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Measurements at the ECN Wind Turbine Test Location Wieringermeer

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Abstract

The ECN Wind Turbine Test Station Wieringermeer (EWTW) is a unique test location for wind turbines that consists of four prototype turbines, five Nordex N80 turbines for research purposes and three large meteorological masts. Two masts reach to 108m height and one mast to 100m. The measurements at the research turbines include load measurements, collection of SCADA data and meteorological measurements. The large amount of data is used in many research projects. For efficient use of validated data a database has been developed by ECN. A description of the database structure is presented and development choices are explained. An important part of the database development is the validation procedure of the measured data.

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Summary

The ECN Wind Turbine Test Station Wieringermeer (EWTW) is a unique test location for wind turbines that consists of four prototype turbines, five Nordex N80 turbines for research purposes and three large meteorological masts. Two masts reach to 108m height and one mast to 100m. The measurements at the research turbines include load measurements, collection of SCADA data and meteorological measurements. The large amount of data is used in many research projects. For efficient use of validated data a database has been developed by ECN. A description of the database structure is presented and development choices are explained. An important part of the database development is the validation procedure of the measured data.

Introduction

Since the summer of 2003 a unique test facility has become available. The ECN Wind turbine Test Station Wieringermeer (EWTW) is located in the Netherlands, 35 km eastwards of ECN, Petten. The wind turbine test station consists of:

- four locations for prototype wind turbines up to 6MW;
- five research turbines of type Nordex N80/2500;
- one 100m and two 108m high meteorological towers;
- a measurement pavilion and measurement network.

Several research projects are carried out at EWTW. The measurements include:

- meteorological measurements at the towers;
- collection of SCADA data (134 signals, ten-minute statistics) of five N80 turbines;
- collection of SCADA data (8 signals, 25Hz) of five N80 turbines;
- condition monitoring data in all five N80 turbines with systems of different suppliers;
- mechanical load measurements in one N80 turbine;
- power performance measurements and noise measurements on the N80 turbines;
- development of blade monitoring system;
- development of WT-bird system to detect and register bird collisions;
- validation of the ECN wind power prediction system.

Wind Farm Description

The wind farm consists of two rows of turbines. The first row consists of four prototype turbines oriented 95º with respect to North and with a spacing of 411m. The second row consists of five research turbines oriented 95º with respect to North and with a spacing of 305m. The main wind direction is South-West. The test site and its surroundings are characterized by flat terrain, consisting of mainly agricultural area, with single farmhouses and rows of trees. The lake IJsselmeer is located at a distance of 1-2 km East of the research turbines. In the North of the wind farm, the small village of Kreileroord is located. The rows of prototype turbines and research turbines have a separation of 1600m. The wind farm lay-out is indicated in Figure 1.

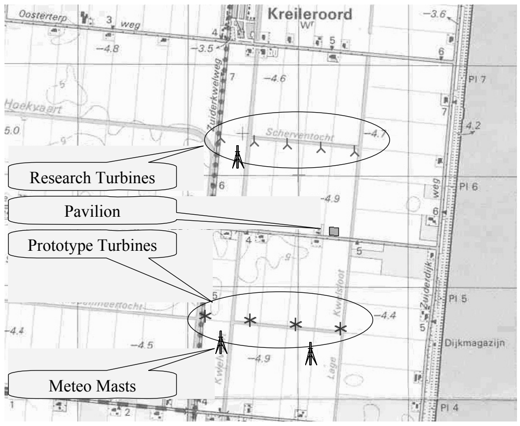

Figure 1. Lay-out of the ECN Wind Turbine Test Station Wieringermeer.

Wind Turbine Description

The five research turbines at EWTW are Nordex N80 turbines with rated power of 2500 kW. The turbines are variable-speed, pitch regulated wind turbines with rotor diameter of 80m and hub height of 80m. The rotor consists of three blades made of glass fibre-reinforced polyester. The blades are equipped with a lightning protection system including a lightning receptor deflecting the lightning to the rotor hub. The gearbox is designed as a two-stage planetary and one-stage spur gear. The gearbox is cooled through an oil-air cooling circuit with stepped cooling capacity respectively oil volume flow. The generator is a double-fed asynchronous machine. The generator is kept in its optimum temperature range by a water-glycol cooling circuit. The N80 turbines operate when the wind speeds at hub height are between 4m/s and 25m/s and reach nominal power around 14m/s.

Wind Farm Data Description

Data are collected at the research site in two ways, one way is the ECN measurement network with local data acquisition units (DANTE systems) and the other is the central Nordex SCADA system. The measurements with ECN measurement network consist of the measurements of instrumentation in the meteorological towers and the fast measurements of SCADA data as well as the mechanical load measurements. The Nordex SCADA system collects all SCADA data from the five turbines in ten-minute statistics values and stores these at a central computer. These measurements are transferred to ECN on a daily basis.

The meteorological data consists of wind speed measurements using cup anemometers and sonic anemometers, wind direction, air pressure and temperature, precipitation and atmospheric stability. The data acquisition system used at EWTW is the DANTE system that has been developed at ECN. The distributed data-acquisition is a very rugged and highly flexible system, suitable for measurements in harsh environments like offshore wind farms. Near the sensors a front-end system is placed, e.g. in the turbine nacelle, the meteorological mast or in the turbine tower. For each sensor, a dedicated signal conditioning & analogue-to-digital-conversion module is installed in the front-end. These sensors can be strain gauges, rotary encoders, anemometers, wind vanes, temperature sensors, accelerometers, etc. A special module interfaces with the ECN telemetric system. Optical fibres connect all front-end systems to the host computer, completing the data-acquisition system.

For each campaign, the data are stored in binary files on a host computer near the experiment. The host computer is connected to the same network where the DANTE systems are attached. At EWTW there is a fibre-optic network connecting all distributed DANTE systems. The host computer for each campaign makes a selection of the signals that are transmitted over the network. The binary files are transferred on a daily basis to the ECN home base in Petten, where the data is inserted in the database.

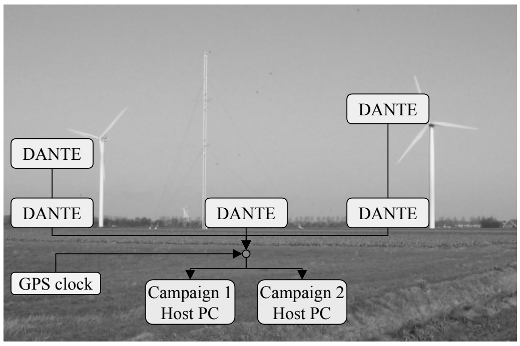

Figure 2. Measurements are done using the fibre-optic network and the distributed data acquisition systems DANTE.

Meteorological Towers

The meteorological towers at EWTW are lattice towers with a height of 100m or 108m. The triangular cross sections with side lengths of 1.6m are equal at all levels. Booms to support measurement instruments are installed at different levels. One boom is pointing to north: 0°, a second one to east-south-east: 120° and a third one to west-south-west: 240°. The booms are 6.5m long so that the influence of the mast on the wind speed and wind direction measurements is less than 1%. The meteorological measurements near the research turbines are at 80m (hub height), at 52m and 108m height. The sonics in the mast are located in the North booms in order to measure the wake conditions of the turbines.

The Wind Data Management System

The storage of the huge amounts of data from sampling hundreds of signals at relatively high frequencies (1–128 Hz) during measuring campaigns lasting months to even years poses no problems. The validation and retrieval of the data are of greater concern. The Wind Data Management System (WDMS) is a system for managing data related to wind energy. It was realized that there was a void between the sheer amount of raw data and the needs of their customers. The analysts want their data ready and validated (cooked and cleaned) without erroneous data points from for example frozen cup anemometers, broken sensors, and other troubles. The WDMS has been developed by ECN to fill this void. On the one hand, it handles and imports the measured data; on the other hand it serves the users by presenting data in various predefined ways. And in between, it handles the cooking and cleaning: collecting data, running it through filters, calculating statistics and validating it against rules; manually if necessary.

Structure of WDMS

In order to manage data one must structure it. Modern ideas about management systems invariably assume that a relational database lies at the core. They have a rich set of functionality, high level languages (SQL), programming interfaces and a structured and optimized way of storing data. For the WDMS, the data analysis certainly did not point towards a database at first. The volume of raw data was too large, the data itself too straightforward and the structure too plain to consider it useful. However, the database structure was preferred on its merits of being ready to use across the network and ready to talk popular protocols. The Open Source PostgreSQL database structure was selected.

Campaigns and data structure

Measurement campaigns periods range from weeks to several years. Each campaign typically has a well-defined set of measured signals, although this set may change during the campaign. Measurements are typically (but not necessarily) performed using the ECN DANTE data acquisition system. The measured signals are treated in DANTE where the first validation is performed. After application of the calibration constants, the measured values (mostly in SI-units) are sampled as binary floating-point numbers. For DANTE, the sample frequency is 128Hz at maximum, which can be scaled down by powers of 2. All binary samples are single precision (32 bit) floating point numbers, which is sufficiently accurate for most measuring instruments. Typical for the measurements in wind energy is the averaging period of 10 minutes. As a result, the sampled data is stored per ten minutes in binary files, producing 144 files per day. Many operations in the WDMS system implicitly assume that they cover ten-minute intervals.

One of the potential problems recognized early on is the handling of the sheer bulk of data, which could accumulate to hundreds, if not thousands of gigabytes. This became even more problematic due to the ISO 17025 requirement that measured date should be stored unaltered. Storing all data in a relational database is near impossible. On the other hand, there are the known limitations of flat-file access. These considerations led to a solution with a dual nature; flat-file access to the original measured data is combined with a relational database for statistics of the data. Derived data, such as equivalent loads, wind spectra, atmospheric stability, etc., are accessed through the database. One accesses raw data by accessing the binary file itself after looking up the filename in the database. This also means some database functions may access the file system if necessary.

When a database is created, each database has its own copy of the software and there is a bundle of common scripts and plug-ins that all databases share. For individual users name spaces can be assigned so that objects with identical names can coexist in different name spaces.

Data

In WDMS there is a clear distinction between measured signals and pseudo signals: measured data originate from an external source (such as binary files) while pseudo signals are derived from other data. Pseudo signals generally depend on one or more different measured signals and a number of parameters such as offset values, gain factors and geometrical quantities. As described earlier, the measured signals of meteorological sensors are mostly in SI units; all calibration factors have readily been applied when the data are stored in binary files at the prescribed sample frequencies. For load measurements the calibration constants are applied in WDMS. The WDMS database automatically generates the standard statistic values of the measured and the derived signals, which are the average, minimum, maximum and standard deviation. These statistic values are stored in the database. Apart from these values other 10-minute statistic values are calculated for some signals, for example the wind speed in the horizontal plane as determined by sonic anemometers, atmospheric stability, rotor speed or equivalent loads for mechanical load measurements. Derived signals may also be determined at the original sample rate, which is often the case for load measurements, or is the case for combinations of measurements of the wind speed components by sonic anemometers.

Since the measured data volume is such a bulk, at first instance the only data stored in the database are the file locations. Data can be extracted on demand. For many analyses, ten-minute statistics are important. These statistics are calculated from the original raw measured data, and the results are stored in the database. Users will frequently retrieve the statistics data.

Validation
We stipulated that analysts want 'cleaned and cooked data.' Most of the cooking is referred to above. It is time to move on to the cleaning of data. The validity of data is a vitally important aspect of the system. Unfortunately, during measurements many things can go wrong. Some of these problems can be detected by self-diagnosis and a flag is set for that data by the data acquisition system, but others may go by undetected. The first source of erroneous data is incomplete ten-minute intervals; these data are invalid. For other sources rule based validation is introduced based on testing the data against smart heuristics. For example, by demanding that the standard deviation of a ten minute time series for a cup anemometer should be at least 0.1. Then, still, some data may be wrong for which an analyst must minutely run through the data and make the so-called post-validation by hand. Automatically generated daily plots of the measured data assist this process. Validation in WDMS covers entire ten-minute time series. Data is available and may be retrieved according Table 1.

Summarizing: three levels of validation are identified:

- *Auto-validation* is done by the data acquisition system itself. It is based on status signals from the hardware plus range-checks of the variables.
- *Rule-based validation* is based on predefined rules.
- *Post-validation* is performed manually.

Table 1. Availability according validation rules.

Auto-validation	Rule-based validation	Post-validation	Available
Valid	Valid	-	Yes
*	*	Valid	Yes
Invalid	*	-	No
*	Invalid	-	No
*	*	Invalid	No

(* means all values, - means information not present)

Meta-data
Up to this point, measured data were considered. WDMS allows the definition of virtually unlimited amounts of meta-data on variables and time series. A practical application of this meta-data is the configuration data of the DANTE system. The DANTE system stores information of (changes in) the instrumentation and variables in a configuration file.

Retrieving data
Once the WDMS database has been set-up, the data have been imported and the validation is completed, it is possible to retrieve data using SQL statements. Statistics data are best exported in comma-separated files, the time series can best be exported as binary data. For the missing values in the tables, various sentinel values can be designed. The standard is an empty space.
The joy of easy access to validated data by means of open source SQL statements stimulates enthusiastic use of the data for a large variety of research.

Accredited Measurements
ECN has large expertise on measurements related to wind energy. ECN is accredited in accordance with IEC 17025 for power curve measurements, noise measurements, and mechanical load measurements. Most of the measurements are carried out in accordance with the valid IEC wind turbine standards and technical recommendations, viz.: IEC 61400 -11, -12, and -13. The measurements are carried out onshore and offshore. The measured data are always stored in the WDMS database structure and can be delivered periodically in any digital format requested by the customer. Clear periodic reports are delivered to allow easy access to the data and to demonstrate the validity of the measurements. Reporting is done in accordance with IEC standards.

R&D Measurements
Various R&D projects are carried out at EWTW in close and beneficial cooperation with industry in order to develop new measurement systems for wind energy purposes, or to collect data for model development and validation. Examples are:

- condition monitoring of drive trains and generators;
- blade monitoring, among others with optical strain gauges (Bragg grating technology);
- WT-Bird, an innovative system for detecting bird collisions;
- nacelle anemometry;
- collection of meteorological data.

Component suppliers have the opportunity to test their prototypes at state of the art multi MegaWatt wind turbines at EWTW. The combination of ECN's broad knowledge on wind energy and the unique test facility EWTW can drastically shorten the time-to-market of new and innovative systems.

Conclusion

At the ECN Wind Turbine Test site Wieringermeer (EWTW) a continuous stream of data is gathered from a wind farm with five Nordex N80 research turbines and a 108m high meteorological mast. The data are measured by a data-acquisition system or obtained otherwise and stored. For storage and analysis of this vast amount of data, a high quality database has been developed. The database is a development of ECN. Its structure is used for all experiments carried out by ECN Wind Energy. The database contains all the necessary information about the measurement hardware, calibrations, etcetera. The measured data originate from meteorological sensors installed in the meteorological towers as well as from sensors in the five N80 turbines for scientific research. From these data other signals are derived and 10-minute statistical values are calculated and stored. In addition 10-minute statistics of the N80 SCADA data, supplied by Nordex, are stored in the database.

Storage of large quantities of data in a database requires extensive validation. The quality of the measured data is ensured by use of calibrated instruments, application of measurement procedures according ISO 17025, signal conditioning in the DANTE data acquisition system and implementation of validation filters and rules in the database structure. The database ensures good accessibility to validated data and unambiguous use in subsequent analyses. The first research results of the measurements will be published. Publications are available from www.ecn.nl.