NeuroQuantology|July2022|Volume20|Issue8|Page7007-7016|doi:10.14704/nq.2022.20.8.NQ44726
Ankur Jyoti Das et al / Improved Fuzzy Controlled Wind Turbine with A Permanent Magnet Synchronous Generator using Pulse Width Modulation Technique

Improved Fuzzy Controlled Wind Turbine with A Permanent Magnet Synchronous Generator using Pulse Width Modulation Technique

[1]Ankur Jyoti Das, [2]Papumoni Saikia
[1]M. Tech Student , [2]Assistant Professor
Department of Electrical Engineering, Jorhat Engineering College,Jorhat, Assam, India
Email-dasankur563@gmail.com , papums123@gmail.com

Abstract:

Wind turbine generators seek independent operation over the whole wind speed range below hurricane conditions. In this paper, it is essential to construct a full-scope feedback control system for the wind turbine voltage, current, active power and reactive power to achieve this goal.The gearbox design is very complex and needs frequent oiling, putting more mechanical stress on the wind turbine.Hence, a gearless wind turbine design is neededto make the wind turbine more reliable, reducing downtime and repair costs and increasing productivity. Taking three different wind speeds, a proposed modelis made in Matlab/ Simulink software. This research introduces enhanced fuzzy rules basedon two controllers,one on the generating side and one on the grid side,that can control the turbine's voltage, currentactive power and reactive power.The two converters, namely rotor(generating) side converters,control the active power via a Mamdani-based fuzzy controller via pulse width modulation and the second converter grid side converter is also Mamdani based fuzzy controller via pulse width modulationtechnique which synchronizes the grid voltage with generating voltage of wind turbine and also controls the reactive power. Following the explanation of various essential principles regarding small-scale wind turbines, building a Mamdani-based fuzzy logic (Mamdani et al., 1975) controller is described. PI controllers have high starting overshoot, sensitivity to controller gains and sluggish response to controller gains.So the fuzzy controller intelligently widens the range of operating conditions, and they are more readily customizable in neutral language terms,stability is better, small overshoot and fast response. 17 kilovolts, 490 amperes, 12 MW of active power, and 1.5 Mvar of reactive power have been achieved using the suggested conceptin Matlab /Simulink software.

Keywords: Wind Speed, Fuzzy Logic, PI, MATLAB, Voltage (KV), Current (A), Activepower (MW), and Reactive Power (Mvar)

DOINumber:10.14704/nq.2022.20.8.NQ44726 **NeuroQuantology2022;20(8):7007-7016**

I. INTRODUCTION

Wind turbine-based wind energy conversion systems capture energy from worldwide wind resources. Wind energy conversion systems need wind turbines. Power production and decreasing wind-speed-induced mechanical stress are vital when constructing wind turbine control systems. Changing the rotor blades' angle is a common way to do this. PID controllers often do this (M. Sinner et al., 2022). Due to our planet's dangerous environmental situation, growing energy demand, and depletion of fossil resources, renewable energy sources are crucial. Renewable energy production is now required worldwide (M. -H. Chiang et al. 2022).

Mexico's solar and wind resources make it fortunate. Several places with abundant wind resources have established wind energy projects (R. Prasad et al., 2022). Multi-MW wind farms are covered (A. Zentani et al. 2022). The current federal government favours medium, mini, and micro wind power for emerging areas (P. Manjeera et al. 2022). Sustainable community activities should implement these technologies.

More people want to use these resources to produce decentralized energy. Small-scale wind power (SSW) is a popular microgeneration technology with low carbon emissions. (J. E. Sierra-García et al 2021) An SSW turbine needs less than 100 kW of power to be viable (H. Gudimindla et al., 2021). A mini-eolic device needs 10% of a solar system's area to create the same amount of energy (Q. Ran et al. 2022). New turbine devices with cheaper pricing have recently arrived on the market (G. S. Sudharsan et al., 2020). They power dwellings.

Whether SSW turbines can cut CO2 emissions while delivering enough electricity.

(G. Fandi et al. 2017) Despite Mexico's abundant wind resources, the residential sector overconsumes. Since Mexico's energy demands need SSW turbines, this is a pressing problem. This intricate operation involves various unknown components. To make an educated decision, consider various additional criteria (T. Ilham et al. 2022). This paper used a fuzzy-based method to overcome this problem.

Next, we'll discuss pertinent literature. In Section 2, the Fuzzy System's basics are explained. Section 3 describes the system's architecture, including planned and actual model findings, and Section 4 discusses conclusions.

II. LITERATURE WORK

This work provides a fuzzy controller for variable-speed wind turbines. A wind turbine baseline controller is recommended. The basic controller allows this. Variable-speed wind turbines use type-2 interval, fuzzy controllers. Modern controls account for wind imprecision. The new controller doesn't measure wind speed. Costs and computations reduced. All zones' wind profiles match the controller's. The research-suggested controller enhances power and decreases mechanical stress (D. Bustan et al., 2022).

Multi-input buck converters adjust wind generator output voltage. Constantly charge batteries. Windmill PMSG (406 PMG). Tri-output fuzzy logic has three inputs. Fuzzy Sugeno-controller. Multi-input buck converters feature 0.012-second delays, 0.1859-second rising times, and 0.1870 peak and settling durations. Timers. 0.1618 V (1.037%) inaccuracy (M. K. Asy'ari et al. 2019).

The study models and simulates a PMSG wind turbine. PMSG speeds up this wind turbine. Wind power is plenty. Wind turbines generate green electricity. Massachusetts needs a massive wind farm. Pre-use testing is possible. Using the pitch controller, this simulation moves wind turbine blades. This boosts turbine output and delays its spin. SIMULINK validates simulations (B. K. Avu et al., 2021).

Work solves these problems: A-RSC maximizes rotor kinetic energy; revised-pitch angle control optimizes operating point tracking (R-PAC). Variable wind speeds prove the algorithm's accuracy. The study introduces operation and data prediction errors to test the method's durability. It checks the method's durability. Real-time simulations indicate the objective can be attained quicker and with fewer resources (R. Prasad et al., 2021).

Extension control improves wind turbines' dynamic performance. Effective. The variable rotor simulation model is first developed using a direct-drive wind turbine with a PMSG (PMSG). Adjusting the output depending on input variables (correlation degree). Changeable rotor testing Simulations use PID and extension controllers. According to simulations, the extension controller’s faster response speed and greater robustness may improve the variable rotor system’s dynamic performance (X. Wang et al., 2021).

Fractional-order intelligent proportional integral SMC (FO-iPISMC). Regulates DFIG rotor current indirectly. Combining iPI with sliding-mode control reduces DFIG tracking error power. Simulations show the suggested (FO-iPISMC) controller reduces rotor harmonic distortion and stator chattering. Planned (FO-iPISMC) (M. Mohamed et al. 2021).

ISMPC increases MPPT efficiency and reduces transmission system transient load. NREL’s FAST model, which simulates turbulent flow, tests the suggested controller’s performance (National Renewable Energy Laboratory) (D. Liu et al. 2019).

This research focuses on blade pitch controls for variable speed wind turbines to maintain rated output. PI pitch controller is suggested. Aero-elastic low-frequency modes boost PI controller performance. The suggested controller was tested on a DTU10MW turbine model. Fatigue stresses at the main shaft bearing were analyzed to guarantee the needed controller won’t generate too much stress (Q. Hawari et al. 2022).

Smart, adaptable PICs. Wind speed, power, and nominal power affect their signals. Signals change controllers to improve power output quality. Controlling Simulink and Matlab. Controllers improve wind power, data show. These controls allow wind turbines to operate under harsh conditions (H. H. H. Aly et al. 2019.

This letter calculates wind turbine aerodynamics using LIDAR. Aerodynamic uncertainty impacts turbine tune and power output precision. PAC may be established using blade scanning data. The estimated turbine power change is incorrect. However, the impact on wind farm power output is small owing to sluggish WFC action. WFC stalled. A WFC technique utilizing PACs can determine aerodynamic coefficients by scanning turbine blades. OEM aerodynamic data isn’t always available. Therefore,wind farms may be modified (A. Stock et al., 2021).

This study examines wind turbines’ small-signal stability during a frequency event and wind speed fluctuations. Then, a unitary auxiliary controller (UAC) will be supplied. Then, a global transfer function links wind speed to rotor speed. Ignoring power grid influences may help estimate the transfer function. UAC simulations employ computer-generated and recorded wind speed profiles. Simulation results show that the complex transfer function is viable for many auxiliary controllers with appropriate UAC values (M. H. Ravanji et al., 2020).

This research model is an induction WTS (IM). Fuzzy controllers improve WTS dynamics (FFOC). MATLAB/Simulink enhances wind turbine performance. Simulation findings show that the control system works and that the wind turbine emulator (WTE) provides crucial WTS metrics, including rotor speed and electromagnetic torque (E. Mousarezaee et al., 2020).

Wind affects turbine output. The paper proposes a sliding-mode controller to preserve system stability. Wind speed variations may be managed using genetic algorithm sliding mode control. Wind power is optimised. TSR improved with PI-GA-adjusted SMC. It increased power and decreased loss. Wind-induced nonlinear pitch angle is addressed. MATLAB Simulink's Type-III wind turbine system is discussed. Simulink vs. DFIG Type-III (B. P. Ganthia et al. 2021).

III. PROPOSED WORK

3.1 Wind turbine model:

The following formula may be used to determine how much mechanical power a wind turbine (Marwan Rosyadi et al. 2013), collected from the wind power produces:

$P_m = 1/2 \times C_p(\lambda,\beta) \times \rho \times A \times V_w^3$

where ρ is the air density (Kg/m3), R is the radius of the rotor blade (m), V_w is wind speed (m/s),and C_p is the power coefficient.

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

$1/ \lambda_i = 1/(\lambda - 0.08 \beta) -0.035/(1+ \beta^3)$

where C_1 to C_6 denote characteristic coefficients of wind turbine (C_1 =0.5176, C_2 =116, C_3 =0.4, C_4 =5, C_5=21 and C_6=0.0068 , λ_i = 11.8717), λ is the tip speed ratio, β is the pitch angle.

3.2 Fuzzy Control

Fuzzy controllers may be used to construct a controller that works similarly to a PI controller in each zone of a partition of the operating range or power curve. To do this, control rules may be set for the control zones and the areas that connect them. Schematic representation of fuzzy controller parts shown in Figure 1.

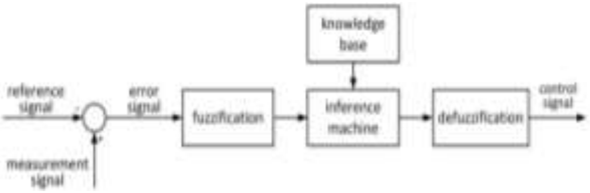

Fig. 1. Schematic of a fuzzy control system.

A linguistic value is ascribed to each numerical value of the inputs during the fuzzification stage, and each one is awarded a degree of membership in a fuzzy set that corresponds to its value. In addition to the trapezoidal, triangular, gaussian, and sigmoid distributions of fuzzy sets and membership functions, there are many additional conceivable configurations. A single rule, many rules, or none might be triggered throughout each iteration of the inference process. The fuzzy controller's knowledge base consists of a set of rules in the form:

IF (the condition), THEN (the result) (consequent) (1)

Proposed rules apply in our model like

Table 1. Proposed fuzzy rules

1. (Error==NB) & (change.of.error==NB) => (output=NB) (1)
2. (Error==NB) & (change.of.error==NM) => (output=NB) (1)
3. (Error==NB) & (change.of.error==NS) => (output=NB) (1)
4. (Error==NB) & (change.of.error==ZE) => (output=NB) (1)
5. (Error==NB) & (change.of.error==PS) => (output=NM) (1)
6. (Error==NB) & (change.of.error==PM) => (output=NS) (1)
7. (Error==NB) & (change.of.error==PB) => (output=ZE) (1)
8. (Error==NM) & (change.of.error==NB) => (output=NB) (1)
9. (Error==NM) & (change.of.error==NM) => (output=NB) (1)
10. (Error==NM) & (change.of.error==NS) => (output=NB) (1)
11. (Error==NM) & (change.of.error==ZE) => (output=NM) (1)
12. (Error==NM) & (change.of.error==PS) => (output=NS) (1)
13. (Error==NM) & (change.of.error==PM) => (output=ZE) (1)
14. (Error==NM) & (change.of.error==PB) => (output=PS) (1)
15. (Error==NS) & (change.of.error==NB) => (output=NB) (1)
16. (Error==NS) & (change.of.error==NM) => (output=NM) (1)
17. (Error==NS) & (change.of.error==NS) => (output=NS) (1)
18. (Error==NS) & (change.of.error==ZE) => (output=NS) (1)
19. (Error==NS) & (change.of.error==PS) => (output=ZE) (1)
20. (Error==NS) & (change.of.error==PM) => (output=PS) (1)
21. (Error==NS) & (change.of.error==PB) => (output=PM) (1)
22. (Error==ZE) & (change.of.error==NB) => (output=NB) (1)
23. (Error==ZE) & (change.of.error==NM) => (output=NM) (1)
24. (Error==ZE) & (change.of.error==NS) => (output=NS) (1)

25. (Error==ZE) & (change.of.error==ZE) => (output=ZE) (1)
26. (Error==ZE) & (change.of.error==PS) => (output=PS) (1)
27. (Error==ZE) & (change.of.error==PM) => (output=PM) (1)
28. (Error==ZE) & (change.of.error==PB) => (output=PB) (1)
29. (Error==PS) & (change.of.error==NB) => (output=NM) (1)
30. (Error==PS) & (change.of.error==NM) => (output=NS) (1)
31. (Error==PS) & (change.of.error==NS) => (output=ZE) (1)
32. (Error==PS) & (change.of.error==ZE) => (output=PS) (1)
33. (Error==PS) & (change.of.error==PS) => (output=PS) (1)
34. (Error==PS) & (change.of.error==PM) => (output=PM) (1)
35. (Error==PS) & (change.of.error==PB) => (output=PB) (1)
36. (Error==PM) & (change.of.error==NB) => (output=NS) (1)
37. (Error==PM) & (change.of.error==NM) => (output=ZE) (1)
38. (Error==PM) & (change.of.error==NS) => (output=PS) (1)
39. (Error==PM) & (change.of.error==ZE) => (output=PM) (1)
40. (Error==PM) & (change.of.error==PS) => (output=PM) (1)
41. (Error==PM) & (change.of.error==PM) => (output=PB) (1)
42. (Error==PM) & (change.of.error==PB) => (output=PB) (1)
43. (Error==PB) & (change.of.error==NB) => (output=ZE) (1)
44. (Error==PB) & (change.of.error==NM) => (output=PS) (1)
45. (Error==PB) & (change.of.error==NS) => (output=PM) (1)
46. (Error==PB) & (change.of.error==ZE) => (output=PB) (1)
47. (Error==PB) & (change.of.error==PS) => (output=PB) (1)
48. (Error==PB) & (change.of.error==PM) => (output=PB) (1)
49. (Error==PB) & (change.of.error==PB) => (output=PB) (1)

Where Negative Big (NB), Negative Medium (NM),Negative Small (NS), Zero (ZE), Positive Small (PS),Positive Big (PB), Positive Medium (PM), Positive Big (PB).

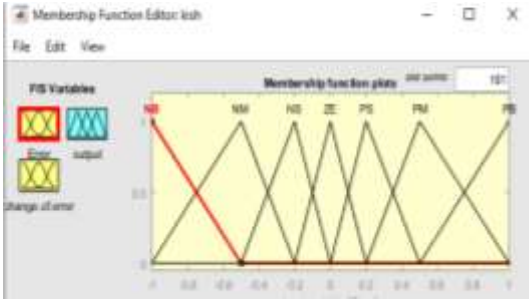

Figure 2. Membership function of error

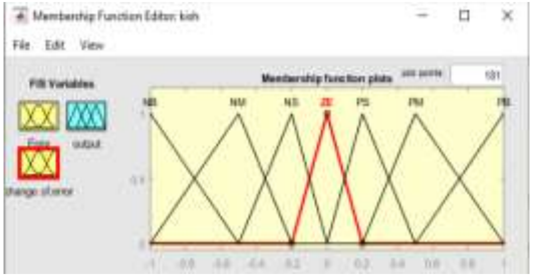

Figure 3. Membership function of change.of.error

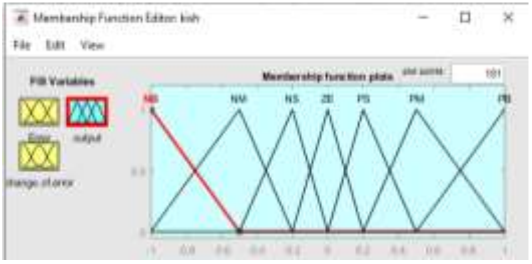

Figure 4. Membership function of output

IV. ANALYSIS AND RESULT

4.1 Hardware and software requirements

Hp Pavilion 14, 11Th Gen Intel Core I7-16Gb Ram/1Tb Ssd 14 Inches Laptop/Intel Iris Xe Graphics/Backlit Keyboard/Alexa/B&O Audio/Fast Charge/Fpr/Windows 11 Home/Ms Office, 14-Dv1029Tu,Natural Silver, MATLAB R2015a.

4.2 Existing results

Table 2. Proportional Integral Controller parameters.

Parameters of Proportional Integral Controller	
Proportional gain (K_p)	**12.98**
Integral gain (K_i)	**6.78**

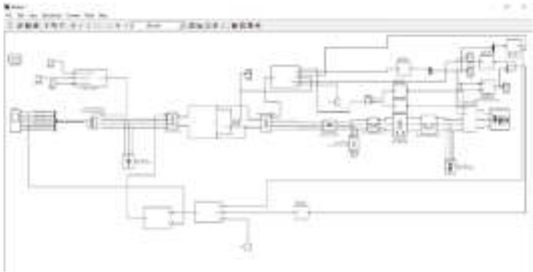

Figure 5. Circuit diagram of existing approach[11]

Figure 6. Result of active power 10MW vs. time [11]

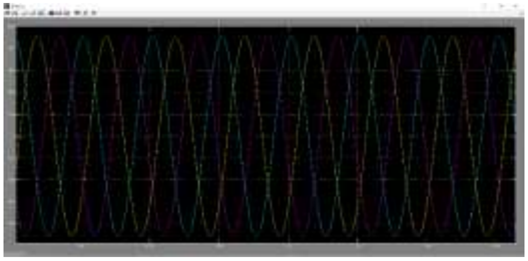

Figure 7. Result of current 440A vs. time [11]

Figure 8. Result of voltage 14KV vs. time [11]

Figure 9. Reactive power 1.12 Mvar vs. time [11]

4.3 Proposed result

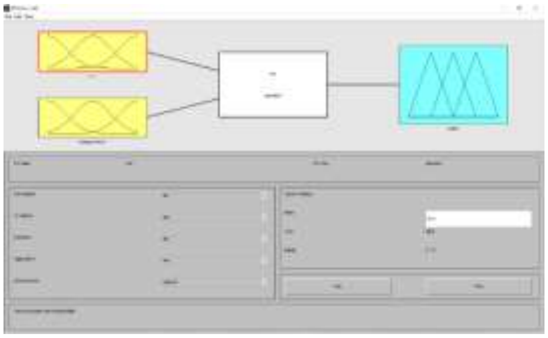

Figure 10. Proposed Fuzzy logic

Figure 11. Proposed fuzzy rules for our new circuit

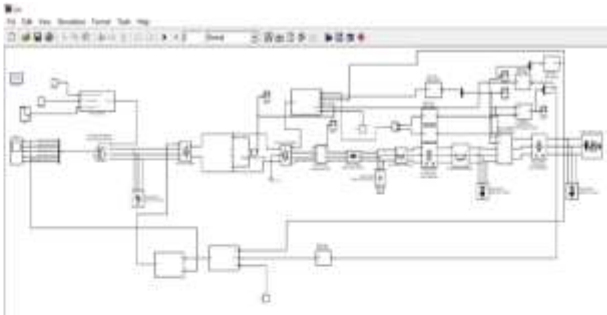

Figure 12. Proposed fuzzy circuit

Figure 13. Proposed current 490A vs. time

Figure 14. Proposed reactive power 1.5Mvar vs. time

Figure 15. Proposed Voltage 17KV vs. time

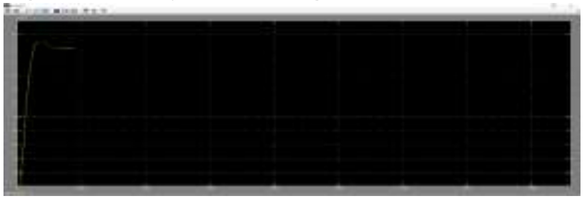

Figure 16. Proposed Active power 12MW Vs. Time

4.4 Comparison between a proposed and existing system based on components

Table 3. Comparison between a proposed and existing system based on components

Comparison between a proposed and existing system based on components	
Proposed results	**Existing results [11]**
3 phase 12 pulse IGBT-based neutral point clamped Inverter	3 phase 6 pulse Inverter
Variable wind speed taken [15m/s,12m/s,10m/s]	Fixed wind speed = 15m/s
Mamdani-based Fuzzy logic controller	PI controller

Shows table 3 Comparison between a proposed and existing system based on components, components of proposed work like 3 phase 12 pulse IGBT based neutral point clamped Inverter, Variable wind speed taken [15m/s,12m/s,10m/s], Mamdani based Fuzzy logic controller, and components of existing work 3 phase 6 pulse Inverter, Fixed wind speed = 15m/s, PI controller.

4.5 Comparison between a proposed and existing system based on parameters

Table 4. Comparison between a proposed and existing system based on parameters

	Proposed results	**Existing results [11]**
Voltage (KV)	**17**	**14**
Current (A)	**490**	**440**
Activepower (MW)	**12**	**10**
Reactive power (Mvar)	**1.5**	**1.12**

Table 4 shows a Comparison between the proposed and existing system based on parameters like voltage (KV) , current (A), activepower (MW), and reactive power (Mvar). Proposed results respectively 17KV, 490A, 12 MW, and 1.5Mvar. Existing results respectively 14 KV, 440 A, 10 MW, 1.12 Mvar.

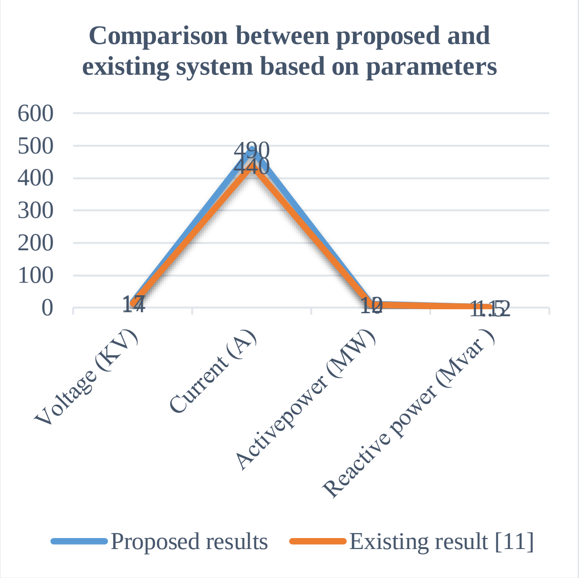

Figure 17. Comparison between a proposed and existing system based on parameters

Figure 17 shows a Comparison between the proposed and existing system based on parameters like voltage (KV) , current (A), activepower (MW), and reactive power (Mvar). Proposed results respectively 17KV, 490A, 12 MW, and 1.5Mvar. Existing resultsrespectively 14 KV, 440 A, 10 MW, 1.12 Mvar.

V. CONCLUSION

Traditional PI controllers can often alter the blade's angular position for 15 m/s only with high starting overshoot and sluggish response to controller gains. From 15 meters per second to 12 meters per second and 10 meters per second of the proposed model for variable wind speed, this research introduces an enhanced fuzzy rules-based controller that can independently manage the turbine's voltage, current, active power and reactive power using the rotor (generating) side converter and grid side converter. It is seen in figure 14. ,fig15. ,fig16 , the proposed model with a fuzzy-based Mamdani controller, the active power reaches a peak power 12.6 MW and at t=0.01 sec it reaches steady state condition with active power 12 MW and reactive power reaches peak power 1.56Mvar and at t=0.01 sec, it reaches a steady state condition with reactive power 1.5 Mvar and also voltage reaches peak to peak voltage 16KV synchronizing with grid whereas in the existing model with PI controller from fig 6. ,fig9. ,fig8. active power reaches a steady state condition at t=0.01 sec 10MW, reactive power reaches a steady state condition at t=0.01sec 1.12Mvar, and voltage reaches peak to peak voltage 14KV synchronizing with grid.Following the explanation of various essential principles regarding small-scale wind turbines, building a Mamdani-based fuzzy logic [1] controller is described. So the fuzzy speed controller shown intelligently widens the range of operating conditions with better stability with small overshoot and fast response. 17 kilovolts, 490 amperes, 12 MW, and 1.5 Mvar of reactive power have been achieved using the suggested concept using Matlab/Simulink software.

Relevant conflicts of interest/financial disclosures:

The authors declare that the research was conducted without any commercial or financial relationships construed as a potential conflict of interest.

Acknowledgement

The author acknowledge mentor and guide Mr Papumoni Saikia, Assistant professor,Department of Electrical Engineering,Jorhat Engineering College ,Jorhat ,Assam for his valuable guidance and support in completing the project and thank for his support in writing the paper.

Conflict of Interest

None.

Funding Source

None.

References

Mamdani, E.H., and S. Assilian. 'An Experiment in Linguistic Synthesis with a Fuzzy Logic Controller'. International Journal of Man-Machine Studies 7, no. 1 (January 1975): 1–13. https://doi.org/10.1016/S0020-7373(75)80002-2.

M. Sinner et al., "Experimental Testing of a Preview-Enabled Model Predictive Controller for Blade Pitch Control of Wind Turbines," in IEEE Transactions on Control Systems Technology, vol. 30, no. 2, pp. 583-597, March 2022, doi: 10.1109/TCST.2021.3070342.

M. -H. Chiang et al., "Dynamic Simulation and Control of a Semi-submersible Floating Offshore Wind Turbine with a Direct-Driving Permanent Magnetic Synchronized Generator," 2022 8th International Conference on Applied System Innovation (ICASI), 2022, pp. 119-122, doi: 10.1109/ICASI55125.2022.9774486.

R. Prasad and N. P. Padhy, "Active Power Dispatch and Tracking Mechanism for DFIG Wind Turbine Generator in Wind Farm Considering Wake Effect," 2022 IEEE International Conference on Power Electronics, Smart Grid, and Renewable Energy (PESGRE), 2022, pp. 1-6, doi: 10.1109/PESGRE52268.2022.9715911.

A. Zentani, A. Almaktoof and M. Kahn, "DC-DC Boost Converter with P&O MPPT Applied to a Stand-Alone Small Wind Turbine System," 2022 30th Southern African Universities Power Engineering Conference (SAUPEC), 2022, pp. 1-5, doi: 10.1109/SAUPEC55179.2022.9730744.

P. Manjeera, G. V. Nagesh Kumar and V. Rafi, “Design and Implementation of Fuzzy logic-2DOF controller for Emulation of wind turbine System,” 2022 12th International Conference on Cloud Computing, Data Science & Engineering (Confluence), 2022, pp. 191-196, doi: 10.1109/Confluence52989.2022.9734164.

J. E. Sierra-García and M. Santos, “Improving Wind Turbine Pitch Control by Effective Wind Neuro-Estimators,” in IEEE Access, vol. 9, pp. 10413-10425, 2021, doi: 10.1109/ACCESS.2021.3051063.

H. Gudimindla, M. S. K and S. Sandhya, “Performance Analysis of Adaptive Speed Reference Tracking QFT Robust Controller for Three Phase Grid connected Wind Turbine under Stochastic Wind Speed Conditions,” 2021 Emerging Trends in Industry 4.0 (ETI 4.0), 2021, pp. 1-6, doi: 10.1109/ETI4.051663.2021.9619223.

Q. Ran and F. Jin, “Robust Adaptive MPPT Control of Wind Turbine Based on Prescribed Performance,” 2022 IEEE 2nd International Conference on Power, Electronics and Computer Applications (ICPECA), 2022, pp. 67-71, doi: 10.1109/ICPECA53709.2022.9719157.

G. S. Sudharsan, J. Vishnupriyan and K. V. Anand, “Active flow control in Horizontal Axis Wind Turbine using PI-R controllers,” 2020 6th International Conference on Advanced Computing and Communication Systems (ICACCS), 2020, pp. 1010-1013, doi: 10.1109/ICACCS48705.2020.9074461.

G. Fandi, F. O. Igbinovia, I. Ahmad, J. Svec and Z. Muller, “Modeling and simulation of a gearless variable speed wind turbine system with PMSG,” 2017 IEEE PES PowerAfrica, 2017, pp. 59-64, doi: 10.1109/PowerAfrica.2017.7991200.

T. Ilham, M. Billel and D. Taibi, “Monitoring of Wind Energy Conversion System by on Dimensional Adaptive Tuning Fuzzy Logic Controller,” 2022 5th International Conference on Advanced Systems and Emergent Technologies (IC_ASET), 2022, pp. 494-499, doi: 10.1109/IC_ASET53395.2022.9765876.

D. Bustan and H. Moodi, “Adaptive Interval Type-2 Fuzzy Controller for Variable-speed Wind Turbine,” in Journal of Modern Power Systems and Clean Energy, vol. 10, no. 2, pp. 524-530, March 2022, doi: 10.35833/MPCE.2019.000374.

M. K. Asy’ari, A. Musyafa’ and K. Indriawati, “Design of Wind Turbine Output Voltage Control Systems in Multi-Input Buck Converter Using Fuzzy Logic Control for Battery Charging,” 2019 International Conference on Advanced Mechatronics, Intelligent Manufacture and Industrial Automation (ICAMIMIA), 2019, pp. 249-252, doi: 10.1109/ICAMIMIA47173.2019.9223417.

B. K. Avu, M. Sainadh Yelamanchili, S. Dugyala, S. G. Kethireddy, S. Preetham Gajji and S. Mishra, “Modelling and Simulation of Wind Turbine Using PMSG,” 2021 4th International Conference on Recent Developments in Control, Automation & Power Engineering (RDCAPE), 2021, pp. 16-20, doi: 10.1109/RDCAPE52977.2021.9633587.

R. Prasad and N. P. Padhy, “Synergistic Frequency Regulation Control Mechanism for DFIG Wind Turbines With Optimal Pitch Dynamics,” 2021 IEEE Power & Energy Society General Meeting (PESGM), 2021, pp. 1-1, doi: 10.1109/PESGM46819.2021.9638258.

X. Wang and M. Wang, “Extension Controller for Wind Turbine Pitch System,” 2021 IEEE 5th Conference on Energy Internet and Energy System Integration (EI2), 2021, pp. 2771-2774, doi: 10.1109/EI252483.2021.9713598.

M. Mohamed, H. Wang and Y. Tiang, “Indirect power control of DFIG based wind turbine using fractional order intelligent proportional integral sliding mode controller,” 2021 40th Chinese Control Conference (CCC), 2021, pp. 5939-5944, doi: 10.23919/CCC52363.2021.9549563.

D. Liu, Y. Xia, R. Li and P. Liu, “Integral sliding mode control of low-speed wind turbine,” 2019 Chinese Automation Congress (CAC), 2019, pp. 605-609, doi: 10.1109/CAC48633.2019.8996272.

Q. Hawari, J. Fleming, T. Kim and C. Ward, “Stability Margin Analysis for PI Pitch Controllers on Large Wind Turbines,” 2022 UKACC 13th International Conference on

Control (CONTROL), 2022, pp. 74-75, doi: 10.1109/Control55989.2022.9781446.

H. H. H. Aly, “A Proposed Intelligent Adaptive Controllers for Wind Turbine Driving DFIG for Improving the Output Generated Power,” 2019 IEEE Canadian Conference of Electrical and Computer Engineering (CCECE), 2019, pp. 1-4, doi: 10.1109/CCECE43985.2019.9052390.

A. Stock, L. Amos, R. Alves and W. Leithead, “Design and Implementation of a Wind Farm Controller Using Aerodynamics Estimated From LIDAR Scans of Wind Turbine Blades,” in IEEE Control Systems Letters, vol. 5, no. 5, pp. 1735-1740, Nov. 2021, doi: 10.1109/LCSYS.2020.3043686.

M. H. Ravanji and M. Parniani, “Small-Signal Stability Analysis of DFIG-based Wind Turbines Equipped with Auxiliary Control Systems under Variable Wind Speed,” 2020 IEEE International Conference on Environment and Electrical Engineering and 2020 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), 2020, pp. 1-7, doi: 10.1109/EEEIC/ICPSEurope49358.2020.9160721.

E. Mousarezaee, A. Polat and L. T. Ergene, “Wind Turbine Emulator Based on Small-Scale PMSG by Fuzzy FOC,” 2020 21st International Symposium on Electrical Apparatus & Technologies (SIELA), 2020, pp. 1-4, doi: 10.1109/SIELA49118.2020.9167128.

B. P. Ganthia, S. K. Barik and B. Nayak, “Sliding Mode Control and Genetic Algorithm Optimized Removal of Wind Power and Torque Nonlinearities in Mathematical Modeled Type-III Wind Turbine System,” 2021 9th International Conference on Cyber and IT Service Management (CITSM), 2021, pp. 1-7, doi: 10.1109/CITSM52892.2021.9587933.

Marwan Rosyadi , “Fuzzy –pi controller design for pm wind generation to improve fault through ride through wind ”, International Journal of Renewable Energy Research, Vol.3,No.2,2013