POWER QUALITY MEASUREMENTS AND ANALISYS FOR WIND TURBINES

M. Sanz A. Llombart A. A. Bayod J. Mur
Universidad de Zaragoza – Dpto. Ingeniería Eléctrica
C. Maria de Luna 3. 50015–Zaragoza (Spain)
Tel.: 34~976761925 Fax: 34~976762226
E-Mail: joako@posta.unizar.es

Abstract

A new system for studying power quality in wind energy conversion systems (WECS) has been designed using a data acquisition board (DAQ), LabVIEW programming software and a portable PC. The system has been installed at two wind turbines and at the power substation. Collected raw data are processed to get the main parameters of the system, power spectrums and dynamic response. The information obtained is completed with the data from a supply network analyser and from a data logger at the meteorological station.

Key words: wind turbines; wind energy conversion systems; harmonic distortion; flicker.

1. Introduction

Increasing penetration of wind energy makes necessary to study the power quality of the generated energy, regarding mainly three factors:

a) Voltage fluctuations and presence of harmonics in the grid, due to wind gusts and due to non-natural wind oscillations caused by the presence of the tower [1].
b) Stability problems at the wind turbines due to faults in the grid [2] (short circuits, lightning surges manoeuvres, etc.), as well as the ones due to the great variability of the wind.
c) Forecast of produced energy and therefore, optimum economical operation [3].

International Standard IEC 61400-21 is being developped to define and specify the measurement to quantify the power quality of a grid connected turbine. It also estimates power quality expected from a specific wind turbine type when deployed at a particular site, possibly in groups [4].

Most of the available supply network analysers do not allow neither the recording of signals at high sampling rate for a long period nor complex calculus with the scanned data, needed in these studies. To achieve the samples, the Electrical Engineering Department of the University of Zaragoza has developed a measurement system that scans data from current and voltage measurement transformers. There are some sensors placed at the wind turbine –speed of blades and generator, blade pitch– and also at a meteorological tower –a propeller anemometer–[5]. The main system, composed by a portable PC, a DAQ and a signal conditioning board, is housed in a steel case [6].

The measuring system is completed with a supply network analyser that registers transients and flicker [7, 8] and the data logger of the meteorological station. The measures of voltage, current and harmonics have been tested in the *Laboratory of Metrology* of our Department.

2. The Measurement System

The measurement system has been installed in two wind farms owned by CEASA –Compañía Eólica Aragonesa, S.A.– with wind turbines in the 600 kW class. Both farms have wound rotor asynchronous generators; Borja generators have an external variable resistor connected to their rotor (VRIG) while Remolinos ones utilise doubly fed induction generators (DFIG).

The installation located in Remolinos (Zaragoza, Spain) is composed by three systems placed at two wind turbines and at the power substation, as shown in figure 1. The wind velocity is taken from the meteorological station, since the measures from the anemometers placed at the rear side of the nacelle (down stream) are very noisy.

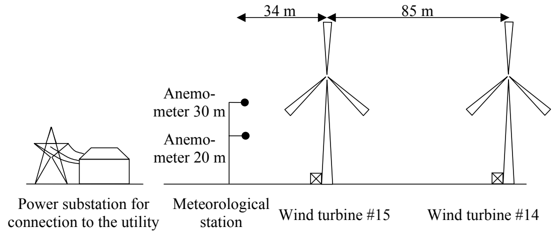
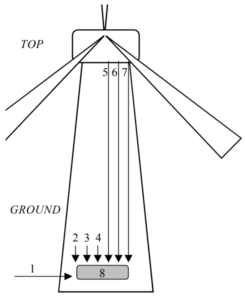


Figure 1: Arrangement of the meteorological tower, the substation and the wind turbines.

At the wind turbines, the signals that come from the top and the ground enter the case placed at the ground. The basic schematic of the signals is shown in figure 2.



1. Wind speed signal from the meteorological tower.
2. Three signals of phase-to-neutral voltage (V_R, V_S, V_T).
3. Three signals of stator currents (I_R, I_S, I_T).
4. Three signals of rotor currents (I_U I_V, I_W).
5. Pitch signal.
6. Generator speed signal.
7. Turbine speed signal.
8. Steel box with the computer.

Figure 2: Schematic of the signals taken at the wind turbines.

Measuring transformers have been used to acquire voltage and current waveforms. The current transformers are of split core and voltage output (readable directly by the acquisition board). The generator and turbine speed are measured with inductive sensors (in some WECS an encoder has also been used). Wind speed is measured by means of an anemometer (propeller type). Signals from sensors are isolated and transmitted in a current loop (figure 3).

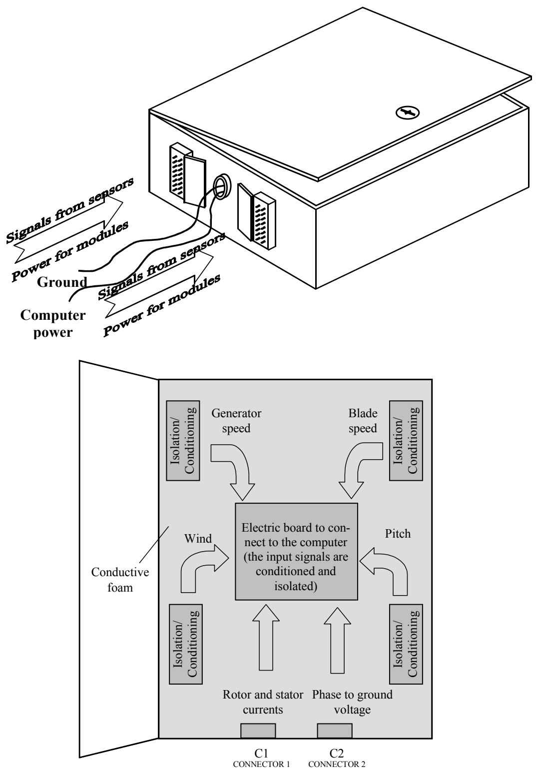


Figure 3: Schematic of the measurement systems.

The signals are recorded in a portable computer – Pentium 133 type– with a PCMCIA acquisition board –DAQCard 700 from National Instruments –.

Power supplied by a doubly fed induction generator is the sum of stator and rotor power. Two separated low voltage windings are utilised (see figure 4) and electrical measurements must be therefore doubled since it is not suitable measuring high voltage inside the WECS. Actually, the transformer ratio and the 690 V winding voltage has been used to compute it in 230 V, since high frequency distortion found in 230 V winding would have required a higher sampling rate to achieve the desired precision. Even in field measurements, some 'True RMS' multimeters showed 17% deviation due to inverter switching.

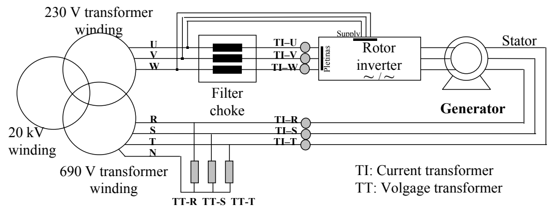


Figure 4: Measurement point for voltage and current in doubly fed induction generator.

In VRIG located in Borja (Zaragoza, Spain), no power is returned by the rotor and therefore measurements are simpler. However, two current measurements are performed: stator current without capacitor compensation and total current (both in 690 V). This has allowed to study the connection and disconnection of capacitor banks installed in those WECS.

Moreover, substation parameters are measured at voltage and current transformers and they served to test the effect of a number of turbines in the point of common coupling (PCC).

3. Acquisition and analysis software

Time intervals to calculate parameters have been adjusted depending on the type of analysis. Wind gust response and starting and stopping cases need current and voltage waveforms with a high sampling rate, whereas power curve from manufacturer is calculated based on 10 minutes intervals.

Therefore, a set of computer programs has been designed to match the requirements of these studies. The system has been used in several points, so when the acquisition program is started, it asks the user the measuring location to adjust the system configuration.

The sampling rate is the same in most of the cases (determined mainly for the maximum scanning rate of the hardware), but the way data is processed and stored varies. For example, when the computer is recording the waveform continuously, it can only store, in binary format, 1 hour of data at a sampling rate of 6 kHz per channel. When a long recording period is necessary, the computer calculates average values of wind and electric parameters every second and the data are stored in a text file readable directly from a spreadsheet or a C program. Data are periodically downloaded with a portable CD-ROM recorder.

Even if LabVIEW has a wide range of analysis subroutines, some care must be taken to assess the required precision in the measurement. All the electric parameters must be calculated based in a whole number of cycles. The grid frequency is slightly variable and the scanning rate can be set only in some values depending on the DAQ configuration [9]. This leads to a disadvantage computing frequency spectrums, since DFT (or an interpolation to obtain the signal resampled at a suitable frequency) must be used instead of faster FFT [10,11]. Therefore some calculus are not fast enough to be performed simultaneously while the DAQ collect data and the system actually works first scanning waveforms, then processing them and finally writing the calculated values.

The acquisition software can work in two modes:

– Digital oscilloscope. The system stores the waveform of all inputs up to 8 kHz per channel, without lost gaps in the signal. This is quite useful to study start-up and shut-down transients as well as some effects of wind gusts, since raw data are stored in CD-ROM and afterwards, numeric treatment is computed (for example, calculus with each period of waveform). The disadvantage of this mode is the low autonomy –about one hour–, due to the high amount of raw data stored.
– Network power supply analyser. Only main parameters of the system are computed every second and stored in a text file. The parameters considered are voltage and current RMS value, power (active and reactive), power factor, harmonics, wind speed, generator speed and blade pitch. The measuring time interval can be varied to accomplish international standard IEC 61400-21 or other requirements.

The future system that is preparing our Department will consist of a standard ATX PC computer to increase the performance and a more cost-effective DAQ with PCI bus mastering. This will allow to process data as they are being acquired. Then, the system will be running as a network power supply analyser without gaps between processed signal. Other improvement will be the use, for slow-varying signals from the weather station, of remote sensor-to-computer modules connected through EIA RS-485 protocol. The cost of the whole system will be below the existing one, $4.200.

4. Analysis of data

The fundamental variables of wind turbines have been related to generator speed, pitch, electrical power and wind speed and the information given by the manufacturer has been checked. Figure 5 shows the power curve of DFIG [12,13]–every point in the graph represents mean power in one minute–.

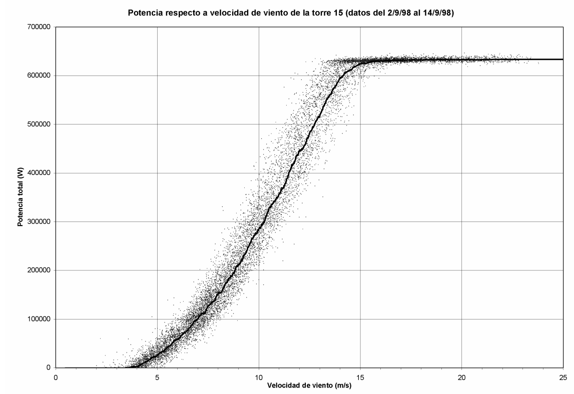


Figure 5: DFIG power curve based in 1 minute mean values.

Voltage and current distortion can be easily viewed in low voltage at WECS starting or stopping [14]. Connection of a capacitor bank is shown in figure 6, where waveforms of 563 V ($690\sqrt{2}/\sqrt{3}$) of amplitude are tree phase to neutral voltage waveforms and the smaller waveform is current of R phase in amperes. X-axis displays time in seconds.

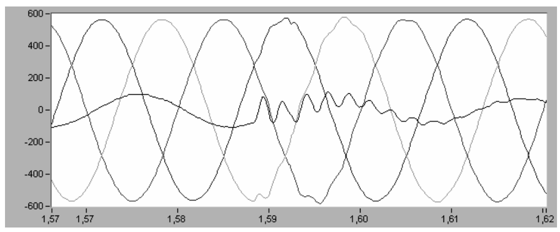


Figure 6: Connection of a capacitor bank, measured at VRIG.

Nevertheless, the effect of switching operations in WECS are notably decreased at PCC due to higher short-circuit power, use of electronics and non simultaneous connection o disconnection [15]. Disconnection of a single WECS at wind farm substation is shown in figure 7, where the effect is much lower since Remolinos wind farm has 18 WECS. Current in figure 7 is in amperes (smaller waveform) and phase to neutral voltage in kilovolts. Measurements have shown that simultaneous switching of more than three WECS is unlikely to happen in this farm in normal operation.

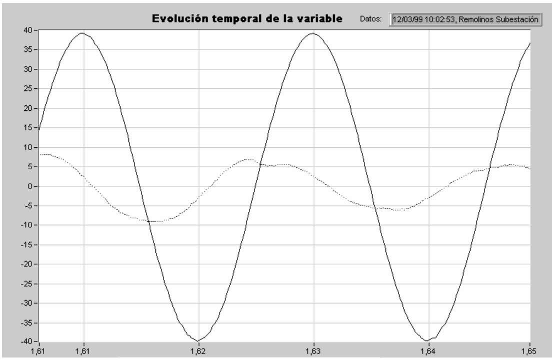


Figure 7: Disconnection of one VRIG, measured at 66 kV substation line.

Distortion levels are bigger in DFIG due to the rotor converter, which commutes at 8 kHz. The distortion caused by the rotor converter can be noticed clearly in figure 8, when it started to operate. High frequency interharmonics are largely filtered by WECS and substation transformers (compare voltage waveforms in figures 7 and 8). Currents in neutral conductor are responsible of 3rd harmonic in phase-to-neutral voltage. The transformer installed inside the WECS has Dy11 connection and hence harmonics that are multiples of 3 are harmless for the grid.

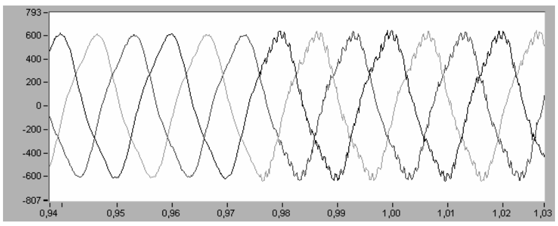


Figure 8: Voltage at DFIG without and with the rotor converter operating.

Current harmonics are lower than voltage ones, even in DFIG, due to the high inductance of filter choke and transformer. Current harmonics are only important during switching operation, especially during starting and stopping events that occurs mainly around 4 or 5 m/s wind speeds. Figure 9 displays current harmonic residue versus wind speed (thin lines represent the limit containing 62 % of measures). Harmonic residue has been used instead of THD –total harmonic distortion– since, during switching operations, RMS value of distortion is comparable to fundamental component.

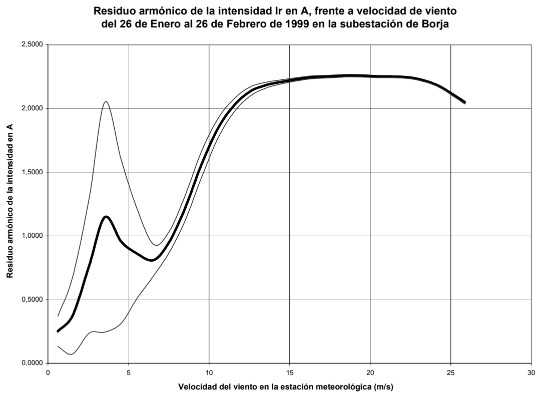


Figure 9: Current residue at Borja substation versus wind speeds in meteorological tower.

Voltage fluctuations are largely imposed by other fluctuating loads and manoeuvres, specially when measuring in HV. For example, grid voltage regulation caused variations in voltage in Borja, (grey line in figure 10), meanwhile voltage in Remolinos was quite constant (black line). On the other hand, voltage in Remolinos contained, from May to August 1998, 2,5 % unbalance, disregarding power generated in the wind farm and causing up to 3% decrease of production in WECS [16].

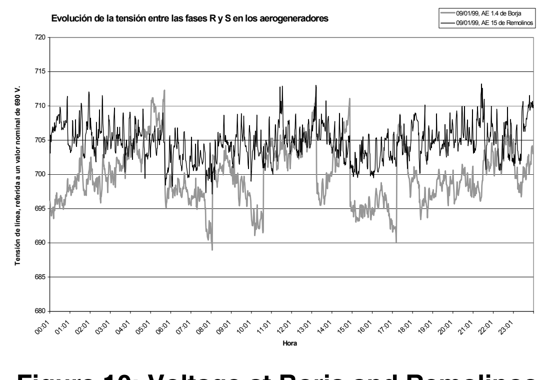


Figure 10: Voltage at Borja and Remolinos WECS in January the 9th, 1999.

Figure 11 shows RMS values of voltage, current and power in VRIG. Voltage is in volts (upper and long dashed line), current in amperes (short dashed line) and power in kilowatts (solid line). Current at connection is very reactive and causes 2,5 % decrease of voltage in WECS although it cannot be seen in the substation. After 1 second, the soft start finishes and tiristors are short-circuited. After 6 seconds, the whole capacitor bank is connected and voltage in WECS is restored. At Borja substation with 22 WECS, only the decrease of power factor is clearly seen during connection at partial load, since it is hard to distinguish between the connection or disconnection of one turbine and a sudden increase o decrease of wind speed due to a gust.

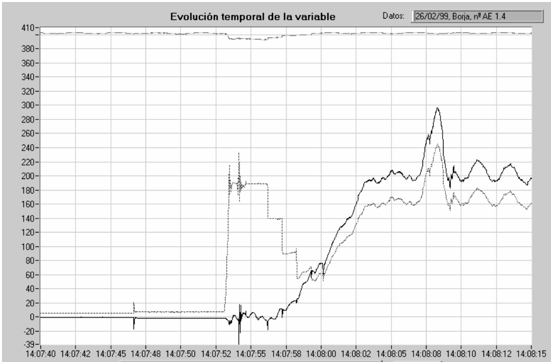


Figure 11: Phase to neutral voltage, current and power during the connection of a WECS.

Power at WECS shows fluctuations in power corresponding to blade passing the tower – approximately 1,54 Hz– and its multiples (similar results have been found in Borja substation and in the WECS). Figure 12 shows the spectrum of the generated power at Remolinos substation [17,18]. Nevertheless, fluctuation is small compared to the nominal power of the farm, 11,2 MW (1122 W at 1,54 Hz, 500 W at 0,74 Hz, 1400 W at 0,5 Hz).

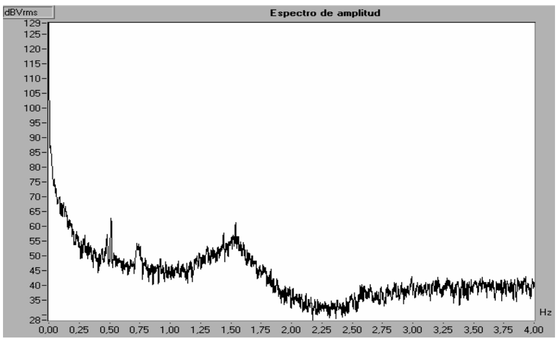


Figure 12: Spectrum of generated power at Remolinos substation with wind speed around 8-10 m/s.

5. Acknowledgements

This work was supported by Department of Education and Culture of Aragón (B134/98 grant) and by Compañía Eólica Aragonesa S.A. (CEASA).

6. Conclusions

A new portable measuring system has been designed in the Electrical Engineering Department of the University of Zaragoza. It makes possible to record one hour of non-stopping waveforms at a high sampling rate or alternatively to process the raw data and store the relevant measures each second for one month. The system is flexible and it allows to change easily the number of inputs, calculus algorithms, measures, etc.

7. References

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