

Comparative studies on the excitation control of a doubly fed induction generator using fuzzy PI controllers and classical PI/PID controllers

I. Szeidert, I. Filip, C. Vasar, D. Bordeasu

Iosif Szeidert*

Department of Automation and Applied Informatics
Politehnica University Timisoara, Romania
300223 Timisoara, Bd. V. Parvan, 2, Romania
*Corresponding author: iosif.szeidert@upt.ro

Ioan Filip

Department of Automation and Applied Informatics
Politehnica University Timisoara, Romania
300223 Timisoara, Bd. V. Parvan, 2, Romania
ioan.filip@upt.ro

Cristian Vasar

Department of Automation and Applied Informatics
Politehnica University Timisoara, Romania
300223 Timisoara, Bd. V. Parvan, 2, Romania
cristian.vasar@upt.ro

Dorin Bordeasu

Department of Automation and Applied Informatics
Politehnica University Timisoara, Romania
300223 Timisoara, Bd. V. Parvan, 2, Romania
dorin.bordeasu@upt.ro

Abstract

The main goal of this paper is to answer the question whether a fuzzy PI control can provide better performance than a conventional PI/PID control in the case of a wind energy conversion system with a Doubly-Fed Induction Generator (DFIG) connected to a power system. The paper emphasizes the main advantage of fuzzy PI controllers: their ability to produce a non-zero control increment even when the output error is zero, but its derivative is not, proving a better performance than a conventional PI/PID solution for the control of high-order and strongly oscillating processes (with an error repeatedly crossing zero). This remark, according to the authors' knowledge, has not been encountered in the specialized literature, being valid also for the fuzzy control of other strongly oscillating processes. To prove the above, the research presents a comparative study on the excitation control of a DFIG, using fuzzy PI controllers, respectively conventional PI/PID

controllers. The goal of the control system is to keep constant the generator terminal voltage under some external disturbances action such as variations of the mechanical torque (due to wind speed changes on the wind turbine) and electrical load/unload (by connecting/disconnecting local consumers). Based on comparative analysis of type-1 and type-2 fuzzy PI control systems, it was concluded that, for the considered process (DFIG), type-2 fuzzy controller does not significantly improve the control performance. Therefore, the type-2 fuzzy controller is not justified, being even more complex and difficult to tune. The comparative study carried out between the fuzzy PI control solution (type-1) and the classical solutions using PI/PID controllers shows that the fuzzy strategy provides superior performance (smaller settling-time, shorter duration oscillations), both in case of a slow mechanical disturbance (mechanical torque variation), as well as for fast electrical disturbances (load/unload). It should also be highlighted that the DFIG is modelled as a nonlinear system of the 7th order (using Park's classical d-q equations) ensuring an increased accuracy for the obtained results in the context of fast transient regimes specific to the considered electrical process.

Keywords: Fuzzy PI controller, doubly fed induction generator, conventional PI/PID control system, wind energy conversion system.

1 Introduction

Although fuzzy logic is no longer a novelty, the interest shown in it, both in the scientific and engineering areas, is still of relevance, as evidenced by both the large number of articles and scientific journals in the field, as well as the domestic and industrial applications where they are used [5][21][22][24]. Fuzzy logic lends itself to the modeling or control of complex processes that are difficult to model analytically or are described by high-order nonlinear models, for which the tuning of control system becomes more difficult.

Based on human experience, fuzzy control systems use fuzzy logic, a type of non-classical logic that allows handling uncertainty and imprecision, in order to perform decisions and control complex systems. Instead of relying on strict and precise values, fuzzy logic works with degrees of truth, providing more flexible and adaptive control compared to traditional control systems. This type of control strategies is used in various fields, from consumer electronics to control engineering and automation. One of the fields in which fuzzy control can be found is that of wind energy conversion systems (WECS), in the current paper a wind energy conversion system (WECS) based on doubly fed induction generator (DFIG) is analyzed. This type of induction generator is an important component in wind energy conversion systems, being used both for supplying electricity to the national grid and in various standalone applications, such as remote microgrids.

For a DFIG, as a complex and nonlinear process with strongly transient operating regimes, the control based on fuzzy logic presents a significant interest among researchers [9][19][23][25][26][32]. A significant advantage of DFIG is its ability to operate at variable speeds, unlike conventional generators that perform well usually at constant speeds. This feature is essential in the case of WECS, considering the random nature of wind energy (due to wind speed variation), and the fact that it can operate efficiently at both lower and higher speeds than the nominal one significantly improves the performances of the system [2][3][25][30].

Due to the widespread usage of variable speed type WECS based on DFIG, obviously several control strategies are presented in technical literature, ranging from classical PI/PID controllers to direct torque control, maximum power point tracking control, field-oriented control, fuzzy logic control etc [4][7][8][10][17].

Depending on the controlled output as well (voltage, power), this very wide range of control techniques (simpler or more complex, each of them having advantages and disadvantages) can offer better performances (compared to each other) depending on the process operating regimes. The big issue raised by some of these complex control systems (using, for example, adaptive control techniques [4][7][8][14][17], optimization techniques [11][12][20]), although they ensure better control performances (quantifiable through control quality indicators such as overshoot, settling-time etc.), is the assurance of the control system robustness [6][27].

In the context of the previously mentioned, the conventional PI/PID control, although it may sometimes offer weaker performances (but still comparable to those of more complex control systems),

ensures a much higher degree of robustness for the controlled system [1][31]. The current research analyzes the case where the use of fuzzy logic together with a dynamic PI component could provide better performance than a conventional solution based only on PI/PID controllers, while also benefiting from the robustness advantage offered by the classic PI controller integrated in the control strategy. In essence, the research carried out presents the design and implementation of a fuzzy PI control system for controlling the excitation of a DFIG, whose performances are compared with those of a simple conventional PI/PID control system.

2 Design of the fuzzy PI control system for DFIG excitation control

The Figure 1 shows the fuzzy PI control structure for a doubly-fed induction generator (DFIG) integrated into a wind energy conversion system and connected to an infinite power grid. Also, local electrical consumers are connected to the generator terminals, whose connection or disconnection can lead to various load/unload regimes. These electrical consumers connections/disconnections, together with the variation of the mechanical torque (as a result of the wind speed variation acting on the turbine) are the external disturbances that affect the behavior of the controlled process. The goal of the control system is to reject the effect of these disturbances in order to maintain a constant voltage at the generator terminals by controlling the excitation voltage (basically, maintaining a constant supply voltage for local consumers).

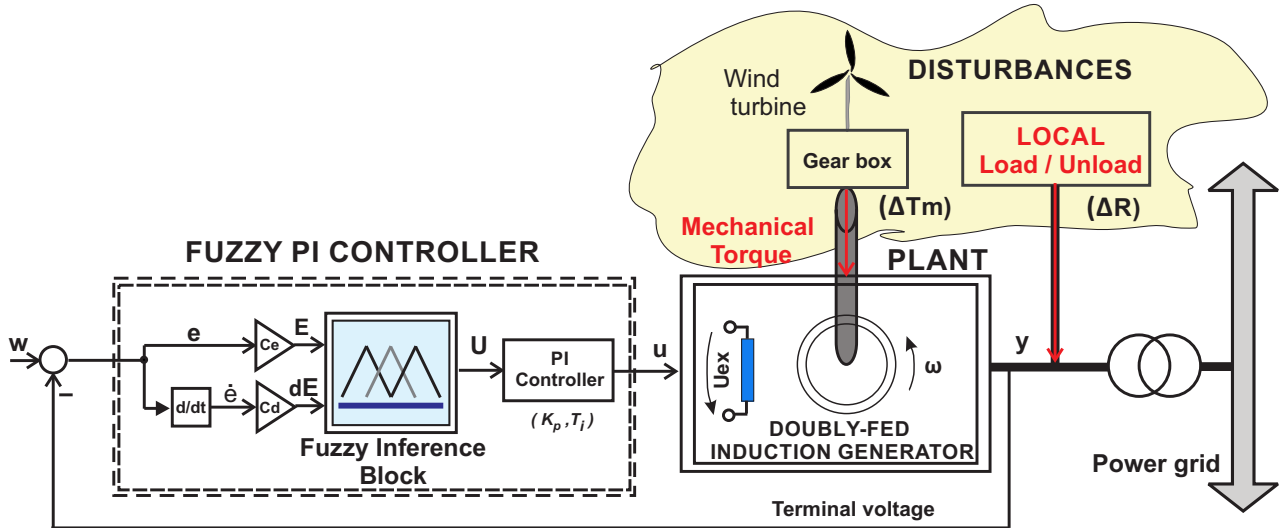


Figure 1: Fuzzy PI control system

Compared to a conventional control structure based on a PI/PID controller (whose input signal is the controlled output error that is canceled), in a fuzzy PI control system, a fuzzy inference block is placed before the PI controller, its inputs being error, respectively the derivative of the error - see Figure 1. In this article, both type 1 and type 2 fuzzy control systems were analyzed. Using the scaling factors c_e and c_d , the two input variables (E , dE) are normalized in the range $[-1,1]$. The design of the inference structure requires the choice of the type of fuzzy membership functions (from a wide range with various shapes: triangular, trapezoidal, singleton-type, Sigmoid-type, etc.). In the current research, triangular membership functions were chosen for the fuzzification of the two input variables (see Figure 2a and Figure 2b for the case of a type-1 fuzzy controller, respectively Figure 3a and Figure 3b for type-2). It can be seen that a number of 5 membership functions were chosen for each of the two input variables. The fuzzy rules (5x5 rules) for this set membership functions are presented in Table 1 (for a Mamdani fuzzy inference system). It should be mentioned that fuzzy structures with a larger number of membership functions (7x7 rules) were also tested in this research, but the performances were not substantially improved [29].

The output of the inference block (defuzzification output U - see Figure 1) is also normalized in (range $[-1,1]$), as can be seen in Figure 2c (for type 1) and Figure 3c (for type 2) representing the

Table 1: The fuzzy rules set

Derivative of error(dE)	Error (E)					
		NB	NM	Z	PM	PB
	NB	NB	NB	NB	NM	Z
	NM	NB	NB	NM	Z	PM
	Z	NB	NM	Z	PM	PB
	PM	NM	Z	PM	PB	PB
	PB	Z	PM	PB	PB	PB

control surfaces. In simple terms, the difference between type 1 and type 2 is that type 1 works with a fixed membership function, while type 2 fuzzy systems use fluctuating membership function (see the footprint of uncertainty - FOU in Figure 3a and Figure 3b). Obviously, type 2 fuzzy systems are more complex and harder to tune. In some cases, their use does not lead to better performances, but in other cases they are able to ensure better performances, capturing more accurately the plant non-linearities. Regardless of the type of fuzzy system (type 1 or 2), the PI (or PID) controller plays a special role in the fuzzy control system dynamics, eliminating the controlled output error.

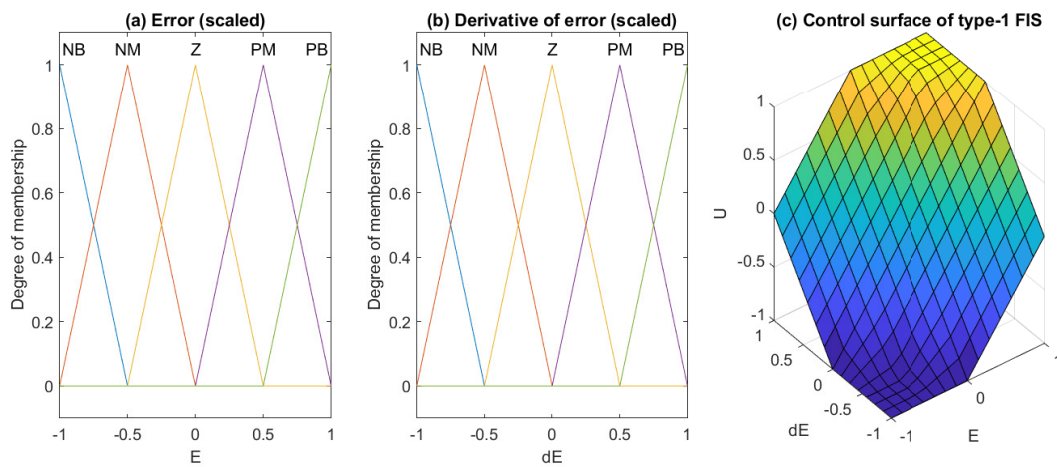


Figure 2: Fuzzy type 1 (membership functions and control surface)

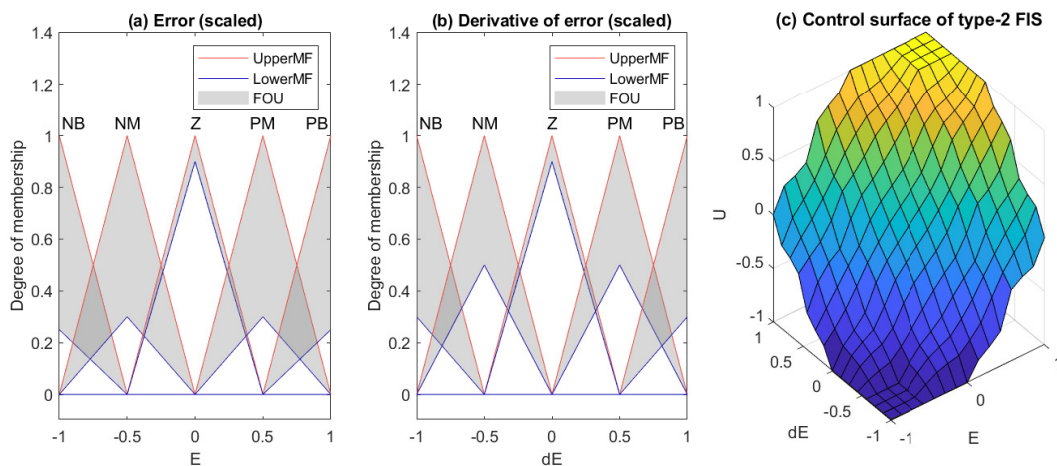


Figure 3: Fuzzy type 2 (membership functions and control surface)

As already mentioned, the driven process is Doubly-Fed Induction Generator (DFIG) integrated in a wind energy conversion system and connected to a power system. For the performed simulations, a nonlinear model of 7th order (the d-q model, known as Park's equation) was considered, describing quite accurately the behavior of the DFIG, completed with the equations modeling the connection to a power system, respectively the connection/disconnection of consumers at generator terminals

[11][12][13][15][16][17][18].

The controlled installation is disturbed by a stochastic noise with zero mean and variation $\sigma^2 = 0.01$, this modeling some variations of the process parameters, respectively of the noise produced by the power system [28].

3 Case studies

As already mentioned, considering the specific operating regimes of an induction generator (integrated in a wind site), the case studies carried out considered two types of external disturbances that affect its operation:

- Mechanical disturbances (with slower action on the process) consisting of mechanical torque variations as a consequence of the variation in the wind speed (driving the turbine);
- Electrical disturbances (with rapid action on the process) consisting of variations in loading/unloading by connecting/disconnecting local electrical consumers at the generator terminals.

3.1 Case 1: Type 1/type 2 fuzzy PI controller – comparison

In this first case study, a comparative analysis of the performances offered by type 1, respectively type 2 fuzzy PI controllers, was carried out. The tests carried out showed practically similar performances for both types of fuzzy controllers, in the context of both categories of previously mentioned disturbances.

To exemplify the previously mentioned, an analysis is presented for the case of a mechanical torque variation $\Delta T_m = 10\%$, (considering a fuzzy inference structure with 5 membership functions, as described in the previous chapter - see Figure 2a and Figure 2b, respectively Figure 3a and Figure 3b). Figure 4a and Figure 4b shows the controlled output error for each of the two types of fuzzy controllers. A great similarity of the control system response can be observed (the results being similar): identical shapes, identical settling-times, small insignificant differences being only for the response overshoot/undershoot. Including the excitation voltages (the controller outputs, see Figure 4c and Figure 4d), respectively the outputs of the fuzzy inference blocks (Figure 4e and Figure 4f) are practically identical (as shape and values). In fact, by analyzing the control surfaces of the two types of fuzzy controllers (Figure 2c and Figure 3c) one can notice the almost identical shapes, thus logically leading to similar responses of control systems.

It must be stated that similar comparative tests were carried out for other variation ranges of the mechanical torque, respectively for electric load/unload regimes, the conclusion being the same: the control performances are practically equal for both types of fuzzy controllers (1 and 2). For this reason, these comparative results are only mentioned in this first study, without being explicitly presented in the article (to basically avoid showing duplicate graphics).

The tuning of type 1 fuzzy PI controller was carried out through repeated trials, analyzing the variation ranges of the inputs (error and error derivative) for fuzzy inference block design, respectively the performance of the control system response for tuning the PI component. The considered membership functions are presented in Figure 2a and Figure 2b, respectively Figure 3a and Figure 3b, mentioning that for type 2 (whose design started from the fixed membership functions of type 1 fuzzy) several variants of membership functions fluctuation were tested in this research, without leading to relevant changes of the control performance, which remains practically similar to that offered by type 1. It should be also emphasized that inference structures with a different number of membership functions (3- too weak performances or 7 – similar performances) were also tried and tested, the solution with 5 functions being the best in terms of performance, respectively complexity.

As a conclusion, based on all mentioned in this first case study, all performed tests prove that the type-2 fuzzy PI controller (much more complex as inference algorithm and much more difficult to tune due to strongly nonlinear plant dynamics) is not justified compared to type 1. For this reason, all the following studies will refer only to type 1 fuzzy PI controller.

The following case studies will consider various ranges of disturbances variation, respectively both types of mentioned disturbances (mechanical torque, electrical load/unload), comparing only the per-

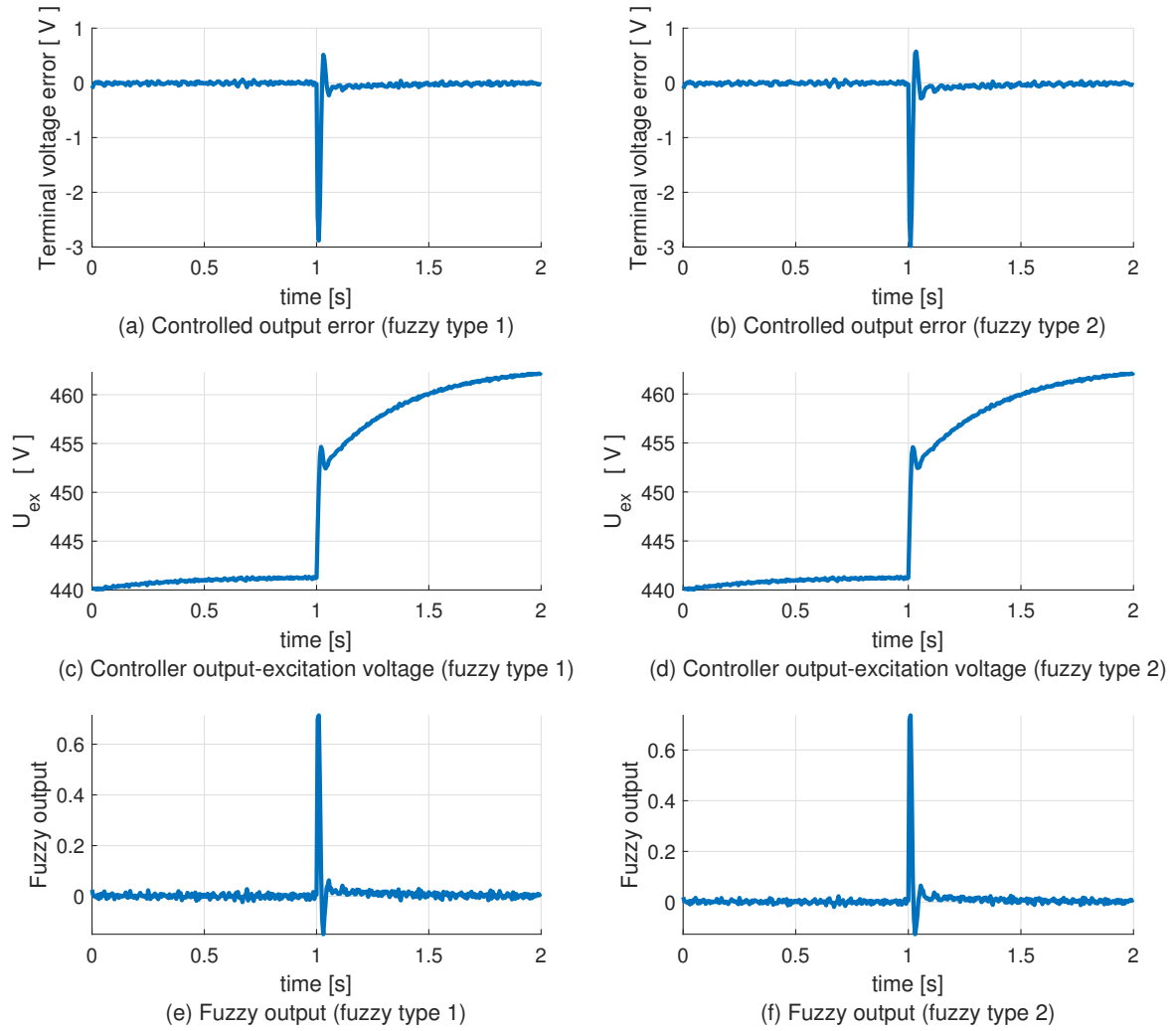


Figure 4: Case 1 results (type 1/type 2 fuzzy PI controller - comparison)

formance of the type-1 fuzzy PI controller (type-2 being already excluded) with that of the conventional PI/PID controllers.

3.2 Case 2: Mechanical torque variation

For a mechanical torque variation $\Delta T_m = 20\%$ (specific to a wind gust), the comparative results regarding the response of the control system (Figures 5a, 5b, 5c), respectively the excitation voltage, basically the output of the controller (Figures 5d, 5e, 5f) for a type-1 fuzzy PI controller and for conventional PI/PID controllers, are analyzed below. The obviously better performances of the fuzzy PI controller can be noted: much lower settling-time, slightly smaller overshoot, respectively shorter duration of the oscillating transient regime (Figures 5a, 5b, 5c). Thus, the settling-time for fuzzy PI controller is 0.2 s, respectively 0.6 s for conventional PI and 0.8 s for PID. It should also be highlighted the lower duration of the transient oscillating regime: 0.1 s for the case of the fuzzy PI controller compared to 0.3 s for the conventional PI, respectively 0.2 s for the PID.

Obviously, the adequate tuning of the PI component integrated in the fuzzy control system led to other parameters values (gain and integral time constant) compared to the case of the PI controller conventionally used (the PID parameters are based on the already tuned PI parameters, adding the derivative component with a role especially in reducing the duration of the oscillating regime). The outputs of the controllers (integrating the execution element) are shown in Figures 5d, 5e, 5f, noting

the smaller variation range of the excitation voltage in the case of the fuzzy PI controller (approx. 440-485 V). The variation of the mechanical torque is an external disturbance with a much slower effect on the process (due to the mechanical inertia of the turbine) compared to the electrical load/unload variations (treated in the following case studies). For this reason, tests corresponding to a negative variation of the mechanical torque (basically a decrease of the wind speed) were no longer presented, these being much less demanding and the performance of the fuzzy PI controller being the best also in these cases.

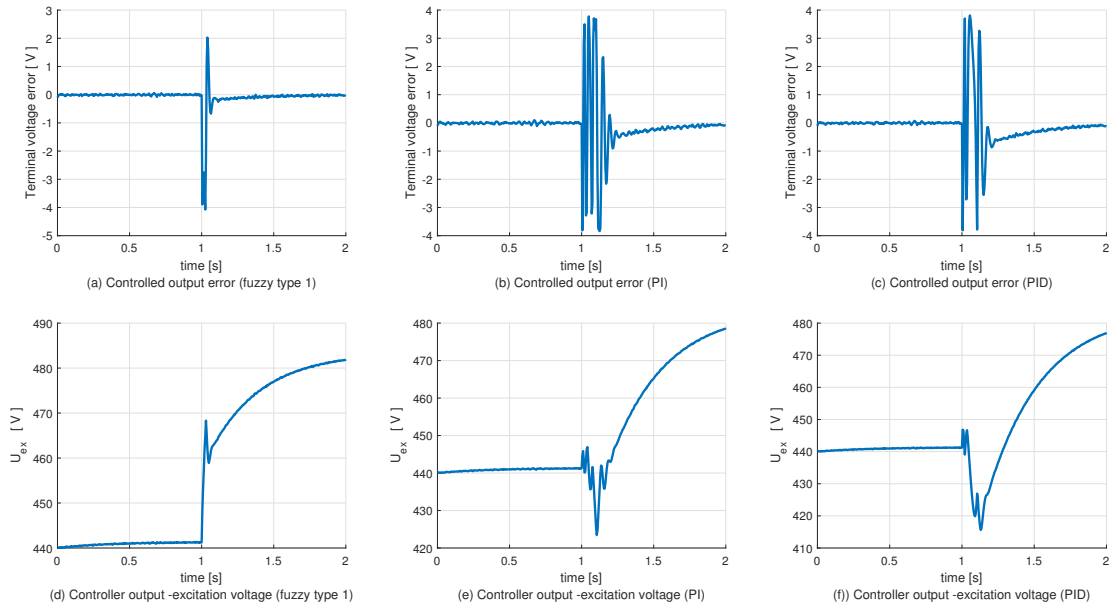


Figure 5: Case 2 results (mechanical torque variation)

3.3 Case 3: Electrical load/unload

Similar results regarding the better performance of the fuzzy PI control system (compared to the conventional PI/PID solutions) were also obtained for the electrical load/unload regimes. Although many more tests were carried out for various situations (resistive, inductive, capacitive load/unload - the conclusions being similar), only the cases of resistive electrical load/unload are presented in the following.

a) $\Delta R = +10\%$ - disconnecting local consumers at generator terminals (electrical unload)

Figures 6a, 6b, 6c shows the controlled output error for the case of an electrical consumer disconnection at generator terminals (10% increase of electrical resistance at terminals). The graphical results clearly show better performance of the fuzzy control system in terms of settling time and duration of the oscillatory regime, which is damped much faster. Note the excitation voltages (outputs of the three analyzed controllers - Figures 6d, 6e, 6f), with a quite different dynamic, the fuzzy controller output being much smoother (less oscillating).

The values of control performance indicators for this study case are presented in line 2 of Table 2, proving the superiority of the fuzzy logic controller.

b) $\Delta R = -10\%$ - connecting local consumers at generator terminals (electrical load)

One of the most demanding operating regimes of the generator is the electrical load. In this case as well, for a resistive load, the response of the fuzzy PI control system is the best (see Figures 7a, 7b, 7c), the quality indicators of the control being presented on the 3rd line of Table 2. In Figures 7d, 7e, 7f are depicted outputs of the three analyzed controllers for this load regime.

It can be seen that the conventional PID controller (compared to the conventional PI) leads to a better damping of the transient regime, the duration of the oscillating regime being shorter. Also,

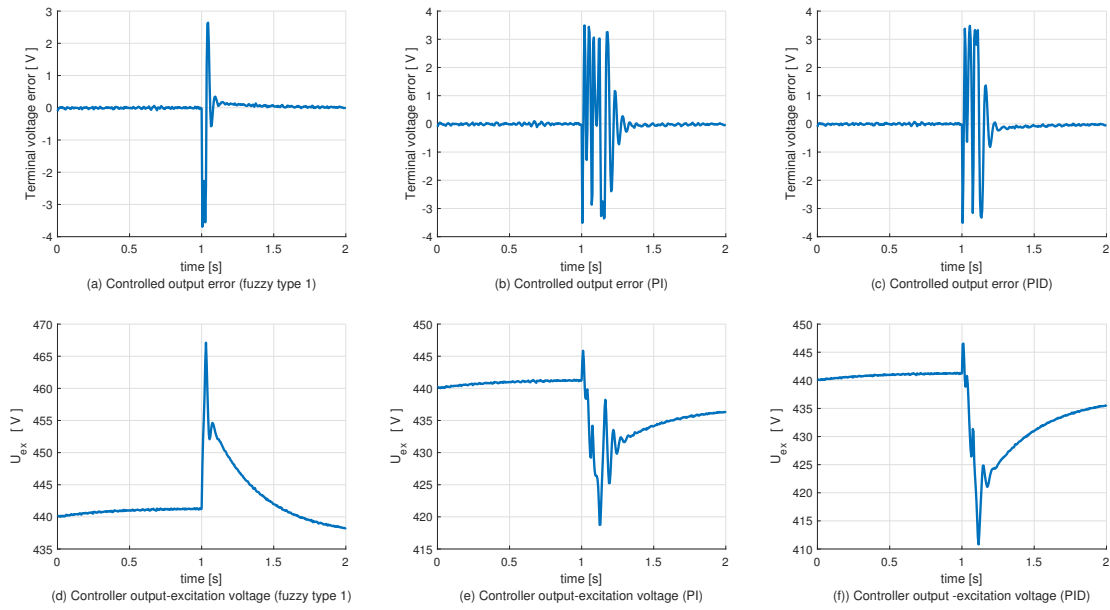


Figure 6: Case 3 results (electrical unload)

only for the electrical load regime, the fuzzy PI controller and the conventional PID controller have relatively similar performances (slightly better fuzzy with a shorter duration of oscillations). The overshoot / undershoot have somewhat similar values in a limited range (as can be seen in all the figures showing the controlled output error, including Figure 8b) due to the connection to a power network (which acts as a constraint on the generator terminals voltage). For this reason, this control quality indicator was not explicitly tracked and analyzed in the presented studies.

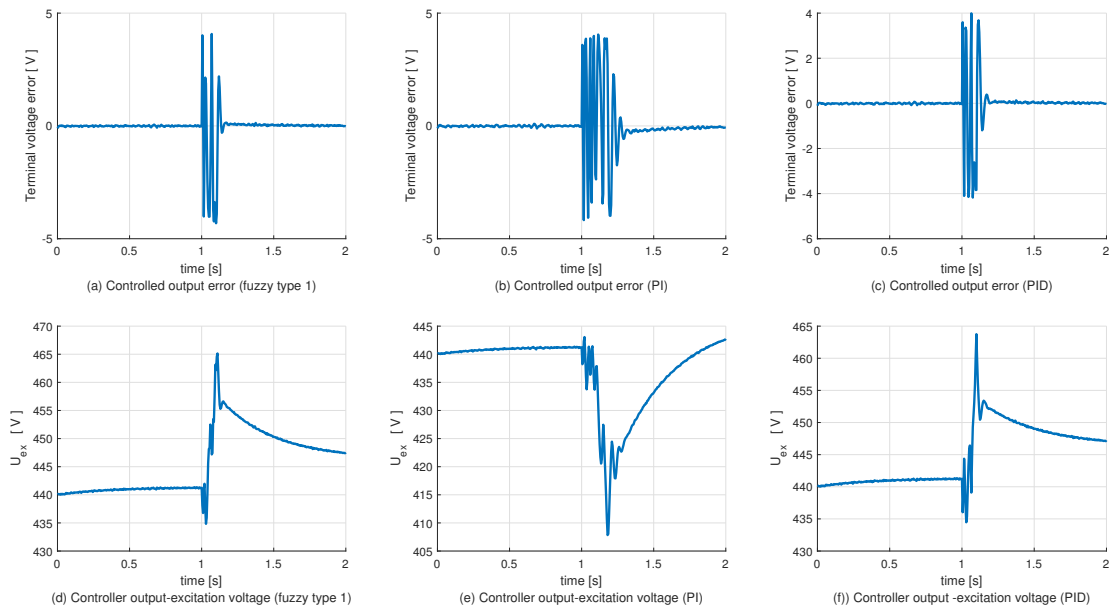


Figure 7: Case 3 results (electrical load)

Overall, for the considered plant, a fuzzy PI control system outperforms the conventional solutions based on classical PI/PID controller, ensuring better performance as can be seen in Table 2, which offers a synthetic presentation of the control quality indicators for all presented case studies (the most relevant ones from a long list of performed but not fully presented tests).

Table 2: Comparative control quality indicators

No.	Disturbance	Fuzzy PI		Classical PI		Classical PID		Best performance
		Settling time [s]	Oscillation time [s]	Settling time [s]	Oscillation time [s]	Settling time [s]	Oscillation time [s]	
1	Mechanical torque variation ($\Delta T_m = 20\%$)	0.2	0.1	0.6	0.3	0.8	0.2	Fuzzy PI
2	Unload ($\Delta R = +10\%$)	0.2	0.1	0.4	0.4	0.3	0.3	Fuzzy PI
2	Load ($\Delta R = -10\%$)	0.2	0.15	0.4	0.3	0.2	0.2	Fuzzy PI and classical PID (comparable)

3.4 Case 4: Robustness validation

The goal of this last, more complex case study is to test and validate the robustness of the PI fuzzy control system under the action of a sequence of external disturbances, mechanical and electrical (mechanical torque variation, electrical load/unload - see Figure 8a, for a longer time. Analyzing the Figure 8b showing the control system response (terminal voltage error), the test shows good performance, as well as the system robustness. It should be noted in this sense its robustness even under the simultaneous action (at moments $t=80, 85, 90$ s) of both mechanical disturbance (variation of the mechanical torque) and electrical disturbance (load/unload). Also, the required excitation voltage (controller output) falls within a reasonable range of physically achievable values (Figure 8c).

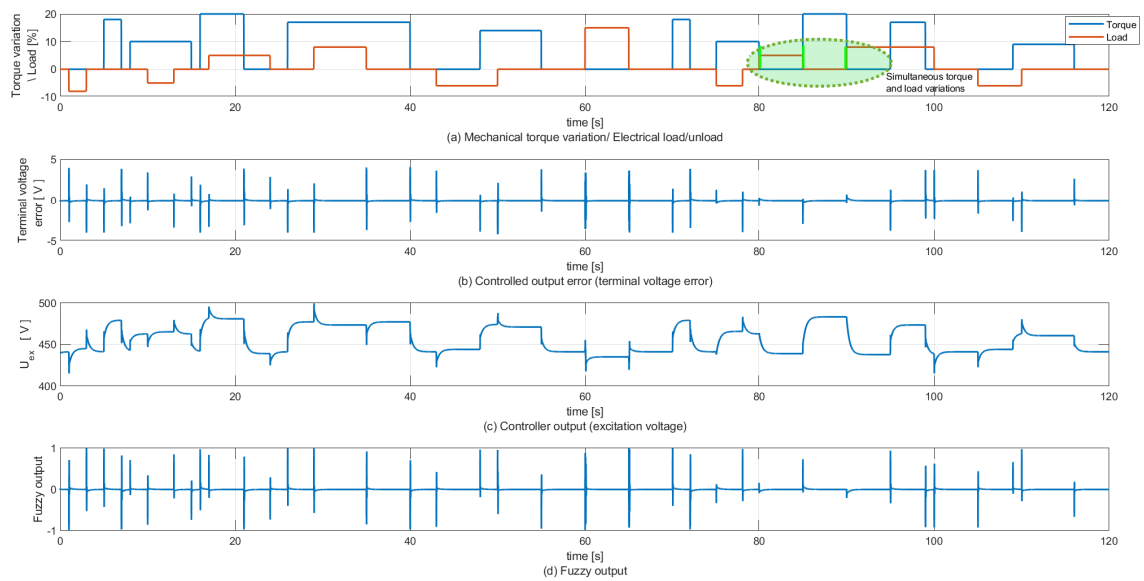


Figure 8: Case 4 results (a) Mechanical torque variation/ Electrical load/unload; (b) Controlled output error (terminal voltage error); (c) Controller output (excitation voltage); (d) Fuzzy output

In the context of this test, Figure 8d shows the variation of the fuzzy inference block output (variable U in Figure 1), which is the input in the dynamic PI component, basically a PI controller.

In a conventional control structure, a PI (or PID) controller cancels its input (which is the system output error). In a fuzzy PI control system, the PI controller ensures the cancellation of the fuzzy inference block output, thus indirectly forcing the cancellation of the control system error (and its derivative). In the design stage of the fuzzy inference block, its output was scaled in the interval $[-1,1]$, and thus its range of variation is much smaller than that of the control system output error. The role of the integrated PI controller in a fuzzy control system being to cancel a smaller input (the inference block output) than in a conventional PI control system (the system output error), his task and goal to cancel a smaller value is practically easier and faster to achieve. Thus, in such a fuzzy control system, the PI controller is faster and so more efficient, and the control performance increases through a faster

response (shorter settling time, shorter oscillating time).

4 Conclusion

The study carried out in this paper shows that the presented control strategy using a fuzzy PI controller to control the excitation of a doubly fed induction generator (DFIG) is a viable solution, being able to provide superior control performance compared to conventional solutions based on classic PI/PID controllers.

It is well known that the integral component of a conventional PI controller provides a null control increment whenever the error of the controlled output is zero. But in the case of a system with a strongly oscillating response around the steady-state value, this error is zero several times (until the permanent steady-state is reached), without its derivative also being zero (the system still being in a transient regime). For a fuzzy-PI controller (according to the fuzzy inference table), for a zero error and non-zero derivative of the error, the output of the fuzzy inference block is non-zero, which means that the PI controller still provides a non-zero increment for the control, which is an adequate response. Only when the steady state is reached (null error and null error derivative simultaneously), the control increment (offset) is zero. In other words, for a process whose output oscillates around the steady state value (high-order nonlinear processes), at various time moments when the error passes through zero (without remaining zero), the control increment should be non-zero. This behavior is specific only for fuzzy PI controllers and not also for conventional PI/PID controllers. And obviously, such behavior leads to more effective control and practically to a smaller settling time and less oscillations (as can be seen from the research results presented for the considered DFIG).

Another research conclusion is that both fuzzy controllers (types 1 and 2) provide similar control performances for the considered process. A simple analysis of the related control surfaces already gives a first hint of the rather large similarity between them. In this context, choosing type-2 fuzzy controller is not justified, the fuzzy algorithm being more complex and much more difficult to tune due to the complexity of the DFIG, modeled as a 7th-order nonlinear system. It should be also highlighted that this nonlinear model describes very well the fast transient regimes, strongly oscillating (specific to electric machines) and provides good accuracy of the simulation results, based on which clear conclusions about control performance were obtained.

Overall, for the considered process (maintaining constant terminal voltage of a doubly fed induction generator through excitation control), a fuzzy PI control system can provide superior performance compared to conventional solutions based on classic PI/PID controllers.

Author contributions

The authors contributed equally to this work.

Conflict of interest

The authors declare no conflict of interest.

References

- [1] Alcantara, S.; Vilanova, R.; Pedret, C.; Skogestad, S. (2012). A look into robustness/performance and servo/regulation issues in PI tuning, *IFAC Proceedings Volumes*, 45(3), 181-186, 2012.
- [2] Anbalagan, P.; Joo, Y. H. (2024). Nonfragile Sampled-Data Control for Interval Type-2 Fuzzy Modeling of Permanent Magnet Synchronous Generator-Based Wind Turbine Systems, *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, DOI: 10.1109/TSMC.2023.3344111, 2426-2439, 2024.
- [3] Aoun, S; Boukadoum, A; Yousfi, L. (2023). Advanced power control of a variable speed wind turbine based on a doubly fed induction generator using field-oriented control with fuzzy and neu-

- ral controllers, *International Journal of Dynamics and Control*, DOI10.1007/s40435-023-01345-9, 2023.
- [4] Arifin, M. S.; Uddin, M. N.; Wang, W. (2023). Neuro-Fuzzy Adaptive Direct Torque and Flux Control of a Grid-Connected DFIG-WECS With Improved Dynamic Performance, *IEEE Transactions on Industry Applications*, DOI: 10.1109/TIA.2023.3302844, 59(6), 7692-7700, 2023.
 - [5] Azadegan, A.; Porobic, L.; Ghazinoory, S.; Samouei, P.; Kheirkhah, A.S. (2011). Fuzzy logic in manufacturing: A review of literature and a specialized application, *International Journal of Production Economics*, 132, 258-270, 2011.
 - [6] Bensaadia, L.R.; Rouabhi, R.; Khodja, D.; Herizi, A. (2023). Adaptive type-1 fuzzy control of a wind energy conversion system based on a double-fed induction machine, *PRZEGLĄD ELEKTROTECHNICZNY*, 99, 110-115.
 - [7] Bustan, D.; Moodi, H. (2022). Adaptive Interval Type-2 Fuzzy Controller for Variable-speed Wind Turbine, *Journal of Modern Power Systems and Clean Energy*, DOI: 10.35833/MPCE.2019.000374, 10(2), 524-530, 2022.
 - [8] Cheng, X. (2023). A Fuzzy Adaptive PID Control Method for Novel Designed Rail Grinding Equipment, *IEEE Access*, DOI: 10.1109/ACCESS.2022.3232578, 11, 118-124, 2023.
 - [9] Elnaghi, B. E.; Abelwhab, M. N.; Abdel-Kader, F. E. S. A.; Ismaiel, A. M.; Mohammed, R. H.; Dessouki, M. E. (2023). Experimental Validation of Second-Order Adaptive Fuzzy Logic Controller for Grid-Connected DFIG Wind Power Plant, *IEEE Access*, DOI: 10.1109/ACCESS.2023.3337829, 11, 135255-135271, 2023.
 - [10] Fekry, H. M.; Eldesouky, A. A.; Kassem, A. M.; Abdelaziz, A. Y. (2020). Power Management Strategy Based on Adaptive Neuro Fuzzy Inference System for AC Microgrid, *IEEE Access*, DOI: 10.1109/ACCESS.2020.3032705, 8, 192087-192100, 2020.
 - [11] Filip, I.; Dragan, F.; Szeidert, I. Albu, A (2020). Minimum-Variance Control System with Variable Control Penalty Factor, *APPLIED SCIENCES*, DOI10.3390/app10072274, 10(17), 2020.
 - [12] Filip, I.; Dragan, F.; Szeidert, I. (2021). Considerations about Parameters Estimation into a Minimum Variance Control System, *APPLIED SCIENCES*, DOI10.3390/app11136165, 11(13), 2021.
 - [13] Filip, I.; Mihet-Popa, L.; Vasar, C.; Prostean, O.; Szeidert, I. (2019). Considerations Regarding the Design of a Minimum Variance Control System for an Induction Generator, *Electronics*, DOI10.3390/electronics8050532, 8(5), 2019.
 - [14] Filip, I.; Szeidert, I. (2017). Tuning the control penalty factor of a minimum variance adaptive controller, *EUROPEAN JOURNAL OF CONTROL*, 37, 16-26, 2017.
 - [15] Filip, I.; Szeidert, I.; Prostean O. (2016). Mathematical Modelling and Numerical Simulation of the Dual Winded Induction Generator's Operating Regimes, 6th International Workshop on Soft Computing Applications (SOFA), 2(357), 1161-1170, 2016.
 - [16] Filip, I.; Szeidert, I.; Prostean, O.; Vasar, C. (2013). Analysis through Simulation of a Self-Tuning Control Structure for Dual Winded Induction Generator, *IEEE 9th International Conference on Computational Cybernetics*, JUL 08-10, 2013, Tihany, Hungary, 147-152, 2013.
 - [17] Filip, I.; Szeidert, I. (2016). Adaptive fuzzy PI controller with shifted control singletons, *Expert Systems With Applications*, DOI10.1016/j.eswa.2016.01.036, 54, 1-12, 2016.
 - [18] Filip, I.; Vasar, C.; Szeidert, I.; Prostean, O. (2019). Self-tuning strategy for a minimum variance control system of a highly disturbed process, *EUROPEAN JOURNAL OF CONTROL*, DOI10.1016/j.ejcon.2018.06.004, 46, 49-62, 2019.

- [19] Haro, A.; Young, H.; Pavez, B. (2021). Fuzzy Logic Active Yaw Control of a Low-Power Wind Generator, *IEEE Latin America Transactions*, doi: 10.1109/TLA.2021.9475848, 19(11), 1941-1948, 2021.
- [20] Kaddache, M.; Drid, S.; Khemis, A.; Rahem, D.; Chrifi-Alaoui, L. (2024). Maximum power point tracking improvement using type-2 fuzzy controller for wind system based on the double fed induction generator, *Electrical Engineering & Electromechanics*, DOI10.20998/2074-272X.2024.2.09, 2, 2024.
- [21] Lu, J.; Guangzhi, M.; Guangquan, Z. (2024). Fuzzy Machine Learning: A Comprehensive Framework and Systematic Review, *IEEE Transactions on Fuzzy Systems*, 32(7), 3861-3878, 2024.
- [22] Mittal, K.; Jain A.; Vaisla, K. S.; Castillo O.; Kacprzyk, J. (2020). A comprehensive review on type 2 fuzzy logic applications: Past, present and future, *Engineering Applications of Artificial Intelligence*, 95, 2020.
- [23] Nguyen, T. -T.; Nguyen, D. -M.; Ngo, Q. -V. (2021). The Power-Sharing System of DFIG-Based Shaft Generator Connected to a Grid of the Ship, *IEEE Access*, DOI: 10.1109/ACCESS.2021.3102659, 9, 109785-109792, 2021.
- [24] Pillutla, H.; Arjunan, A. (2018). A Brief Review of Fuzzy Logic and Its Usage Towards Counter-Security Issues, *International Conference on Wireless Communications, Signal Processing and Networking*, Chennai, India, 22-24 March 2018.
- [25] Puchalapalli, S.; Singh, B. (2020). Viewpoint research evaluation for computer science, *IEEE Transactions on Sustainable Energy*, DOI: 10.1109/TSTE.2019.2898115, 11(2), 595-607, 2020.
- [26] Rouabhi, R; Herizi, A; Djeriou,; Zemmit, A. (2024). Hybrid Type-1 and 2 fuzzy sliding mode control of the induction motor, *Revue Roumaine des Sciences Techniques-Serie Electrotechnique et Energetique*, DOI10.59277/RRST-EE.2024.69.2.5, 69 (2), 2024.
- [27] Shanmugam, L.; Joo, Y. H. (2021). Stability and Stabilization for T-S Fuzzy Large-Scale Interconnected Power System With Wind Farm via Sampled-Data Control, *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, DOI: 10.1109/TSMC.2020.2965577, 51(4), 2134-2144, 2021.
- [28] Sharmila, V.; Rakkiyappan, R.; Joo, Y. H. (2021). Fuzzy Sampled-Data Control for DFIG-Based Wind Turbine With Stochastic Actuator Failures, *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, DOI: 10.1109/TSMC.2019.2946873, 51(4), 2199-2211, 2021.
- [29] Soliman, M. A.; Hasanien, H. M.; Azazi, H. Z.; El-Kholy, E. E. ; Mahmoud, S. A. (2019). An Adaptive Fuzzy Logic Control Strategy for Performance Enhancement of a Grid-Connected PMSG-Based Wind Turbine, *IEEE Transactions on Industrial Informatics*, DOI: 10.1109/TII.2018.2875922, 15(6), 3163-3173, 2019.
- [30] Ullah, N.; Sami, I.; Chowdhury, M. S.; Techato, K.; Alkhamash, H. I. (2020). Artificial Intelligence Integrated Fractional Order Control of Doubly Fed Induction Generator-Based Wind Energy System, *IEEE Access*, DOI: 10.1109/ACCESS.2020.3048420, 9, 5734-5748, 2021.
- [31] Vilanova, R.; Alfaro, V.M.; Arrieta, O. (2012). Robustness in PID Control. In: Vilanova, R., Visioli, A. (eds) *PID Control in the Third Millennium. Advances in Industrial Control*. Springer, London, 113-145, 2012.
- [32] Xu, M.; Jin, Y.; Ma, J.; Wang, C.; Liu, P. (2023). Fuzzy Frequency Droop Control of DFIG Wind Turbine Generators Adapted to Continuous Changes in Wind Speeds, *IEEE Access*, DOI: 10.1109/ACCESS.2023.3325245, 11, 115011-115024, 2023.



Copyright ©2025 by the authors. Licensee Agora University, Oradea, Romania.

This is an open access article distributed under the terms and conditions of the Creative Commons Attribution-NonCommercial 4.0 International License.

Journal's webpage: <http://univagora.ro/jour/index.php/ijccc/>



This journal is a member of, and subscribes to the principles of,
the Committee on Publication Ethics (COPE).

<https://publicationethics.org/members/international-journal-computers-communications-and-control>

Cite this paper as:

Szeidert, I.; Filip, I.; Vasar, C.; Bordeasu, D. (2025). Comparative studies on the excitation control of a doubly fed induction generator using fuzzy PI controllers and classical PI/PID controllers, *International Journal of Computers Communications & Control*, 20(6), 6887, 2025.

<https://doi.org/10.15837/ijccc.2025.6.6887>