МОНІТОРИНГ, ДІАГНОСТИКА ТА КЕРУВАННЯ ЕНЕРГЕТИЧНИМИ ПРОЦЕСАМИ ТА ОБЛАДНАННЯМ.

MONITORING, DIAGNOSTICS AND CONTROL OF ENERGY PROCESSES AND EQUIPMENT

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ANALYSIS OF THE CONTROL SYSTEM OF A WIND PLANT CONNECTED TO THE AC NETWORK

The dynamics of the development of alternative power sources over the past few decades are presented, which gives reason to talk about the trends in the further development of wind energy. An analysis of the structures and technical characteristics of wind generators is provided, namely, types of electric motors, power circuits of semiconductor converters that provide the generation of electrical energy to the general industrial electrical network. The issue of the possibility of operation of wind generators in wide wind ranges, the issue of emission of reactive power and higher harmonics of currents to the general industrial electrical network, as well as the issue of the efficiency of various structures of wind generators are considered. A wind turbine control system with an asynchronous generator is proposed. A study of transient control processes and energy compatibility of a full energy conversion wind turbine with a power supply network by simulation computer modeling in the Matlab / Simulink software environment is given. The obtained result indicates the possibility of operation of an asynchronous generator with a short-circuited rotor as part of a wind turbine, which makes it possible to provide power to the alternating current network at low wind speeds.

Keywords: *alternative energy source, asynchronous generator, wind turbine, wind energy, power plant, control system.*

Introduction

Wind energy is a relevant and promising type of renewable energy. Since 2014, 85 countries of the world use wind energy on a commercial basis. Large wind farms are included in the general grid, smaller ones are used to supply electricity to remote areas. In 2020, the total installed capacity of all wind generators was 743 GW, which exceeded the total installed capacity of nuclear power [1, 2].

Thus, the amount of electricity generated by wind power has been growing exponentially in recent years (Fig. 1).

The construction of wind power plants is associated with some technical and economic difficulties that slow down the spread of wind energy. In particular, the variability of wind flows does not create problems with a small share of wind energy in the total production of electricity, but with the growth of this share, the problems of the reliability of electricity production also increase. Intelligent power distribution management is used to solve such problems. The task of the wind power plant conversion system is to generate sinusoidal output voltages with a stable amplitude and frequency. Different types of semiconductor converters, as well as different control systems, can be used to generate a sinusoidal output voltage [3, 4].

Analysis of Recent Research and Publications

Most wind turbines use a DFIG (double-fed induction generator) system, which allows for variable speed power generation. The papers [5, 6] with DFIG have contributed to the control of wind systems (step-back control, sliding mode control, MPPT control, PCHD model control, D-FOC control). The main disadvantage of such control is that it is based on a strict mathematical aspect for synthesis.

The paper [7] proposed the use of a high-voltage direct current (HVDC) transmission system, which has technical advantages in creating an asynchronous connection and mass supply of electricity over long distances. However, the disadvantages of such a system include the high cost of building the system. A converter station is much more expensive to build than a conventional AC substation of similar capacity, as many more components are required for the better performance of an HVDC system. At the same time, the number of harmonics increases, which affect the quality of electricity and can lead to system oscillations.

Thus, the task of determining the optimal layout and control system of a wind turbine with full energy conversion is an actual unsolved task.

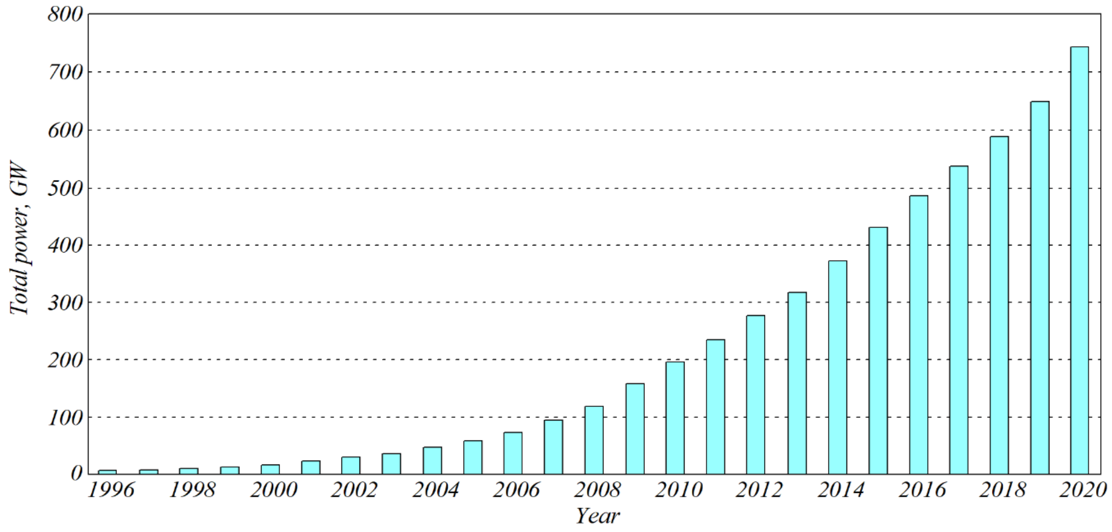

Figure 1 – Dynamics of wind energy growth

Purpose and Objectives of the Study.

The purpose of the study is to analyze the influence of the wind turbine control system with an asynchronous generator on the energy indicators of the wind turbine, which will make it possible to supply power to networks with low alternating current. To achieve this purpose, the following tasks are set:

– comparison of possible topologies of wind power plants and the efficiency of using wind turbines with different layouts;

– determine the requirements for the transmission of wind energy into the power supply network and the quality of electricity;

– research of transient control processes and energy compatibility of a wind turbine with full energy conversion with the power supply network.

Main Material of the Study. Wind turbine control includes both fast and slow control dynamics. In general, the power must be controlled by an aerodynamic system and must respond to a setpoint (given either by the control center or locally) in order to maximize energy production based on the available wind energy. The power controller should also be able to limit the power.

When operating a wind power plant with a dual-feed generator system, the wind turbine will usually change speed in proportion to the wind speed and maintain a fixed pitch angle. In very light winds, the turbine speed will be locked at the maximum allowable slip to avoid overstressing. The pitch controller limits power when the turbine reaches rated power. The generated electricity is produced by driving a doubly fed generator through a rotor-side converter. Controlling the inverter from the mains side simply maintains a fixed DC voltage. Both converters use internal current loops, which are usually linear PI controllers. Power converters on the network side and on the rotor side are voltage source converters [8, 9].

Very high technical requirements are imposed on generating units, such as frequency and voltage control, regulation of active and reactive power, quick response to transient and dynamic situations of the power system, for example, reduction of power from nominal to 20 % of power within 2 seconds.

Power electronics technology is an important part of the control system configuration. A wind farm equipped with power electronic converters can control both active and reactive power, as well as control variable-speed wind turbines to maximize useful energy and reduce mechanical stress and acoustic noise [10, 11]. A DFIG-based wind power plant connected to an AC network (type A wind turbine) is shown in Fig. 2.

In an HVDC transmission system, the low or medium AC voltage at the wind farm is converted to high DC voltage on the transmission side, and the DC power is transferred to the system where the DC voltage is converted to AC voltage. Such a topology can make it possible to change the speed of the wind turbines of the entire wind farm.

A DC drive system configuration is possible where each wind turbine has its own power electronic converter, allowing each wind turbine to be operated at an individual optimum speed.

Wind energy requirements cover a wide range of voltage levels from medium to very high voltage. Grid codes for wind energy address the issues that make wind farms behave like conventional power plants on the electricity grid. These requirements focus on controllability, power quality, fault remediability, and network support during failures [12, 13].

According to the requirements, the wind turbines must be able to drive the active point of the common connection in a given power range. The active power is usually regulated with respect to the system frequency so that the power supplied to the grid is reduced when the grid frequency exceeds 50 Hz.

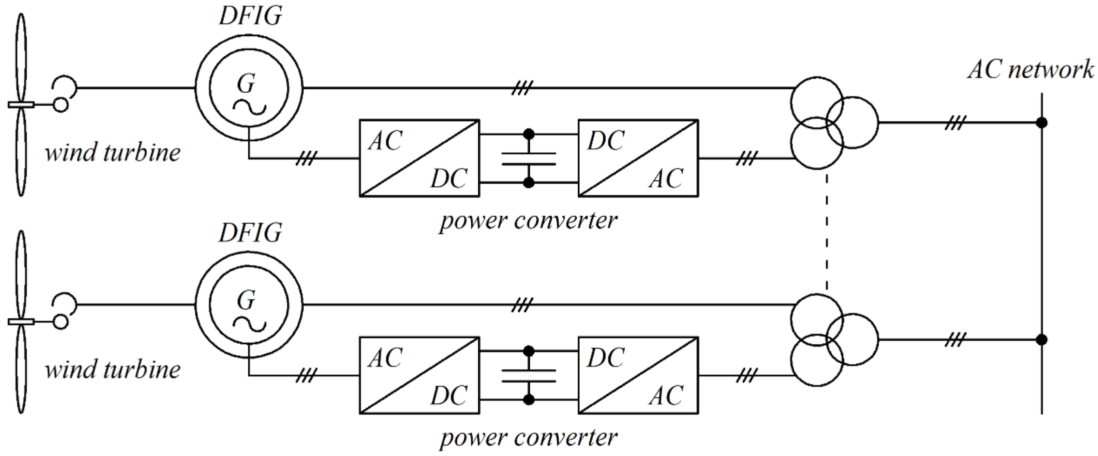

Figure 2 – A DFIG-based wind power plant connected to an AC network

Wind farms connected at the transmission level must act like conventional power plants, providing a wide range of output power control based on the requirements of the transmission system operator, as well as participating in primary and secondary control. Seven control functions are required to control a wind farm. Among such priority active power control functions implemented in the wind farm controller in accordance with the requirements of grid regulations should be the following: delta control, balance control, absolute performance and system protection [14, 15].

Power quality issues are resolved primarily for wind turbines connected to medium voltage networks. Two standards are mainly used to define power quality parameters, namely IEC 61000-x-x and EN 50160. Specific values are given for rapid voltage changes, short-term flicker strength, long-term flicker strength and total harmonic distortion.

Software Modeling of the Simulation Model

In order to evaluate the effectiveness of the application of wind turbines of a particular layout, it is necessary to conduct studies of transient control processes and energy compatibility with the network. In the Matlab / Simulink software environment, a simulation model of a wind turbine with a full energy conversion of 120 kW was developed (Fig. 3). According to the review, this wind turbine belongs to the medium power class and is most often used with an asynchronous generator.

The simulation model of the wind turbine consists of a turbine with a capacity of 130 kW, an asynchronous generator with a capacity of 110 kW, two inverters – excitation and mains, a control unit and a mains. Such an arrangement allows power to be supplied to the alternating current network at a non-constant frequency of rotation of the wind motor shaft, which provides an increase in the control range and use of the wind turbine at low wind speeds. The use of an asynchronous generator is associated with its low cost and high reliability, which are important parameters for small and medium power installations.

In the framework of the simulation model, the operation of the wind turbine consists in the transformation of the mechanical energy of the wind engine, implemented with the help of the "Wind Turbine" unit. It should be noted that this block does not take into account the moment of inertia of the wind engine, so it should be taken into account in the simulation model of the asynchronous generator. The excitation inverter of the asynchronous generator is implemented by the "Motor inverter" unit, is controlled using space-vector modulation and provides control of the asynchronous generator.

The connection to the alternating current network is provided by the "Grid inverter" block. The network inverter converts the energy of the direct current circuit into alternating current energy for transmission to the network with parameters regulated by the requirements for the quality of electrical networks.

The asynchronous generator control system is built according to the frequency-current principle, which is sufficient, since the generator rotation frequency sensor is used in the scheme. The switching frequency of semiconductor gates is set at 2 kHz.

In case of loss of connection to the network (line break or emergency shutdown), the circuit provides a braking resistor "Rt".

The result of simulation of the operation of the wind turbine when the speed changes from 4 m/s to 6 m/s is shown in Fig. 4.

The obtained result indicates the possibility of operation of an asynchronous generator with a short-circuited rotor as part of a wind turbine operating in conditions of variable wind speed. This can be used to develop a wind turbine control algorithm that will maximize the power output.

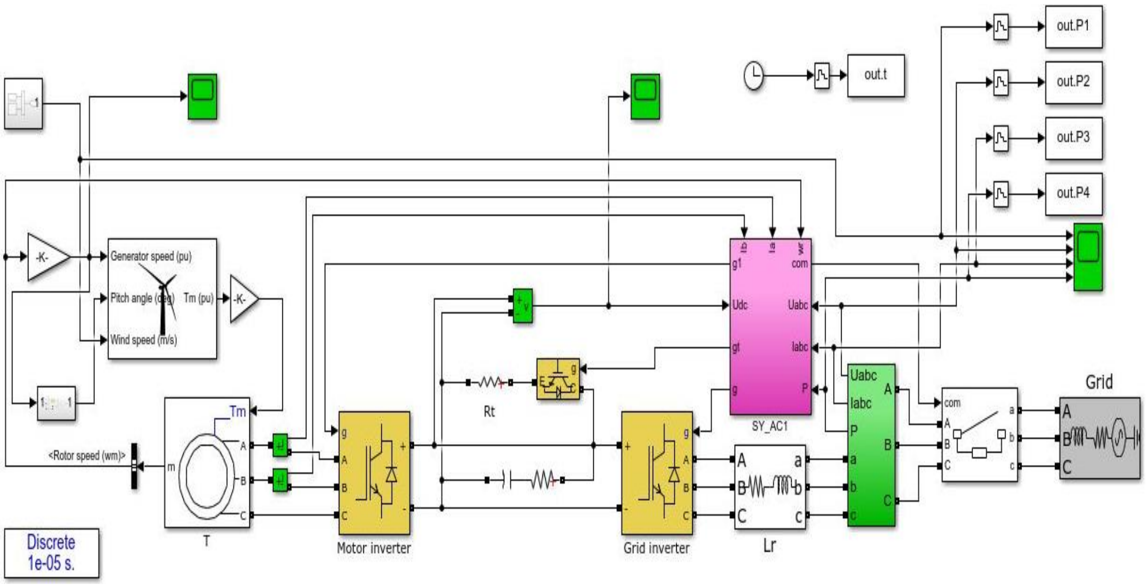

Figure 3 – Simulation model of a wind turbine with full energy conversion

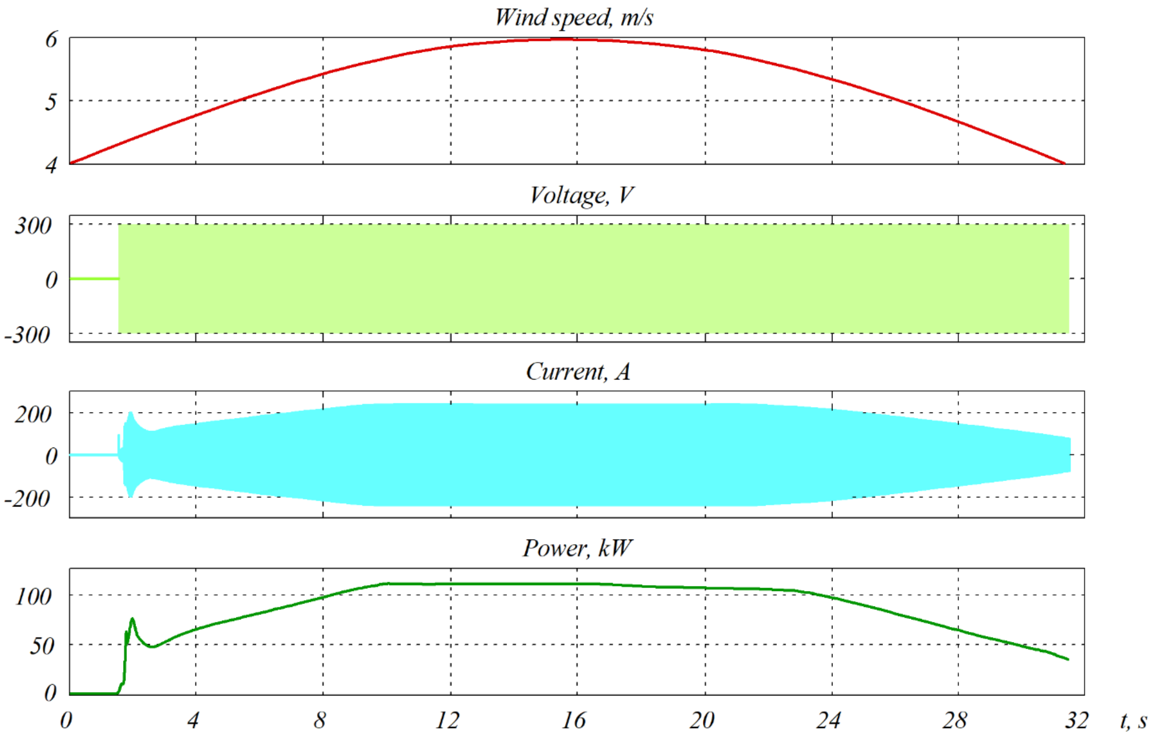

Figure 4 – Transitional process of wind turbine operation

Conclusions

On the basis of the conducted research, the following conclusions can be drawn:

– a comparison of the structures and technical characteristics of wind generators of well-known power stations was carried out. The most effective is the installation of a wind turbine with an asynchronous generator;

– wind power stations connected to level transmissions should operate like ordinary power stations, providing a wide range of output power control;

– the proposed layout of the wind turbine with full energy conversion allows to give power to the alternating current network at a non-constant frequency of rotation of the wind motor shaft, which ensures an increase in the control range and use of the wind turbine at low wind speeds.

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АНАЛІЗ СИСТЕМИ КЕРУВАННЯ ВІТРОВОЮ УСТАНОВКОЮ, ПІДКЛЮЧЕНОЇ ДО МЕРЕЖІ ЗМІННОГО СТРУМУ

Представлено динаміку розвитку альтернативних джерел живлення за останні декілька десятиліть, що дає підстави говорити про тенденції подальшого розвитку вітрової енергетики. Приведено аналіз структур та технічних характеристик вітрових генераторів, а саме типи електричних двигунів, силові схеми напівпровідникових перетворювачів, що забезпечують генерацію електричної енергії до загальнопромислової електричної мережі. Розглянуто питання можливості роботи вітрових генераторів в широких діапазонах вітру, питання емісії реактивної потужності та вищих гармонік струмів до загальнопромислової електричної мережі, а також питання ККД різних структур вітрогенераторів. Запропоновано систему керування вітровою турбіною з асинхронним генератором. Наведено дослідження перехідних процесів керування та енергетичної сумісності вітроустановки повного перетворення енергії з мережею живлення шляхом імітаційного комп'ютерного моделювання в програмному середовищі Matlab / Simulink. Отриманий результат вказує на можливість роботи асинхронного генератора з короткозамкненим ротором у складі вітроустановки, що дає змогу віддавати потужність до мережі змінного струму при низьких швидкостях вітру.

Ключові слова: *альтернативні джерела енергії, асинхронний генератор, вітрова турбіна, вітроенергетика, електростанція, система керування.*

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