CONNECTION OF WIND FARMS TO THE POWER GRID

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Professional article

Summary: *In order to maintain the established way of life, which implies extensive consumption of the planet's energy resources, the human species threatens the flora and fauna of planet Earth. "Green transition" of the electric power system is based on solving the problem of environmental destruction during the construction and exploitation of power plants that use fossil fuels for power. The goal of writing this paper is to raise awareness of the importance of the environment, as well as to find optimal ways of using renewable sources of energy resources, which could be transformed for the needs of citizens. Through the work, more information related to wind farms was presented; from the theoretical approach, through the budget, to the method and process of connecting it to the power grid.*

Key words: *windturbins, wind energy, power grid*

1. INTRODUCTION

Considering the constant increase in the number of inhabitants on planet Earth, the demand for electricity is also increasing. It has long been known that energy can neither be created nor disappear, but can be transformed from one form to another. Due to its multifunctionality, the most used form of energy is, precisely, electrical energy, where it is not used as "raw" energy, but exclusively in transformed forms. In order to produce it, it is necessary to have a renewable or non-renewable source of energy. In order to reduce CO2, more and more attention is being paid to the decarbonization of the power system, whereby the use of renewable energy sources is advocated in order to avoid the complete depletion of reserves of non-renewable energy sources, as well as over-pollution of the environment.

From an economic point of view, renewable energy sources are free, which would reduce the costs of energy purchase. However, on the other hand, these types of energy sources are extremely unreliable, and it is evident that none of them will occur daily and constantly, so they are used as a supplement to registered hydroelectric and thermal power plants.

2. WIND POWER PLANTS

A wind turbine (wind generator) is a rotary machine that transforms the kinetic energy of the wind into mechanical energy, and then into electrical energy, until it reaches the level of practical use. Converted mechanical energy found its application in the water pumping system that supplies rural and remote places. The basic characteristic of wind turbines is their dependence on energy and the occurrence of wind. In order for it to be properly designed, it is necessary to ensure the uninterrupted supply of electricity to consumers from supplementary sources during periods of absence of wind, by forming reserves within the accumulator or managing the system in such a way that, through automation, consumers are redirected to power supply from the power plant. network supplied by a hydropower plant or thermal power plant. Turbine subsystems include:

- Rotor with wings - converts wind energy into rotational energy of the shaft
- Gandola-implies the shaft transmission, which includes the reducer and the generator
- Tower-supports the rotor and gandola
- Electrical equipment - controllers, electrical cables, and connection equipment

The design of wind turbines can be carried out in two ways, with a horizontal axis and a vertical axis. With the help of elements for self-rotation of the turbine axis, wind turbines with a horizontal axis have the ability to follow the direction of the wind. In order for this type of wind turbine to function correctly, it is necessary that its blades face normally to the direction of the wind. Materials for making propeller-type rotor blades are selected based on certain factors, the most important of which is mechanical durability under all wind pressures and environmental conditions. Unlike wind turbines with a horizontal axis, those with a vertical axis are much more common due to their simpler construction and the possibility of working at higher wind speeds.

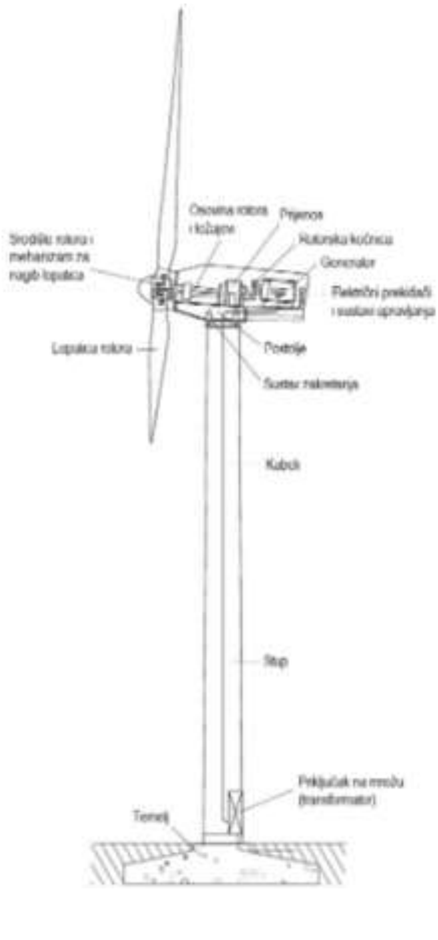

Figure 1. The basic parts of a wind turbine, source: Mađar, E., (2015), „Performance of wind turbines with a vertical axis of rotation", University of Rijeka,

Faculty of Engineering, http://old.riteh.hr/nast/obrane/strucni_el/Radovi_072015/0069056983108_Madjar%20_Edi.pdf

2.1 Wind turbine positioning

When positioning wind turbines in places between buildings or mountain passes, i.e. in narrow spaces, where the wind flows faster due to air dilution, the tunnel effect occurs. In order to use it adequately, the tunnel should be placed "softly" in the space, because strong turbulence would occur as a result of encountering sharp edges.

When dealing with wind power plants, it is known that they are usually positioned on top of a hill or some elevation. The reason for this is the rarefaction of the wind on the windy side of the hill, where the wind speed is much higher in those areas compared to the surrounding area. At the moment when the wind reaches the top of the hill, it begins to expand again, and descends again into the area of low pressure.

Ukoliko se javi potreba za pozicioniranjem vjetroturbina na teritorijama koje se nalaze u blizini morske obale, prilikom proračuna, neophodno je uzeti u obzir nailazak vjetra na otoke, svjetionike ili druga tijela koja mogu predstavljati otpor. Površina vode je izuzetno glatka, te sa povećanjem brzine vjetra (čiji je smjer uvijek prema obali), većinski dio energije vjetra otpada na stvaranje talasa na površini mora što uzrokuje povećanje hrapavosti površine.

2.2 Wind farm calculations

Bernoulli's equation reads:

$$\frac{v_1^2}{2g}+\frac{p_1}{\rho g}+z_1=\frac{v_2^2}{2g}+\frac{p_2}{\rho g}+z_2$$

(1)

at which they are:

$z-$ geodetic height (height of the center of gravity of the cross-section in relation to a horizontal plane)

$\frac{p}{\rho g}$ – piezometric pressure or pressure head

$\frac{v^2}{2g}-$ the speed that the body would have in free fall

The part in the expression $\frac{p}{\rho g}+z$ represents potential energy, while $\frac{v^2}{2g}$ it represents mechanical energy. Due to the small air mass, the potential energy is negligible, so it follows that the wind has only mechanical energy. Expression (1) takes the following form:

$$E_k=\frac{mv^2}{2}$$

(2)

If are A cross section, v velocity i ρ density, air mass is:

$$m=A\cdot v\cdot \rho$$

(3)

By inserting expression (3) into expression (2), the power of the windmill is obtained as the kinetic energy of the air mass per unit time per unit area through A which it flows: $P_v=\frac{\rho\cdot v^3\cdot A}{2}$

(4)

At the turbine shaft, the mechanical power would be:

$$P_T=C_p\cdot\frac{\rho\cdot v^3\cdot A}{2}=C_p\cdot\frac{\rho\cdot v^3}{2}\cdot d^2\cdot\frac{\pi}{4}$$

(5)

where are they:

$A-$ turbine rotor surface

C_p- mechanical degree of utilization of the turbine (represents the ratio of useful power and wind flow power)

The resulting force of all the elementary forces acting on the wind turbine is called the aerodynamic force and, as such, can be represented by the relation:

$$F=\frac{1}{2}\cdot\rho\cdot v^2\cdot C_r\cdot S=C_r\cdot q\cdot S$$

(6)

where the marks are:

$q-$ dynamic pressure

$S-$ wing surface

C_r- coefficient of the resulting aerodynamic force (depends on the shape of the wing and its position in relation to the direction of movement speed

The wind load on the structure is determined as:

$$w = f_d \cdot c_f \cdot w_0 \cdot A$$

(7)

where are they:

$f_d -$ dynamic factor

$w_0 -$ basic wind load

$c_f -$ corrected shape coefficient $\left(c_f = \psi \cdot c_{f0}\right)$

$c_{f0} -$ basic shape coefficient

$\psi -$ reduction factor

The relationship between the speed of rotation of the tip of the blade and the speed of the wind is called the speed factor and is determined by the formula:

$$\lambda = \frac{r\omega}{v}$$

(8)

where are they:

$r -$ the radius of the circle formed by the tip of the blade when rotating

$\omega -$ blade tip rotation speed

Predefined wind speed values:

- Wind turbine start-up speed: $v_{uklj} = 2.5 - 4.5\left[\frac{m}{s}\right]$
- Value of the wind speed for which the wind turbine is designed: $v_{vt} = 6 - 10\left[\frac{m}{s}\right]$
- Nominal wind speed: $v_n = 10 - 16\left[\frac{m}{s}\right]$
- Wind turbine shutdown speed: $v_{isklj} = 20 - 30\left[\frac{m}{s}\right]$

2.3 Unpredictability (variability) of wind energy

Wind energy represents an inexhaustible and large source of energy, but its supply is largely unpredictable and intermittent, from which it can be concluded that the investor of this project is never sure how much energy his power plant will produce. This is one of the possible reasons why investors are in doubt about allocating funds for the investment in its construction. Unlike wind power plants, photovoltaic power plants have a much higher degree of reliability in planning the produced electricity, which is also very important when balancing the operation of the power system. For the integration and use of wind power plants in the power system, it is extremely important to understand phenomena, as well as their prediction. According to the duration, variations in production can be short-term and long-term. The duration of short-term variations is from a few seconds to several hours, whereby the second variations are completely negligible.

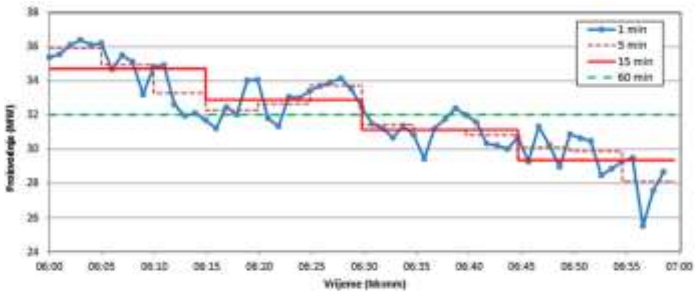

Figure 2. Variations of electricity production from wind farms with different time periods, source: Vodopija, S., (2017), „Forecasting production from RES and management of distributed systems for storing electricity in the power grid under market conditions", qualification exam, University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Shipbuilding, „https://data.fesb.unist.hr/public/news/Kvalifikacijski_ispit_Stipe_Vodopija-6fa4216fa7.pdf

2.4 Connecting the wind farm to the power grid

According to the method of management and regulation, wind turbines can be: with a fixed speed of rotation, with a limited variable speed of rotation, with a double-sided powered asynchronous generator, and fully controllable wind turbines. Unlike the first mentioned type, wind turbines with variable rotation speed depend, in addition to the load, on the wind speed. In order to obtain a fixed frequency at the point of connection to the network, it is necessary to achieve separation of the output voltage (which has the frequency of the network) from the produced voltage of variable frequency. In the case of wind farms, which contain a bilaterally fed synchronous generator, a change in speed is achieved by regulating the excitation, and it is not necessary for the converter to be designed for the total power that is delivered to the grid.

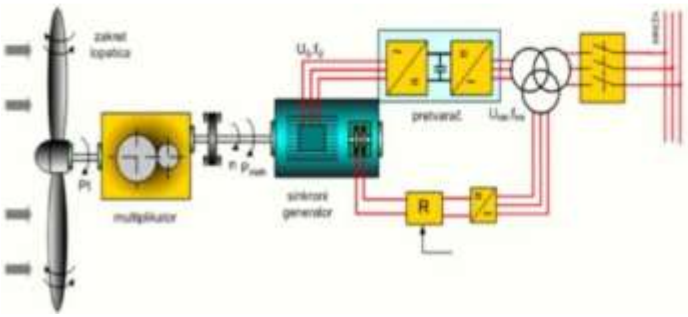

Figure 3. Wind turbine with synchronous generator, source: Rajković, D., (2011), „Proizvodnja i pretvorba energije", skripta iz kolegija, Rudarsko-geološko-naftni fakultet, Sveučilište u Zagrebu

In such plants, a frequency converter (back to back-AC/DC/AC) composed of two three-phase frequency and voltage converters and a DC intermediate circuit is most often used. On the generator side, a three-phase converter is called a generator converter, while on the grid side, it is called a grid converter. The basic task of the generator converter is to convert the produced alternating energy into direct current, and to regulate the produced amount of working (total) energy. On the other hand, the mains converter has the task of converting the voltage of the DC intermediate circuit into a three-phase alternating voltage, whereby, in addition to working energy, a certain amount of reactive (reactive) energy is delivered to the network. The role of the DC link is to separate the two converters and enable each converter to be controlled separately, while keeping the DC link voltage approximately constant.

Controlling the mains converter (inverter) means manipulation of the modulation index of the reference sine signal for the PWM pulse generator. The mentioned process is carried out by applying the power distribution technique, which means defining the voltage of the DC intermediate circuit that contains the maximum power for certain characteristics of the DC voltage. The grid controller is also responsible for delivering the quality of electricity that is delivered to the grid.

A higher level of management also includes stator frequency control, given that its change is made in parallel with the change in the DC intermediate circuit voltage. Making a comparison with photovoltaic systems, this type of regulation can be compared with MPPT (Maximum Power Point Tracking), that is, an inverter used in photovoltaic panels where the input to the inverter is adjusted to the optimal operating point.

Anemometer is a device used to measure wind speed. It is made of three hemispheres that have the function of "catching" the wind. The achieved number of revolutions per minute is electronically registered on the vertical axis of the instrument itself. It is most often positioned together with an anemometer that shows the direction of wind movement. By measuring the speed of the wind movement, the MPPT controller of the wind farm provides a reference whose value is compared with the current production and, based on the obtained data, determines the new working point of the DC voltage and performs the correction of the PWM signal.

On the generator side of the converter, with the aim of achieving maximum rotor power, the optimal rotor speed is determined for each wind speed, voltage and current measurements are made in the DC intermediate circuit, generator power calculations are made, and, in relation to the current reference (its increase or decrease), also changes the operating point (MPPT). Depending on the supplier's requirements, the network converter manages the line current in such a way that it maintains a sinusoidal shape and ensures the required power factor.

2.4.1 Conditions for connecting the wind farm to the power grid

The main goal of the development of the electric power network is to satisfy the requirements of the electric power system in terms of satisfying the quality of the delivered electricity to the end customers (consumers), whereby quality means supplying customers with a voltage under certain limits. In order for the electric power network to function properly, it is necessary to take into account the load on the elements of the network itself in order to prevent excessive heating, which has a significant impact on the improvement of the aging process and the occurrence of frequent failures.

The first item that needs to be paid attention to is, precisely, the aforementioned thermal heating of individual elements of the power grid. During the production of all elements, manufacturers define the nominal values of current and power, as well as maximum load values, which means temperature, humidity, wind and the like. Analyzing the operation of the electric power network, the main criterion that is observed is whether all elements are under the permitted load value, with the exception that the maximum power in the normal operating mode may be slightly above or below the specified value.

Problems in the high and medium voltage power grid also occur in terms of voltage limits, the values of which are quite low and apply to the entire network. One of the aforementioned solutions is the definition of voltage limits of high and medium voltage junctions, whereby it is guaranteed that, under all conditions of taking energy from the transmission network, end customers will be supplied with energy that will meet the defined voltage limits.

After the mentioned technical conditions and limitations in terms of the entire electric power network, it is concluded that the main goal of all of the above is the preservation of the most important features of the system, namely power supply security, reliability and quality of delivered electricity. In this sense, in order to connect a wind farm to the power grid, it is necessary to meet certain criteria, some of which are:

- Requirements depending on the frequency:
  - Determining the frequency range of the system
  - Knowledge of the maximum permitted power that the wind power plant is allowed to deliver to the grid, and management of production power
  - Monitoring the change in load speed
- Voltage requirements:
  - Voltage range, as well as its changes
  - Provision of automatic voltage regulation
  - Application of reactive power compensation
  - Enabling the start and stop of the wind turbine
  - Ensuring operating reserves
- Requirements from the aspect of failure:
  - Maintaining stability
  - Stability of angle and voltage
  - Application of the wind power protection system
  - Modeling of wind farms
- Requirements in terms of the quality of delivered electricity:
  - Determining the short circuit level
  - Monitoring of switching operations
  - Flicker emission (voltage drops that cause light bulbs to flicker)
  - Voltage fluctuation
  - Harmonic tracking
  - Occurrence of interference with telecommunication lines and equipment for remote control

Testing the connection of the wind farm to the grid consists of a series of steps, namely:

- Satisfying all previously mentioned conditions
- Testing:
  - Commissioning of the wind power plant
  - Stopping the operation of the wind power plant under conditions of high wind speed
  - Monitoring of changes in system frequency and voltage
  - Checking the quality of the received energy

3. CONCLUSION

Bearing in mind the fact that man could use energy, which is all around us, the development of the most adequate way of obtaining and transmitting electrical energy is still ongoing. Electricity has become the foundation of civilization and represents a secondary form of energy suitable for transmission and re-conversion into other forms of energy. As I already mentioned in the introductory part of the paper, special attention is paid to the decarbonization of the power system in general, and the application of unconventional energy sources is increasingly resorted to.

With constant development, the modern world is turning more and more towards the use of other forms of energy, among which wind energy is considered as the cheapest source for the production of electricity. With the constant improvement of the production of wind turbines, their potential also grew, whereby the data of the annual growth of wind energy, as a branch of energy, in the amount of about 35% is recorded. Thanks to the extremely high degree of safety and readiness for work (up to 97%), it stands out from other types of power plants that use renewable energy sources. Taking into account the fact that the wind is an extremely unpredictable source, the possibility of applying additional sources is left, i.e. the possibility of combined operation with photovoltaic and gas power plants.

The price of electricity, obtained from the conversion of wind energy, is already today comparable to the price of electricity obtained from fossil fuels, and it is believed that this trend will increase even more due to the high prices of monitoring and other external costs.

In order to create the most perfect plant, it is necessary to solve the problem of overall dimensions and noise reduction in normal operating modes. Autonomy between produced and consumed electrical energy, and flexibility in the operation of the electrical power network, is based on the formation of reserves, more precisely on the storage of electrical energy. Storage is done when production exceeds consumption, and reserves when consumption exceeds production. By comparing photovoltaic plants with wind power plants, we come to the conclusion that this system of functioning in the use of wind potential is still not resolved, which calls for finding an adequate solution to this problem.

As for the territory of Bosnia and Herzegovina, three wind farms have been built so far, two of which are located in the area of Tomislavgrad ("Mesihovina" and "Jelovača"), and one in the area of Mostar ("Podveležje"). In the near future, the construction of another wind farm named "Ivovik" is planned in the area of Tomislavgrad and Livno (in the southwest of Bosnia and Herzegovina), which was publicly announced as the first wind farm in the territory of the mentioned country to be invested by China.

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