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A LabView Based Instrumentation System for a Wind-Solar Hybrid Power Station

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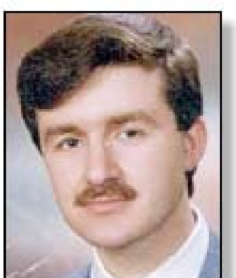

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A LabView Based Instrumentation System for a Wind-Solar Hybrid Power Station

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Abstract
Renewable energy technologies range from the well established, such as hydropower, to the emergent, such as a wind-solar hybrid system. Each technology has its own individual instrumentation requirements to measure and control system variables. National Instrument's LabView™ data acquisition hardware and software module has become one of the most widely used tools to capture, view, and process controls, instrumentation, and power system data both in academia and the industry (Franz, 2003, and Travis, 2002). This paper describes a LabView™based real time data acquisition and instrumentation of a 1.5 kW wind-solar hybrid renewable energy system. The wind-solar power generation station is used as an instructional resource for teaching renewable energy concepts to Industrial Technology students at the University of Northern Iowa (UNI). The addition of the new LabView™module to the system provides the much needed real time information on the system variables, such as wind speed, wind direction, dc power, ac power, ac/dc voltages and currents. This real-time data acquisition system is being used extensively to provide the students a hands-on laboratory experience related to electrical, electronics, and instrumentation. In this paper, discussions on many aspects of data acquisition, instrumentation, interfacing, and programming are based on an existing 1.5 kW wind-solar hybrid power station at the University of Northern Iowa.

Introduction
At the simplest level, data acquisition can be accomplished manually using paper and pencil, recording readings from a multimeter or any other instrument. For some applications this form of data acquisition may be adequate. However, data recording applications that require large number of data readings where very frequent recordings are necessary must include instruments or microcontrollers to acquire and record data precisely (Rigby and Dalby, 1995). *Lab*oratory *V*irtual *I*nstrument Engineering *W*orkbench (LabView™) is a powerful and flexible instrumentation and analysis software application tool which was developed in 1986 by the National Instruments (National Instruments, 2002). LabView™ has become a vital tool in today's emerging technologies and widely adopted throughout academia, industry, and government laboratories as the standard for data acquisition, instrument control and analysis software.

An existing 1.5 kW rated wind-solar hybrid power station is shown in Figure 1. The design and construction of the renewable energy based power system was reported earlier (Pecen, et al., 2000). The existing wind-solar testbed at UNI campus has been an excellent educational opportunity for undergraduate and graduate students to study complex interactions in the electrical power grid between conventional coal-fired power plants and wind-solar based power stations. Particularly some components in the renewable energy plants such as batteries and dc-to-ac power inverters can lead to power quality and grid stability problems when wind-solar power systems are tied to fossil-fuel based turbine and generators (Patel, 1999). These interactions are mostly due to the vast dynamics differences involved in wind turbines and steam turbines. Figure 1 shows four Photovoltaic (PV) solar panels with a power rating of 120 W for each, one mast-mounted wind turbine with 1 kW, and an anemometer that includes a wind direction and a speed sensor. The hybrid wind-solar power station operates in parallel, and charges a 12 V battery bank which includes six deep cycle lead acid batteries. The solar panels are installed on a frame which tracks the sun light during the day from an initial position of 0 degree to 320 degree. The system also includes a 1.5 kVA rated dc-to-ac power inverter based on solid-state devices, protection equipment such as ac and dc circuit breakers, fuses, surge arrester, a set of linear and non-linear loads, connecting cables, and junction boxes. Students are introduced to the studies of steady state voltage and currents in the system, illustrating power quality problems due to small linear and nonlinear load effects (Pecen and Timmerman, 1999). The wind-solar hybrid power station has been used as part of the undergraduate electrical power and machinery laboratory content as well as a demonstration unit for visiting high school and community college students (Pecen, et al., 2003).

Although the power system and renewable energy content of the project have helped in teaching real-world applications of the renewable energy, the lack of computer aided instrumentation and data acquisition modules prevented us from developing a state-of-the-art data monitoring and processing system in 1999. This paper will focus mainly on recently completed LabView™based data acquisition module for monitoring and processing the following system state variables: dc voltage, dc current, ac voltage, ac current, wind speed, wind direction, dc power, and ac power from the existing wind-solar power station.

The instrumentation system provides students with an opportunity to gain practical experience on National Instruments (NI) data acquisition hardware, and the LabView™ Version 6i software for the real-time monitoring of dc voltage, dc current, wind speed, wind direction, dc and ac power waveforms. Other most useful benefits of the project include the students' ability to interface devices such as voltage and current sensors on both ac and dc sides, and the use of isolation amplifiers between sensor outputs and computer inputs. The developed system has not only been used for data acquisition and instrument control applications, but also for general purpose applications such as database development, data analysis programs, and network communications. For example, the computer executing the real-time virtual instrumentation of the wind-solar power system is networked to the university server, and can be accessed by any remote computer on campus through the network for real-time monitoring purposes.

An alumni survey covering last 15 year of graduates was completed in summer 2001 in the Department of Industrial Technology at UNI. The survey instrument was sent to 120 alumni who are involved in electromechanical/electronic systems of their respective companies. The completed survey data was obtained from 70 (58.33% of the targeted group) and 58 (82.86% of total respondents) of them indicated that employers prefer hiring of graduates with a working knowledge of analog or digital data acquisition, analysis and interpretation. They have also indicated that an ability to formulate a range of alternative problem solutions, and computer literacy specific to electromechanical and electronic systems is a plus. Survey instrument is not included in this paper. Industrial advisory board members of the Industrial Technology Department during the academic year of 2002-2003 have also indicated the necessity of data acquisition skills for their prospective employees. Thus, this LabView™ instrumentation system will help the students to develop skills in data acquisition, and analysis.

Literature Review

The literature on fundamentals and applications of data acquisition, instrumentation, and control to engineering and technology is very extensive. Today in any type of computer aided manufacturing project work and laboratory tests, precision and reliability of instrumentation and data acquisition techniques may cause major impacts on results and outcomes. Therefore, students in technology programs must gain knowledge and skills pertinent to their curriculum and job requirements when they need to obtain any type of physical or virtual data on manufacturing, testing, measurement, and protection areas. An overview and importance of data acquisition and automation in general are listed well in the literature (Curtis, 2003, and Wolf, Smith, 1990). An excellent book for instructional use is "Learning with LabView™" by Bishop (2001) that covers the basics, rational, virtual instruments, programming, data acquisition, control, and applications appropriate for Industrial Technology students. Every academic year, National Instrument Inc. provides a

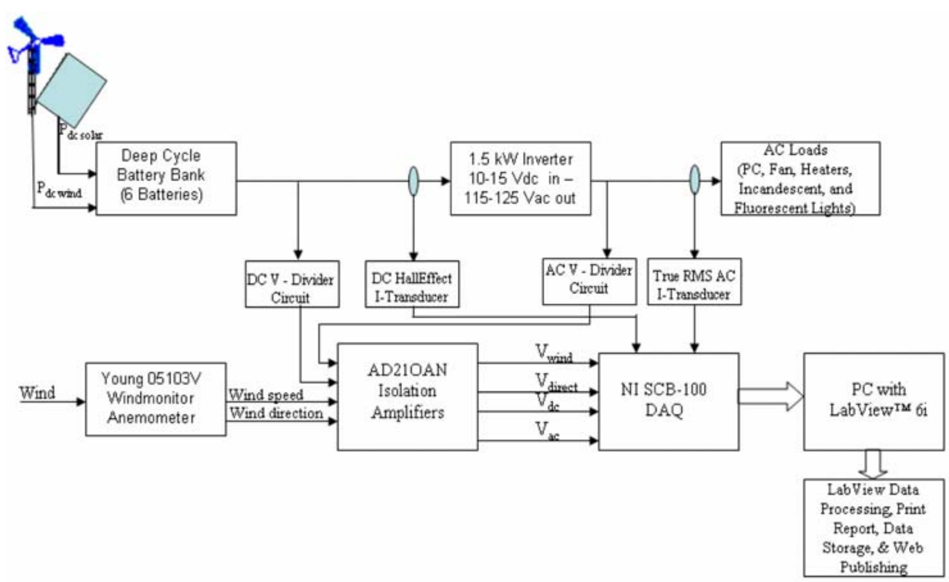
Figure 1. Existing1.5 kW Wind-Solar hybrid power generation unit.

number of updated academic resources such as courseware, academic applications, reference books, product information, and worldwide resources (National Instruments, 2003). According to National Instruments and many researchers in Data Acquisition area, LabView™is revolutionizing industry and dramatically affecting traditional academic research and teaching. A LabView™based laboratory makes researchers more productive and enhances the learning experience (Franz, 2003). Rather than focusing on time consuming methods of gathering data, educators and students can focus on results and concepts (National Instruments, 2003). Another book entitled "LabView for Everyone 2nd Edition" by Travis (2002) covers also fundamentals to advanced levels of LabView Environment, and interfacing the computer to the real world using LabView in general technology and engineering students. "LabView for Electric Circuits, machines, Drives, and Laboratories" by Ertugrul (2002) includes excellent information on hardware and software applications in the area of energy and power technology students. Most of the LabView Virtual Instruments called as Virtual Instrument (VI) block diagrams and front panel information covered in Ertugrul's book are also available free for academia through the National Instruments. Many articles have appeared on the applications of LabView™in a variety of industrial setups. The Worldwide Conference on Measurement and Automation lists all the LabView papers for researchers covering automation, control, and instrumentation as NIWeeks (1998). A few studies included data acquisition and monitoring of environmental data management systems. Sun, et al. (2002) reported a study on environmental data management system also covering wind speed and direction. Kostic (1997) has described a data acquisition and control using LabView for an innovative thermal conductivity apparatus. Hennessey, et al. (2001) have developed a LabView™ and Proportional-Integral-Differential (PID) based automatic control system to monitor pressure measurement and converting it to a wind tunnel speed and making appropriate updates to the wind tunnel speed via a general purpose interface bus (GPIB) card. Kiritsis, et al. (2003) developed a multi-purpose vibration experiment using LabView. Higa, et al. (2002) published introductory LabView™laboratory projects for undergraduate students in circuits and electronics classes. Arthur and Sexton (2002) developed steam power plant, and a cooling tower experiments and their corresponding computer aided instrumentation using LabView™ The graphical simulation of actual systems in real-time provided an excellent opportunity to student learning. Sun, Turner, Parten, and Maxwell (2002) developed virtual instrumentation of a fuel-cell electrical vehicle which included monitoring of pressure, Hydrogen, Oxygen, water, conductivity, battery voltage levels, humidity, temperature levels for fuel-cell, water tank, and air stack.

Computer Aided Instrumentation and Interface of the Wind-Solar Power System

The objective is to transform the six experimental variables: DC voltage, DC current, AC voltage, AC current, wind speed, and wind direction into a form readable by the computer, display and store the results in real-time. The DC power and AC power need to be calculated and monitored through the other predetermined variables using LabView's programming capabilities. The signal conditioning hardware to condition and isolate the voltage and wind information signals before being connected to the DAQ board will play a significant role in the virtual instrumentation of the overall system. The instrumentation phase of the wind-solar power station includes the following hardware: One CR4110-10 True RMS AC Current Transducer and one CR5210-50 DC Hall-Effect Current Transducer from CR Magnetics, voltage and current divider and scaling circuits, one wind monitoring device called anemometer, a LabView 6i Professional Development System for Windows NT/98, one PCI-6071E I/O Board, one NI-DAQ Driver Software, one SH 100100 Shielded Cable, SCSI-II Connectors, one SCB-100 Shielded Connector Block, one isolation amplifier circuit, and a PC. A DMM and an oscilloscope to check the analog signals would also be very useful. Figure 2 illustrates a block diagram of the overall instrumentation system. DC voltage generated by four solar panels and one wind generator is applied to the battery bank.

Figure 2. Functional block diagram of the overall instrumentation system.



A Young 05103V Anemometer provides two voltage signals corresponding to wind speed and wind direction values. These wind signals are fed to AD21OAN Isolation Amplifiers and the output is applied to National Instrument's SCB-100 Data Acquisition Board (DAQ). Two voltage signals, one from battery output and one from inverter output are also applied to isolation amplifiers through their corresponding voltage divider-scaling circuits. Two current signals, one from battery output through a DC Hall-Effect current transducer, and the other from inverter output through one true rms AC current transducer are fed directly to the DAQ board. The CR 5210-50 DC Hall-effect current transducer may provide 0-5.0 V DC for an input current of 0-50 A DC. Similarly, the CR 4110-10 AC current transducer may provide a signal of 0-5 V DC for an input current of 0-10 A AC. Figure 3 depicts the inverter and AC load bank which includes a Pentium III computer, a variety of energy efficient fluorescent lights, several incandescent lights, one electrical heater, and a fan. The total power rating of the AC loads is about 1400 W. The instrumentation system basically uses a computer whose power is supplied by wind and solar hybrid system.

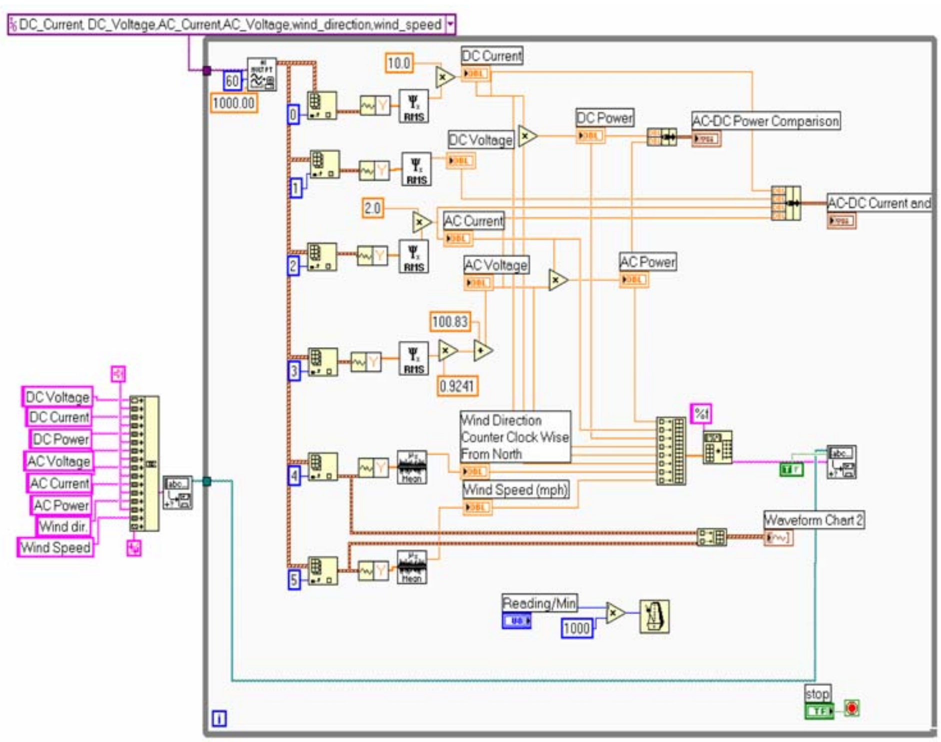
Figure 4. depicts a CR4110-10 true RMS AC current transducer connected to inverter output just before the AC load bank. A circuit for voltage divider and scaling purposes is also shown in Figure 4. Similarly a CR5210-50 DC Hall-Effect current transducer is shown in Figure 2 between the battery bank output and the inverter input.

Figure 5 depicts the Virtual Instrument (VI) block diagram where the source code for the specific VI for this work is developed. The VI block diagrams include data processing modules, and predefined mathematical models such as adders, substructures, integrators, etc. used in a mixed modality platform. In the block diagram, there is a terminal for every object created in the front panel. The DC/AC voltage and current, wind speed, and wind direction need to be read in real-time. A channel number

Figure 3. AC/DC loads in the wind-solar power station and data acquisition to the computer.

Figure 4. AC voltage divider and true RMS current transducer.

Figure 5. Overall diagram of the data acquisition virtual instrument (VI).



is specified for each variable as shown in Figure 5. Since the reading levels are limited to 0-5 V, a scaling has to be done to display the signals on their original values in the LabView™ software.

To view the displayed waveforms in actual ranges, the preconditioned signals require appropriate calibration using the arithmetic and/or logic function futures available in LabView™ Figure 6 depicts the front panel of the data acquisition VI for the time period of 5:15 pm to 5:32 pm. As seen in Figure 7, the DC power has a value of 241.97 W while the AC power has a value of 238.65 W. The difference corresponds to losses through the inverter. The power generation and corresponding monitoring values increase up to 1500 W during full sun and/or wind conditions. The wind direction is shown as counter clock wise from north. An average wind speed of 5.2 mph was recorded during the time period of 6:25 pm to 6:26 pm. The number of readings per minute can be adjusted through the palette as shown in the front panel.

One of the advantages of LabView™ Data Acquisition is the ability to download the monitored data into the Microsoft Excel. This characteristic enables the lab activities very user friendly since students may easily download the logged data into their reports through the Excel. Figure 7 illustrates Excel plots of DC and AC power monitoring while Figure 8 illustrates the wind speed monitoring of the system for an approximate time period of 10 minutes. Students may download data to a floppy disk for later inclusion in their lab reports.

Cost Analysis of the Power and Instrumentation System

Table 1 illustrates detailed parts list and costs for the overall power system and its instrumentation excluding existing one PC and variety of other ac loads. UNI Department of Industrial Technology, College of Natural Sciences Annual student research grants (SOAR), and UNI Center for Environ-

Figure 6. Front panel of the data acquisition virtual instrument.

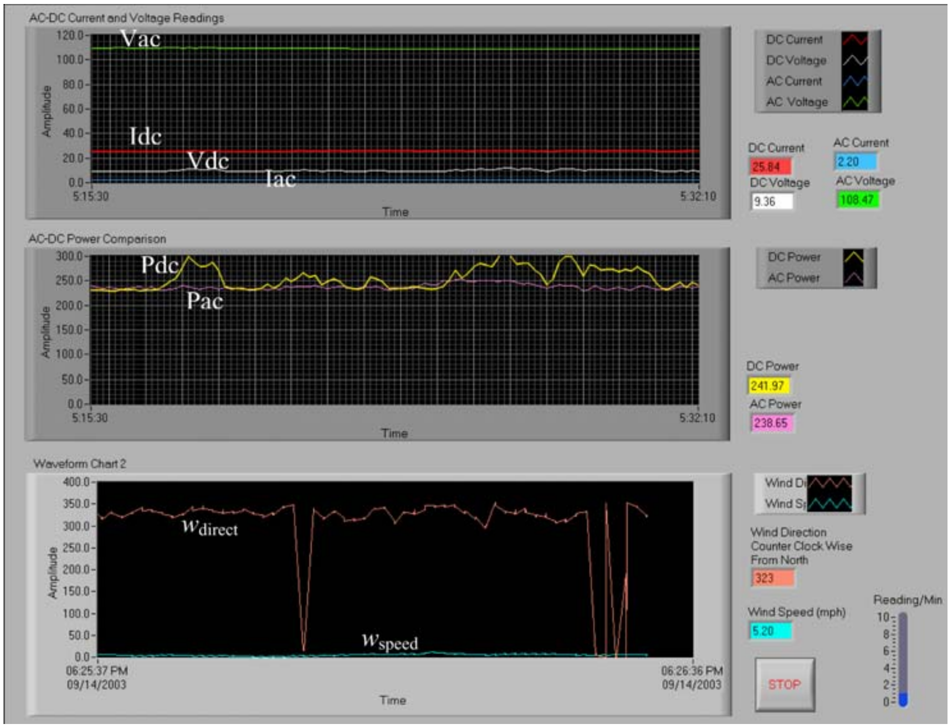


Figure 7. Pdc and Pac waveforms for a 10 min time period.

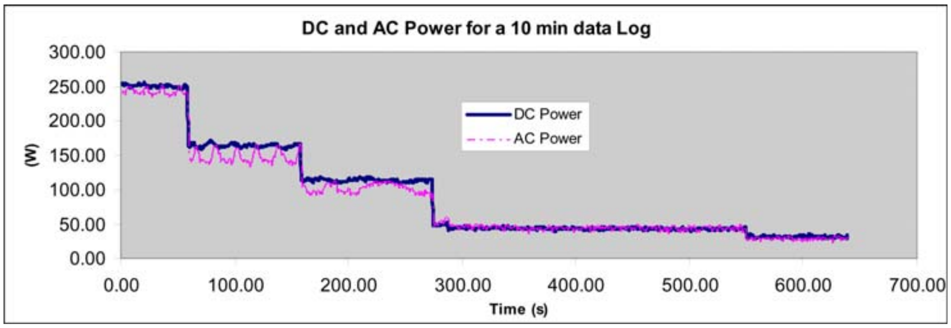
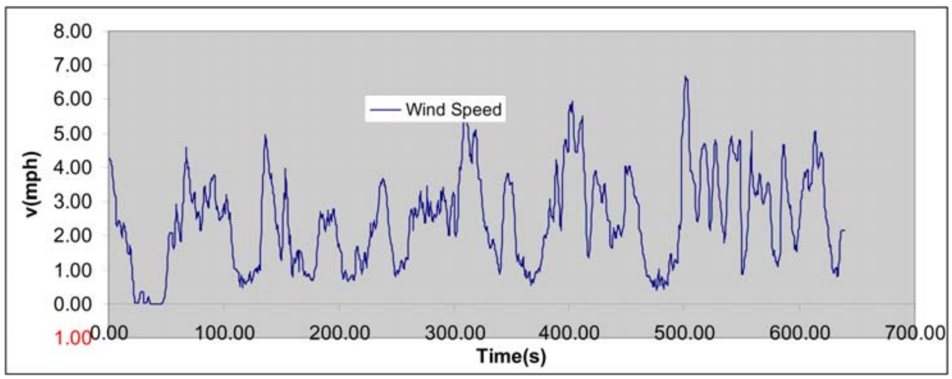


Figure 8. Wind speed w_{speed} (in mph) monitoring for a 10 min time period.



ment and Energy Education (CEEE) are sponsors of this project. The major cost of the instrumentation is the software for the LabView™ professional development system for Windows 98/NT as appears in Table 1. Addition of more stations to the system will only require LabView™Student Edition which costs $50 per copy. The additional costs would be approximately $395 for a PCI6025E DAQ board, and $70 for a SC68 connector board. LabView™ Student Edition delivers all of the graphical programming capabilities of the LabView 6i professional edition in a package that is even easier to use and learn. With the student edition, students can design graphical programming solutions for their classroom problems and laboratory experiments on their personal computers. The departmental site license for LabView™costs about $4,995 as of September 2003.

Conclusions and Future Directions of Work

Development of an instrumentation and data acquisition of a wind-solar hybrid power station is presented. LabView™based instrumentation has generated student interests both in traditional and renewable energy as observed in the classes and laboratories. Any experience in LabView™also prepares technology students for careers in the manufacturing industry where a number of similar graphical instrumentation tools have played a significant role in the data acquisition area. LabView™based instruction at UNI Industrial Technology Department has received very positive responses from its local industrial partners such as Deere and Company, Rockwell-Collins Inc., and Waterloo Industries. Also it provides an incredible opportunity for the research students to undertake practice-oriented real-world laboratory projects. Most importantly, it is a valuable asset to lab instruction, research, demonstration, and recruitment.

The authors conclude that although virtual instruments are steadily replacing their free-standing counterparts in the industrial and technology laboratories due to the rising costs of laboratory trainer and instruments, for many valid pedagogical reasons such as exposing students to conventional hardware instruments, many faculty members have been reluctant to *completely* abandon the real laboratory experiences where a number of hardware and connecting wires are used.

Future work of this instrumentation project will include: (1) monitoring solar array position, (2) recording outside temperature, and (3) visualizing windmill speed versus dc power output. This will enable the students to observe mathematical relationships among the solar tracking, wind speed, and the dc power output variables. Also several LabView-based data acquisition stations in the electrical power and electronics laboratories will be developed.

Acknowledgement

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References

Arthur, J.H., Sexton, M. R. (2002). LabView Application: Energy Laboratory Upgrade. Proceedings of the 2002 American Society for Engineering Education (ASEE) Annual Conference & Exposition, Session 3233.

Bishop, R. H. (2001). Learning with LabView 6i. Prentice Hall, Upper Saddle River, NJ.

Ertugrul N. (2002). LabView for Electric Circuits, Machines, Drives, and Laboratories. Prentice Hall PTR, Upper Saddle River, NJ.

Franz H. (2003). Use of LabView™Software for Virtual Instrumentation Technology. Proceedings of the 2003 American Society for Engineering Education (ASEE) Annual Conference & Exposition.

Hennessey, R., Loya, H., Diong B., Wicker R. (2001). Using LabView to develop an automated Control System. NI Instrumentation Newsletter, Special Academic Edition. [Available Online]. http://www.nemesis-online.it/newsletters/Academic% 20Newsletter%201%202001 .pdf

Higa, M.L., Tawy, D. M., Lord, S. M. (2002). An Introduction to LabView exercise for an Electronics Class. Proceedings of 32nd ASEE/IEEE Frontiers in Education Conference, Session T1D-13.

Johnson, C. D. (2003). Process Control Instrumentation Technology, 7th

Table 1. Cost Analysis for overall power and data acquisition system

Item	Price
Air 403 DC Wind Generator 12 V	$960
Solar Panels (4 Solid)	$1,800
80 ft Wind Tower - Schedule 40 Pipes	$350
Welding Assemblies	$180
Batteries & Cables	$180
CBs, Fuses, Switching Devices	$320
Junction Boxes, Conduit, Loads	$260
LabView Professional Dev System Windows NT/98	$2,200
PCI-6071 E I/O Board, NI-DAQ Driver Software	$1,795
SH 100100 Shielded Cable, SCSI-II Connectors	$135
SCB-100 Shielded Connector Block	$265
CR Current and Voltage Sensors	$310
Parts for Voltage Divider and Scaling Circuits	$130
Anemometer & Frame Assembly	$640
Solar Panel Frame with Tracking Mechanism	$450
DC to AC Inverter	$920
Miscellaneous	$450
Total	$11,345

Edition. Prentice Hall, Upper Saddle River, NJ.

Kiritsis N., Huang, Y. W. and Ayrapetyan, D. (2003). A Multi-Purpose Vibration Experiment Using LabView. Proceedings of the 2003 ASEE Annual Conference & Exposition. Session 1426.

Kostic, M. (1997). Data Acquisition and Control Using LabView™ Virtual Instrument for an Innovative Thermal Conductivity Apparatus. Proceedings of Virtual Instrumentation in Education 1997 Conference. June 12, 1997, pp. 131-136, MIT.

McDonald D., Mahajan A., (1998). Data Acquisition Systems: An Integral part of Undergraduate Engineering and Technology Programs. Proceedings of the 1998 American Society for Engineering Education (ASEE) Annual Conference & Exposition. Session 1559, 1998.

National Instruments Academic Resources, (2003). [Available online] ni.com/academic

National Instruments LabView Manual, (2002). National Instruments Corporate Headquarters, Austin, TX.

NIWeek Papers (1998). The World-wide Conference on Measurement and Automation. [Available online] http://iawww3.epfl.ch/NIWeek98/pages/labview.htm

Patel, M. R., (1999) Wind and Solar Power Systems. CRC Press, Boca Raton, FL.

Pecen, R., Salim MD and Timmerman M (2000), A Hybrid Solar-Wind Power Generation System as an Instructional resource for Industrial Technology Students. Journal of Industrial Technology, Volume 16, Number 3, May-July 2000.

Pecen, R. and Timmerman M., (1999, November). A novel power quality scheme to improve a utility interface in a small-sized hybrid solar/wind generation unit. 10th. International Power Quality Conference.

Pecen, R., Hall, T., Chalkiadakis F. and Zora, A. (2003). Renewable Energy Based Capstone Design Applications for an Undergraduate Engineering Technology Curriculum. Proceedings of 33rd ASEE/IEEE 2003 Frontiers in Education Conference, Session S1E on Multidisciplinary Approaches, Boulder, CO.

Rigby, W. H., Dalby, T. (1995). Computer Interfacing: A Practical Approach to Data Acquisition and Control. Prentice Hall, Englewood Cliffs, NJ.

Sun B., Turner W., Parten M. and Maxwell T. (2001). Instrumentation of a PEM Fuel Cell Vehicle. Proceedings of the 2002 ASEE Annual Conference & Exposition.

Sun, L., Lei S., Chen, Y., Hsieh, H. T. and Peper, D. (2002). Environmental Data Management System – From Data Monitoring, Acquisition, Presentation to Analysis. [Available Online] http://www.unlv.edu/Research_Centers/NCACM/HTML/ research/daq/publication_daq__pdcs2002.pdf

Travis, J. (2002). LabView for Everyone, 2nd Ed. Prentice Hall, Upper Saddle River, NJ.

Waterbury R., (1994). Software Trends Lead to Control Forefront. ISA Intech, Vol. 41, No. 6.

Wolf, S. and Smith, R. F. M. (1990). Student Reference Manual for Electronics Instrumentation Laboratories. Prentice Hall, Englewood Cliffs, NJ.