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On the effect of the utility grid characteristics in a wind park power output fluctuations.

SYNOPSIS In this paper a dynamic wind park model previously developed is used to simulate two turbines wind park. The objective is to determine the influence of the utility grid characteristics in the performance of the park as well as on the power output and the on grid voltage fluctuations. The characteristics of the utility grid were modelled by the short circuit power values at the interconnection point to the park. These were taken as typical of a 'weak' and a 'strong' grid. That enable to conclude that this parameter does not seem to have a strong influence on the wind park power's output fluctuations, but on the other hand is determinant in what concerns on the fluctuations of the interconnection voltage busbar.

1 INTRODUCTION

Distributed System Generation (DSG) is one of the ways used to produce electric energy with a lower negative impact on the environment.

The potential investors in DSG are becoming to the conclusion that these power plants they have to be of the order of the tens of megawatts so as to be economically interesting. So one may expect the rated power of these power plants to increase in the near future.

There is a lack of 'available tools' in what concerns the study of the impact of the distributed power systems (DSG) have in the utility grid stability and performance.

The situation becomes more serious if the DSG is a wind park or a wind turbine that delivers a continuously fluctuating power to utility grid even in steady state working mode.

The objective of the work that has been carried out is to develop such a 'tool' that enables both the wind park investors and the utility grid technical staff to perform the necessary preliminary studies before connecting wind parks in windy remote areas, which, most of the times, have a weak connection to the main power plants and are characterised by a low short circuit power value.

In a first step a dynamic model of a two wind turbine park was developed [1,2]. The model includes the utility grid near the wind power plant and enables to perform studies addressing the influence that wind power fluctuations have in the local consumers' voltage and frequency regulations.

Furthermore a Shinozuka method based wind model was developed and modified to be possible to generate

correlated wind synthetic series to achieve the influence of the turbulence's smoothing effect in the power output of a wind park.

This paper concludes a preliminary study in order to assess the influence of the different parameters that affect the performance of a wind park in terms of the electrical output. This first step aims to achieve the parameters that may, or may not, be neglected in the future complete dynamic model of a wind park to be developed.

2 THE WIND PARK MODEL

The wind park time dependent model used was detailed described in previous publications [1,6,11]. Nevertheless the main characteristics of the model are presented here. The model is based in a dynamic turbine wind series input and electric quantities' time series output model.

The behaviour of the wind turbine is accomplished through a characteristic equation of the wind rotor and the differential equations that describe the generator and the grid.

The wind park is an integrated model that includes the influence of the turbulence, the dynamics of the turbine, the electric interference between the generators, capacitors and transformers inside the park and the grid/consumers near the park. The integrated model includes sub models that address the different phenomena:

- i) a spatial and time wind correlation method;
- ii) a time-domain model of the WECS and the electrical system;

iii) the characteristics of the utility grid in the inter-connection busbar to the wind park

The wind park model is able to simulate a wind park connected to the grid topology represented in Figure 1

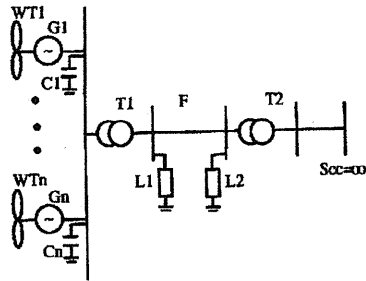


Fig. 1 - The wind park and grid's model scheme

A simple wind model to generate correlated wind time series was previously developed to assess the influence of the cross correlation's effect in the fluctuations of the power output [1,4].

This WECS model consists on the integration of a time domain wind turbine's model that integrates the aeroelastic effects in the blades and accounts for the time variation of the torque and the shaft rotational speed [6,7] and an induction generator model that includes the saturation effects of the magnetic materials [5] thus addressing its non linear working range.

These models were adapted to perform the WECS typical behaviour with time variable torque and slip and were first presented in [6,7]. They are now implemented in a software package named INDUSAT, which allows to perform several studies either in steady-state or transient conditions [10,11].

2.1 Wind Model

A dynamic model of a wind park must account for the effect of the different wind time series that affect the different turbines. Thus the knowledge of the simultaneous wind velocity time series at the various turbine locations is needed, including not just average wind velocities but also the superimposed turbulence. This is required by the low inertia of the electric system and by the existence of phenomena associated with turbulence effects on the turbine's power output either in transient and steady state.

A preliminary wind model was developed, based on the so called "Shinozuka method", i.e. the generation of time series from the amplitude and phase spectra. For the current case, the amplitude spectrum is obtained from a parametrised wind power's spectrum density (PSD). The phase spectrum is randomly generated for a (first) reference series; for the other

series, the phase values are dependent on the desired cross correlations among series [1,4].

The wind model is based on:

- i) the Taylor hypothesis of "frozen" homogeneous turbulence;
- ii) the assumption that each size class of eddies is represented in the power spectrum by the energy at the frequency $f = L/v$, where L is the eddy size (along wind) and v the mean wind speed; and
- iii) the assumption that eddies with size less than the distance H between two certain sites will be too small to affect both of them at the same time - and therefore will bring a null average contribution to the cross-correlation.

Within these hypotheses, the Shinozuka method is used to generate cross-correlated wind speed series for any two places H apart taking the phase spectrum as equal for both places up to $f=H/v$, and random thereon [4].

The well-known "Davenport spectrum" shape was used as the wind PSD for both places, with common average speeds at 10 m high [t] and roughness coefficients of 0.008.

Samples from the model's stochastic wind series where taken as appropriate when yielding cross-correlations close to those estimated with exponential fits to field observations, with decay lengths of 200 m along-wind, and 50 m across-wind.

2.2 Wind turbine Model

To simulate the wind turbine performance the already mentioned time dependent model that uses as input the wind's velocity instantaneous value was used.

This model is based in the well know momentum /strip theory and takes the system as rigid and thus does not consider the aeroelastic effects in the blades

To describe the torque's characteristic of the turbine's rotor a characteristic equation that accounts for the shaft's rotational speed and torque time variation is used [6,7]

2.3 Induction generator and utility grid Model

The local loads were modelled as constant active and reactive power for the computation of initial conditions and as a constant impedance in the wind park model. The transformers, the feeder and the a.c. system were modelled also as constant impedance.

In order to obtain the initial conditions for the set of differential equations that accurately describe the system, a numerical model taking as input only the system parameters and the instantaneous wind speed was built.

This technique enables the computation- of the initial steady-state operating point through a modified power flow (to include the induction generator) which takes into account the electromechanical characteristics of the turbine/ generator groups to evaluate the rotor speed of each machine.

The interactions between the two turbine/generator groups inside the power plant and the conditions at the interconnection busbar were established through the short circuit power value in order to correctly model and determine the influence of this parameter in the electric power and voltage output fluctuations.

3 APPLICATION OF THE WIND PARK MODEL

The model described above enable us to assess the influence of parameters as the mean wind speed the turbulence and the grid characteristics in the electric output of the wind park in order to draw some conclusions on their effect on the stability of the park and also what happens in the local grid.

Most of the wind turbine/park models work in the frequency domain, but a time domain analysis is preferred by utility electric engineers since its results are quite important when the study of electric performance through the electric output quantities, (voltage and currents) is regarded, even if only steady state working mode is addressed. Another important factor if one builds a complete differential equation model is that easily also studies the transient working mode of the park.

The time domain models put the problem of the representativity of one simulation of wind time series input/electric power or voltage and current time series output to the whole process. That limitation was overcome by performing a large amount of simulations, thus regarding each simulation as a representation of a stochastic process.

The wind park model described above and illustrated in Fig. 1 was applied to the simplest configuration of both the wind park and the grid as shown in Fig. 2 where the local consumed power was set to zero, and only two turbines were considered. This was mainly due to the large amount of time needed to accomplish each simulation (1minute real time to each 1 sec simulation approximately).

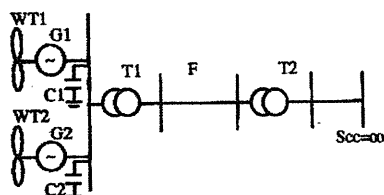


Fig. 2 - Topology of the grid to which the model was applied. The local consumers were not considered.

The wind turbines are two small 12 m diameter prototypes with stall regulated rotor detailed described in previous publications [5,11]. The electric generator is an induction machine with 24 kVA rated power. Each wind turbine is locally compensated by a 4 kVAr capacitor bank.

The transformer T1 represents the step-up transformer in the wind park and is a 400V/30 CV, 100 kVA, 5% transformer. The 30 CV transmission line has 20 km of length and is represented by an impedance of $0.411+j0.275 \Omega/\text{km}$. T2 represents the substation transformer which steps-up the voltage from 30 CV to 60 CV being the rated power equal to 10 MVA and the short circuit voltage equal 8.35 %.

The objective of these studies is to determine which are the dominant, among the input parameters, in the wind park performance.

The effect that wind time series cross correlation's factors have in the wind park power's output was already addressed in a previous publication [1].

In this paper the model was used to assess the influence of the grid characteristics (via the short circuit power value in the interconnection busbar) is the main objective so, having in mind the necessity of representativity of the results, a large amount of simulations with a short circuit value characteristic of a strong and weak grid was performed.

The short circuit value typical of a weak grid was set to 5 times the rated power of the wind park (values lower than this were tested and the wind park has an unstable working mode and doesn't remain in parallel with the grid for medium to strong winds).

The short circuit value to characterise a strong grid was taken as 20 times the rated power of the park. This value was chosen mainly because is the lower limit stated in Portuguese law to connect DSG to the utility grid. Above this value the grid is considered a 'strong' grid in Portuguese law terms.

The mean wind speed is, of course, determinant in the amount of energy produced but its influence on the voltage busbar fluctuations is a bit vague so some simulations with different wind speed mean values (and uncorrelated series) were performed for the weak and the strong grid cases.

4 ANALYSIS OF THE RESULTS

The output of the simulations was analysed statistically both in time and frequency domain. The results are presented in Figures 3 to 10.

In the cases presented in figures 3 to 8, which correspond to the study of the performance under constant mean speed and variable cross correlation factor and short circuit power value, the wind time series used as input of the wind park were obtained

after the same 'Davenport spectrum' with 7.0 m/s mean wind speed at 10 m high

In Fig 3 and 4 the difference in the behaviour of the busbar voltage and the power output respectively for both the strong and weak grids versus the cross correlation factor of the input wind time series is illustrated.

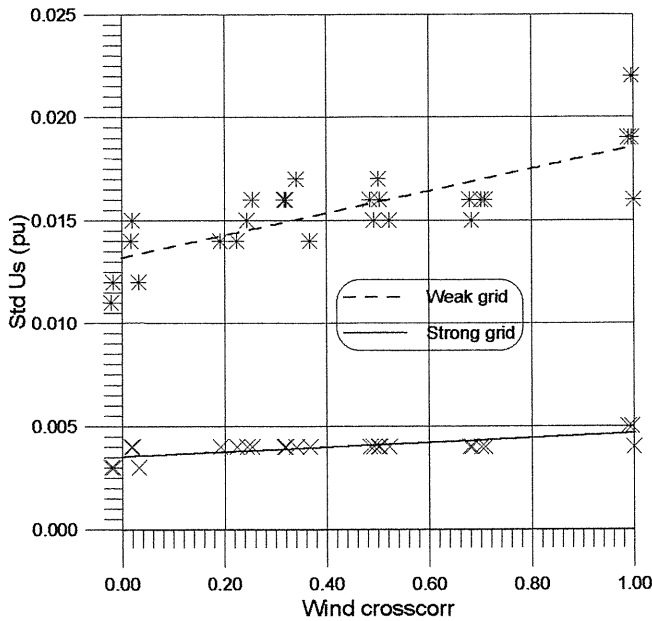


Fig.3 - Busbar voltage standard deviation versus wind cross correlation. Comparison between strong and weak grid. (Mean wind speed =7.0 m/s).

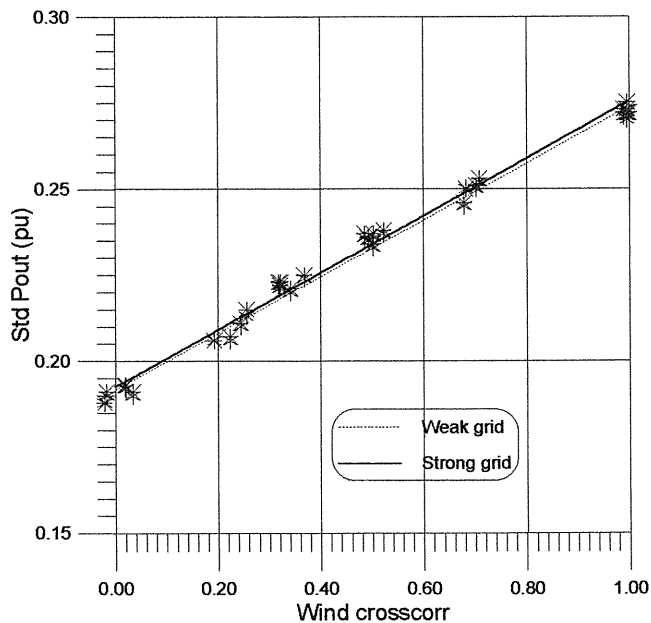


Fig. 4 - Power output standard deviation versus wind cross correlation. Comparison between weak and strong grid. (Mean wind speed =7.0 m/s).

In figure 5 are represented the PSD's of the power output of the wind park and the individual turbines, for weak grid's case.

In figure 6 is showed the comparison between weak and strong grid connection in terms of wind park power

output fluctuations' PSD In both cases the PSD's correspond to the averaged 'spectra' of the five samples simulated with cross correlation factor equal to 0.33.

In figure 7 simulation samples of the voltage time series for the two grid cases are represented to illustrate the time's behaviour of this quantity. The input wind time series (the same for the weak and strong grid simulations) are uncorrelated in this case.

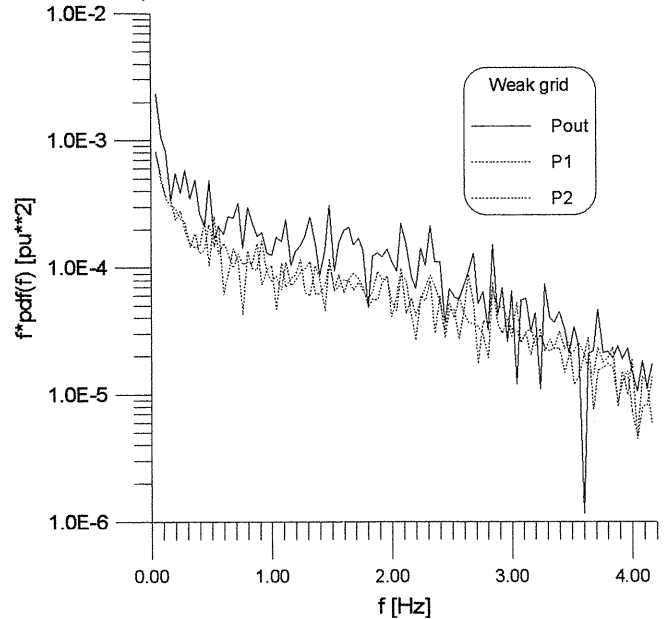


Fig. 5 - PSD of the wind park and the individual turbines' power output for the weak grid. (0.33 cross correlation, mean wind velocity =7.0 m/s)

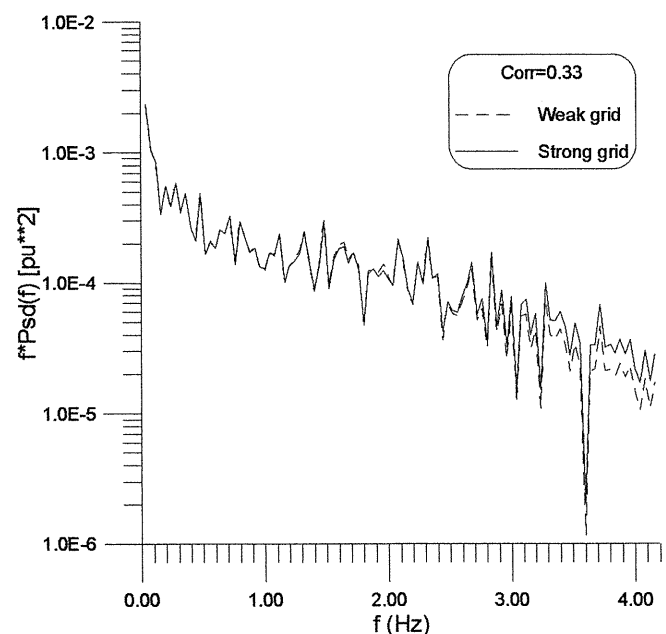


Fig. 6 - PSD of the wind park and the individual turbines' power output for the weak grid. (0.33 cross correlation, mean wind velocity =7.0 m/s)

In figure 8 the power output for both weak and strong grids that corresponds to the same simulations is shown. Both weak and strong grids are in the graphic but it is not obvious since the power output is the same and the curves are overlotted.

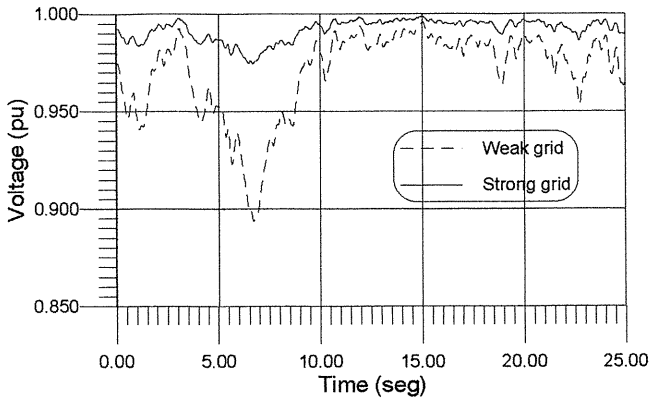


Fig.7 - Voltage fluctuation in the wind park busbar for strong and weak grids. The input wind time series are uncorrelated (Mean wind speed =7.0 m/s)

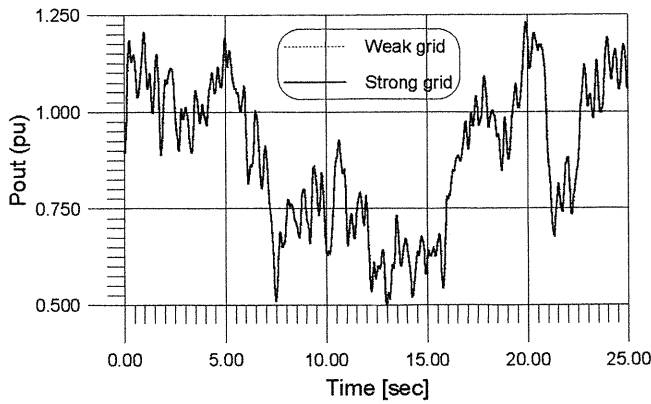


Fig.8 - Power output fluctuations for strong and weak grids. The input wind time series are uncorrelated (Mean wind speed =7.0 m/s)

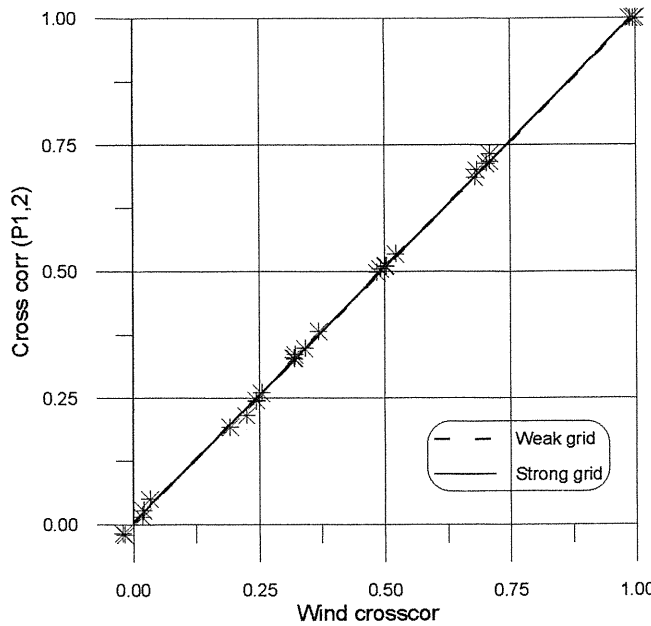


Fig. 9 - Cross correlation of the individual turbine power output versus the wind series input for both strong and weak grids (Mean wind speed =7.0 m/s)

In figure 9 the cross correlation of the individual turbines' power output against the cross correlation of the input wind time series is presented. Again the two curves are not visible since this parameter has no on the power output fluctuations and the curves are again overplotted.

The mean wind speed is, of course, the most influent parameter in a wind park output and its effect is illustrated in figures 10, 11 and 12.

In figure 10 and 11 the standard deviation of the interconnection voltage busbar and the power output, respectively, are plotted against the mean wind speed. In figure 12 the mean voltage dependence on this parameter is presented.

In figures 10, 11 and 12, for the weak grid case, results above 8 m/s of mean wind speed are not available in the graphics, because the wind park presents, most of the times, an unstable working mode.

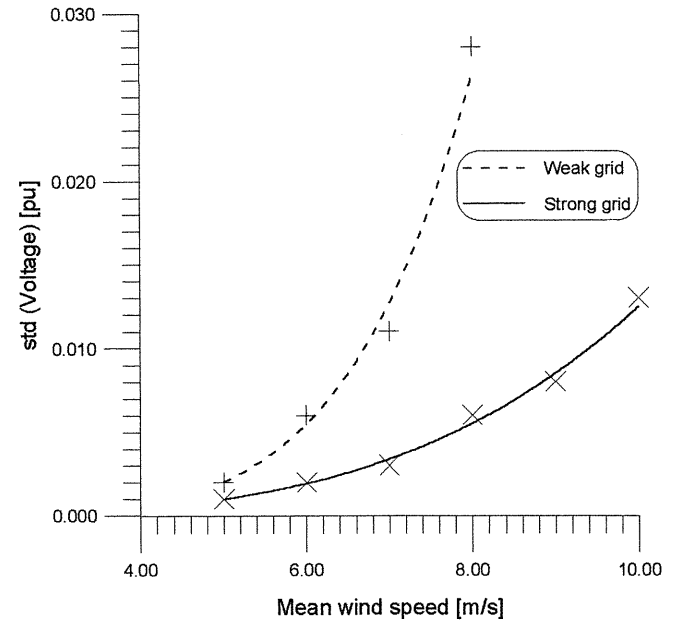


Fig. 10 - Standard deviation of the wind park's voltage busbar versus the mean wind speed for both weak and strong grids (uncorrelated wind time series).

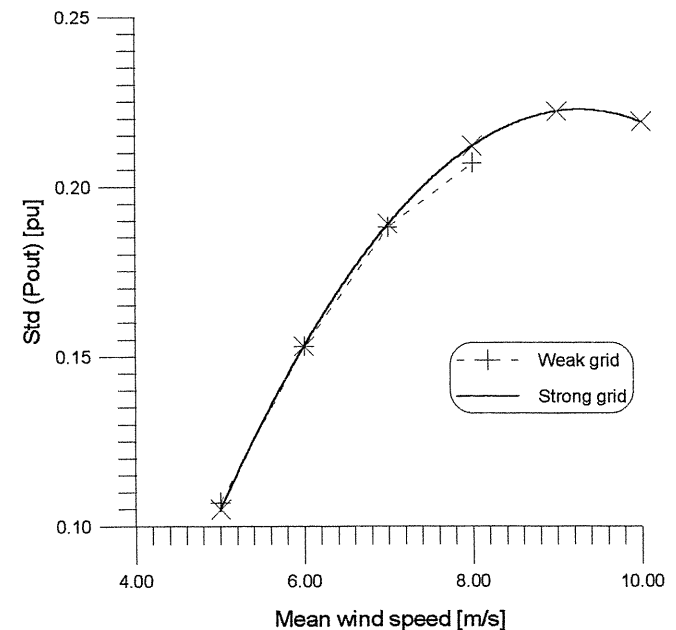


Fig. 11 - Standard deviation of the wind park power's output fluctuations versus the mean wind speed for both weak and strong grids (uncorrelated wind time series).

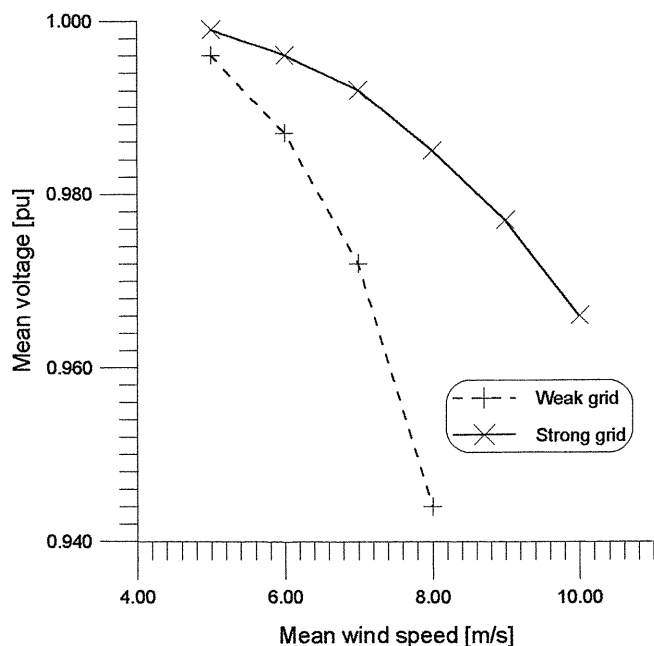


Fig. 12 - Mean voltage in the wind park busbar versus the mean wind speed for both weak and strong grids (uncorrelated wind time series).

5 CONCLUSIONS

The effect of the utility grid characteristics may be neglected when the electric power fluctuation is the only parameter to be studied. However, in terms of electrical analysis, the voltage fluctuation in the wind park's interconnection busbar is much more important than the power fluctuations since it affects the local consumers connected to the busbar. It may be easily concluded from figures 7, 10 and 12 that the grid characteristics strongly affect the voltage at the wind park's interconnection busbar, so it is a major parameter to include in wind park future models.

The smoothing effect of low wind cross correlation's factor in the wind park power fluctuations was already studied by many authors [1,2,3,12,14,15] and is confirmed again here (Fig.5, 6). This is a quite important conclusion since most wind park models use mean wind speed values neglecting the turbulence effects. Figure 6 also points out a low amount of energy in the high frequency range ($>2\text{Hz}$) for the weak grid case. This may be explained by a higher smoothing effect in the weak grid due to higher fluctuations in the time series.

Finally one may conclude that the higher the mean wind speed in a local is the more careful the study has to be since the voltage fluctuation in steady increase dramatically with this parameter.

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