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Power Quality analysis in Renewable Energy Systems Supplying Distribution Grids

N. Golovanov[1], G.C. Lazaroiu[1], M. Roscia[2], D. Zaninelli[3]

[1] Department of Power Systems
University Politehnica of Bucharest,
Splaiul Independentei 313, 060042 Bucharest (Romania)
Phone/Fax number:+0040 724528546, e-mail: nicolae_golovanov@yahoo.com, clazaroiu@yahoo.com

[2] University of Bergamo
5 Marconi Street, 24044 Dalmine, Bergamo, Italy
e-mail: cristina.roscia@unibg.it

[3] Politecnico di Milano
Via La Masa 34, 20156 Milan, Italy
e-mail: dario.zaninelli@polimi.it

Abstract. The paper deals with power quality case studies conducted on existing renewable sources based systems. Voltage fluctuations determined by a 0.65 MVA wind turbine are analyzed. The impact of photovoltaic systems on steady state voltage variations and current harmonics is investigated. The correlation between the generated power and the main power quality indices is highlighted.

Key words

power quality, small scale renewable sources, voltage fluctuations, harmonics.

1. Introduction

The increasing penetration rate of RES in the power systems is raising technical problems, as voltage regulation, network protection coordination, loss of mains detection, and RES operation following disturbances on the distribution network [1]. These problems must be quickly solved in order to deeply exploit the opportunities and benefits offered by the RES technologies.

As the RES are interconnected to the existing distribution system, the utility network is required to make use of RES maintaining and improving the supply continuity and power quality delivered to the customers [2].

The present paper deals with the experimental investigation of the impact of renewable sources on power quality. The voltage fluctuations generated by wind turbines during continuous operation are analyzed.

The steady state voltage variation at the point of common coupling due to the PV system connection is analyzed for sunny and cloudy days. The PV systems interfaced to the main grid with the help of inverters are injecting harmonics in the 50 Hz grid. The correlation between the PV generated power and the main harmonic distortion indices is presented.

2. Voltage fluctuations (flicker effect)

The estimation of voltage flicker determined by continuous operation of renewable sources is difficult, because depend of the source's type, of generator's characteristics and network impedance [3].

The values of flicker indicator for wind turbines [5], 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}:

$$P_{st} = P_{lt} = c(\psi_{sc}, v_a)\frac{S_r}{S_{sc}}. \quad (1)$$

where S_r – rated power of the installation, and S_{sc} – fault level at point of common coupling (PCC).

The flicker coefficient $c(\psi_{sc}, \upsilon_a)$ for an angle ψ_{sc}, wind speed υ_a and certain installation is given by the installation manufacturer, or can be determined experimentally based on standard procedures. Depending on the voltage level where the wind generator (wind farms) is connected, the angle ψ_{sc} can take values between 30° (for the medium voltage network) and 85° (for the high voltage network). Flicker evaluation is based on the IEC standard 61000-3-7 [5], which provides guidelines for emission limits for fluctuating loads in medium and high voltage networks. Table I lists the recommended values.

Table I. - Flicker planning levels for medium voltage (MV) and high voltage (HV) networks.

Flicker severity factor	Planning levels	
	MV	HV
P_{st}	0.9	0.8
P_{lt}	0.7	0.6

The flicker evaluation determined by a wind turbine of 0.65 MVA is analyzed. The wind turbine has a tower height of 80 m, the rotor diameter is 47 m, and the swept area is 1,735 m2. The electrical energy production during the months of February and March were 127,095 kWh and 192,782 kWh, respectively. The average wind speed, measured at 60 m height, during February was 6.37 m/s, while during March it was 7.32 m/s. The measurement data for the month of February are reported in Table II. The experimental data for the month of March are reported in Table III.

Table II. - Wind turbine experimental data during the month of February.

Average wind speed at hub height (m/s)		
60 m	50 m	40 m
6.37	6.30	6.045

Table III. - Wind turbine experimental data during the month of March.

Average wind speed at hub height (m/s)		
60 m	50 m	40 m
7.32	7.165	6.95

Measurements were conducted on the wind turbine system described in this paper. The variation of wind speed over the monitoring period is shown in Figure 1. The variation of turbine output power is shown in Figure 2. The intermittent character of the produced power is clearly visible.

The 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 IV.

Table IV. -Values of the flicker factor for various values of the wind speed va and for various angles ψ_{sc}

Annual wind speed v_a [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

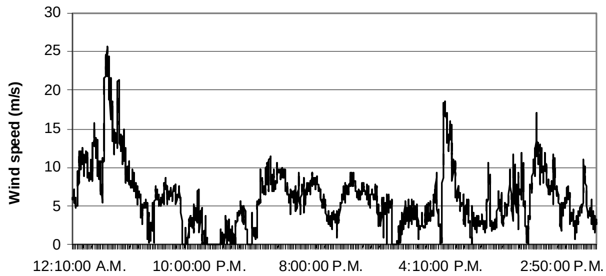

Figure 1. Wind speed variation during the one month monitoring period.

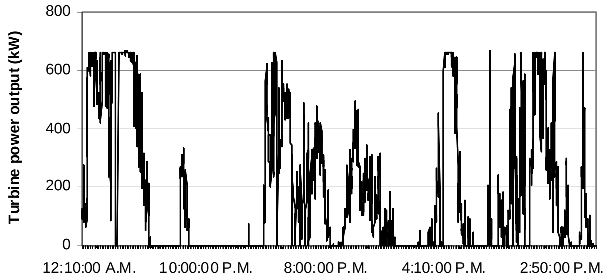

Figure 2. Turbine output power variation during the one month monitoring period.

The computations based on the values reported in Table IV lead to the flicker indicator values for wind turbines continuous operation, annual average wind speed υ_a=7.5, interconnection with the medium voltage network (ψ_{sc}=50°, S_{sc} = 300 MVA, S_r = 0.65MVA)

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

The presented voltage fluctuations study, made for one turbine, becomes necessary in large wind farms as the wind power penetration level increases quickly.

3. Steady state voltage variations

The weather changes or passing clouds and the variable nature of solar radiation can cause variations of PV output power [6]. The variation of the power produced by a 30 kW PV system is illustrated in Figure 3. Typically, the photovoltaic panels installed on house roves generate up to 5 kW.

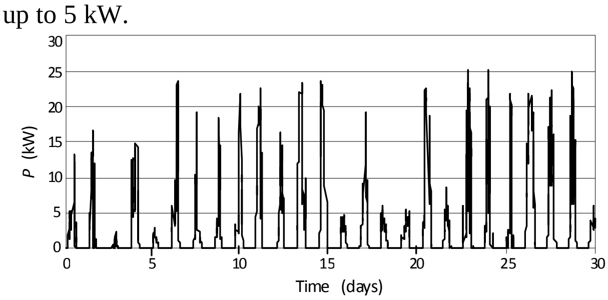

Figure 3. Variation of PV system power output during a month.

The connection of these variable renewable sources can cause a voltage rise at PCC and in the grid. The utility has the general obligation to ensure that customer voltages are kept within prescribed limits. A voltage variation ΔV between V_{max} and V_{min} can appear on short periods. This voltage variation can highly stress the electrical devices supplied by the power system, and in particular the owner of the photovoltaic facility (as shown in Figure 4). Figure 4 illustrates the possible case of a summer mid-day, when the load downstream PCC is relatively small and the PV output power exceeds the demand.

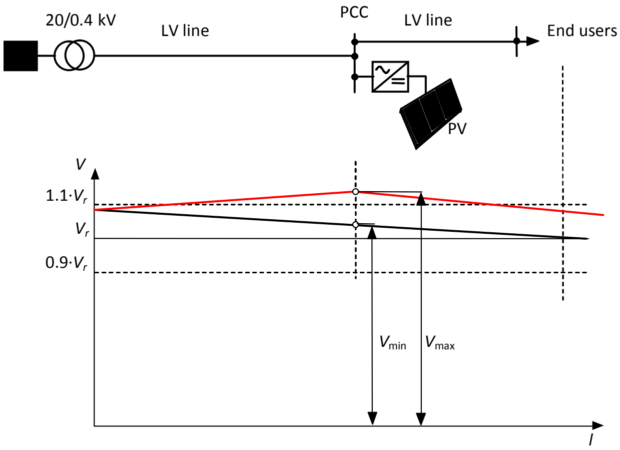

Figure 4. Influence of PV on voltage level: without PV source generating (black line); with PV source generating (red line).

The voltage variations can affect the characteristics of the electrical equipment and household appliances (loss of the guaranteed performances, modifications of the efficiency) leading in some cases even to the interruption of operation [6]. The voltage variation at PCC can be expressed as:

$$\Delta V = \frac{S_{PV}}{S_{sc}} \cdot \cos\left(\psi_{sc} - \varphi\right) \quad (2)$$

where S_{PV} is the power produced by PV, S_{sc} is the short circuit power at PCC, $\psi_{sc} = \arctan(X/R)$ is the angle of the network short circuit impedance, φ is the phase angle of the PV output current (we consider that the electric quantities are sinusoidal). In existing power systems, there are measures such that the line voltage to be sinusoidal.

The analysis of (2) highlights that limiting the voltage variation ΔV requires a careful analysis of the grid where the PV installation is connected. A power system characterized by a high short-circuit current (high short-circuit power) and a small angle ψ will be characterized by reduced voltage variations at PCC. For the medium voltage network ($\psi_{sc} \approx 50°$) and the low voltage network ($\psi_{sc} \approx 30°$), with small short-circuit powers, especially if the PCC is far from the substation point, large voltage variations may occur caused by PV installation of large capacity.

4. Current harmonic perturbations

The interconnection between the PV power systems and the 50 Hz grid is realized with the help of an inverter that transforms the dc output power of the PV to the 50Hz ac.
The harmonic spectrum is a function of inverter topology, switching frequency, control, etc. The measurements were conducted for a particular case of a photovoltaic plant connected to the main supply through a 6-pulse converter. The influence of converter configuration on harmonic spectrum was not analyzed. The experimental measurements reveal high values, but not relevant, of *THDI*. The function of photovoltaic systems is accompanied by the injection of some harmonic perturbation into the grid, with a total harmonic distortion factor dependent on the generated power.

Figure 5 illustrates the correlation between the generated power and total current harmonic distortion factor *THDI*, for one monitored day. The analysis of the total harmonic distortion factor has to consider that, for high variability installations, the large *THDI* values can lead to inappropriate conclusions. The total harmonic factor is related to the fundamental component of the electric current I_1:

$$THDI = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1} \quad (3)$$

For the periods with low irradiation (especially during the morning and evening periods), the electric current injected into the grid presents a reduced fundamental component, resulting in a high distortion factor. As the electrical current has small values, the voltage drops in the power system are negligible, and thus the voltage waveform at PCCC is not affected.

For assessing the operation of PV installations in terms of harmonic disturbances injected at PCC, the use of a new indicator *Total Generator Distortion Index* (*TGDI*) is proposed. This indicator is useful for high variability sources, which is related to the rated fundamental current of photovoltaic system I_r:

$$TGDI = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_r} \quad (4)$$

where the rated current I_r is established and indicated for pure sinusoidal measures (a constant current value of the installation).

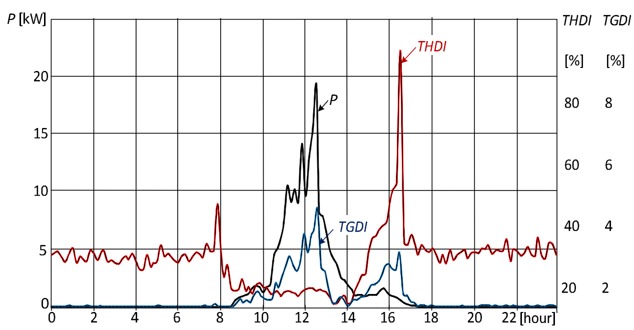

Figure 5. Correlation between the generated power, the total current harmonic distortion factor THDI and the total generator distortion index TGDI.

When the generated power is high (large value of RMS electrical current), the fundamental current is high and the *THDI* is small [7, 8]. For small generated powers, the fundamental current is small and the *THDI* is high. From a practical point of view, this fact is not highly important as the small current values do not influence the voltage quality at point of common coupling. The analysis of waveforms illustrated in Figure 5 shows that the indicator *TGDI* better defines the effect of harmonics into the power grid, with a variation corresponding to the power injected into the network and which determines the voltage waveform at PCC, without transmitting insignificant information for the periods with very low generation.

5. Conclusions

The voltage flicker due to wind turbine continuous operation is investigated. The voltage flicker study becomes necessary as the wind power penetration level increases quickly.

The connection of variable renewable sources can determine a voltage rise at PCC, which can influence the characteristics of the electrical equipment and household appliances.

The photovoltaic sources, connected to the power system through power electronic converters, can pollute the electrical network with harmonic components that must not exceed the stipulated limits. Harmonic indices correlated with the generating power are proposed and monitored for the PV installations.

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