Validation of power factor regulation of a wind turbine

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Abstract. The correct power factor regulation of wind turbines is a necessary step for the regulation of the power factor of a wind farm.

When the regulation of the reactive power does not correspond with the fixed references in the operation of a wind farm, it is necessary to check whether all the involved elements are working correctly.

One of the, most important elements of a wind farm is the wind turbine itself.

This article shows how to determine and validate the power factor regulation through the use of a wind turbine. We are dealing with a machine whose manufacturer went bankrupt, and following his disappearance the existing documentation does not allow one to directly draw reliable conclusions.

The problem associated with the determination of a practical model on the basis of the measurements realized on the real machine is presented.

For machines with technical support from the manufacturer, the presented study can be useful to improve the working of the wind farm.

The conclusions are valid for both contrasting and evaluating the machine under study and any other machine.

Key words

Modelling of wind turbine generating units, Reactive power, wind farms, power factor control.

1. Introduction

Wind farms are one of the most widely used renewable energy sources today. They are integrated by multiple wind turbines connected in parallel to a power network.

Inside the wind farm itself, different technologies can be used/interconnected. The differences may be due to the electrical generator or from the electronics that control it [1], [2].

Each of the machines is driven by a different wind force, which changes rapidly; even below an electrical cycle (the figure 1 shows how the currents changes rapidly). This results in the energy injection of each machine being different. Therefore, the ability to inject reactive power into the network will depend on each machine, and it will depend on both the technology with which it was made and the active power injected into the time of study.
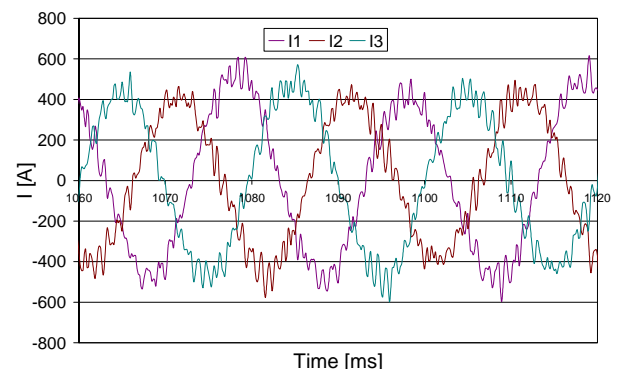

Fig. 1. Currents oscillogram before filter.

When one tries to operate a wind farm as a classic power plant, it is possible to implement various control strategies [3], [4]. Each one can involve a form of operation.

Another secondary objective of reactive power control is the control of voltage in power systems [5].

When the aim is to carry out an economic study in order to maximize the compensation of reactive energy [6], all of the technologies of the machines do not always allow implementation of the rules established by legislation [7], [8].

Thus, independently of the final objective, the control of the reactive energy of a farm needs to characterize the generation curves of the wind turbines.

The goal is to achieve the adjustment of reactive power is simply by following the instructions of the machine

manufacturer. However, sometimes, when the system does not behave as expected, it is necessary to verify and/or correct the information given by the supplier in order to implement control strategies.

This paper illustrates a real case, in which it was suspected that a group of wind turbines from a "missing" manufacturer, who left his clients without technical support, were insufficiently regulating (the specifications given by the manufacturer not being paid attention to) the reactive energy.

To validate the actual behaviour of the machine, it was subjected to a set of field tests in order to define its performance.

The measurements were taken by using a power quality analyzer and a network analyzer. So it was also possible to validate whether the characterization measurements could be taken by means of systems of low cost, as well as what kind of precautions should be taken in the configuration and analysis of the said measurements.

The studied machine consists of a synchronous generator which, through the use of power electronics and control, should be capable of working to constant power factor or to constant reactive power. Therefore, it appears as a very versatile piece within a reactive energy regulation system.

2. Methodology

The methodology used in the work to determine the reactive power regulation of a synchronous wind turbine, described in this paper, is very simple. Basically it can be summarized in three steps. First of all, the correct working of the instrument transformers that take the data of voltage and current used by the control module is validated. The second step consists in making a set of measurements that enable characterization of to the machine. The third and last step is to carry out the data filter and analysis of measurements taken in step 2.
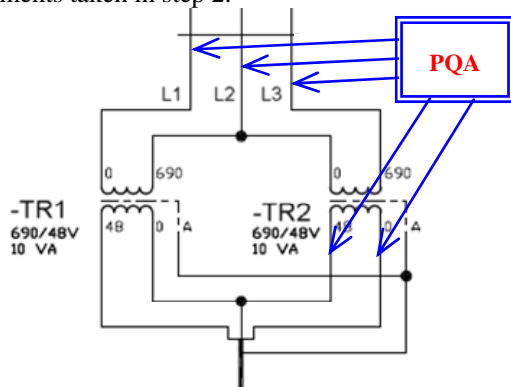
Fig. 2. Connection of the meters to validate the voltage transformers.

A. Validation of the instrument transformers.

Instrument transformers of the controller are responsible both to give the reference of the voltage waveform, and to evaluate the current injected into the network. Thus an error in the measurement of voltage and/or current has a

direct bearing on the correct functioning of control systems.

To validate the operation of the voltage transformers, waveforms in the primary and secondary windings were captured (figure 2). This process was done with the machine connected to the network without generating energy, and while energy was being generated.

As a result of these field tests, it was verified that the operation of the transformers was adequate.

B. Field measurement

The design of the field measurements was made to study the two modalities of working of the wind turbine and its coupling with the network, in the instants before the generation of energy. The two modalities of operation are: constant reactive power factor and reactive power constant.

The parameters of voltage, current and power of each one of the phases and of the neutral-ground voltage and leakage current were registered every minute by means of the electric measurements associated with the power quality analyzer. For each of these parameters, the fundamental component and the first 50 harmonic RMS value were recorded; for each of these the average, minimum and maximum values of the record period were also recorded.

In addition the networks analyzer was used to capture the oscillograms of the four voltages and currents, which lasted several seconds, in order to be able to carry out studies related to the instantaneous measurements. These oscillograms were recorded periodically at intervals of 1 minute. Figure 3 shows a window of one of these oscillograms.
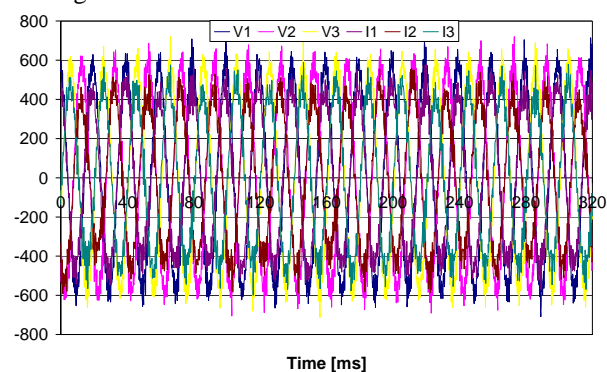
Fig. 3. Voltages and currents oscillogram.

Likewise, using a network analyzer, the same parameters were recorded for the fundamental component. The power measurement was recorded separately for the four quadrants. The rate of registration was varied from 1 second to 10 minutes.

As regards the connection point of the meters, the voltage probes were connected in parallel with the primary winding of the voltage transformers; for the networks analyzer before the connection relay, and for the power

quality analyzer afterwards. The current probes were connected upstream from the power electronics filter; on the side of low voltage of the power transformer. Figure 4 shows the connection of the meters.
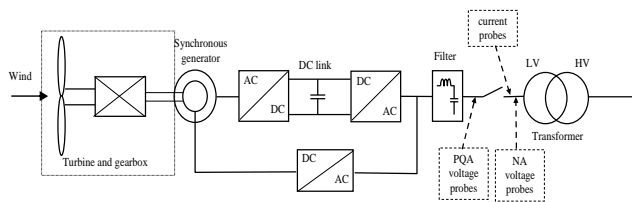

Fig. 4. Connection of the meters.

C. Information filtering and measurements analysis.

As the temporary evolution of the power injected into the network is very fast; even faster than a cycle, there will be four types of records. The first set includes the time at which the machine is still not connected to the power network. In the second set, the machine is connected to the network throughout the whole registration period, but is still not generating energy. In the third set, the machine is generating all the time. And lastly the fourth set, which arises as a mixture of set 3 type measurements with anyone of the other two types.

When the machine is not yet coupled, voltage measurements are not recorded on the quality analyzer, since the switching relay will not allow current flow to the transformer. However, there will be a current consumption (the generator is a load) associated with feeding the control circuitry of the machine.

When the machine is coupled with the network, but it is not generating, the situation is similar to the previous case, except that in this case the filter of the wind turbine is also connected to the network.

When the machine is generating continuously, the registration of active energy and power of generation will constantly be generation. This is true both for the minimum values as for the maximum and average, and in all phases.
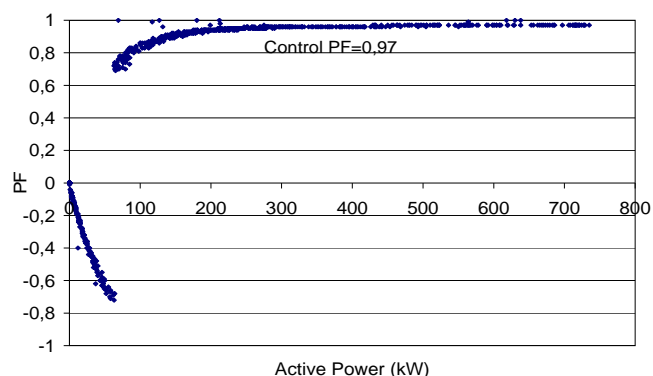

Fig. 5. Power factor evolution of the wind turbine with regard to the active power.

When the machine is generating, but it has periods of no generation, the minimum records will be negative and the maximum positive.

The identification of each of the four operating conditions (data filtered) within each of the measurement periods is a necessary step in drawing conclusions, as will be discussed later.

Data analysis was performed considering firstly the PQ curves for each operating regulation point, since the power factor curves were not representative, nor were they when the operation of the machine with constant power factor was studied.

Figure 5 shows the curve of evolution of the power factor of the machine when it is regulated to work at constant power factor. Although direct conclusions cannot be drawn, the machine measurements are mainly concentrated in two groups of data, one composed of positive values and the other composed of negative values. This indicates that there is a set of measurements related to generation and other sets related to power demand. Therefore, as mentioned previously, it will be necessary to classify the records according to the machine operation.

3. Results

It was verified that the response of the instrument transformers was in line with the use. However, although it was not the object of the tests, it was found that when the power injected to the network was small, in comparison with the rated power of wind turbine, wave voltage of the machine suffered a harmonic distortion of around 4.5%.

In the analysis of measurements, as shown in Figure 5, the first thing to note is that the power injection of the machine is not regulated in the classic electric concept (1).

$$PF = P/S = \cos (arctg\ Q/P) \qquad (1)$$

However, mathematically, we can understand the power factor as the slope of the line that relates the active and reactive powers. And in case that this line does not pass through the coordinate's origin, we should assume the existence of a constant error in the computation of reactive power. The figure 6 represents the same group of measurements that 5, but plotted mathematically.

The representation of the figure 6 shows three distinct groups points. Two groups that are fit to straight and a third one that is separated visually from the line. If each set of points is analyzed, it could be seen that correspond to different types of operation.
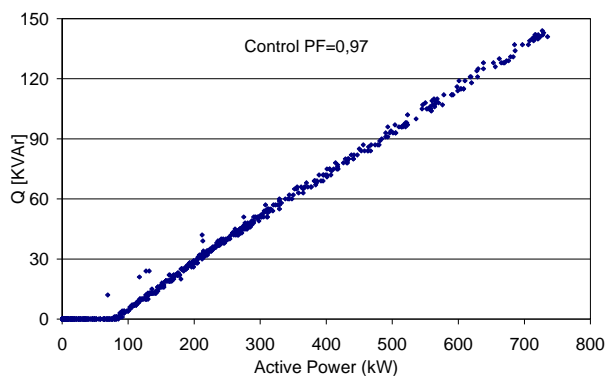
Fig. 6. Reactive power evolution of the wind turbine with regard to the active power.

Firstly, it must be checked whether the set of generation data is a slogan. For this purpose, figure 7 shows how to remove records involving total or partial consumption; the records can be adjusted to a line with very small error.
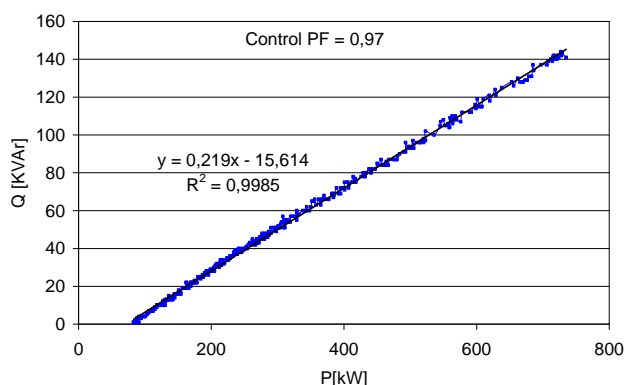

Fig. 7. Reactive power evolution of the wind turbine with regard to the active power. Filtered measurements.

Evaluating the power factor by the equation (1) produces a value of 0.9768. Although the line has an offset added of 15.614 KVAr.

The analysis of the measurements set when the machine worked with constant reactive power reveals similar results. Even though the problem is different, on this occasion the interest is a zero slope of the line.
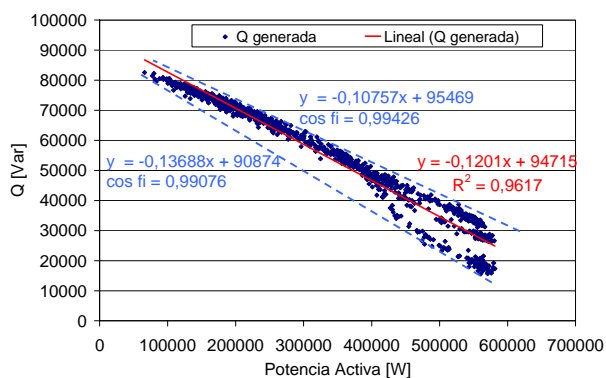

Fig. 8. Reactive power evolution of the wind turbine with regard to the active power. Filtered measurements.

Furthermore, a group less uniform around the line of reactive power is observed in some of the measurements/ regulations.

In the study of the other groups of points (figure 8), those associated with the coupling with the network of the machine are particularly important. When the machine is coupled but is not generating, it can be observed that there is a reactive power injection on the network that corresponds to the capacitor of harmonics filter associated with the power electronics.

When a comparative analysis between the measurements from the power quality and the network analyzer is made, it can be seen that the records taken by them are equally significant. The difference can be found in the versatility of the instruments: capacity of data storage, format of storage /presentation and accuracy of data output.

Actually, the information on the disturbance is not significant within the power factor parameter. The wind turbine is controlled to inject power only at the fundamental frequency.

4. Conclusions

Analysis of the behaviour of a synchronous wind turbine in terms of reactive power injection on the power network has been carried out.

It has been found that the machines interpret the power factor as the equation of the line linking the active and reactive powers. Hence the classical curves, power factor over active power, are not indicative.

The validity of the network analysers for taking measurement has been demonstrated.

Acknowledgement

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