Dalibor IGREC[1], Amor CHOWDHURY[1,2], Miralem HADŽISELIMOVIĆ[3,2], Bojan ŠTUMBERGER[3,2]

MARGENTO R&D d.o.o. (1), University of Maribor, Faculty of EE and CS (2), University of Maribor, Faculty of Energy Technology (3)

Environmental values measuring cell for assessment of wind and solar energy resources

Abstract. *A precise understanding of the area's wind resource is the cornerstone of any wind project. Professional wind measurement and its accuracy and reliability are thus very important in predicting economic viability before starting a wind farm. Therefore, for the prospective development of a wind turbine, it is important to consider the wind resources, how regularly the wind blows, the direction of the wind and the variations in wind speed.*

Streszczenie. *Dokładne zrozumienie I poznanie źródeł wiatru w obszarze elektrowni wiatrowej jest kluczowe dla projektowania takiej elektrowni. Profesjonalny pomiar siły wiatru, a przede wszystkim jego dokładność i wiarygodność są bardzo ważne w predykcji rentowności ekonomicznej farmy wiatrowej. Stąd, dla rozwoju turbin wiatrowych niezbędne jest przeprowadzić badanie źródeł wiatru, jego regularności, kierunku oraz zmienności w szybkości. (**Stacja pomiarowa wielkości środowiskowych dla oceny źródeł energii wiatrowej i słonecznej**)*

Keywords: wind resources, measurement cell, turbulence intensity, wind power density
Słowa kluczowe: in this line the Editor inserts Polish translation of keywords.

Introduction

Global agreements on influencing climate change with the use of renewable energy sources have led to an increased global trend in the research of alternative energy sources. Renewable energy sources include solar energy, wind energy, water energy and biomass with geothermal energy. The EU's environmental policy is the first important step in reducing greenhouse gas emissions and thus establishing global balance [1]. Today much work is directed into the optimization of usage of renewable energy sources especially into the optimization of wind farms usage where the environmental characteristics are crucial.

Production of electricity from alternative and renewable natural sources is usually accompanied by substantial investment. If for the solar and hydro potential is enough to have general information on the macro level, for the wind potential a more accurate assessment at the micro level is needed. To obtain the wind potential at the micro level it requires a significant amount of data collection, and research before the first turbine begins to spin. For the project of wind farm setup a specialized services of consultants, contractors, and legal representatives are needed to avoid problems that could end the operation before it starts. Even a small change in the wind speed in a particular area can significantly affect the power yield efficiency of the wind turbine. Before investment, it is necessary to acquire information on wind resources for an individual area, which would justify building a wind farm.

On the basis of the measured information, performance control mechanisms are integrated in the wind turbine. We have therefore decided to develop system equipment for measuring wind resources [2]. The article is presenting wind potential measurement system that is compounded from the backend database subsystem and the measurement cell subsystem with the corresponding results.

Objectives

The wind is the fuel for the wind power station. Small changes in wind speed produce greater changes in the commercial value of a wind farm. For example: a 1% increase in the wind speed might expect to yield approximately 2% increase in energy production.

Wind turbine power characteristic represents the dependence of the wind turbine power to the wind speed. The characteristic can be determined on the basis of theoretical calculations or based on field measurements. The last is measured in average winds (10 minute intervals) to avoid dynamic differences. The key parameters of wind turbine power characteristic are: (1) "cut-in wind speed" – minimum wind speed at which the propeller begins to rotate, (2) "cut-out wind speed" – maximum wind speed at which the wind turbine stops due to high wind speeds, (3) "rated power" - the maximum power output of wind turbine generator and (4) "rated wind speed" - wind speed at which rated power is produced by wind turbines.

To acquire these parameters and obtain the power characteristics of a certain micro-area it is necessary to perform measurements on a larger area. Initial measurement area is selected on the basis of existing meteorological data [3]. If any of the selected measured areas' data are particularly negative, we move the measuring cell to another location [4].

Measurement system

The best and the most accurate indication of the wind characteristics at a site are through on-site measurement using the measurement cell. It represents an independent, autonomous, and affordable measuring point.

The measurements at the end represent the importance of having an accurate knowledge of the specific area wind potential. A high quality measurement cell is therefore of crucial importance in reducing the uncertainty in the predicted energy production. The goal of a measurement cell is to provide information to allow the best possible estimate of the energy on the site to be provided and resolve the question of how many turbines to use and how tall they should be [5].

According to the area size, which is being measured for a wind resources, depends the number of used measurement cells. For a small wind farm area, it is likely that one measurement cell is sufficient to provide an accurate assessment of the wind resource at the site. For a medium wind farms (around 20 MW), located in complex terrain, it is likely that more than one measurement cell will be required to give an adequate definition of the wind resource across the site. For a large wind farms (around 100 MW), located in complex terrain, it is particularly important to take great care in designing a monitoring system to measure the necessary data for a robust analysis in a cost-effective way. The main goal of these measurements is determining potential windy areas and to produce maps of suitable terrain for wind farm and turbine placement.

All of this is possible with the system described in this article. Generally a system consists of two parts: the measurement cell subsystem (the clients) and the backend database subsystem (server). Figure (1) shows diagram of a single client (measurement cell), while figure (2) shows complete system block diagram (backend with many clients and the users).

Energy self sufficient measurement cell

It consists of watertight housing with an appropriate IP protection, CPU with a memory to store the measurements, GPRS communication, sensor input, internal battery and a solar cell. The solar cell enables complete autonomy, meaning that the system can be installed in places with no external power supply. Captured data are stored in an internal memory and sent to the collection centre at predefined time intervals. The data are sent with an internal GPRS modem. The system thus enables continuous remote control of the device and the corresponding sensors. The data are sent using a TCP/IP protocol. For this, a private APN channel is used.

In the areas, where GSM/GPRS signal is not available, satellite communication can be used.

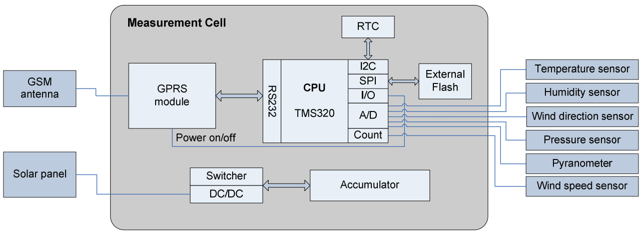

Fig.1. Measuring cell diagram

SQL and WEB server

On the server, a service is installed that operates in the TCP/IP server mode. Simultaneous connections of aforementioned cells are possible. Measurements from all measurement cells are stored into the SQL database. A web application is implemented on the server, enabling registered users to access the specified measuring cell data. The data of any time interval can be viewed graphically, in tables, or they can be exported to a local file for processing in other specialized applications.

Link to the web application: http://wind.margento.com

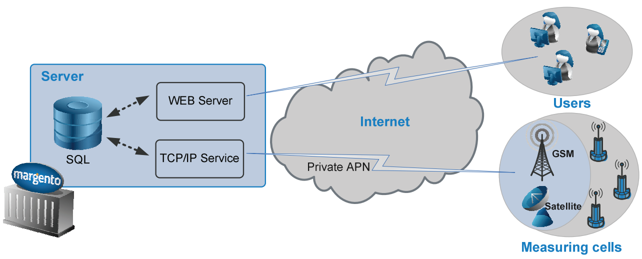

Fig.2. System block diagram

Sensors

The basis for monitoring wind resources is collecting data. These data are basic for acquiring key information needed to assess the reasonableness of establishing a wind farm.

Wind speed

Wind speed data are the most important indicator of a site's wind energy resources [6]. A cup anemometer is the most commonly used type for the measurement of near-horizontal wind speed. We used a model PA2 cup anemometer with two pulses per revolution [7].

Wind direction

Wind direction information is important for identifying preferred terrain shapes and orientations, and for optimizing the layout of wind turbines within a wind farm [6]. A wind vane is used to measure wind direction. We used a model PRV wind vane with 5 kΩ potentiometer output [7].

Fig.3. PA2 cup anemometer

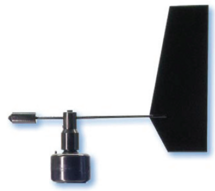

Fig.4. PRV Wind vane

Air temperature and relative humidity

Air temperature is an important descriptor of wind farm's operating environment, and it is normally measured either near ground level (2 to 3 m), or near hub height [6]. Relative humidity may be defined as the ratio of water vapour density (mass per unit volume) to the saturation water vapour density. We used a HTM2500LF combined sensor model, which is an all-in-one sensor (temperature and relative humidity module in one) [8].

4. Air pressure

A barometer measures atmospheric (barometric) pressure. Most sensors use a piezoelectric transducer that provides a standard output. Barometric pressure is used with air temperature to determine air density. It is difficult to measure accurately in windy environments because of the dynamic pressures induced when wind flows across an instrument enclosure. We used a model MPX4100A [9].

Fig.5. Temperature and Humidity

Fig.6. Air pressure

Optional parameters

We can expand our monitoring efforts to include additional measurement parameters. Possible optional parameters are presented below.

Solar Radiation

We can take advantage of a wind monitoring program to measure the solar resource for later solar energy evaluation studies. Solar radiation, when used in conjunction with wind speed and time of day, can also be an indicator of atmospheric stability and is used in numerical wind flow modeling. The recommended measurement height is 3 to 4 m above ground [6].

Vertical wind speed

This parameter provides more detail about a site's turbulence and can be a good predictor of wind turbine loads. Historically this parameter has been a research measurement, but as wind energy development spreads into new regions of the country, regional information on vertical wind velocity may become important. To measure the vertical wind component (w) as an indicator of wind turbulence, a "w" anemometer should be located near the upper basic wind speed monitoring level (but not at exactly the same level to avoid instrument clutter) [6].

Change in temperature with height

This measurement, also referred to as delta temperature (ΔT), provides information about turbulence and historically has been used to indicate atmospheric stability. A matched set of temperature sensors should be located near the lower and upper measurement levels without interfering with the wind measurements [6].

Analysis

When the data validation step is complete, the data set must be subjected to various data processing procedures to evaluate the wind resource. This typically involves performing calculations on the data set, as well as binning (sorting) the data values into useful subsets based on the requested choice of averaging interval. From this, informative reports can be produced, such as summary tables and performance graphs. Hourly averages are normally used for reporting purposes.

A description of each parameter and calculation method is presented in detail below.

Vertical wind shear exponent

Wind shear is defined as the change in horizontal wind speed with a change in height [6]. The wind shear exponent (α) should be determined for each site, because its magnitude is influenced by site-specific characteristics. The 1/7th power law (as used in the initial site screening) may not be applied for this purpose, as actual shear values may vary significantly from this value. Solving the power law equation for α gives

$$\alpha = \frac{Log_{10}\left[\frac{v_2}{v_1}\right]}{Log_{10}\left[\frac{z_2}{z_1}\right]} \tag{1}$$

where: v_2 is the wind speed at height z_2, and v_1 is the wind speed at height z_1.

Turbulence intensity

Wind turbulence is rapid disturbances or irregularities in the wind speed, direction, and vertical component. It is an important site characteristic, because high turbulence levels may decrease power output and cause extreme loading on wind turbine components [6]. The most common indicator of turbulence for siting purposes is the standard deviation (σ) of wind speed. Normalizing this value with the mean wind speed gives the turbulence intensity (TI). This value allows for an overall assessment of the site's turbulence. TI is a relative indicator of turbulence with low levels indicated by values less than or equal to 0.10, moderate levels to 0.25, and high levels greater than 0.25. TI is defined as

$$TI = \frac{\sigma}{V} \tag{2}$$

where: σ is the standard deviation of wind speed and V is the mean wind speed.

Wind power density

Wind power density (WPD) is a truer indication of the site's wind energy potential than wind speed alone [6]. Its value combines the effect of a site's wind speed distribution and its dependence on air density and wind speed. WPD is defined as the wind power available per unit area swept by the turbine blades and is given by the following equation

$$WPD = \frac{1}{2n}\sum_{i=1}^{n}(\rho)\left(v_i^3\right)\left(W/m^2\right) \tag{3}$$

where: n is the number of records in the averaging interval, ρ is the air density (kg/m³) and v_i^3 is the cube of the i^{th} wind speed (m/s) value.

As evident from the summation sign (Σ), this equation should only be used for all wind speed values (n>1) during an averaging period and not for a single long term average (e.g., monthly, yearly). The reason comes from the normal variability of the wind and the cubic wind speed relationship.

The air density in the WPD must be calculated. It depends on temperature and pressure (thus altitude) and can vary 10% to 15% seasonally. If the site pressure is known (e.g., measured as an optional parameter), the hourly air density values with respect to air temperature can be calculated from the following equation

$$\rho = \frac{P}{RT}\left(kg/m^3\right) \tag{4}$$

where: P is the air pressure (Pa or N/m²), R is the specific gas constant for air (287 J/kg· K), and T is the air temperature in degrees Kelvin (°C+273).

If site pressure is not available, air density can be estimated as a function of site elevation (z) and temperature (T) as follows

$$\rho = \left(\frac{P_0}{RT}\right)\exp^{\left(\frac{-g\cdot z}{RT}\right)}\left(kg/m^3\right) \tag{5}$$

where: P_o is the standard sea level atmospheric pressure (101,325 Pa), or the actual sea level adjusted pressure reading from a local airport, g is the gravitational constant (9.8 m/s²), and z is the site elevation above sea level (m).

Wind speed distribution

The next important parameter determining the output of a wind farm is the wind speed distribution. This distribution describes the amount of time on a particular site that the wind speed is between different levels. The characteristic can be very important, but is often inadequately treated. This distribution is important since it is the combination of the wind speed distribution and the power characteristic of the proposed turbine which together determine the energy production.

Wind rose

A "wind rose" is the term given to the way in which the joint wind speed and direction distribution is defined. The wind rose can be thought of as a wheel with spokes, spaced, at several degrees. For each sector, the wind is considered separately. The duration for which the wind comes from this sector is shown by the length of the spoke and the speed is shown by the thickness of the spoke. The design of a wind farm is sensitive to the shape of the wind rose for the site. In some areas, particularly in areas where the wind is driven by thermal effects, the wind can be very unidirectional.

Measuring results

Measurement results provide a robust prediction of the expected energy production over a wind turbine lifetime.

The results presented in tables and graphs are based on measurements of 10.8.2011.

Turbulence intensity: TI=0.31

Table 1. Hourly wind speed average with wind power density

Hour	Wind Speed (m/s)	Wind Power Density (W/m^2)	Hour	Wind Speed (m/s)	Wind Power Density (W/m^2)
0	4.22	46.55	12	6.75	185.23
1	7.21	232.25	13	7.26	230.91
2	6.72	188.12	14	7.13	218.61
3	6.64	181.73	15	7.6	264.45
4	5.8	121.34	16	6.64	175.93
5	7.47	259.83	17	7	206.48
6	8.13	335.33	18	5.14	81.89
7	7.09	222.25	19	2.42	8.57
8	7.52	262.52	20	1.72	3.14
9	5.27	89.04	21	2.76	13.09
10	5.85	121.29	22	3.68	31.11
11	6.74	184.91	23	3.62	29.72

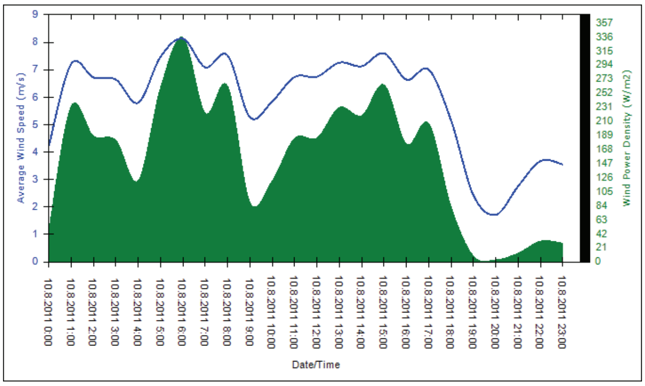

Fig.7. Average wind speed and wind power density distribution

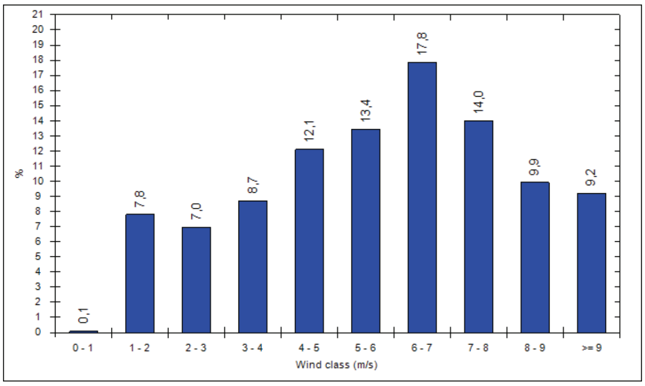

Fig.8. Wind speed distribution

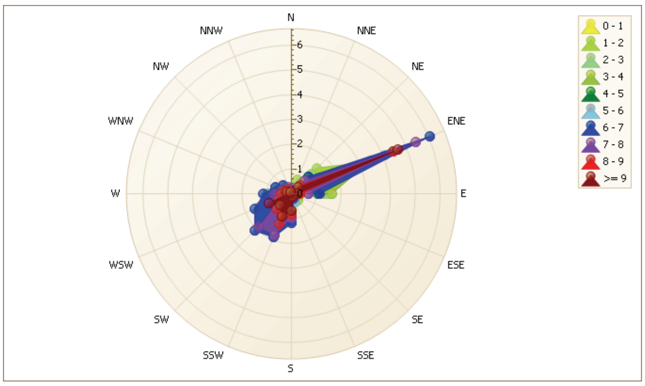

Fig.9. Wind rose diagram

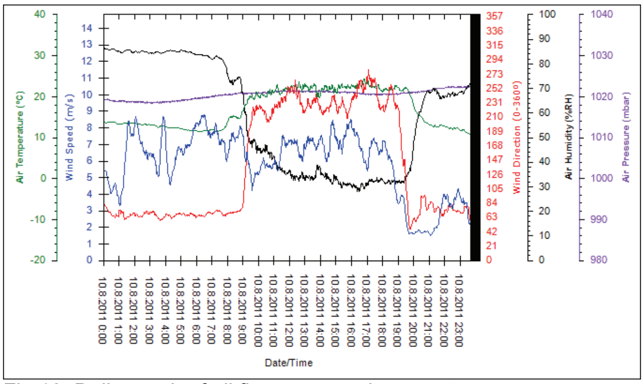

Fig.10. Daily graph of all five measured parameters

Conclusion

The financial risk is very high in the wind farm development due to various reasons. It can be reduced if proper wind assessment is done. Therefore an accurate assessment of wind resources in a given area is a key element for the successful establishment of an economically justified wind farm.

The longer the period of the measurements on a certain micro-location is, the better the profile of this terrain is. This led us to contribute to this area and develop a measurement device that is completely autonomous, that performs measurements on the mentioned sensors, and that sends the data in defined time intervals to the database. These data are then used in analyzing the viability of establishing wind farms. Because of high investment costs, investment into a wind-resources assessment system is completely justified.

The main objective is to create advanced energy self-sufficient mobile measurement and sensor systems that enable: measurements of geological movements of the ground under major viaducts, monitoring of oil and gas pipelines (pumping station, joints detection), meteorology and research of climate changes in a region (measurement of environmental values).

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***Authors**: MSc. Dalibor Igrec, E-mail: dalibor.igrec@margento.com; Phd. Amor Chowdhury, E-mail: amor.chowdhury@margento.com; both from Margento R&D d.o.o., Gospovsetska cesta 84, SI-2000 Maribor, Slovenia; Phd. Miralem Hadžiselimović, E-mail: miralem.h@uni-mb.si; Phd. Bojan Štumberger, E-mail: bojan.stumberger@uni-mb.si; both from University of Maribor, Faculty of Energy Technology, Hočevarjev trg 1, SI-8270 Krško, Slovenia.*