WIND TURBINES IN THE HIGH VOLTAGE NETWORKS OF CZECH REPUBLIC

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SUMMARY

It has been generated a lot of gigawatthours from new wind farms all over the world in the last years. Otherwise, there appeared problems with connection and operation associated with this "boom" of wind power. Questions like voltage changes, flicker, harmonic currents, behaviour during network disturbances and regulation of reactive power are presently discussed.

The purpose of this article is to show possibilities of wind power in Czech Republic, with aspects of integration to the high voltage networks. The rules for operation of transmission and distribution lines are determined by Energy Regulatory Office. According to these rules, which include the connecting conditions and evaluation of wind turbine grid impacts, is made an evaluation of small wind farm grid connection.

Keywords: *wind turbine, legislature, connecting conditions, grid impacts, wind farm, voltage change*

1. INTRODUCTION

A continental position of Czech Republic (CR) and complicated topographical conditions implicate the decrease and variability of wind speed. Hence, the proper locations can be nearly always found in higher above sea levels, usually above 600 metres. After the reduction of the legislative, ecologically and wind potential insufficient locations the viable technical potential of CR is according to some judgments 700 – 1000 MW, which represents the production of 1.5 – 2.5 TWh yearly.

Although CR has a quite satisfactory viable potential of wind power, the proper locations are situated mostly at mountains or foothills regions. But these locations represent from the power system (grid) point of view the undersized ends of distribution grids. Therefore, it is important to ensure high-quality conditions when connecting the wind turbines (WT) to the grid, so the standard power supply quality for other customers would not be disturbed.

2. LEGISLATIVE CONDITIONS

According to the power law, the Czech distribution companies released the rules of the power systems operation. It means that on the whole territory of CR pay the same rules, which vary only in the details of appropriate company. These rules apply to all kinds of renewable energy sources. The manufacturers of renewable energy have as well the right of priority to be connected to the electric grid. The decisive requirements concerning the grid connection of WT are included in appendix no. 4 – "The rules for parallel operation of sources with LV or HV grids". Except these rules, it must be of course adhered the valid norms, the business standards and the regulations for work safety, when operating renewable sources.

Next two chapters mention the most important conditions, that have to be fulfilled when connecting the WT to the grids, and whereby evaluate their grid impacts [1, 2].

2.1 CONNECTING CONDITIONS

2.1.1 Switching device

When connecting WT to grid, it has to be used the switching device, with the minimally ability of switching-off the load. Such a device can be e.g. a circuit-breaker, a switch-disconnector-fuse or a section-disconnecting switch.

2.1.2 Voltage changes at steady and switching operations

These voltage changes must be in comparison with the voltage at their disconnection in the most adverse case:

– in LV grids $\left|\Delta U\right| \leq 3\% U_n$ (1)

– in HV grids $\left|\Delta U\right| \leq 2\% U_n$ (2)

where:
ΔU - voltage change
U_n - nominal network voltage

The values may be tolerated higher after the settlement with distribution company, according to the starting-up duration. Respecting the minimisation of grid impacts, it is however necessary to prevent the simultaneous switching of more generators. The technical solution is realized by a time step of each switching operation, which is dependent upon the evoked voltage changes. For WT pays a special "factor of switching dependent upon grid", whereby evaluates their switching operations and which also respects a short time transient phenomena.

2.1.3 Connecting the synchronous generators

At synchronous generators, it is necessary such a synchronizing unit, whereby the conditions for synchronizing may be fulfilled:

– voltage difference $|\Delta U| \leq 10\% U_n$ (3)

– frequency difference $|\Delta f| < \pm 0{,}5 Hz$ (4)

– phase difference $< \pm 10°$ (5)

2.1.4 Connecting the asynchronous generators

Asynchronous generators started-up by wind must be switched unloaded with the revolutions in 95 %–to–105 % range of a synchronous speed. At induction generators, which are able to “island running” and are not switching unloaded, it is necessary to keep the terms of the switching operations such as for the synchronous generators.

2.1.5 WT with inverters, frequency converters

The inverters may be switched only at such time, when their AC side is unloaded. At the WT with inverters, which are not switching unloaded, it is necessary to keep the terms, valid for the synchronous generators.

2.1.6 Protections

To protect the single unit and the units of other customers are necessary the protections, which trigger the appropriate switching device at voltage and frequency variations. It is necessary to ensure the protections with these functions:

Function	setting range	
Under-voltage	1,0 Un to 0,70 Un	3 phase
Over-voltage	1,0 Un to 1,2 Un	
Under-frequency	50 Hz to 48 Hz	1 phase
Over-frequency	50 Hz to 52 Hz	

Tab. 1 Protections of WT

In some cases other setting ranges can be necessary, respecting the grid conditions. In grids operated with the system of circuit reclosing, it is even necessary a special protection. It can be e.g. a power jump relay, a voltage vector step change relay (only at synchronous generators), or a two-stage voltage and frequency protection. The single unit must be protected – e.g. with a short-circuit protection, with an overload protection.

2.1.7 Regulation of reactive power

Keeping the power factor of WT in the 0.95-to-0.98 inductive range, according to former rules, would not in many cases fit the demands on the required voltage level and economic operation. It would also uselessly limit the grid connections of these sources. The sources with power higher than 5 MW (in reasonable cases higher than 1 MW) must be supplied for some mode of the following reactive power regulation:

– keeping the engaged power factor

– keeping the engaged reactive power value (demand/supply) in terms of the unit operation diagram (PQ diagram)

– keeping the voltage in connection point in terms of limitations, engaged by PQ diagram

The way of reactive power regulation, which is determined by the distribution company depends always on the concrete place of grid and technical possibilities of WT. The demand of reactive power depends analogical upon the conditions in that place. Setting-up the power factor range is one of the crucial questions, which influences available connecting power. According to local reactive power balance, it can be inconvenient for distribution company to insist on the supplies with inductive power factor (supplies of reactive power) and also to agree with capacitive power factor (consumption of reactive power).

2.2 GRID IMPACTS

The grid impacts express at WT above all like voltage changes and harmonics. The immediately perceptible effects are e.g.:

– a fluctuation of lamp and bulb brightness (flicker)

– an affection of remote signalling and computer technique units

– a defective operation of centralized telecontrol (CT) acceptors and electronic controls

It is necessary to examine the grid impacts from the following boundary conditions:

2.2.1 Voltage changes

If the condition according to point b of previous chapter is met, the voltage changes in connection point don't evoke any unacceptable grid impacts. The maximum acceptable voltage changes are dependent upon their percent occurrence, i.e. flicker curve. Criteria for their evaluation are a flicker indexes Plt, Alt. They are investigated by measurement of the real unit in connection point or are estimated and depend on the flicker factor c. It is necessary to fulfil the limiting value, in connection point:

$$P_{lt} \leq 0.46 \ (A_{lt} \leq 0.1) \quad (6)$$

where:
P_{lt} - long time severity index
A_{lt} - flicker factor disturbance

2.2.2 Flicker

The flicker factor c of WT indicates an index of subjective perceptions at the luminous flux changes. Producer determines it. It depends above all on the operation regularity of the unit and at his classification used to be the WT critical. Their flicker factors are up to 40, according to experiences. Index Plt can be calculated according to:

$$P_{lt} = \left[c \cdot \frac{S_A}{S_{kV}} \cdot \cos(\psi_{kV} + \varphi_i) \right] \quad (7)$$

where:
S_A - apparent power of the unit
S_{kV} - short-circuit power in connection point
ψ_{kV} - phase angle of short-circuit impedance
φ_i - phase angle of unit current

It pays for WT, that:

- at units with inverters is a tendency to the lower c values than at units with direct grid connected asynchronous or synchronous generators
- if the plant consists of n same generators, it happens a particular "compensation" of each generator flicker factor

2.2.3 Harmonic currents

The harmonics occur above all at units with inverters or frequency converters. If the voltages of harmonics are higher than limits, it comes into question:

- an installation of harmonic filters
- a connection to the point with lower grid impedance, so with higher short-circuit power

2.2.4 Impacts on CT signal

The CT system is usually operated with frequency between 180 and 1050 Hz. Its level must not in each grid point decrease about more than 10 % to 20 % below the desired value. From this reason it is necessary to consider these aspects:

- the synchronous or asynchronous generators, connected to the grid over the transformer, generate the lower signal decrease, the higher is the grid short-circuit power
- the evoked interfering voltage, whose frequency matches or is very closely to the locally used CT frequency, must not exceed 0,1 % Un

3. EXAMPLE OF GRID CONNECTION EVALUATION [3]

The wind farm consists of 5 WT and is situated in Krusne Hory region, in one of the windiest and for wind power supply most promising region in Czech Republic. Upon the evaluation of wind speeds was chosen the most suitable type of WT. Vestas V52 has a nominal power of 850 kW and is applied with the most widely used technology – with variable speed asynchronous generator. Close to the location can be found a distribution substation (DS) and the HV distribution grid 22 kV. To this voltage level it is possible to connect a farm at most of five WT. Larger farm would be necessary to connect to 110 kV grid, which is 6 kilometres far, and though would considerably increase the cost of investments.

3.1 Technical concept of grid connection

The way of connection the farm to grid was considered according to figure 1, to the DS "Celnice" with the 22 kV cable 3x AXEKVCEY 1x70 mm2. The length of the cables was considered jointly 300 metres according to the distance of each WT. The distance from DS was considered 500 metres, according to hygienic rules.

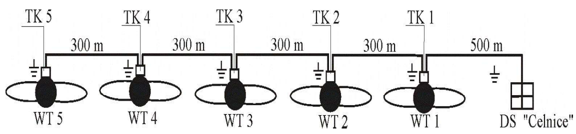

Fig. 1 Scheme of wind farm grid connection

At each WT is placed a transformation kiosk (TK), fitted with the transformer 22/0.69 kV. In each kiosk is placed a switch-board of HV 22 kV, with the SF6 gas isolation to protect the transformer and to connect the HV 22 kV. In WT2 to WT5 are the switch-boards equipped with fuse sets. Switch-board in WT1 is equipped with the circuit-breaker, with current and voltage measuring transformers and with the directive protection. This protection is able to react at short-circuits, at over-currents, at unipolar ground faults in foreign unit, perhaps even at over-voltages from WT. At frequency decrease it prevents the "island running".

For the cable connection to grid it is used an existing backlog in DS. The way of the cable connection in DS allows to distribution company to remote-control the switch-disconnector of the cable. Measuring of the power supply is carried out at HV side, DS is therefore necessary to equip with current and voltage measuring transformers. It is possible to read the values over modem line.

3.2 Grid impacts of wind farm

The calculation of grid impacts was simulated in a computer program. In the model were used the parameters declared by Vestas. The scheme of connection in figure 2 is described in table II

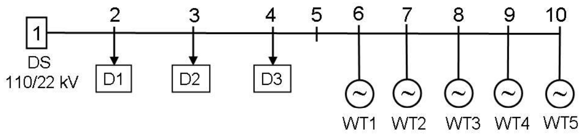

Fig. 2 Scheme of 22 kV circuit from DS "Ostrov"

DS	U_n [kV]	S_k [MVA]	I_k [kA]	Z_0/Z_1	R/X
110/22 kV	23.1	276	6.9	1	0
Demand	U [kV]	I [A]	S [kVA]	P [kW]	cos φ
D1	23	83.84	3340	3173	0.95
D2	23	46.69	1860	1767	0.95
D3	23	77.57	3090	2935.5	0.95
WT1–WT5	S_n [kVA]	cos φ_n	k	cos φ_k	c
V52	894	0.95	3	0.3	3

Tab. 2 Parameters of each element

where:

Ik short-circuit current
Sk short-circuit power
cos φn nominal power factor
cos φk short-circuit power factor
K ratio between starting and nominal current
C flicker factor

With the calculation, the voltage changes were determined in each node up to the circuit outlet in DS "Ostrov". The system was then classified in three operational situations; the results are in figure 3.

a) at steady operation
b) at start up of WT1 and others disconnected
c) at start up of WT1 and others at steady operation

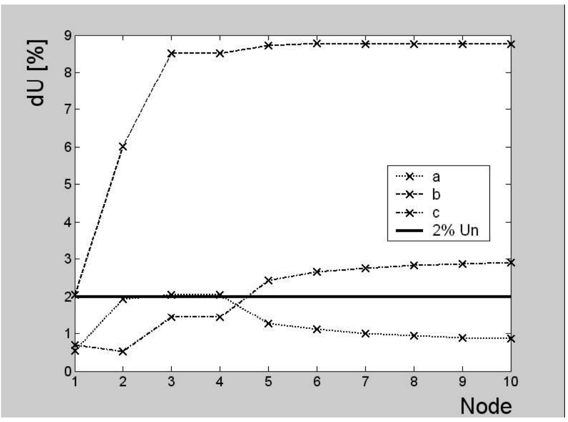

Fig. 3 Voltage changes in each node

As is seen in figure 3, it is met the condition for voltage changes at steady operation (according to chapter 2.1). In both starting-up variants, the unacceptable voltage changes however occur. If the switching would not be more often than once per day, it would be possible to tolerate these changes, after the settlement with distribution company. Otherwise it is necessary to adjust the generator start-up, e.g. by using a soft-starter (thyristor starter), a frequency converter, an Y-delta change-over switch or to start-up the WT by wind. In the worst case, it is then necessary to connect the farm to the point with higher short-circuit power. Harmonic currents declared by Vestas meet the limits given by distribution company, moreover the short-circuit power in connection place is sufficient. The CT signal will not be influenced as a result of using the block transformers.

4. CONCLUSION

Today, wind power is a fully established branch on the electricity market in EU. The energy gain is not the only criteria to be considered when installing new wind turbines. Any device connected to the electric grid must fulfil the Power Quality standards and this is a particularly interesting and important issue to be considered in the case of wind power installations.

The subject of this article was above all an outline of solving these problems in Czech Republic. They were mentioned the present and future rules for grid connections of wind turbines and the questions of their grid impacts. On a concrete was classified the possibility of connection the wind farm with a view to the evoked voltage changes, above all.

REFERENCES

[1] Distribution companies: The rules for parallel operation of sources with LV or HV distribution grids 2004. (in czech)

[2] Procházka, K.: Current requirements and specifications for evaluation the connection of dispersed sources in distribution grids, EGC-EnerGoConsult Ltd., 2003. (in czech)

[3] Novák, P.: Project of wind farm in Bozi Dar region, diploma thesis, Pilsen 2003. (in czech)

[4] Zander, W.: Connection and operation of wind turbines in power systems, Büro für Energiewirtschaft und technische Planung GmbH, 2003. (in czech)

BIOGRAPHY

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Pavel Novák graduated at Faculty of Electrical Engineering, West Bohemia University in Pilsen in 2003. Now he is an internal post graduate (PhD.) student. Thesis title is "Integration of renewable energy sources to the electricity supply system".