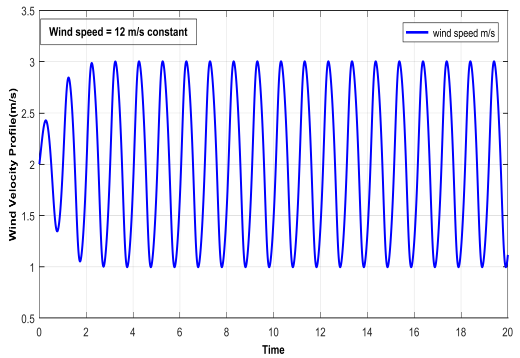


(c)

Figure 4. Display various profiles of the target signal based on (a) step static signal, (b) static step_ sequence signal, and (c) sinusoidal signal

To investigate control strategies efficiency in this article, desired finding presented in the article are considered to target signals such as step signal, stair sequential signal, and sinusoidal signal [21]. For wind random signal based on the table.1data (0 to 12 m/s), a nonlinear oscillator equation with asymptotic stable cycles presented in [19] and [20] has been used.



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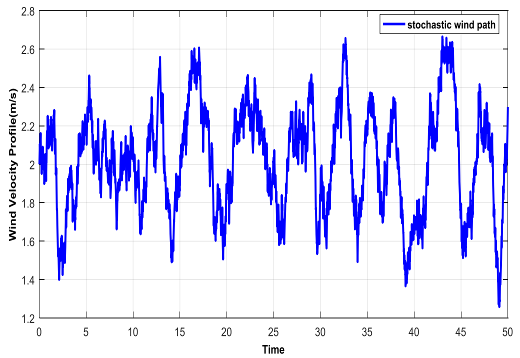

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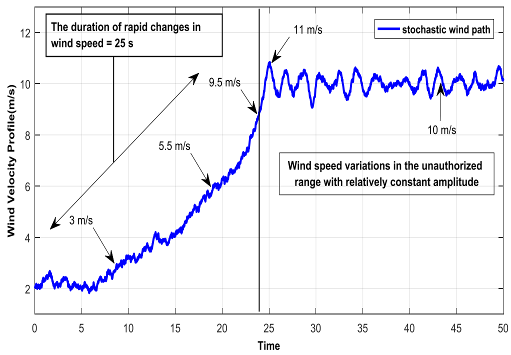

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Figure 5. The oscillatory behaviour of wind: (a) constant speed, (b) variable speed, and (c) different slopes of wind speed

4. Wind turbine dynamic model

WECS or wind energy conversion systems are generally used to convert wind energy to consumable electrical energy. In the power plant unit of SWT6.0mw turbine, wind turbine and generator are connected without a gearbox by the power converter. Obtained mechanical energy from wind kinetic energy in the turbine is converted to electrical energy through a drive train generator. Mechanical parts of Permanent Magnet Synchronous Generator (PMSG) are shown in Figure 6.

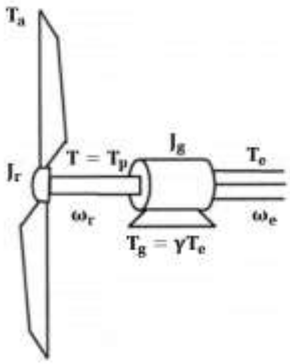


Figure 6. Mechanical schematic of generator connection to turbine blades

WECS can be categorized based on generators types, power control systems, and variable or fixed speed performance. Generated power in the rotor ($P_{\omega r}$) and generator output power curve are effective important factors on output power, rotor speed, turbine angular velocity, and necessary changes in blade step angle in Wind Turbine (WT) [22].

$$P_{\omega r} = \frac{1}{2}\rho\pi R^2{}_{Wr} v^3{}_{W} C_p(\lambda,\beta) \tag{1}$$

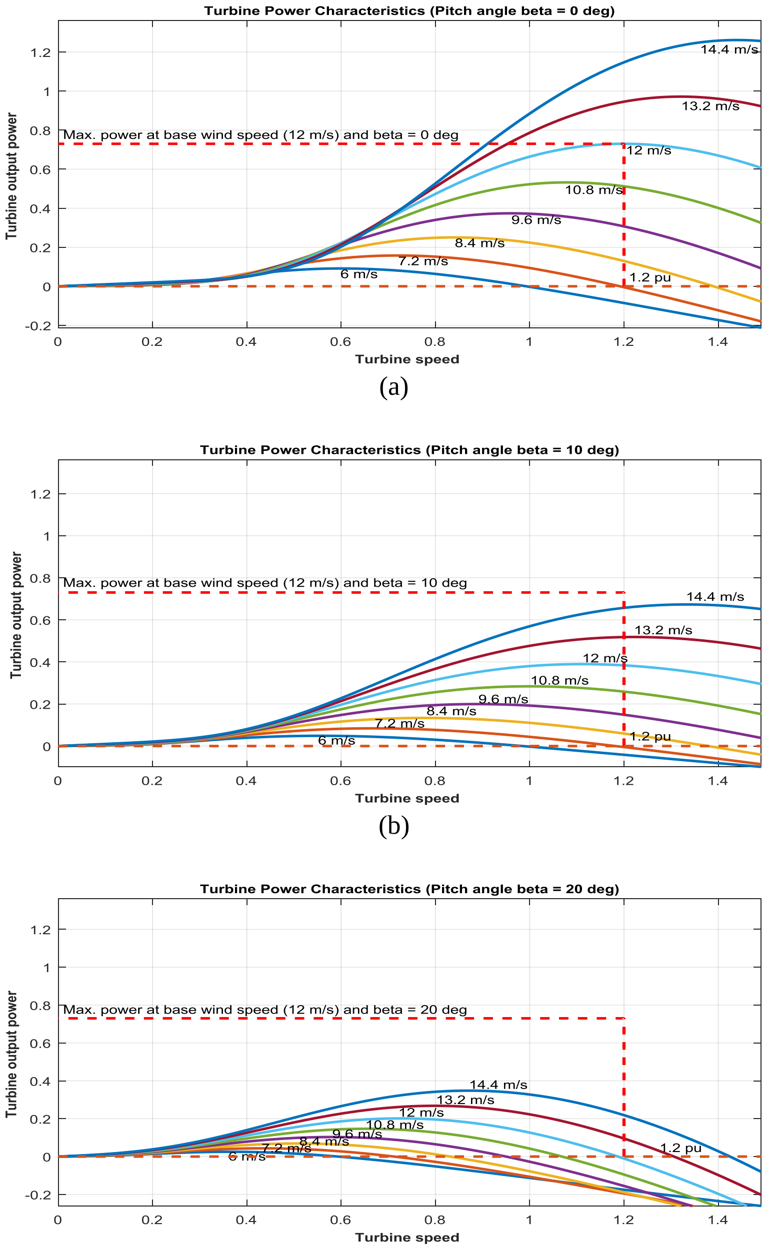
Where ρ is air density, R R is rotor radius, v is wind velocity, β is blade step angle, λ is blade top speed ratio to wind speed which is defined as:

$$\lambda = \frac{\Omega_{\omega r} R_{\omega r}}{v_W} \tag{2}$$

Where ω_r is rotor speed and $C_p(\lambda,\beta)$ are WT power coefficient, which are considered as nonlinear function of speed ratio and step angle [23, 24, 29-34]:

$$C_p(\lambda,\beta) = C_1\left(\frac{C_2}{\lambda_i} - C_3\beta - C_4\beta^{C_5} - C_6\right)e^{\frac{C_7}{\lambda_i}}$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + C_8\beta} - \frac{C_9}{\beta^3 + 1} \tag{3}$$



(a)

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Figure 7. display turbine output power changes than rotor rotation speed in the presence of wind constant speed in various angles of turbine blades pitch (a) 0 degree (b) 10degree (c) 20degree

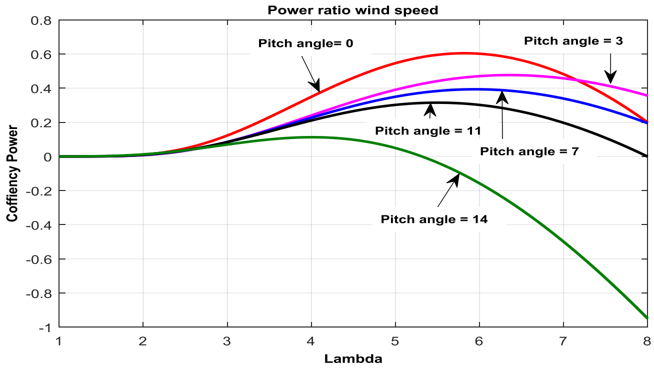


Figure 8. turbine power coefficient values than blades various angles based on Anderson and Bose theory.

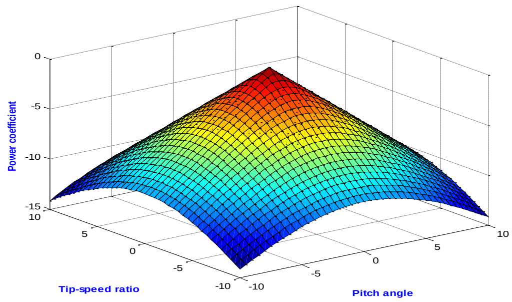


Figure 9. Power coefficient variations as non-linear function blade step angle and speed ratio to blade top

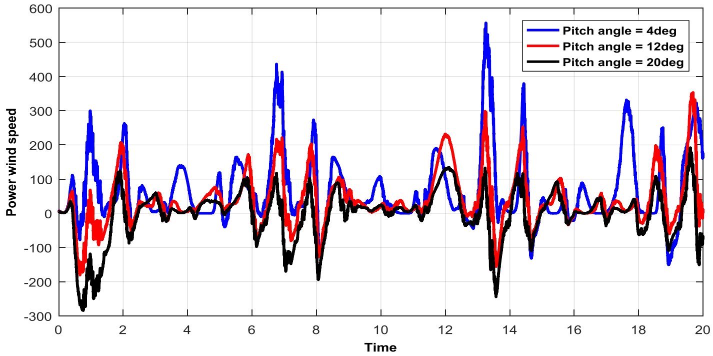


Figure 10. Variations ratio in wind speed at various angles of wind turbine blades

Figures 7, 8 and 9, demonstrate the variations in power coefficient with respect to different blade angles, blade pitch angle, and Figure 10 presents the ratio of wind speed variations. It should be noted that equation (3) is obtained from experimental data using the curve fit method seen from previous researches. Since experimental actions have not been considered in this research range, we have to use the current equation. However, for each obtained $C_p(\lambda,\beta)$ function for each specific wind turbine, proposed control strategy in this article can be applied and implemented [23, 24, 29-34]. Presented researches to adopt equation (3), WTs various speed control using adaptive algorithm [24], includes intelligent approach for maximum power tracking control strategy, WTs control previous and current position, overall model for various speed WTs in power system simulation [29], adaptive investigation of generator rotor rotation speed topologies and control strategies for harmonic operations of WT generator systems, small WTs roles in wind turbines market, and current devices theories [30,31]. Based on equations (1) to (3) for rotor speed constant value, top-speed ratio λ and finally power coefficients C_p are variable [32]. As a result, WT generated output power will be changed. Based on Betts law in WT systems, power factor is less than 0.59, while for three-blade horizontal axis WT, its amplitude is as $0.24 < C_p < 0.5$ [33,34]. Based on Figureure 6, in the presence of input aerodynamic torque T_a, wind turbine rotor is run at speed ω_r. The gearbox is used to transfer output torque T_p to generator in which axis torque T_e is generated angular speed ω_g. Due to use gearbox, rotor speed and generator speed are not the same. Although gearbox components may show non-linear characteristics, this is considered ideal [35]. Based on Figureure 6 system dynamics of the wind turbine generator are expressed as:

$$T_a\text{-}T=J_r\ddot{\theta}_r+C_r\dot{\theta}_r+K_r\theta_r$$
$$T_p\text{-}T_e=J_g\ddot{\theta}_g+C_g\dot{\theta}_g+K_g\theta_g$$
$$T_p\dot{\theta}_g=T\dot{\theta}_r \quad (4)$$

In equation (4), J is momentary inertia for turbine blades rotor, C is damping, and K is shaft rotation hardness. While r and g are abbreviations for rotor and generator so, generator output torque, and previous and next gearbox torques are shown with T, T_e, and T_p. γ is introduced as gearbox gear ratio(equation(5)) and are considered for simplicity $\dot{\theta}_r=\omega_r, \dot{\theta}_g=\omega_g$ definition. ω_r is turbine blade rotor speed and ω_g is wind turbine generator rotor speed.

$$\gamma=\frac{\omega_g}{\omega_r} \quad (5)$$
$$T_a=\frac{1}{2\lambda}\rho\pi R_{Wr}C_p(\lambda,\beta) \quad (6)$$

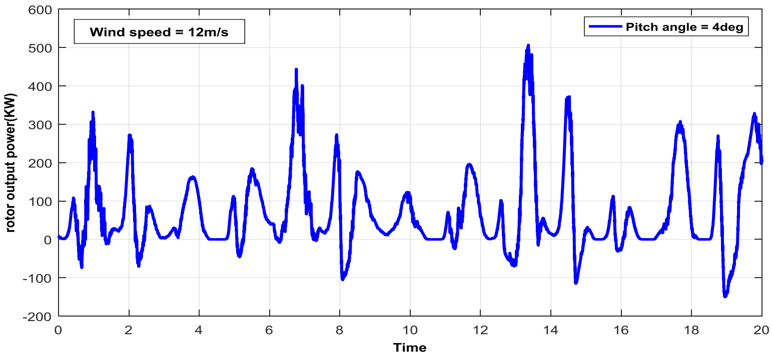
Substituting equation (6) in (4), after simplifying dynamics we have (equation (7)):

$$J_r\ddot{\theta}_r+C_r\dot{\theta}_r+K_r\theta_r=T_a\text{-}\bar{T}_g$$
$$J_r\ddot{\theta}_r+C_r\dot{\theta}_r+K_r\theta_r=\frac{p_a}{w}\text{-}\gamma\frac{p_e}{\omega_e} \quad (7)$$

For the wind turbine generator system as an parametric uncertainty model, in which (equation (8)):

$$J_t=J_r+\gamma^2J_g$$
$$C_t=C_r+\gamma^2C_g$$
$$K_t=K_r+\gamma^2K_g \quad (8)$$

Based on equation (7), there are two control inputs: blade step angle β, which affects aerodynamic torque T_a and generator torque $\overline{T}_g$. It has been accurately shown that the time constants of the two controller variables are far away from each other, resulting in un-connected dynamics. Under these conditions, showing multi-variables systems as two single-variable system while the control matrix becomes diagonal is possible [36, 37]. Based on the used method for less wind speed condition than the rated value which is called indirect control in torque technique, generator torque can be controlled in a constant value [10, 38]. Generator torque is controlled by a factor power converter in power flow between the generator and power grid [39]. Therefore, in the most previous control investigations, generator torque is considered in nominal and apparent value. This assumption makes the controller one-variable at blade step angle [39-47].



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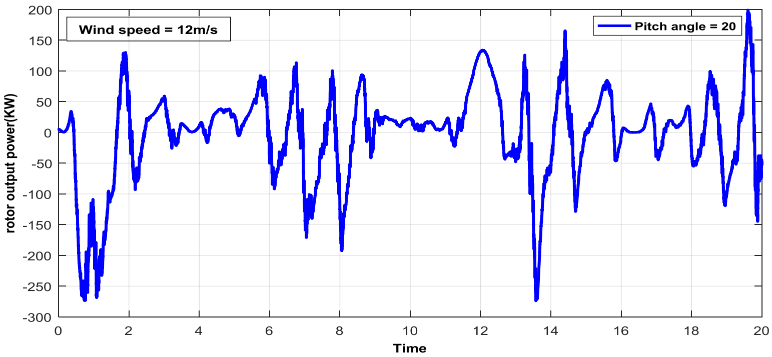


(b)

Figure 11. The response of the ring system depends on the variation of the output power of the rotor for the maximum permissible wind speed and the angle of 4 degrees (a) and 20 degrees (b) turbine blades

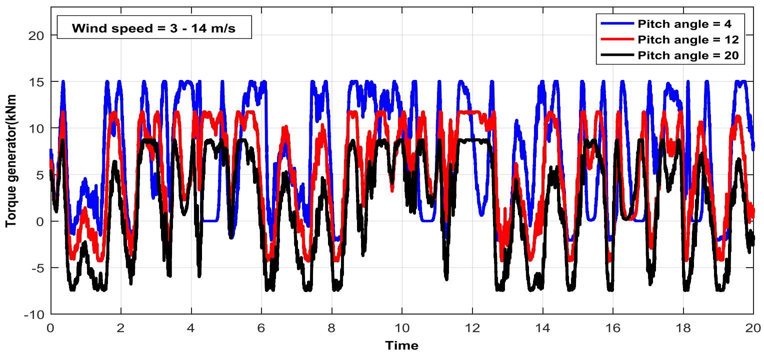


Figure 12. closed-loop variations response to generator torque for desired multiple angles

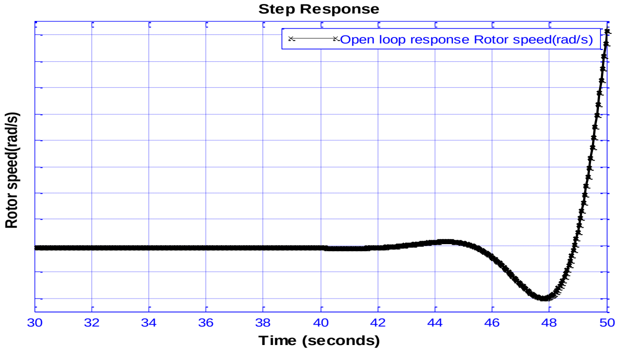
The behavior of the closed-loop system for variations of output power of the rotor for different angles is shown in Figure 11. Generator torque variations for different angles is presented in Figure 12. In the most control researches, generator torque is considered in constant nominal value. With the assumption that generator torque is fixed around its nominal value ($\bar{T}_g$) and is considered to plant by control signal input definition $u=T_a-\bar{T}_g$ (equation 9).

$$J_t\ddot{\theta}_r + C_t\dot{\theta}_r + K_t\theta_r = T_a - \bar{T}_g$$
$$J_t\ddot{\theta}_r + C_t\dot{\theta}_r + K_t\theta_r = u \quad (9)$$

While control input of a nonlinear function is explicit of speed-top ratio and blades step angle. Above equation transformation to Laplace, creates following transformation function matrix for the turbine rotor speed and turbine blade step angle (equation10):

$$\begin{bmatrix}\omega_r(s)\\ \beta(s)\end{bmatrix} = \begin{bmatrix}\frac{s}{J_t s^2 + C_t s + K_t} & 0\\ 0 & \frac{1}{\tau s+2}\end{bmatrix}\begin{bmatrix}u_r\\ \beta_s\end{bmatrix} \quad (10)$$

Figure 13 shows open-loop system behaviour changes of the wind turbine to the wind speed of 4 m/s to nominal plant as unit step responses, frequency response, and system poles and zeros location due to input applying. Based on Figure.13, the open-loop system response is unstable without uncertainty for turbine rotor speed and blade step angle and required measures to control system against wind speed changes for tracking various profiles be done.



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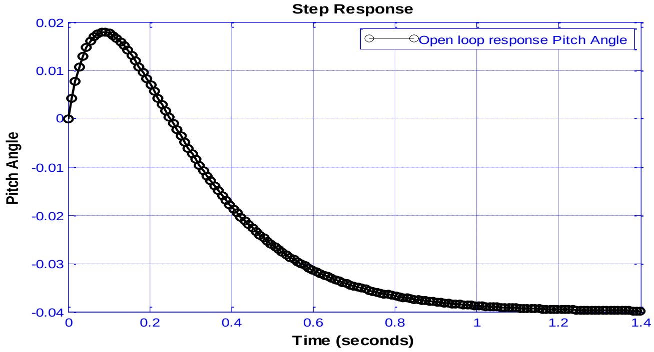

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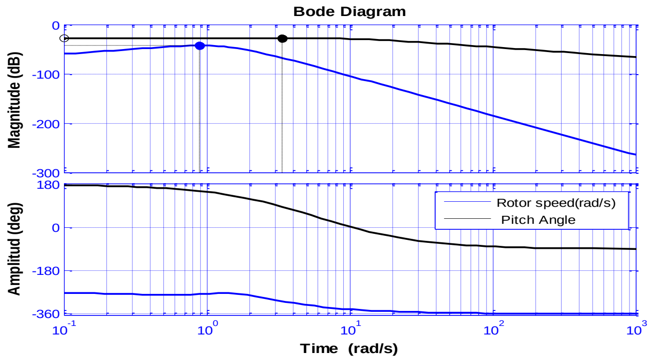

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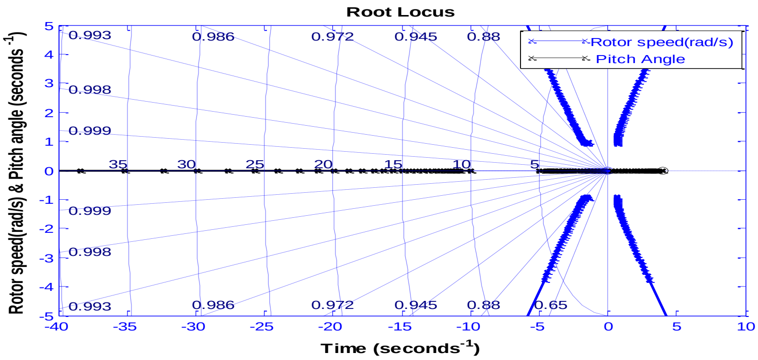


(d)

Figure 13. display open-loop response with nominal parameters of rotor model and blade step angle in the presence of wind swinging speed (4m/s) to rotor speed step response (a) blade step angle step response, (b) frequency response to amplitude changes and open-loop system size, and (c) also, poles placing and nominal plant zeros due to applied wind speed to plant (d)

5. Design classical and improved controller

In this section, design and analysis of classic controller based on tracking various profiles and wind swinging speed to extract governing responses on two outputs of multi-variable transformation function matrix due to the physical structure with one degree of freedom (SDOF) is presented. The classic controller is designed based on roots geometric locus. Due to wind swinging speed and uncertainty changes governing on model transformation function characteristic equation, obtaining control coefficients and input signal energy to real system model is considered essential [48]. Classic controller multiplies fault signals in an integrator and derivative constant and applies their answer to the system. Classic controller design is based on PID to show accuracy and consistency against model uncertainties and wind swinging speed to study and evaluate more accurate considering obtained responses of a comparison operation controller of stable resistance controller. Classic controller based on wind swinging generates an integral-based feedback and fault-derivative in model output [49].There are several methods to obtain PID controller coefficients such as Ziggler Nichols [50], Harnes Wich [51], Skoog Ostad [52], and so on. The theoric method and based on various trial and error tests in practical and theoretical systems is Ziggler Nichols method. This method was invented by Ziegler and Nichols in 1942. This method is presented based on two closed-loop and open-looped control. In the open-loop method, coefficients are considered based on no-feedback from the output as equation (11). For closed-loop control based on coefficients definition feedback K_p, K_D and K_I a compensator function in Laplace domain with a two-order function has been used [53] equation (12).

$$G_c(s)=K_p+\frac{K_I}{s}+K_D s=\frac{K_D s^2+K_p s+K_I}{s} \quad (11)$$

$$G_C(s)=K_P\times(1+\frac{1}{T_I s}+T_D s),T_I=\frac{K_p}{K_I},T_D=\frac{K_D}{K_P} \quad (12)$$

Due to instability important factors of system real model and existence derivative element in the PID controller in the compensator conversion function, which causes speed incensement and unsteadiness of model output changes is used to delete instability effect of a grade 1 filter (equation 13).

$$C(s)=K_D(s)\times C_D(s),\frac{K_D(s)}{1+T_F} \quad (13)$$

By adding first-order transformation function as a system instability effect elimination filter, the improved compensator equation is written as equation (14):

$$C(s)=K_P(s)+\frac{K_I}{s}+\frac{K_D}{T_F s+1} \quad (14)$$

In PI controller, without unstable factor d which causes increase in changes speed in the output, obtained fault from crosses from integral and is made in a multiplication constant and feedback factor due to fault integral (equation 15):

$$G_C(s)=K_P+\frac{K_I}{s},\frac{K_P+K_I}{s} \quad (15)$$

To reduce excessive value in the low frequency of system response and increase response speed, the Ziggler Nichols open-loop improved method has been used; actually, PID controller in Ziggler Nichols method will improve system steady-state response control. But it ruins the system transient response to reach reference value. To track with negligible fault and transient fluctuations at initial times, first characteristic multinomial in the frame of a closed-loop multinomial are formulated and then integral gain is applied to control signal input to reduce fault and using a derivative controller with a low-pass filter to increase system speed and initial swinging in system output by assuming an optimal multinomial $\Delta des(s)$ for plant model using CHR method. The characteristic equation governing on turbine rotor speed with a PID controller is shown in Equations (16,17,18,19) and (20) [54-56].

$$\Delta des(s)=(s+\alpha\omega_n)\times(s^2+2\xi\omega_n s+\omega_n{}^2) \quad (16)$$

$$\Delta S_{\omega_r}=1+L(s) \quad (17)$$

$$\Delta S_{\omega_r}=(1+K_D)s^3+(C_t+(K_D\times 0)+K_P)s^2+(K_t+(K_P\times 0)+K_I)s+K_I \quad (18)$$

$$\omega_r(s)=C_t+K_D+K_P,(1+K_D)(\alpha+2\xi)\times\omega_n \quad (19)$$

$$K_t+K_I=(1+K_D)\times(1+2\alpha\xi)\times\omega_n{}^2 \quad (20)$$

Damping coefficients ξ and natural frequency ω_n and also constant value α of linear equation system are used to design the PID controller parameters using CHR method due to rotor speed nominal method as the state-space matrix is formed. Hybrid mode space realization for system model and controller (equation 21):

$$\omega_r{}^1(s)=\begin{bmatrix}1 & 0 & 0\text{-}1(\alpha+2\xi)\omega_n\\ 0 & 1 & -1(1+2\alpha\xi)\omega_n{}^2\\ 0 & 0 & -1\alpha\omega_n{}^3\end{bmatrix}\begin{bmatrix}K_P\\ K_I\\ K_D\end{bmatrix},\begin{bmatrix}-C_t+(\alpha+2\xi)\omega_n\\ -K_t+(1+2\xi)\omega_n{}^2\\ \alpha\omega_n{}^3\end{bmatrix} \quad (21)$$

Controller conversion function of equation (15), after being applied to the system model, causes the steady-state fault and excessive percentage due to wind swinging speed disturbances in tracking problems. The occurred fault is a nonzero value. Reducing in the wind turbine dynamic model can solve this problem but this is impossible. But an integrator in the presence of complete turbine dynamics can be considered to delete system steady-state mode, equations (22 and 23):

$$K=(K_P T_D s^2+K_P s+\frac{K_P}{T_I})\times\frac{1}{s} \quad (22)$$

$$K=\frac{K_P T_D s^2+K_P s+\frac{K_P}{T_I}}{s} \tag{23}$$

Figure14. Shows the block diagram of the control diagram for the wind turbine system**.**

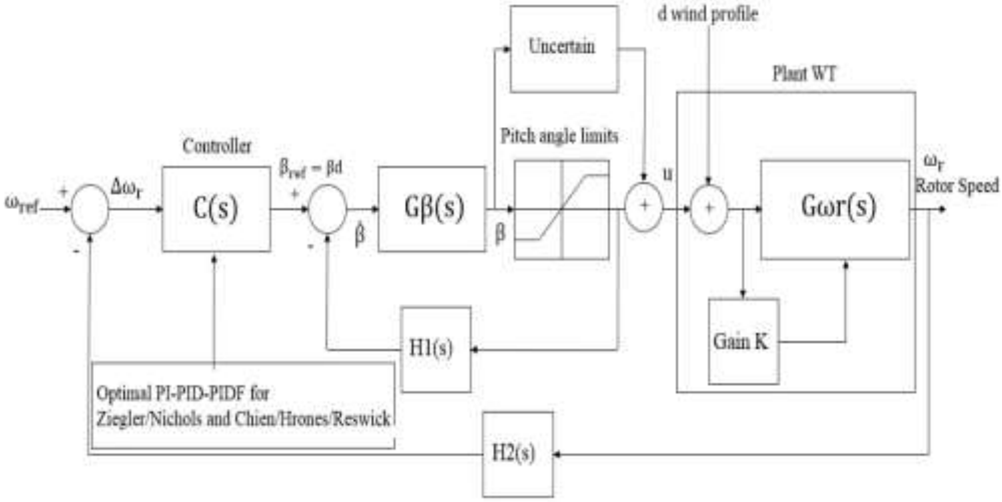


Figure 14. Control block diagram for wind turbine system

6. Results and Simulation

By providing an algorithm based on auto tuning ZN and CHR methods (Chen-Hernes-Wich), optimal coefficients of PI, PIDF, and PID controller, and also trial and error to substitute system pole and zero of closed-loop control and analysis root geometric locus due to apply wind speed input and model uncertainty through SISOtool toolbar in Matlab software, following optimal values of controller are obtained (Table.2). To validity and preciseness proposed methods with controller's various structures, the control system is considered based on the model with nominal parameters and uncertainty parameters in wind swinging speed with limited area, as shown in Table.3

Table 2. Determine coefficients of PID, PI, and PIDF controller based on ZH and CHR

Controller	K_P	K_I	K_D	T_F
PI-Z-H	7.673	15.46	0	0
PID-Z-H	9.270	33.98	0.6253	0
PIDF-Z-H	4.05	10.2	7.85	0.9
PI-CHR	2.685	1.437	0	0
PID-CHR	4.604	2.953	0.3111	0
PIDF-CHR	2.23	7.48	4.75	0.555

Obtained results of Figure 15 shows two PI controllers based on ZN and CHR, have the weak operation to track target profiles for the uncertain model and wind swinging area and also have the clear steady-state fault, which indicates controllers inoperability and update feature on wind turbine plant. Figure 16 shows necessary changes for turbine blades pitch angle drive in turbine rotor speed tracking signals for wind speed swinging profile after running PI-ZN and PI-CFR controller on the model with 5% uncertainty for three (a) step ,(b) Sequence-step and (c) sinusoidal. Figureure16 shows required changes control the energy value of blades pitch angle to track turbine rotor speed in various target profiles based on the nominal model and uncertainty model.

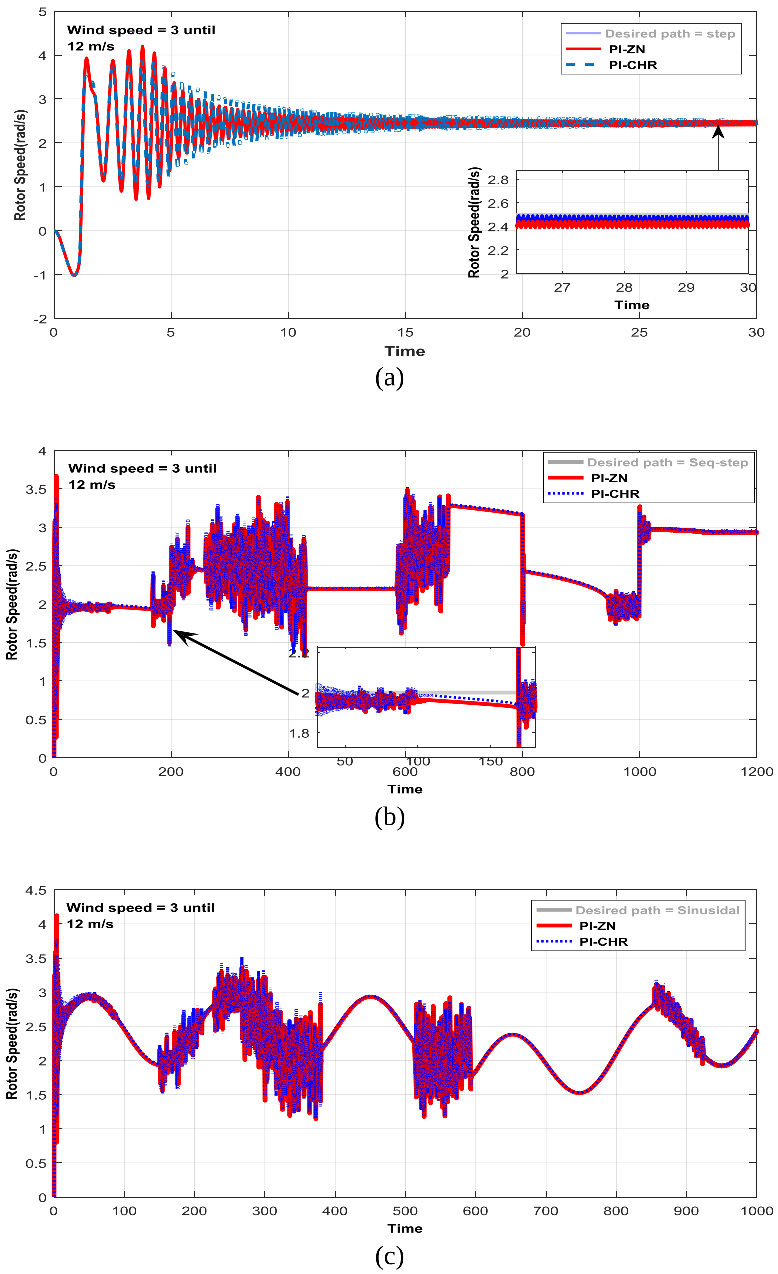
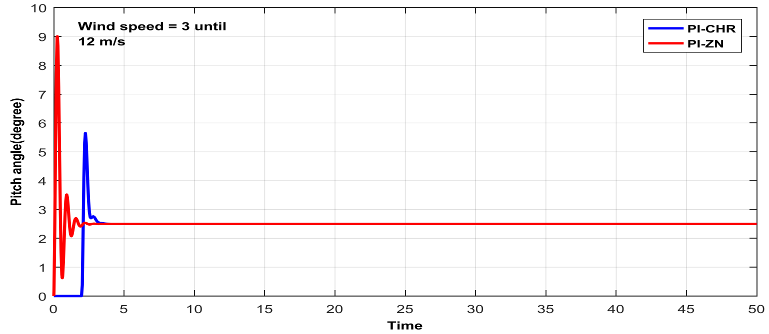
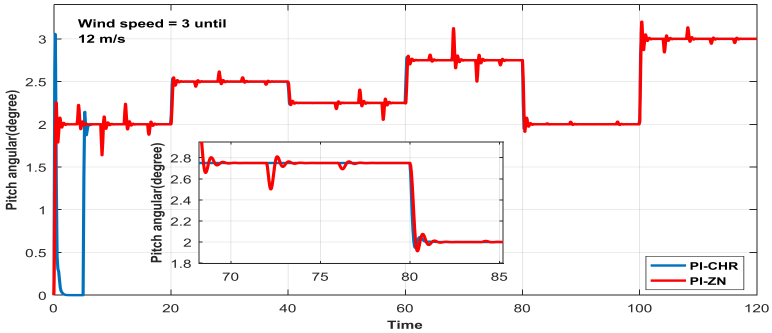


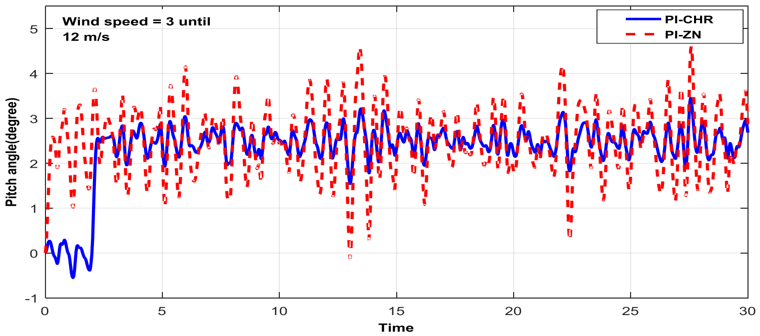
Figure 15 .Time response of the wind turbine rotor speed to track step signal after designing PI-ZN and PI_CHR controller on uncertainty model (20%) for (a) step, (b) Sequence-step and (c) sinusoidal wind speed various profiles.



(a)



(b)



(c)

Figure 16. Required changes for blade step angle driver to track signals (a) step, (b) Step-sequence, and (c) sinusoidal of turbine rotor speed for wind speed swinging profile after running controller based on 5%uncertainty model.

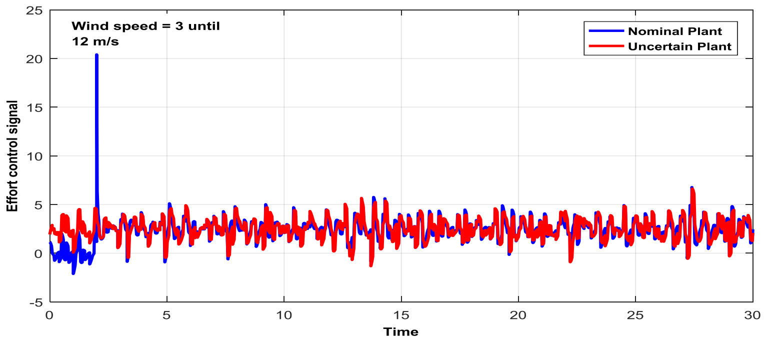
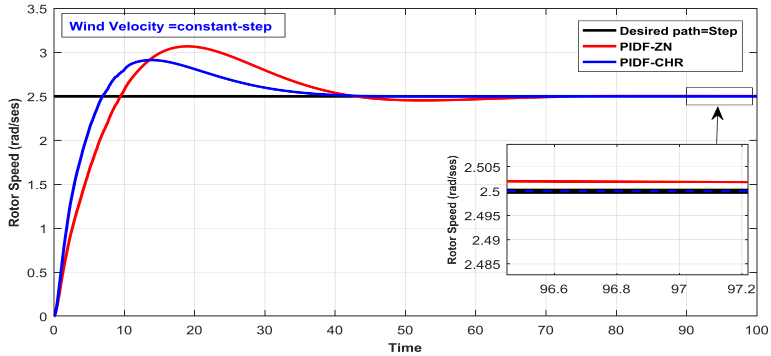
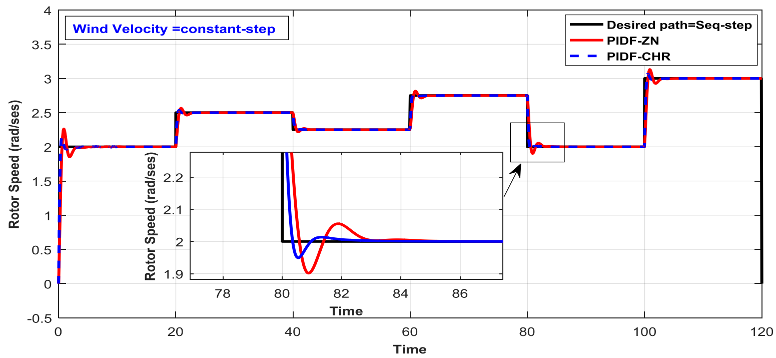


Figure 17. Showing required changes control energy value of blade pitch angle to track turbine rotor speed after running PI-ZN and PI-CHR controller based on nominal and uncertainty model.

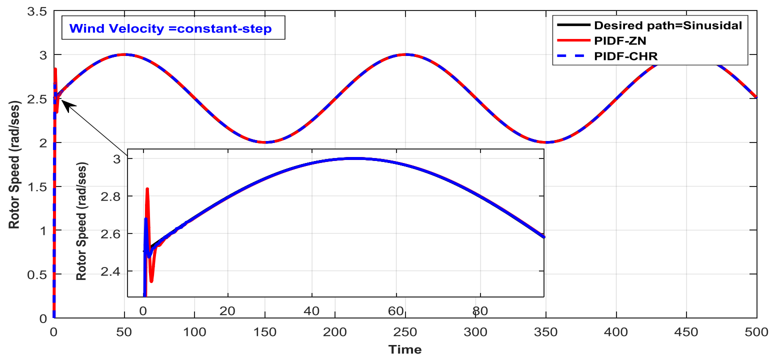
Figure 17 shows required changes control energy value of blade pitch angle to track turbine rotor speed after running PI-ZN and PI-CHR controller based on nominal and uncertainty model. Figureure 18 shows rotor speed time response of wind turbine to track target various signals, after designing PIDF-ZN and PIDF-CHR controller for model with nominal model and uncertainty model for constant wind speed, and to investigate categorized data from rotor speed tracking than target profiles and required changes ratio for blade step angle and also for system behaviour data such as signals uplifting values in initial moments, as well as initial moments, as well as fault RMS value and other information is shown in Figureure 18 for PI-CHR, PI-ZN, PIDF-ZN, PID-CHR, PID-ZN, and PIDF-CHR have been compared.



(a)

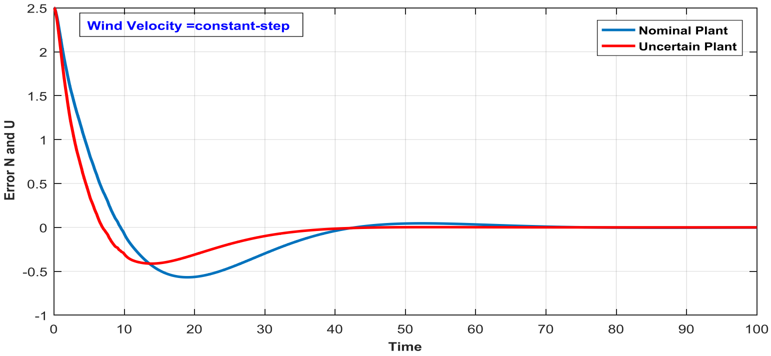


(b)

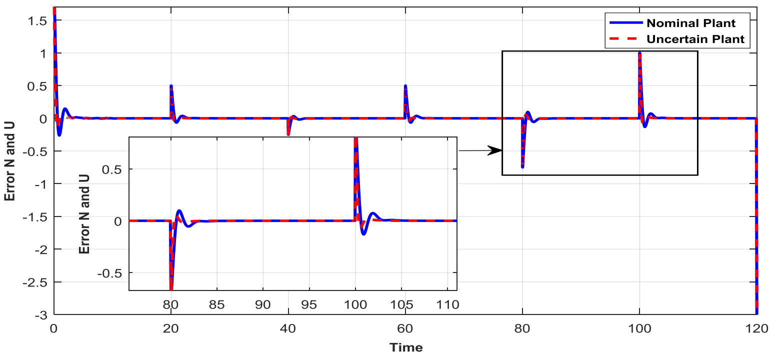


(c)

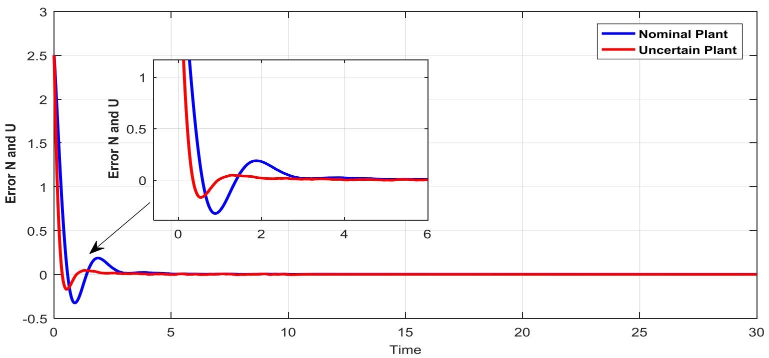
Figure 18. Rotor speed time response of wind turbine to track target profiles (a) step, (b) Step-sequence, (c) and sinusoidal after designing PIDF-ZN and PIDF-CHR controller on an uncertainty model (20%) for wind speed constant profiles



(a)



(b)



(c)

Figure 19. Indefinite fault response of wind turbine rotor speed for the nominal model and uncertainty model for three tracking profiles(a) step, (b) Step-sequence, and (c) sinusoidal

Figureure19 shows uncertain fault response for an uncertainty model after designing controller in the presence of constant wind speed and various tracking signals to validity PIDF-CHR controller operation to delete fault and converge turbine rotor speed to tracking signals. Table.3 shows comparison of two classic controllers for wind swinging speed with a 20% uncertainty of the system nominal model to validity designed controller operation.

Table 3. The compares classic controllers for wind turbine rotor speed and provide basic parameters to analyse system behaviour

Type	Uncertainty %	Rise Time	Settling Time	Overshoot	Peck Time	RMS	MSE
PI_ZN	20%	0.102	1.12	18.4%	1.912	2.401	0.482
PI_CHR	20%	0.126	1.38	13.77%	1.90	2.39	0.418
PID_ZN	20%	0.215	1.47	10.522%	1.456	2.202	0.321
PID_CHR	20%	0.237	1.60	8.222%	1.10	2.162	0.304
PIDF_ZR	20%	0.433	2.61	7.645%	1.08	1.505	0.271
PIDF_CHR	20%	0.468	2.87	4.826%	0.95	1.424	0.195

7. Conclusion

In this article, in addition to modeling and simulating of PMSG generator rotor rotation speed and blade step angle, design PID classic controller based on Ziggler Nichols (ZN) and Chen Hernes-Vich (CHR) methods with a signal-removing filter of immediate changes unstable signals of model uncertainty have been investigated. To validity controller operation in various operation conditions, results based on swinging and constant speed profile of wind speed and also target signal profiles are investigated. Although the classical PID controller is well suited to track target signal problem for turbine rotor rotation speed and required changes to drive blade step angle to have proper operation, transient response at initial times results in inverse oscillating behaviour with output signal uplifting that to solve this problem a PIDF controller and disturbance effect remove filter to increase time operation speed for rotor speed output and blade step drive angle in the presence of wind changes immediate fluctuation has been used. Also, the obtained results show that using CHR method has relative superiority than ZN method in the face of uncertainty and wind swing speed and RMS value and standard error are reached to the lowest value.

8. References

[1]. H. H. El-Tamaly and Adel A. Elbaset Mohammed, “Modeling and Simulation of Photovoltaic/Wind Hybrid Electric Power System Interconnected with Electrical Utility ", *12th International Middle-East Power System Conference, MEPCON 2008, pp 645-649, 2008*.

[2]. 2015 Half-year Report, The World Wind Energy Association, pp. 1-2, 2015.

[3]. World Wind Energy Association, World wind energy installed capacity.Available:http://www.wwindea.org, Accessed April / 1 / 2015.

[4]. Olimpo Anaya-Lara, 'Offshore wind energy generation, control, protection, and Integration to electrical system', Wily, 2014.

[5]. Jens Fortmann "Modeling of Wind Turbines with Doubly Fed Generator System" Dissertation University Duisburg-Essen, 2014.

[6]. Sathyajith Mathew, "Wind Energy Fundamentals, Resource Analysis and Economics", Springer-Verlag Berlin Heidelberg, 2013.

[7]. Siemens, Siemens 6.0 MW Offshore Wind Turbine. Available: http://www.Siemens.com, Accessed October/ 1 /2016.

[8]. Djohra Saheb-Koussa, Mourad Haddadi," Modeling and Simulation of Wind generator with Fixed Speed Wind Turbine Under Matlab-Simulink" *Clean Energy Solutions for Sustainable Environment (CESSE)*, Volume 18, 2014, Pages 701-708.

[9]. N. Jenkins, Z. Saad, “A simplification model for large wind trubines: design task”, *Int. Journal of Control*, vol. 13, pp. 1189-1214, 2000.

[10]. R. Cardenas, Control of wind turbines using a switched reluctance generator, Phd Dissertation, University of Nottingham, 1996.

[11]. Munteanu I, Cutululis N, Iuliana A, Ceanga E. Optimization of variable speed wind power systems based on a LQG approach. *Control Eng Pract* 2005.

[12]. Eisenhut, C., Krug, F., and Schram, C. "Wind Turbine Model for System Simulations Near CutIn Wind Speed", *IEEE Transactions on Energy Conversion*, vol (22), NO.2,2007.
[13]. Mohamed Kesraoui, Sid Ahmed Lagraf, Ahmed Chaib," Aerodynamic power control of wind turbine using fuzzy logic" *Renewable and Sustainable Energy Conference (IRSEC)*, 10-13 Dec. 2015.
[14]. H. Habibi, A. Yousefi Koma and A. Sharifian,"Power and Velocity Control of Wind Turbines by Adaptive Fuzzy Controller During Full Load Operation" *Iranian Journal of Fuzzy Systems* Vol. 13, No. 3, pp. 35-48, 2016.
[15]. E.V. Solomin , E.A. Sirotkin, A.S. Martyanov," Adaptive Control Over the Permanent Characteristics of a Wind Turbine " *International Conference on Industrial Engineering*, Volume 129, Pages 640-646,2015.
[16]. Abdulhamed Hwas and Reza Katebi, Wind Turbine Control Using PI Pitch Angle Controller, *IFAC Conference on Advances in PID Control PID'12 Brescia (Italy)*, March 28-30, 2001.
[17]. T. Unchim and A. Oonsivilai ,"A Study of Wind Speed Characteristic in PI Controller based DFIGURE Wind Turbine" *International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering* Vol:5, No:12, 2011.
[18]. Sasmita Behera, Bidyadhar Subudhi," Design of PI Controller in Pitch Control of Wind Turbine: A Comparison of PSO and PS Algorithm" *International Journal of Renewable Energy Research* S.Behera et al., Vol.6, No.1, 2016.
[19]. Y. Orlov, L. Aguilar, L. Acho and A. Ortiz, "Asymptotic harmonic generator and its application to finite time orbital stabilization of a friction pendulum with experimental verification", *International Journal of Control*, vol. 81, no. 2, pp. 227--234, 2007.
[20]. Iulia Dumitrescu, "Modeling and Characterization of Oscillator Circuits by Van der Pol Model using Parameter Estimation", *Journal of Circuits, Systems, and Computers*, Paper 98, 2011.
[21]. Hamed Moradi*, Gholamreza Vossoughi," Robust control of the variable speed wind turbines in the presence of uncertainties: A comparison between H∞ and PID controllers , Contents lists available at ScienceDirec Energy , *Elsevier journal*, pp 1-14,2015.
[22]. Song YD, Dhinakaran B, Bao XY. Variable speed control of wind turbines using nonlinear and adaptive algorithms. *J Wind Eng Industrial Aerodynamics* 2000; 85(3):293e308.
[23]. Burton T, Sharpe D, Jenkins N, Bossanyi E. Wind energy handbook. New Jersey, USA: John Wiley & Sons; 2001.
[24]. Song YD, Dhinakaran B, Bao XY. Variable speed control of wind turbines using nonlinear and adaptive algorithms. J Wind Eng Industrial Aerodynamics 2000; 85(3):293e308.
[25]. Salle SA, Reardon D, Leithead WE, Grimble MJ. Review of wind turbine control. *Int J Control* 1990;52(6):1295e310.
[26]. Seixas M, Melício R, Mendes VMF. Offshore wind turbine simulation: multimode drive train. Back-to-back NPC (neutral point clamped) converters. *Fractional-order control. Energy* 2014; 69:357e69.
[27]. Thirnger T, Linders J. Control of variable speed of a fixed-pitch wind turbine operating in a wide speed range. *IEEE Trans Energy Convers* 1993; 8(3):520e6.
[28]. Van Baars GE, Bongers PM. Wind turbine control design and implementation based on experimental models. *In: Proceedings of the 31st conference*.
[29]. Min Lin W, Ming Hong, C.. Intelligent approach to maximum power point tracking control strategy for variable-speed wind turbine generation system. *Energy* 2010; 35(6):2440e7.
[30]. Laks JH, Pao LY, Wright AD. Control of wind turbines: past, present, and future. In: *Proceedings of the 2009 American control conference, st. Louis, Missouri, USA*; 2009. p. 2096e103.
[31]. Slootweg JG, De Haan SW, Polinder H, Kling WL. General model for representing variable speed wind turbines in power system dynamics simulations. *IEEE Trans Power Syst* 2003; 18(1):144e51.

[32]. Melício R, Mendes VM, Catalao JP. Comparative study of power converter ~ topologies and control strategies for the harmonic performance of variable speed wind turbine generator systems. *Energy* 2011;36(1):520e9.

[33]. Simic Z, Havelka JG, Bozicevic Vrhovcak M. Small wind turbines e A unique segment of the wind power market. *Renew Energy* 2013; 50:1027e36.

[34]. Betz A. Introduction to the theory of flow machines, (D. G. Randall, Trans.). UK: Oxford Pergamon Press; 1966.

[35]. Moradi H, Salarieh H. Analysis of nonlinear oscillations in spur gear pairs with approximated modelling of backlash nonlinearity. Mech Mach Theory 2012; 51:14e31.

[36]. Cardenas R. Control of wind turbines using a switched reluctance generator [Ph.D. dissertation]. UK: University of Nottingham; 1996.

[37]. Leithead WE, Connor B. Control of variable speed wind turbines: design task. *Int J Control* 2000; 73(13):1189e212.

[38]. Boukhezzar B, Siguerdidjane H. Comparison between linear and nonlinear control strategies for variable speed wind turbines. *Control Eng Prac* 2010;18(12):1357e68.

[39]. Sayigh A. Renewable energy e the way forward. Appl Energy 1999;64(1e4): 15e30.

[40]. Camblong H. Digital robust control of a variable speed pitch regulated wind turbine for above rated wind speeds. *Control Eng Pract* 2008;16(8):946e58.

[41]. Bianchi FD, Battista HD, Mantz RJ. Wind turbine control systems: principles modelling and gain scheduling design. 2nd ed. USA: Springer; 2006.

[42]. Salle SA, Reardon D, Leithead WE, Grimble MJ. Review of wind turbine control. *Int J Control* 1990; 52(6):1295e310.

[43]. Song YD, Dhinakaran B, Bao XY. Variable speed control of wind turbines using nonlinear and adaptive algorithms. *J Wind Eng Industrial Aerodynamics* 2000;85(3):293e308.

[44]. Burton T, Sharpe D, Jenkins N, Bossanyi E. Wind energy handbook. New Jersey, USA: John Wiley & Sons; 2001.

[45]. Van Baars GE, Bongers PM. Wind turbine control design and implementation based on experimental models. In: *Proceedings of the 31st conference on decision and control, Tucson, Arizona, USA*; December 1992. p. 2596e600.

[46]. Zinger DS, Muljadi E, Miller A. A simple control scheme for variable speed wind turbines. In: *Conference Reco d of the IEEE Industry Applications Conference 31st IAS Annual Meeting3*; 1996.

[47]. Hand M. Variable-speed wind turbine controller systematic designs methodology: a comparison of nonlinear and linear model-based designs. NREL report TP-500e25540. Golden, Colorado, USA: *National Renewable Energy Laboratory*; July 1999.

[48]. Automation Control system,8th Edition,Benjamin C. Kuo. Wily &Sons,2003.

[49]. Variable-Speed Wind Turbine Controller Systematic Design Methodology: A Comparison of Non-Linear and Linear ModelBased Designs, M. M. Hand, *National Renewable Energy Laboratory*, July 1999 .

[50]. K.J.ÅströmT.Hägglund, Revisiting the Ziegler–Nichols step response method for PID control, *Journal of Process Control*, Volume 14, Issue 6, September 2004, Pages 635-650.

[51]. Kendall, L., Balas, M.J., Lee, Y.J., and Fingersh, “Application of Proportional-Integral and Disturbance Accommodating Control to Variablespeed Variable Pitch Horizontal Axis Wind Turbines,” *Wind Engineering* (12:1), pp. 21-38, 1997.

[52]. SigurdSkogestad, Simple analytic rules for model reduction and PID controller tuning, *Journal of Process Control*, Volume 13, Issue 4, June 2003, Pages 291-309.

[53]. Wang C. Control, stability analysis and grid integration of wind turbines". PhD Thesis, Imperial College London. (2008).

[54]. Astrom K,J, T. Hagllund; ”PID controllers Theory, Design and Tuning ”, 2nd edition, Instrument Society of America,1994.

[55]. V. Selvi Sowmya, S. Priya dharsini, R.Priya Dharshini, P. Aravind, Application of various PID Controller Tuning Techniques for a Temperature System, *International Journal of Computer Applications* (0975 – 8887) Volume 103 – No.14, October 2014.

[56]. J. Lieslehto, PID controller tuning using evolutionary programming, *American Control Conference, 2001. Proceedings of the 2001*.

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