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A Meteorological front-end data transmission unit for a Small Wind Turbine - Power Curve Evaluation System

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Abstract — **This paper presents the design and programming issues involved in the production of a meteorological front-end data transmission unit oriented for use with a Small Wind Turbine - Power Curve Evaluation System (SWT-PCES), following the guidelines of IEC 61400-12-1 annex H. Preliminary data from systems installed in Chubut is also shown.**

Key Words — **Wind Power, Power Curve Evaluation, Meteorological sensors, Data Transmission.**

I. INTRODUCTION

Small Wind Turbines for battery charging are becoming a widespread solution for electrical power supply in isolated areas, specially the wind-swept plains in Southern Patagonia. Many new systems are being installed with international support through renewable energy programs such as PERMER (Proyecto de Energías Renovables en el Mercado Rural), originated as a World Bank – GEF initiative. Evaluation of system performance at these locations is a main concern for funding institutions, and also a challenging technical problem requiring a combination of rugged equipment, dependable storage and software, and compliance with international standards at moderate cost. Additionally, the evaluation of small wind turbine power curves (a graph of power output vs. wind intensity) for battery charging systems has had a rather complex and lengthy process of standards definition, and it is usually accomplished with general-purpose data acquisition systems requiring programming knowledge [Forsyth et al, 2003], combined with commercial meteorological stations. Some of the manufacturers of these stations offer a Wind Power Curve evaluation package [Second Wind, 2002], but are oriented to conventional grid-connected turbines and have no provision for battery level monitoring.

This paper describes some of the design, programming and construction issues of a meteorological front-end unit oriented for use in a Small Wind Turbine - Power Curve Evaluation System (SWT-PCES), following the guidelines of the latest IEC standard [IEC, 2005] which includes specific provisions for evaluation of low power, battery-charging wind turbines. This unit is located at the foot of the associated meteorological tower and collects wind, temperature and atmospheric pressure data, packetizing it at regular intervals and transmitting the data through a conventional RS-485 link to the main PCES controller.

The importance of meteorological data to evaluate the power curve can be found by observing the main relationship governing a wind turbine's output. Power from the wind turbine can be calculated from the following expression:

$$P = \frac{1}{2}\rho S \eta C_p V^3 \qquad (1)$$

where ρ is air density (nominally 1.225kg/m^3), S is the rotor swept surface, η is generator and turbine overall efficiency, C_p the turbine's aerodynamic coefficient, depending on Wind intensity V and angular rotor speed, V is wind intensity in m/s and P output power in W. The cubic relationship between P and V, supposing S y η constant, shapes $P(V)$ together with C_p. A less notable influence (but still important) is given by air density variations due to temperature and atmospheric pressure, as given by:

$$\rho = 100 * \frac{B}{RT} \quad \left[\frac{\text{kg}}{\text{m}^3}\right] \qquad (2)$$

where B is atmospheric pressure in mB, T is temperature in K and R is the gas constant of dry air, equivalent to 287,05 J/kgK. The 100 coefficient is originated from unit conversions.

II. DESIGN CONSIDERATIONS

A. Front-End concept

The IEC standard calls for wind intensity and direction sensors located at hub-height, in a separate meteorological tower. Temperature and barometric pressure sensors need not be at hub-height, and can be located at a lower location. In typical systems, a hub height of 10 to 20m implies that the meteorological tower be located at similar distances from the wind-turbine tower. Since the main PCES controller is located indoors near the rectifier, battery bank and regulator, cable runs of 50m or more for each sensor would not be unusual. This not only implies a higher cabling cost, but also a signal integrity issue, specially for sensors working with low analog voltage levels, if each sensor is cabled directly to the main PCES.

The Front-End concept (Figure 1) implies that the meteorological signals are acquired and digitized at the foot of the meteorological tower by a stand-alone processor, which also brings data together in a 48-character packet.

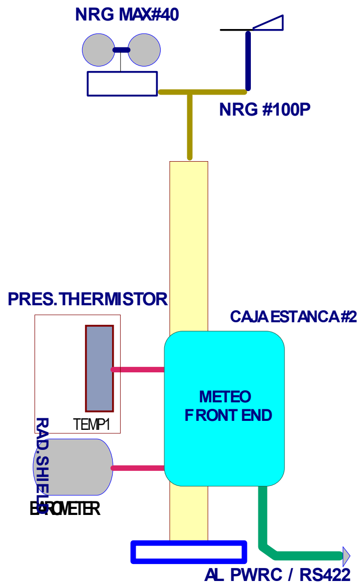

Figure 1 – Meteorological Front-end diagram

These packets are sent at a 0.5Hz rate to the main PCES controller using a non-isolated RS-485 link, which gives a greater noise immunity than standard serial links. Since the controller output is RS-232 at 38.4kbaud, further immunity (for example in lightning-prone regions) can be achieved by replacing the conventional RS485 converter with isolated, optical or RF link boards.

B. Controller implementation

The **Meteo Front-End** unit is based on a Cypress PSoC (Programmable System-on-Chip) 8C29466 controller in a 28-pin package. This controller features a powerful combination of software-configurable analog and digital modules, and a combination of 32kB of program Flash memory and 2kB of static RAM. The internal module interconnection is defined at design-time using a freely-available graphical IDE package. Programming can be done in assembler or a license for a C-Compiler can be purchased. For this project, all software was coded in C for faster development and greater legibility. The controller is located on a general-purpose printed circuit board (DLCy) with industry-standard I^2C bus support and a general-purpose RS232 interface circuit. The system uses a multiplexed input 13-bit analog to digital (A/D) converter from the module library, and a combination of digital modules to read frequency information from period measurement to compute wind speed.

C. Sensor interface

For the sensor interface, a special printed circuit board (MetAnlg) was developed. The sensors used are an NRG Max#40 anemometer, an NRG #200P wind vane, an integrated Motorola pressure sensor and an Epcos calibrated NTC temperature sensor. The anemometer conveys a voltage sinewave with frequency (and amplitude) proportional to the wind's speed, while the wind vane is a 10K potentiometer connected so as to produce a 0 to 5V signal proportional to the direction of the wind. Both instruments are regarded as industry-standard in medium to high precision wind measurements worldwide. As for barometric pressure, the sensor's analog output is processed by a low-noise, rail-to-rail operational amplifier and a precision 4.096V voltage reference to produce a valid output for pressures in the range of 542 to 1152mB. The same voltage reference and a precision resistor connected as a voltage divider with the NTC resistor is used to produce a temperature signal. This voltage signal has a non-linear dependence with temperature, which would be solved with a look-up table as a simple solution. Since floating point routines are available for the C compiler, a greater precision routine is possible. Calling the fixed resistor R_2 and $R_{NTC}(T)$ the sensor resistance, the voltage divider output has the following form:

$$V_o = V_{ref}\left[\frac{R_2}{R_{NTC}(T)+R_2}\right] \qquad (3)$$

from where,

$$R_{NTC}(T) = R_2\left[\frac{V_{ref}-V_o}{V_o}\right] \qquad (4)$$

On the other hand, the relationship between $R_{NTC}(T)$ and temperature is given by the Steinhart-Hart [Van Ess, 2002] equation, as follows:

$$1/T = A + B\ln(R_{NTC}(T)) + C(\ln(R_{NTC}(T)))^3 \qquad (5)$$

where A,B and C are coefficients which depend on the sensor used, for the EPCOS 1% precision NTC the following values were used:

$A =$ *0.001130151*
$B =$ *0.000234011*
$C =$ *0.000000088*

The C code for the calculation sequence follows:

```
// The resistance value of the
// thermistor is used to calculate the
// temperature given the follow equation
//
//     1/T =  A + B*ln(R) + C*ln(R)^3
//
// SteinHart-Hart Constants for EPCOS 10K 1%..
// A, B, C constants:

float rA = 0.001130151;
float rB = 0.000234011;
float rC = 0.000000088;
```

```
// Resistance calculated with floating point math
// Vref should not be > than 4.096V == 6709 counts
// Rmin(100ºC)= 680Ohms

if (iV05 > 6709) iV05 = 6709;  // Check limit hi
if (iV05 < 50) iV05 = 50;      // Check limit lo
rNTC  = (float)(6709)/ (float)(iV05) - 1.0;
if (rNTC < 0.06773) rNTC = 0.06773;   // Min 680
rNTC = rNTC * (float)RREF;   // RREF = 10000.0
rLogR = log(rNTC);
FV05_Temp = (1.0/(rA+(rB*rLogR)+
     +(rC*pow(rLogR,3.0)))); // ºK value in *val..
TXIvalues.iVTempKx100 = (UWORD)(FV05_Temp * 100.0);
```

The value FV05_Temp is proportional to absolute temperature in K. Since values are transmitted serially, the `TXIvalues.iVTempKx100` integer equal to FV05_Temp*100 is used to avoid a decimal point in the transmission buffer. The following telemetry packet is used:

```
UUU$ttttt.bbbbb.dddd.sss.vvv.xxxx*QQQ
```

Where t is scaled absolute temperature in K, b is scaled (x10) barometric pressure in mB, d is the scaled (x10) value of direction, s is the scaled (x10) value of wind speed, and x is the checksum value in hexadecimal. The v sequence is not used.

For systems requiring externally calibrated instruments, both temperature and barometric pressure sensors can be replaced with NRG #110S Temperature Sensor and/or BP20 Barometric Pressure Sensor. A factory-calibrated version of the NRG Max#40 anemometer is also available.

Wind intensity is computed from period length information (since frequencies are below 100Hz), and the system uses a zero-crossing detector at input on the MetAnlg board.

Figure 2 – Meteo Fr/End internals

III. CONSTRUCTION AND INTERFACE

D. System deployment

Meteo Fr/End behaves in consequence as a slave data-acquisition unit of the main PCES, to obtain meteorological information necessary to evaluate the *P(V)* curve of the wind turbine. A double lockable cabinet (metal/PVC) for the system provides greater insulation for cold winters and protection for the internal circuits. The system consists of the two previously mentioned boards (see Figure 2) plus an RS485 conversion board located on the left part of the cabinet. Power consumption is low, and is provided as 12V run through the serial link cable.

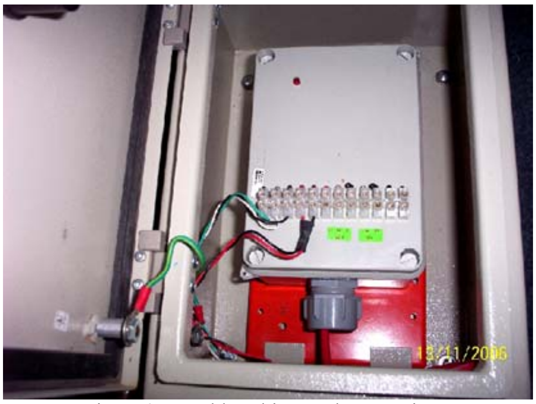

Figure 3 - Double cabinet and connections.

Figure 4 – Prototype installation

The main PCES [Oliva & Vallejos 2006] unit (Figure 5) is based on an AVR ATMega 128 processor, and uses SD (Secure Disk) flash memory storage devices. Data is converted from the serial link back to floating point values, and calibration coefficients are stored within PCES in non-volatile memory. Wind values are normalized according to IEC's recommendations taking into account pressure values.

The time-series of meteorological, voltage and power from the wind turbine are stored in the SD cards in CSV (comma separated values) text format, and these files are readable directly from a conventional PC. The values can be graphed with spreadsheet programs such as Excel or using two software packages provided for time series graphs and power curve construction.

Figure 6 – (Left) Main PCES and (right) Met tower beside the wind turbine in Quichaura, Chubut

IV. FIRST RESULTS AND CONCLUSIONS

Although overall results were very encouraging, the first series of data acquired form the Meteo units showed problems with noise in frequency, in the form of extremely high wind values at random times. Additional filtering for inputs has been the remedy suggested by NRG and solutions are been implemented for installed systems (Figure 6). In figure 7 these random frequency peaks are shown.

Systems have been operating reliably since the last month of 2006, new installations have been pursued in 2007, and an important perspective exists for further requirements of this type of unit within PERMER and other programs.

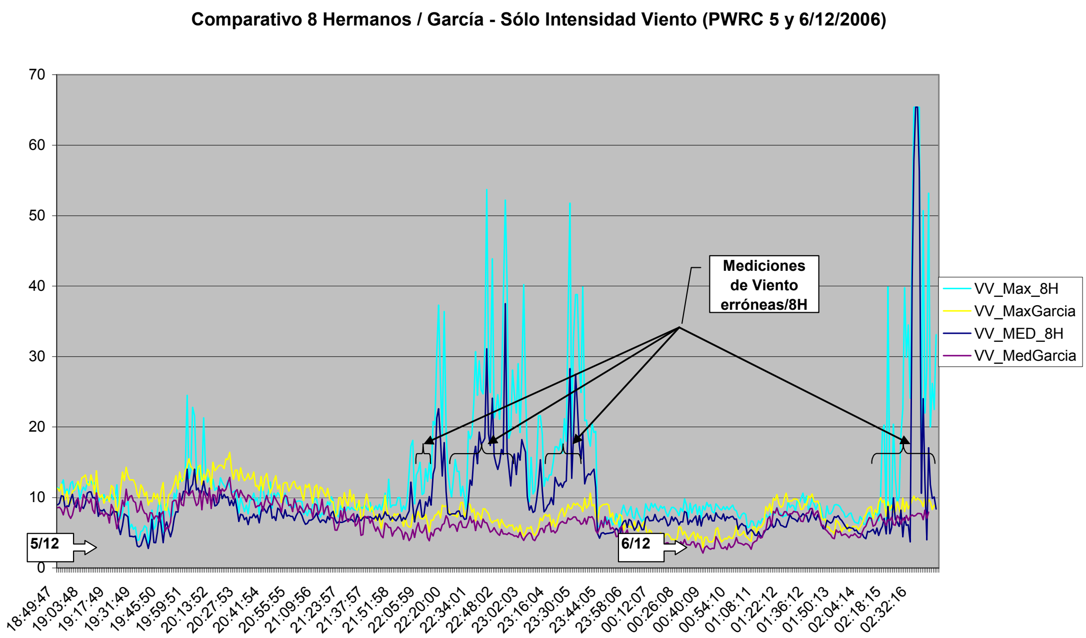

Figure 7 - Comparative wind measurements at two nearby locations in Chubut showing erroneous wind peaks – 5 al 7/12/06

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