INFLUENCES OF WIND POWER PLANTS ON POWER SYSTEM

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ABSTRACT

This paper deals with influences of the wind power plants connection on the operation of distribution and transmission systems. There are briefly explained and described the most severe and significant of these unfavourable impacts in term of local and system.

1. INTRODUCTION

The generation of electrical energy from wind is, from the perspective of the direct dependence of the instantaneous power on actual climatic conditions and from that resulting impossibility of any supply power adaptation to system needs, or more precisely to consumer requirements, generally regarded as the most problematic of all renewable energy sources. This reality is also confirmed by very low value of the utilization time of the installed capacity, which moves around only 2,000 hours per year in the case of a wind power plants operation in some suitable locality, which is one of the smallest values of all renewable energy sources, next to photovoltaic power plants.

For an analysis of wind power plants influences on the operation of power systems it is possible to divide this question into two fields, namely into local and system influences. Impacts, that negatively affect distribution systems and that are especially connected with connection and operation conditions and with the ensuring of the necessary quality of an electricity supply, can be marked as the local. On the other hand, influences, that negatively affect the operation of transmission systems and that include mainly impacts on the stability or control of some power system and the ensuring of the sufficient reliability of an electricity supply, can be marked as the system.

2. LOCAL IMPACTS

Among unfavourable influences in terms of distribution parts of power systems are ranked especially a voltage fluctuation, which is influenced by a compensation of wind power plants, a grids overloading, that originate owing to a fluctuation of generation in these sources, and also increases in short-circuit conditions as a result of their implementation. Because of regulation, based on power electronics, wind power plants are often also sources of some disturbance in the electrical grid, which is connected with a rise of high harmonics, with a rise of the flicker, or with an attenuation of the centralized telecontrol signal. A calculation evaluation procedure of these backward influences is determined in literature, for example in the [2], which is the company technical standard.

2.1. Grids overloading

The basic condition for the connection of any source of electricity to the power system is a sufficient sizing of this grid from a connection point up to a consumption place, eventually to a transformation point, which is instrumental to a distant transmission. Therefore, to prevent an overloading of the grid by increased electricity supply, each wind power plant must be connected to right selected connection point and its power capacity must be installed in a part of the grid with some appropriate structure and arrangement. In the case of a connection of a wind power plant to some insufficiently sized grid, it is necessary to make its strengthen, as a protection from damage of individual operating facilities owing to undesirable influences, such as rise of overheating or not allowed voltage changes.

2.2. Short-circuit conditions

At the connecting of new sources to some power system it is also necessary to take into account their contributions to a short-circuit current, that are cause for increases of the value of a short-circuit power in a connection point, and also a possibility of changes in the power flow direction in the grid. Mainly, a change in short-circuit conditions can results in excess of short-circuit capabilities of distribution system facilities and in their damage. At the same time, it is also necessary to consider the connection from the perspective of short-circuit capability of devices of source alone, to prevention of its damage by a short-circuit current of the grid, to which it is connected.

The size of the three-phase short-circuit power, or more precisely current, of the grid is also quite fundamental for an assessment of backward influences of sources on the system. At the determination of them, it is necessary to go from such normal operational conditions, at which these values are the lowest. Transient extra configurations of the grid, subject to operation, aren’t taken into account. A grid impedance in the connection point V is then determined as the sum of a supergrid impedance and of impedances of transformers and lines. The influence of connected devices and facilities, such as lines leakage resistances and capacities, can be usually neglected.

For a facilities sizing for effects of short-circuit currents, the supergrid is usually characterised by the maximal short-circuit current I_k'' or power S_k''. The relation among these values and the impedance of the grid Z_k'' in the point Q, for the calculation of electrically remote short-circuit in distribution systems by the international technical standard [3] is:

$$Z''_{kQ} = \frac{c_u \cdot U_n^2}{S''_{kQ}} = \frac{c_u \cdot U_{nQ}}{\sqrt{3} \cdot I''_{kQ}}, \qquad (1)$$

where S_{kQ}'' is an apparent initial impulse symmetrical short-circuit power, c_u is an voltage coefficient of some equivalent voltage source, U_n is an effective value of the nominal phase-to-phase grid voltage, Z_{kQ}'' is an equivalent impedance of the grid in the point Q and I_{kQ}'' is the value of an initial impulse symmetrical short-circuit current.

For an attenuation of backward influences on the grid, the minimal value of these currents or powers and the corresponding maximal grid impedance are determinant, during the normal operational status of the system and during symmetrical non-resistance short-circuits. For the determination of minimal currents at the assessment of backward influences, it is recommended to use the effective impedance of the system Z_{kQ} and go from modified values S_{kQ} by the equation:

$$S_{kQ} = \frac{U_{nQ}^2}{Z_{kQ}} = \frac{U_{nQ}^2}{c \cdot Z''_{kQ}} \qquad (2)$$

If the point Q, with known short-circuit parameters, is also the point of common coupling V, then the short-circuit power S_{kV} is equal to the short-circuit power S_{kQ}. In other cases the S_{kV} can be calculated from the active component R_{kV} and the inductive component X_{kV} of the grid impedance in the point of common coupling. These components result from the sum of the impedance in the point Q and the total impedance of transformers and lines between points V and Q.

2.3. Voltage changes

One of the most important influences, induced by the wind power plants connection and operation, are voltage changes. Beside a stable increase in voltage, which is caused by an increase in electricity supply owing to the source connection to the grid, it can be also a short-time changes caused by manipulations, that rise owing to the switching of individual plants, or commutation drops, that have origin in the structure and principle of all electronic elements used for the grid connection. A mutual relationship between the short-time voltage change and the stable voltage increase ΔV_{An} is shown in Figure 1, which illustrates the time course of voltage changes that result from the connection of some asynchronous generator to the grid.

The stable voltage increase can be exactly calculated by using some computer analysis of load flows, where it is possible to take into account a variable supply of a reactive power or where it is possible to monitor voltage levels in more nodes, during a simultaneous respecting of compensation capacitors. It is applied especially at the supply to more connection points and in the case of more complicated grid configurations, such as loop and meshed systems. In very simple cases, such as the supply to one connection point, it is possible to make also a manual calculation, which then serves as rough estimation. The stable voltage increase ΔU_{An} in any grid point is then determined as a difference between a supply voltage at the supply from the grid and from all power plants in its relevant part and a supply voltage during a disconnection of these sources. The value of a relative voltage increase Δu_{An} can be determined from the next formula:

$$\Delta u_{An} = \frac{\Delta U_{An}}{U_V} = \frac{S_{rE\max}}{S_{kV}} \cdot \cos(\psi - \varphi_E), \tag{3}$$

where U_{V} is the voltage in the connection point, S_{rEmax} is the maximal supply power, S_{kV} is the value of the short-circuit power in the connection point, ψ is the angle of the grid impedance and φ_{E} is the angle between active and apparent source power. Signs correspond to source orientation.

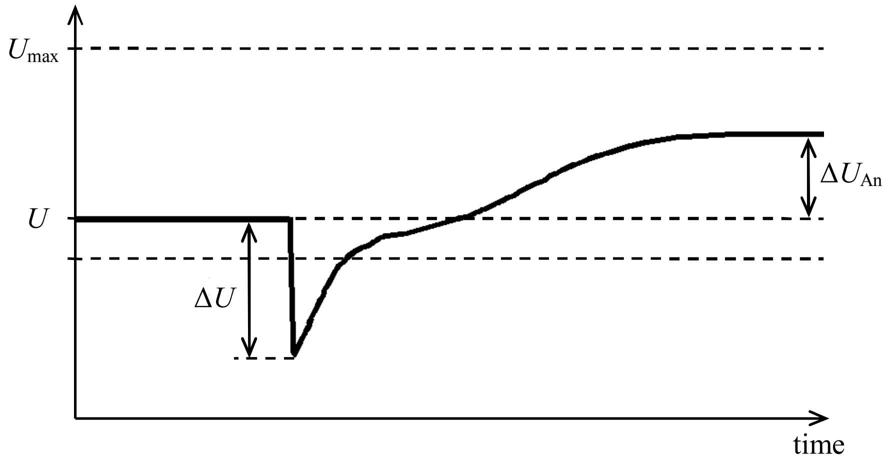

Figure 1 - Short-time voltage change ad stable voltage increase

During the assessment of voltage changes that are caused by the connection and the disconnection of decentralized sources, it is necessary to take into account a type of generator and also a way of its grid connection. If the supply is ensured by some converter or inverter, the change in load is the same as the value of the nominal power output of the generation unit, whereas the worse situation is during the disconnection, which is usually followed by a jump failure of the supply, than the connection which is mostly characterised by a continuous increase in the sphere of a partial power output. In the case of asynchronous generators, that are switched with almost synchronous speed, within the range from 95 to 105 percent, the load change is, at the neglecting of the first two oscillations, mostly lower than the quadruple of the generator power, whereas in the first half-wave current peaks can touch the value of the octuple of the nominal current. The connection of synchronous generators isn’t, at meeting usual synchronisation criteria, conducive to any significant load change. The value of the relative voltage change d_{c} caused by manipulations can be calculated from this relation:

$$d_c = \frac{\Delta U}{U_V} = \frac{\Delta S_A}{S_{kV}} \cdot \cos(\psi - \varphi), \tag{4}$$

where ΔU is a change of voltage, which is caused by switching of the source, ΔS_{A} is a change in load and φ is an angle of this change. For the assessment of wind power plant switching, it is possible to use the value of a grid-dependent switching coefficient $k_{\mathrm{i}\psi}$, which respects very short transients of asynchronous machines connecting to the grid with approximately synchronous speed. This coefficient takes into account the value and the time course of the current during the transient effect and it is determined as the function of the grid impedance angle ψ for each facility. By the help of this, a fictive relative change of voltage d can be determined by the formula:

$$d = k_{i\psi} \cdot \frac{S_{rE\max}}{S_{kV}} \tag{5}$$

If the value of the angle φ isn’t known, then either it must be calculated in virtue of practical values, or it is necessary to do estimation for the worst case so that the cosine element is equated to one. Signs correspond to consumption orientation.

The calculation of commutation drops is meaningful only for facilities that are supplied through grid controlled inverters, because they are caused by phase to phase short-circuits on terminals of thyristor converters. A relative drop depth d_{kom}, or a periodical transient drop of voltage, is determined as:

$$d_{kom} = \frac{\Delta U_{kom}}{U_1}, \tag{6}$$

where ΔU_{kom} is the value of a highest deviation of the system voltage from the instantaneous value of a fundamental harmonic and U_1 is the peak value of a fundamental harmonic.

2.4. Voltage fluctuation

By an influence of power supply instability, wind power plants cause a voltage changes sequence in the point of common coupling. This voltage fluctuation in the grid can be conducive to a fluctuation of luminous flux in light sources, which is called as flicker, which have a negative influence on human eyes and can affect also human mental condition. Causes of its origin can be two, namely an influence of wind blast, which is partly eliminated by the inertia of rotating parts and by some turbine power control, and an influence of shadow effect, which is conducive to a periodical drop in output during alignment of a turbine blade with the tower. The result of these periodical drops in active and reactive power is a voltage drop ΔU, which originates in grid impedance and which size is generally dependent on a number of rotor blades. In the case of three-blade turbine, it can be up to one third of total power output. This voltage drop can be expressed by the next formula:

$$\Delta U = \frac{\Delta P \cdot R + \Delta Q \cdot X}{\sqrt{3} U_n}, \tag{7}$$

where the ΔP and ΔQ are changes in an active and reactive power output of the plant, R is a resistance and X is a reactance of the grid. From this relation result the fact that the voltage change causing the flicker doesn’t exist in grids with markedly inductive character, because active power changes, that are usually much bigger then reactive power changes, have a minor effect on a low system resistance. For the relative voltage drop Δu can be written:

$$\Delta u = \frac{\Delta U}{U_n} = \frac{\Delta S}{S_{kV}} \cos(\psi + \varphi_f), \tag{8}$$

where φ_{f} is a relative angle of the flicker and ΔS is a change of apparent power. Frequency of these drops $f_{\Delta \mathrm{v}}$ depends on a number of rotor blades a, or on the value of turbine rotational speed n. A period of drops is determined by a tower thickness D and by a tip speed ω at the end of the turbine blade with a radius R. Relations among these parameters are characterized by equations:

$$f_{\Delta u} = a \cdot \frac{n}{60}, \quad t = \frac{D}{\omega \cdot R} \qquad (9), (10)$$

A corresponding value to the relative drop in voltage, which is caused by flicker, is the quantity, which is used for its assessment and which is called as a flicker emission or as a flicker perception ratio. In practice, it is possible to differentiate the short-time flicker perception ratio P_{st}, which is calculated and measured in the time interval of ten minutes, and the long-time flicker perception ratio P_{lt}, which is determined in the interval of two hours. The value of P_{lt} for the grid with one plant is:

$$P_{lt} = k_f \cdot \frac{S_{rE}}{S_{kV}} \left| \cos(\psi + \varphi_f) \right|, \tag{11}$$

where k_{f} is a flicker coefficient of the facility and S_{rE} is a nominal output of the power plant. For a grid with more plants or units with nominal power outputs S_{rEi}, that are connected to common point, it is necessary to do this calculation for each unit separately. A resultant value for a wind farm with the different or with n same units can be determined like this:

$$P_{lt} = \sqrt{\sum_{i=1}^{n} P_{lti}^2} \text{ or } P_{lt} = \sqrt{n} \cdot P_{lti} \tag{12}$$

If more generation units are connected to different connection points, the calculation is relatively complicated and the resultant value P_{lt} for simpler grid configurations, for example for unilaterally supplied tap with n generation units, can be estimated. In this case, the value $P_{\mathrm{lt\,jj}}$ must be calculated for each unit j in its connection point $k = j$ by the previous equations and then values of its contribution $P_{\mathrm{lt\,jk}}$ in other connection points $k \neq j$ by the next equations:

$$S_{kV\,j} < S_{kV\,k} \Rightarrow P_{lt\,jk} = P_{lt\,jj} \cdot \frac{S_{kV\,j}}{S_{kV\,k}}, \qquad S_{kV\,j} \geq S_{kV\,k} \Rightarrow P_{lt\,jk} = P_{lt\,jj} \tag{13}$$

where $S_{\mathrm{kV\,j}}$ and $S_{\mathrm{kV\,k}}$ are short-circuit powers in connection points j and k. From these individual values, it is possible to calculate resultant values of the flicker perception ratio $P_{\mathrm{lt\,k}}$ for all connection points by this formula:

$$P_{lt\,k} = \sqrt{\sum_{j,k=1}^{n} P_{lt\,jk}^{2}} \tag{14}$$

In cases of complicated grid configurations, such as loop and meshed systems, it isn’t possible to do this calculation and it is necessary to determine resultant values of the flicker perception ratio by the help of a computer simulation.

2.5. *Harmonics and inter-harmonics*

An origin of sinusoidal courses with higher frequencies is connected especially with facilities that use semiconductor frequency converters and inverters that are used in wind power plants by the reason of the generation of the alternating voltage with frequencies differing from grid frequency. The voltage, which is made by these elements, contains, in addition to first harmonic, also some amount of higher harmonics that distort the sine wave. The real course of voltage from the inverter depends also on the way of its control, such as for example pulse width modulation.

A distortion of voltage curve in the point of common coupling results in additional stress of other facilities of other grid users and it can be the reason of a rise of their function failures or for shortening of their lifetime. With respect to these negative influences, it is necessary to determine, for each new connecting wind power plant, a factor of higher harmonics that are emitted by it to the grid. During its assessment, it is possible to go from values of a total harmonic factor *THF* and of a total harmonic distortion *THD* that are determined as:

$$THF_V = \frac{\sqrt{\sum_{h=2}^{40} U_h^2}}{U}, \tag{15}$$

$$THD_V = \frac{\sqrt{\sum_{h=2}^{40} U_h^2}}{U_1}, \tag{16}$$

where U_1 is the effective value of a fundamental harmonic, U_{h} is the resulting voltage of a harmonic order h in the point of common coupling and h is a harmonic order. As a criterion for the assessment of harmonics, it is determined that every user can supply to the power grid a harmonic power, which is proportional to his contract power.

Wind power plants are mostly also sources of inter-harmonics that originate during the operation of asynchronous machines and owing to the variability of their generation. These inter-harmonics are conducive to a distortion, non-periodical in comparison to grid frequency, and contribute to rise of the flicker. For their assessment, the reference value of inter-harmonics v_{m} is used. It is defined as:

$$v_m = \frac{U_m}{U_n} \cdot 100, \tag{17}$$

where U_m is the resulting voltage of inter-harmonics. Regarding to a nature of an origin of these voltages, there isn’t any arithmetical adding of their levels from different sources in the grid, except situations, when the frequency and the phase are equal.

2.6. Influence on centralized telecontrol signal

The centralized telecontrol is a set of technical facilities that enable to emit commands and signals in order to a switching of appliances or tariffs. This system uses power lines of the electrical grid for a transmission of information and its right function can be affected by other facilities, especially by sources of disturbing harmonic and inter-harmonic voltages in its frequency band. Wind power plants are also, such as other decentralized electricity sources, conducive to an additional load of centralized telecontrol receivers. The signal level can be affected also by capacitors of rectifiers with capacitive filtration or by condenser batteries.

3. SYSTEM IMPACTS

Influences that negatively affect transmission parts of the power grid, are related especially to power systems with a large share of wind power plants on the total electricity supply, where electric outputs of large wind farms practically gradually substitute a significant part of power, which was previously supplied by more stable sources, mainly by generators of thermal power plants that also ensured the sufficient ability to regulation. In these power systems, as a result of dependence on actual weather conditions, rapid changes in energy flows with unpredictable directions and sizes can originate. In the system, demands on ensuring of its transmission abilities and on the size of regulation power increase.

3.1. Reliability of electricity supply

Connecting of a large number of wind power plants and wind farms negatively affects, considering the high rate of their power instability, a reliability of the electricity supply, which normally depends mainly on a maximal transmission ability of the power system, which is given for a situation, when N of their elements are in operation. The transmission of the maximal power must be ensured also in the case of a failure of some of these system elements and the safety criterion N-1 must be fulfilled, by which a preparation of the power system is controlled. The highest dangerous of an exceeding of the power system transmission ability by sudden unpredictable high energy flows is then during the state, when some one element is disconnected.

With respect to an unreliability of wind power plants as electrical energy sources and a necessity to backup their power by other sources that are able to respond to sudden changes in the generation and consumption, the important role for the ensuring of the electricity supply reliability is played also by a reliability of these power stations. At a sudden disconnection of a large number of wind power plants, it is necessary to quickly substitute their output, which increases the risk of a consumption uncovering, especially during a failure of some of sources that are intended to this purpose.

3.2. Stability and control of system

A definition of power system operation stability is given by a codex of the transmission system [4] as its ability to keep a steady state during the normal operation and also after transient effects caused by external influences, a dispatching control and also by fault failures of facilities. This means, that if some change of the supplied power take place in the power system, it must get back to the steady state with values in allowable limits, whereas the system as a whole stay unaffected.

This ability depends on the ensuring of a sufficient amount of a control power, which practically means, in systems with the high share of wind power plants, a necessity of ensuring of larger range of system services, or more precisely support services that serve to their realization. In comparison to classical, well-controllable, sources the connecting of wind power plants causes a growth of demands on the size of necessary power reserves for a primary control, which autonomously acts during a time of several seconds on large generation units and compensate influences of failures or sudden changes in the sources electric output. It also increase demands on a secondary control, which decrease during a time of thirty minutes, with the help of a central regulator of frequency and transferred powers with the use of rotary reserve mainly, a power deficit in controlled area. And finally, it increase demands on dispatcher reserves, mainly on quickly starting reserves, for example in water power plants.

A dispatcher control also must, in addition to insufficiency of the power, solve a problem of its surplus over load size, which is, to a certain extent, enlarged by sources that increase their output at the time of a low consumption and among them wind power plants are also ranked. It increases mainly demands on the operation of classical units in term of requirements of their more frequent shut-down, which causes the higher wear and decreases the lifetime of these facilities. Therefore, the existence of a sufficient number of reliable units, that are able to provide these services, is important.

3.3. Energy flows in interconnected power systems

The whole problem of unfavourable influences caused by the operation of wind power plants and wind farms with large electric output is more complicated in term of systems interconnection, when systems of neighbouring countries are interconnected for example in terms of UCTE. Connecting lines can transmit electricity supply from abroad producers or electricity transit for consumers in other systems, as it is illustrated in figure 2, which shows power cross-border flows at the time of weak electricity generation in wind power plants.

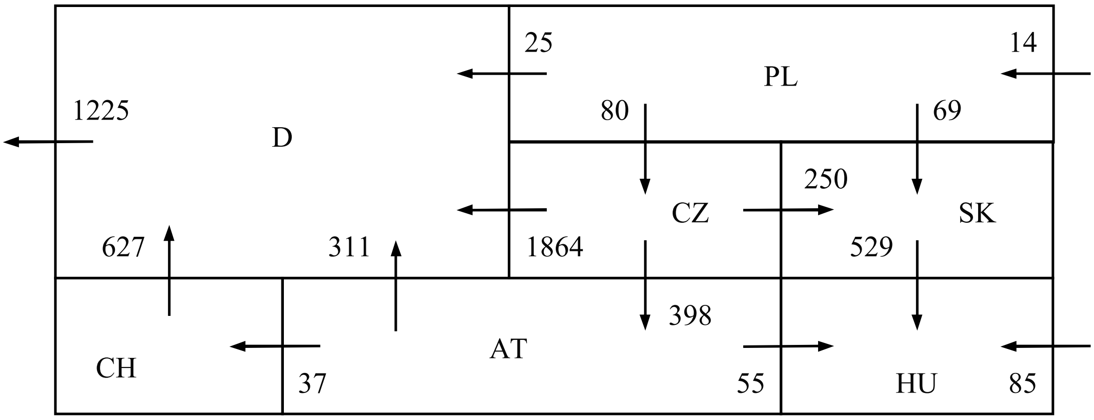

Figure 2 - Power cross-border flows in MW during weak generation in wind power plants

The size of energy flows that run through some power system is determined by a summary of several parts. The first of them is an agreed exchange between neighbouring systems, which means a trade, when the size and time of the supply from abroad power sources are exactly determined. The second is formed by circular flows that originate owing to an influence of the primary control of individual interconnected systems, when energy overflows owing to a compensation of the balance between the generation and consumption in one of these systems. The third part is formed by parallel flows, that are caused by the interconnection and that run through the system owing to agreed exchanges between other systems, because these flows are split into all cross-border profiles, proportionally to their electrical parameters, and they mismatch to originally planned direction and size of the trade.

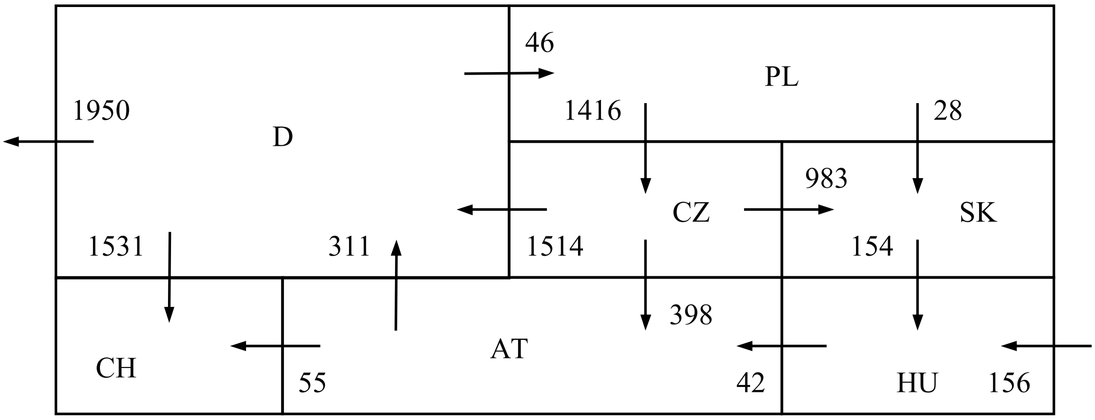

Figure 3 - Power cross-border flows in MW during strong generation in wind power plants

It means that the operation of wind power plants not affects only systems, into which these sources are connected, but also neighbouring systems. This situation is illustrated in figure 3, which shows, in contrast to previous figure, values and directions of cross-border flows at the time of strong generation n wind power plants. At the comparison of both pictures, it is clear, that these flows can differentiate in dependence on electricity supply from wind power plants and can cause problems to neighbouring systems, including loading their lines by transit powers.

3.4. Size of transmission losses

Owing to an irregularity of a wind power plants placing, which make sense only in areas with specific natural conditions, and to the insufficiency of sources in other areas, where electricity consumption is high, it is necessary to transmit large volumes of energy on long distances. This transmission increases a load of transmission lines between these areas, which causes, in addition to the increasing of the risk of overloading, also growth of transmission losses, that depend on the size of the current, which run through the line and which goes up with growing power at the same voltage level.

4. CONCLUSIONS

There are a lot of unfavourable influences of wind power plants on the operation of power systems and it is necessary to solving them by reason of the ensuring of the electricity quality and the power supply reliability, which is one of the most important things in modern times. In spite of the fact, that the most of these problems, especially in terms of distribution grids, is easily solvable by some compensations or filters, the influence of the connection of every new source must be rigorously assessed before its integration. In the case of influences in terms of transmission systems, it is mainly necessary to solve the problem of the power systems strengthening and the ensuring of better possibilities of regulation for example by the use of electricity accumulation technologies or by the use of conceptions of active grids, such as smart grids that are very discussed in at the present time.

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