The research work addressed in this study can be applied in the field of renewable energies and can even be extended and combined with other tools such as wavelets and artificial intelligence, as illustrated in references, [13], [14].

7 Conclusions

In our study, we thoroughly examined the use of backstepping control in managing a grid connected wind power generation system that utilizes a permanent magnet synchronous generator (PMSG) connected to the grid through an AC/DC/AC converter. We conducted simulations based on varying wind speeds to reflect real-world conditions. The results demonstrate the capability of the system to optimize power extraction, from wind sources maintain DC bus voltage, and manage the exchange of reactive and active power, with the grid effectively. The objective of this research was to develop a robust and efficient control scheme that can ensure stable operation, seamless grid synchronization, and optimal power transfer in grid connected wind power systems.

References:

[1] A. Drabyk, "Renewable Energy--Its Physics, Engineering, Environmental Impacts, Economics and Planning," *Journal of Environmental Quality*, vol. 30, p. 1098, 2001, https://doi.org/10.2134/jeq2001.3031098-ax.

[2] K. Ghedamsi, D. Aouzellag, and E. Berkouk, "Control of wind generator associated to a flywheel energy storage system," *Renewable Energy*, vol. 33, pp. 2145-2156, 2008, https://doi.org/10.1016/j.renene.2007.12.009.

[3] N. Harrabi, M. Souissi, A. Aitouche, and M. Chaabane, "Intelligent control of grid-connected AC–DC–AC converters for a WECS based on T–S fuzzy interconnected systems modelling," *IET Power Electronics*, vol. 11, pp. 1507-1518, 2018, https://doi.org/10.1049/iet-pel.2017.0174.

[4] A. Singh and O. Roy, "Performance analysis of a PMSM drive using PID controllers," *Electronics Information and Planning*, vol. 37, pp. 80-87, December 2010.

[5] M. A. Melnichenko, A. I. Gorkaviy, and M. A. Gorkaviy, "Combined control in the system with modal pi-regulator," in Current Problems and Ways of Industry Development: Equipment and Technologies, ed: Springer, 2021, pp. 507-517. (In Komsomolsk-on-Amur, Russia), https://doi.org/10.1007/978-3-030-69421-0_54.

[6] S. Rebouh, A. Kaddouri, R. Abdessemed, and A. Haddoun, "Nonlinear control by input-output linearization scheme for EV permanent magnet synchronous motor," in *2007 IEEE Vehicle Power and Propulsion Conference*, 2007, pp. 185-190. (In Arlington, TX, USA), DOI: 10.1109/VPPC.2007.4544122.

[7] M. A. Hamida, A. Glumineau, J. De Leon, and L. Loron, "Robust adaptive high order sliding-mode optimum controller for sensorless interior permanent magnet synchronous motors," *Mathematics and Computers in Simulation*, vol. 105, pp. 79-104, 2014, https://doi.org/10.1016/j.matcom.2014.05.006.

[8] Y. Chaou, S. Ziani, H. B. Achour, and A. Daoudia, "Nonlinear control of the permanent magnet synchronous motor PMSM using backstepping method," *WSEAS Transactions on Systems and Control*, vol. 17, pp. 56-61, 2022, https://doi.org/10.37394/23203.2022.17.7.

[9] C. Youssef, Z. Said, and D. Abdelkarim, "Backstepping Control of the Permanent Magnet Synchronous Generator (PMSG) Used in a Wind Power System," in *The International Conference on Artificial Intelligence and Smart Environment*, 2022, pp. 276-281. (In Errachidia, Morocco), DOI: 10.1007/978-3-031-26254-8_38.

[10] C. Youssef, Z. Said, and D. Abdelkarim, "Electric Vehicle Backstepping Controller Using Synchronous Machine," in *The International Conference on Artificial Intelligence and Smart Environment*, 2022, pp. 367-373. (In Errachidia, Morocco), DOI: 10.1007/978-3-031-26254-8_52.

[11] J. Wang, D. Bo, X. Ma, Y. Zhang, Z. Li, and Q. Miao, "Adaptive back-stepping control for a permanent magnet synchronous generator wind energy conversion system," *international journal of hydrogen energy*, vol. 44, pp. 3240-3249, 2019, https://doi.org/10.1016/j.ijhydene.2018.12.023.

[12] J. Zhou and Y. Wang, "Real-time nonlinear adaptive backstepping speed control for a PM synchronous motor," *Control Engineering Practice*, vol. 13, pp. 1259-1269, 2005, https://doi.org/10.1016/j.conengprac.2004.11.007.

[13] Q. Xu, T. Dragicevic, L. Xie, and F. Blaabjerg, "Artificial intelligence-based control design for reliable virtual synchronous generators," *IEEE Transactions on Power Electronics*, vol. 36, pp. 9453-9464, 2021, DOI: 10.1109/TPEL.2021.3050197.

[14] H. Yousuf, A. Y. Zainal, M. Alshurideh, and S. A. Salloum, "Artificial intelligence models in power system analysis," *in Artificial intelligence for sustainable development: Theory, practice and future applications*, ed: Springer, 2020, pp. 231-242, https://doi.org/10.1007/978-3-030-51920-9_12.

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The authors have no conflicts of interest to declare.