Increasing Wind Penetration on Fernando de Noronha Wind/Diesel System

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Abstract:
This paper presents the analysis of increasing wind penetration on the Fernando de Noronha island wind/diesel system. The goal is to augment the wind energy penetration to around 25% and increase fuel savings while maintaining system simplicity and robustness. The challenge is to ensure reliable and stable supply without using storage devices and a minimum of power electronics. Some experimental measurements and operational data collected in 2001 are used for the hybrid system analysis.

1. Introduction

The archipelago of Fernando de Noronha is located in the Atlantic Ocean 345km off the coast of Brazil. A large part of it is a National Park with restricted areas. The main island of the archipelago, with a fixed population of around 2.000 people and 500 tourists (during high season) has electricity supplied by a diesel power plant.

The use of wind energy for electricity generation in Fernando de Noronha started in 1992 with the installation of a 75kW wind turbine [1]. The design of the system, a simple approach that has been considered the key for the success, included:

- Standard wind turbine with induction generator directly connected to the grid.
- There is no energy storage, dump load or special controllers.
- No changes on operating conditions for diesel generators due to the low wind penetration (~10%).

In 2000, the Brazilian Wind Energy Centre – CBEE and the Brazilian Regulatory Agency for Electricity – ANEEL initiated the second phase of the Fernando de Noronha Project with the installation of a second wind turbine, rated 225kW, aiming to augment the wind penetration and increase fuel savings.

The challenge of this phase is to achieve monthly averages of 25% wind penetration while ensuring reliable supply and good power quality.

The hybrid wind/diesel system design uses the "simple and robust" concept [2] with a minimum of power electronics and no supervisory controller. This leads to possible instantaneous wind penetration of more than 50%, which can be considered a concern for stable and reliable operation. In order to investigate these issues the wind turbine has been set to a maximum of 150kW and a special power quality measurements campaign has been carried out by CBEE and RISØ National Laboratory/Denmark during June 2001.

This paper shows some of the results of those measurements and normal operation data collected during October-December of 2001.

2. Description of the Power System

An illustrative diagram of the Island's wind/diesel system is presented in Figure 1. A new diesel generation capacity has been recently added to the system. The diesel generation system is composed of two groups: Group 1 with two (new) 910kVA Caterpillar generator sets and Group 2 with a 450kVA Volvo/Leroy generator set, which is only used as an emergency unit. The 75kW wind turbine is out of operation since beginning of 2000 due to maintenance problems.

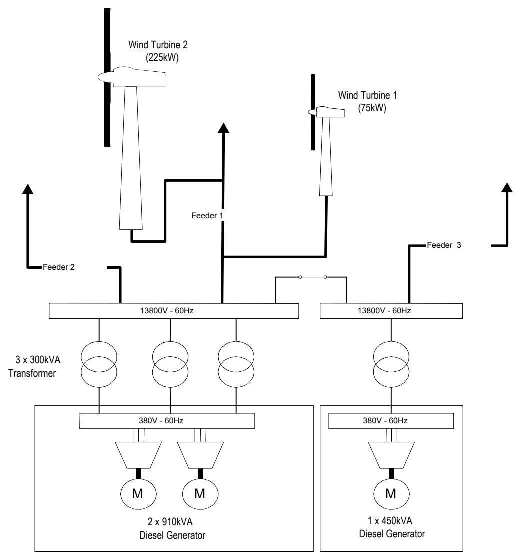

Figure 1. Simple diagram of the wind/diesel hybrid power system.

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The low voltage diesel generation is rated 380VAC/60Hz and the distribution lines, which have only few kilometres, are medium voltage (13.8kV).

The consumers are connected to three main feeders. Feeder 1 has the majority of the loads as well as the wind turbines connected. In 2001, the peak load, recorded instantaneously, was 750kW with a correspondent reactive load of 400kVAr.

A 75kVAr capacitor bank is connected to the high voltage side of the diesel power station increasing the reactive power reserve. Another 300kVAr capacitor bank with automatic control was installed by the Utility in September 2001 at the low voltage side of the diesel station. The objective is to alleviate the generator reactive power production (a compensation for new reactive loads at the Island – including the 225kW wind turbine) keeping the power factor at 0.96.

The 225kW wind turbine is a commercial Vestas V27, pitch regulated, double induction generator (225/50kW), fixed speed installed at 30m height. The maximum power output of the wind turbine has been set up to 150kW as required by the Utility in order to gain confidence and experience in parallel operation of wind/diesel. Some parameters of the control system have been adjusted to improve operation in situations of relatively large frequency and voltage variations.

3. Power System Analysis

The measurements have been carried out by CBEE and RISØ during 21-26 of June, 2001. The data acquisition system measured the power quality at the power station bus bar and at the PCC of the wind turbine simultaneously. All three phase currents and voltages have been sampled at 480Hz (8 samples per grid period at 60Hz) and saved on a computer's hard disk.

This section presents results of the measurement campaign, steady-state analysis and dynamic analysis of the wind/diesel system.

3.1. Steady-State Analysis

Steady-state aspects deal with the steady-state voltage and frequency deviations during normal operation. It is also known as slow dynamic variations. The time frame of the analysis is from 10 minutes up to hours. As a secondary task, nevertheless important, the stability is also addressed.

The main concerns are operational limits of the diesel generator set – synchronous generator and respective controls technical limits – and dispatch strategies. The active power limit is directly related to the speed variations, i.e., frequency variations and the reactive power is related to the voltage deviations and controllability.

The active power output capability is limited to the diesel motor capability and to the thermal limits of the synchronous generator. A conventional diesel machine has basically two operational limits: maximum load and minimum load. Synchronous generators are rated in terms of the maximum MVA output at a specified power factor that they can carry continuously without overheating. The continuous reactive power output capability is limited to three effects: armature current limit; field current limit and end region heating limit.

Figure 1 presents the active and reactive power limits for the diesel generator installed in Fernando de Noronha Island based on Caterpillar data sheets and models presented in [3]. The vertical lines are diesel engine manufacturer's recommendations for minimum and maximum long-duration loads.

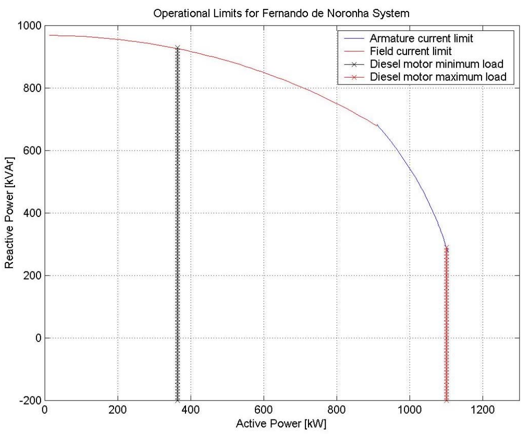

Figure 1. Operational limits of the 910kVA diesel generator.

During the measurement campaign all observed data are within the limits presented in Figure 1. Even maximum values recorded in time averages of 0.2 seconds are within the limits drawn for a 10 minutes average in the figure.

A sample of the measurements is shown in the Figure 3 below. The data consists of 8 minutes of active power produced by one diesel and wind turbine. It can be seen the shift from smaller to larger wind turbine generator due to increase of wind speeds. The electrical grid frequency is also presented in the figure.

The frequency variation is less then 0.5% during all the period measured. However, during transients, e.g. start-up/shut down of wind turbine, the frequency varies up to 1% during 3s.

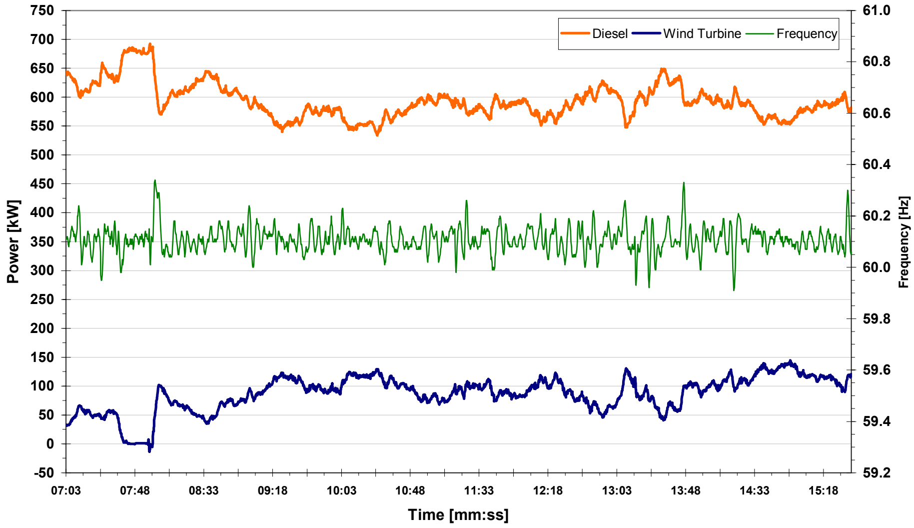

Figure 3. Measured active power of diesel and wind turbine, and grid frequency on June 25, 2001. The wind turbine shifts generators at time 7:48.

Normally voltage deviations did not exceed 3%. But short periods (0.2 seconds) voltage drops larger than 3% can be seen during events such as start-up of large motors in the network, and the wind turbine start-up. However, the reactive power reserve at the diesel station is still enough to enable a good voltage regulation

3.2. Dynamic analysis

The main aspects of the dynamic analysis are:

- Power quality and stability in continuous operation;
- Voltage and frequency variation during start-up and shut down of the wind turbine;
- Stability after disturbances in the power system, i.e. short circuits;

The dynamic problems affecting wind/diesel power systems are related to the frequency and voltage oscillations. The speed governor and voltage regulator of a diesel generator set shall keep the frequency and voltage constant, respectively. Nevertheless, frequency and voltage variations will occur due to relatively large load changes and the close relation between the time response of the regulators and the system eigenfrequencies badly damped of the power system.

In the following the electrical power, voltage and frequency are analysed in the frequency range from 0 to 30 Hz.

The dynamics of such relatively small power system is strongly dependent on the characteristics of the voltage regulator and the speed governor of the diesel sets. These dynamic regulators are related to electro-mechanical modes in the power system, usually in the range from 0.05 to a few hertz (e.g. 2Hz). It is then possible that small frequency and voltage oscillations will not be compensated but amplified due to the fast acting diesel regulators.

The spectral density of the electrical power measured at the diesel generator terminals with and without wind turbine is shown in Figure 4.

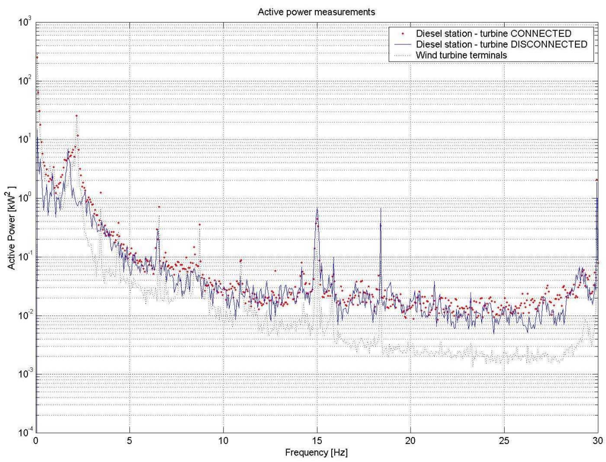

Figure 4. Power spectral density of the active power measured at the diesel station.

For the diesel only operation, i.e. wind turbine disconnected, the main energy content of the power is on the frequencies: 1.8, 6.4, 15 and 18.4Hz. The frequency of a single cylinder stroke is expected to be around 15Hz.

When the power is measured with the wind turbine connected, the main energy content of power oscillations changes for the following frequencies: 2, 6.4, 8.7, 15 and 18.4Hz. The characteristic 3p frequency of the wind turbine, around 2Hz, is very evident in the figure. The dominant diesel engine eigenfrequencies are present on both measurements.

The power spectral density of the voltage showed in Figure 5 compares measurements of voltage at the diesel station with the wind turbine connected (dots) and disconnected (line).

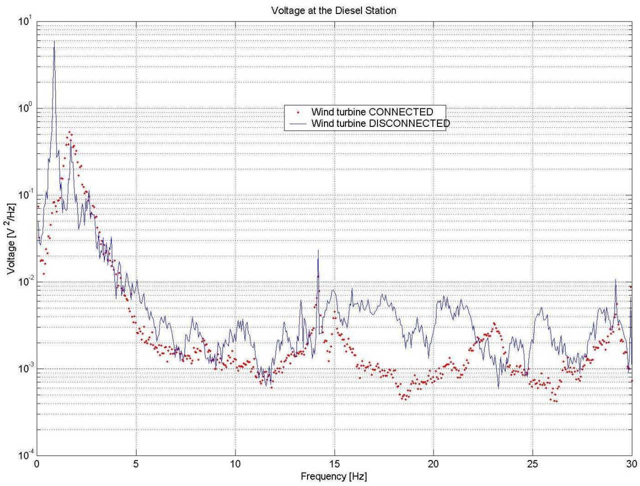

Figure 5. Power spectral density of the voltage measured at the diesel station.

The main energy content of voltage oscillations when the diesel is operating alone is around 1Hz. Other main frequencies are 2Hz, 14.2 Hz and 29Hz. When the wind turbine is connected, the voltage variations are greatly reduced. In this case, the dominant and more important frequency changes to 2Hz. The eigenfrequency of 1Hz is still present but very damped when the wind turbine is connected.

The fast response of the diesel's speed regulator is apparent in the Figure 6, which shows the variation of grid frequency during an emergency stop of the wind turbine. It corresponds to a diesel step change from 400kW to 500kW. It can be seen that the regulator compensates almost immediately and it takes only 3 seconds for bringing the frequency back to the original levels.

The first three months of operation after the installation of the new diesel sets and reactive power compensation unit, the wind turbine generated 174MWh, operating 79% of the time. The average wind energy penetration in the period was 15%.

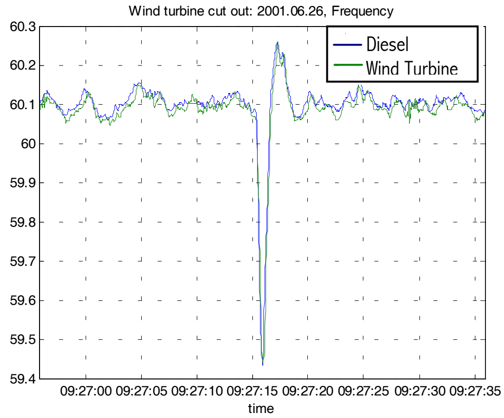

Figure 6. Frequency (in Hz) variations during an emergency stop of the wind turbine.

4. Conclusions

The analysis of the power quality measurements shows that the hybrid wind/diesel system of Fernando de Noronha is stable and diesel regulators are able to control voltage and frequency in all situations.

The maximum active and reactive load peaks measured (700kW and 500kVAr) are much lower than the limits of the diesel synchronous generators. However there can be situations of low load and high winds where the diesel would operate below the minimum active load recommended by the manufacturer (45% of the nominal). But the observations show that these situations are rare.

The voltage variations are greatly reduced during wind/diesel operation compared with diesel only operation. The speed governor of the diesel engine, which is responsible for the frequency/active power regulation, has shown a very fast response even in 25% step change situations.

5. Acknowledgments

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6. References

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