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МАТЕРІАЛИ МІЖНАРОДНОЇ НАУКОВО-ПРАКТИЧНОЇ КОНФЕРЕНЦІЇ

2023 СЕУТТОО

СУЧАСНІ ЕНЕРГЕТИЧНІ УСТАНОВКИ НА ТРАНСПОРТІ, ТЕХНОЛОГІЇ ТА ОБЛАДНАННЯ ДЛЯ ЇХ ОБСЛУГОВУВАННЯ

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14-ї Міжнародної науково-практичної конференції

«СУЧАСНІ ЕНЕРГЕТИЧНІ УСТАНОВКИ НА ТРАНСПОРТІ, ТЕХНОЛОГІЇ ТА ОБЛАДНАННЯ ДЛЯ ЇХ ОБСЛУГОВУВАННЯ»

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Херсон – 2023

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Сучасні енергетичні установки на транспорті і технології та обладнання для їх обслуговування. 14-а Міжнародна науково-практична конференція, 16-18 березня 2023 р. – Херсон: Херсонська державна морська академія.

У матеріалах 14-ї Міжнародної науково-практичної конференції «Сучасні енергетичні установки на транспорті і технології та обладнання для їх обслуговування» представлені тези, які присвячені проблемам експлуатації, виробництва та проектування енергетичних установок та устаткування на транспорті, а також підготовці спеціалістів у сфері транспортної енергетики й устаткування.

RESEARCH OF THE ENERGY CHARACTERISTICS OF A WIND GENERATOR WITH A HYBRID INVERTER CONTROL SYSTEM

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Keywords:
Blade, control system, power electronics, semiconductor converter, wind energy, wind generator.

Abstract

An analysis of the technical characteristics of the main types of wind generators is given. The question of the possibility of adjusting the speed of rotation of the wind generator blades, the parameters of the power semiconductor part, which ensures the mode of smooth start of the generator, is considered. Power converters are given and more modern control functions are described. A system of two-circuit self-regulation of the hybrid inverter is proposed. The study of transient processes of wind generator control by simulation modeling in the Matlab software is given.

Introduction

The world consumption of electricity is growing, so there is a demand for increased power. The production, distribution and use of energy must be as technologically efficient as there are opportunities and incentives for the end user to save energy. Energy regulation has reduced investments in large power plants, which means that the need for new sources of electricity may be very high in the near future [1, 2].

Two main trends will play an important role in solving future problems. One of them is to change the sources of electricity production from traditional, fossil and short-term sources of energy to renewable energy sources. Another provides for the use of highly efficient power electronics in electric power, transmission and distribution of electric power to end users [3, 4].

In classical energy systems, large power plants located in appropriate geographical points produce the majority of the energy, which is then transmitted over long distances by electric lines. Control centers constantly monitor and regulate the energy system to ensure the quality of electricity, namely the frequency and voltage [5, 6].

However, the overall power system is changing, with a large number of distributed generation units, including both renewable and non-renewable sources, such as wind turbines, wave generators, photovoltaic generators, small hydro, fuel cells and gas (steam) combined heat and power plants. There is widespread use of renewable energy sources in distribution networks [7, 8].

The main advantages of using renewable energy sources are the elimination of harmful emissions and inexhaustible primary energy resources [9, 10]. The availability of renewable energy sources has clear diurnal and seasonal patterns, and the demand for electricity from consumers can vary in characteristics. Therefore, it is difficult to operate a power system in which only renewable generation units are installed, due to differences in characteristics and high uncertainty in the availability of renewable energy sources.

Relevance of research

Wind turbine technology is one of the developing technologies for using renewable energy sources. According to research [11, 12], the technology used in wind turbines was initially based on a short-circuited rotor of an asynchronous generator connected directly to the network. Wind energy production initially did not affect the management of the power system, but now, due to the development of capacities, it must play an active role in the power system and requires new technical solutions.

According to research [13, 14], wind power pulsations are almost directly transmitted to the electrical network. In addition, there is no control of active and reactive power, which are usually important control parameters for frequency and voltage regulation. As the power range of turbines increases, these control parameters become increasingly important, and power electronics must be introduced as an interface between the wind turbine and the network.

Power electronics changes the basic characteristic of a wind turbine from an energy source to a source of active power [15, 16]. The technology used in wind turbines is not new, but it is relevant because it contributes to the development of semiconductor devices and the reduction of the price of power electronics.

The main material of the study

In recent years, the number of power electronics components has increased, mainly due to the development of semiconductor devices and microprocessor technology. A typical power system consisting of a power converter, a load (generator) and a control unit is shown in Fig. 1.

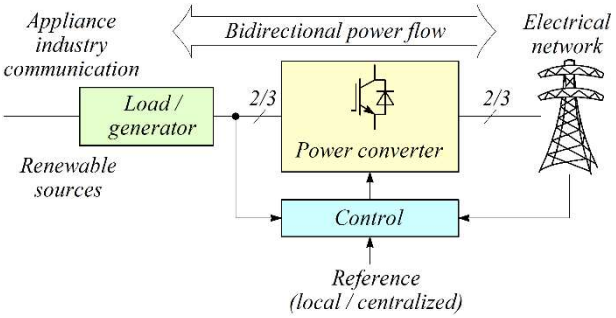

Figure 1. *Wind energy conversion power system*

The power converter is the interface between the load (generator) and the electrical network. Power can flow in both directions depending on the topology. The use of such a system raises concerns about three important issues. The first is reliability, the second is efficiency, and the third is cost. At present, the cost of power semiconductor devices decreases annually by 1...5 % with the same initial characteristics for the power electronic system. An example of an electronic system that is commercially available and competitive in power is the variable speed drive. The transformation of power electronics is reduced in volume and weight. A switch driver of this development is that power electronics technology is still in its infancy [17, 18].

Wind turbines capture wind energy using blades of a rotating aerodynamic structure and convert it into mechanical energy. The number of blades is usually three. Since the tip speed of the blade must be less than half the speed of sound, the rotational speed will decrease as the blade radius increases. For wind turbines with a capacity of several MW, the rotation frequency will be 10...15 rpm.

The most economical way to convert low-speed, high-torque power into electrical energy is to use a gearbox and a standard fixed-speed generator, as shown in Fig. 2.

Due to the operation at a fixed speed, wind speed fluctuations are transformed into mechanical torque fluctuations. The advantage of fixed speed wind turbine is that it is simple, strong, reliable, has low power consumption and low cost of electrical part. Disadvantages of such a system are uncontrolled consumption of reactive power, mechanical loads and limited power quality control.

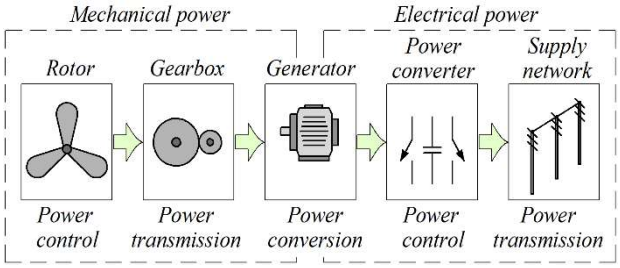

Figure 2. *Conversion of mechanical wind energy*

Wind turbines with adjustable speed are designed to achieve maximum aerodynamic efficiency in a wide range of frequencies. Variable speed operation can be continuously adapted (speeding up or slowing down the speed of the wind turbine) to the wind speed so that the blade speed ratio remains constant at a set value corresponding to the maximum power factor. Unlike a fixed-speed system, a variable-speed system keeps the generator torque nearly constant. From a wind turbine's perspective, the most important advantages of variable speed operation compared to conventional fixed speed operation are: reduced mechanical stress on mechanical components such as the shaft and gearbox, increased power output and reduced noise.

In addition, the presence of energy converters in wind turbines also provides high potential control capabilities for both large modern wind turbines and wind farms to meet the high technical requirements of grid operators, such as:

– adjustable active and reactive power (frequency and voltage control);

– quick response to transient and dynamic situations of the power system;

– impact on network stability and improvement of electricity quality.

The configuration of a variable-speed wind generator with full power conversion corresponds to a fully variable-speed wind turbine, with the generator connected to the grid through a full-scale frequency converter, as shown in Fig. 3.

The frequency converter performs reactive power compensation and smooth connection to the network for the entire speed range.

The generator can be electrically excited (synchronous generator with phase rotor WRSG) or with excitation from permanent magnets (synchronous generator with permanent magnets

PMSG). The stator windings are connected to the network through a full-fledged power converter.

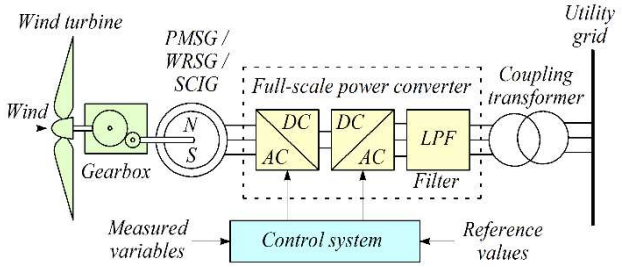

Figure 3. *Type D wind turbine*

To determine the energy characteristics of fourth-generation (type D) wind generators, a simulation was carried out in the Matlab software. The simulation model of the system "asynchronous wind generator – rectifier – hybrid inverter – electric three-phase network" is shown in Fig. 4.

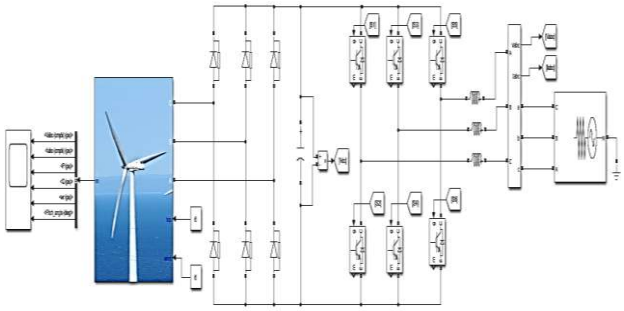

Figure 4. *Simulation model of a wind turbine*

The power characteristics of the wind turbine of the wind generator are shown in Fig. 5.

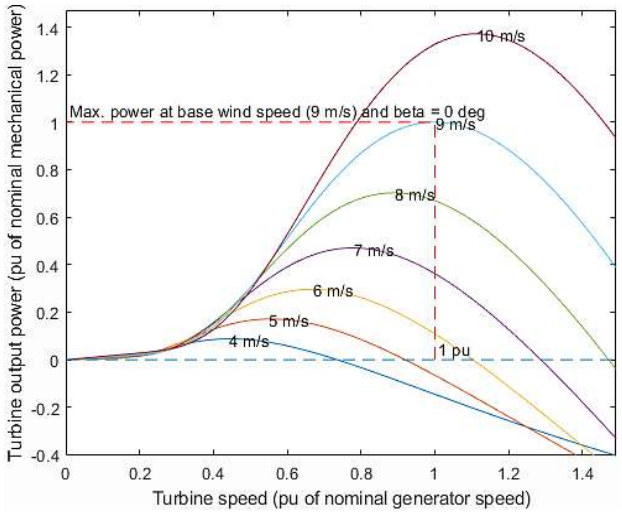

Figure 5. *The family of energy characteristics of the wind generator (relative maximum power depending on the wind speed)*

The control system of the hybrid inverter is implemented on the basis of pulse width modulation with a frequency of 1 kHz.

Thus, a two-loop system of autoregulation of the hybrid inverter was implemented, which was performed under the following conditions:

– maintaining the voltage in the direct current circuit higher than the line voltage of the network;

– maintenance of the power factor close to unity;

– the balance of the power of the wind generator and the power generated to the electric network from the hybrid inverter.

Conclusion

An analysis of the technical characteristics of the main types of wind generators was carried out, which showed that wind generators with adjustable blade rotation speed provide a smooth start-up mode.

A wind generator configuration with adjustable speed and full power conversion is presented. The frequency converter performs reactive power compensation and smooth connection to the network for the entire speed range.

A hybrid inverter control system is proposed, which provides electricity generation to a three-phase electric network in current source mode with a power factor close to unity and a fairly low content of higher current harmonics.

References

[1] Chaudhuri A., Datta R., Kumar M. P., Davim J. P., Pramanik S. Energy Conversion Strategies for Wind Energy System: Electrical, Mechanical and Material Aspects. *Materials*. 2022. Vol. 15, No. 3, 1232. P. 1–36.

[2] Fouad A., Alali Ch., Gainullina L. Increasing the efficiency of wind farms. *iPolytech Journal*. 2022. Vol. 26. P. 217–227. doi:10.21285/1814-3520-2022-2-217-227

[3] Cao D., Hu W., Zhao J., Zhang G., Zhang B., Liu Z., Chen Z., Blaabjerg F. Reinforcement learning and its applications in modern power and energy systems: A review. *J. Mod. Power Syst. Clean Energy*. 2020. Vol. 8, No. 6. P. 1029–1042.

[4] Nerubatskyi V., Plakhtii O., Hordiienko D., Khoruzhevskyi H. Study of energy parameters in alternative power source microgrid systems with multilevel inverters. *International scientific journal «Industry 4.0»*. 2020. Vol. 5, Issue 3. P. 118–121.

[5] Stock S., Babazadeh D., Becker C. Applications of Artificial Intelligence in Distribution Power System Operation. *IEEE Access*. 2021. Vol. 9. P. 150098–150119. doi:10.1109/ACCESS.2021.3125102

[6] Nerubatskyi V., Plakhtii O., Hordiienko D., Mykhalkiv S., Ravlyuk V. A method for calculating the parameters of the sine filter of the frequency converter, taking into account the criterion of starting current limitation and pulse-width modulation frequency. *Eastern-European Journal of Enterprise Technologies*. 2021. Vol. 1, No. 8 (109). P. 6–16. doi:10.15587/1729-4061.2021.225327

[7] Shourangiz-Haghighi A. Developing More Efficient Wind Turbines: A Survey of Control Challenges and Opportunities. *IEEE Industrial Electronics Magazine*. 2020. Vol. 14, No. 4. P. 53–64. doi:10.1109/MIE.2020.2990353

[8] Hasan A., Elgammal T., Jackson R., Amano R. Comparative Study of the Inline Configuration Wind Farm. *Journal of Energy Resources Technology*. 2019. Vol. 142, No. 6. P. 1–23. doi:10.1115/1.4045463

[9] Ortega Izquierdo M., Del Rio P. An analysis of the socioeconomic and environmental benefits of wind energy deployment in Europe. *Renewable Energy*. 2020. Vol. 160. P. 1067–1080. doi:10.1016/j.renene.2020.06.133

[10] Watson S., Moro A., Reis V., Baniotopoulos C., Barth S., Bartoli G., Bauer F. Future emerging technologies in the wind power sector: A European perspective. *Renewable and Sustainable Energy Reviews*. 2019. Vol. 113, 109270. P. 1–21. doi:10.1016/j.rser.2019.109270

[11] Muhammad Shahzad N., Nisar A., Muhammad B., Hafiz M. N. Potential environmental impacts of wind energy development. *A global perspective. Current Opinion in Environmental Science & Health*. 2020. Vol. 13. P. 85–90. doi:10.1016/j.coesh.2020.01.002

[12] Jaen-Sola P., McDonald A. S., Oterkus E. Lightweight design of direct-drive wind turbine electrical generators: A comparison between steel and composite material structures. *Ocean Eng.* 2019. Vol. 181. P. 330–341. doi:10.1016/j.oceaneng.2019.03.053

[13] Ohya Y., Karasudani T., Nagai T., Watanabe K. Wind lens technology and its application to wind and water turbine and beyond. *Renew. Energy Environ. Sustain.* 2017. Vol. 2. P. 1–6. doi:10.1051/rees/2016022

[14] Torres-Madronero J. L., Alvarez-Montoya J., Restrepo-Montoya D., Tamayo-Avendano J. M., Nieto-Londono C., Sierra-Perez J. Technological and operational aspects that limit small wind turbines performance. *Energies*. 2020. Vol. 13, No. 22, 6123. DOI: doi:10.3390/en13226123

[15] Qadr H. An Exploration into Wind Turbines, Their Impacts and Potential Solutions. *Journal of Environmental Science and Public Health*. 2018. Vol. 2, Issue 1. P. 64–69. doi:10.26502/jesph.96120029

[16] Chandan R., Kiran T., Swapna G., Muni V Intelligent control strategy for energy management system with FC/battery/SC. *Journal of critical reviews*. 2022. Vol. 7, Issue 2. P. 344–348. doi:10.31838/jcr.07.02.66

[17] Nerubatskyi V., Plakhtii O., Hordiienko D. Control and accounting of parameters of electricity consumption in distribution networks. *2021 XXXI International Scientific Symposium Metrology and Metrology Assurance (MMA)*. 2021. P. 114–117. doi:10.1109/MMA52675.2021.9610907

[18] Nerubatskyi V. P., Plakhtii O. A., Hordiienko D. A., Syniavskyi A. V., Philipjeva M. V. Use of modern technologies in the problems of automation of data collection in intellectual power supply systems. *Modern engineering and innovative technologies*. 2022. Issue 19, Part 1. P. 38–51. doi:10.30890/2567-5273.2022-19-01-058

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