Rev. Roum. Sci. Techn.– Électrotechn. et Énerg.
Vol. **68**, *3*, pp. 271–276, Bucarest, 2023

A STUDY OF VOLTAGE SAG IN DISTRIBUTION SYSTEM AND EVALUATION OF THE EFFECT OF WIND FARM EQUIPPED WITH DOUBLY-FED INDUCTION GENERATOR

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Keywords: Distribution system; Doubly-fed induction generator (DFIG); Voltage sag; Wind farm.

The DFIG's ability to perform variable speed, reactive power control, and reduce converter rating are the main reasons for the popular choice of DFIG for wind power applications. The dynamic behavior of a wind farm based on a DFIG disturbed in the electrical distribution network is described in this paper. Controlling the output power and voltage of the DFIG terminal is the main task of the rotor converter. The effect of wind energy on various system parameters, such as voltage drop and load current, is presented. The system is simulated in Matlab/Simulink software. In the studied system, the wind turbine farm is connected to a distribution system that delivers electricity to the 120 kV network through a feeder. Simulation studies have been performed using Matlab/Simulink to analyze the effect of different DFIG control modes on power quality in a DFIG-based wind farm distribution system. In other operating conditions, the system's response is simulated and compared. The simulation results are shown and discussed in two modes: reactive power regulation and voltage regulation.

1. INTRODUCTION

The electricity industry includes the generation of electricity, the transmission of electricity, and finally, the distribution of electricity [1,2]. The ability of electrical equipment to consume energy refers to the quality of power [3,4]. There are many types of disturbances that may affect power quality. Some issues related to electricity quality are voltage sag, long interruptions, very short interruptions, voltage spike, voltage swell, event source allocation, harmful harmonic distortion, voltage instability, poor power factor, instrument transformer usage, noise, and voltage imbalance [5,6]. A microgrid is an electrical distribution system with interconnected consumption and distributed generation sources acting as a single controlled source within clearly defined electrical boundaries. Renewable energy, often called clean energy, is derived from natural processes that are replenished constantly [7,8]. About 11 % of the world's energy comprises renewable energies.

The major types of renewable energy sources, as shown in Fig. 1, are hydropower energy [9], geothermal energy [10], biomass energy [11], wind energy [12], and solar energy [13]. Wind energy is a clean energy source [14]. Wind farms absorb wind energy using turbines and convert it into electricity [15]. A set of wind turbines is used to generate electricity from a wind farm or farm. The rotor blades convert the wind's kinetic energy into mechanical energy in the wind energy conversion system. Then, a generator converts mechanical energy into electrical energy, so a wind turbine is one of the most important elements in a wind energy system.

Different types of systems are used to convert wind energy, and each is different. There are different benefits in the environmental, technical, and economic fields to connecting wind energy to the distribution system, such as increasing reliability and power loss reduction [16,17]. One of the most common wind turbines installed in power systems is DFIG. Flexible control, high efficiency, and low investment requirements are the features of DFIG. There are two control modes for DFIG based on operation: control mode for constant voltage and control mode for reactive power and constant power factor [18]. The types of power quality problems in networks connected to wind farms and their effects are shown in Fig. 2 [19,20].

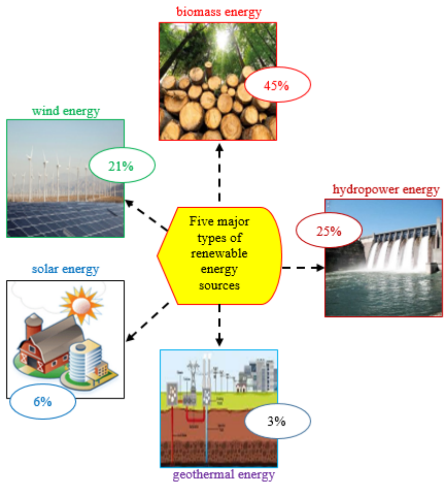

Fig. 1 – Renewable energy source types.

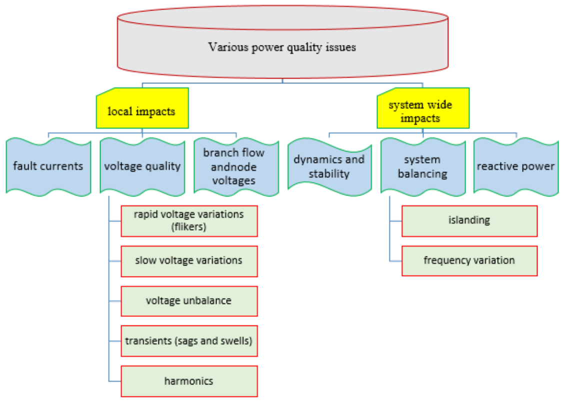

Fig. 2 – Classification of various power quality issues.

Several researchers have studied the improvement of power quality in grid-connected wind farms [21,22]. To improve the transient stability of the power system equipped with a DFIG-based wind farm, a method for controlling the active output power in [23] is proposed, which uses a DFIG terminal bus frequency change to adjust the torque reference or in other words, DFIG output power is used in post-perturbation conditions. A practical method to reduce flicker emission and improve power quality for a relatively weak network connected to a DFIG-based wind farm is described in [24], where a DFIG rotor side converter controls the reactive output power. A bridge-type fault current limiter based on a nonlinear

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DOI: 10.59277/RRST-EE.2023.68.3.4

controller has been proposed to enhance the transient stability of the DFIG-based 20 MW wind farm [25], and an improved voltage profile with a fault current minimized during the fault has been observed. Measurement methods for simultaneous multi-point recordings in offshore wind farms are presented in [26], which show how to deal with the challenges of recording the quality of simultaneous power of several continuous points in wind turbines about the expected phenomena. To increase power quality and improve LRTC in a medium voltage three-phase network, the use of a DVR has been proposed in [27], in which the grid includes a photovoltaic power plant and a wind turbine generator, connected to a hybrid DG system and also the wind turbine generator consists of a DFIG generator connected to the grid via a step-up transformer. A DFIG-based wind farm distribution system is studied in this paper, and its behavior is simulated. When voltage sag or any fault occurs in the system, the most critical electrical parameters in the DFIG vary strictly. As a result, these events generated two major points in the network: (a) the rotor and stator over current and (b) over-voltage occurred in the dc-link.

This article is a study of the energy system. The following can be stated from its innovation:

- This paper studies and analyzes the voltage droop in the distribution system equipped with a dual-power induction generator.
- The system's response is simulated and compared in different operating conditions.
- The simulation results are shown and discussed in two modes: reactive power regulation and voltage regulation.

Following this introduction in section 1, the voltage drop across the distribution system is investigated in section 2. An overview of the principle of DFIG operation is presented in section 3. Section 4 shows the single-line diagram and the distribution system's operation principle. In section 5, simulation studies using Matlab software Simulink are carried out to examine the operation of DFIG-based wind turbines under different types of voltage sags. Finally, the conclusion is given in section 6.

2. SUMMARY OF VOLTAGE SAG

Voltage sag (or voltage dip) is one of the most common occurrences in industrial power distribution systems [28]. This reduces the normal voltage level at the power frequency for 0.5 cycles to 60 milliseconds. Also, it has amplitudes ranging from 10–90 % in the root mean square value voltage or current [29,30]. According to the IEEE standard, the voltage dip can be classified into three categories based on the time duration, as shown in Fig. 3 [31]. The slope duration between the event's starting point and its endpoint. An example of a voltage sag in an industrial power plant is shown in Fig. 4, where a 115 kV system supplies the plant. Several factors cause voltage dips, such as transformer connections, electric machine startup, sudden load changes, and some transmission line faults. Depending on the cause of the droop, the voltage sag can be symmetrical or asymmetric [32]. Various methods have been proposed to measure and detect voltage sag, such as Fourier transform methods [33], wavelet transforms [34], rms value method [35], essential component technique [36], reference frame rotating simultaneously [37], peak voltage detection [38], missed voltage method [39].

Several paper or research work on voltage reduction has been reported in distribution systems [40,41]. The voltage sag in loop power distribution systems has been evaluated and analyzed by installing a superconducting fault current limiter [42], and the results are compared in two radial and loop power distribution systems. The allocation of power quality monitors in distribution systems using a multi-objective optimization approach is proposed in [43], which uses a multi-objective evolutionary algorithm with tables to solve the problem. A study on wind farm stability issues based on DFIG in a variable wind speed power system [44] has been conducted in both strong and weak networks the following is an analysis of the effect of power system stabilizer (PSS) and SSSC on the stability of wind power system. The error response of synchronous-based distributed generation (DG) and inverter-based DG has been studied in [45], and an improved current-based method has been proposed. Also, the analysis is based on DG models for two periods before and during sag voltage.

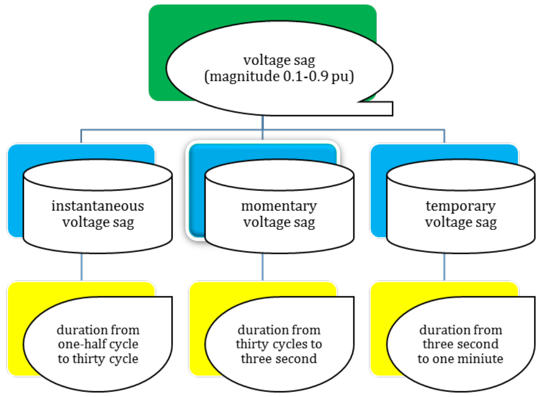


Fig. 3 – Classification of voltage sag.

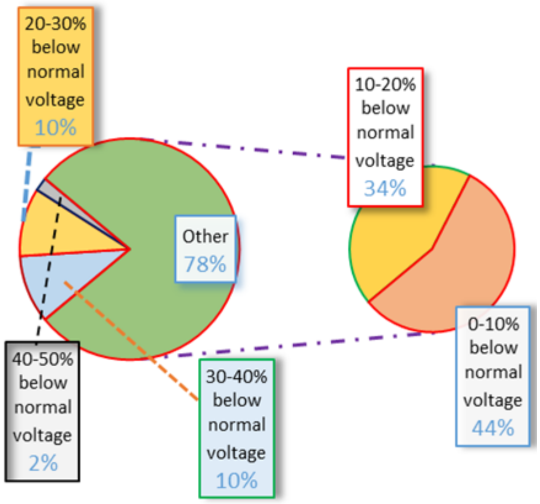


Fig. 4 – Displays the percentage of voltage sag measured in an industrial power plant.

3. OVERVIEW OF DFIG

Active power control of the DFIG wind turbine is achieved by convenient rotor voltage control. DFIG can inject reactive power into the grid [46,47]. This is a production principle that is widely used in wind turbines. Fig. 5 shows the schematic diagram of a DFIG wind turbine. The system introduction parameters are given in Table 1. The low-speed wind turbine in this system is connected to DFIG via a gearbox. From control system components and a modeling point of view, a DFIG based wind turbine includes the mechanical and electrical parts [48,49]. The overall structure of a DFIG has been shown in Fig. 6 [50,51]. The mechanical parts have a large time constant.

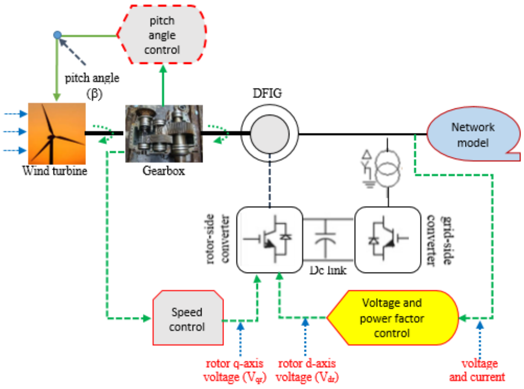


Fig. 5 – Schematic for DFIG wind turbine system.

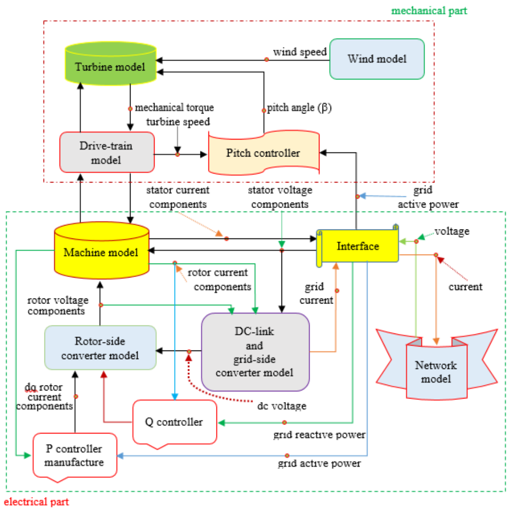


Fig. 6 – The overall model and control structure of a DFIG-WT.

4. DISTRIBUTION SYSTEM UNDER STUDY

The simplified single-line diagram of the wind farm distribution system considered in this paper is shown in Fig. 7.

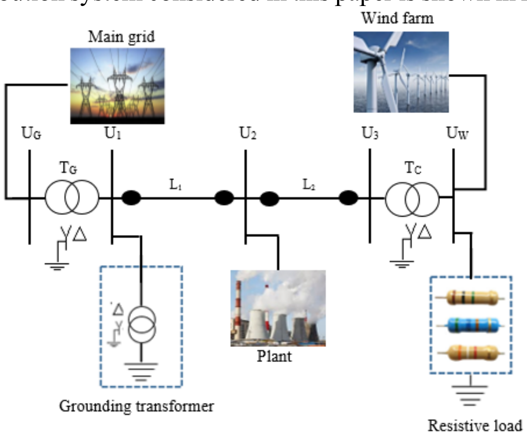


Fig. 7 – Fittings in the distribution of the studied system.

A conventional distribution system is equipped with protection devices. In the distribution system under study, the wind turbine and the motor load each have a protection system that monitors the machine's current, voltage, and speed. There are different loads and wind farms in the studied power system. The loads are connected to a 25 kV distribution network using a 30 km feeder and deliver power to a 120 kV network. The wind farm has a total capacity of 9 MW. The wind farm substation is connected to the network with a 5 MVA, 11kV/110kV power transformer.

The wind farm substation is connected to the network through a 5 MVA, 11kV/110 kV power transformer. At the bus U3 (575 V) wind farm, a resistive load (500 kW) is connected. Also, on the U2 bus (25 kV), a power plant (2 MW) is connected. The nominal of the system components is shown in Table 2. The proportional–integral (PI) controllers regulate the inner and outer control loop. K_P and K_I are proportional controller gain and integrator controller gain, respectively. The gains of controllers are listed in Table 3.

Table 2

System components rated values.

System component		Value
Generator	Generator power	10 MVA
	Frequency	60 Hz
	Inertia constant	5.04
Turbine	Wind turbine mechanical	9 MW
	Power factor	0.9
	Maximum pitch angle	45°
	Maximum change of pitch angle	2° 1/s
Controller	Maximum change of reference reactive power	100 pu/s
	Maximum change of reference power	1 pu/s
	Maximum change of converter reference currents	200 pu/s
Plant	Instantaneous AC overcurrent	10 pu
	Start time for protection system	1 s
Converter	DC bus capacitor	6×10^4 μF
	Maximum power	0.5 pu
	DC bus voltage	1200 V

Table 3

Controller gains

Controller	Gains	
	K_P	K_I
Regulator for grid voltage	1.25	300
Regulator for power	1	100
DC bus voltage regulator	0.002	0.05
Reactive power regulator	0.05	5
Current regulator for rotor side converter	0.3	8
Current regulator for network side converter	1	100
Pitch angle controller	500	-

4. SIMULATION RESULTS

In this section, the behavior of the studied system (Fig. 8) has been evaluated in different conditions in MATLAB Simulink. The response of the described system is evaluated and compared in different contexts.

The 2.3 kV, 2 MVA power plant model with its protection for simulation in Matlab Simulink is shown in Fig. 9 and 10, respectively. The plant has two loads: an induction motor (1.68 MW at 0.93 PF) and a 200 kW resistive load.

The wind speed of 8 m/s is considered constant. The voltage source is subjected to an 85 % voltage drop for 0.5 s. A voltage droop of 0.15 pu takes 5 seconds to 5.5 seconds. The active power produced by the wind power plant is 1.87 MW. Simulation results are shown for two modes: (a) reactive power regulation and (b) voltage regulation.

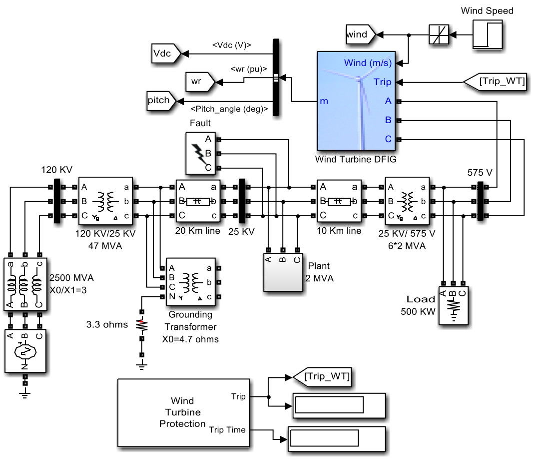


Fig. 8. The system model in Simulink

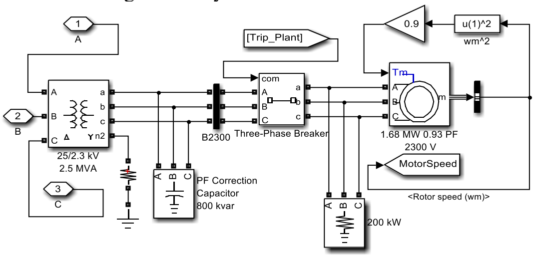


Fig. 9 – Power plant equivalent model for simulation.

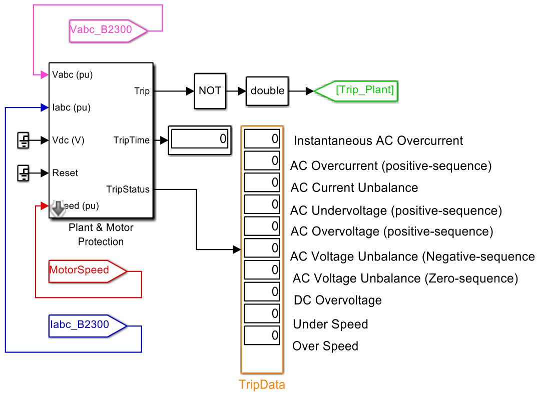


Fig. 10 – Protection of the plant.

4.1 VAR REGULATION MODE (REACTIVE POWER REGULATION MODE)

In power factor control mode, the reactive power of the turbine must be controlled at a constant ratio to match the active power output. If terminal voltage control is used, reactive power generation must be controlled to achieve the target voltage at the bus. This section initially sets the wind farm operation mode to VAR setting mode with zero reference reactive power ($Q_{ref} = 0$). This operation is typically used as a unity power factor operation or other power factor values (*e.g.*, 0.95 leading to 0.95 lagging). As shown in Fig. 11, in 5 s, the voltage drops to less than 0.9 pu, and the power protection system shuts off in 5.22 s, as low voltage occurs and lasts for more than 0.21 s.

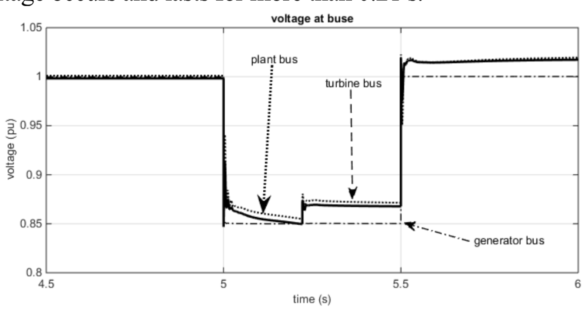
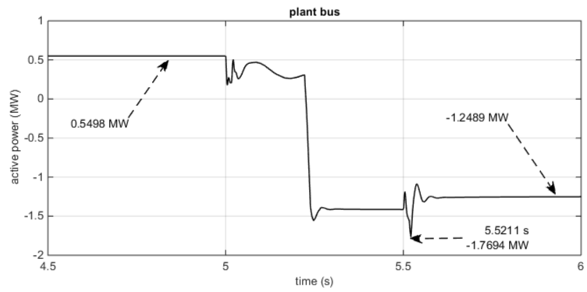
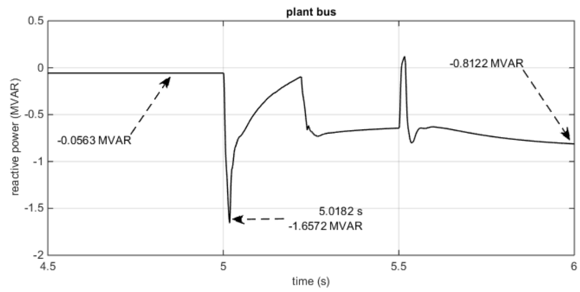


Fig. 11. Voltage at buses (VAr regulation mode)

The reactive power required by the rotor is generated by the rotor side converter. Active and reactive power in the power plant bus during voltage sag are shown in fig. 12. Fig. 13 shows the active and reactive powers generated by the wind farm during a voltage drop. Can notice that the wind farm produces 1.87 MW and zero MVAR. Figure 14 shows the dc link voltage of the back-to-back converters during voltage sag. Here, the dc link voltage is around 1200 V. As you can see, the dc link voltage is 1210.4, 1193.7, and 1206.5 V at 5.0067, 5.5211, and 5.6266 ss, respectively. Initially, voltage variation concerning time is noticeable, but at steady state, voltage variation range is limited dc link voltage is maintained at reference value. As can be seen, the power plant current is zero. The engine speed also decreases gradually, while the wind farm's active power generation is at 1.87 MW. Therefore, 1.25 MW of electricity is exported to the grid after the power plant is shut down.

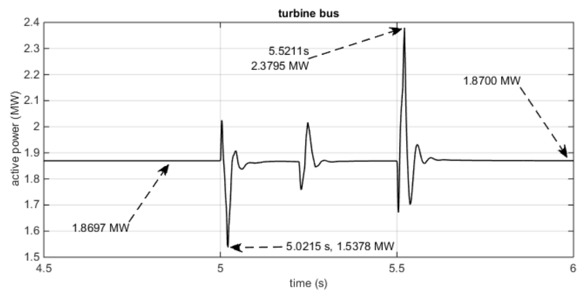


(a) active

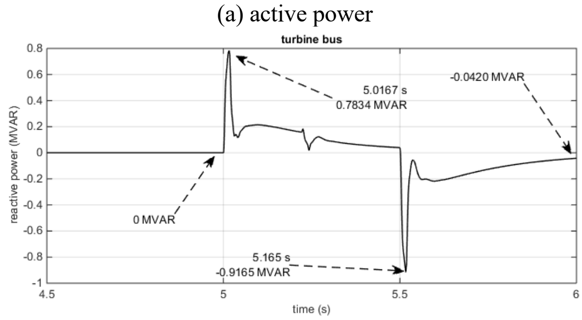


(b) reactive

Fig. 12 – Power at the plant bus (VAR regulation mode).



(a) active power



(b) reactive power

Fig. 13 – Power at the wind turbine bus (VAr regulation mode).

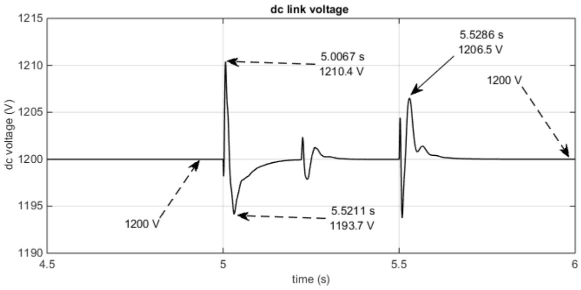


Fig. 14 – Dc link voltage (VAr regualtion mode).

4.2 VOLTAGE REGULATION MODE

This section sets the wind farm's working mode in voltage regulation. The value of the terminal reference voltage is 1 pu. The response of the power generated by the wind turbines when they operate in voltage regulating mode is shown in Fig. 15. As can be seen, the maximum reactive power is 5.6282 MVAr in 5.0491 s, and the minimum is -0.4138 MVAr in 5.5495 s. During the voltage sag (Fig. 16), the plant voltage and wind farm are 0.9322 per unit and 0.9893 per unit, respectively. It shows that the plant does not trip anymore. As can be seen, the cement factory is no trip collapsing. The power plant voltage is kept above the protection threshold, which is voltage support by the wind farm because reactive power is generated during voltage sag. Power generation in wind energy conversion systems directly relates to the rotating machines used in them. The output power of the wind energy conversion system changes with the wind speed. Real power and reactive power can be controlled independently by DFIGs, so reactive power modulation can be used to regulate voltage and increase their ability to dampen power fluctuations.

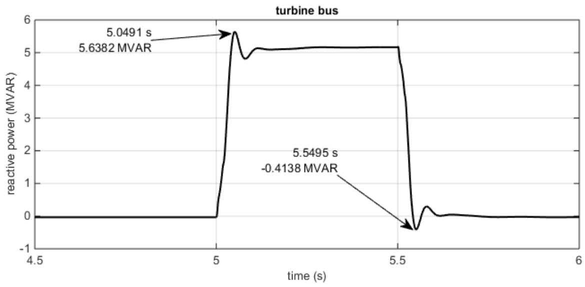


Fig. 15. Power at the wind turbine bus (voltage regulation mode)

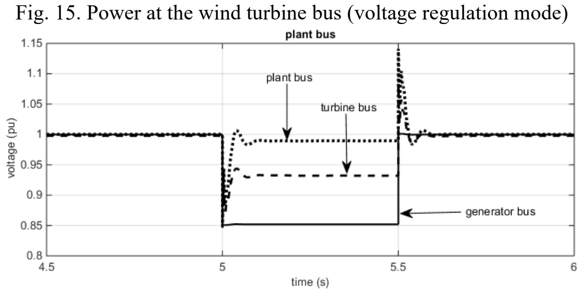


Fig. 16. Voltage at buses (voltage regulation mode)

5. **CONCLUSION**

Wind turbines play an important role in microgrids as sources of energy production One of the most important variable wind generators is DFIG. DFIG is a wound rotor induction machine. The DFIG-based wind farm is very sensitive to network distribution. Simulation studies for a DFIG-based wind farm distribution system are presented in this paper to analyze wind energy efficiency in different operating conditions. To present the simulation results, two working modes, including reactive power adjustment mode and voltage adjustment mode have been considered. DFIG systems are cost-effective. To maximize the power output, the turbine speed is adjusted as a function of the wind speed. This action improves the flicker reduction in the system. To continue the study, it is suggested that the control methods in the system be investigated. Also, other types of induction generators should be used, and the system's dynamic behavior should be studied and simulated.

Received on 25 December 2022

REFERENCES

1. F.M. Zamani, M. Hashemi, G. Shahgholian, *Adaptive control of nonlinear time delay systems in the presence of output constraints and actuator's faults*, International Journal of Control, **96**, *3*, pp. 541–553 (2023).
2. I.V. Nemoianu, R.M. Ciuceanu, *Characterization of non-linear three-phase unbalanced circuits powers flow supplied with symmetrical voltages*, Rev. Roum. Sci. Techn. – Électrotechn. Et Énerg., **60**, *4*, pp. 355–365 (2015).
3. A. Kharrazi, V. Sreeram, Y. Mishra, *Assessment techniques of the impact of grid-tied rooftop photovoltaic generation on the power quality of low voltage distribution network- A review*, Renewable and Sustainable Energy Reviews, **120**, Article 109643 (2020).
4. F.H. Gandoman, A. Ahmadi, A. M. Sharaf, P. Siano, J. Pou, B. Hredzak, V. G. Agelidis, *Review of FACTS technologies and applications for power quality in smart grids with renewable energy systems*, Renewable and Sustainable Energy Reviews, **82**, pp. 502–514 (2018).
5. M. Rahmani, F. Faghihi, H. Moradi-Cheshmeh-Beigi, S. Hosseini, *Frequency control of islanded microgrids based on fuzzy cooperative and influence of STATCOM on frequency of microgrids*, Journal of Renewable Energy and Environment, **5**, *4*, pp. 27–33 (2018).
6. S. Ahmadi, I. Sadeghkhani, G. Shahgholian, B. Fani, J.M. Guerrero, *Protection of LVDC microgrids in grid-connected and islanded modes using bifurcation theory*, IEEE Journal of Emerging and Selected Topics in Power Electronics, **9**, *3*, pp. 1–8 (2021).
7. S. Agalar, Y.A. Kaplan, *Power quality improvement using STS and DVR in wind energy system*, Renewable Energy, **118**, pp. 1031–1040 (2018).
8. A. Sedaghat, M.E.H. Assad, M. Gaith, *Aerodynamics performance of continuously variable speed horizontal axis wind turbine with* optimal blades, Energy, **77**, pp. 752–759 (2014).
9. N. Kefif, B. Melzi, M. Hashemian, M.E.H. Assad, S. Hoseinzadeh, *Feasibility and optimal operation of micro energy hybrid system (hydro/wind) in the rural valley region*, International Journal of Low-Carbon Technologies, **17**, pp. 58–68 (2022).
10. A. Jouanne, T.K.A. Brekken, *Ocean and geothermal energy systems*, Proceedings of the IEEE, **105**, *11*, pp. 2147–2165 (2017).
11. K. Zhang, B. Zhou, Q. Wu, Y. Cao, N. Liu, N. Voropai, E. Barakhtenko, *Modeling and utilization of biomass-to-syngas for industrial multi-energy systems*, CSEE Journal of Power and Energy Systems, **7**, *5*, pp. 932–942 (2021).
12. E. Hosseini, G. Shahgholian, H. Mahdavi-Nasab, F. Mesrinejad, *Variable speed wind turbine pitch angle control using three-term fuzzy controller*, International Journal of Smart Electrical Engineering, **11**, *2*, pp. 63–70 (2022).
13. F. Hajimohammadi, B. Fani, I. Sadeghkhani, *Fuse saving scheme in highly photovoltaic-integrated distribution networks*, International Transactions on Electrical Energy Systems, **30**, *1*, e12148 (2020).
14. M. Makkiabadi, S. Hoseinzadeh, M. Mohammadi, S.A. Nowdeh, S. Bayati, U. Jafaraghaei, S.M. Mirkiai, M.E.H. Assad, *Energy feasibility of hybrid PV/wind systems with electricity generation assessment under Iran environment*, Applied Solar Energy, **56**, pp. 517–525 (2020).
15. S. Jenab, B. Fani, H. Ghasvari, *Transient performance improvement of wind turbines with doubly fed induction generators using fractional order control strategy*, Journal of Intelligent Procedures in Electrical Technology, **4**, *16*, pp. 17–28 (2014).
16. A.M.S. Yunus, A. Abu-Siada, M.A.S. Masoum, M.F. El-Naggar, J.X. Jin, *Enhancement of DFIG LVRT capability during extreme short-wind gust events using SMES technology*, IEEE Access, **8**, pp. 47264-47271 (2020).

17. S. Huang, Q. Wu, Y. Guo, F. Rong, *Hierarchical active power control of DFIG-based wind farm with distributed energy storage systems based on ADMM*, IEEE Trans. on Sustainable Energy, **11**, *3*, pp. 1528–1538 (2020).
18. H. Ghaedi, G. Shahgholian, M. Hashemi. *Comparison of the effects of two flatness-based control methods for STATCOM on improving stability in power systems including DFIG-based wind farms*, Iranian Electric Industry Journal of Quality and Productivity, **8**, *15*, pp. 81–90 (2019).
19. A.R.A. Jerin, K. Palanisamy, S. Umashankar, A.D. Thirumoorthy, *Power quality improvement of grid-connected wind farms through voltage restoration using dynamic voltage restorer*, International Journal of Renewable Energy Research, **6**, *1*, pp. 53–60 (2016).
20. T. Tarasiuk, S.G. Jayasinghe, M. Gorniak, A. Pilat, V. Shagar, W. Liu, J.M. Guerrero, *Review of power quality issues in maritime microgrids*, IEEE Access, **9**, pp. 81798–81817 (2021).
21. J. Liu, W. Yao, J. Wen, J. Fang, L. Jiang, H. He, S. Cheng, *Impact of power grid strength and PLL parameters on stability of grid-connected DFIG wind farm*, IEEE Trans. on Sustainable Energy, **11**, *1*, pp. 545–557 (2020).
22. X. Zhang, Y. Chen, Y. Wang, X. Zha, S. Yue, X. Cheng, L. Gao, *Deloading power coordinated distribution method for frequency regulation by wind farms considering wind speed differences*, IEEE Access, **7**, pp. 122573–122582 (2019).
23. A. Mitra, D. Chatterjee, *Active power control of DFIG-based wind farm for improvement of transient stability of power systems*, IEEE Trans. on Power Systems, **31**, *1*, pp. 82–93 (2016).
24. H. Mahvash, S.A. Taher, M. Rahimi, *A new approach for power quality improvement of DFIG-based wind farms connected to weak utility grid*, Ain Shams Engineering Journal, **8**, *3*, pp. 415–430 (2017).
25. M.E. Hossain, *A non-linear controller based new bridge type fault current limiter for transient stability enhancement of DFIG based wind farm*, Electric Power Systems Research, **152**, pp. 466–484 (2017).
26. R. Ferdinand, M. Cupelli, A. Monti, *Multipoint synchronized recordings in offshore wind farms with continuous measurement power quality meters*, IEEE Trans. on Instrumentation and Measurement, **67**, *12*, pp. 2785–2795 (2018).
27. A. Benali, M. Khiat, T. Allaoui, M. Denaï, *Power quality improvement and low voltage ride through capability in hybrid wind-PV farms grid-connected using dynamic voltage restorer*, IEEE Access, **6**, pp. 68634–68648 (2018).
28. S. Hasan, A. R. Nair, R. Bhattarai, S. Kamalasadan, K. M. Muttaqi, A coordinated *optimal feedback control of distributed generators for mitigation of motor starting voltage sags in distribution networks*, IEEE Trans. on Industry Applications, **56**, *1*, pp. 864–875 (2020).
29. K. Zhu, Y. Wang, P. Yin, J. Ni, *Voltage sag source location technology based on corresponding sequence components*, IET Generation, Transmission and Distribution, **9**, *9*, pp. 820-827 (2015).
30. J. Morren, S.W.H. de Haan, *Ridethrough of wind turbines with doubly-fed induction generator during a voltage dip*, IEEE Trans. on Energy Conversion, **20**, *2*, pp. 435–441 (2005).
31. S. Kamble, C. Thorat, *Voltage sag characterization in a distribution system: A case study*, Journal of Power and Energy Engineering, **2**, pp. 546-553 (2014).
32. A.M. Saeed, S.H.E. Abdel Aleem, A.M. Ibrahim, M.E. Balci, E.E.A. El-Zahab, *Power conditioning using dynamic voltage restorers under different voltage sag types*, Journal of Advanced Research, **7**, *1*, pp. 95–103 (2016).
33. S. Hasan, K.M. Muttaqi, D. Sutanto, *Application of the automatic segmented Hilbert Huang transform method for the evaluation of the single-event characteristics of voltage sags in power systems*, IEEE Transactions on Industry Applications, **57**, *2*, pp. 1882–1891 (2021).
34. O. Poisson, P. Rioual, M. Meunier, *Detection and measurement of power quality disturbances using wavelet transform*, IEEE Transactions on Power Delivery, **15**, *3*, pp. 1039–1044 (2000).
35. S. Dedeoglu, G.C. Konstantopoulos, A.G. Paspatis, *Grid-supporting three-phase inverters with inherent root mean square current limitation under balanced grid voltage sags*, IEEE Transactions on Industrial Electronics, **68**, *11*, pp. 11379-11389 (2021).
36. S. Hasan, K.M. Muttaqi, D. Sutanto, *Detection and characterization of time-variant nonstationary voltage sag waveforms using segmented Hilbert–Huang transform*, IEEE Transactions on Industry Applications, **56**, *4*, pp. 4563-4574 (2020).
37. Y. Sillapawicharn, *A hybrid synchronously rotating reference frame-based voltage sag detection under distorted grid voltages*, Proceeding of the IEEE/ECTICON, **1**, *1-4*, Nakhon Ratchasima, Thailand (2014).
38. R. Naidoo, P. Pillay, *A new method of voltage sag and swell detection*, IEEE Transactions on Power Delivery, **22**, 2, pp. 1056-1063 (2007.
39. S. Hasan, K.M. Muttaqi, D. Sutanto, M.A. Rahman, *A novel dual slope delta modulation technique for a current source inverter based dynamic voltage restorer for mitigation of voltage sags*, IEEE Transactions on Industry Applications, **57**, *5*, pp. 5437-5447 (2021).
40. E.M. Molla, C.C. Kuo, *Voltage sag enhancement of grid-connected hybrid PV-wind power system using battery and SMES based dynamic voltage restorer*, IEEE Access, **8**, pp. 130003-130013 (2020).
41. P. Rajasekhar, C. Narayana, *Mitigation of voltage sag and swell using distributed power flow controller*, International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, **3**, *8*, Aug. 2014).
42. J. Moon, J. Kim, *Voltage sag analysis in loop power distribution system with SFCL*, IEEE Trans. on Applied Superconductivity, **23**, *3*, pp. 1-4 (2013).
43. H.M.G.C. Branco, M. Oleskovicz, D.V. Coury, A.C.B. Delbem, *Multiobjective optimization for power quality monitoring allocation considering voltage sags in distribution systems*, International Journal of Electrical Power and Energy Systems, **97**, pp. 1-10 (2018).
44. J. Bhukya, V. Mahajan, *Optimization of damping controller for PSS and SSSC to improve stability of interconnected system with DFIG based wind farm*, International Journal of Electrical Power and Energy Systems, **108**, pp. 314-335 (2019).
45. Y. Mohammadi, R.C. Leborgne, *A new approach for voltage sag source relative location in active distribution systems with the presence of inverter-based distributed generations*, Electric Power Systems Research, **182**, Article 106222 (2020).
46. A. Izanlo, A. Gholamian, M.V. Kazemi, *Comparative study between two sensorless methods for direct power control of doubly fed induction generator*, Rev. Roum. Sci. Techn. – Électrotechn. Et Énerg., **62**, *4*, pp. 358–364 (2017).
47. M. Tavoosi, B. Fani, E. Adib, *Stability analysis and control of dfig based wind turbine using FBC strategy*, Journal of Intelligent Procedures in Electrical Technology, **4**, *15*, pp. 31-42 (2013).
48. F. Amrane, A. Chaiba, B.E. Babes, S. Mekhilef, *Design and implementation of high performance field oriented control for grid-connected doubly fed induction generator via hysteresis rotor current controller*, Rev. Roum. Sci. Techn. – Électrotechn. Et Énerg., **61**, *4*, pp. 319-324 (2016).
49. E. Hosseini, G. Shahgholian, *Different types of pitch angle control strategies used in wind turbine system applications*, Journal of Renewable Energy and Environment, **4**, *1*, pp. 20-35 (2017).
50. H. Moghadassi, M.R. Moradian, *Dynamic response and low-voltage ride-through improvement for a DFIG, using an integral sliding mode controller with an adjustable reactive power reference value*, Journal of Intelligent Procedures in Electrical Technology, **14**, *55*, pp. 13-26 (2023).
51. S. Arezki, M. Boudour, *Study and regulation of dc bus voltages of wind-photovoltaic system*, Rev. Roum. Sci. Techn. – Électrotechn. Et Énerg., **59**, *1*, 35–36 (2014).