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MODELING OF THE FREQUENCY CHANGE OF THE ELECTRIC ENERGY SYSTEMS WITH WIND ELECTRIC INSTALLATIONS OF THE VARIABLE ROTATION SPEED AND DOUBLY FED ASYNCHRONOUS GENERATORS

The impact of the wind electric installations of variable rotation speed with doubly fed asynchronous generators on frequency regulation in electric systems (EES) is considered. Model of the research is developed in the programming complex Power Factory DIg SILENT GmbH, the results of frequency change modeling on the change of various portion of loading are given. This generalized model is recommended to use for the determination of the frequency change in EES with wind electric installations of the variable rotation speed and doubly fed asynchronous generators.

Key words: *doubly fed asynchronous generator, renewable sources of energy , wind power plant , wind power installation of the variable rotation speed, electric energy system, electric grid, short-circuiting , power electronics, synchronous generator , frequency.*

Introduction

The growth of the electric energy generation by means of the renewable sources of energy (RSE), namely, wind energy, stipulates the necessity of studying the impact of wind energy installations on the electric energy systems (EES). In modern wind energy installations various types of generators are used. Nowadays, for the operation within the EES wind power plants with variable rotation speed| and doubly fed asynchronous generators of 2 MW and higher are widely used. One of the advantages of this type of generators is the possibility to control active and reactive power. One of the drawbacks of this installation, in particular with doubly fed asynchronous generator, is the impossibility to regulate the EES frequency [2, 3, 5].

Frequency is an important parameter of each EES. Any changes in the load balance of EES lead to the frequency change, in its turn, this results in the additional generation losses or the consumption deficiency and increases the risk of the power system outage. Frequency of the EES is directly connected with the rotation speed of the «conventional» synchronous generators (SG), which are the basic components of the powerful EES. Nowadays wind power plants with variable operation speed do not participate in the process of frequency regulation. This is connected with the design features of this type of WPP, as they use power electronics (PE) for partial power transformation, i. e., they do not increase or decrease their power during frequency deviation from the nominal value. As frequency maintaining in EES is necessary to provide their reliability and stability, this problem will lead to the limitation of the share of wind power plants (WPP) in the available EES. That is why, there appears the necessity to determine the admissible share of WPP with variable rotation speed| in EES without great impact on the frequency or their involvement in the frequency regulation, similarly to the synchronous generators (SG) [2, 3, 5].

Aim of the research – study the impact of WPP with variable rotation speed and doubly fed asynchronous generators on the frequency and develop the generalized model of EES with WPP with variable rotation speed and doubly fed asynchronous generators in the programming complex Power Factory DIg SILENT GmbH [4] for the determination of EES frequency change at various shares of load change.

Results of the research

Wind power plants (WPP) with variable rotation speed and doubly fed asynchronous generators have been widely used during recent three decades. They are constructed to obtain maximum aerodynamic effect in the wide range of the wind speeds [5]. In case of variable wind speed it is possible to adapt the rotation speed of WPP (increasing or decreasing) to the wind speed. Thus, the ratio of the angular velocity remains constant to the determined value and corresponds to the maximum power output factor. WPP with variable rotation speed maintain the torque almost constant – changes of the wind speed absorb the changes of generator speed.

Nowadays, the amount of WPP with variable rotation speed and doubly fed asynchronous generators of 2 MW and more, operating in EES increased from 5 % of the installed capacity of all WPP in 2004 up to 60 % in 2015 [6]. This type of WPP is developed by various manufactures, such as GE, Vestas, Gamesa, Repower, Nordex, Ecotecnia.

Windings of doubly fed asynchronous generator stator are directly connected to the electric grid (EG), and the rotor – across the power electronics (PE), more often with the intermediate section of the direct current (Fig. 1). This system is universal, with the minimal cost of the equipment and high efficiency factor, as only the part of the generator power is transformed (as a rule, approximately 25 – 30%), i. e., the generator operates in a rather wide slip range – up to ± 30% [5].

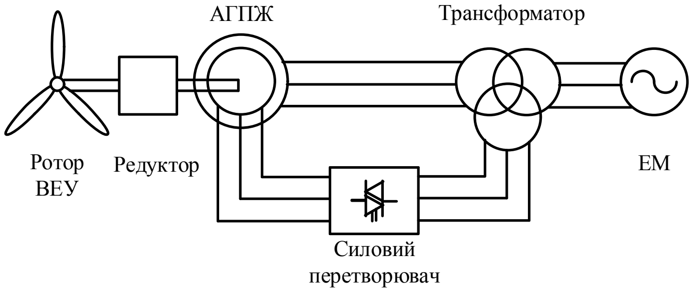

Fig. 1. WPP with variable rotation speed and doubly fed asynchronous generator

Maximum possible generation or consumption of the reactive power of WPP is limited by the maximum allowable value of PE current and the level of the generated electric power (depending on the wind mode). As a rule, regulation of the reactive power can be performed during several milliseconds [5].

Main advantages of WPP with doubly fed asynchronous generator:

– ability to control the voltage and power factor;

– requires PE of small nominal power that reduces its cost;

– control systems are constantly improved;

– energy of the rotor is not dissipated but is supplied into the electric grid by means of power electronics;

– PE on the side of the electric grid can perform compensation of the reactive power and smooth start.

Main drawbacks of WPP are:

– the necessity to use the gear as the rotation speed of doubly fed asynchronous generator is higher (750 – 1500 rpm, depending of the number of the pairs of poles) than the rotation speed of the wind wheel (10 – 25 rpm) that leads to the increase of the maintenance cost and growth of the acoustic noise;

– presence of moving electrical contacts (contact rings) considerably complicates the construction and decreases the reliability of WPP. In non-standard environmental conditions the brush contact loses its operation abilities, creates additional electrical and mechanical losses, complicates the maintenance of the doubly fed asynchronous generator, polluting the internal cavities with the graphite dust, that reduces the electric strength of the insulation, especially in case of the closed cooling system, when the volume of the air is limited;

– sliding rings are used to transfer the rotor power by means of power electronics (PE), which requires regular maintenance;

– to provide trouble-free operation of WPP in case of serious accident in EES the protection system must be used;

– during the short-circuits large currents of the stator lead to the large currents of the rotor, that is why, it is necessary to protect PE against damages;

– according to the grid code they must withstand short-circuit currents .

EES frequency regulation. It is a well known fact that the «traditional» generators react on frequency changes, releasing or absorbing the kinetic energy of their rotating masses. But in contrast with them, WPP with with variable rotation speed doubly and doubly fed asynchronous generator do not participate in frequency regulation, this is connected with the design features of this type of WPP, as they use PE for partial power conversion. Fig. 2 shows the reserves activation, depending on the time for the situation, when powerful power station is disconnected from EES [5].

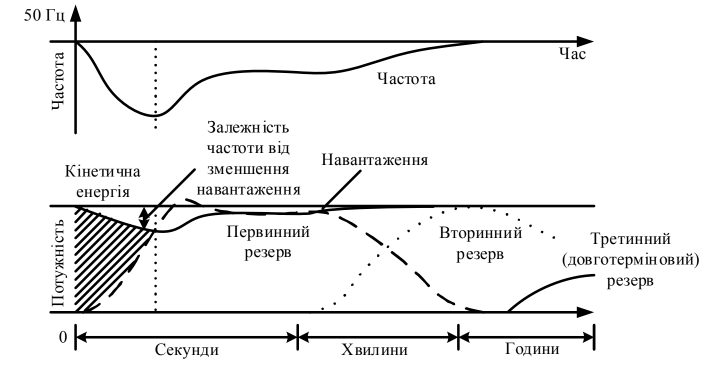

Fig. 2. Frequency and activation of the power reserve in case of the disconnection of the powerful electric plant

Inertia of EES is proportional to the amount of the rotating masses in it [5]. It determines the rate of frequency change after the load change. The greater inertia of EES, the less frequency change rate after the power imbalance is. Every time when there is a discrepancy between the demand and supply in EES, the rotors of the connected generators and motors release or absorb the kinetic energy – and, as a result, rotation speed and frequency change. It is called «reaction» of the inertia.

«Reaction» of the inertia will be available immediately after the load change and its action lasts 3 – 5 sec. Any control facility will not be activated during this time.

At the next stage after the load change when frequency change exceeds the set value, speed regulator will adjust the primary motor of the turbine and in such a way will delay the additional speed change. Initial action of the regulator, known as the primary (basic) control, establishes the balance of the active power between the generation and the consumption by means of the proportional control action, also known as the drop regulation and prevents the frequency drop [5].

Primary reserve is switched on automatically during 30 sec. after the disconnection. Secondary reserve is activated 5 – 10 min after the frequency drop. It replaces the primary reserve and operates until the tertiary reserve is activated. In normal operation mode the output active power of WPP may vary within 15 % of the installed capacity in the range of 15 min. Thus, generated power of WPP can be involved in the primary and secondary controls. WPP must generate more power to provide the secondary control of the frequency, if it is lower than the nominal value. If the frequency in EES increases, certain WPP can be disconnected.

The Rules of technical operation of EES require the participation of WPP in the primary and secondary regulation of the frequency but according to the rules WPP must not regulate frequency by means of inertia "reaction". According to the requirements to frequency control in different countries the frequency must be close to its nominal value. In European countries, as a rule, the frequency must be maintained between 50 ± 0.1 Hz and seldom varies between 49 and 50.3 Hz [5]. According to the Ukrainian requirements [1], in case of frequency deviation WPP of 25 MW must be able to provide frequency regulation in the grid (50 Hz). Accuracy of frequency measurement must be not less than ±10 mHz. The possibility of the adjustment of frequency regulation system in the range of 47 Hz – 52 Hz with the accuracy of 20 mHz must be provided.

Investigation model (Fig. 3) is developed in the programming complex Power Factory DIg SILENT GmbH [4]. Fig. 3 shows: EES – electric energy system; DFAG – group of doubly fed asynchronous generators of 2 MW each; T1, T2 and T3 – power transformers; U 110 kV, U 20 kV, U 0.69 kV and U_{load} – voltage on the buses of 110, 20, 0,69 kV and 0,4 kV , correspondingly. For simulation the models of the controllers Power Factory DIg SILENT GmbH were used [4]. 60 WPP with variable rotation speed and doubly fed asynchronous generators are installed, they generate maximum power of 120 MW. The set share of the static and dynamic components of EES – 100 and

0 % ,correspondingly.

For the evidence of the modeling results the disconnection of various parts of loading from 12 MW – 10 % to 60 MW – 50 % (share of loading is taken from the share of WPP, i. e. from 120 MW) during 1 sec is considered, peak value of the frequency at the buses U 110 kV, U 20 kV, U 0.69 kV and U_{load} **is measured** . In the investigation model (as one of the variants, possible in the programming complex Power Factory DIg SILENT GmbH) EES is set by the short circuit power, in this case – 6000 MW·A and short circuit current – 31.5 кA, and EES is considered to be the reference point and its inertia is not set.

The results of modeling are shown in Table 1 and Fig. 4.

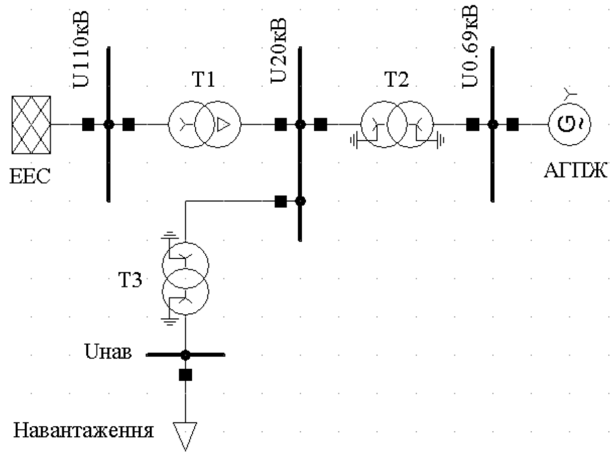

Fig. 3. EES with WPP with variable rotation speed and doubly fed asynchronous generator

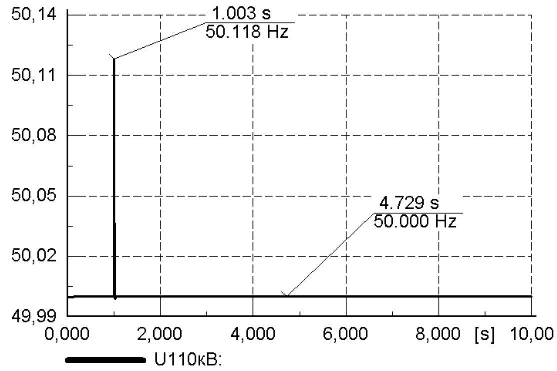

Fig. 4. Frequency change at the buses of 110 kV in case of 50 % load change

Table 1

Frequency change depending on the change of the disconnected load share

Frequency	Load change				
	10 %	20 %	30 %	40 %	50 %
f, Hz	50,024	50,047	50,071	50,095	50,118

The results of modeling show different change of frequency in case of the change of different share of loading.

Conclusions

The result of modeling show the change of frequency when the load share changes. Frequency deviation occurs, it exceeds 50.1 Hz when 50 % of load is disconnected , as it is seen in Fig. 4, after that the frequency returns to its normal value. This shows that such simplified model of EES with WPP of variable rotation speed and doubly fed asynchronous generator can be used for the determination of EES frequency change if load share changes.

Increase of WPP with variable rotation speed and doubly fed asynchronous generator usage requires the assessment of their impact on EES frequency not only during generation change but also during consumption change, as at the moment of WPP maximum power generation there is not always a need in the consumption.

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