DEVELOPMENT OF A WIND MEASUREMENT SYSTEM PROTOTYPE, AIMED TO CONDUCT WIND ENERGY RESOURCE ASSESSMENTS

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SUMMARY

TITLE:

Development of a low cost wind measurement system prototype, aimed to conduct wind energy resource assessments.[1]

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Jesús David Hernández Ortiz[2].

KEY WORDS:

Wind energy resource assessment, wind power.

DESCRIPTION:

This work describes how a wind measurement device aimed to conduct wind power assessments was designed and implemented. The device also was used to evaluate the opportunity of developing a wind project on a probe´s site. The document is divided into four parts as follow: at first, a global wind energy generation overview is made, pointing out also small and medium applications for the industry in Colombia. In the Second part, the work is focused on the measuring system design, particularly, issues as sensors' selection, R & D (Research and Development) data logger´s process and testing processes are carefully detailed. In third place, wind measurements were made with the developed system, in order to conduct a basic wind resource assessment. Such study includes the energy production estimation, economical feasibility and turbine´s selection process. Finally, important observations and conclusions are reported.

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RESUMEN

TITULO:

Implementación de un sistema de bajo costo para medición de viento, que permita realizar análisis de viabilidad en proyectos de generación eléctrica eólica[3].

AUTORES:

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Jesús David Hernández Ortiz[4].

PALABRAS CLAVES:

Estudio del recurso eólico, energía del viento.

RESUMEN:

El presente trabajo describe el proceso de desarrollo e implementación de un sistema de medición de viento enfocado a realizar estudios de viabilidad en proyectos de generación eléctrica eólica. Además, el dispositivo es también utilizado para evaluar la viabilidad de una granja eólica en un punto de prueba aleatorio. El documento se halla subdivido en 4 partes así: en primera instancia, se hace un recorrido rápido sobre el desarrollo de la energía eólica en el mundo, discutiendo a la par posibles aplicaciones de pequeña y mediana escala, que podrían favorecer el desarrollo de esta industria en Colombia. En la segunda parte se discute diseño del sistema como tal, haciendo especial énfasis en los procesos de selección de sensores, investigación y desarrollo del *data logger*, así como también se ilustran los resultados de los experimentos de prueba realizados al sistema. En tercer lugar, se utiliza el sistema para recolectar información del viento y con ello realizar un estudio de viabilidad para un proyecto de generación eólica en el sitio estudiado. Esto comprende además del estudio energético, el análisis económico y el proceso de selección de la turbina. Finalmente, se elaboran una serie de conclusiones que abarcan todo el rango del trabajo.

[3] Trabajo de Grado.

[4] Facultad de Ingenierías Fisico-Mecánicas. Escuela de Ingeniería Eléctrica, Electrónica y Telecomunicaciones. Director. Ph.D., Ms.C., Ingeniero Eléctrico, Hermann Raúl Vargas Torres. Codirector. Ms.C., Ingeniero Electrónico, Alfredo Rafael Acevedo Picón.

DEVELOPMENT OF A WIND MEASUREMENT SYSTEM PROTOTYPE AIMED TO CONDUCT WIND ENERGY RESOURCE ASSESSMENTS.

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ABSTRACT

This article describes how a wind measurement device aimed to conduct wind power assessments was designed and implemented. The device also was used to evaluate the opportunity of developing a wind project on a probe´s site. At first, a global wind energy generation overview is made, pointing out also small and medium applications for the industry in Colombia. Afterwards, issues as sensors' selection, R & D data logger´s process and testing processes are carefully detailed. Finally, data analysis, turbine´s selection and a feasibility study was reported.

Keywords: Wind resource assessment, feasibility assessment, wind energy, logging systems, anemometers, wind vanes, data loggers.

I. INTRODUCTION

In the mid fifties, Danish country´s side people and small communities came together owning small wind turbines of few kW to satisfy their electrification needs [1]. This successful model experienced a quick growth, stimulating the industry to develop larger turbines and projects. This created a multimillion dollar business where wind farms with hundreds of MW installed are the common model.

Today, it has been proved that our electric power generating methods are not as efficient and reliable as we thought [2]. The imminent end of fossil fuels, the affected rain cycles due to the climate change and the limited uranium resources have promoted discussions about a possible energy crisis [3]. Wind power generation have overcome these problems emerging not only as a clean and renewable energy source but also as the most efficient and profitable among renewable ones [4].

In the Colombian scope, big on shore wind farms can be developed along the Departamento de la Guajira as well as in some places in the Cordillera Oriental (East Ranges). Also big off shore wind farm projects can be developed on the Caribbean ocean [5]. However, there are places in Cesar, Santander, Boyacá, Cundinamarca, Bolivar, Tolima, Quindío and Antioquia where small wind projects can be developed, looking forward supplying energy to places where bringing the electrical network is difficult.

Without matter on the project´s scale, wind resource assessments must to be conducted in order to guarantee the investment. As a thumb rule, wind assessments for big projects can reach the 10% of the total cost [1]. Something different happens on small scale, where this percentage can increase dramatically. The wind resource assessment´s cost for small projects is close related to measurement stations' costs. On the market, these stations can reach prices of 10000 dollars while a 5 kW turbine could have the same price. Choosing properly the sensors, the tower and the data logger, big savings can be obtained, making wind generation at small scale even more attractive on national environment.

II. BACKGROUND

Wind measurement system are constituted basically by two kinds of elements, they are:

- The sensors, anemometer and wind vanes, they measure the wind speed and wind direction respectively.
- Data Logger is the electronic device which processes the sensor´s signals and saves the information.

The devices to be selected depend on the application the user will be working on. The IEC 61400-12 and the AWEA 8.1 standards state the different features the devices must to accomplish with, when working on wind industry applications. Briefly, these standards state parameters as accuracy and precision´s system, measurement ranges, type of data to be recorded, measurement highs, sensors arrangements, conducting time periods, among many others. Table 1 summarizes the basic parameters stated by the wind energy standards [6].

The biggest difference between meteorological and wind industry equipment is how the data logger works. In one hand, meteorology data loggers´ sampling periods are pretty long and no extra information is recorded[5]. In the other hand, wind energy loggers accomplish with lots requirements. In Table 2, some wind assessment data loggers are compared.

	Variable	
Parameter	Velocity	Direction
Average	x	x
Maximun	x	x
Minimun	x	x
Standar Deviation	x	
Sampling period	1 sec	1 sec
Averaging period	10 mins	10 mins

Table 1. Data Logger Parameters

Furthermore, the Danish Wind Industry Association recommends that the device should work by itself without any supervision for almost 6 months time, avoiding in this sense, unnecessary visits to the site for extracting information or replacing batteries [7].

Data Logger	Counter Channels	Analog Channels	Sampling Interval[seg]	Averaging Interval [min]	Storage Medium	Recorded Parameters	Price [USD]
APRS WORLD DATA LOGGER	3	3	10-50000	NA	SD Card	Sampled	295
NRG SIMPHONY PLUS	9	6	2	10	SD Card	Average, std dev, max, min.	1350
SECOND WIND NOMAD2	12	8	1	1,10,60	SD Card	Average, std dev, max, min, total cycles.	1450
AMMONIT METEO 32	3	6	1-60	1-9999 Samp. Intervals	1 Mb, EEProm	Average, std dev, max, min.	2608

Table 2. Data Loggers comparative table

III. SYSTEM DEVELOPMENT

To develop a low cost wind measurement device, focused on conducting resource studies for

[5] This is deduced from seeing the meteorological equipment. Some reference devices are the Davis Instruments Vantage Pro2 Plus , Campbell Scientific CR200X Data logger or the HOBO UH30.

small scale projects (below 200kW) was the main task of this work. This kind of projects require no more than one measurement station with just one anemometer and one wind vane. The market offers systems from 2000 to 7000 dollars, depending on system configuration and the sensors ´quality. This cost does not include the tower price, which usually cost nearly 4000 dollars.

1. Sensors Selection

For the system, a NRG 40H anemometer without calibrating was selected as the wind speed sensor. This Hall Effect based device creates a square voltage signal with frequency “f”, which increases linearly with wind speed increments. Table 3 compares the NRG 40H against other devices in the market.

Anemometer	Sensor range [m/s]	Accuracy [m/s]	Threshold [m/s], [Deg]	Distance constant [m]	Signal Output	Price [USD]
NRG #40H	1-96	0.1	0.78	3	Square signal voltage	160
NRG #40C Calibrated	1-97	0.1	0.78	3	AC voltage	395
SECOND WIND C3C M.I.T. Calibrated	1-96	0.1	0.78	3	AC voltage	295
R.M. YOUNG GILL MICROVANE & 3 CUP	1-60,0-355		0.5,0.4	_	DC voltage, DC voltage	1348
R.M. YOUNG WIND MONITOR 05103	0-100, 0-355	0.3, 3	1, 1.1	_	AC voltage, DC voltage	1148
WINDSENSOR P2546A, Measnet Calibrated	0-70	1%	0.4	_	AC voltage	1595
MET ONE 010C	0-60	1%	0.22	1.5	PWM, AC or DC	1050
THIES FIRST CLASS	0.3-75	3%	0.3	_	PWM voltage	975

Table 3. Anemometers comparative table

Wind direction changes are measured with the NRG 200P wind vane. This vane has a 10k embedded potentiometer that provides a DC voltage signal linearly to the wind vane deflection from its equilibrium point. Differences between top quality vane good quality ones are not appreciable. Table 4 compares some vanes used for wind resource assessments.

Figure 1. System´s anemometer and wind vane

Vane	Sensor Range [Deg]	Linearity [%]	Death Band [Deg]	Threshold [m/s]	Signal Output	Price [USD]
APRS WIND VANE	0-355	_	5	1	DC voltage	145
NRG #200P	0-360	1%	8	1	DC voltage	205
SECOND WIND SWI PV-1	0-360	1.5%	8	1.3	DC voltage	245
METONE 020C	0-360	1%	_	0.22	DC voltage	780
THIES AMMONIT COMPACT	0-360	1.5%	_	_	DC voltage	973
THIES CLIMA FIRST CLASS	0-360	0.4%	_	_	9 bit Digital	1895

Table 4. Wind vanes comparative table

These sensors offer high quality and reliability at a low price. The sensors already mounted in the measuring tower are showed in the Figure 1.

2. Logger Design.

All data logger devices are nothing else but a set of three modules; two of them are analog (the power supply and the conditioning signal stage). The last module, which basically is built on a microcontroller, is the responsible for making all the digital processing tasks, including the recording process.

2.1 Hardware

The development platform selection process was driven in conjunction with the memory´s selection. Firstly, the memory should have simple communication protocols, having into account that the communication process between the device and any personal computer has to be easy. Also, the memory should be able to store lots of information as well as to have low cost. Three different kinds of memories are compared on the Table 5.

Memory Type	Capacity	Comm. Protocol	Compatible with	Cost	Observations
EEPROM	2 MB	SPI	All Micros	Highest	Non removable, Low capacity
USB	16 GB	USB	Just Microchip, Slave Mode	Medium	Requieres interface, Increases Cost
SD	32 GB	SPI-SD	All Micros	Lowest	Requieres 3.3 V, Increases Cost

Table 5. Memories comparative table

Regarding to the development platform, selection was based on availability, cost, easy use of compiler, debugger and programmer, included libraries in the compiler, and finally, it should offers good support as well as to have enough and reliable documentation sources. In this sense, SD memory and Microchip PICKIT2 MikroC were selected. MikroC, developed by MikroElektronika[6], is easy to use and comes with rich resources, such as a large number of built-in libraries, including SD Memories and FAT16 file system´s structure functions [8]. Different compilers, debuggers and programmers are contrasted on the Table 6.

Platform	Referencies	FAT16 Libraries	Debbuger	Cost
Microchip PICKIT2 PICC Lite	GOOD	NO	Software Assembler	Lowest
Microchip PICKIT2 MIKROC	BAD	YES	NO	High
Microchip ICD MIKROC	BAD	YES	Hardware C	Highest
Freescale DEMOQE 128 CodeWarrior	GOOD	NO	Software C, Hardware C	Low

Table 6. Development Platforms comparative table

The selected sensors operate correctly when 4.5 volts are supplied, at least. Choosing a standard voltage of 5V, the anemometer will produce square signal (5V for high, 0V for low) while the wind vane will generate a DC voltage from 0 to 5 volts depending on the wind direction. Driven also this voltage to the microcontroller, there is no need of signal´s level conditioning stages for the system. Moreover, supplying the same tension to sensors and microcontroller, keeping it as low as possible, the system will have the lowest power consumption. The 5 volts are supplied by a high efficiency switching adapter from any 120V wall plug. The SD memory works in the range of 3 to 3.6 volts. To supply this tension, a LDO REG113 in its standard configuration was used. Data logger system´s diagram block is showed in the Figure 2.

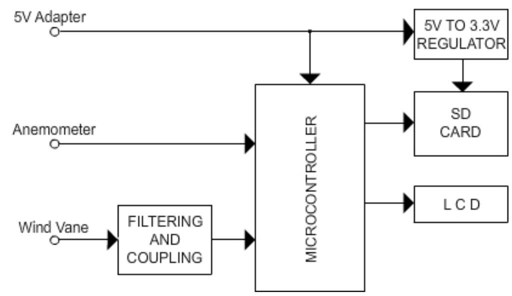

Figure 2. Data logger´s block diagram

The digital module´s core is a PIC18F2550. This device satisfies the requirement of SPI, external interrupts and ADC modules as well as the necessity of 15 digital pins (for connection with the SD card, the Hitachi HD44780 standard LCD and control buttons) and 2 input pins, one digital for the anemometer, the other one analogical for the wind vane. The 2550F also provides enough program memory for managing the SD and FAT libraries (30 KB). Finally, its low cost and 5V tension supply conducted to its selection.

A passive RC filter with cut off frequency at 10 Hz, followed by a buffer based on the OPA365AID was designed for conditioning the vane´s signal properly to the microcontroller´s ADC input [9]. This module was implemented in order to avoid loading effects on the ADC´s RC circuit. Without this insulation, the 10K wind vane resistance will increase the ADC conversion time, creating so unpredictable errors in the data conversion process [10]. The implemented data logger with its respective SD card and LCD interfaces can be observed in the Figure 3.

Noise analysis in the system is neglected due to the tension levels and the signal kind worked with. In the whole system, the only appreciable error source is the wind vane and anemometer accuracy, being the first one 1% (50mV) and the second one 1 m-s. These values make insignificant

[6] Mikroelectronika´s web site: http://www.mikroe.com/en/compilers/

the contributed noise by the resistances and the integrate circuits.

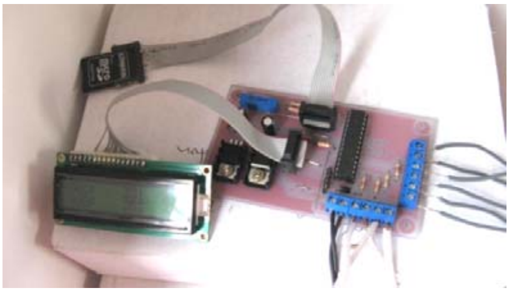

Figure 3. Data Logger Device

2.2 Software

The microcontroller uses the external interruption module to identify all the falling edges as well as the timer module to calculate the anemometer´s signal frequency. In addition, the timer causes a program interruption every second, saving on a memory´s buffer the last sampled velocity and direction data. This information is compared against maximum and minimum values stored in the previous sampling process, and updated only if necessary. While this happens, each 600 interruptions, speed and direction averages and standard deviations are calculated, stopping momentarily all interruptions to avoid interferences in the saving process on the SD card. Microntroller-SD card communication uses SPI protocol due its universality and simplicity [11]. Besides, the programs starts with a time and date configuration routine which later will be updated every second according the timer interruptions.

IV. VALIDATION EXPERIMENTS

As soon as the sensors characterization process was finished and the data logger operation was verified, the system´s calibration process was carried out at the Universidad Potificia Bolivariana de Medellin Aerodynamics' laboratory. Laboratory´s facilities include a wind tunnel in certification process that can be used to conduct tests at speeds between 3 and 40 m/s. Taking this tunnel as the standard device, the calibration process consisted in a comparison routine between wind speed sensed by device and tunnel´s wind speed, along the 3 to 25 m/s range[7] [12], with 0.3 m/s speed´s increments[8] [13]. The obtained results in this experiment where introduced in MS EXCEL and summarized in Figures 4 and 5.

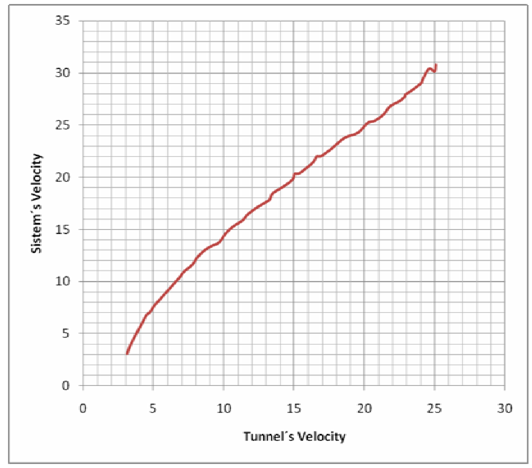

Figure 4. Uncalibrated system response.

Figure 4 suggested that a linearization process should be carried out in 5 different velocity ranges. These ranges were selected by analyzing the above graphic and the process was repeated. The second test shows no significant differences compared with the first one, so an average between these two set of data was done and the linearization process was done by means of EXCEL´s s linear regression function.

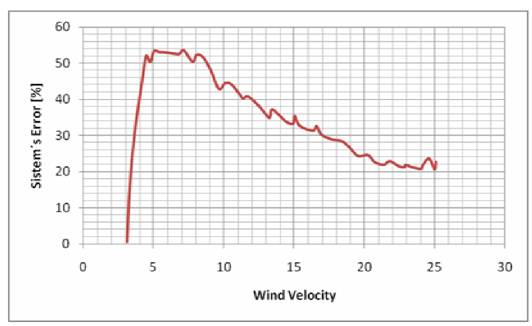

Figure 5. Uncalibrated system error.

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7 This range was selected due to 25 m/s is the turbines´ top speed. Over this velocity, turbines stops and no energy production is obtained.

8 The process was similarly conducted to the NRG original calibration process.

	Linear Regression No.									
	1		2		3		4		5	
Range [m/s]	[0 ; 5]		(5 ; 8]		(8 ; 14.4]		(14.4 ; 17.6]		(17.6 ; 25.1]	
Regression Parameter	m	b	m	b	m	b	m	b	m	b
Calculated	0,4	177	0,67	-14,7	0,88	-270	0,88	-270	0,89	-289
Coefficient of determination	0,9903		0,9986		0,9926		0,9926		0,9904	
Random match	2,2095E-08		6,4248E-11		6,4248E-11		3,2863E-10		6,7258E-19	

Table 7. Regression´s results.

Table 7 shows the linearization results for each of the 5 velocity ranges. The coefficient of determination and the Random match were calculated also in order to verify the result´s truthfulness and reliability. The coefficient of determination obtained[9] corroborates the high correlation between data and the calculated regression while the extremely low random match parameter indicates almost the impossibility of the linearization´s high reliability was by chance [14].

The microcontroller´s program was updated with the respective linearization and a final test was carried out. Final results of the calibration process are illustrated by Figures 6 and 7.

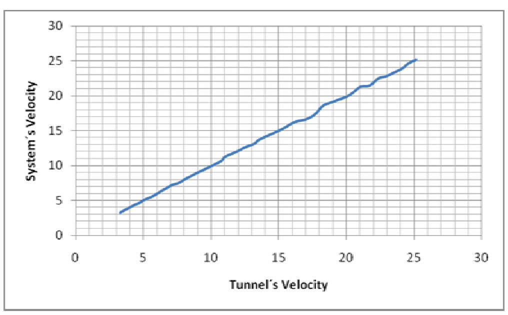

Figure 6. System Response

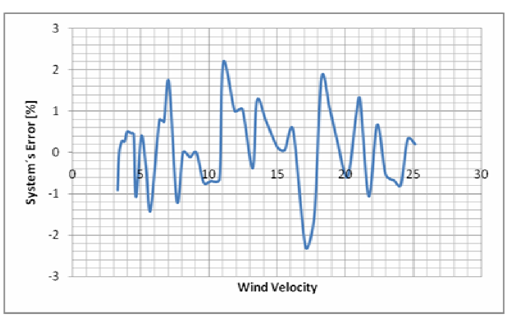

Figure 7. System Error

[9] The Coefficient is very close to 1. It indicates that there is a high correlation between calculated and real data.

V. WIND RESOURCE ASSESSMENT

Having verified the system´s operation and its reliability, it was placed on a 3 meters tower and lived in site to collect information for nearly 60 hours. Sensors where mounted following the general rules to follow for tubular towers [15]. They are resumed in the Figure 8.

A wind assessment after the measurement process can only be conducted if assuming a practical application case. This time, a businessman with a monthly energy consumption of 5 MWh (7kWh roughly), who wants to implement a wind turbine to reduce it electricity bill was the supposed scenario.

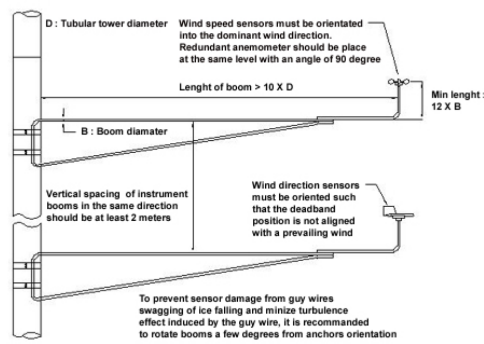

Figure 8. Sensors mounting roules[15]

The collected information along the 3 days measuring time was introduced in MS EXCEL for its analysis. In first place, data was extrapolated to one year measuring time with the purpose of making coherent the energy calculations. Secondly, wind velocity at 20, 30 and 40 meters[10] over ground level was estimated through the formula (1).

$$V_2 = V_1 \, (h_2 / h_1)^{\alpha} \qquad (1)$$

Where: *V1* = wind speed measured at the reference height *h1*. *V2* = wind speed estimated at height *h2*, and *α* = ground surface friction coefficient[11]. *α* = 0,4 in this case [16].

For all cases, wind speeds were under 10 m/s, suggesting this situation that a turbine with peak power output at the lowest speed possible

[10] Possible turbine´s hubs highs.

[11] α changes depending on the surface terrain type. It has, for instance, a value of 0.1 for lakes and oceans while for forest and lightly wooded land is 0.25 and 0.4 for cities with tall buildings.

should be selected. Finally, the information was organized and wind speed´s frequency (Figure 10) and the sector´s wind frequency were deducted. This last information is introduced in the Danish Wind Energy Association web´s page where a free program can be used in order to obtain the wind rose[17] (Figure 9).

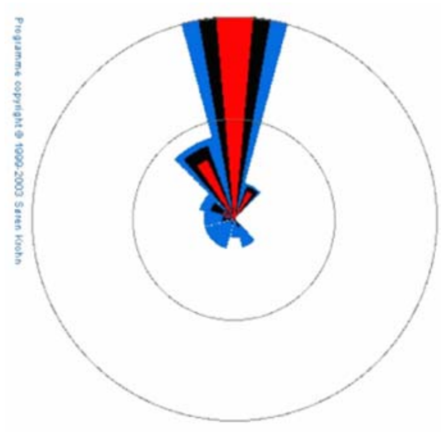

Figure 9. Site´s wind rose [40m].

To select the most appropriate turbine, 7 turbines were compared in the Table 8. The selection criterion was focused as it was said above, in a low peak power speed and a low cost. Despite Redriven 10kW seemed to be the most appropriate option, analyzing its power curve, a low efficiency can be observed at low speeds, where wind blows the most. The Evoco 10kW was the most suitable choice for this scenario [18], due to its high energy production at speeds between 6 and 8 m/s (Figure 11), being nearly the double of the Redriven one.

Turbine	Peak Power [kW]	Peak Power Speed [m/s]	Cut in Speed [m/s]	Price [USD]
Bergey Excel 10kW	11.790	15	3	29.500
Eco 10kW	12.400	12	3	32.000
Evoco 10 kW	10.400	9,5	2	59.700
Gaia 11kW	11.800	11	3	83.900
Proven 35	12.680	12	3	88.000
ReDriven 10kW	11.000	11	3	22.200
Westwind 10kW	10.200	15	3	56.500

Table 8. Turbines comparison

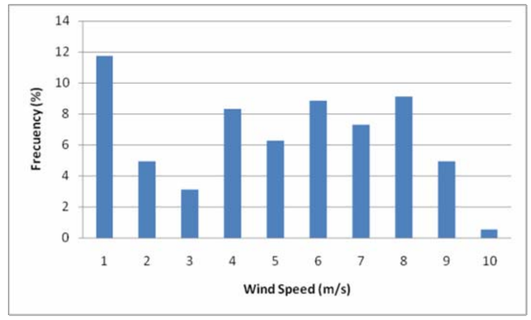

Figure 10. Site´s wind speed frequency [40m].

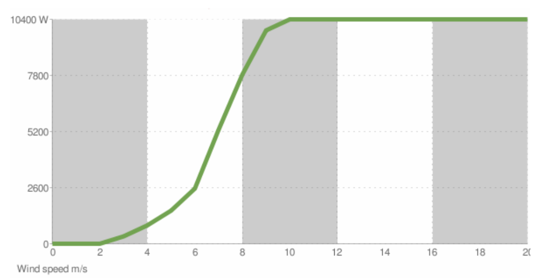

Figure 11. Evoco10kW output curve

The annual energy production can be calculated multiplying the wind speed frequency by the turbine´s output curve [19]. Table 9 summarizes the process.

Vel[m/s]	Power [kW]	Time [h]	Produced Energy [kWh]
1	0,0	1026,56	0,00
2	0,0	433,44	0,00
3	0,0	273,75	0,00
4	1,1	730,00	803,00
5	2,8	547,50	1533,00
6	5,0	775,63	3878,13
7	7,3	638,75	4662,88
8	8,9	798,44	7106,09
9	10,4	433,44	4507,75
10	11,4	45,63	520,13
		TOTAL:	23010,97

Table 9 .Turbine annual energy production

A simple economical analysis was done supposing the next market conditions: $360 COP (0,18 USD, 1USD = 2000 COP) kWh cost, a yearly inflation rate equal to DTF, a 2% yearly from turbine`s cost due to operation and maintenance (O&M)[12] [20], and a project´s

[12] O&M costs include: routine check, periodic maintenance, periodic testing, blade cleaning, electrical equipment maintenance, and unscheduled maintenance costs.

financing of 100% by loan[13] with a 1% monthly interest.

Annual energy production: 23010 kWh.

Investment cost: 50000 USD

Financing: 50000 USD

Unit energy cost: 0,18 USD / kWh

Annual O&M: 1200 USD

Under these conditions, the annual net income will be:

$$ANI = 23010 * 0,18 - 1200 = 2943 \text{ USD} \quad (2)$$

An easy cost analysis for evaluating project´s viability is to calculate the present value of total revenues and compare it with the initial cost. The present value is calculated by the equation (3):

$$PV = f_c \cdot R \quad (3)$$

Where PV = present value, f_c = capitalization factor, given in equation (4) and R = revenue.

$$f_c = (q^n - 1) / (r \cdot q^n) \quad (4)$$

where r = real interest (interest - inflation), n = number of years and $q = 1 + r$. So, the present value of the net income is:

$$PVN = 9.3405 * 2.943 = 27.490 \text{ USD} \quad (5)$$

So the profit after 20 years is given by (6):

$$27.490 - 50.000 = - 22.511 \text{ USD} \quad (6)$$

This situation illustrates that under this market and wind conditions, the project is an economical disaster.

VI. CONCLUSIONS

A system for measuring wind conditions to conduct wind energy assessments was successfully designed and developed.

While having the opportunity of calibrating free of charge the wind sensors, extra cost for calibrated sensor are not justified. However, if using a wind tunnel is not possible, the calibrated sensors are the best option. As example, before calibrating process was conducted, the system reached errors of 50%.

The systems probed to be user friendly, accurate and reliable according to the testing results. Any error in the measurement may be conferred to the user.

Despite of difficulties on creating the software with the MikroC Platform, (due to its precarious debugger software, which notoriously increments the developing time), this choice simplified the overall programming time thanks to its SD and FAT16 libraries. The authors strongly believe that writing a code for controlling the SD card and the FAT16 structure could take almost a year time.

The system´s results are fully MS Excel compatible. Excel allows analyzing properly and quick the information, generating by itself the pre feasibility study report.

The 11 levels building´s top in Bucaramanga city was the testing point. The study showed that such place has no enough wind to implement wind turbines for electricity generation.

Colombia has a low cost electrical energy generation compared with the developed countries. This condition makes even less profitable the use of wind turbines for generating electrical energy.

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VIII. REFERENCES

[1] Tore Wizelius, "Developing wind power projects, Theory and Practice", First edition, Earthscan, 2007, p. 10, 243 – 244.

[2] Rik DeGunter, "Alternative energy for dummies", What a Mess, Chapter 1, Willey Publishing, 2009

[13] In this loan, the sum of the amortization and interest still constant.

[3] Manfred Stiebler, “Wind Energy Systems for Electric Power Generation”, Green energy technology series, Inst. of Energy and Automation Technology Einsteinufer 11, D-10587 Berlin Germany, Springer, 2008, p.1 – 3.

[4] World Wind Energy Association WWEA, “World Wind Energy Report 2008”, February 2009.

[5] Ministerio de Minas y Energía, IDEAM, UPME, “Atlas de Viento y Energía Eólica de Colombia”, 2002, p. 75 – 76.

[6] AWS Scientific, Inc, CESTM, “Wind Resource Assessment Handbook”, NREL Subcontract No. TAT-5-15283-01, 251 Fuller Road, Albany, NY 12203, April1997, p. 4-1 – 4-4.

[7] Danish wind industry association, Wind Speed Measurement in Practice, available from: http://guidedtour.windpower.org/en/tour/wres/wndwndsp.htm [Accessed: January 20, 2009]

[8] Dogan Ibrahim, “Advanced PIC Microcontroller Projects in C. From USB to ZIGBEE with PIC 18F series”, Newnes Press, 2008, p. 121 – 122.

[9] Ron Mancini, “Opamps For Everyone”, Texas Instruments, 2002, p. A-31.

[10] Microchip Technology Incorporated, PIC 18F2550 Data sheet, 2006, p. 264.

[11] SD Group, Matsushita Electric Industrial Co., Ltd. (Panasonic), SanDisk Corporation, Toshiba Corporation , “SD Specifications, Physical Layer”, Simplified Specification, Part 1, Version 2.00, 2006, p. 93.

[12] Wind Energy Research Unit, CSIRO land and water, “Wind Resource Assessment in Australia” – A Planners Guide, Version 1.01, 2003, p. 37 – 38.

[13] Bruce H. Bailey, Project Manager AWS Scientific, Inc., “The NRG Maximum Type 40 Anemometer Calibration Project”, NRG White papers, 251 Fuller Road Albany, NY 12203, 1998.

[14] Microsoft Office EXCEL 2007, “Linear.Regression”, Help Tool.

[15] Wind Assessment, available from: http://www.energogreen.com/index.php?option=coc_content&view=article&id=33&Itemid=4&lang=en [accessed: January 27, 2010]

[16] Mukund R. Patel, “Wind and Solar Power Systems”, CRC Press, 1999, p. 68 – 69.

[17] Danish wind industry association, Wind Rose Plotter Programme, Available from: http://guidedtour.windpower.org/en/tour/wres/roseplot.htm [Accessed: January 25, 2010]

[18] Evoco 10 kW Wind Turbine, Available from: http://www.bettergeneration.com/wind-turbine-reviews/evoco-10-kw-wind-turbine.html [Acessed: January 27, 2009]

[19] Alvaro Pinilla S., Ph.D., M.Sc., “Manual De Aplicación De La Energía Eólica”, INEA, 1997, p. 21 – 25.

[20] J. F. Manwell, J. G. MacGowan, A. L. Rogers, “Wind Energy Explained”, University of Massachusetts, Wiley Publishing, 2002, p. 441 – 444.