Correcting and/or Measuring Wind Speed using RMS Voltage:

Another way to use NRG #40 Anemometers

by

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Introduction

I use clock-timers to measure wind speeds. Clock-timers are very precise except at low wind speeds, when false triggers of the clock-timer circuit can make you think there are hurricane-force winds when, in fact, winds are nearly calm. Some anemometers us AC voltages of variable frequency to measure wind speed. Other anemometers use switch closures, i.e., as the anemometer spins one or more switches are momentarily closed per revolution of spin. At a recent NREL conference I have learned about cases in which anemometers can come to rest near the switch closure point and ‘record’ hurricane-force winds when, in fact, the winds are calm. I have noticed the same problem with some anemometers that do not use switch closures to measure wind speed.

The anemometers, made by NRG Systems, produce variable voltage and variable frequency AC signals as they spin. They are miniature wind turbines. In these anemometers increasing wind speed corresponds to increasing frequency and increasing AC root-mean-square voltage (V_{rms}). I got the idea that it might be possible to discriminate between good and falsely-high wind-speeds by measuring both the V_{rms} voltage AND the frequency (Hz). I also wondered if you could measure wind speed accurately by measuring ONLY the AC voltage (V_{rms}).

How anemometer measurements are done

The cup anemometers sold by NRG System Inc (Model #40C) are mini-generators that produce variable AC voltage (V_{rms}) and variable frequency (Hz). Wind speed is a very linear function of Hz. The nominal calibration factor is

$$U\ (\text{m/s}) = 0.76\ \text{Hz} + 0.35 \qquad (1)$$

The NRG #40C anemometers come with NIST traceable wind-tunnel calibrations that meet International Standard ISO/IEC 17025:2005 standards. Calibrations of Hz versus U are usually done between 3.5 and 26 m/s and are highly linear with residual errors around ±0.1 m/s over the entire calibration range. The residual error is probably a good measure of the accuracy of wind speed measurement.

The most precise way to monitor the NRG #40C anemometer is to use a clock timer circuit to measure the period between rising (or falling) edges of the AC signal. The AC signals are low level (typically 0 to 1.5 V_{rms}). Hence most clock timer circuits need an interface to boost the NRG-signals to TTL-level pulses. The measurement of period is made highly precise using clock-timers. A clock-timer starts measuring time (counting ticks) when the rising edge of anemometer signal is detected. Timing continues until the next rising edge is detected. At that instant the timer count is placed in a read-buffer and a new timing begins from zero. The clock-timer reading is the period of the anemometer frequency (Hz = 1/period).

For accurate reading of period the clock-timer has to be provided a fast clock signal of frequency f_t to count. For example, I use a timer frequency of $f_t = 37{,}500$ Hz. When the rising edge of the anemometer is detected the clock-timer starts counting pulses at 37,500 Hz (ticks per second). Hence if anemometer Hz = 1.00000 (= about 1.01 m/s wind speed) the clock timer will record 37,500 ± 1 pulses before the next rising edge gates the count onto a 'read register' and timing starts again from zero. Hence the period is measured with a precision of 1 in 37,500 ≅ 0.003%, which is very high measurement resolution. What about high wind speeds? If the anemometer Hz = 37.5 then the clock timer will measure a count of 1000 ± 1 ticks which yields a resolution of 0.1%. For a NRG#40 anemometer 37.5 Hz = 28.85 m/s hence this speed can be read within 0.1% or about ±0.03 m/s, hence the resolution of measurement is about 3 times better than the accuracy of the anemometer calibration. In general the Hz of an anemometer measured by an clock-timer is given by: Hz = f_t/(tick-count).

The clock-timer circuit can however, produce garbage values when there is electrical noise in the AC signal coming from the anemometer. In my case, I measure wind speed near a wind-turbine and its inverter. My inverter produces a lot of high frequency noise (5 to 20 kHz) which can cause false-triggers of the clock-timer. This is usually corrected by using a 'debounce' circuit, which most clock-timers need when measuring switch-closures because switches usually bounce on and off several times in the millisecond during which the switch closes or opens. However, debounce circuits do not work very well when winds become almost calm. The clock timer detects some very high frequency noise just as the anemometer signal approaches zero V_{rms} and zero Hz which causes the false recording of wind speeds between >30 m/s when the wind speed is really < 1 m/s. If the anemometer comes to rest with a high reading in the read buffer, that false reading will be repeatedly read by the logger until cleared out by another spin of the anemometer. These falsely-high readings are the source of many stray-points in turbine power-curves where nearly-zero power readings have very high, but false, wind-speed values.

Methods

Although you can buy circuits that boost low lever AC signals to TTL pulses (e.g., Model LLAC4, Campbell Scientific, Logan, Utah), I could not find any inexpensive circuit that would measure low level AC-V_{rms} values in the frequency range of 1 to 30 Hz. So I built my own. My circuit is based on two common chips (AD736 and LM319). The AD736 is the chip used in most hand-held digital voltmeters where it is used to measure V_{rms} values from 0 to 200 mV at > 40 Hz; the chip has a precision full wave rectifier and outputs a DC signal = to V_{rms}. The LM319 is a high-speed comparator with an open-collector output, hence when the output is sent to a clock-timer a pull-up resistor is needed. The circuit I used is shown in Fig. 1 below:

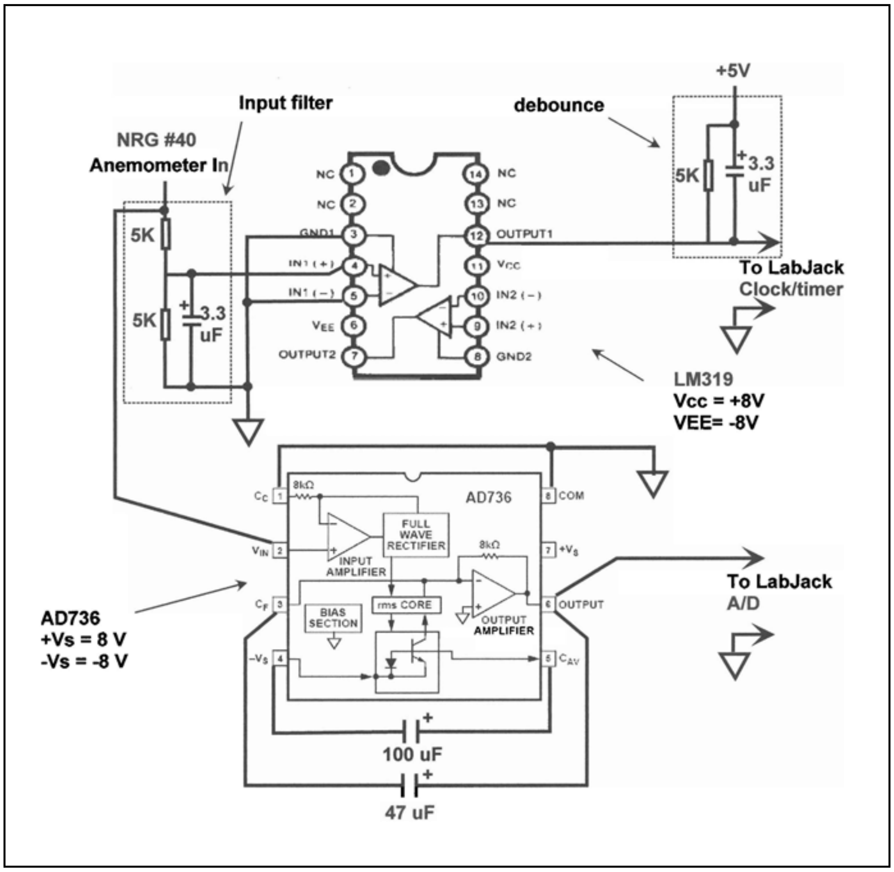


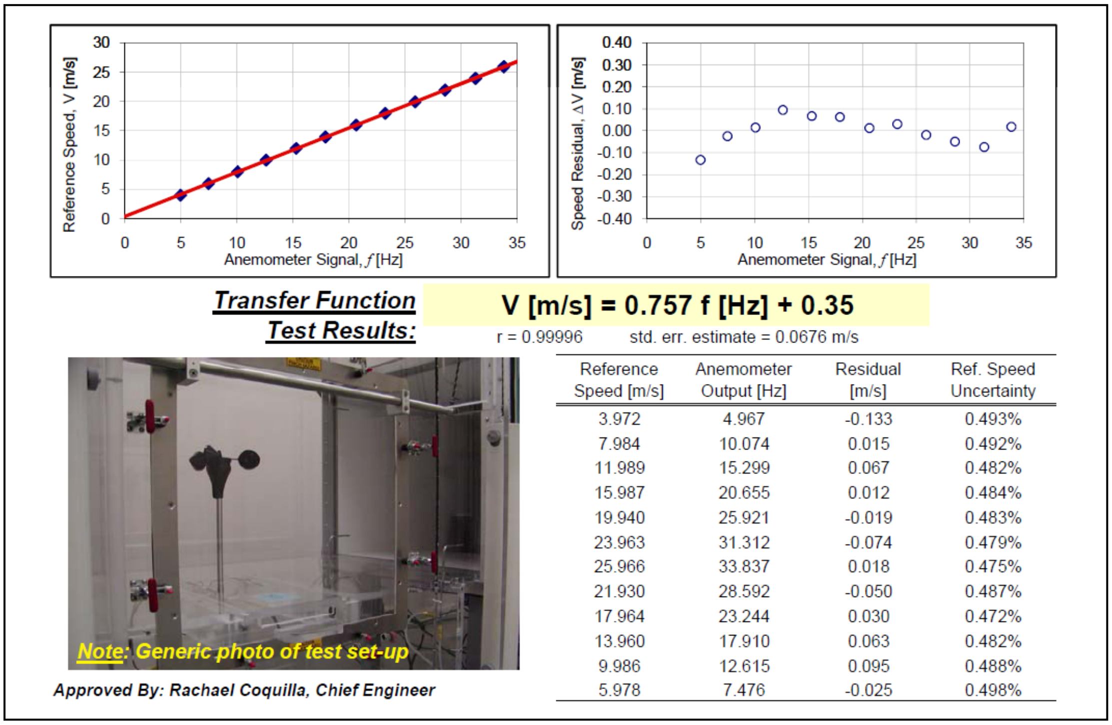
Figure 1: The input filter above eliminates the high-frequency noise that is generated by a small turbine and its grid-tied inverter. The debounce circuit provides both a pull-up resistor and a debounce RC-circuit. The LabJack UE9 data-logger provides the +5V supply. The LabJack has low-voltage TTL logic. When used with a LabJack UE9, his debounce circuit can measure frequencies up to about 62 Hz (*U* = 47 m/s wind-speed) If your clock timer is a '5V TTL' system you may need to reduce the value of the resistor or capacitor. The value of RC determines the maximum frequency that can be measured. I found that the debounce circuit has to be mounted immediately in front of the timer-clock input. Putting it in a plastic box on the same circuit-board as the LM319 does not work! Although I show the reference voltage for the comparator (IN1 –) connected to ground I have it connected to a low-level adjustable DC signal in case I want to trigger TTL-pulses above the zero-cross over voltage of the anemometer.

Wind tunnel measurements

I tested the above circuit on a new NRG #40C cup anemometer placed in a wind tunnel located at the Department of Mechanical Engineering, University of Alberta. The anemometer came with a calibration curve reproduced below in Fig. 2. I did my own calibration using a Pitot-static tube to measure wind speed (same technique as used in Fig. 2) and confirmed the calibration with similar residual errors. The Pitot-static tube produces a pressure differential (ΔP) that is a square root function proportional to wind speed.

$$U = \sqrt{\frac{2\Delta P}{\rho}} \qquad (2)$$

where ρ is the air density which is computed from the ideal gas law, barometric pressure and air temperature.



Transfer Function

Test Results:

V [m/s] = 0.757 f [Hz] + 0.35

r = 0.99996 std. err. estimate = 0.0676 m/s

Reference Speed [m/s]	Anemometer Output [Hz]	Residual [m/s]	Ref. Speed Uncertainty
3.972	4.967	-0.133	0.493%
7.984	10.074	0.015	0.492%
11.989	15.299	0.067	0.482%
15.987	20.655	0.012	0.484%
19.940	25.921	-0.019	0.483%
23.963	31.312	-0.074	0.479%
25.966	33.837	0.018	0.475%
21.930	28.592	-0.050	0.487%
17.964	23.244	0.030	0.472%
13.960	17.910	0.063	0.482%
9.986	12.615	0.095	0.488%
5.978	7.476	-0.025	0.498%

Note: Generic photo of test set-up

Approved By: Rachael Coquilla, Chief Engineer

Figure 2: Calibration done by Otech Engineering Inc. for NRG Systems Inc on test anemometer serial number 179500111519.

The basic measurement consists of adjusting the wind speed by changing the power going to blowers in the wind tunnel and measuring, Hz, V_{rms}, air temperature, barometric pressure, and Pitot-tube pressure drop using an inclined water manometer. Manometer pressure could be resolved to water heights of about 0.13 mm (0.005 inches water), which corresponds to an uncertainty in ΔP of ±1.3 Pa and this was the biggest source of error in Eq. (2) resulting in an uncertainty of ± 0.05 m/s at 30 m/s to ± 0.3 m/s at 3 m/s.

Results

My calibration curve of wind speed versus V_{rms} voltage is shown in Figure 3. Calibration curves versus Hz were similar to those in Figure 2, which come from Otech Engineering. I have calibrated more than one cup anemometer and can tell you that U vs V_{rms} varies by more between anemometers than does U vs Hz (data not shown). This is probably a result of the variation between units in placement of the permanent magnets and stator coils. I also had a digital oscilloscope connected to the anemometer output and spot checks (not recorded) confirmed that the AD736 chip was measuring the correct V_{rms} and the clock-timers the correct Hz.

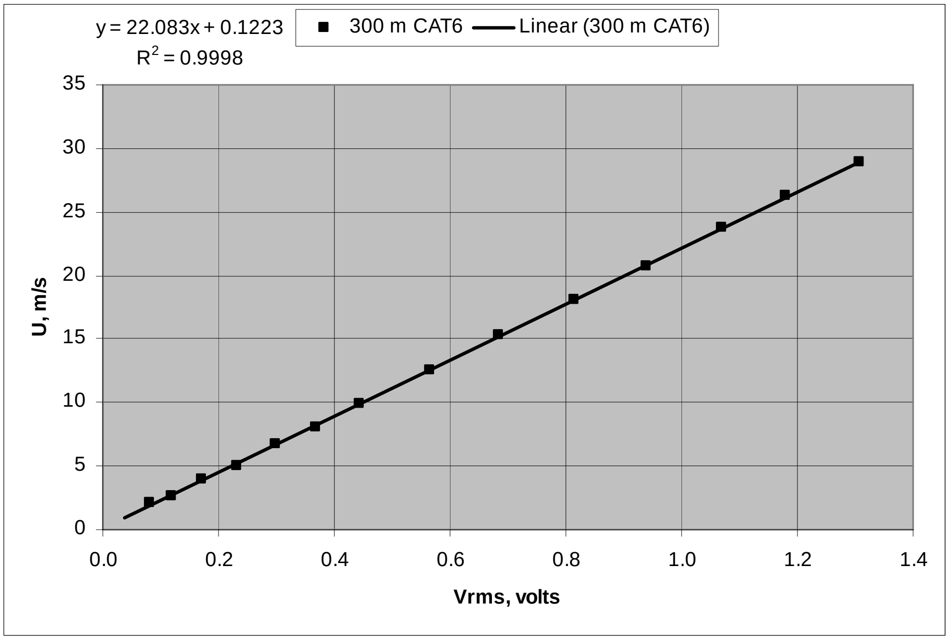


Figure 3 : Measured value of wind speed (U) versus measured V_{rms}. These measurements were done with the anemometer signal passing through 300 m of CAT6 internet cable. Virtually the same values are measured when connected through 4 m of CAT6 cable.

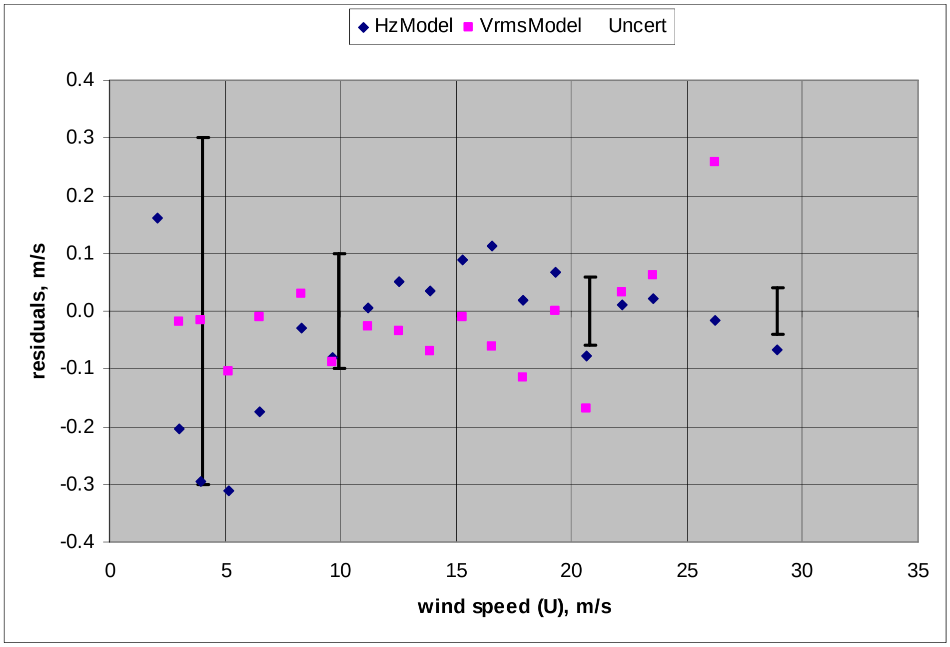


Figure 4: Residuals of the anemometer calibrations using Hz or V_{rms} on the x-axis. The x-axis of Figure 4 is the computed wind speed from the Pitot-static tube. The large error bars are the uncertainty of the wind-speed based on the Pitot-static tube measurements. The diamonds and squares are the residuals based on the regression like that in Figure 3. Note that most residuals fall within the uncertainty of wind-speed measurements. The average (root-mean-square) residuals were the same for the calibration versus Hz or V_{rms} = 0.117 and 0.115 m/s, respectively.

Discussion

So why don't we measure wind speed using measurements V_{rms} instead Hz? Has anyone else tried this? If anyone knows please write to me at mtyree@ualberta.ca! My guess is that this had been tried and that the calibration curve of U vs V_{rms} changes with temperature and air pressure whereas the calibration against Hz does not. I am gearing up for a project in which I will be measuring 16 cup anemometers and power output from 8 small turbines in NY State and Alberta. So I am going to monitor both Hz and V_{rms} output from all 16 anemometers. That way I will know how reliable V_{rms}-values are.

Measurements of V_{rms} are less subject to errors at low wind speed that cause falsely high Hz values from timer-counters (see introduction). So at the very least, I will now have a way to eliminate falsely-high reading of wind speed when winds are nearly calm. I will do this by relying more on the calibration curve in Fig. 3 for V_{rms} values below 0.2 V and will rely more on the calibration curve in Fig 2 when Hz > 5.

I will post a follow-up study in about 1 year. It would be useful if winds-speed can be reliably measured with V_{rms} because it is easier to find data loggers with lots of A/D channel than it is to find loggers with lots of clock-timers.

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