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Modelling the Integration of Wind Parks onto Weak Grids

SYNOPSIS In this paper the dynamic wind park models developed - INPark - are applied to the case study of S. Jorge Island in Azores. The simulation results, in what concerns the voltage and power fluctuations and other relevant quantities are presented both in time and frequency domain for different wind power penetration values and local loads. Some conclusions are drawn regarding the use of simulation models in the feasibility study phase of wind parks and the ability to propose measures in order to prevent high fluctuation that occur in weak grids (specially islands) and affect the local consumer's power quality.

1. INTRODUCTION

The wind park models developed - INPark - are based in a wind turbine dynamic approach and its main objective is to assess the effect of wind parks integration in the utility grid [1,2]. These model(s) were developed in time domain and include the turbine, induction generator, local power transformers and cabling, addressing also the local loads and the utility grid characteristics that may affect the behaviour of the park.

INPark models are able to simulate a set of situations that occur in a wind park normal operation, both in steady and transient states, being then particularly adequate to assess its integration in the utility grid. The foremost 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 certain substation (or busbar) without disturb the local consumers and guaranteeing the overall power quality of the grid.

This study of the wind power effect in the local consumers becomes the main subject in a wind park design - after the resource assessment - when a wind park connection to a weak ac. system is intended.

The model previously developed is applied to a grid topology similar to the one existing in the island of S. Jorge (Azores) where a five wind turbine park is connected. This island was selected due to the high level of wind power penetration occurring for some wind and load conditions with no stability problems (reported by local utility, EDA). S. Jorge island is an ideal case study to apply a wind park model since the wind turbines work in very adverse conditions from the electrical point of view, as the voltage and power fluctuations that characterise the wind power output in any grid, are particularly critical in this case.

2. INPARK MODEL

INPark is a wind park time-dependent model which development objective is to assess the wind power grid integration effects both in transient and stationary operation. This model is meant to apply to wind parks constituted by horizontal axis wind turbines - HAWT, equipped with standard induction generators at, what is usually called, "*constant speed constant frequency*" working mode.

The time dependent WTGS model has a wind velocity time series at the rotor height as

input, the output being the mechanical torque, the shaft's rotational speed and all the relevant electrical quantities.

INPark is constituted by a set of models each addressing a different phenomena or part of the wind park system. The individual INPark sub-models consist on: a wind model, a wind turbine dynamic and flexible rotor and transmission models, an induction generator model and a local grid and loads model.

2.1 - Wind Model

The wind model included in INPark is based in an approach similar to the Shinozuka method. It is assumed that the mechanical turbulence is correctly represented by a Power Spectral Density Function. Wind time syntethic series are generated after the wind "spectrum" through FFT technique.

The INPark wind model includes the time series cross-correlation effect due to the distance between wind turbines in cross and along wind directions. A method to generate "long" series (one hour) representing the energy content of the wind "spectrum" up to 10 Hz was also implemented.

2.2 - Wind Turbine Flexible Rotor Model

The INPark flexible dynamic wind rotor model was presented with detail in reference [1]. This model is based on the well-known blade element/momentum theory analysis developed by Glauert and on the flexible DUWECS dynamic flexible approach. This approach enables both flap and lead-lag degrees of freedom for the blades [1,3,4]. The displacement of the blades is concentrated on the hub as the blades are taken as rigid bodies.

The rotor averaging effect is included through the "filtering function" presented on Smeedman [5]:

$$H(n) = \left\{ \left(1 + \frac{8}{3} n \frac{\pi r}{U} \right) \left(1 + 4 n \frac{r}{U} \right) \right\}^{-1}$$

after an original aerodynamic transfer function presented by Davenport for buildings [6]

2.3 - Induction Generator Model

The analytical model that describes the induction generator performance is presented in [7,8]. Its main characteristic is to include the saturation effect of the electrical machine magnetic circuit thus enabling to simulate its non-linear behaviour. It neglects magnetic circuit hysteresis assuming that it's possible to describe the machine electromagnetic characteristic through a unique function.

2.4 - Local Grid and Load Models

It these study both the transmission lines and the local loads are modelled by time constant impedances.

4. APPLICATION OF INPARK MODEL

INPark is an integrated model that enables to obtain the wind turbine and park's performance, the electric interference between the generators, capacitors and transformers inside the park, its influence in the grid and thereby in the local consumers, and most of all it enables to design the maximum wind power penetration factor without affecting the grid's power quality.

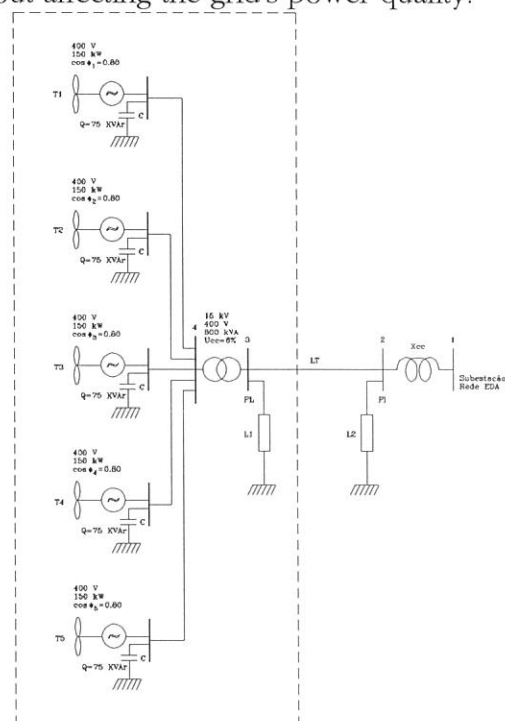


Fig. 1 - A topology of S. Jorge Wind Park connection to EDA Grid (used for INPark simulations).

Some simplifications were included in the flexible model since a standard rigid turbine is being modelled. The tower motion effect was neglected in the flapping and lead-lag governing equations and the shaft's damping and stiffness were not included in the transmissions equation [1]. The gear box was take as ideal. The lift and drag coefficients were taken as linearly dependent of the blades attack angle for the NACA 63.2xx blade profiles [9,10].

4.1. The Wind Turbine Model

Wind Rotor and Blades Characteristics

The wind park modelled here is constituted by five NORDTANK NTK 150 XLR stall regulated upwind wind turbines. These 150 kW nominal rating power turbines are equipped with LM Glasfiber 12H blades with NACA 63.2xx profiles. The rotor swept area is 475 m² and the nominal rotor speed is 39 rpm. Each blade weights 830 Kg and has a maximum twist of 20.5 degrees.

The blade was divided in ten sections being the chord, twist and thickness evolution along the blade presented in Fig. 2.

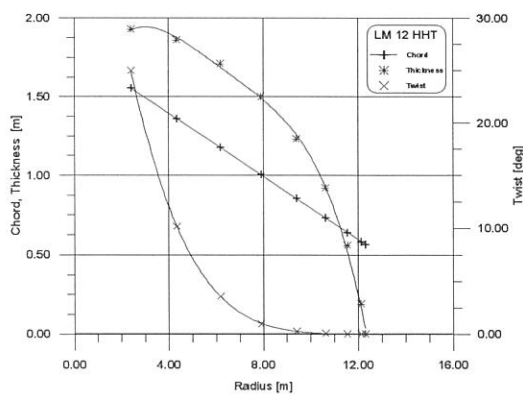


Fig. 2 - LM 12 HHT chord, thickness and twist along the blade.

Generator and Gearbox

The generator is a 150 kW nominal power (165 kW maximum) 50 Hz, 3x400 V, HXV 315 MA, 4 pole manufactured by ABB Motor. The rotational speed range is 1500-1512 rpm and its nominal power factor is 0.8. The characteristics of the induction machine equivalent circuit are the following: $R_s = 0.0072\Omega$

Stator resistance:	$R_s = 0.00724\Omega$
Stator reactance:	$X_s = 0.0694\Omega$

Rotor resistance:	$R_R = 0.0075\Omega$
Rotor reactance:	$X_R = 0.136\Omega$
Loss resistance:	$R_m = 0.042\Omega$
Magnetising reactance:	$X_m = 1.73\Omega$

The gearbox is a two step parallel shafts/helical type, 175 kW nominal mechanical power with 1:39.9 ratio, 38 rpm low speed shaft and 1512 rpm high speed shaft maximum values.

Wind Velocity

The wind time series "driving", the five wind turbines have zero correlation so the effects of the cross-correlation factor in the wind park power output is not addressed here.

In Figure 3 the stochastic wind time series are presented (applied to turbine 1 to 5 in the present simulations). The series used as the simulation input were obtained after the same 'Davenport spectrum' of horizontal turbulence [11] with 8.0 m/s mean wind speed at the hub height and 0.008 equivalent roughness coefficient. Wind series characteristic turbulence intensity is *** (common to all series).

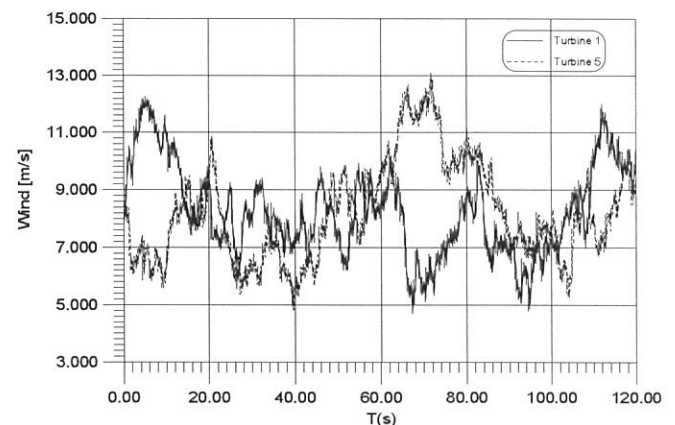


Fig. 4 - The input wind time series for wind turbine T1 and T5 (uncorrelated, mean wind speed =8.0 m/s)

Local Grid and Load Characteristics

The local loads, the transformers, the feeder and the ac. system were modelled as time constant impedances as referred above.

The needed reactive power may be delivered by the utility grid or by local capacitor banks. In the present simulations the capacitor bank is 75 KVar (Fig.2) being the rest of the reactive consumption delivered by the grid.

In this paper only "weak" to "very weak" grids are addressed. The conditions at the grid interconnection busbar were established through the short circuit power ratio:

$$r_{cc} = S_{cc} / S_{park}$$

r_{cc} - ratio between the fault level at the grid's busbar (1) and the nominal power of the wind park (2).

To perform this study three different short circuit ratio values were selected: $r_{cc} = 20, 10$ and 3 . These values were chosen by particular reasons; $r_{cc} = 20$ is the minimum allowed by Portuguese independent producers regulations; $r_{cc} = 10$ is a common value allowed by most of the Danish utilities; $r_{cc} = 3$ represents a minimum limit, close to the grid ratio for the wind/load conditions in S. Jorge Island (S. Jorge load peak is 2.1 MW and the yearly mean wind speed is 8.9 m/s).

The effect of the grid characteristics in these three cases, on the park and grid's busbar voltage fluctuations, as well as on the local consumers current and voltage and on the current/power delivered to the grid is assessed in this paper.

Furthermore the local loads consumption effect on the above variables is also addressed by comparing two simulations with different load 2 (connected to busbar 2, L2 in Fig.1) consumptions.

LOAD A	$S_2=(152+j52)$ kVA
LOAD B	$S_2=(445+j146)$ kVA

The load 1 (L1, connected to busbar 3) represents a small consumption in the wind park busbar and assumes the constant value $S_1=10+j5$ kVA.

The Wind Turbine Power Curve

The NORDTANK NTK 150 XLR power curve for 15°C air temperature, 1013 hPa air pressure and a maximum air turbulence of 15% is represented in Fig. 4 against the INPark simulation results for the "linear" (non-stall) working range. The wind turbine power output plotted corresponds to a $r_{cc}=20$ grid condition,

load B case, and Fig. 3 wind time series ($V_{med}=8.0$ m/s).

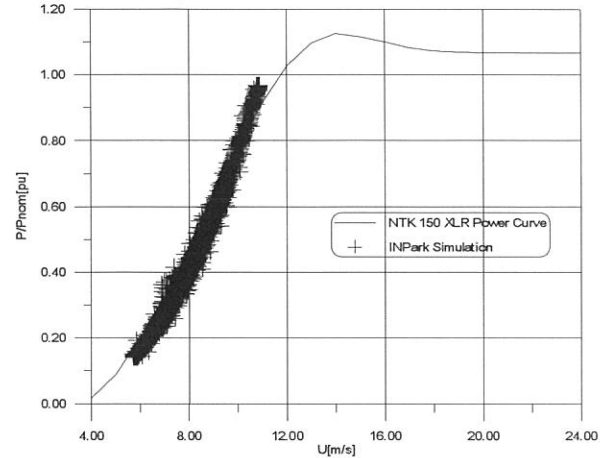


Fig. 4 - NTK 150 XLR Manufacturer Power Curve and INPark results in the linear (pre-stall) working range.

5 INPark MODELLING RESULTS

The output of the simulations was analysed statistically both in time and frequency domains. The time outputs presented in Figures 5 to 13 are all in per unit values ($S_{base} = 187,5$ kVA, $I_{base} = 270.6$ A, $U_{base} = U_{busbar}$).

The voltage fluctuations in the park and grid busbars for the three short circuit ratios, Load Case A and the wind time series plotted in Fig. 3, are presented respectively in Figures 5 and 6.

Figures 7 to 9 illustrate the effect of strength of the grid on transmission line, local loads and utility interconnection substation.

In Fig. 10 and 11 the effect of the amount of power (Load 2, Cases A and B) connected to the wind park close busbars is shown.

Wind park active power output and reactive power consumption is shown in Fig. 12.

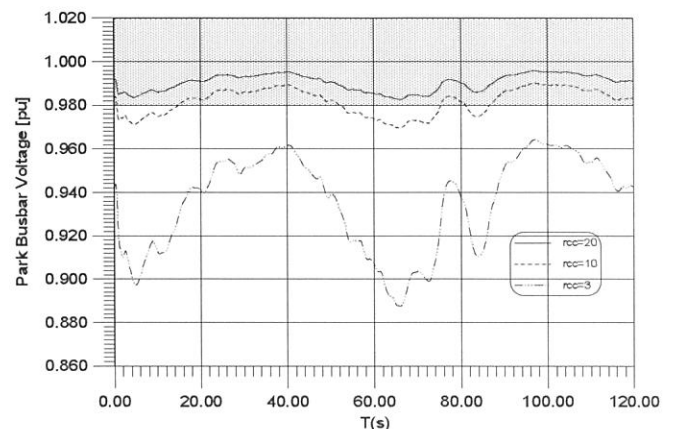


Fig.5 - Wind Park busbar voltage fluctuation for three wind power penetration values (load A).

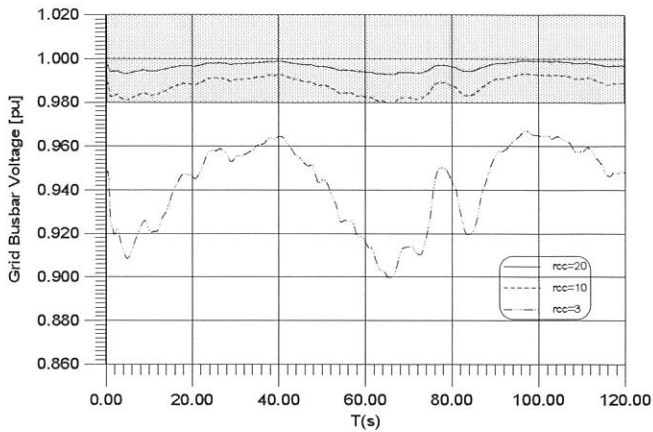


Fig.6 - Grid busbar voltage fluctuation for three wind power penetration values (load A).

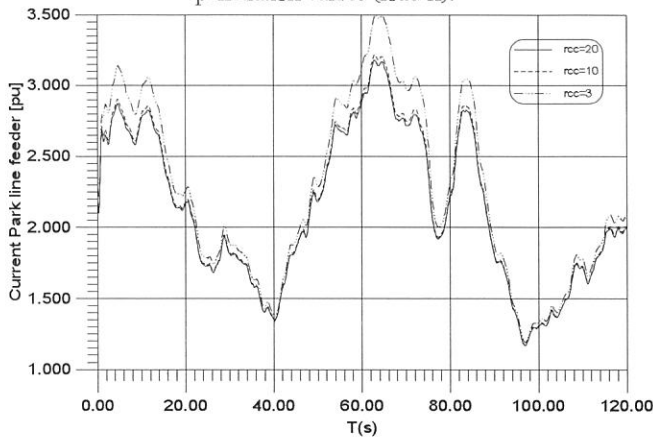


Fig.7 - Transmission line currents for the three wind power penetration values and load case A.

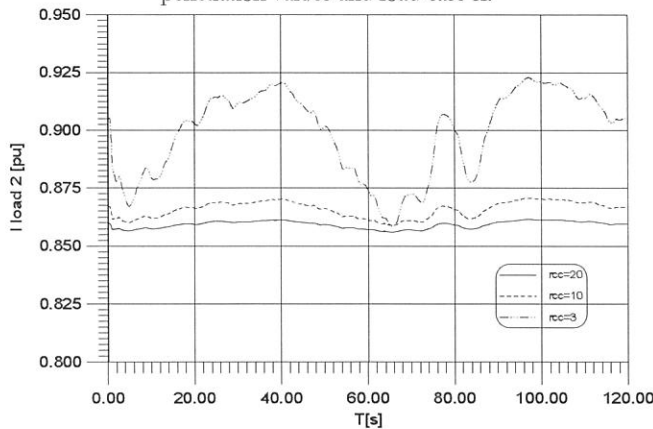


Fig.8 - Load 2 currents for the three wind power penetration values and load case A.

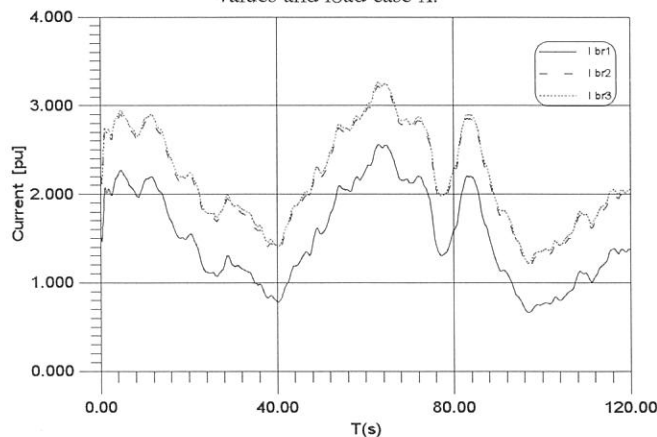


Fig.9 - Grid currents in branches 1, 2 and 3 of the local grid (rcc=20).

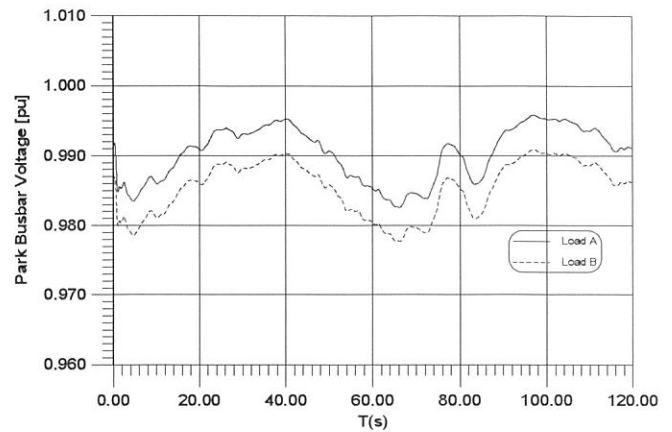


Fig.10 - Wind Park busbar voltage fluctuation for the two load cases (rcc=20)

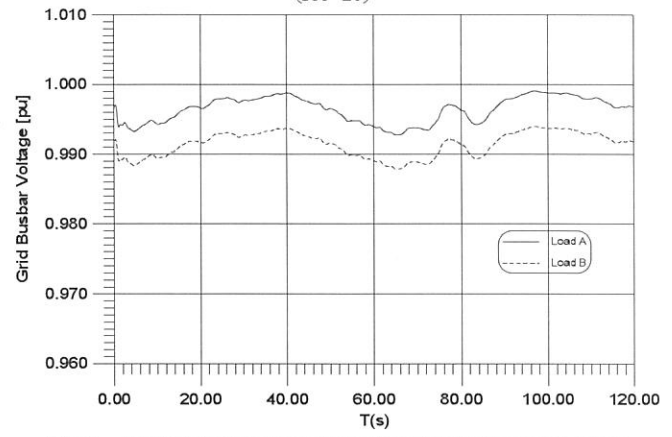


Fig.11 - Grid busbar voltage fluctuation for the two load cases (rcc=20)

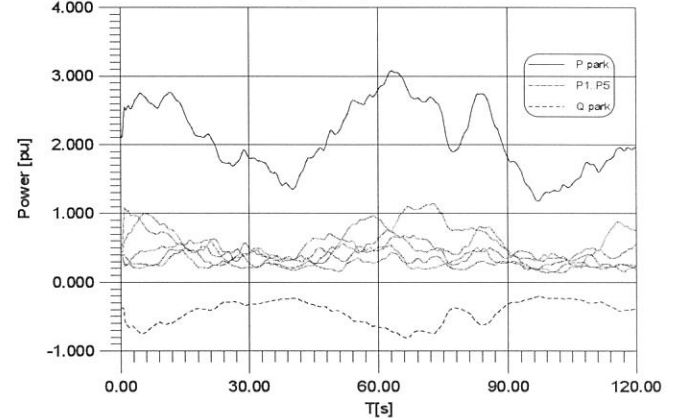


Fig.12 - Wind Park active and reactive power output fluctuations and individual turbine production. (rcc=3, load A, 5 turbines, zero correlation wind)

6 CONCLUSIONS AND ANALYSIS OF THE RESULTS

(não ligar a este ponto)

The S. Jorge Wind Park is currently under modelling and analysis.

Finally in Figure 13 the effect of the power penetration higher than 5% of fault level in the active and reactive power fluctuations in the wind park busbars represented.

However, and as expected from the typical wind park behaviour, it is clear from the results

analysis that (...) the may introduce large deviations in the voltage (...) wind parks simulation performance.

(+++)

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