Integrating RES into the Romanian transport system

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***Abstract*--** **The interconnection of wind sources characterized by a significant variability of generated power and the continuous growth of installed power in wind farms raises a number of specific problems both to the utilities and to the power system operator. One of these issues is to ensure the safe operation of the power system when the reduction of the wind generated power occurs. The compensation of not generated power by these wind sources has to be done by other sources that must ensure the necessary power reserve. The paper deals with the access of the wind farms to the Romanian transport system, both from the legislative (policies, regulations, certificates, and incentives) and from the power quality point of view. The flicker study becomes necessary as the wind power penetration level increases quickly.**

***Index Terms*—wind generators, legislation, flicker**

I. INTRODUCTION

THE renewable energy sources, with powers varying from 100 kW to few MW, are increasingly present in the electrical networks. The economic opportunities, the liberalization and the potential benefits for the electrical utilities (peak shaving, support for distribution and transmission networks) are contributing to the already existing trend, leading to a more decentralized energy market [1].

In Romania, nowadays, there are 8 MW of wind turbines installed and interconnected to the electrical networks. Promotion of the consume and production of electrical energy from renewable sources of energy is encouraged by the legislation, in which is established as objective a percentage of 30% energy production from renewable energy sources from the national gross consume until 2010 [2-6].

As these renewable sources are increasingly penetrating the power systems, the impact of the wind turbines on network operation and power quality is becoming important [7]. Due to the output power variations of the wind turbines, electrical flicker is produced. The capability of the power system to absorb this perturbation is depending on the fault level at the point of common coupling. In weak networks or in power systems with a high wind generation penetration, the integration of these sources can be limited by the flicker level that must not exceed the standardized limits.

Section II presents the Romanian wind generation status, section III deals with the green certificates market from Romania, reporting the targets assumed. Section Iv deals with the variability of the wind farms, and in particular the power reserve. Section V focuses on the flicker perturbation produced by the wind turbines, caused by the switching operations (start and stop of the wind turbine) and by the continuous operation. Section V presents calculations of the flicker level both during switching and continuous operation of the wind turbine. Section VI reports the conclusions.

II. ROMANIAN WIND GENERATION STATUS

In the last years, the interest for installing wind turbines in Romania has increasingly growth [5, 6]. The major request is in the east part of Romania. In conformity with the present regulations, the independent producers must obtain the technical interconnection approval, which consist in the following documents presented to the Transmission Grid Operator: an interconnection study for the wind turbines, urbanism certificate, and the property certificate. In Romania, the request for installing wind turbines is greater than the transmission grid real possibilities to evacuate the produced energy.

Table I reports the studies conducted in Romania for interconnecting wind turbines.

TABLE I. STUDIES CONDUCTED FOR INTERCONNECTING WIND TURBINES IN THE EAST AREA OF ROMANIA

Area	**Total installed power**	**Rated power WT (MW)**
Tulcea	1063	1 ÷ 300
Constanta	2339,8	0,8 ÷ 600
Moldova	1219	36 ÷ 400
TOTAL	**4621,8**	

The intermittent character of the wind constrains the power system to have an available power reserve in order to overcome the turn on/off of the wind turbines.

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III. THE GREEN CERTIFICATES MARKET

The market for the green certificates is operating in accordance with the legislation emitted by the National Agency for Energy Regulations 40/2005 [8]. The green certificate is a document that states a 1MWh electrical energy produced by renewable sources.

The legislative regulation to improve the duty to produce green electricity is based on the necessity to specify the differences between several systems of renewable energy sources and:

- modality of the declaration on the amount of the conventional electricity subordinate to the duty;
- modality of certification of the green energy systems and component;
- rules for the issue and the sale of green certificates.

The change in the electric field has been characterized by the following:

- the electricity production has been liberalized;
- the auto-production and auto-consumption has been extended and release from many bonds;
- the production of electricity from renewable energy sources has been entire liberalized abolishing all the bonds.

The value of the green certificates is established through market mechanisms:

- through bilateral contracts between the producers and the suppliers;

- on a centralized market organized by the Commercial operator (OPCOM)

The price for the green certificates varies in an interval min – max [8]. The minimum price is imposed for the producers protection and the maximum price, for the consumers protection. For the period 2005-2012, the minimum and maximum year values for the transactions with green certificates is of 24 Euro/certificate, respectively 42 Euro/certificate. The shares are established in conformity with the objective assumed by Romania in the negotiations for entering the European Union, respectively 33% energy production from renewable sources from the intern electrical energy gross consume in 2010-2012.

The obligatory annual shares are reported in Table II.

TABLE II. OBLIGATORY ANNUAL SHARE OF GREEN CERTIFICATES

Share applied to the suppliers (%)	Year
0.7	2005
2.22	2006
3.74	2007
5.26	2008
6.78	2009
8.3	2010-2012

IV. VARIABILITY OF WIND FARMS

The growth of the installed power in wind farms requires addressing specific issues for ensuring the safe operation of the power system. The variability of generated power and the forecast 24 hours before, still insufficiently precise, of the generated power determine the system operator to solve additional issues with respect to a power system with conventional power plants. A greater flexibility of the power system management is required. This can lead to the growth of the power reserve in the electrical network. Certainly these measures induce some costs that are included in the selling price of electricity to end users.

The detail knowledge of the wind turbines parameters, organizational measures needed to conduct their operational and informational links between wind parks operators and the system operator may limit the implications of wind power generation variability and ensure a safe and stable operation of power system.

The variability of wind source is an important feature of the wind farms generation, but its importance may be limited if the wind speed is estimated on the basis of 24 hours ahead forecast. The power P generated by the wind source, function of wind speed v, can be estimated with [9]

$$P = \frac{P_{max}}{1 + e^{\frac{v - v_0}{w}}} \tag{1}$$

In (1) a sigmoid curve, for the power variation function of wind speed, is considered. This curve is very close to the power variation curve of the existing facilities. Power P_{max} corresponds to the maximum power, and the measurements v_0 and w are determined form the real curve of the wind turbine. In Fig. 1, the power variation curve of a 660 kW wind turbine, function of wind speed (measured values), and the sigmoid curve are illustrated.

The analysis of the two curves highlights that, knowing through forecast the wind speed with sufficiently good accuracy, can be determined analytically the power generated by the wind turbine.

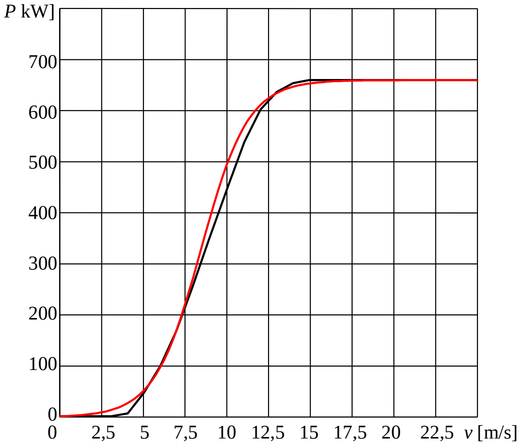

Fig. 1. Approximation of the power generated by a 660kW wind turbine through a sigmoid curve (v_0=8,4686; w=-1,4);
– measured curve; – approximated curve

Uncertainty of electricity production from wind resources is highly dependent on the accuracy of wind speed forecast. Current systems for monitoring wind speed allow an hourly forecast, for a day before, with a maximum error of 6-8%, and 4 hours ahead the forecast error is not greater of 4-6%.

The achievement of a correct forecast is the objective of wind park operator. Data from meteorological centers placed, usually, outside the wind park should be corrected such that to be in accordance with its placement. For this, the accuracy degree of the forecast depends largely on wind park operator's ability to interpret data from the weather metering points in the area.

In general, wind park operator knows, for a particular site and a certain period, the way in which varies the power generated. In Fig. 2, the variation of power generated by a windmill, with nominal power of 660 kW at a site near the Black Sea coast, during the 6 days in September is illustrated. Curve peaks are recorded around the 21 hours, and the minimum are recorded around the 17 hours.

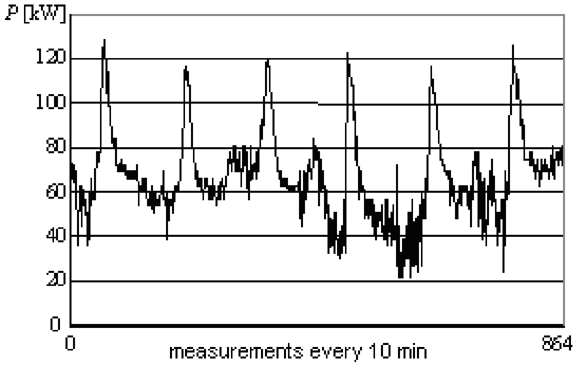

Fig. 2. Variation of the power generated by 660kW wind turbine, for 6 days (month of September)

The power generated by a wind farm has a high variability, but it is predictable, with relatively small negative errors.

Variability of power generated in the wind parks, with different locations, is significantly reduced compared to the case of a single group wind turbine.

Experience of power system operators, with wind farms interconnected to the electrical network, highlighted that the level of reserve required to balance the variability of power production from these facilities is of the same order of magnitude with deviations from forecast (see Fig. 3).

For example, in Germany, the power reserve is about 9% of installed power in wind farms, and in England a reserve of 1.6% of installed power in wind farms has been used [10]. In general, if the power generated by wind farms is less than 5% of power generated in the system, the increase of power reserve in the system is not necessary [9].

In Fig. 3, Germany is considering the forecast the day before, England and Sweden computes the power reserve on the basis of 4 hours ahead forecast, and the other countries base on the hourly forecast.

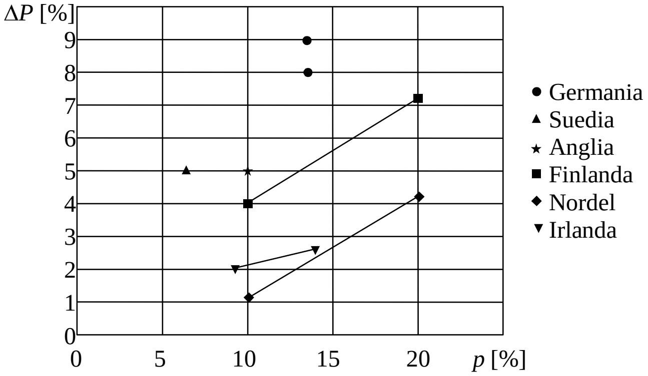

Fig. 3. Variation of power reserve growth ΔP with the penetration rate p of wind turbines

The data in Fig. 3 highlight a variation between 1% and 9% of the reserve, function of the specific conditions of each country, structure of system production, and possibility of accessing the energy balance from neighboring countries. In all cases the reserve ΔP is obtained, according to existing regulations, function of the installed power of the operating wind turbines, and the integration rate p is determined function of the installed power in the electrical system.

In assessing the necessary reserve for compensating the deviations from the hourly forecast of wind turbines production, the consideration that the wind turbines generate the maximum power for a short period of time has to be made. In Fig. 4 the curve of power generated in the power system (curve 1) and the curve of power generated by wind power (curve 2) are illustrated [11].

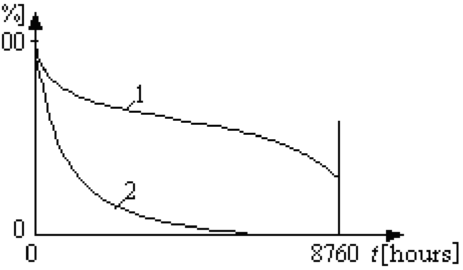

Fig. 4. The power generated by the power system (curve 1) and the power generated by the wind turbines (curve 2)

Analysis of the curves in Fig. 4 highlights that, in reality, a 8% power reserve of the wind farms installed power represents a much larger reserve with respect to the power generated.

Interconnecting wind farms to the Romanian power system, with an installed power of 2000 MW, will require the increase of the system power reserve of about 150 MW, which corresponds to an increase of about 20% of the current power reserve.

V. FLICKER PRODUCED BY WIND TURBINES

A possibility for reducing flicker supposes the establishment of some regulations, when and how often the wind turbines operators can start or vary the output power of these systems. In some cases, flicker problems can be solved without a detailed study, by simply adjusting a control element, until the flicker level is diminishing under the permitted value. In some other cases, complex analysis for limiting flicker is requested.

Determination of flicker due to output power variations of renewable sources is difficult, because depends of the source's type, of generator's characteristics and network impedance.

For the case of wind turbines, the long term flicker coefficient P_{lt} due to commutations, computed over a 120 min interval and for step variations, becomes [12]:

$$P_{lt} = \frac{8}{S_{sc}} \cdot N_{120}^{1/3.2} \cdot k_f(\psi_{sc}) \cdot S_n \tag{2}$$

where N_{120} is the number of possible commutations in a 120 min interval, $k_f(\psi_{sc})$ is the flicker factor defined for angle $\psi_{sc} = \arctan(X_{sc}/R_{sc})$, S_n – rated power of the installation, and S_{sc} – fault level at point of common coupling (PCC)

For N wind generators connected at PCC, the summing level of the flicker perturbation is given by

$$P_{lt,\Sigma} = \frac{8}{S_{sc}} \cdot \left\{ \sum_{i=1}^{N} N_{120,i} \cdot \left[k_{f,i}(\psi_{sc}) \cdot S_{n,i} \right]^{3.2} \right\}^{0.31} \tag{3}$$

where $N_{120,i}$ is the number of possible commutations in a 120 min interval of the installation i, $k_{f,i}(\psi_{sc})$ is the flicker factor of installation i, and S_n – rated power of the installation i.

When the wind farms have the same type of installation, (3) becomes

$$P_{lt,\Sigma} = \frac{8}{S_{sc}} \cdot N_{120}^{0.31} \cdot k_f(\psi_{sc}) \cdot S_n \cdot N^{0.31} \tag{4}$$

For a 10 minutes interval, the short-term flicker P_{st} is defined [12]:

$$P_{st} = \frac{18}{S_{sc}} \cdot N_{10}^{1/3.2} \cdot k_f(\psi_{sc}) \cdot S_n \tag{5}$$

where N_{10} is the number of possible commutations in a 120 min interval

For N wind generators connected at PCC, the summing level of the flicker perturbation is given by

$$P_{st,\Sigma} = \frac{18}{S_{sc}} \cdot \left\{ \sum_{i=1}^{N} N_{10,i} \cdot \left[k_{f,i}(\psi_{sc}) \cdot S_{n,i} \right]^{3.2} \right\}^{0.31} \tag{6}$$

where $N_{10,i}$ is the number of possible commutations in a 20 min interval of the installation i, $k_{f,i}(\psi_{sc})$ is the flicker factor of installation i, and S_n – rated power of the installation i.

When the wind farms have the same type of installation, (6) becomes

$$P_{st,\Sigma} = \frac{18}{S_{sc}} \cdot N_{10}^{0.31} \cdot k_f(\psi_{sc}) \cdot S_n \cdot N^{0.31} \tag{7}$$

The values of flicker indicator for wind turbines, due to normal operation, can be evaluated using flicker coefficient $c(\psi_{sc}, \upsilon_a)$, dependent on average annual wind speed, υ_a, in the point where the wind turbine is installed, and the phase angle of short circuit impedance, ψ_{sc}:

$$P_{st} = P_{lt} = c(\psi_{sc}, v_a) \cdot \frac{S_n}{S_{sc}}. \tag{8}$$

The flicker coefficient $c(\psi_{sc}, \upsilon_a)$ for a specified value of the angle ψ_{sc}, for a specified value of the wind speed υ_a and for a certain installation is given by the installation manufacturer, or can be experimentally determined based on standard procedures [12]. Depending on the voltage level where the wind generator (wind farms) is connected, the angle ψ_{sc} can take values between 30° and 85°.

When at the point of common coupling (PCC) more wind generators are connected, the summing of the flicker perturbations is done in accordance with:

$$P_{st,\Sigma} = P_{lt,\Sigma} = \frac{1}{S_{sc}} \cdot \sqrt{\sum_{i=1}^{N} \left[c_i(\psi_{sc}, v_a) \cdot S_{n,i} \right]^2} \tag{9}$$

where $c(\psi_{sc}, \upsilon_a)$ is the flicker coefficient for the installation i, $S_{n,i}$ – rated power of the installation i, and N is the total number of wind generators connected at PCC.

In many cases, the wind farms connected at PCC have the same type of installation and (9) becomes:

$$P_{st,\Sigma} = P_{lt,\Sigma} = \frac{S_r}{S_{sc}} \cdot c(\psi_{sc}, v_a) \cdot \sqrt{N}\ . \tag{10}$$

Equation (10) is established considering the N generators as being independent from the perturbation emission point of view. For the wind generator installations with asynchronous generators are possible the synchronization of the blades rotation and in this case, from the perturbation point of view, the wind farm is operating as an equivalent generator, and the flicker level can be computed using:

$$P_{st,\Sigma} = P_{lt,\Sigma} = \frac{N \cdot S_r}{S_{sc}} \cdot c(\psi_{sc}, v_a). \tag{11}$$

Flicker evaluation is based on the IEC standard 61000-3-7 [13] which gives guidelines for emission limits for fluctuating loads in medium voltage and high voltage networks. Table III reports the recommended values.

TABLE III. FLICKER PLANNING AND EMISSION LEVELS FOR MEDIUM VOLTAGE (MV) AND HIGH VOLTAGE (HV) NETWORKS

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

VI. CASE STUDIES

The case studies refer to a wind turbine of 650kVA installed in the district of Tulcea, Romania. The tower height is 80 meters, the rotor diameter is 47 m, and the swept area is 1735 m^2. The electrical energy production during the months of February and March 2008 were 127095 kWh, respectively 192782 kWh. The average wind speeds, measured at 60m height, during February was 6.37m/s while during march was 7.32m/s.

The measurements data for the month of February are reported in Table III.

Table III. Wind Turbine Experimental Data during the Month of February

Average wind speed at hub height[m/s]		
60m	50m	40m
6.37	6.30	6.045

The experimental data for the month of March are reported in Table IV.

Table IV. Wind Turbine Experimental Data during the Month of March

Average wind speed at hub height[m/s]		
60m	50m	40m
7.32	7.165	6.95

Measurements were conducted on the wind turbine system described above for the month of January 2008. The variation of the wind speed over the monitoring period is shown in Fig. 5. The variation of the RMS value of the turbine output power is shown in Fig. 6. The intermittent character of the produced power is clearly evident.

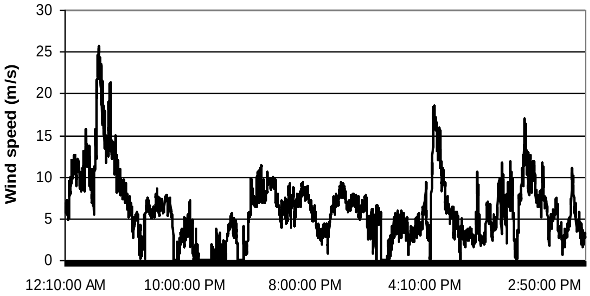

Fig. 5. Wind speed variation during the 1 month monitoring period

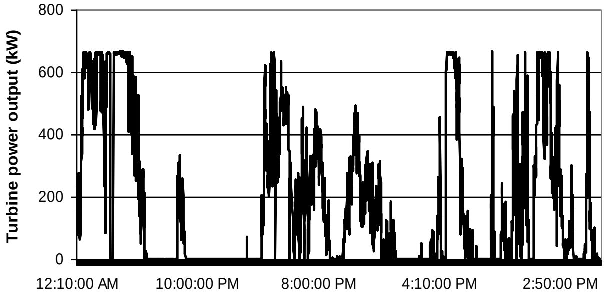

Fig. 6. Turbine output power variation during the 1 month monitoring period

The tower shadow effect for the wind generator determines a variation of the absorbed energy, which is measured as a power variation at generator terminals. Fig. 7,a) shows the wind generator, while Fig. 7,b) illustrates the tower shadow effect corresponding variation of the generator output power.

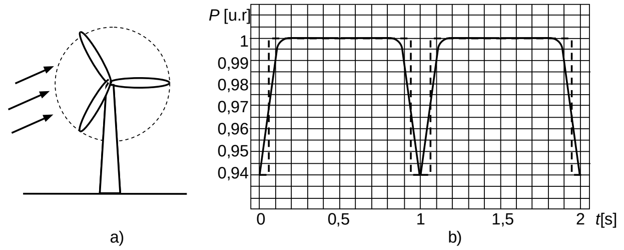

Fig. 7. Variation of the wind generator output power due to the tower shadow effect

The measured values of the flicker coefficient $c(\psi_{sc}, \upsilon_a)$ for different values of the annual average wind speed υ_a and for different network impedance angle ψ_{sc} are reported in Table V. Table VI reports the flicker coefficient k_f values for voltage step variations, for the same wind generator.

Table V. Values of the Flicker Factor for Various Values of the Wind Speed υ_a and for Various Angles ψ_{sc}

Annual wind speed [m/s]	Network impedance angle ψ_{sc} [°]			
	30º	50º	70º	85º
6	3.1	2.9	3.6	4.0
7.5	3.1	3.0	3.8	4.2
8.5	3.1	3.0	3.8	4.2
10	3.1	3.1	3.8	4.2

Table VI. Values of the Flicker Factor k_f

		Network impedance angle ψ_{sc} [°]			
		30º	50º	70º	85º
Flicker factor k_f for voltage step variations	With start at minimum speed	0.02	0.02	0.01	0.01
	With start at rated speed	0.12	0.09	0.06	0.06
Installation is sized for $N_{10} = 3$; $N_{120}=35$					

The computations based on the values reported in Table V and Table VI lead to the flicker indicator values:

- continuous operation, annual average wind speed υ_a=7.5, interconnection with the medium voltage network (ψ_{sc}=50°, S_{sc} = 300 MVA)

$$P_{st} = P_{lt} = \frac{S_r}{S_{sc}} \cdot c(\psi_{sc}, v_a) = \frac{0.65}{300} \cdot 3 = 0.0065 .$$

- generator interconnection at minimum speed of the wind turbine

$$P_{st} = 18 \cdot N_{10}^{0,31} \cdot k_f(\psi_{sc}) \cdot \frac{S_r}{S_{sc}} = 18 \cdot 3^{0,31} \cdot 0,02 \cdot \frac{0.65}{300} = 0,00109 ;$$

$$P_{lt} = 8 \cdot N_{120}^{0,31} \cdot k_f(\psi_{sc}) \cdot \frac{S_r}{S_{sc}} = 8 \cdot 35^{0,31} \cdot 0,02 \cdot \frac{0.65}{300} = 0,00104 .$$

- generator interconnection at rated speed of the wind turbine

$$P_{st} = 18 \cdot N_{10}^{0,31} \cdot k_f(\psi_{sc}) \cdot \frac{S_r}{S_{sc}} = 18 \cdot 3^{0,31} \cdot 0{,}09 \cdot \frac{0.65}{300} = 0{,}0049\,;$$

$$P_{lt} = 8 \cdot N_{120}^{0,31} \cdot k_f(\psi_{sc}) \cdot \frac{S_r}{S_{sc}} = 8 \cdot 35^{0,31} \cdot 0{,}09 \cdot \frac{0.65}{300} = 0{,}0047\,.$$

VII. CONCLUSIONS

In the last years, the interest for installing wind turbines in Romania has increasingly growth.

The power reserve level in the system, for solving the problems related to wind farms interconnection, highly depends on the accuracy with which the wind farm operator provides the production forecast the day before, on the basis of the data regarding wind forecast.

The best solution for limiting the problems regarding the variability of the wind farms production is the improvement of wind forecast. In this regard, the wind farms operator can provide a forecast one day ahead and an improved forecast 4 hours before.

Due to the output power variations of the wind turbines, electrical flicker is produced. Electrical flicker is produced due to the wind turbine switching operations (start or stop), and due to the continuous operation. The flicker study becomes necessary as the wind power penetration level increases quickly.

The concrete determination of the perturbation level of the voltage fluctuations, in the power system, requires information from equipment producers regarding the flicker factors and the operation type of the installations.

In present, there are technical solutions for limiting the voltage fluctuations until the desired level. Still, a precise knowledge of the perturbation characteristics and the choice of the best solution, form technical and economical point of view, are required.

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