

## NATO SFS PROJECT PO-MISTRAL: STATUS OF THE EXPERIMENTAL VALIDATION PHASE

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**ABSTRACT:** In order to develop a tool which is able to assess the transient behaviour of a wind park connected to an existing a.c. system, NATO SFS Project Po-MISTRAL on "Modelling Machine Interaction in a Wind Park With Regard to Stability and Regulation" is underway. Issues such as the inter-machine oscillations inside the park and the impact of the wind park in the grid are being addressed through appropriate detailed and reduced-order wind park models. These models are to be validated against experimental data. This paper presents the first results obtained from the field campaign currently underway at São Jorge wind park in the Portuguese Archipelago of Açores. Details of the set-up of the experimental work are given, as well as a description of the installed Data Acquisition System and transducer equipment. Finally, a selected set of measured data concerning some of the relevant quantities was presented, and some comments on the results obtained were drawn. It is worth to say that the presented measured data includes a transient situation caused by the switching off of the reactive power compensation system of one of the WECS being monitored.

**Keywords:** Wind parks, Data acquisition system, Transducer Equipment, Experimental results.

### 1. INTRODUCTION

Most of the European Union countries have set targets for the installation of Wind Energy Conversion Systems (WECS) up to year 2000. Figures of 1995 reported that the installed capacity of WECS in the EU member countries is greater than 2 000 MW. If one compares this figure with the 400 MW reported for 1991 it may be concluded that a very high growth rate is being attained. Moreover, in 1991 only 6 of the EU member countries had electric energy produced by WECS, whereas today only one country has not resorted to this form of electric energy production.

The foreseen increase in the levels of wind energy penetration will rise some technical issues which must be dealt with in order to guarantee that the quality of the utility power is not affected. Actually, wind energy being a reliable source of energy on a "year to year" basis, is an intermittent source of energy on a "day to day" basis, meaning that it is a non-dispatchable form of energy. Moreover, the power generated by the WECS generally fluctuates in amplitude over a wide frequency range which may have a non-negligible impact in the quality of the utility power, specially in cases where wind power is a significant component of the utility generation mix.

If one further takes into account that WECS are generally connected to the distribution system and not to the transmission system, one may foresee the necessity of performing an assessment of the level of wind penetration in local terms, even in cases where, globally, the wind energy penetration is modest when compared to the utility power mix.

In order to address these technical issues it is necessary to possess design tools that are able to correctly simulate the impact of the wind energy penetration in the utility distribution grids. Currently these tools do exist whenever the case of a single WECS is to be assessed. However, as far as wind parks are concerned, questions such as the level of smoothing of the power produced by the wind park and the dynamics within the park that are relevant for the operation of the grid are still unanswered.

In order to provide some answers and help to solve the problems that are still pending, namely in what concerns the impact of the integration of wind parks in the utility distribution systems, a consortium involving a research institution - INTERG, two state laboratories - INETI and LNEC and the electric utilities of Açores and Portugal - EDA and EDP, was formed in 1994 and is being sup-

ported since then by these institutions and by NATO Science for Stability Programme III.

The main aim of Po-MISTRAL Project on "Modelling Machine Interaction in a Wind Park With Regard to Stability and Regulation" is to develop computational tools that will assist both wind park and distribution system planners and designers. In order to reach this objective it is necessary:

- To develop and validate a wind model that is able to generate synthetic sequences of wind speed for any number of places in the park, maintaining the same probabilistic and sequential characteristics as for the observed data. This model must further be able to take into account the presence of active turbines and the development of wakes.
- To develop and validate detailed wind park models that are able to simulate the transient behaviour of each WECS belonging to a park, as well as the transient behaviour of the park with respect to the utility system.
- To develop and validate reduced order models that are able to simulate the relevant dynamics of the park with respect to the utility system.

These models address different problems and will be able to assist designers and planners in different but complementary issues. Whereas the detailed wind park models will assist in the design of the configuration of the wind park, the wind park reduced order models will assist in the interconnection between the wind park and the utility distribution grid.

In order to reach the proposed objectives several tasks, assembled in WorkPackages (WP), have been devised in Po-MISTRAL Project (table I).

Table I: Basic structure of Po-MISTRAL Project.

WP	Title
1	A New Wind Model for Wind Parks.
2	Non-Linear and Linear Models for Wind Parks. Machine Interactions Inside the Park.
3	Dynamic Equivalent for Wind Parks.
4	Wind Power Effects on the a.c. System Regulation. The Special Case of Weak Systems.
5	Validation of Wind Parks Models.

WorkPackages 1, 2 and 3 are almost concluded and the models are at its final stage of tuning. Results achieved up to now have already been presented elsewhere [1-3], [5-6]. Workpackage 4 is currently under development [4].

This paper is concerned with *WP5 - Validation of Wind Park Models*, within which the models previously developed are to be validated by specific experimentation carried out in a selected wind farm. In this paper, the Data Acquisition System (DAS) and the transducers, as well as

the first experimental results obtained with them are presented and discussed.

## 2. SET-UP OF THE EXPERIMENTAL CAMPAIGN

An existing wind park operating at the Island of São Jorge in the Portuguese Archipelago of Açores was selected to monitor and validate the wind park models. São Jorge is a five wind turbines park with a total installed capacity of 550 kW (4x100+1x150). Each WECS is equipped with an induction generator which has its own local reactive power compensation system composed by a bank of fixed capacitors. Additional compensation is provided at the park output substation level by a bank of variable capacitors.

The monitoring campaign at São Jorge wind park was initiated with the installation of a normal cup/vane anemometer. The objective of this procedure was mainly to obtain the required information on the wind direction, which was not measured when the park was erected.

This information was used to decide the correct sitting of a definitive 30 meter meteorological tower equipped with a 3D high frequency sonic anemometer at the nacelle height and cup/vane anemometers both at 30 meter and 10 meter high. Therefore, it has been decided to place the sonic anemometer near the WECS #2 (100 kW).

It is worth to mention that all wind transducers and atmospheric flow measuring equipment were previously calibrated at the wind tunnel.

Also, the Data Acquisition System and the transducer equipment have been successfully commissioned and are already in operation. The only transducers that are still to be installed are the torque and speed transducers. A spare shaft is currently being instrumented with strain gauges.

## 3. DATA ACQUISITION SYSTEM & TRANSDUCERS

The installed DAS allows for synchronised data recordings, remote access by modem and appropriate translation to engineering units, and consists of four Data Acquisition Units (DAU's) connected to a Central Processor (CP).

The DAU's provide both signal conditioning and analogue filtering as well as A/D conversion. The main characteristics of each DAU are as follows:

- 8 differential analogue channels;
- 16 software selectable amplifier gains covering the range 1 to 8000;
- 6-pole Butterworth programmable anti-aliasing filter, with a software selectable cut-off frequency from 5 to 50 Hz;
- software selectable sampling rate from 1 to 75 Hz per channel;
- synchronised data samples;
- 16 bit A/D converter.

The CP is the overall controller and performs the data processing. It is based on a 68 MHz PC with a multi-tasking operating system, equipped with a modem for remote access.

One of the 100kW (WECS #2) and the 150kW (WECS #5) wind turbines are being monitored, together with the grid busbar and the sonic anemometer.

The quantities being measured are shown in table II.

Table II: DAS recorded data.

	WECS #2	WECS #5	Grid busbar	Sonic Anemom.
1	voltage	voltage	voltage	wind speed x
2	stator current	stator current	active power	wind speed y
3	line current	line current	reactive power	wind speed z
4	active power	active power	line current	
5	reactive power	reactive power	frequency	
6		shaft torque		
7		rotor speed		

Three types of electric transducers have been installed:

- a.c. current and voltage
- frequency
- active and reactive power

#### 4. FIRST EXPERIMENTAL RESULTS

Recently, the first results from the experimental campaign underway became available and some of these results are presented after. The sampling rate was chosen to be 40 Hz, and the filter cut-off frequency 20 Hz.

Figure 1 shows the resultant wind speed as measured by the sonic anemometer.

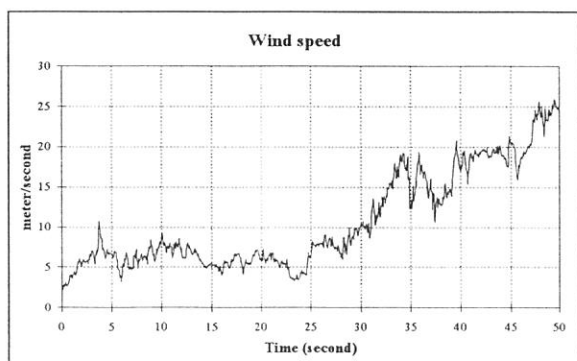


Figure 1: Wind speed.

The induction generator current and the line current at WECS #2 are displayed in Figure 2. One may note a peak current at  $t = 20$  sec which was caused by the switching off of the capacitor bank providing local reactive power compensation of WECS #2. In fact, by this time the control system was preparing the shut down of WECS #2 due to low wind speed. However, a subsequent increase in the wind speed inhibited this procedure. It is worth to mention that the measured peak value was limited to 500 A due to the saturation characteristics of the current transformer.

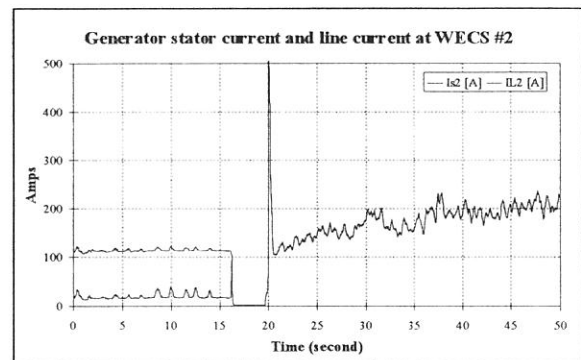


Figure 2: Generator stator current and line current at WECS #2.

The disconnection of the capacitors is also apparent from figure 3, which presents the active and reactive power output of WECS #2. Also, the foreseen increase in the reactive power "input" to the induction generator is confirmed by the experimental results.

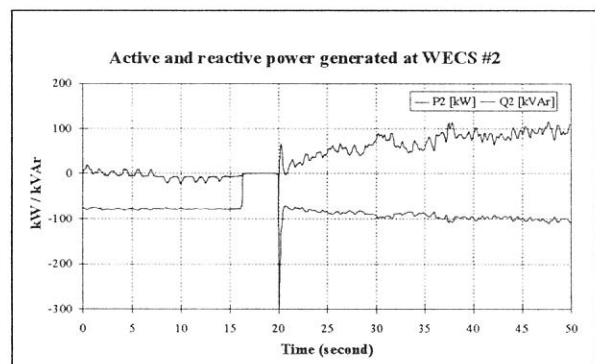


Figure 3: Active power and reactive power generated at WECS #2.

Figure 4 shows both the generator and line currents at WECS #5, the 150 kW turbine. It is clear that no events caused by a lack of wind had occurred during this period. The currents present an identical time evolution, since the capacitor bank current is almost constant.

Finally, figures 5 and 6 depict the wind park active and reactive power output, respectively. It should be stressed that only the two mentioned WECS were being monitored, but four WECS were operating, which explains the results obtained.

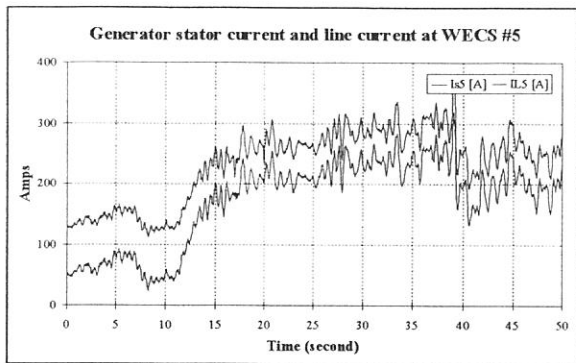


Figure 4: Generator stator current and line current at WECS #5.

As far as figure 6 is concerned, it can be seen that at the beginning of the period the park is exporting reactive power to the grid, but a kVAR deficit condition was established, after the switching off of two capacitor banks.

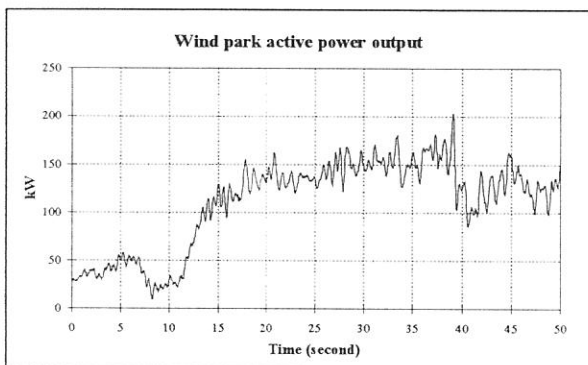


Figure 5: Wind park active power output.

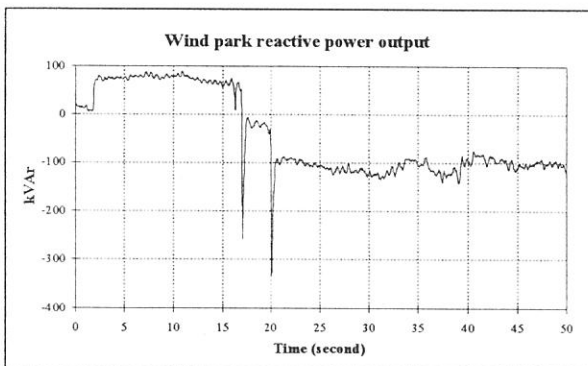


Figure 6: Wind park reactive power output.

## 5. CONCLUSIONS

In the scope of NATO Sfs Project Po-MISTRAL on "Modelling Machine Interaction in a Wind Park With Regard to Stability and Regulation" an experimental campaign is currently underway at São Jorge wind park in the Portuguese Island of Açores.

One of the main aims of such an experimentation is to gather data with the purpose of validating wind park de-

tailed and reduced-order models currently at its final stage of development.

This paper presents the first experimental results available from the dedicated Data Acquisition System and specific transducer equipment recently installed in the park. A selected set of measured data was presented and some comments on the results obtained were drawn. It is worth to say that this data includes a transient situation caused by the switching off of the reactive power compensation system of one of WECS being monitored.

## 6. ACKNOWLEDGEMENTS

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