A WIND PARK GRID INTEGRATION MODEL FOR POWER QUALITY ASSESSMENT

A.I. Estanqueiro*, J.M. Ferreira de Jesus*, J. Gil Saraiva**

* INETI, ITE/DER, Az. Lameiros, 1699 Lisboa Codex, PORTUGAL
Tel - 351 1 7162712; Fax - 351 1 7160901; email - peel@der.ineti.pt
**LNEC, Av. do Brasil-101, 1799 Lisboa Codex, PORTUGAL
Tel - 351 1 8482131; Fax - 351 1 8497660; email - jsaraiva@lnec.pt

ABSTRACT: The integration of large wind parks having a rated power of the order of the tens of megawatts and delivering a continuously fluctuating non dispatchable power to the utility grid may introduce some problems in a weak grid. After the resource assessment the study of the wind power effect in the local grid power quality becomes the main subject in a wind park design when the connection of a large wind park to a weak a.c. system is intended. In this paper INPARK, a wind park detailed numerical model is applied to topology of an island weak utility grid in order to determine the optimum reactive power compensation levels and the expectable dynamic voltage and power fluctuations that may lead to unacceptable conditions for some wind/load situations.

Keywords: Dynamic Models, Utility-Integration, Power Quality, Wind Farm.

1. INTRODUCTION

The increasing penetration of Distributed System Generation (DSG) onto the utility grids is introducing some new problems specially when the connection of these power plants into weak points of the grid is intended.

The lack of available 'tools' in what concerns the study of the wind parks impact on the overall utility grid power quality is often overcome by simulating a wind power plant as a constant negative load of rated power value using the disseminated "user-friendly" load flow software packages. The negative impact of this procedure on the potential investors is evident if one thinks that, in an average site, seldom the park produces the rated power of the machines, and that the connection and disconnection transients of the individual turbines inside a park are usually not time coincident, leading to a wind park performance quite distant, and fortunately much less drastic, then the "negative load" situation.

Apart from some research groups, an increasing number of wind energy consultancy companies and investors are beginning to consider the grid integration of these power plants a major issue that must be dealt carefully since the initial phase of a wind park design. This new attitude is not only due to the economical impact that the grid connection assumes on the overall cost of a wind park but also due to the utilities technical restrictions associated to the natural evolution and increasing penetration of this form of energy conversion with the consequent installation of the wind power plants in more remote places where utility grid connection is weaker than desired or even non-existent.

Detailed models are seldom used to assess the wind park grid integration and its effect on the local power quality. The reason being not only the natural complexity of these "tools" but also the conservative idea that utility grids should have the capacity to accept the wind park fluctuating power without being disturbed. This is unfortunately not true for weak systems and grid characteristics are found to be one of the most restrictive factors for the installation of large wind parks in remote windy places of countries like Portugal, Spain, Ireland, Greece or even Scotland.

The wind park model used in this paper - INPARK - is being developed and improved for some years now and was designed to assess the effect of wind parks integration in the utility grid [1].

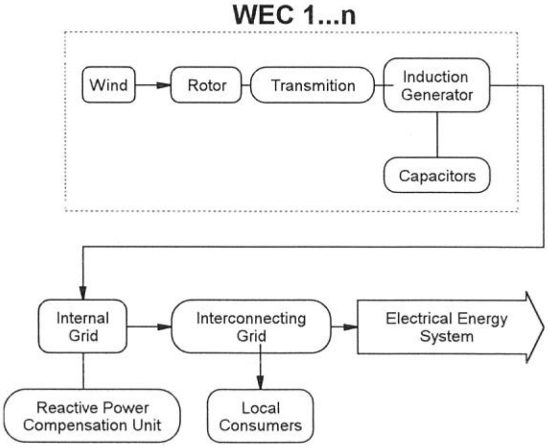

Figure 1 - INPARK Structure and sub-models

The aim of INPARK development is the study of the effect of wind park power fluctuations in the grid and the evaluation - in the feasibility study phase of the wind park - of the maximum wind power penetration value at particular substations (or busbars) without disturbing the local consumers and guaranteeing the overall power quality of the grid.

In this paper the methodology to model the different components of a wind park relevant for the power quality assessment purpose is presented (Fig.1). INPARK model is then applied to the existing wind park and local grid topology of S. Jorge in the Azores Islands (Fig.2) and its results on the optimal reactive compensation and maximum voltage and power fluctuations are compared to those obtained via a wind park conventional electrical design approach. Some conclusions are drawn on the necessity of the use of detailed models in the preliminary phase of a wind park project.

2. *INPARK* MODEL

The model developed - INPARK - was designed to simulate a set of situations occurring within a wind park normal operation, both in steady and transient situations, being then particularly adequate to assess its integration in the utility grid. This time domain model includes the wind rotor, the transmission shaft, the tower shadow effect, the induction generator, the power transformers and cables inside the park, addressing also the local loads and the utility grid characteristics that may affect the park behaviour.

The main aim of the INPARK development under the NATO SfS PO-MISTRAL Project entitled "Modelling Machine Interaction in a Wind Park with Regard to Stability and Regulation" is to develop and validate against experimental data a computational "user friendly tool" to assist both wind park and distribution system planners and designers to perform the necessary evaluation - in the feasibility study phase of the wind park - of the maximum wind power penetration value at a particular point of the utility grid maintaining its characteristic power quality, as well as to assist the design of the wind park protection systems, the reactive power compensation units and the internal grid lay-out.

2.1 Wind Turbine Model

This model addresses the wind parks constituted by horizontal axis stall or pitch controlled wind turbines - HAWT, equipped with standard induction generators. The WECS model has an equivalent wind velocity time series at the hub height as input, the output being the mechanical torque, the shaft's rotational speed and all the relevant electrical quantities in the park.

The INPARK flexible dynamic wind rotor model was presented with detail in references [1,2]. This model is based on the well-known blade element/momentum theory analysis developed by Glauert to determine the aerodynamic forces in the blades and its structural dynamic flexible approach enables both flap and lead-lag degrees of freedom for the blades [3]. These are taken as rigid bodies, being only considered their clamp conditions at the hub.

The tower shadow effect and its interference on the blades aerodynamic characteristics is modelled after Zdravkovich work on staggered cylinders [4].

2.2 Local Grid and Induction Generator Models

The induction generator is simulated through a 5th order model including saturation, the detailed analytical model being presented in reference [5]. Local loads are modelled through constant impedances and the transmission lines inside the park are described by their π-equivalent representation [6]. In previous papers the necessary studies in order to assess the influence of the different parameters affecting the wind parks power quality were performed and the relevant parameters were identified [1,2,7].

2.3 Local Wind Model

A simple wind model is included in INPARK. This is based on an approach similar to the Shinozuka method. It is assumed that the turbulence is mechanical and may be represented by a PSD function. Wind velocity *syntethic* time series are generated after the wind local "spectrum" through the FFTI technique.

To address the eventual power fluctuations smoothing effect due to the turbulence, INPARK wind model includes the wind time series cross-correlation associated to the distance between wind turbines in cross and along wind directions. A method to generate "long" series based on hourly or ten minutes mean velocities, containing the energy of the wind "spectrum" above the spectral gap up to 10 Hz is also implemented.

3. S. JORGE CASE STUDY

The selection of a wind park in the island of S. Jorge in the Atlantic archipelago of Azores is mainly due to the particular and adverse conditions in terms of weak grid and strong turbulent winds the turbines face here.

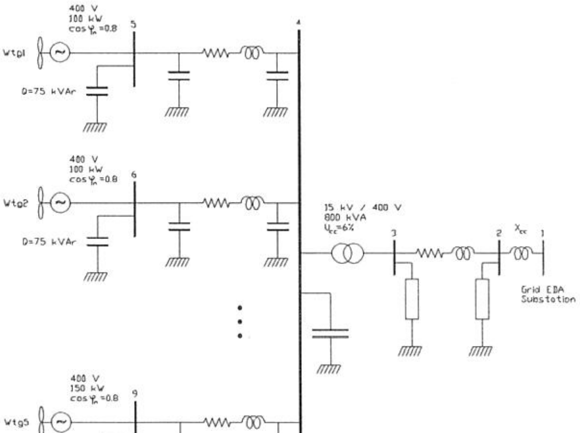

Figure 2 - Topology of S.Jorge wind park (4*NTK 99 LM/F +1 NTK 150 XLR).

In this paper the methodology to model the different components of a standard wind park relevant for the power quality assessment purpose is presented. INPARK model is then applied to the existing topology of the grid of the Azores Island of S. Jorge where a five wind turbine park is connected (Fig. 2). The existing local consumers are simulated through S_1=122+j50 kVA and S_2=4+3 kVA.

The park is owned by the local utility EDA- Electricity of Azores. The island constitutes a typical medium sized wind-diesel system where the wind power penetration reaches 40-50 % with no stability problems and considerable fuel savings (reported by EDA).

The diesel production capacity installed in the island isolated grid is 5020 MVA the peak demand being 2.1 MW. Some of these groups work as emergency units and others only as synchronous compensators (since reactive power consumption is not paid the cosφ in the island is very low). The installed wind power capacity is 550 kW and the annual mean wind velocity is 9.7 m/s thus being unsurprising the high wind power penetration values reported. This island wind park has just started to be monitored under the project SfS NATO PO-Mistral.

4. INPARK RESULTS

In this paper the simulation of S. Jorge existing wind park is performed in order to optimise the capacitor bank installed on the LV busbar of the substation and assess the dynamic voltage levels and fluctuations at the turbines, park and grid busbars.

The simulation conditions correspond to an hourly mean wind velocity of 8 m/s. In the simulation non-correlated wind time series with 17% of turbulence intensity given after Davenport along wind mechanical turbulence power spectral density having its complete energy content for the frequencies above the spectral gap are used.

The WECS installed are standard Nordtank turbines, being machines one to four NTK 99LM/F rated 100 kW, and the fifth turbine a NTK 150 XLR rated 150 kW. Most of the necessary data to perform the simulations is available from the turbine catalogue. The rest is available on request from the manufacturer of the turbines or its components and no specific tests are requested.

The wind turbines manufacturer power curves (in per unit values, S_b =187.7 kVA) and the simulated performance are presented in Fig. 3.

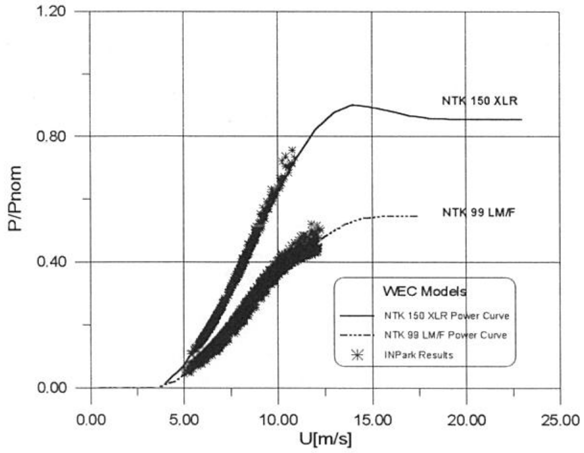

Figure 3 - Wind turbine manufacturer and simulated power curves (p.u. values).

The grid characteristics correspond to a fault ratio (S_k/S_{rated}) of five and very low X/R ratio depending on the turbine, (typically X/R=1.12 for turbine number one, 2.86 for turbine number two and 1.62 for turbine number five).

The results obtained on the voltage and power fluctuations that enable to assess the maximum wind power penetration are presented in Fig. 4 and 5). These voltages can be compared to those obtained via a wind park conventional electrical design approach (load-flow) presented on Table 1.

Table 1: Busbar voltages obtained through load-flow analysis for mean wind velocity 8 m/s.

Busbar	U[pu]	
	Q=20 kVAr	Q=160 kVAr
Grid (2)	0.972	0.998
Wind park (4)	0.967	0.999
WECS 1	0.979	1.003
WECS 2	0.971	1.014
WECS 3	0.969	1.006
WECS 4	0.974	1.005
WECS 5	0.978	1.013

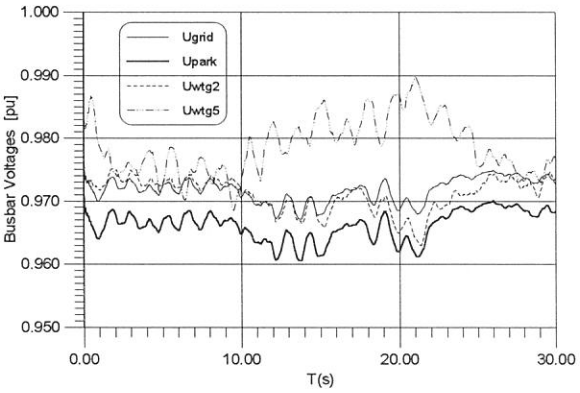

Figure 4 -Voltage levels and fluctuations with a capacitor bank (Q=20 kVAr) at the wind park LV busbar.

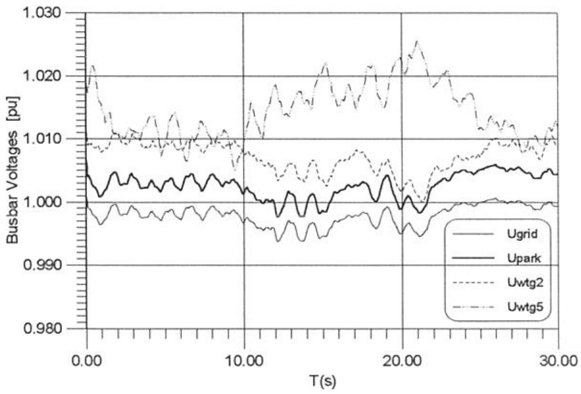

Figure 5 - Voltage levels and fluctuations with a capacitor bank (Q=160 kVAr) at the wind park LV busbar.

From the load-flow and INPark results one may conclude that the conventional analysis gives an acceptable approach to the mean voltage levels but clearly underestimates the voltage deviations occurring in the busbars by neglecting the dynamics of the wind and turbines due to the wind turbulence and the tower shadow effect.

For this situation the most favourable voltage levels in the grid interconnection busbar (2) occur when the wind park is delivering reactive power to the grid, although the wind turbines may be operating from 1 to 3% above rated voltage. This corresponds the situation implemented due to the reactive power deficit in S. Jorge Island.

Although expected these results reinforce that is neither advisable to use load-flow analysis in very weak grids where the voltage fluctuations may be crucial nor in the design of variable capacitor banks nor in the wind park and local grid protection design.

In Figures 6 and 7 the active power production of the turbines and the wind park as well as its demand/production of reactive power with relation to the utility grid are presented.

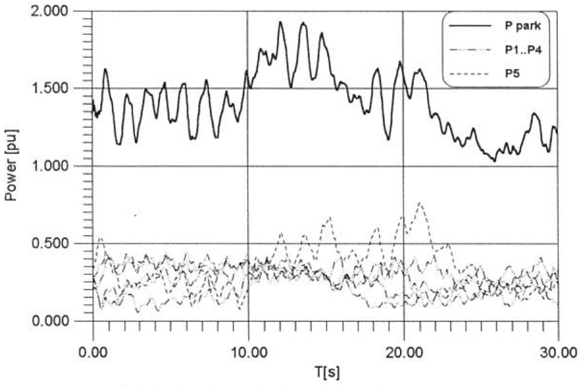

Figure 6 - Individual and total wind park active power output.

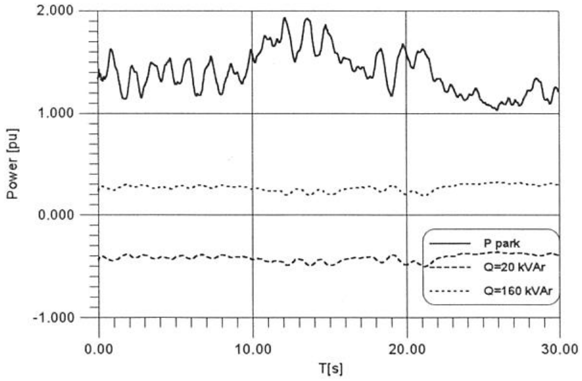

Figure 7 - Total wind park active power output and reactive power flow on the wind park busbar (4) for Q=20 and 160 kVAr.

When the wind park internal grid is included on the wind park model, INPARK wind turbine individual power output results show a tendency for the four 100 kW similar turbines to synchronise (at least turbine one to three), being the total active power output fluctuations higher then the oscillations of the individual machines. This effect was recently reported to occur in existing wind parks [8].

Figure 8 shows the spectrum of the wind park active power output where the energy peaks due to rotational speed (1p, 1p'), the blade passage (3p, 3p') of the two type of turbines and some multiples (6p) are identified.

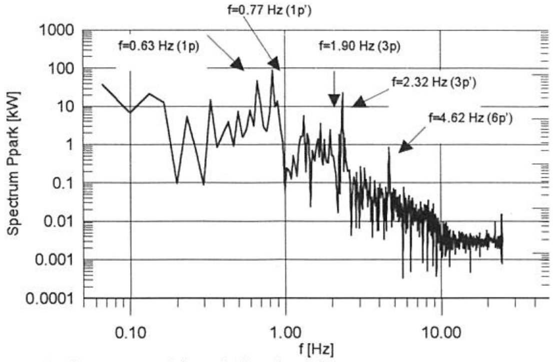

Figure 8 - Spectrum of the wind park active power output.

Acknowledgements

The dynamic modelling of an existing and operating wind park is a laborious and multi-disciplinary work which can not be attributed only to the intervening authors of this paper. Among other persons and institutions the authors would specially like to thank the contribution of Eng. Lars Kielruff (AT&C), Eng. Luís B. Oliveira and Mr. José E. Maciel from Azores Utility - EDA, the project Po-Mistral Consultant Dr. Peter Cristhiansen, the Graduation and Master students Marcos Alves, Anke Gärtner and Volker Neumann, and finally the NATO Science for Stability Programme III for sponsoring this work through Project PO-Mistral.

REFERENCES

[1] A.I Estanqueiro, Rui M. Castro, J.M. Ferreira de Jesus, J.A. Gil Saraiva, "Modelling the Integration of Wind Parks onto Weak Grids", Procedings BWEA'17 (1995), 167.

[2] A.I Estanqueiro, Rui M. Castro, J.M. Ferreira de Jesus, J.A. Gil Saraiva, "The use of Stiff and Flexible Rotor Models with Regard to Wind Turbines Power Quality Assessment", Procedings BWEA'16, (1994), 71.

[3] Bongers, P.; Von Baars, G.; Dijkstra, S.; Bosgra, O. "Dynamic Models for Wind Turbines", TUD, memt28, 1993.

[4] M. M. Zdravkovich, "The Effects of Interference Between Circular Cylinders in Cross Flow", *Journal of Fluids and Structures*, Vol.1 , (1987) 239.

[5] J.M. Ferreira de Jesus, "A Model for Saturation in Induction Machines", *IEEE Trans. Energy Conversion*, Vol EC-3, (1988).

[6] Rodrigues Alves, M.V. "Modelação da Rede Interna de um Parque Eólico". Graduation Thesis (to be pub.), (1996)

[7] A.I Estanqueiro, R. Aguiar, Rui M. Castro, J.M. Ferreira de Jesus, J.A. Gil Saraiva, "The Development and Application of a Model for Power Output Fluctuation in a Wind Park", ECWEC'93 Procedings, (1993) 798.

[8] Thiringer, T., "Power Quality Measurements Performed on a Low-Voltage Grid Equipped with Two Wind Turbines", IEEE Winter Meeting, Baltimore, (1996).