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Wind Turbine Noise Measurements in practice

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Summary

A set of tools used by DELTA for wind turbine noise measurements helps simplify the complex work flow of standardized measurements. We will describe our practical experience in interfacing to turbine control systems, microphone mounting and windscreen, synchronization of multiple signal sources, wireless microphone connections, wind binning challenges, robustness of data recording, post-processing tools and tone analysis, as well as system calibration and certification. In addition, operating training requirements and check lists and system configuration management play an important role in ensure quality measurements. A deep understanding of various noise standards is required to ensure conformance to local requirements. Finally, custom built software that helps simplify the process will be described.

1. Introduction

Wind turbine noise measurements must fulfill some relatively complex standards and the measurements must also be closely correlated to meteorological conditions and turbine operational parameters. This means that a practical measurement system must also measure a significant number of turbine process parameters. As part of its consultancy DELTA has developed a number of tools to simplify the process.

2. Applicable Standards

Although there are international standards such as IEC for wind turbine noise, many countries have their individual rule sets, hence making it more difficult to standardize equipment and processing algorithms for wind turbine measurements. This results in a standardized acoustic front end with back-end processing routines to accommodate the various local requirements. Ironically, Denmark with its important position in both wind turbine development and deployment has its own set of rules, pre-dating the current IEC standard.

3. System Architecture

Figure 1. Considerable logistics are involved in current wind turbine measurements.

3.1 Acoustic Front End

Measurements to IEC 61400 are specified to use a microphone mounted on a reflecting ground plane to give a deterministic position and influence of the mounting surface. Wind noise, by definition is a major challenge, and specially developed and calibrated wind screens are used. The calibration factors for the windscreen are also entered into the measurement system (hereafter referred to as WMS, Wind Turbine Measurement System), with individual correction tables for each channel.

Often microphones are placed at fairly long distances from the turbine and from each other, resulting in significant cabling and set-up issues. This led to the development of a wireless microphone system, which met significant challenges in achieving reliable transmission over distances of up to 150 meters. After working with multiple manufacturers of wi-fi routers, devices used in the transportation industry were chosen.

Power is not always readily available which means that fairly heavy batteries must be used to meet the demands of the wireless routes, and other associated equipment.

Figure 2. Two microphones placed on reflecting surfaces on the ground covered by windshields. The Wi-Fi transmission antennae are also shown.

Figure 3. Close-up of a wireless node.

3.2 Meteorology mast

A 10 meter wind mast is used to log wind speed real time. Devices are available with both analog and digital outputs, where the analog output is often a pulse modulated signal which must be digitized, linearized, scaled, and calibrated properly. In addition, there is some unknown, but relatively small latency, in the data acquisition. Calibration transfer functions are entered into the WMS system to linearize the output of these devices.

Figure 4. Meteorology mast

3.3 Wind Turbine Process parameters

There is no standardized protocol for different manufacturer's process parameters, which normally are transmitted on a RS-232 interface. Therefore a generic parser, which relatively easily could be configured to match the data format of specific parameters, was developed. The table driven configuration tool, which assigns channel names and performs generic offset and scaling, covered many needs, but some custom program development was still required. Again, data from the turbines has an undefined latency, though we generally perceive it to be below 1 second. This must be seen relative to the shortest observation window of 10 s for wind binning.

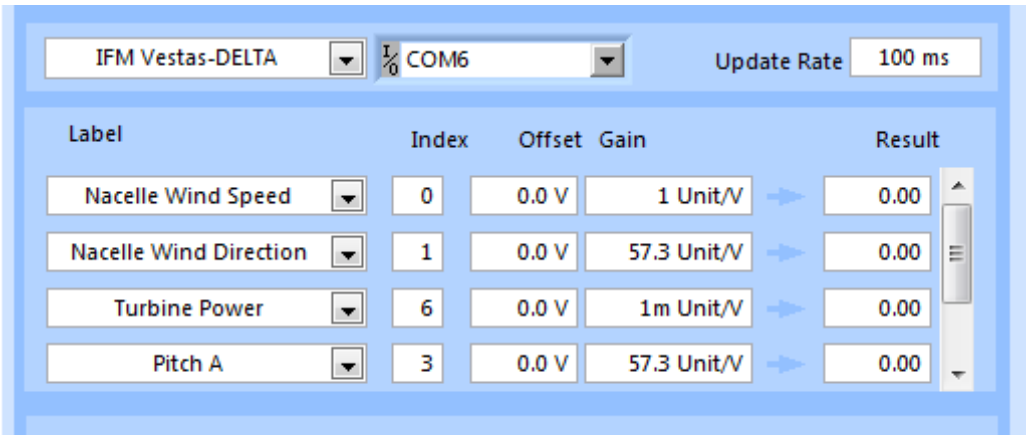

Figure 5. Wind Turbine Parameters Front Panel as transferred and scaled from the digital output of the turbine DCS system.

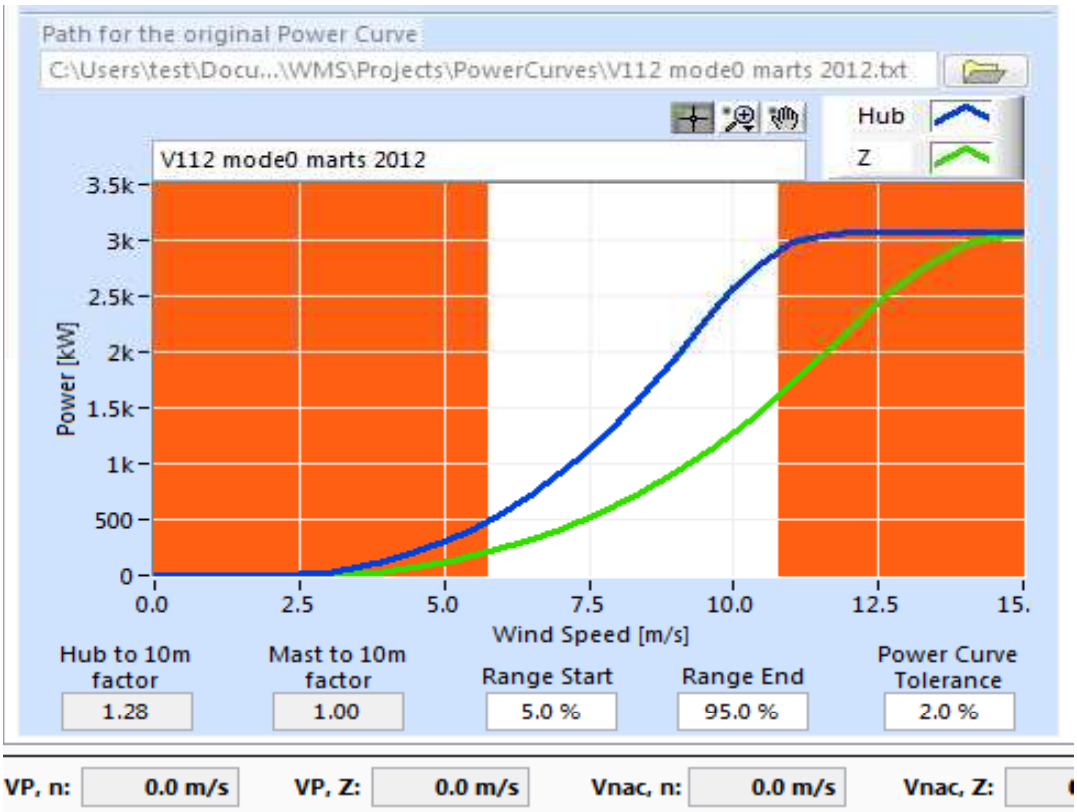

Figure 6 Typical Wind Turbine power curve with the white area showing the permitted operating range for noise measurements.

3.4 Data Processing and Storage

Fortunately data storage has become extremely inexpensive, and one of the best investments in PC's for this application is a modern laptop with USB 3 interface which has more than adequate disk bandwidth and storage capability. It is our experience that portable USB 3 drives are robust since they are designed for laptop use, and readily can handle 80 to 120 Mbytes/s transfer rates. For even higher performance, at a cost, external USB-3 flash drives can attain up to 400 Mbytes/s, which is far beyond most requirements, but has the advantage of disk access not being a major performance factor.

Raw data goes through multiple stages of processing, providing real time monitoring, both by listening to a given channel, or viewing selectable waveforms, and their associated spectra (both 1/3 octave and FFT). In parallel, the data is synchronized and time-stamped using the TDMS format, which is a very high performance wave storage format that also is robust, in

terms of surviving crashes. Parallel to the synchronized raw waveform storage, the FFT and 1/3 octave spectra are computed and streamed to disk, typically using integration periods that match the wind binning period of 10 or 60 s. From a robustness standpoint, these data are written serially to a simple text file, which then at the end of the measurement process is converted to an appropriate spread sheet format.

In parallel with all of these, a number of wind turbine and wind speed derived parameters, including estimated hub height speed, and turbine power, are computed using pre-loaded power curves for the specific wind turbine. Scatter plots of live or logged parameters may also be viewed during the measurements, where a choice of over 20 parameters may be plotted against each other. Here the use of the TDMS format (developed by National Instruments) is a big advantage in that it allows multiple processes to safely access the same data file, even as it is being written to at high speed.

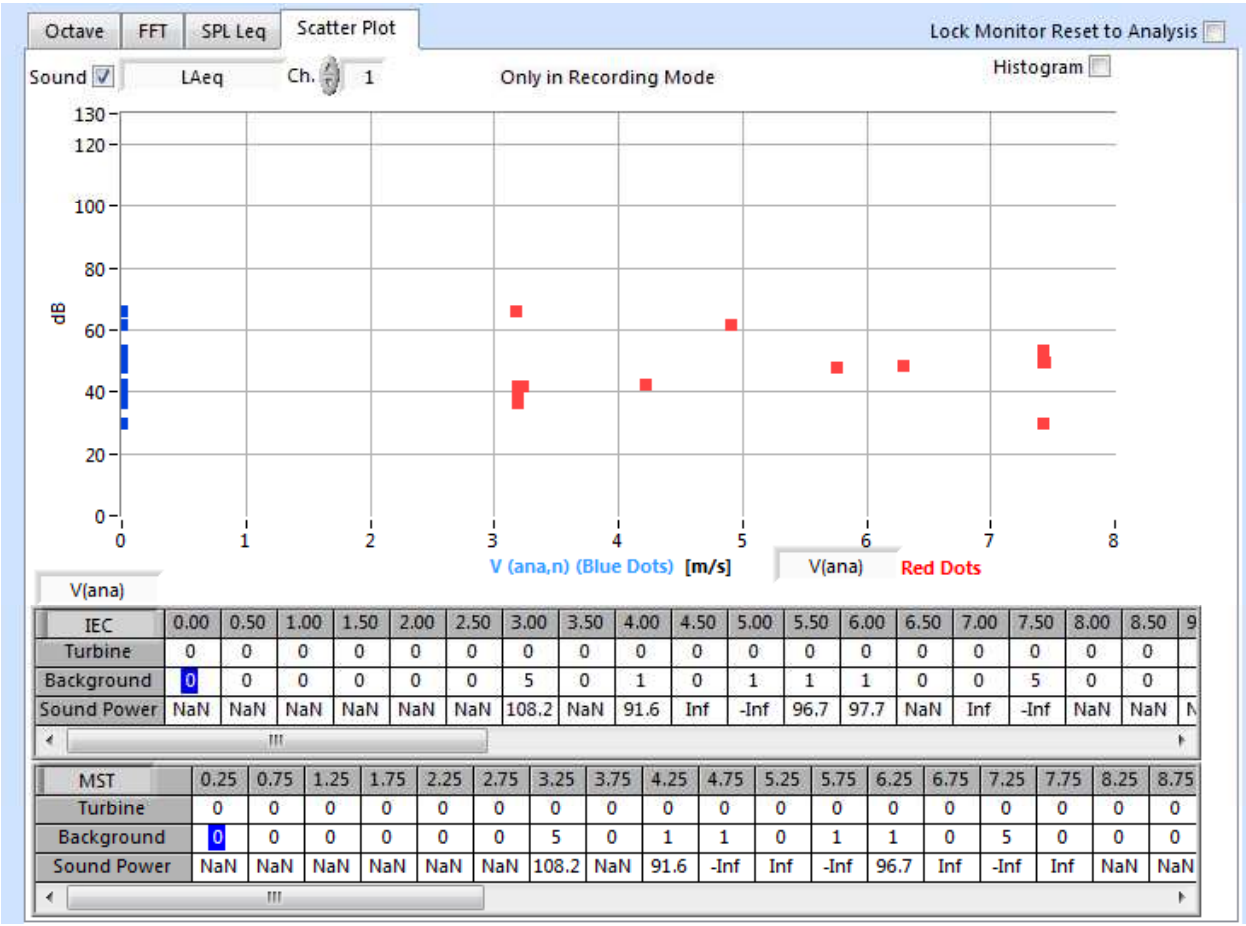

Figure 7. Real Time scatter plot of turbine parameters (any combination of parameters can be monitored).

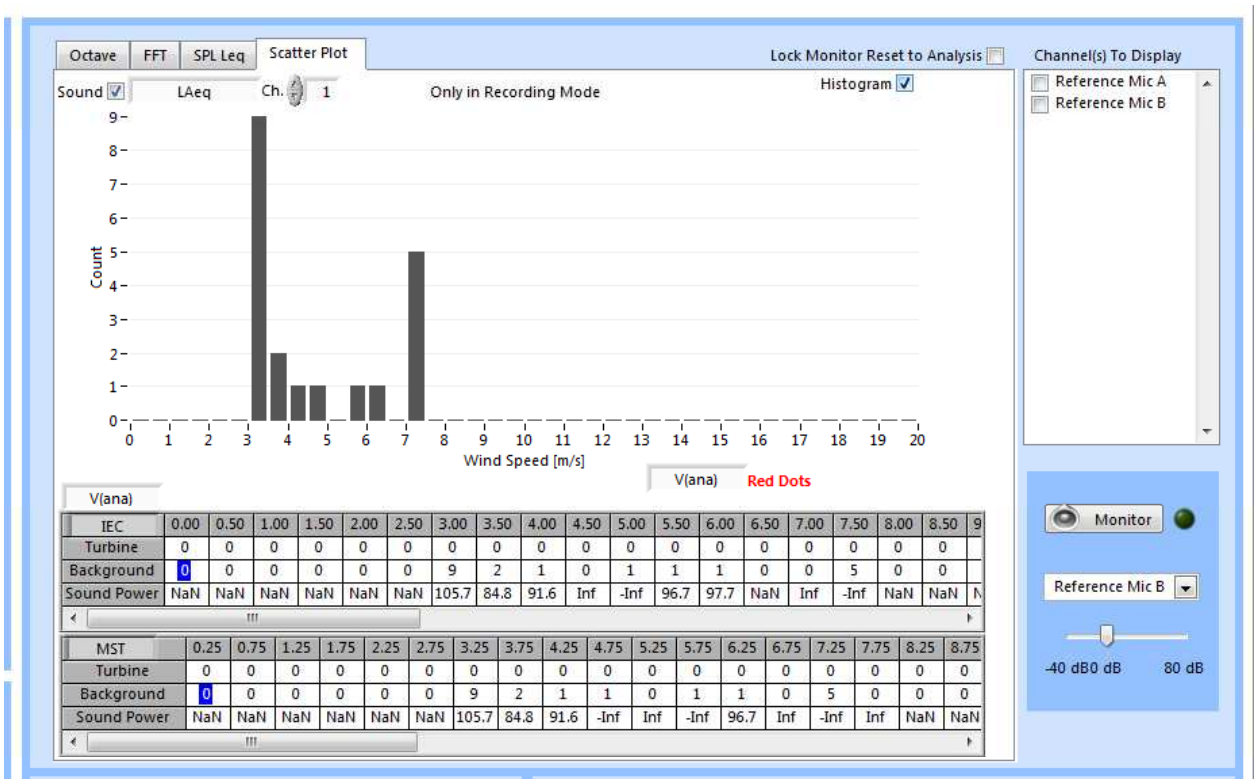

Figure 8: Real Time Histogram used to monitor the distribution of measurements in the various wind bins.

3.5 Post-Processing

The averaged FFT spectra may be passed on to a variety of tools for tone analysis, all depending on the relevant standard required. For ISO 1996 Annex 2 related tone analysis, the spectra can directly read by noiseLAB which then performs the necessary analysis. Other standards are supported to MATLAB routines. In DELTA's extensive experience with various tone analysis technique, we have also built a significant knowledge of the robustness or sensitivity of various techniques, which may be suitable for other papers and standardization work.

Since every configuration or turbine farm is somewhat unique, the actual report generation, consists of a collection of utilities plus some manual work to create the final report.

3.6 Tone Analysis

With a wide range of techniques available, it is important to use good engineering judgment in the application of these. This starts with listening to the turbine, and understanding its tonality, its level related to background and masking, and how stationary it is. It is crucial to choose appropriate observation windows and analysis bandwidths to properly capture and characterize the tonality. Therefore the good ear must be married to an understanding of signal processing fundaments, where too narrow a bandwidth or too short an observation window (averaging time) may give false spectral peaks which simply are an indication of a stochastic process, and not related to the psycho-acoustics of tones. Likewise, if the tones are non-stationary, the analysis bandwidth must be increased so that the observation window may be shorted to be able to the tonality of a frequency or amplitude modulated signal. A good tradition embodied in several standards is to start with the listening and evaluation, and then tune the analysis settings as appropriate. Thus the role of engineering judgment and skill is far from replaced by computer algorithms, which are then used to support the analysis.

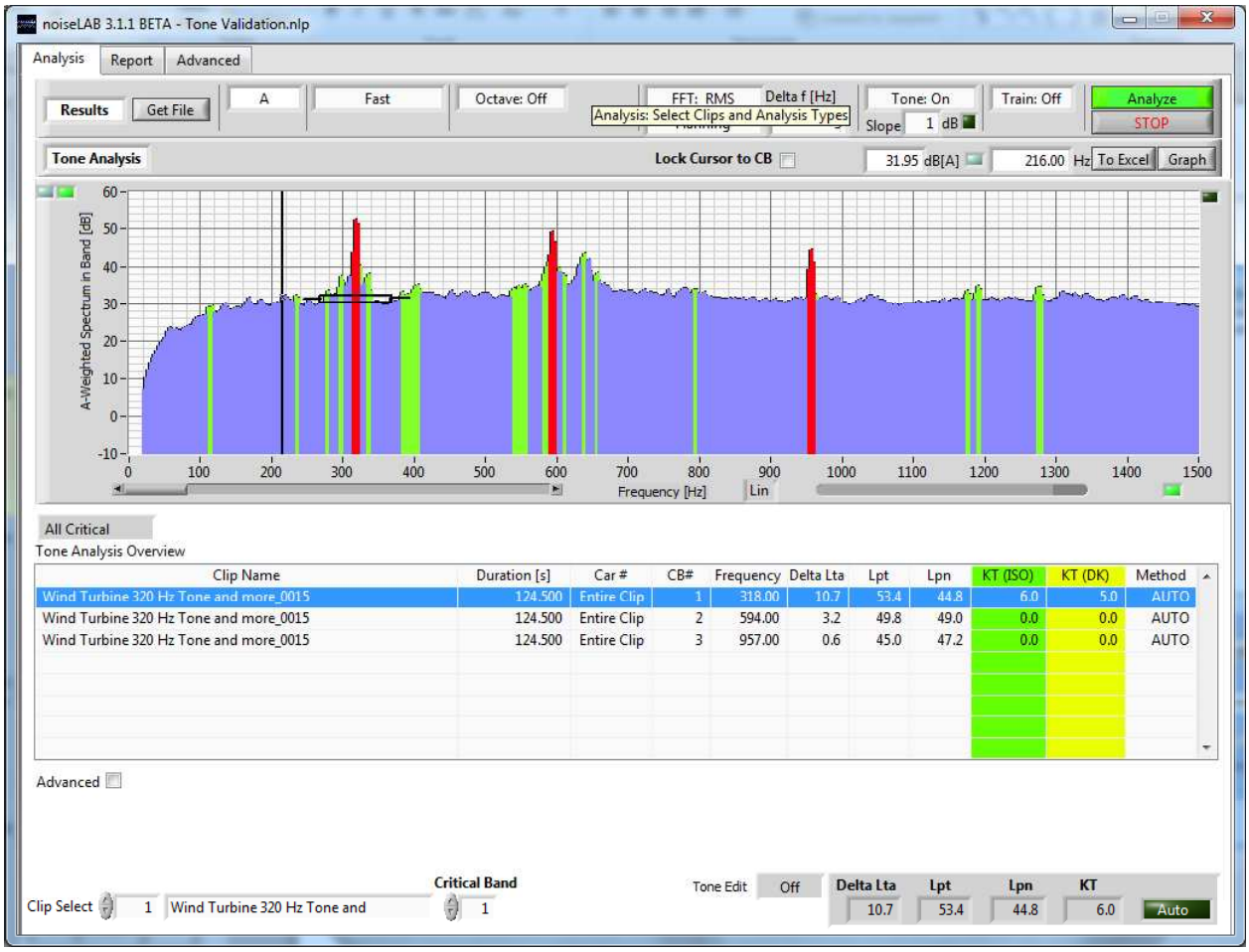

Figure 9. Typical Tone analysis to ISO 1996 Annex 2.

3.0 Challenges

The question of time delays becomes interesting because significant propagation delays occur acoustically due to the large distances from source to microphone. Therefore delays of half a second are not unusual for large turbines. This raises an interesting, but unsolved issue with respect to synchronizing this data with other data sources. In addition, microphone signals are digitized by a high quality analog to digital converter running off its own crystal oscillator. Typical oscillators run with 50 ppm accuracy, which gives up to 5 seconds drift in a 24 hour period between independent digitizers. Since wind binning measurements often require long measurement times, this clock drift can have an impact, but is mediated by time stamping the data from multiple sources "on the way in the door" of the PC and then realigning them in a large FIFO. However, when clock drift is large, this can eventually lead to the crash of the PC due to memory overflow. Also, as previously mentioned, unknown latencies occur on transfer of turbine parameters from its control system.

Operator training is important due to the complexity of the standards and the measurement process. This is supported by check lists, calibration processes, and a set of documentation that makes it possible for the system to be independently certified to relevant standards.

4.0 Conclusions

The complexity of wind turbine measurements is handled by a toolbox of data acquisition, analysis, data logging and post-processing tools, which also require significant training and understanding of the standardized requirements. The timing issues described in the paper which can give time scale offsets of more than 1 second, especially for longer measurements, have no cost effective method of being addressed. Fortunately these drifts, if understood and managed will generally be averaged out by the law of large numbers, although a 10 second

wind bin, which is based on asynchronous data sources, can have time based errors of multiple seconds. We believe that within a few years, GPS synchronized sensors will become common place hence removing some of the uncertainty in the time base, but obviously this demands that all sources have stable clocks and deterministic latencies for their data acquisition and transmission. But from a practical engineering standpoint, the fact that the turbines are relatively stable in their medium term noise signature means that these errors do not lead to critical issues. With care in all phases of the measurements and post-processing, the total error budgets can be kept low compared to the relevant requirements.