AC 2012-5175: DESIGN AND IMPLEMENTATION OF A 10 KW WIND POWER AND INSTRUMENTATION SYSTEM

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Design and Implementation of a 10 kW Wind Power and Instrumentation System

Abstract

Students and faculty at University of Northern Iowa established a 1.5kW grid connected wind-solar hybrid power station on campus in 2002. This older system has been used for teaching and research purposes besides the small amount of the green power generation on campus. There has been an increase on number of students and interest to renewable energy systems and related projects. This increase brought a demand to increase capacity and size of the solar-wind energy system and laboratory activities on renewable energy technology. In addition, the university administration has been supporting renewable energy projects on campus since initial system has been established. The capacity of existing solar-wind hybrid power system was increased and improved to 10kW system by the technology (electrical engineering technology, and manufacturing technology) students and faculty. This work was supported by the State of Iowa and University administration as part of renewable energy promotion in the state and university community.

This system was built mainly by the engineering technology students either as part of their class projects and voluntarily. In addition to amount of renewable energy generated, the system is also used as an educational and research demonstration module on smart grid, STEM education, and energy efficiency issues. Community members and students are scheduled to be invited to demonstrate the system. Especially local farmers showed interest to learn and established similar systems on their properties. A group of students are helping local community to do property audits to establish appropriate systems and give an idea to neighbors. Also a real-time data is available online of the system for the research and teaching purposes. It is goal of this project to save an estimated annual total of energy around 8 MWh. This estimated saving is calculated according to the local utility company rate charges. The outcomes of the project are a) power and economy b) environmental c) educational and community outreach, and d) research.

Introduction

Education and training of workforce of Iowa in renewable energy applications have become a significant factor. Although having technicians with AAS degrees in electromechanical and wind technology areas may address the wind industry's workforce needs in the short term, having a skilled technical workforce with a BS degree in EET with an emphasis on advanced wind power projects such as variable wind speed and frequency issues, turbine generator testing, troubleshooting, data acquisition, monitoring, and advances on grid-tie technologies, together with knowledge on liberal arts courses will foster more satisfactory and efficient citizens who can help advance the wind power development[1-7].

The main objective of this project was to design and build a 10 kW wind power station and associated wireless sensors and a graphical based monitoring instrumentation system to provide a teaching and research facility on renewable energy areas for students and faculty members in Electrical and Manufacturing Engineering Technology programs at the University of Northern Iowa. This project required to purchase a 10 kW Bergey Excel-S wind turbine with a Power Sink

II utility intertie module (208 V/240V AC, 60 Hz), and related power and instrumentation/data acquisition hardware with a major funding from Iowa Alliance for Wind Innovation and Novel Development (IAWIND.org). The electricity generated by this power station is used as a renewable energy input for a smart grid based greenhouse educational demonstration project to aid the teaching and research on wind power system development, wind turbine and tower selection, smart grid and energy efficiency issues[8-11]. The following classes use this proposed testbed as a laboratory/demonstration activities; Introduction to Electrical Power/Machinery, Advanced Electrical Power Systems, Wind Energy Applications, and Wind Energy Management. There are also workshops planned for the area STEM teachers as well as local farmers' education and training on wind power systems. Previous workshops organized by UNI Continuing and Distance Education have been very successful.

Project Purpose

The current 1.5 kW wind-solar hybrid power station at UNI campus that was built in 2002 is not sufficient due to growing student numbers, increasing interest on wind-solar projects, growing needs on more advanced laboratory activities on renewable energy systems, and emerging requirements of a larger testbed with grid inter-tie and smart grid features. In order to address the shortcomings of existing instructional techniques for electrical power systems, controls, wired/wireless instrumentation and data acquisition, a larger scale hybrid wind-solar power system with grid-tie features must be constructed in the Electrical Engineering Technology (EET) program at UNI. According to alumni and current student surveys, more EET professionals are interested in working in wind or wind-PV power systems. Education and training of workforce of Iowa in renewable energy applications have become a significant factor.

The system designed and implemented with the following goals:

- To be completely different from conventional electrical power labs and to be fresh and interesting using wired and wireless sensors providing communication among existing 1.5 kW wind/solar power system, the proposed 10 kW wind turbine system and the main computer that provides data acquisition and monitoring through wireless sensors, LabView software and NI FPGA data acquisition module.
- To be intimately related to real-world power issues such as power quality and ac/dc power interactions. Fluke power quality analyzer for handy use is available for AC voltage and current monitoring.
- To show a complex, interrelated system that is closer to the "real world" than the usual simple systems covered in educational labs.
- To motivate learning by introducing such elements as energy, environmental and economic concerns of practical interest to the students and workshop attendants on wind power systems.
- To promote wind energy technologies since the major source of electrical power in the wind/solar hybrid power system is from the wind.

Design and Construction Phases of the Wind Power System

The unit contains 10 kW Bergey Excel-S wind turbine installed on a 100 ft tower at UNI campus. It is connected and synchronized in parallel to the UNI power grid as part of laboratory activities on wind power systems and grid-tie interactions. The overall project block diagram is presented in Figure 1.

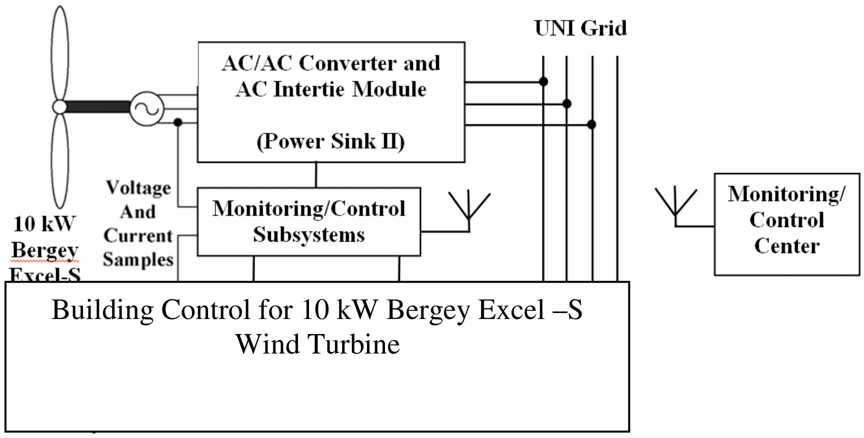


Figure 1. Proposed 10 kW wind power system at the University of Northern Iowa

The wind turbine was installed at the top of a new steel tower which has a height of approximately 100 ft. The wind turbine depicted is a 10 kW Bergey Excel-S with its grid-tie intertie module called “Power Sink II”. The instrumentation panel depicted monitors the outputs of the generator using digital panel meters.

A 10kW wind turbine was chosen for its low maintenance and many safety features. One of the low maintenance features is the turbine’s permanent magnet generator and an internal governor. The turbine generates 10 kW when turning at its rated speed of 13 m/s (29 mph). The turbine’s blades are made of three fiber glass blades that will intentionally deform as the turbine reaches its rated output. This deformation effect changes the shape of the blade, causing it to go into a stall mode, thus limiting the rotation speed of the alternator and preventing damage in high winds. Another feature of the wind turbine is a sophisticated internal regulator that periodically checks the line voltage and corrects for low voltage conditions. As widely known, one of the largest problems in systems containing power inverters is power quality. This problem becomes serious if the inverter used in the system does not have a good sinusoidal waveform output and causes problems such as harmonic contamination and poor voltage regulation. According to the IEEE (a professional society which codifies such issues) standards, a maximum of 3 to 4% total harmonic distortion (this is a quantitative measure of how bad the harmonic contamination is) may be allowed from inverter outputs. However, many inverter outputs may have much more harmonic distortion than what is allowed.

To monitor and store the voltage, current, power, and harmonic contamination data, two Fluke power quality analyzers (types 39 and 41) are used in the system. In addition, permanently mounted AC/DC digital panel meters form part of the system’s instrumentation. Figure 3 shows functional block diagram of the existing 1.5 kW wind-PV hybrid power system that the proposed new system will also interact. A major difference between the existing wind-PV system shown in Figure 2 and the proposed system shown in Figure 1 is much larger wind power output, using wireless sensors, and wireless communication among wind turbines, and the main computer.

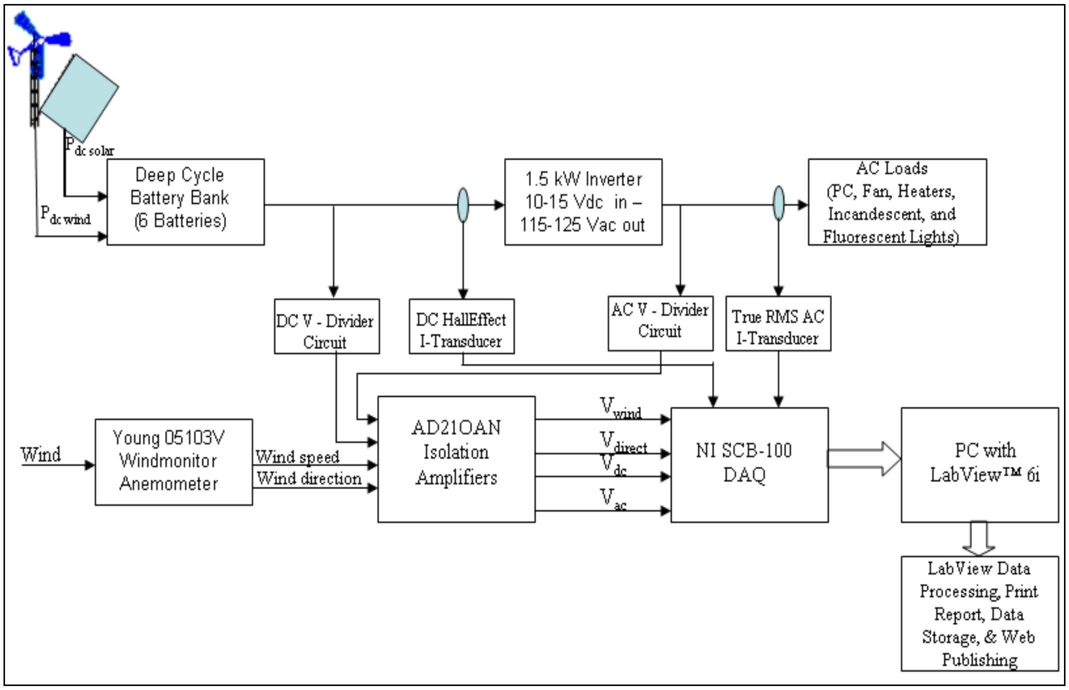


Figure 2. Instrumentation and Data Acquisition Functional Block Diagram.

Initial Study on Wind Power Capacity

Using Iowa Energy Center's wind assessment study[12-13], the following table is obtained to provide information on average wind speed and estimated annual energy output (kWh). An estimated energy amount of 18, 835 kWh wind power is expected to be harnessed as shown in Table 1.

The following lab activities are planned to be completed.

- Power Curve Determination of 10 kW Bergey Excel-S.
- Annual Ave energy production using the data from anemometer
- Transient phenomena due to sudden load changes
- Voltage, current, power (V, I, P)measurements at both DC and AC buses
- V, I, P transients due to sudden load changes at AC power grid
- Overall System Efficiency Measurement and Monitoring
- Vibration Monitoring using NI9234 Sensor Module that includes monitor vibrations on the turbine structure at the base and on the nacelle.
- Yearly Wind Speed, Direction, Temperature Monitoring and Data Storage
- Strain monitoring, a common technique for determining structural health since this information is becoming increasingly more important in the wind turbine industry.
- Wind turbine noise impact measurements using NI sound and vibration analysis software. This data is commonly used to ensure that the wind system complies with standards such as IEC 61400-11:2002.

- Temperature measurement to be used for preventive and predictive maintenance.
- Power quality monitoring: It can degrade as a result of wind speed, turbulence, and switching events. This will include monitoring peak power output, reactive power, voltage fluctuations, and harmonics.
- AC/DC Power system interactions due to sudden source and load changes.
- Temperature changes impact to overall system efficiency.
- Wireless sensors networks impact to overall system response during source and load fluctuations as well as sudden wind changes. Any new control schemes as advanced senior (capstone) design projects to be developed to monitor and control frequency and voltage of the AC grid.

Table 1. Estimated energy output from a 10 kW Bergey Excel-S Wind Turbine at City: Cedar Falls Turbine**:** Bergey Excel; 10 kW Loss Factor **(%):** 12 Tower Height: 100 feet

Period	Average Speed (mph)	Air Density *	Average Wind Power Density (W/m2)	Capacity Factor (%)	Estimated Output for Period (kWh)
Annual	13.50	1.233	229	21.65	18,835
Jan	14.62	1.291	278	26.45	1,867
Feb	14.35	1.286	276	25.65	1,642
Mar	15.00	1.252	295	27.27	1,985
Apr	15.16	1.222	316	27.45	1,981
May	13.58	1.193	223	21.15	1,616
Jun	12.63	1.174	175	17.39	1,306
Jul	11.51	1.163	124	12.97	1,017
Aug	11.13	1.168	110	11.63	907
Sep	12.07	1.182	144	14.99	1,119
Oct	13.21	1.216	192	19.45	1,458
Nov	14.14	1.252	268	24.40	1,718
Dec	14.31	1.285	275	25.49	1,808

The objectives of a typical wind power education in a Baccalaureate degree program should include basic mathematics, physics, statistical analysis, computer programming, electrical circuits, analog devices, digital electronics, conventional and renewable energy fundamentals, electrical machines, power electronics, programmable logic controllers (PLCs), electro mechanics, measurement and protection fundamentals, power transmission lines, power system interactions, and instrumentation/interface using wired/wireless sensors and networks[14-15]. This proposed wind testbed will foster an excellent learning experience for the undergraduate and graduate students. The Electrical Engineering Technology (EET) program at UNI is Iowa's first and only state institution offering a BS degree in the EET area. Almost 40 % of our incoming students are transferred from Iowa community colleges with AAS degrees in the EET and similar areas. The program was recently reviewed for an ABET-TAC accreditation and the findings from the ABET visiting team are very promising. One of the reported observations for the program was students' exposure to hands-on renewable energy curriculum and applications in wind power areas[16]. The proposed testbed will strengthen Iowa's efforts on renewable energy education and will provide a major resource for the workshops to be arranged for area STEM teachers and local farmers. One STEM workshop organized by the PI in 2008 for promoting Math/ Science education by using limited renewable energy equipment was very successful, and 20 area teachers completed the workshop in Fall 2008 followed by school visits and real-time project demonstrations in Spring 2009 [17].

Project Implementation

Students from electrical engineering technology, manufacturing technology, and metallurgy were involved in this project from beginning to completion on both undergraduate and graduate levels. Pictures of different level of construction and installation process are shown in Figures 4-6.

Figure 3. Wind turbine (WT) foundation construction with e-bars and grounding equipment.

Figure 4. 100 ft long tower is installed and 10 kW Bergey WT is being installed on the tower.

Figure 5. WT blades are strengthened and checked.

Figure 6. 100 ft wind tower and 10 kW Bergey WT are finally installed and operating.

Outcomes and Student Involvement

Summary, student involvement and outcomes of the project are given as follows:

- Power and Economy outcomes:
  • The 10 kW wind turbine project saved an estimated annual total energy of 7 MWh between January 2011 and January 2012.
  • Economy savings are estimated according to Cedar Falls Utility rate charge
  • 7 MWh x \$0.1/kWh ≈ \$700 per year

- Environmental outcomes:
  • The proposed project will help in reducing CO_2 emissions at a rate of 1.416 lbs per kWh:
  • 7 MWh x 1.416 pounds/kWh = 9,912 lbs CO_2 emissions saved at UNI campus

- Educational Outcomes and Community Outreach:
  • Providing a hands-on and a remote laboratory application through a dynamic website.
  • Generating several lab activities in solar-wind technology that will be used in educational and research purposes.
  • Promoting wind and solar energy for middle and high school students.
  • Promoting Science Technology Engineering Mathematics (STEM) Education at UNI
  • Five undergraduate EET senior students worked in the project for about one academic year including one additional summer semester. Their varying responsibilities were included in the areas of electrical, mechanical, and instrumentation for the successful completion of three separate senior design projects in the EET program.

Using the 10 kW Wind Power System in the Wind Energy Engineering Class at UNI

A new senior and graduate level class titled "Wind Energy Engineering" is developed to help Iowa's demand on future wind energy technical workforce at UNI. The class includes an understanding of wind energy with respect to environmental, economic, technical, and political issues. It also promotes the value of increased use of wind energy and related research, development, and manufacturing for Iowa's energy independence efforts. The class web site is open to other educational institutions at the following Google site.
https://sites.google.com/a/uni.edu/windpower/

This new wind power system has been facilitated as a laboratory tool in the class. The student interest and involvement have been very positive. Students can analyze the wind and power monitoring data from their own home computers by accessing the wind turbine output in real-time. Figure 7 shows interface of the real-time data monitoring through web site. A basic wind power equation is given as follows[18]:

$$P=1/2\rho Av^3 \qquad \text{(Eq. 1)}$$

where P is the electrical power (W), ρ is the air density (kg/m^3), A is wind swept area (m^2), and v is the wind velocity in (m/s). For example, a wind turbine with a radius of 2 m, giving a swept area of $A=12.6m^2$, would have approximately 100 kW of wind power across that area due to a 25 m/s wind speed. Students can observe that a maximum theoretical efficiency for wind turbine would be 59% [19].

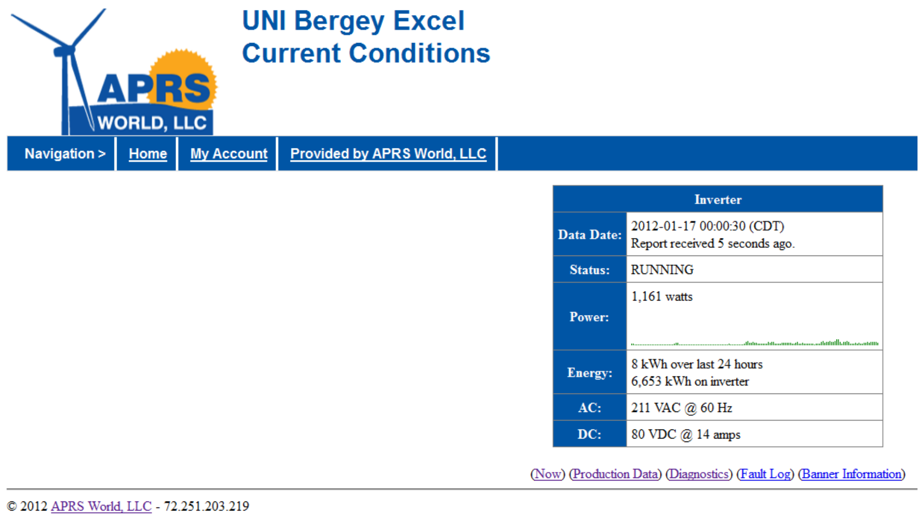
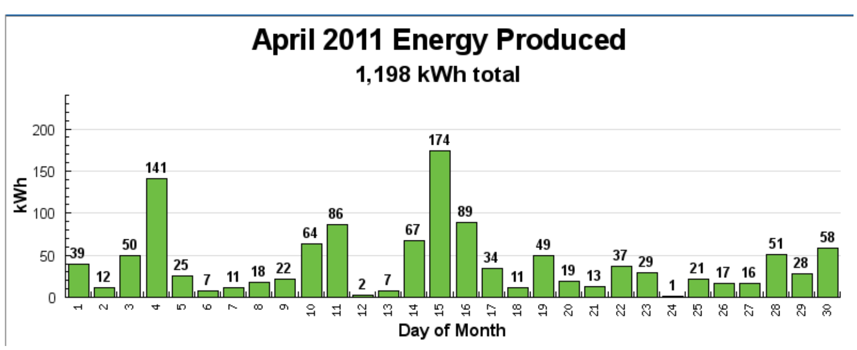
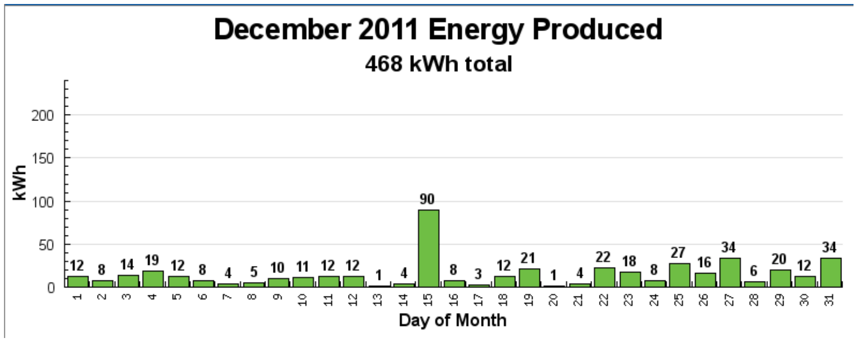


Figure 7.Real-time data monitoring of the 10 kW wind power system.
http://data.aprsworld.com/data/ps2/current.php?station_id=A2671

Conclusion

A complete 10 kW wind power and instrumentation/data acquisition system was completed and synchronized with the AC power grid with a number of graduate and undergraduate students involvement. The wireless sensors collecting data on wind, temperature, vibration, sound, voltage, current, power, load changes at both wind and solar power systems is communicating with NI data acquisition hardware and the main computer. A graphical based instrumentation and data acquisition system is also providing data to a dynamic web site in real-time. This provides a remote access to the wind power system by all permitted institutions requesting real-time data.





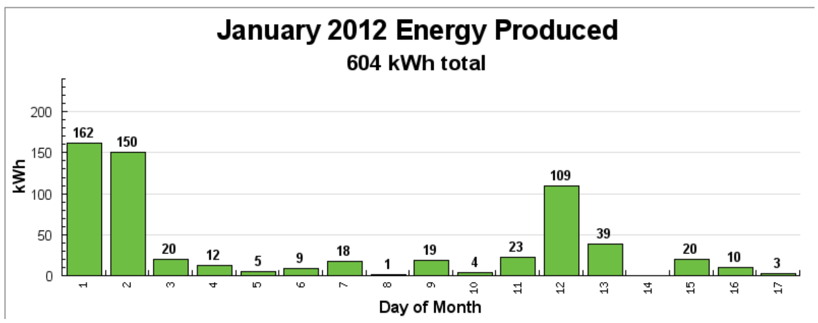


Figure 8. Wind power generation in selected three months.

In addition to curriculum development in courses Introduction to Electrical Power/Machinery, Advanced Electrical Power Systems, Wind Energy Engineering, and Wind Power Applications, there are also workshops planned for the Cedar Valley area STEM teachers and local farmers interested in establishing small-scale wind power systems in the area. The proposed equipment is part of a program initiative to improve our laboratory facilities to better reflect on the current and future renewable energy technologies. The proposed testbed allows students to be educated and trained in the utilization of real-time electrical power systems and additionally will allow them to gain valuable “hand-on” experience in setting up a real-time data acquisition system specifically in grid-tied wind power systems. In terms of student learning and satisfaction, the project was a success. With the increasing importance of renewable energy resources in present and future energy scenarios, an ability to design and analyze renewable energy systems becomes essential for engineering and technology educators and students. All students in the project showed improvement in learning and understanding concepts about renewable energy sources by complementing a theory-based lecture with hands-on experiments.

Acknowledgments

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Russett, unfortunately passed away after few months of his graduation and his passion and honorable memory in the project will be always remembered in peace and appreciation.

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