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# The connection to the grid of wind turbines

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***Abstract*** — With a view to the integration in national power system of new power plants based on renewable energy sources, such as wind energy, this paper presents the technical requirements related to the connection of the wind power plants to the main grid. Grid connected wind turbines may cause power quality problems, such as voltage variation and flicker, and therefore, the connection of wind farms requires new connecting rules to avoid negative effects on the existing electrical system. System operators usually issue these rules in the form of grid codes. The paper should be helpful to facilitate the orientation in finding of adequate type of wind turbines that can be installed in the intended sites, dependent on specific conditions.

***Index Terms*** — wind turbine, wind farm, power system, power quality, active power control, reactive power control, voltage control, frequency control, grid code.

## I. INTRODUCTION

THE use of renewable energy sources for electricity generation will increase in the future to reduce the dependence on fossil fuels. Moreover, due to the environmental pressures, many governments are promoting the use of the renewable energy sources, and presently almost European countries have implemented their own strategies regarding support schemes for electricity generation. From the point of view of the consumer, security of power supplies depends on the diversity of sources and ability of power plants to provide a cushion against forced system outages or loss of energy supplies. The output of some renewable generation, such as wind and solar generators, is determined by the climate and weather conditions. However, wind energy is the fastest growing renewable energy source because of its abundant availability in nature and the maturity of its technology [1]. The electricity generation from wind fluctuates greatly, requiring additional reserves of conventional capacity. The impact of wind power depends on the power system size, generation capacity mix, the degree of interconnection to neighbouring systems and load variations [5]. The new wind farms are generally of similar size as conventional power plants, and in way of consequence they must at least meet the same grid connecting conditions to maintain the power system stability.

## II. THE PERFORMANCE INDICATORS OF THE WIND POWER PLANTS

The connection of wind turbines to the distribution networks may affect the voltage quality offered to the consumers. Therefore, the integration of wind power plants makes new connecting rules and proper incentives necessary to avoid negative effects on the existing electrical system [1], [11]. The wind turbines are subjected to environmental and electrical conditions that may affect their loading, durability and operation. To ensure the appropriate level of safety and reliability, the environmental, electrical and soil parameters shall be taken into account in the project. Electrical conditions refer to either the grid connection of wind farms or fulfilment the power supply by hybrid systems for isolated villages. It is very important to the profitability of the wind turbine project the finding of type of turbine best suited to installation at the intended site. In order to establish what type of turbine is best suited to the site in question, it is necessary to study information about the wind conditions [2], [5], [12] and the features of the landscape. The shape of the landscape has a significant effect on the strength and stability of the wind. For example, an area of woodland containing high trees or a built-up zone will be rougher than an open field. Therefore, the wind blows more strongly over the sea than across the land, and more strongly over open land than in wooden or built-up areas. The implementation of a wind turbine project is always preceded by months or years of measurement of factors such as wind speed and wind direction at the intended site. The wind direction is principally used to determinate how the turbines are to be positioned in relation to each other. The necessary distance between the turbines and rows is in fact heavily dependent on not only the wind speed, but also the wind direction as it is important to ensure that the turbines do not generate turbulence or block the wind for each other [14]. The tower height of wind turbine is an important factor that is to be considered towards the selection of the type of the turbine. The reason behind the above fact is that there is a

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considerable change in the wind velocity profile at different heights.

Wind turbines differ from conventional power generators in that their performance depends on the characteristics of the site where they are erected. Most of the time wind turbines operate at partial loads, depending on the wind speed. From the power system point of view, wind turbines can be regarded as production assets with an average of 25 – 30% of rated power. The rated power, and namely the nameplate power, is the maximum power reached only 1 to 10% of time [5].

The output power of wind plant is dependent on wind speed due to the fact that the wind turbines use the kinetic energy of the wind to produce mechanical power and than to generate electricity by generator system. Some of the available power in the wind is converted by the rotor blades to mechanical power acting on the rotor shaft of wind turbine. The mechanical power, $P_{mech}$, can be determined by:

$$P_{mech} = \frac{1}{2}\rho A_r C_p(\lambda,\beta)\omega^3 \qquad (1)$$

$$\lambda = \frac{\Omega_r r_r}{\omega} \qquad (2)$$

Where: $C_p$ is the power coefficient, $\beta$ is the pitch angle, $\lambda$ is the tip speed ratio, $\omega$ is the wind speed, $\Omega_r$ is the rotor speed, $r_r$ is the rotor-plane radius, $\rho$ is the air density and $A_r$ is the area swept by the rotor [10].

Wind power is different from conventional sources of energy due to three main reasons: prime mover is different from the others, and the locations of resources with respect to load and the type of electrical machines.

The energy conversion of most modern WT can be divided into two main concepts, and namely, fixed speed machines with one or two speeds and variable speed machines.

Wind power performance indicators are related to the principal wind turbine specifications, and namely, rated power and rotor diameter. In view of the variety in the market, it is useful to characterise the electrical wind turbine concepts by type of generator and by method of power control into four types [5]:

- Fixed speed, with the concept based on a squirrel cage induction generator;
- Limited variable speed, with a wound rotor induction generator;
- Improved variable speed with doubly fed induction generator;
- Variable speed with full-scale frequency converter, using various types of generators: synchronous generators with wound rotors, permanent magnet generators and squirrel cage induction generators.

The fixed speed wind turbine is provided with a classical squirrel cage induction generator, directly connected to the grid, and the turbulence of the wind will result in power variations, and thus it can affect the power quality of the grid. The low rotational speed of the turbine rotor $n_{rotor}$ is translated into the generator rotational speed $n_{generator}$ by a gearbox with the transmission ratio *r*. The generator speed depends on the number of pole pairs *p* and the frequency of the grid $f_{grid}$, [10].

$$n_{rotor} = \frac{n_{generator}}{r} \qquad (3)$$

$$n_{generator} = \frac{f_{grid}}{p} \qquad (4)$$

$$n_{rotor} = \frac{f_{grid}}{r \cdot p} \qquad (5)$$

The disadvantages of induction generators are high starting currents and their demand for reactive power. Having in view the grid connection requirements, a specific rule should be applied for classical induction generators [1] [11] [12]: their reactive power needs and the possibly required additional reactive power generation are provided by capacitor banks connected either to the producer's installation or to the High Voltage/Medium Voltage substation. For fixed speed wind turbines, in Fig. 1 is given an example of a $C_p(\lambda,\beta)$ curve and the shaft power as a function of the wind speed for rated rotor speed and in Fig. 2 the solid line corresponds to a fixed pitch angle, β, while dashed line corresponds to a varying β for active stall [13].

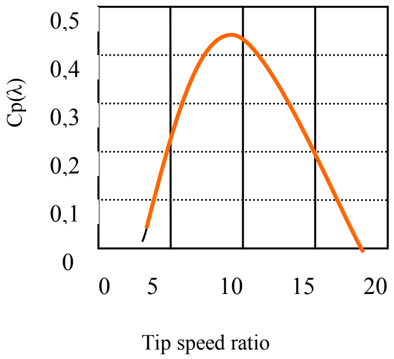

Fig.1. The power coefficient as a function of the tip speed ratio, for fixed-speed wind turbine

At high wind speeds it is necessary to limit the input power to the wind turbine, i.e., aerodynamic power control. There are three ways of performing the aerodynamic power control: by stall, pitch, or active stall control. Almost all variable wind turbines use pitch control. For a variable speed wind turbine, the generator is controlled by power electronic equipment, assuring the control of rotor speed. In this way the power fluctuations caused by wind variations can be more or less absorbed by changing of the rotor speed and thus power variations originating from the wind conversion and the drive train can be reduced [13]. In the Fig. 3 and Fig. 4 are given the main characteristics of variable speed wind turbines. Fig. 3 shows an example of how the mechanical power, derived from $C_p(\lambda,\beta)$ curve, and the rotor speed vary with the wind speed for a variable-speed wind turbine.

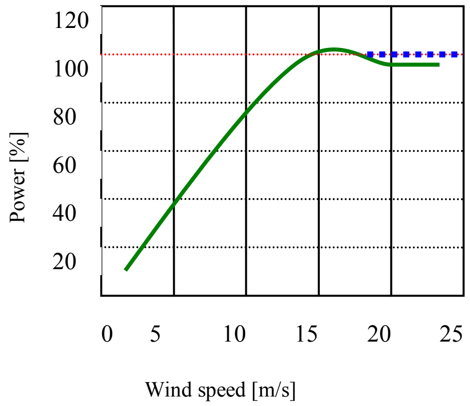

Fig. 2. Mechanical power as a function of wind speed at rated rotor speed, for fixed-speed wind turbine (solid line is fixed pitch angle, i.e., stall control and dashed line is active stall

As seen in Fig. 3 the turbine in this example reaches the rated power at a wind speed of approximately 13 m/s. Note that there is a possibility to optimize the radius of the wind turbine rotor, to suit sites with different average wind speeds, so this implies that $r_r$ is increased, the output power of the turbine is also increased, according to (1) and (2).

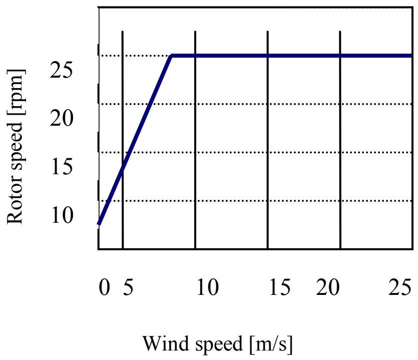

Fig. 3. Rotor speed as a function of wind speed for a variable-speed wind turbine

The nominal power will be reached for a lower wind speed, referred to Fig. 4. However, increasing the rotor radius implies that for higher wind speed the output power must be limited by pitch control, so that the nominal power of the generator is not exceeded. In particular, wind farm are now more and more often asked to provide ancillary services such as contribution to voltage and reactive power control and also to frequency regulation. Voltage and reactive power control can be performed: by the wind turbines generators themselves and by additional devices located in the wind turbines or on the internal network of the wind farm [12]. To provide the wind power installation with power system control capabilities and to improve the influence on the power system stability, central power electronic units in large wind farms are a promising technical solution. Central units may be connected to the power system at wind farm connection point, and consequently could contribute to the control of the voltage and frequency at that point. In this respect, wind farms with central power electronic units can act more like a regular power plant [3].

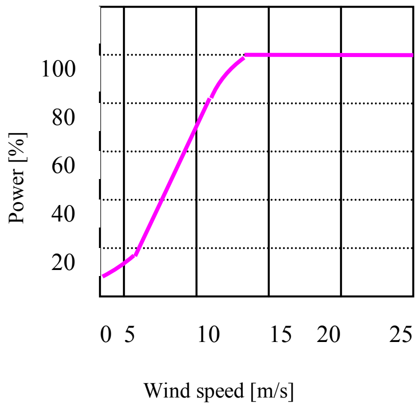

Fig. 4. Mechanical power as a function of wind speed for a variable-speed wind turbine

Additional devices combined with wind farms can provide the reactive power and voltage control capability, either totally as in the case of classical squirrel cage induction generator, or as a complement to the existing capability of wind turbine generator technology, used as doubly-fed induction generators and synchronous generators [12]. The most used unit to compensate for reactive power in the power systems are either synchronous condensers or shunt capacitors, the latter either with mechanical switches or with thyristor switch, as in Static VAR Compensator (SVC). The disadvantage of using shunt capacitors is that the reactive power supplied is proportional to the square of the voltage. Consequently, the reactive power supplied from the capacitors decreases rapidly when the voltage decreases. The reactive power is needed to maintain voltage stability [3]. Another regulating device used on alternating current electricity transmission networks is STATCOM that is based on a controllable voltage source converter (VSC) that generates a voltage with the amplitude and phase being continuously and rapidly controlled, so as to effectively perform reactive power control. By control of the voltage source converter output voltage in relation to the grid voltage, the voltage source converter will appear as a generator or absorber of reactive power [6]. When system voltage is low, the STATCOM generates reactive power (STATCOM capacitive). When system voltage is high, it absorbs reactive power (STATCOM inductive). A circuit configuration of using STATCOM as a compensation device is presented in the Fig. 5, where STATCOM is connected in shunt to bus to mitigate the flicker level during continuous operation of the grid connected wind turbine. The reactive power generated or absorbed by the STATCOM may be varied with the output active power of the wind turbine. As an example in the Fig. 5, the wind turbine output reactive power $Q_{\mathrm{WTG}}$ is normally controlled as zero to keep the unity power factor, regulating the reactive power generated or absorbed by the STATCOM, $\mathrm{Q}_{\mathrm{STAT}}$ , that may change the reactive power flow on the line 1-2. Thus the difference between the grid impedance angle $\psi_k$

and the line power factor angle φ approaches 90 degrees, and the flicker emission is minimized. Therefore the reactive power absorbed by the STATCOM, can be controlled in proportion to the wind turbine output active power, so that the power factor angle φ, of the line 1-2 is adjusted at the value of ($\psi_k$ +90°).

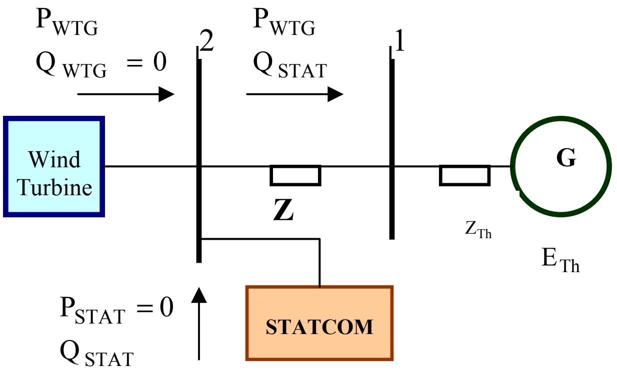

Fig. 5. STATCOM and a wind turbine in the system for voltage quality

The above-mentioned additional devices for reactive power and voltage control can provide the wind farm with a Fault Ride Through (FRT) capability, such that the wind farm will not disconnect in case of a voltage dip in the network [1], [12], [13], [14].

Before introducing a new type of wind turbine, it is necessary to test the energy production, power quality and noise level. Numerous parameters come into play when choosing the optimal type of turbine for a specific site. The most common are related to the local restrictions regarding turbine height, noise levels, nature conservation and other requirements from the authorities [14].

Having in view the choosing of suitable site shall be taken into account the assuring of environment protection in some areas. Many studies and observations were made about problems caused by wind turbines [5], [7]. A part of technical and economical problems should be: the difficulty of keeping to the production schedules caused by wind farms leads to certain costs, due to imbalance; the installed and expected wind and renewable capacity needs new grid infrastructure. On the other hand, the industry recognizes also that the flicker of reflected light on one side and shadow on the other, affect the health of people and animals, when they are situated near wind turbines at a distance more less than 1000 m.

## III. THE GRID CONNECTED WIND TURBINE REQUIREMENTS

The power systems and in particular distribution networks were initially designed to operate with unidirectional power flows and namely, from the centralized power plants to the loads. With a view to the integration of new distributed generation units like wind farms, it is expected to occur new problems and constraints at different levels: modification of the power flows, of the voltage profile, of the steady-state and short-circuit currents, degradation of network stability, interaction with protection system, and possible degradation of the quality supply, etc. [12]. One of the factors contributing to this effect is provided by the rapid variations of the wind turbine output, which cause fluctuations in the supply voltage, referred to as flicker. Wind turbine flicker emissions are receiving a lot of attention and international standards are being developed to establish the methods of assessment, e.g. IEC 61000-4-15, IEC 61000-3-7, IEC 61400-21, etc. Harmonics that are produced by different types of electrical equipment are associated with the distortion of the fundamental wave of the grid voltages, being sinusoidal in the ideal situation [2].

According to the above-mentioned standards, the manufacturers of wind turbines have to specify the continuous operation flicker coefficient, derived from a specific measurement procedure, as a function of the network impedance phase angle and the ten minutes average of the wind speed. Flicker emission due to switching operations should be given as well. This information is then used to evaluate the expected flicker levels when the wind turbine is connected to a specific point in the grid and also to examine the conformity with the applicable emission levels, as provided by national regulations, prepared on the basis of the technical specifications and European standards (e.g. EN 50160, EN 61400-21 that is identical with IEC 61400-21, etc.) adopted as national standards.

In normal operation condition, the main electrical parameters, which are used to characterise the power quality - or more correct, the voltage quality – in a given grid connection point of a wind turbine or a wind farm, may be assessed in the terms of steady-state voltage and flicker under continuous operation and switching operation [6], [8], [9] as they are described in the following:

a) Steady-state voltage

Due to the fact that the operation of a wind turbine may affect the steady-state voltage in the connected grid, the load-flow analyses are recommended to assess this effect.

A simple method for the calculation of the steady-state voltage change, according to the reference [2], is given by:

$$d = \left|\cos(\psi_k + \varphi)\right| \cdot \frac{S_{60}}{S_k} \qquad (6)$$

only valid for cos ($\psi_k + \varphi$)>0,1

where: $S_k$ is short-circuit apparent power of the grid at point of common coupling (PCC);
$S_{60}$ is the apparent power at the 1-min. active power peak;
$d$ is the steady-state voltage change of the grid at PCC (normalised to nominal voltage);
$\varphi$ is the phase angle between voltage and current;
$\psi_k$ is the grid impedance angle

### b) Voltage fluctuations

A fluctuating installation means an installation that may be a load or a generator that produces voltage flicker and / or rapid voltage changes. Fast and small variations are called flicker. The voltage fluctuations occur in the continuous operation and switching operation:

#### 1) Continuous operation

According to the reference [8], the flicker emission from a single wind turbine during continuous operation shall be estimated by:

$$P_{\mathrm{st}} = P_{\mathrm{lt}} = c(\psi_{\mathrm{k}}, v_{\mathrm{a}}) \cdot \frac{S_{\mathrm{n}}}{S_{\mathrm{k}}} \qquad (7)$$

Where: $P_{\mathrm{st}}$ and $P_{\mathrm{lt}}$ are the short and long-term flicker emissions; $c\ (\psi_{\mathrm{k}}, v_{\mathrm{a}})$ is the flicker coefficient of the wind; turbine for the given network impedance phase angle, $\psi_{\mathrm{k}}$ at the PCC, and for the given annual average wind speed, $v_{\mathrm{a}}$ at hub-height of the wind turbine at the site; $S_{\mathrm{n}}$ is the rated apparent power of the wind turbine and $S_{\mathrm{k}}$ is the short-circuit apparent power at the PCC.

#### 2) Switching operation

With a view to the switching operations shall be checked: the voltage change due to inrush current of a switching and the flicker effect of the switching [2].

The relative voltage change due to a switching operation of a single wind turbine should be estimated as:

$$d = 100 \cdot k_{\mathrm{u}}(\psi_{\mathrm{k}}) \cdot \frac{S_{\mathrm{n}}}{S_{\mathrm{k}}} \qquad (8)$$

Where:

$d$ is the relative voltage change in %;

$k_{\mathrm{u}}(\psi_{\mathrm{k}})$ is the voltage change factor of the wind turbine for the given $\psi_{\mathrm{k}}$ at the PCC;

$S_{\mathrm{n}}$ is the rated apparent power of the wind turbine;

$S_{\mathrm{k}}$ is the short-circuit apparent power at the PCC.

The flicker emission due to switching operations of a single wind turbine shall be estimated, according to the reference [8], applying:

$$P_{\mathrm{st}} = 18 \cdot N_{10}^{0{,}31} \cdot k_{\mathrm{f}}(\psi_{\mathrm{k}}) \cdot \frac{S_{\mathrm{n}}}{S_{\mathrm{k}}} \qquad (9)$$

$$\mathrm{P}_{\mathrm{lt}} = 8 \cdot \mathrm{N}_{120}^{0{,}31} \cdot \mathrm{k}_{\mathrm{f}}(\psi_{\mathrm{k}}) \cdot \frac{\mathrm{S}_{\mathrm{n}}}{\mathrm{S}_{\mathrm{k}}} \qquad (10)$$

Where $k_{\mathrm{f}}(\psi_{\mathrm{k}})$ is the flicker step factor of the wind turbine for the given $\psi_{\mathrm{k}}$ at the PCC.

When a wind farm is connected to the PCC, the flicker emission from the sum of wind turbines can be estimated from equation 12 and equation 13 below.

$$P_{\mathrm{st}\,\Sigma} = \frac{18}{S_{\mathrm{k}}} \cdot \left( \sum_{i=1}^{N_{\mathrm{wt}}} N_{10,\mathrm{i}} \cdot \left(k_{\mathrm{f,i}}(\psi_{\mathrm{k}}) \cdot S_{\mathrm{n,i}}\right)^{3{,}2} \right)^{0{,}31} \qquad (11)$$

$$P_{\mathrm{lt}\,\Sigma} = \frac{8}{S_{\mathrm{k}}} \cdot \left( \sum_{i=1}^{N_{\mathrm{wt}}} N_{120,\mathrm{i}} \cdot \left(k_{\mathrm{f,i}}(\psi_{\mathrm{k}}) \cdot S_{\mathrm{n,i}}\right)^{3{,}2} \right)^{0{,}31} \qquad (12)$$

Where

$N_{10,\mathrm{i}}$ and $N_{120,\mathrm{i}}$ are the number of switching operations of the individual wind turbine within a 10 min and 2 h period respectively;

$k_{\mathrm{f,i}}(\psi_{\mathrm{k}})$ is the flicker step factor of the individual wind turbine;

$S_{\mathrm{n,i}}$ is the rated power of the individual wind turbine.

In the following an example is given for the calculation of the perturbation of the grid by wind turbines. The assessment is provided according to the methods given in IEC 61400-21.

Example:

A wind farm, consisting of 6 wind turbines, each of 600 kW rated power, should be connected to a 20 kV medium voltage grid. For this purpose, the wind turbines of type V 42 or V44/ 600 manufactured by VESTAS in Denmark [8] or other wind turbines with the same characteristics and a hub height of 53m or more can be used. A load corresponding to the consumer loads in the nearby area, having a rated power of 5% from the short-circuit power of the grid and a power factor of 0,8 is taken into account to be connected in the PCC. A circuit breaker for the disconnection of the whole wind farm shall be installed at PCC. The simplified schema for one wind turbine connected to the 20 kV network is given in Fig. 6.

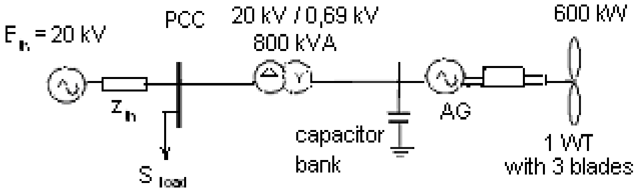

Fig. 6. Example of power system corresponding to one directly grid connected wind turbine with a squirrel-cage induction generator

The circuit breaker is located at the medium voltage system inside a substation, where also the electricity meter is installed. The medium voltage (MV) distribution grid is represented by its Thevenin equivalent, consisting of a voltage source $E_{th}$ and the series impedance $Z_{th}$ . An equivalent Thevenin grid characterized by a short-circuit power of $S_{\mathrm{k}}$ = 40 MVA and a grid impedance with a ratio $R_{th} / X_{th}$ of 0,1 have been considered. This impedance ratio corresponds to an approximate value of 80º for the grid voltage angle $\psi_{th}$ in the Point of Common Coupling (PCC), calculated by:

$$\varphi_{th} = \arctan(X_{th}/R_{th}) \qquad (13)$$

The values of $R_{th}$ and $X_{th}$ are chosen so as to $\varphi_{th}$ is equal with the real grid impedance phase angles $\varphi_k$ at specified site. The ability of the grid to absorb disturbances is directly related to the short circuit power level at PCC. The ratio Rs = Sk / Pinstalled is a measure of the strength, and namely: a grid is weak with respect to the installation if *Rs* is below 8 to 10 times, and a grid is strong when the ratio *Rs*. above 20 to 25 times, as described in the reference [2] and also in other technical regulations in different countries. In this example, the ratio Rs is 11.

The data of the network shall be provided by the utility, but for given example the following data are taken into account:

annual average wind speed: $v_a$ =7,2 m/s
nominal voltage of the grid: 20 kV
short-circuit power of the grid: *S*k = 40 MVA
grid impedance angle: $\varphi_k$ = 80º
number of wind turbines: N = 6
type of wind turbines: stall, direct grid coupled induction generator

From the power quality measurement of a single wind turbine, which was performed in conformity with IEC 61400-21, the data provided by manufacturer in the reference [2] are:

rated power Pn =600 kW
rated apparent power: Sn=607 kVA
rated voltage: Un=690 V
rated current In=508 A
maximum power P60=645 kW
maximum reactive power Q60=114 kvar

The wind turbine flicker coefficient for continuous operation, $c\ (\psi_k, v_a)$ has been stated for the grid impedance phase angles $\psi_k$ = 30°, 50°, 70° and 85° in the Table I.1 for four different wind speed distributions with annual average wind speed $v_a$ = 6 m/s, 7,5 m/s, 8,5m/s and 10 m/s respectively.

TABLE I.1
DATA OF THE WIND TURBINE, RELATED TO THE VVOLTAGE FLUCTUATIONS FOR CONTINUOUS OPERATION

| Grid impedance angle $\psi_k$ in PCC | 30º | 50º | 70º | 85º |
|---|---|---|---|---|
| Annual average wind speed $v_a$ [m/s] | Flicker coefficient, $c\ (\psi_k, v_a)$ | | | |
| 6 | 7,1 | 5,9 | 5,1 | 6,4 |
| 7,5 | 7,4 | 6,0 | 5,2 | 6,6 |
| 8,5 | 7,8 | 6,5 | 5,6 | 7,2 |
| 10 | 7,9 | 6,6 | 5,7 | 7,3 |

The voltage change factor $k_u(\psi_k)$ and the flicker step factor $k_f(\psi_k)$ of the wind turbine for the actual $\psi_k$ at the site may be found from the Table I.2 by applying linear interpolation.

a) Steady-state voltage:

The calculation for steady-state voltage by (6), having in view that the apparent power at the 1-min. active power peak is given by:

$$S_{60} = \sqrt{P_{60}^2 + Q_{60}^2} \qquad (14)$$

$$S_{60} = 655 \text{ kVA}$$

$$\varphi = \arctan(Q_{60}/R_{60}) \qquad (15)$$

From (15) is obtained φ=10° inductive.

For only one wind turbine, the steady-state voltage change of the grid at PCC, by applying (6) will be:

$d$ = 0,00256 or 0,256 %

For the wind farm with 6 WT the voltage change is as follows:

$d_{6WT}$ = 6*0,00256 =0,01536 or 1,54 %.

TABLE I.2
DATA OF THE WIND TURBINE, RELATED TO VOLTAGE FLUCTUATIONS FOR SWITCHING OPERATION

| **Case of switching operation** | **Start-up at cut-in wind speed** | | | |
|---|---|---|---|---|
| Maximum number of switching operations, $N_{10}$ | 3 | | | |
| Maximum number of switching operations, $N_{120}$ | 30 | | | |
| Network impedance phase angle, $\psi_k$ (deg.) | 30º | 50º | 70º | 85º |
| Flicker step factor, $k_f(\psi_k)$ | 0,35 | 0,34 | 0,38 | 0,43 |
| Voltage change factor, $k_u(\psi_k)$ | 0,7 | 0,7 | 0,8 | 0,9 |
| **Case of switching operation** | **Start-up at rated wind speed** | | | |
| Maximum number of switching operations, $N_{10}$ | 1 | | | |
| Maximum number of switching operations, $N_{120}$ | 8 | | | |
| Network impedance phase angle, $\psi_k$ (deg.) | 30º | 50º | 70º | 85º |
| Flicker step factor, $k_f(\psi_k)$ | 0,35 | 0,34 | 0,38 | 0,43 |
| Voltage change factor, $k_u(\psi_k)$ | 1,30 | 0,85 | 1,05 | 1,60 |

b) Flicker:

1) The flicker distortion for continuos operation

For the given example the annual average wind speed of the site of the wind farm at hub height of the turbines is 7,2 m/s, corresponding to the wind speed class of 7,5 m/s. The power quality data sheet, corresponding to the flicker coefficients $c(\psi_k, v_a)$ has been stated at the grid impedance phase angles $\psi_k$ 70° and 85°. The wind turbine flicker coefficient for continuous operation is found by linear interpolation of data in Table I.1: $c\ (\psi_k,\ v_a) = c\ (80^o,\ 7{,}2\ m/s) = 6{,}1$ The planning levels and emission levels of $P_{st}$ and $P_{lt}$ shall be compared with the specifications in Table II, provided by IEC 61300-3-7. In conformity with the reference [9] the maximum permitted flicker level for medium voltage grids is $P_{lt} = 0{,}25$. The flicker distortion for continuos operation of a single wind turbine can be calculated using (7) with the above flicker coefficient. For one wind turbine, the long-term flicker emissions: $P_{lt}$=6,1*607/40000=0,093<0,25.

TABLE II
FLICKER PLANNING AND EMISSION LEVELS
FOR MEDIUM AND HIGH VOLTAGE

| Flicker severity factor | Planning levels | | Emission levels |
|---|---|---|---|
| | MV | HV | MV and HV |
| $P_{st}$ | 0,9 | 0,8 | 0,35 |
| $P_{lt}$ | 0,7 | 0,6 | 0,25 |

For the whole wind farm, the long-term flicker emissions from the sum of wind turbines may be approximated as:

$$P_{lt\Sigma} = P_{lt(1WT)} \cdot \sqrt{\sum_{i=1}^{N_{wt}}} \qquad (16)$$

From (16), the long-term flicker emissions for wind farm: $P_{lt\Sigma}$ =0,2278 <0,25. Thus the flicker during continuous operation is within the limits.

2) The flicker distortion for switching operation

Having in view the switching operations, the voltage change due to the inrush current of a switching and the flicker effect of the switching shall be checked.

On the assumption that the control of wind farm ensures, that two or more wind turbines are not switched on simultaneously, using (8) can result the voltage change due to the inrush current corresponding to a switching operation of only one wind turbine, approximated as:

$$d = 1{,}32\ \%$$

Where, the voltage change factor $k_u(\psi_k)$ is 0,87 for the case of switching operation of wind turbine at rated wind speed, considered as the worth case of switching.

The flicker emission due to switching operations of a single wind turbine, corresponding to cut-in at rated wind speed, can be calculated using (10), and will result:

$$P_{lt} = 8 \cdot 8^{0,31} \cdot 0{,}413 \frac{607}{40000} = 0{,}0955$$

where, the flicker step factor of the wind turbine at the PCC is $k_f(80°) = 0{,}413$.

The flicker effect has to be calculated for both types of switching: for the cut-in at cut-in wind speed and for the cut-in at rated wind speed. Thus it can be calculated:

Type of switching: cut-in at cut-in wind speed
- number of switchings: $N \cdot N_{120} = 6 \times 30$
- flicker step factor: $k_f(\psi_k) = 0{,}413$
- the flicker distorsion: $P_{lt} = 0{,}25$

Type of switching: cut-in at rated wind speed
- number of switchings: $N \cdot N_{120} = 6 \times \cdot 8$
- flicker step factor: $k_f(\psi_k) = 0{,}413$
- the flicker distorsion: $P_{lt} = 0{,}17$

For the wind farm that consist of 6 wind turbines, the grid can sustain the disturbances without reinforcement, because in both cases of switching, $P_{lt} < 0{,}25$. If the wind farm will consist of 9 wind turbines of the same type as those above-mentioned, will result $P_{lt} = 0{,}28$ for switching at cut-in at cut-in wind speed, and $P_{lt} = 0{,}19$ for the switching at cut-in at rated wind speed. Due to the fact that the emission level is over the accepted value, the improvement should be made by strengthen the grid or by improve the power quality, either by limiting the number of switching within 2-hours or by decreasing the flicker emission during switching.

The limits of the flicker emissions provide the maximum allowable number of wind turbines that can be connected to the grid, and for this purpose the essential grid code requirements are related to frequency, voltage and wind turbine behaviour in case of grid faults [1], [4], [5], [6], [14].

## IV. THE GRID CODE

In many European countries, the requirements for connections to the transmission system are based on the characteristic of synchronous generating plants [11]. New power grid code requirements need to be constantly updated in compliance with new technology developments in order to allow an easier access to the transmission system for unconventional forms of generation. The grid codes differ, often significantly, from country to country. The rules should basically be harmonised across Europe, because of power system stability. These rules are related to: behavior of wind power plant in normal network conditions; behavior during and after network disturbances; frequency response / active power control; voltage control / reactive power; verification and testing, and site-related aspects [4], [6]. Finally, in more countries the grid codes must be updated to include new rules.

## V. CONCLUSIONS

With a view to meet the grid code requirements of new wind farms, this paper should be helpful to easier orientation in finding of adequate type of wind turbines that can be installed in the intended sites, depending on the specific conditions, because is here some simplified evaluation mentioned with references to the specific literature. The existing power grids must be reinforced, and also the new grid code requirements demand to be constantly updated in compliance with new technology developments in order to allow an easier access to the transmission system for unconventional forms of generation. Currently, more grid operators are changing the interconnection requirements for wind power, especially for the transmission systems [6]. This means that more wind power will enter into the electrical system in the near future.

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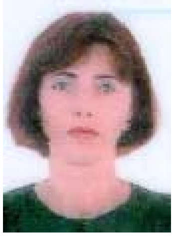
## VIII. BIOGRAFIES



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