Signal Processing and Renewable Energy
June 2023, (pp. 17-32)
ISSN: 2588-7327
eISSN: 2588-7335

Analysis and Simulation of the Static Synchronous Compensation Effect in the Distribution System with Wind Farms Based on SCIG

Sayed Mohammadali Zanjani [*1,2], Majid Moazzami [1,2], and Mohammad Amin Honarvar [1,2]

[1] Department of Electrical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran.
[2] Smart Microgrid Research Center, Najafabad Branch, Islamic Azad University, Najafabad, Iran.

Received: 22-Aug-2022, Accepted: 11-Jan-2023.

Abstract
Wind energy is one of the renewable energy sources. Using the maximum power available in the wind is necessary to achieve the performance of the wind turbine at maximum pow-er. One of the ways to control the voltage at the connection point of the wind turbine to the power grid is to use flexible ac transmission systems (FACTS) controller. In this paper, the effect of static synchronous compensator (STATCOM) in a distribution system with induc-tion generator wind farm is analyzed and simulated. The studied system consists of a 9 MW wind farm connected to a 25 kV distribution system that delivers power to the grid through a 25 kV feeder. The results show that the STATCOM can, in addition to providing active power in short-circuit fault conditions, adjust the voltage changes at the common connection point between the wind farm and the grid in normal and fault conditions.

Keywords: Distribution System, Wind Turbine, Static Synchronous Compensator.

1. INTRODUCTION

Wind energy is one of the main types of renewable energy, and it is geographically widely distributed and decentralized and it is almost always available [1,2].

The kinetic energy in wind turbines is converted into mechanical energy and then into electrical energy.

The kinetic energy of the wind is proportional to the second power of the wind speed and the wind power is proportional to the cube of the wind speed [3,4]. Therefore, as the wind speed increases, the wind power will also increase. Technical use of wind

*****Corresponding Authors Email: zanjani.sma@gmail.com

energy is possible when the average wind speed is in the range of 5 m/s to 25 m/s (90 km/h) [5,6]. Relatively less wind energy compared to fossil energy in the long term and high maneuverability in exploitation (from several watts to several megawatts) are the advantages of wind energy.

In addition to providing a part of the electricity demand, wind energy has other advantages such as the wind turbine does not consume fuel, diversifies energy sources and creates a sustainable energy system, does not need water, and does not pollute the environment [7,8].

Flexible ac transmission systems are used for proper control to achieve power system flexibility [9,10]. These controllers can be used to improve system performance [11,12]. Among their effects, we can mention increasing the power transmission capacity, improving the stability of the power system, increasing the control capability, and increasing the power transmission capability of the network [13,14].

Static synchronous compensator (STATCOM) is one of the FACTS devices, whose structure is based on the voltage source converter and is installed in parallel in the power system to control the transmission line voltage. The static synchronous compensator can inject active and reactive power into the system in a short time and affect the steady state and dynamic performance of the system and improve the system damping and voltage profile [15].

Common types of wind generators used in wind energy conversion systems are [16]: induction generator including squirrel cage induction generator (SCIG) [17,18], wound rotor induction generator with variable resistance in the rotor [19], double-fed induction generator (DFIG) [20,21] and synchronous generators including classically excited (wound rotor) synchronous generator (WRSG) [22] and permanent magnet synchronous generator (PMSG) [23,24].

So far, various studies have been conducted on the application of FACTS devices in wind farm [25,26].

The optimal location of the static synchronous compensator to increase the transient voltage stability of a distribution network with wind power generation is proposed in [27], which is the studied network of fixed and variable speed wind turbines connected to a rural load center. Also, the dynamic reactive power requirement of wind turbines has been considered to determine the compensating rating.

Two non-linear control methods based on differential smoothness for static synchronous compensator to adjust the voltage in the 9-bus network of wind energy conversion system including wind farms based on dual feeding induction generator have been compared in [28], which results are similar. It shows the effectiveness of two control methods compared to the traditional PI linear control method.

The performance of wind farm with squirrel cage induction generator, wind farm with double fed induction generator, and hybrid wind farm during three-phase grid fault is studied in [29], which SCIG and DFIG wind farms are series compensators. Static Synchronous series compensators (SSSC) are equipped, but the combined wind farm (with the equal number of DFIG and SCIG) has no compensator. The result of the study has shown that during a three-phase grid fault, although SSSC has improved the performance of DFIG and SCIG wind farms, the hybrid wind farm without SSSC controller has the best performance.

A stability analysis based on impedance network of wind turbine generator sequence for wind farms is presented in [30] and the compensating effect on damping is evaluated quantitatively. An innovative intelligence algorithm has been used to solve the STATC-OM controller parameters to obtain the optimal stability margin of the wind farm under optimal performance constraints.

In various contexts of wind energy conversion system performance, voltage changes at the connection point of the generator to the network is a very important indicator, and voltage control at this point is important and necessary. In this paper, the effect of one of the FACTS devices called static synchronous compensator in the distribution system with wind farms is analyzed and simulated. The structure of the paper is as follows. In the second part, a brief description of wind energy conversion system and wind turbine performance in four different areas is given. In the third part, the compensatory structure and its functioning are mentioned. In the fourth part, the studied system is mentioned. In the fifth part, the results of system simulation using Matlab Simulink software are presented. At the end, the conclusion is stated.

2. WIND ENERGY CONVERSION SYSTEM

The components of a wind energy conversion system are: wind generator, diode rectifier, power converter, and power control system. The wind generator consists of a wind turbine and a generator connected to it. Power production in wind energy conversion systems has a direct relationship with the rotary machines used in them [31,32]. The output power of the wind energy conversion system changes with the wind speed [33,34]. The power produced by wind turbine is [35,36]:

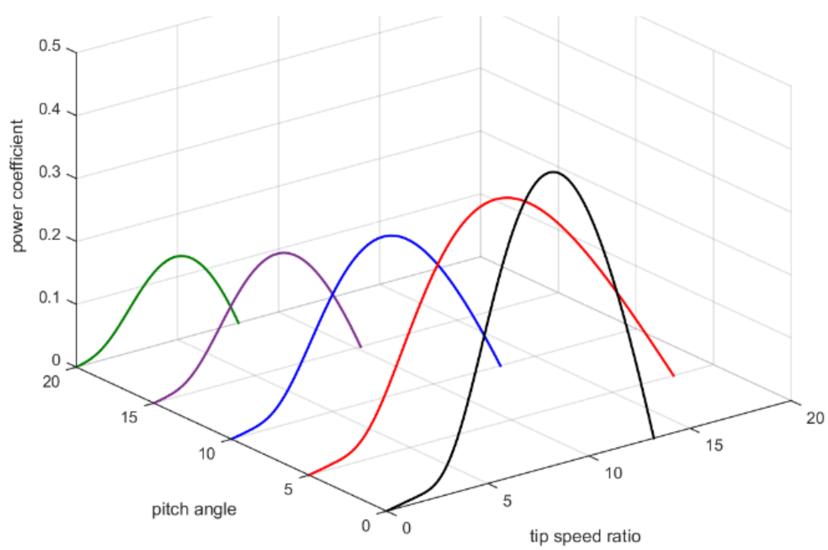

Fig. 1. The power factor curve of a wind turbine in terms of blade tip speed ratio.

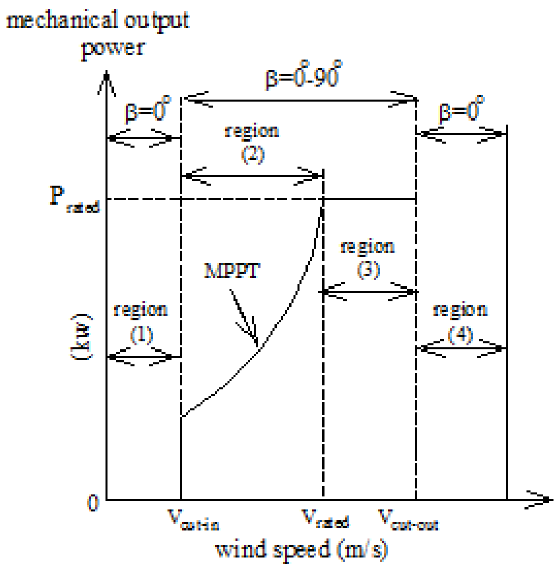

Fig. 2. Wind turbine performance areas according to wind speed.

$$P_W = \frac{1}{2}\pi\,\rho\,C_P(\lambda,\beta)\,R^2 V_w^3 \qquad (1)$$

where R is the turbine radius (m), V_W is the wind speed (m/s), ρ is the air density (kg/m^3), C_P is the power factor, λ is the tip speed ratio (TSR), and β is the pitch angle [37,38].

The turbine power factor $C_P(\lambda,\beta)$ is a non-linear function of λ and β. The power factor for a particular choice has a maximum value of λ_{opt}. For large wind turbines, the optimal TSR value is about 6 [39,40]. In common modern wind turbine systems, the maximum power factor is about 0.45 [41,42]. The higher the power factor, the greater the aerodynamic efficiency of the blades. Fig. 1 shows the power factor curve of a wind turbine according to the blade tip speed ratio.

Wind speed is the determining factor of reference power, torque, or turbine speed. Based on the wind speed, turbine performance can be divided into four general modes. Fig. 2 shows the mechanical output power of the wind turbine in terms of wind speed in four different areas, which are (1) wind speed less than the low cutoff speed, (2) speed, torque and power control function, (3) wind speed more than the nominal value and less than the high cutoff value and (4) wind speed exceeding the high cutoff speed [43,44]. If the wind speed is higher than the cut-off speed (V_{co}), the rotor is braked both electrically and mechanically so that it is stationary and the wind turbine is prevented from being damaged due to excessive speed.

3. STATIC SYNCHRONOUS COMPENSATOR

The static synchronous compensator consists of three main parts: voltage converter, transformer, and controller which is connected to the network in parallel and acts as a synchronous voltage source [45,46]. This compensator is capable of compensating a certain reactive power regardless of the system voltage level. Among the characteristics of this compensator, we can mention the reduction of fluctuations of active power and reactive power consumed by the load, no harmonic production, and reduction of voltage filter [47,48].

The one-line diagram of the compensator connection to the bus is shown in Fig. 3, where the static compensator consists of a voltage source converter (VSC) connected to the grid through a transformer. The reactive power of the exchange between the converter and the ac system is controlled by changing the three-phase output voltage range of the converter, and the reactive power of the exchange changes. The power exchange of

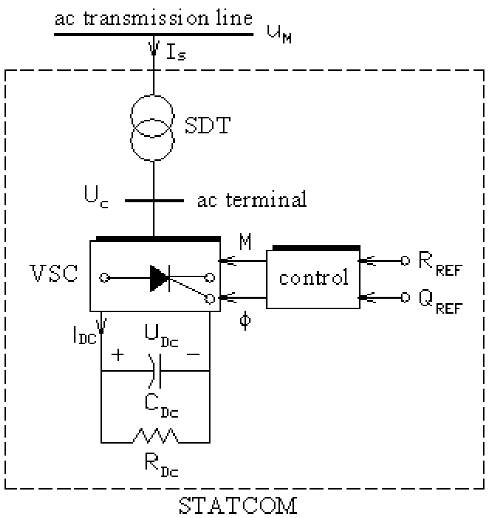

Fig. 3. One-line diagram of the compensating connection to the bus.

the converter with the system is the charging and discharging of the capacitor, and the function of the capacitor is to provide the voltage level of the converter and the dc voltage level of the capacitor must remain constant in all stages of operation. P_{REF} and Q_{REF} signals determine the size of the generated voltage and its phase angle. The R_{DC} parallel resistance shows the sum of the switching losses of the inverter and the power losses in the parallel capacitor C_{DC}.

Fig. 4 shows the changes in compensator output power for three states without compensator, maximum, and minimum compensator current.

4. STUDIED SYSTEM

The studied system, is a wind farm consisting of six 1.5 MW wind turbines (three pairs of 1.5 MW wind turbines), which are connected to a 25 kV distribution system and fed through a 25 kV-25 km feeder. It exports electricity to a 120 kV network. Squirrel cage induction generators are used in wind turbines, whose stator winding is directly connected to the 60 Hz grid, and the rotor is driven by a variable pitch wind turbine. The rated speed is 9 m/s and the pitch angle is controlled to limit the output power of the generator in its rated value for winds higher

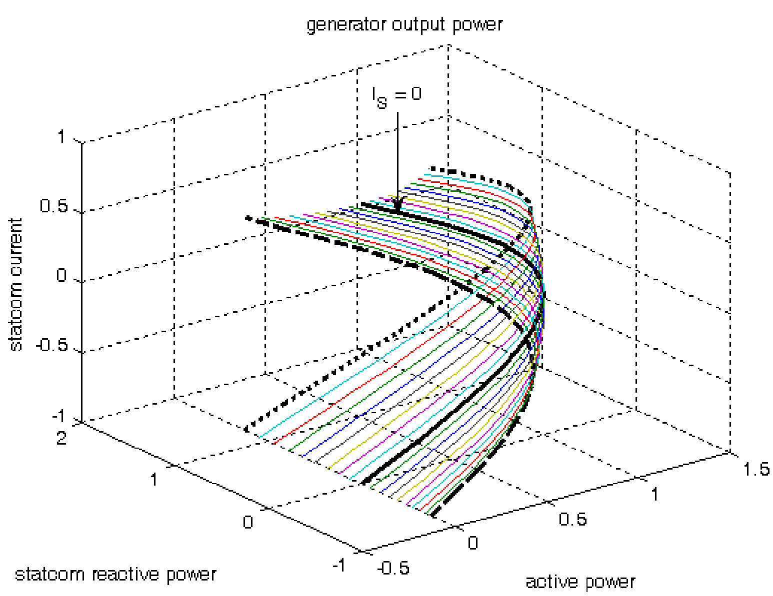

Fig. 4. Effect of compensating current on output power.

Table 1. ***Set parameters of turbines.***

Parameter	Value
Proportional gain of pitch angle controller	5
The gain of the pitch angle controller integrator	25
Maximum pitch angle change rate	2 deg/s
Nominal mechanical output power of the wind turbine	$2\times1.5\times10^6$ W
Base wind speed	9 m/s
Base rotation speed	1 pu/base generator speed

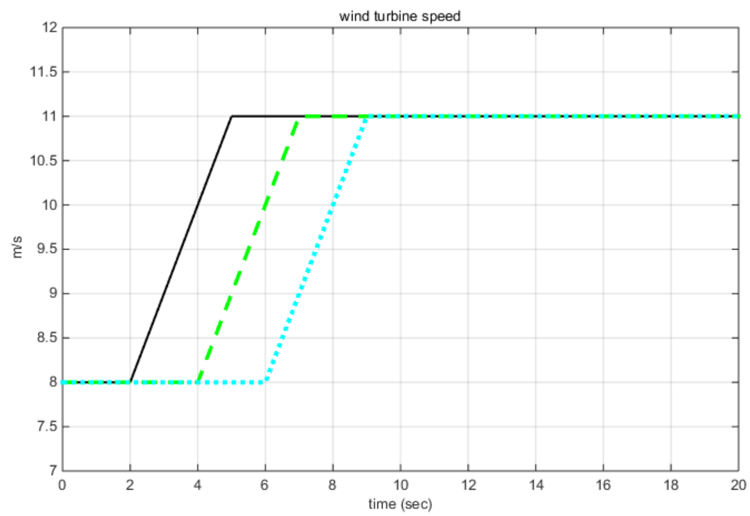

Fig. 5. Wind turbine speed.

than the rated speed. To generate power, the speed of the induction generator should be slightly higher than the synchronous speed. The speed varies between approximately 1 pu at no load and 1.005 pu at full load. Each wind turbine has a protection system to monitor voltage, current, and machine speed. The reactive power absorbed by the induction generators is partially compensated by the capacitor banks connected to each low voltage bus of the wind turbine. For each pair of 1.5 MW turbines, this power is 400 KW. The rest of the reactive power required to maintain the voltage of 25 kV in the 25 kV distribution bus close to one unit is supplied by a 3 MW static synchronous compensator with a 3% droop setting. The basic power is considered to be 3 MVA. The rated speed of the wind that creates the rated mechanical power is 9 m/s.

5. SIMULATION RESULTS

In this section, the simulation results for a period of 20 seconds using Simulink Matlab software are shown.

In the simulation results, the behavior of three turbines is shown with a solid line (black color) for turbine 1, a dashed line (green color) for turbine 2, and a dotted line (blue color) for turbine 3, respectively. At first, the wind speed for all turbines is considered to be 8 m/s. The speed of turbines one, two, and three change to 11 m/s in 2, 4, and 6 seconds respectively for three seconds (Fig. 5). During 15 seconds a temporary fault is applied to the wind turbine terminal 2 (low voltage 575 volts). Table 1 shows the parameters set for three pairs of turbines for simulation.

Figs. 6 and 7 show the voltage of bus 25 without and with compensator. As can be seen, without the compensator, the voltage drop in the steady state has increased.

Figures 8 and 9 show active bass power in two modes. As you can see, in steady state, one of the turbines is out of the circuit and the throughput is 6 MW.

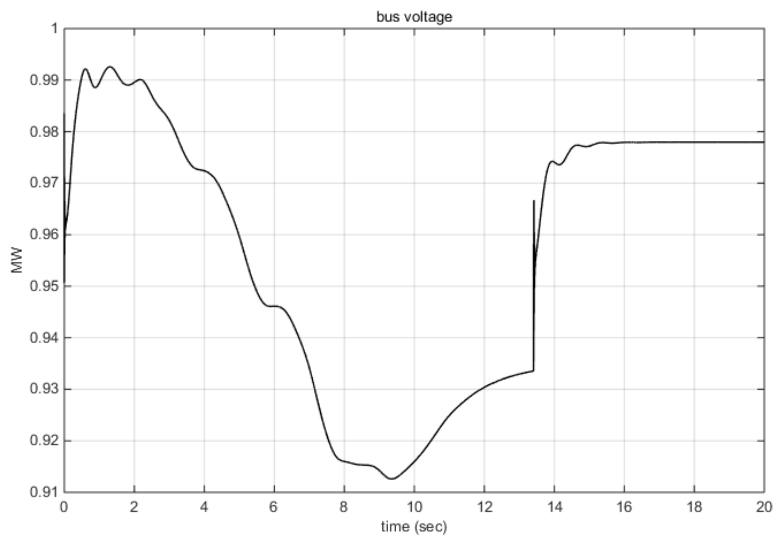

Fig. 6. Bus voltage (without compensator).

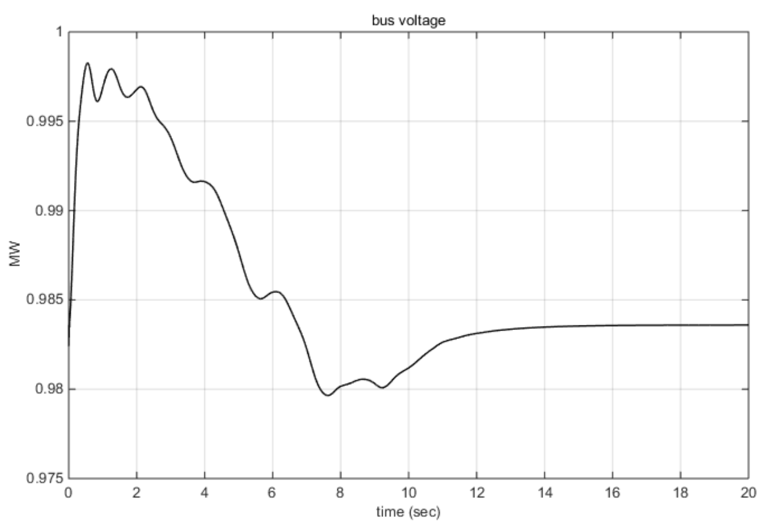

Fig. 7. Voltage bus (with compensator).

The Figs. 10 and 11 show the productive active power and the Figs. 12 and 13 show the productive reactive power of wind turbines in two states. With the presence of the compensator, the turbines are in the circuit and each of them produces 1.5 MW.

Figs. 14 and 15 show the pitch angle for two cases. Figs. 16 and 17 show the size of the compensator bass and the reactive power produced by the compensator. The compensator prevents voltage drop by generating reactive power and injecting it into the network.

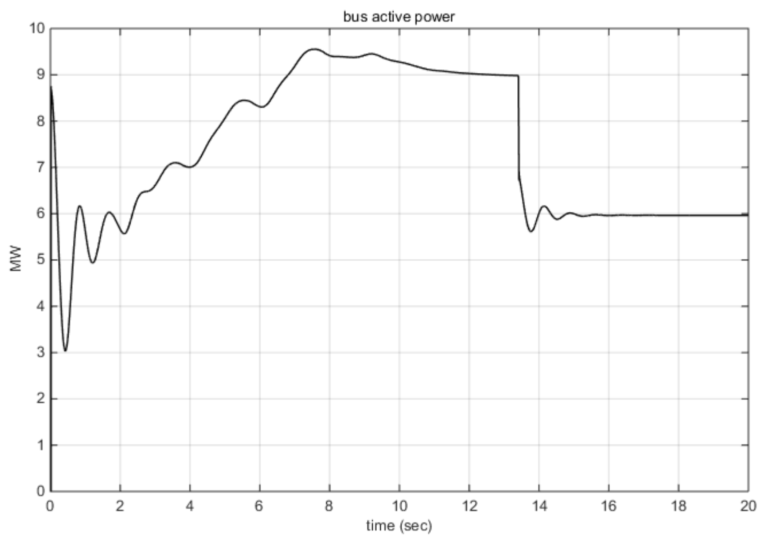

Fig. 8. Bus voltage active power (without compensator).

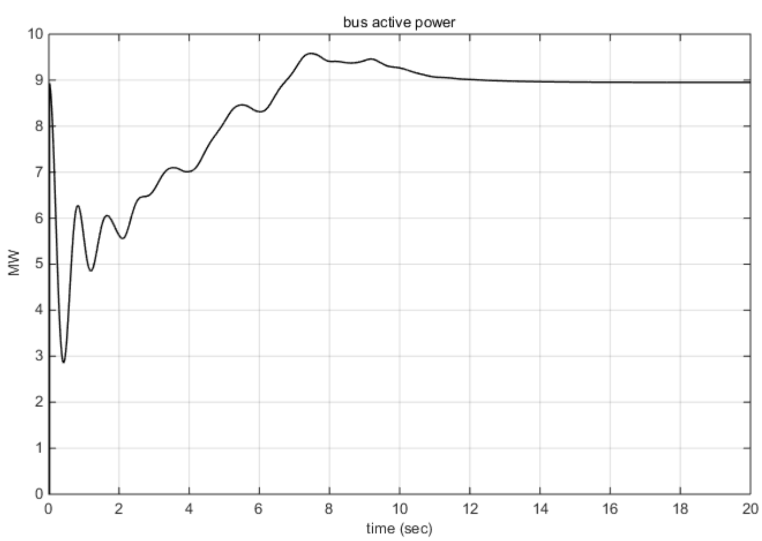

Fig. 9. Bus active power (with compensator).

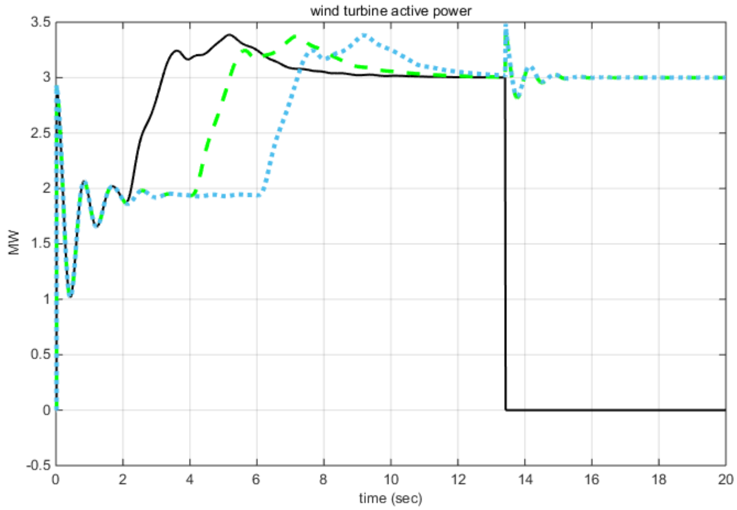

Fig. 10. Wind turbine active power (without compensator).

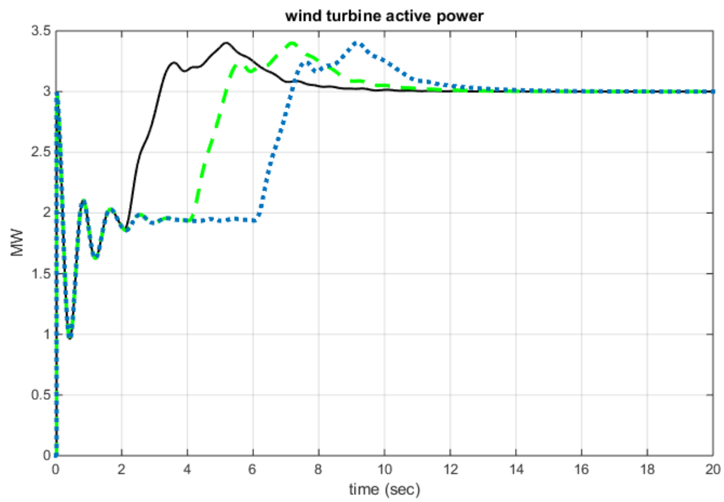

Fig. 11. Wind turbine active power (with compensator).

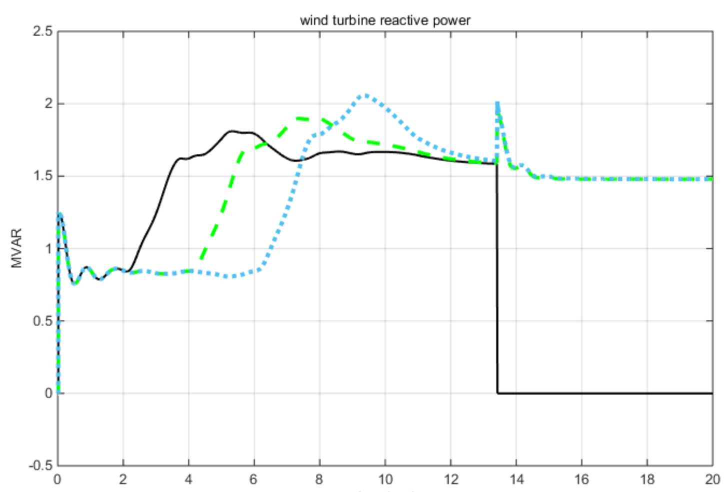

Fig. 12. Wind turbine reactive power (without compensator).

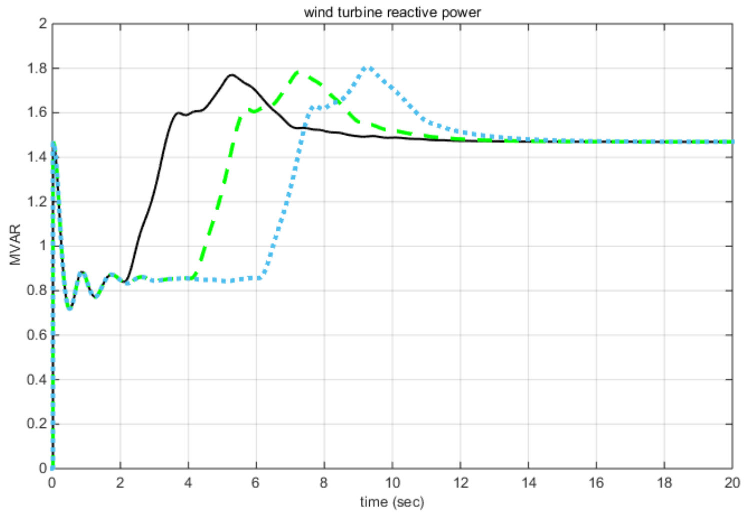

Fig. 13. Wind turbine reactive power (with compensator).

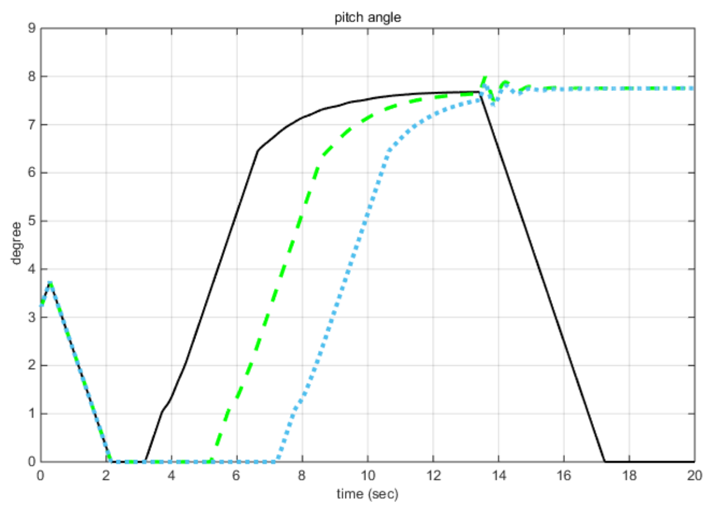

Fig. 14. Pitch angle (without compensator).

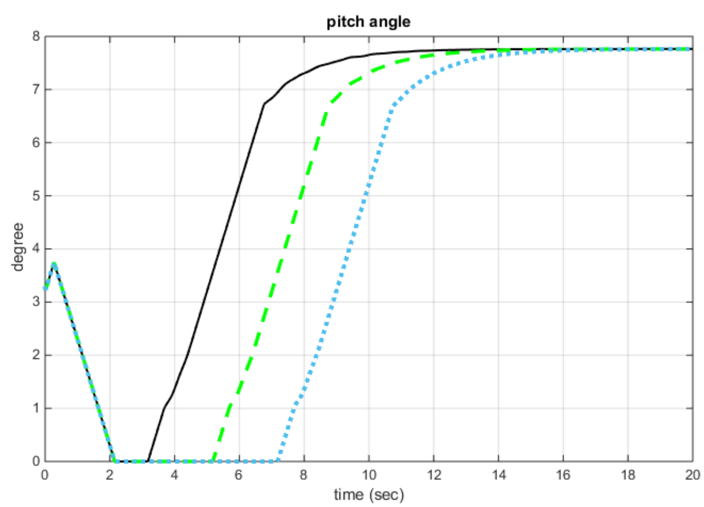

Fig. 15. Pitch angle (with compensator).

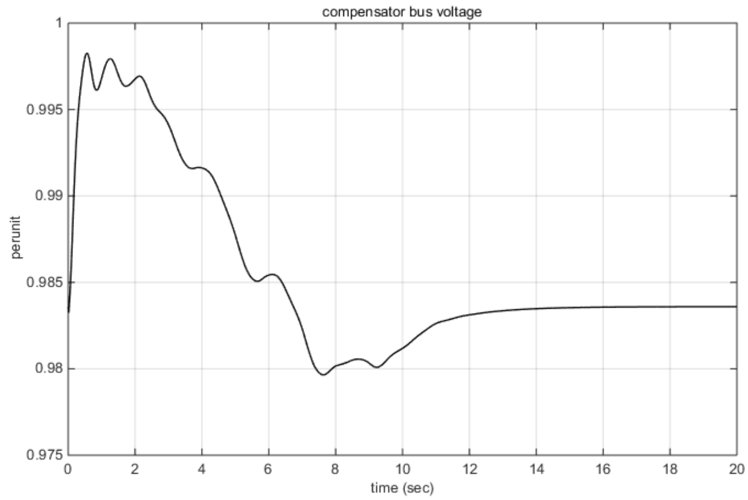

Fig. 16. Compensator bus voltage.

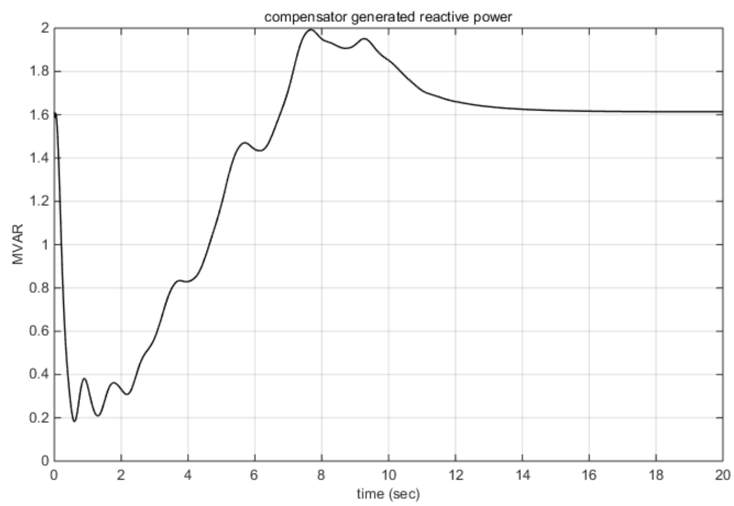

Fig. 17. Compensator generated reactive power.

6. CONCLUSION

Wind energy changes continuously with the change in wind speed during the day. The amount of power output from a wind energy production system depends on the accuracy of tracking the peak power points, regardless of the type of generator used.

In this paper, the effect of static synchronous compensator on the behavior of the distribution system was shown. Three pairs of turbines with speed variations were considered. The simulation results showed the compensatory effect of preventing the voltage drop and the exit of the turbines from the circuit.

REFERENCES

[1] H.H.H. Mousa, A.R. Youssef, E.E.M. Mohamed, "State of the art perturb and observe MPPT algorithms based wind energy conversion systems: A technology review", International

Journal of Electrical Power and Energy Systems, vol. 126, Article Number: 106598, March 2021, doi: 10.1016/j.ijepes.2020.106598.

[2] R. Tiwari, N.R. Babu, “Recent developments of control strategies for wind energy conversion system”, Renewable and Sustainable Energy Reviews, vol. 66, pp. 268-285, Dec. 2016, doi: 10.1016/j.rser.2016.08.005.

[3] M. Moradian, A. Soltani-Mohammadi, A. "A new control system for a dual stator-winding cage rotor induction generator in direct grid connected condition with maximum power point tracking of wind turbine”, Journal of Intelligent Procedures in Electrical Technology, vol. 9, no. 35, pp. 3-10, Nov. 2019, dor: 20.1001.1.23223871-.1397.9.35.1.4.

[4] S. Agalar, Y.A. Kaplan, "Power quality improvement using STS and DVR in wind energy system", Renewable Energy, vol. 118, pp. 1031-1040, April 2018, doi: 10.1016/j.renene.2017.01.0-13.

[5] C. Ai, L. Zhang, W. Gao, G. Yang, D. Wu, L. Chen, W. Chen, A. Plummer, “A review of energy storage technologies in hydraulic wind turbines”, Energy Conversion and Management, vol. 264, Article Number: 115584, July 2022, doi: 10.1016/j.enconman.2022.115584.

[6] N. Taheri, H. Orojlo, F. Ebrahimi, "Damping controller design in offshore wind power plants to improve power system stability using fractional order PID controllers based on optimized exchange market algorithm", Journal of Intelligent Procedures in Electrical Technology, vol. 13, no. 51, pp. 91-110, Dec. 2022, dor: 20.1001.1.2322-3871.1401.13.51.6.9.

[7] E. Hosseini, G. Shahgholian, "Partial- or full-power production in WECS: A survey of control and structural strategies", European Power Electronics and Drives, vol. 27, no. 3, pp. 125-142, Dec. 2017, doi: 10.1080/09398368.2017.1413161.

[8] R. Jahanshahi Bavandpour, H. Ghadiri, H. Khodadadi, "Optimal design of a hybrid solar–wind–battery system using the grasshopper optimization algorithm for minimization of the loss of power supply probability", Journal of Intelligent Procedures in Electrical Technology, vol. 13, no. 51, pp. 139-156, Dec. 2022, dor: 20.1001.1.23-223871.1401.13.51.9.2.

[9] S. Galvani, M.T. Hagh, M.B.B. Sharifian, B. Mohammadi-Ivatloo, "Multiobjective predictability-based optimal placement and parameters setting of UPFC in wind power included power systems", IEEE Trans. on Industrial Informatics, vol. 15, no. 2, pp. 878-888, Feb. 2019, doi: 10.1109/TII.2018.2818821.

[10] A.A.R. Mohamed, H.M. Sharaf, D.K. Ibrahim, "Enhancing distance protection of long transmission lines compensated with TCSC and connected with wind power", IEEE Access, vol. 9, pp. 46717-46730, 2021, doi: 10.1109/ACCESS.2021.3067701.

[11] G. S. Chawda, A. G. Shaik, O. P. Mahela, S. Padmanaban, J. B. Holm-Nielsen, "Comprehensive review of

distributed FACTS control algorithms for power quality enhancement in utility grid with renewable energy penetration", IEEE Access, vol. 8, pp. 107614-107634, 2020, doi: 10.1109/ACCESS.2020.3000931.

[12] G. Shahgholian, J. Faiz, "Coordinated control of power system stabilizer and FACTS devices for dynamic performance enhancement- State of art ", Proceeding of the IEEE/IEPS, pp. 1-6, Kyiv, Ukraine, June 2016, doi: 10.1109/IEPS.2016.7521865.

[13] G. Shahgholian, M. Mahdavian, M. Janghorbani, I. Eshaghpour, E. Ganji, "Analysis and simulation of UPFC in electrical power system for power flow control", Proceeding of the IEEE/ECTICON, pp. 62-65, Phuket, Thailand, June 2017, doi: 10.1109/ECTICon.2017.8096173.

[14] E. Jafari, A. Marjanian, S. Silaymani, G. Shahgholian, "Designing an emotional intelligent controller for IPFC to improve the transient stability based on energy function", Journal of Electrical Engineering and Technology, vol. 8, no. 3, pp. 478-489, 2013, doi: /10.5370/JEET.2-013.8.3.478.

[15] T. Zhang, X. Xu, Z. Li, A. Abu-Siada, Y. Guo, "Optimum location and para-meter setting of STATCOM based on improved differential evolution harm-ony search algorithm", IEEE Access, vol. 8, pp. 87810-87819, 2020, doi: 10.1109/ACCESS.2020.2993066.

[16] M. Mahdavian, N. Behzadfar, “A review of wind energy conversion system and application of various indu-ction generators”, Journal of Novel Researches on Electrical Power, vol. 8, no. 4, pp. 55-66, 2020.

[17] K. Tan, "Squirrel-cage induction generator system using wavelet petri fuzzy neural network control for wind power applications", IEEE Trans. on Power Electronics, vol. 31, no. 7, pp. 5242-5254, July 2016, doi: 10.1109/TPEL.2015.2480407.

[18] S. Ahsan, A.S. Siddiqui, “Dynamic compensation of real and reactive power in wind farms using STATCO-M”, Perspectives in Science, vol. 8, pp. 519-521, Sept. 2016, doi: 10.1016/j.p-isc.2016.06.008.

[19] T. Sandhya, K.S. Chandan, "Control and operation of opti-slip induction generator in wind farms", Proceeding of the IEEE/ICCCET, pp. 450-454, Tirunelveli, India, March 2011, doi: 10.1109/ICCCET.2011.5762517.

[20] J. Samanes, E. Gubia, J. Lopez and R. Burgos, "Sub-synchronous resonance damping control strategy for DFIG wind turbines", IEEE Access, vol. 8, pp. 223359-223372, 2020, doi: 10.1109/ACCESS.2020.3043818.

[21] J. Ouyang, T. Tang, J. Yao, M. Li, "Active voltage control for DFIG-based wind farm integrated power system by coordinating active and reactive powers under wind speed variations", IEEE Trans. on Energy Conversion, vol. 34, no. 3, pp. 1504-1511, Sept. 2019, doi: 10.1109/TEC.2019.2905673.

[22] R.S. Muñoz-Aguilar, A. Dòria-Cerezo, E. Fossas, “Extended SMC for a stand-

alone wound rotor synchronous generator”, International Journal of Electrical Power and Energy Systems, vol. 84, pp. 25-33, Jan. 2017, doi: 10.1016/j.ijepes.2016.04.052.

[23] A. Watil, A. E. Magri, A. Raihani, R. Lajouad, F. Giri, “An adaptive nonlinear observer for sensorless wind energy conversion syst em with PMSG”, Control Engineering Practice, vol. 98, Article 104356, May 2020 (doi: j.conengprac.2020.104356).

[24] D. Cortes-Vega, F. Ornelas-Tellez, J. Anzurez-Marin, "Nonlinear optimal control for PMSG-based wind energy conversion systems", IEEE Latin America Transactions, vol. 19, no. 7, pp. 1191-1198, July 2021, doi: 10.1109/TLA.2021.9461848.

[25] X.Y. Bian, Y. Geng, K.L. Lo, Y. Fu, Q.B. Zhou, "Coordination of PSSs and SVC damping controller to improve probabilistic small-signal stability of power system with wind farm integration", IEEE Trans. on Power Systems, vol. 31, no. 3, pp. 2371-2382, May 2016, doi: 10.1109/TPWRS.2015.2458980.

[26] M.I. Mosaad, N.A. Sabiha, "Ferroresonance overvoltage mitigation using STATCOM for grid-connected wind energy conversion systems", Journal of Modern Power Systems and Clean Energy, vol. 10, no. 2, pp. 407-415, March 2022, doi: 10.35833/MPCE.2020.000286.

[27] Y.K. Gounder, D. Nanjundappan, V. Boominathan, "Enhancement of transient stability of distribution system with SCIG and DFIG based wind farms using STATCOM", IET Renewable Power Generation, vol. 2016, no. 8, pp. 1171-1180, Sep. 2016, doi: 10.1049/iet-rpg.2016.0022.

[28] 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, vol. 8, no. 15, pp. 81-90, 2019, dor: 20.1001.1.23222344.1398.8.1.9.0.

[29] A. Rashad, S. Kamel, F. Jurado, “Stability improvement of power systems connected with developed wind farms using SSSC controller”, Ain Shams Engineering Journal, vol. 9, no. 4, pp. 2767-2779, Dec. 2018, doi: 10.1016/j.asej.2017.03.015.

[30] Y. Zhang, Y. Yang, X. Chen, C. Gong, "Intelligent parameter design-based impedance optimization of STATCOM to mitigate resonance in wind farms", IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 9, no. 3, pp. 3201-3215, June 2021, doi: 10.1109/JESTPE.2020.3020434.

[31] J. Pande, P. Nasikkar, K. Kotecha, V. Varadarajan, “A review of maximum power point tracking algorithms for wind energy conversion systems”, Journal of Marine Science and Engineering, vol.9, Article Number: 1187, Oct. 2021, doi: 10.3390/jmse9111187.

[32] A.O. Aluko, D.G. Dorrell, R.P. Carpanen and E.E. Ojo, “Heuristic optimization of virtual inertia control in grid-connected wind energy conversion

systems for frequency support in a restructured environment", Energies, vol. 13, no. 3, Article Number: 564, 2020, doi: 10.3390/en13030564.

[33] G. Shahgholian, K. Khani, M. Moazzami, "Frequency control in autanamous microgrid in the presence of DFIG based wind turbine", Journal of Intelligent Procedures in Electrical Technology, vol. 6, no. 23, pp. 3-12, December 2015 dor: 20.1001.1.23-223871.1394.6.23.1.9.

[34] M. Fooladgar, E. Rok-Rok, B. Fani, G. Shahgholian, "Evaluation of the trajectory sensitivity analysis of the DFIG control parameters in response to changes in wind speed and the line impedance connection to the grid DFIG", Journal of Intelligent Procedures in Electrical Technology, vol. 5, no. 20, pp. 37-54, March 2015, dor: 20.1001.1.23223871.1393.5.20.4.9.

[35] H.T. Nguyen, A.S. Al-Sumaiti, V.P. Vu, A. Al-Durra, T.D. Do, "Optimal power tracking of PMSG based wind energy conversion systems by constrained direct control with fast convergence rates", International Journal of Electrical Power and Energy Systems, vol. 118, Article 105807, June 2020, doi: 10.1016/j.ijepes.2019.105807.

[36] Y. Li, Z. Xu, K. Meng, "Optimal power sharing control of wind turbines", IEEE Trans. on Power Systems, vol. 32, no. 1, pp. 824-825, Jan. 2017, doi: 10.110 9/TPWRS.2016.2549741.

[37] K. Khani, G. Shahgholian, "Analysis and optimization of frequency control in isolated microgrid with double-fed induction-generators based wind turbine", Journal of International Council on Electrical Engineering, vol. 9, no. 1, pp. 24-37, Feb. 2019, doi: 10.1080/22348972.2018.1564547.

[38] M. Cheng, Y. Zhu, "The state of the art of wind energy conversion systems and technologies: A review", Energy Conversion and Management, vol. 88, pp. 332-347, Dec. 2014, doi: 10.1016/j.enconman.2014.08.037.

[39] R. Abdelli, D. Rekioua, T. Rekioua, A. Tounzi, "Improved direct torque control of an induction generator used in a wind conversion system connected to the grid", ISA Transactions, vol. 52, np. 4, pp. 525-538, 2013, doi: 10.1016/j.isatra.2013.03.001.

[40] 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, vol. 152, pp. 466-484, Nov. 2017, doi:10.1016/j.epsr.2017.07.033.

[41] N. Ramesh-Babu, P. Arulmozhivarman, "Wind energy conversion systems: A technical review", Journal of Engineering Science and Technology, vol. 8, no. 4, pp. 493 – 507, 2013.

[42] R.M. Linus, P. Damodharan, "Maximum power point tracking method using a modified perturb and observe algorithm for grid connected wind energy conversion systems", IET Renewable Power Generation, vol. 9, no. 6, pp. 682-689, Aug. 2015, doi: 10.1049/iet-rpg.2014.0070.

[43] 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, vol. 108, pp. 314-335, June 2019, doi: 10.1016/j.ijepes.2019.01. 017.

[44] G. Shahgholian, "Analysis and simulation of dynamic performance for DFIG-based wind farm connected to a distrubition system", Energy Equipment and Systems, vol. 6, no. 2, pp. 117-130, June 2018, doi: 10.22059/EES.2018. 315 31.

[45] G. Shahgholian, S. Eshtehardiha, H. Mahdavinasab, M.R. Yousefi, "A novel approach in automatic control based on the genetic algorithm in STATCOM for improvement power system transient stability", Proceeding of the IEEE/ICIS, vol. 1, pp.14-19, Varna, Sep. 2008, doi: 10.1109/IS.2008.4670419.

[46] R.K. Varma, H. Maleki, "PV solar system control as STATCOM (PV-STATCOM) for power oscillation damping", IEEE Trans. on Sustainable Energy, vol. 10, no. 4, pp. 1793-1803, Oct. 2019, doi: 10.1109/TSTE.2018.-2871074.

[47] M. Mahdavian, G. Shahgholian, N. Rasti, "Modeling and damping controller design for static synchronous compensator", Proceeding of the IEEE/ECTICON, pp. 300-304, Pattaya, Chonburi, May 2009, doi: 10.110-9/ECTICON.2009.5137013.

[48] G. Shahgholian, S. Fazeli-Nejad, M. Moazzami, M. Mahdavian, M. Azadeh, M. Janghorbani, S. Farazpey, "Power system oscillations damping by optimal coordinated design between PSS and STATCOM using PSO and ABC algorithms", Proceeding of the IEEE/ECTI-CON, Chiang Mai, Thailand, pp. 1-6, July 2016, doi: 10.1109/ECTICon.2016.7561458.