LISTENING TO THE WIND
TVA Experience with Installation and Operation of Ultrasonic Wind Sensors

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The Tennessee Valley Authority (TVA) installed ultrasonic wind sensors at its nuclear plants during October 2000-March 2002—Watts Bar Nuclear (WBN) in October 2000, Browns Ferry Nuclear (BFN) in February 2001, and Sequoyah Nuclear (SQN) in March 2002. This report discusses the activities related to installation of the new sensors and describes TVA experiences with operating the ultrasonic sensors.

Background

From 1977 to 2000, the wind data collected from TVA nuclear plant meteorological towers were obtained using Climet* wind vane/cup anemometer systems. While the Climet sensors provided excellent service, they had become obsolete with spare parts becoming difficult to obtain. In addition, the Climet sensors required routine bearing replacement as part of normal maintenance, and had a history of occasional problems due to failure of mechanical components.

TVA identified a number of wind vane/anemometer systems that satisfied applicable requirements, but rejected them because they did not reduce the level of maintenance. Instead, TVA selected another option—**ultrasonic wind sensors**—because they are all-electronic, require minimal maintenance, and had become available at a cost and durability suitable for operational applications.

TVA selected the Vaisala* (formerly Handar) 425AH ultrasonic wind sensor as most suitable based on the manufacturer specifications and capabilities for integration into the TVA meteorological monitoring system. The Vaisala sensor in analog mode could not directly replace the Climet sensors, because the overall error of the TVA monitoring system would violate accuracy requirements. Fortunately, the Vaisala sensor can transmit digital outputs directly to the data logging computer, so the wind translators and signal processing equipment could be removed to eliminate those error contributions, and permit the overall system error to meet the applicable requirements.

TVA conducted laboratory tests and a side-by-side comparison of an ultrasonic wind sensor with a Climet wind vane/anemometer system to document that the ultrasonic sensors are suitable to replace the Climet system ("Comparison of Wind Sensors - Ultrasonic versus Wind Vane/Anemometer," NUMUG Meeting, Las Vegas, NV, October 2000). Based on these tests, TVA concluded that the Vaisala ultrasonic wind sensor meets the applicable accuracy requirements and can be used as a replacement for the wind vane/anemometer system.

Installation

Installation consisted of three steps:

1. Obtain the necessary approvals.

   TVA did not obtain prior Nuclear Regulatory Commission (NRC) approval for installation of the ultrasonic wind sensors. Applicable regulatory guidance does not specify methodologies for obtaining wind direction/speed data--only the specific data values required, the error limits, and the sampling intervals. The new sensors were going to be installed in the same positions as the older sensors, would be sampled at the same intervals, would undergo the same data processing calculations, and would produce data that were not changed from the user point-of-view. Based on the comparison test results, they were treated as "equivalent" to the old wind vane/anemometer system.

* Identification of a particular manufacturer or model does not constitute endorsement by TVA.

The NRC was subsequently notified through a revision to the applicable Final Safety Analysis Report (FSAR) after the sensors were installed at each plant. The FSAR revision involved preparing a Safety Assessment according to the 10 CFR 50.59 process that permits changes to the facility without prior NRC approval. In the 50.59 process, it must be documented that the change will result in no more than a "minimal increase" in the frequency, likelihood, or consequences of an accident involving a system that is important to safety of the public. Further, the change was approved by the Plant Operations Review Committee (PORC) before it was implemented. In addition, the BFN PORC required an additional 6-month durability test to ensure that the sensors could operate for a full calibration cycle.

2. Develop sensor acceptance criteria.

Each sensor was subjected to a set of acceptance criteria prior to release for field use. The criteria consisted of tests in the TVA wind tunnel to verify that the sensor was operating correctly and producing proper data output.

<u>Wind direction (WD)</u>—Verify that the sensor reports the correct wind direction.

a. Orient the sensor to display the desired wind direction.
b. Set the wind tunnel speed to about 10 miles-per-hour (mph).
c. Verify that sensor output equals the desired wind direction (±3°).

Wind Direction	Description
360º	Verify that a known (and easy to set) direction is reported correctly.
30º	Verify correct direction when speed along one axis is near 0.0 (i.e., data are only available from two axes).
150º	
270º	
45º	Verify correct direction when no face is parallel or perpendicular to wind flow

<u>Wind speed (WS)</u>—Verify that the sensor reports the correct wind speed for the normal full range.

a. Orient the sensor to display wind direction = 45º.
b. Verify that sensor output equals the desired wind speed.

Wind Speed	Description
0.0 mph	Set tunnel speed = 0.0 mph. Verify that sensor reports WS = **0.0 mph**.
Threshold (≤ 1.0 mph)	Slowly increase tunnel speed until sensor reports a constant valid WS (±0.3 mph). Verify that sensor reports a constant WS ≤ **1.0 mph.**
1.0 mph	For each WS, set the tunnel speed to the desired speed (±0.10 mph). For each WS, verify the sensor reports wind speed = **tunnel speed** (±0.3 mph).
2.0 mph	
5.0 mph	
10.0 mph	
20.0 mph	
30.0 mph	

3. Perform field installation.

Installation was conducted over two days according to the normal Limited Condition of Operation (LCO) requirements for the applicable nuclear plant. A workplan was prepared in advance to guide the installation process and served as a checklist to ensure that all activities were performed. In addition, prior to installation, maintenance and engineering personnel examined existing wiring and connections to determine site-specific configurations that needed to be addressed.

The installation process was not complete until a meteorologist verified that data were acceptable and were being properly transmitted as required.

However, like everything else, even the best planned process can be impacted by unexpected and unplanned items.

At one site, the installation was delayed because proper survey equipment was not initially available to perform "as-found" sensor alignment for the old wind vanes. This emphasizes the need to ensure that all required equipment and supplies are identified and available beforehand.

At another site, the acceptance of the new sensors was delayed because a required test was inconclusive. Specifically, the manufacturer provides a test box ("margin verifier") to provide a "zero" wind speed environment--when placed in the test box, the sensor is expected to report a wind speed near 0.0 mph. However, at this particular site, some sensors passed the test at ground-level (when connected directly to the processing computer) but failed the same test when installed in operating configuration. Based on the vendor manual and discussions with a vendor representative, it was determined that passing the test at ground-level was adequate to show the sensors were working correctly.

At the third site, scheduling restrictions limited the specific days available for installation. As a result, the installation was interrupted for several hours by passage of a storm system and the order of installation was changed in an attempt to minimize the exposure of the tower climber to the storm system. In addition, further delays occurred because existing wiring at one tower level was not consistent with the other levels and did not agree with drawings—a hardware change had been made but drawings were not updated. This emphasizes the need for up-to-date drawings of meteorological tower wiring.

Finally, at BFN, a slight change in elevation of the tower top wind sensors was planned. Specifically, to facilitate maintenance, the pole that extended above the top of the tower (93 meters elevation) would be replaced by a mounting arm that extends from the side of the tower (91 meters). However, due to existing conduits on the tower, the final elevation was slightly lower than intended (90 meters).

In all cases, none of these problems presented major problems because a meteorologist was onsite throughout the installation and had the authority to make adjustments to the workplan. After verifying correct operation, the meteorologist provided final acceptance of the installation.

Operational Experience

A number of changes/improvements have occurred in the operation of the meteorological monitoring program because of the installation of the ultrasonic sensors.

A. The sensor calibration process changed--Previously, only the wind speed sensor was sent to a central laboratory to be calibrated in a wind tunnel. The wind direction sensor was calibrated at the field site, which significantly reduced the time the sensor was unavailable. Now the single sensor that combines both wind speed and wind direction must be calibrated in the central laboratory wind tunnel. The overall increase in sensor reliability more than compensates for the longer time sensors are unavailable due to calibration.

B. The level of maintenance has decreased--As expected, the non-mechanical nature of the ultrasonic sensors means that there is no need to address mechanical malfunctions. Of the 15 sonic sensors installed, only two have had to be removed from service prior to their scheduled six-month exchange interval. One simply needed to have its configuration reset (see item 2 in the following) and one had to be returned to the vendor for testing. Maintenance personnel spend less time on corrective maintenance and there are fewer tower climbs to replace sensors. In addition, since the wind sensors are now directly connected to the data logger computer, fewer channels are used in the switch controller/digital voltmeter interface for the other meteorological data. This permitted a simpler, more reliable interface to be installed; resulting in reduced maintenance for another high-maintenance item.

C. Strip chart recorders are no longer used--Data recovery requirements are satisfied without a strip-chart recorder backup, so maintenance savings have resulted from the elimination of equipment. While the ultrasonic sensors do not produce an analog signal that can be recorded directly, a simulated strip chart display can be constructed using the individual data samples (720 readings per hour).

D. Exceedances of calibration tolerances have decreased—The previous system frequently failed the "as-found"calibrations for both wind speed and direction after operation. The error tolerances have been maintained at the same level for the new system (±0.3 mi./h for wind speed, < 1.0 mi./h for wind speed threshold and ±3° for wind direction). Of the four routine sensor changeouts so far, none of the tolerances have been exceeded for the "as-founds." This significantly reduces documentation and data validation efforts.

E. Optical isolators provide effective lightning protection—Since the digital output from the sensor is fed directly into the processing computer, inexpensive optical isolators were installed to provide a buffer against lightning strikes damaging the computer. This has been very effective as four isolators have had to be replaced so far from lightning, but no damage has resulted in the computer.

Like any new system, there are also new problems that have to be addressed.

1. In addition to the usual site exposure criteria for wind measurements (e.g., 1-to-10 height-to-distance ratio), the "noise" environment must now be considered. For example, activity at the firing range adjacent to the BFN meteorological tower has resulted in some individual data values being lost. Also, ambient noise such as thunder must be considered in data validation.

2. The central laboratory configures the sensor communications settings before the sensor is sent to the field. However, it is possible for the settings to be changed inadvertently due to environmental factors (such as an electrical surge). When this happens (only 1 or 2 times in about 8 sensor-years of operation) the sensor cannot communicate with the data logger computer and the settings must be reset. Since sending a sensor to the central laboratory is a major effort (involving a tower climb and as-found/as-left calibrations), a methodology was developed to permit maintenance and computer personnel to reset the sensor in its operating position.

3. Finally, the problems with the "margin verifier" that were identified during installation have not been fully resolved. It may be necessary to change installation/exchange procedures or other system components to address these problems.

Data Changes

The new sensors produce wind speed and direction data in a format that is identical to the previous methodology. However, some minor differences must be recognized in interpreting the data. Specifically, each sample is now an independent measurement that is not necessarily related to the previous value. There is no damping effect as the wind vane changes from one direction to another, and no acceleration/deceleration as the anemometer changes speed. In general, these effects are expected to be very small and would be lost within the overall system "noise".

To confirm this, data were examined for periods both before and after the sensors were installed (Tables 1-2). To help ensure that the data periods are comparable, equivalent periods are used (that is, the analysis period before the installation covers the same portion of the year as the analysis period after the installation). In addition, the range of the values from the 10-year period from 1990-1999 is provided as a reference.

In general, there is little difference between the 'before' and 'after' data periods, which indicates that the data from the new sensors are comparable to the old sensors. Where differences occur, they are usually within (or close to) the 10-year range and therefore represent the normal year-to-year variability. However, two differences are significant—data recovery percentage and the number of calms.

A. The data recovery percentage increased or stayed at a high level in all cases, except for the BFN 90-meter level. This BFN exception was due to storm damage.

B. The number of calms dropped significantly in all cases, even though the calm definition (wind speed < 0.6 mph) remained unchanged, and three of four cases had a decrease in the mean wind speed. This indicates that the ultrasonic sensor is better able to measure light wind speeds. However, until the impact of lower wind speeds can be evaluated, TVA will make no changes in the minimum wind speed values used for dispersion and transport applications.

<u>Other Tidbits</u>

Two other items of interest resulted from TVA's testing and installation of ultrasonic sensors.

1. The testing configuration at BFN consisted of the wind vane/anemometer sensors mounted on a pole that extended above the tower while the ultrasonic sensor was mounted on an arm extending two tower widths from the tower. This provided an opportunity to examine the impact of the tower structure on the wind measurements. During the field test, 554 wind samples represented directions when the wind was blowing through the tower structure towards the ultrasonic sensor. As summarized below, even at the recommended distance from the tower, there is still a significant impact on wind measurements.

	Differences in 15-minute Averages (wind vane/anemometer minus ultrasonic)			
	Vector Wind Direction (º)	Vector WS (mph)	Average WS (mph)	Sigma-Theta (º)
Minimum	-100	-0.4	-0.4	-57
Mean	0	2.1	2.1	-1
Maximum	+145	+7.6	+7.6	+9
Standard Deviation	8	1.4	1.4	3

Wind direction differences, although noticeable, still result in identifying the correct downwind (22.5º) sector approximately 88% of the time. However, the wind speeds are significantly reduced and the sigma theta values indicated much more variability downwind from the tower due to increased turbulence in the tower wake.

For TVA, the impact of the tower wake effect is minimized by orienting the wind sensors to minimize the time period when the wind blows through the tower. In this particular case, the 554 samples represent only 6% of the total data set.

2. As described above, the wind sensor level was changed at BFN as part of the ultrasonic sensor installation. However, since the sensor comparison was conducted in a common data regime (as defined by ASTM standard D 4430-96) and the new sensor level was between the two test levels, data collected by the new sensor is considered as equivalent to data collected by the previous sensor.

<u>Conclusion</u>

Based on the TVA experience, care must be taken to verify that ultrasonic wind sensors will be suitable for operational applications, and changes must be well documented. With use of new technology, unexpected problems can be expected to occur. However, ultrasonic wind sensors have proven acceptable for TVA applications and represent a significant improvement over the previous wind vane/anemometer methodology. Specifically, calibration tolerances are now being met consistently and less corrective maintenance has been necessary.

--Table 1 –

Browns Ferry

Notes: **2000** and **2001** are data values for Feb. 24-Dec. 31 (85% of year) so the comparison periods are similar.
Range is the upper and lower values from annual summaries for 1990-1999.

90-meter Wind Direction

	Percent Occurrence			
WD	2000	2001	Difference	Range
N	*6.3*	7.8	+1.5	6.4-8.5
NNE	7.5	7.9	+0.4	5.6-8.2
NE	*6.1*	4.0	-2.1	3.9-5.7
ENE	3.2	2.9	-0.3	2.2-3.5
E	2.8	2.4	-0.4	1.9-3.5
ESE	6.6	6.1	-0.5	5.1-8.5
SE	10.2	12.6	+2.4	10.0-13.3
SSE	9.3	*11.0*	+1.7	9.1-10.6
S	9.2	9.6	+0.4	6.8-11.0
SSW	7.9	8.3	+0.4	5.5-9.3
SW	5.5	5.4	-0.1	4.0-6.3
WSW	3.9	4.4	+0.5	3.8-5.7
W	5.1	*4.5*	-0.6	4.6-5.7
WNW	5.4	*4.1*	-1.3	4.7-6.6
NW	6.0	*4.4*	-1.6	4.5-6.7
NNW	5.0	4.6	-0.4	4.2-7.1

90-meter Wind Speed

	Percent Occurrence			
avg. WS (mph)	2000	2001	Difference	Range
Calm	0.1	0.0	-0.1	0.0-0.5
0.6-1.4	0.5	0.4	-0.1	0.4-0.9
1.5-3.4	4.9	6.0	+1.1	4.6-7.1
3.5-5.4	8.9	*11.1*	+2.2	8.6-11.0
5.5-7.4	12.1	12.5	+0.4	10.1-12.7
7.5-12.4	*33.4*	32.3	-1.1	29.4-32.6
12.5-18.4	29.2	27.2	-2.0	25.4-29.8
18.5-24.4	8.8	8.5	-0.3	8.2-12.1
>=24.5	2.1	2.0	-0.1	2.0-3.9

90-meter Summary

	2000	2001	Difference	Range
Data Recovery (%)	96.9	96.7	-0.2	94.6-99.0
Mean Average Wind Speed (mph)	11.46	11.13	-0.33	10.97-12.14
Number of Calms	7	***0***	-7	3-40

10-meter Summary

	2000	2001	Difference	Range
Data Recovery (%)	99.1	99.2	+0.1	93.9-99.3
Mean Average Wind Speed (mph)	4.80	*4.34*	-0.46	4.42-4.89
Number of Calms	34	***3***	-31	17-271

--Table 2 –
Watts Bar

Notes: **2000** and **2001** are data values for Jan. 1-Oct. 22 (81% of year) so the comparison periods are similar.
Range is the upper and lower values from annual summaries for 1990-1999.

10-meter Wind Direction

	Percent Occurrence			
WD	2000	2001	Difference	Range
N	7.8	7.3	-0.5	6.4-8.8
NNE	7.7	7.8	+0.1	6.9-10.4
NE	5.2	*3.8*	-1.4	5.0-9.2
ENE	*3.9*	*3.0*	-0.9	4.3-6.5
E	*2.0*	*1.9*	-0.1	2.2-3.2
ESE	1.3	1.1	-0.2	1.1-1.8
SE	1.3	1.5	+0.2	1.3-2.7
SSE	2.5	2.4	-0.1	2.5-3.5
S	7.4	7.9	+0.5	6.7-8.9
SSW	16.3	*18.0*	+1.7	13.2-17.3
SW	9.0	9.3	+0.3	7.9-9.6
WSW	7.2	7.4	+0.2	4.8-7.5
W	7.0	7.8	+0.8	5.3-7.7
WNW	*8.0*	7.0	-1.0	5.8-7.9
NW	7.0	7.2	+0.2	5.3-7.9
NNW	*6.4*	*6.6*	+0.2	5.0-6.2

10-meter Wind Speed

	Percent Occurrence			
avg. WS (mph)	2000	2001	Difference	Range
Calm	3.1	*0.1*	-3.0	1.6-13.1
0.6-1.4	25.7	22.1	-3.6	20.4-27.7
1.5-3.4	28.3	*33.3*	+5.0	24.9-32.7
3.5-5.4	20.0	19.0	-1.0	18.0-21.8
5.5-7.4	11.9	12.2	+0.3	10.6-12.6
7.5-12.4	10.4	*12.0*	+1.6	8.5-11.8
12.5-18.4	0.6	1.2	+0.6	0.4-1.2
18.5-24.4	0.0	*0.1*	+0.1	0.0-0.0
>=24.5	0.0	0.0	±0.0	0.0-0.0

10-meter Summary

	2000	2001	Difference	Range
Data Recovery (%)	94.4	***99.5***	+5.1	93.0-98.8
Mean Average Wind Speed (mph)	3.57	*3.90*	+0.33	3.37-3.75
Number of Calms	210	***9***	-201	139-1111

91-meter Summary

	2000	2001	Difference	Range
Data Recovery (%)	94.3	***99.4***	+5.1	90.9-96.9
Mean Average Wind Speed (mph)	*7.58*	7.42	-0.16	6.60-7.49
Number of Calms	*4*	***0***	-4	15-183