Data Acquisition in Photovoltaic Systems

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1. Introduction

During the last decades, human lifestyle and economic growth has had a profound effect on the energetic sector considerably changing the perspective on the energy issue (Ambros et al., 2004). The increasing energy demand and variable oil price, insecure energy resources and carbon dioxide emission have made us aware of the fact that energy is indeed a limited product (Awerbuch, 2002).
Regarding energy resources, the International Energy Agency estimates that oil resources will be over in 40 years, natural gas resources in 60 years and coil resources in 200 years. Renewable energy and coal are the fastest growing energy sources, with consumption increasing by 2.1 percent per year and 2.0 percent, respectively. A significant number of studies and scenarios have investigated the contribution of renewable energy to satisfy global needs in energy, indicating that during the first half of XXI century its contribution will increase from 20 to 50%.
Estimating the exploitable technical potential of renewable energy in Romania, it observed there is a high potential of our country, for the usage this type of renewable energy, and Romania's strategy in this area provides for 2012 a energy production of: 1860 MWh from photovoltaic (PV) sources, 314,000 MWh wind sources; 18,200,000 MWh hydroelectric sources and 1,134,000 MWh biomass. Total of 19,650,000 MWh should represent 30% of country`s electricity consumption (Vasile, 2009).
PV systems produce power in proportion to the intensity of sunlight striking the solar array surface. The intensity of light on a surface varies throughout a day, as well as day to day, so the actual output of a solar power system can vary substantialy. There are other factors that affect the output of a solar power system. These factors need to be understood so that the customer has realistic expectations of overall system output and economic benefits under variable environmental conditions over time. From this perspective, the development of photovoltaic systems is closely linked to development of measurement and monitoring techniques, built-in data acquisition systems.
Data acquisition systems (DAQ) can measure and store data collected from hundreds of channels simultaneously. The majority of systems contain from eight to 32 channels, typically in multiples of eight. An ideal data acquisition system uses a single ADC for each measurement channel. In this way, all data are captured in parallel and events in each channel can be compared in real time. But using a multiplexer that switches among the

inputs of multiple channels and drives a single ADC can substantially reduce the cost of a system (Szekely, 1997).
Specialized data acquisition systems for PV installations require a study of sample rates and an optimal configuration of the measuring chain. This chapter brings informations regarding the structure of data acquisition systems used in the monitoring of photovoltaic installations. It shows the operating principles of building blocks and the operation is performed by simulations using LabVIEW™ - Laboratory Virtual Instrumentation Engineering Workbench.
An important part of the presentation is dedicated to current measurement and data acquisition systems dedicated for monitoring PV systems. Applied solutions and experimental results are discussed in terms of accuracy and optimization needs of the operation.

2. PV system and data acquisition

The chapter presents the authors activity and results regarding the operation of a PV system and aspects on monitoring the electric energy supplied by a PV system built in University "Valahia" of Targoviste, Romania.

a) North view b) South view

Fig. 1. PV system

Part of the ICOP DEMO 4080-90 European research program, this PV system has been realized by the staff of the Electrical Engineering Faculty, Targoviste, Romania (Andrei et al., 2007).
The PV system integrated into the roof of the building has been designed using 66 Optisol SFM 72Bx glass roof integrated multi crystalline Si modules produced by Pilkington Solar and 24 ST40 thin film modules produced by Siemens which generates a total amount of 10 kWp. Position of panels on the southern front is shown in Figure 2. These modules can be serial or parallel connected. The dc voltage produced by the PV system is converted by the Sunny Boy inverters (SWR 700, SWR 1100, SWR 2000 and SWR 2500) and supplied directly into the public electricity system – Figure 3.
The use of a controller to monitor the operating parameters ensures the sine-wave form of the voltage and current, with a low amount of harmonics. The control of operations serves to totally automated functioning and to adjustement of the MPP (maximum power point).

The connection diagram of the PV system has been designed after a series of shading effects analyse and buiding placement restrictions (Dogaru Ulieru et al., 2009).

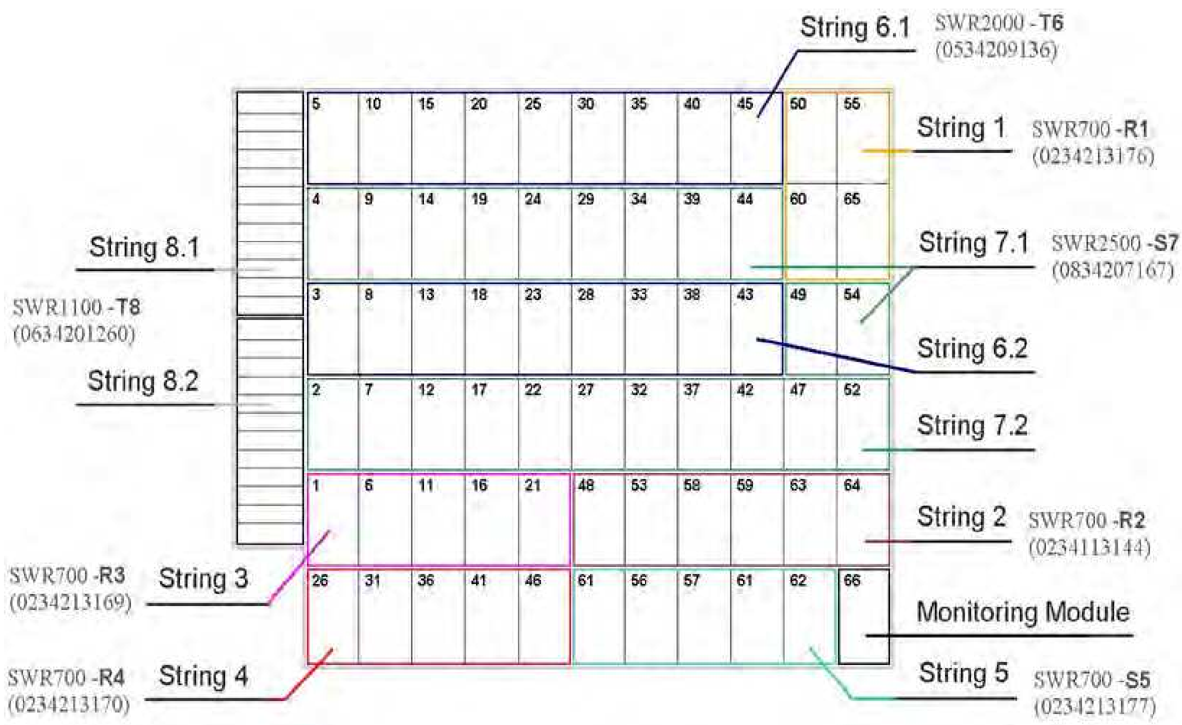


Fig. 2. Panel position

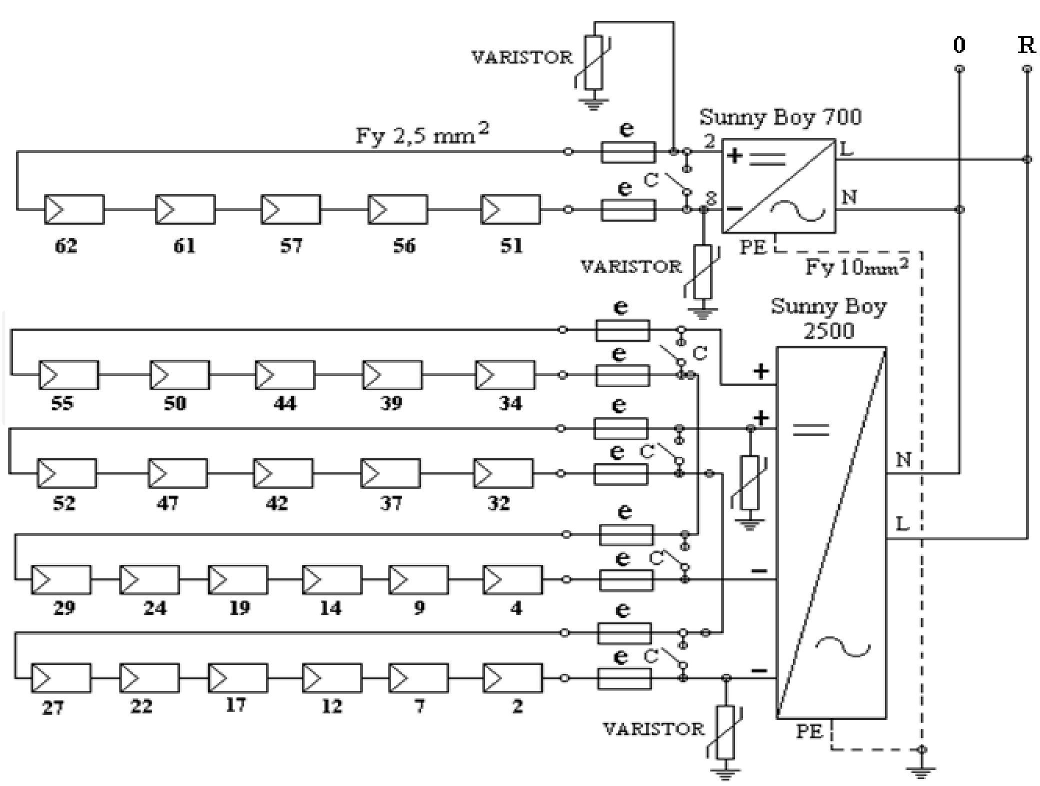


Fig. 3. Electric energy producing system using photovoltaic panels (phase A)

PV system monitoring was done by two methods:

- Sunny Data Control equipment – Figure 4 - automatically reads the selected measuring data from the memory of Sunny Boy Control and stores it on the PC. Sampling interval has been preset to 10 minutes (day and night).
- The data acquisition system - represented by an association between the hardware equipment (AT-MIO 16XE50 acquisition board, a signal conditioning device) and the application software (LabVIEW™) which implements the required functions, playing the part of an interface between the human operator and the measurement system .

To ensure the accuracy of the measurement, the operating parameters of the PV system and the configuration of the acquisition system are taken into account and have imposed the signal conditioning and the setting of the signal source, of the field and of the channels. Analog inputs can be differently configured, with a voltage level of ±2.5V, ±5V, ±10V (bipolar/single polar) which can be selected through the configuration program of the acquisition board. The block diagram of the acquisition system is presented in Figure 5. Figure 6 shows the LabVIEW™ block diagram of the virtual instrument attached to the data acquisition system (Cepisca et al., 2004).

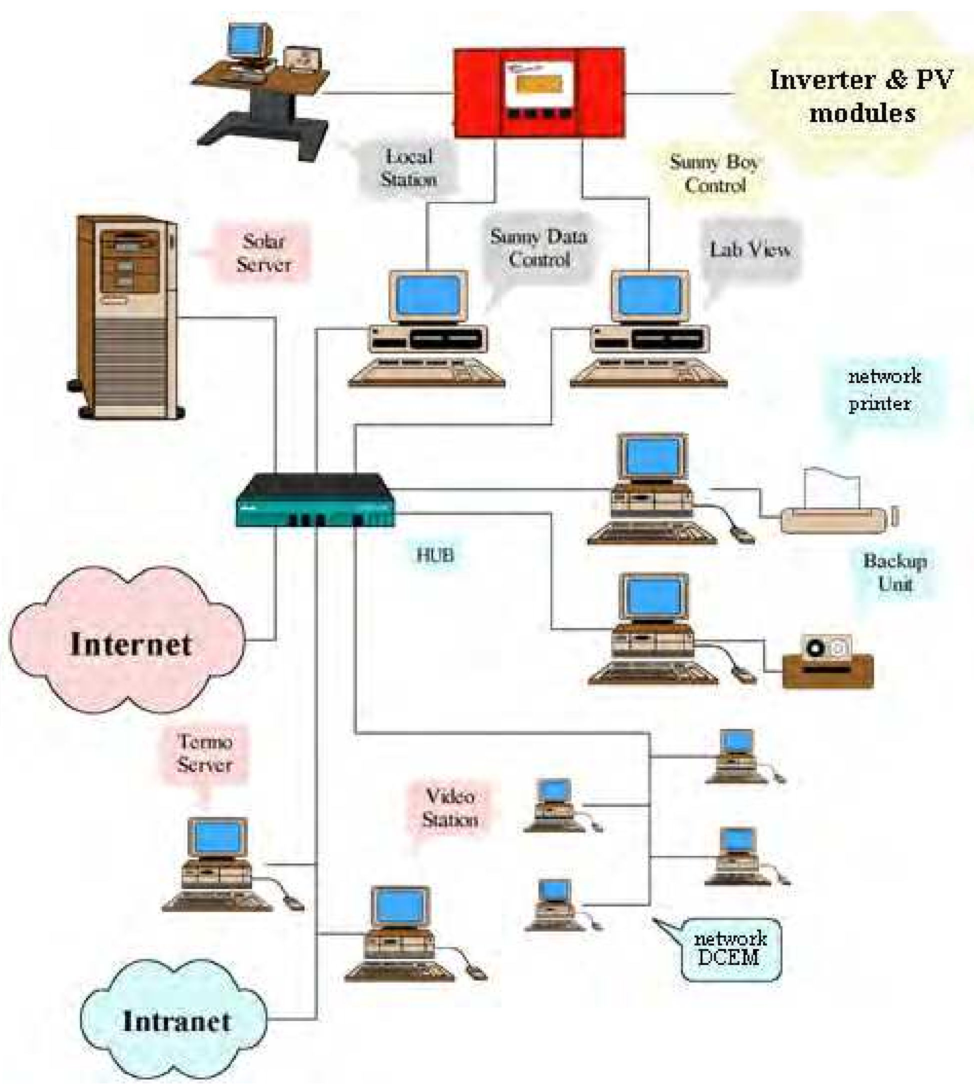


Fig. 4. Monitoring system Sunny

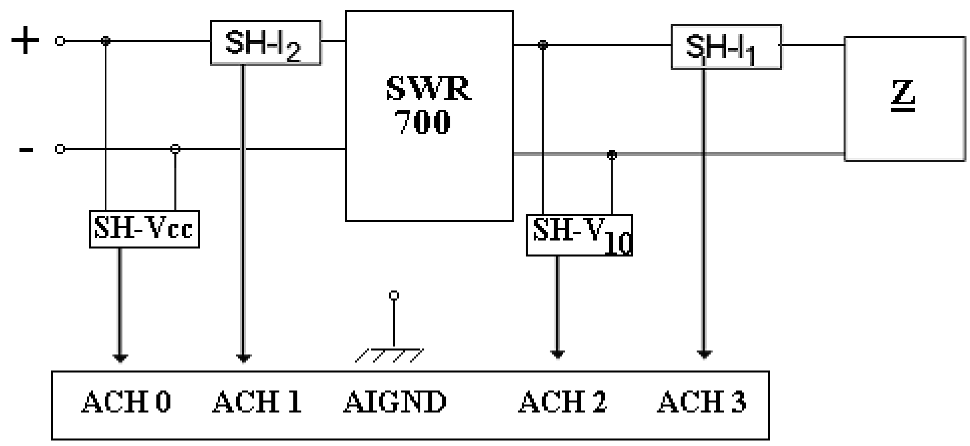


Fig. 5. DAQ Block diagram

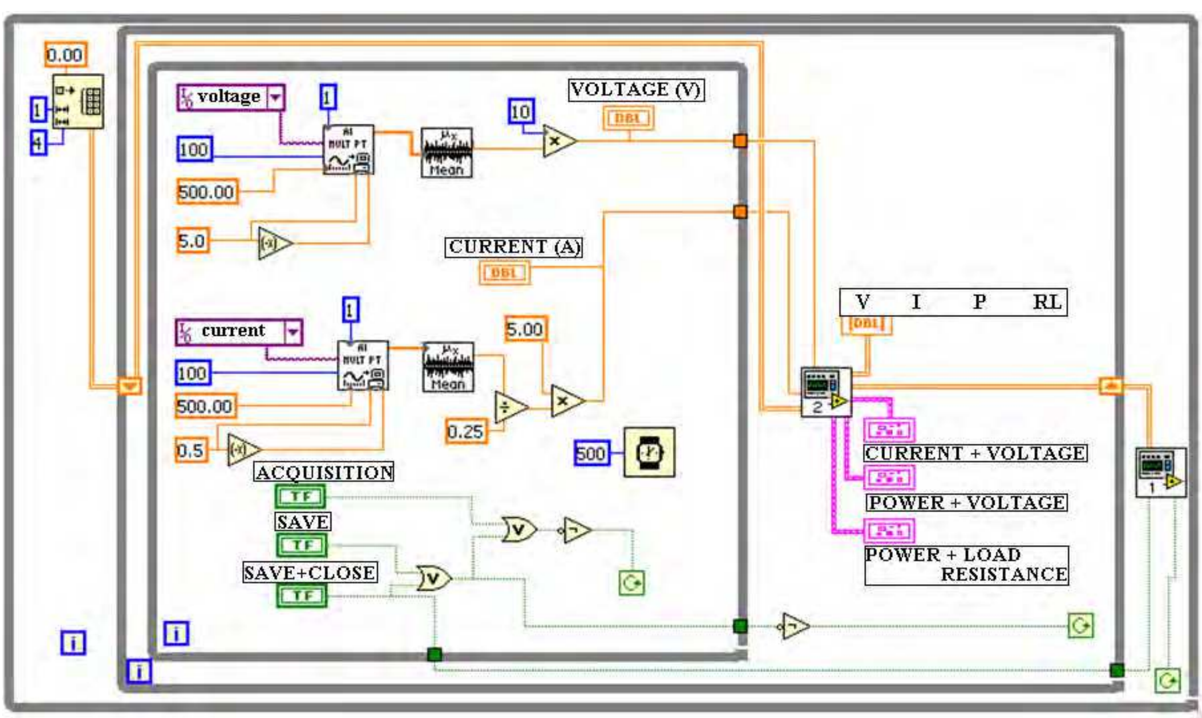


Fig. 6. LabVIEW™ block diagram

3. General principles of data acquisition systems

Data acquisition systems are products and/or processes used to collect informations that can be processed or stored by a computer to document or analyze some phenomenon (Judd, 2008). Measurement systems are used in the data acquisition industry since 1981 and have supplied several million data acquisition channels on an international basis.

Data acquisition systems come in many different PC technology forms to offer flexibility when choosing a measurement system. The organization of information flow in the system is an important problem in designing and operating the measurement. Two aspects are essential for this organization: the kind of transmission in the system (serial, bit-by bit, parallel) and the mode of information exchange between system devices (Nawrocki, 2005).

The functional components of a basic data acquisition are:
- Transducers and sensors;
- Conditioners or circuits standardizing the level of transducer signal to the range of the input voltage of the analog-to digital converter (ADC);
- Analog-to digital converters (ADCs) to convert analog into digital signals;
- Devices for visual display of measurement results (display of digital measurement instruments, oscilloscopes or a computer monitor);
- Computer with dedicated software and memory resources.

More complicated data acquisition systems can be constructed in the hierarchical structure. On the lowest level are subsystems to collect data from physical quantities. The main controller of the system receives processed measuring data and sends commands relating to the execution of a measuring procedure or a set of commands to subsystems.
Analog-to-Digital (A/D) conversion of an analog signal involves two processes:

- Sampling – after this operation signal is represented by a set of values $\{x(kT_s)\}$, drawn at time periods T_s – Figure 7. Sampling frequency should be high enough to provide a number of samples sufficient to reproduce the signal in the analog form. According to the Shannon theorem, the sampling frequency f_s should not be lower than twice the upper frequency f_u of the sampled signal spectrum:

$$f_s > 2 f_u \tag{1}$$

Otherwice, the reproduction of the discrete signal recorded yields a distorted analog signal, caused by a too low sampling frequency, phenomenon called aliasing. In order to eliminate aliasing, is utilised a lowpass input filter or an antialiasing filter.

- Quantizing: assigning to every sample a value from a set of N values into which the measurement range is divided. Figure 8 shows a LabVIEW™ application for the quantizing of voltage into an n=3 bit digital signal, the number of quants is 2^3=8.

The A/D converter is connected to an analog input signal; it measures the analog input and then provides the measurement in digital form suitable for use by a computer. The resolution of an A/D input channel describes the number or range of different possible measurements the system is capable of providing. This specification is almost universally provided in term of "bits". For example, 8-bit resolution corresponds to a resolution of one part in 2^8 – 1 or 255, 12-bit corresponds to one part in 2^{16} -1 or 65,536. To determine the resolution in engineering units, simply divide the range of the input by the resolution. A16-bit input with a 0-10 Volt input range provides 10 V / 2^{16} or 152.6 microvolts. Table 1 provides a comparison of the resolutions for the most commonly used converters in data acquisition systems.

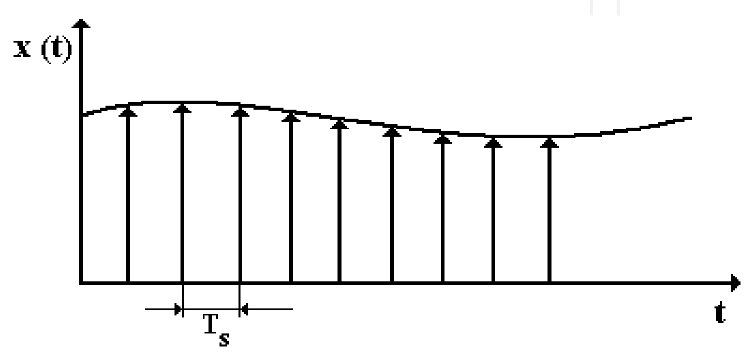


Fig. 7. Signal sampling

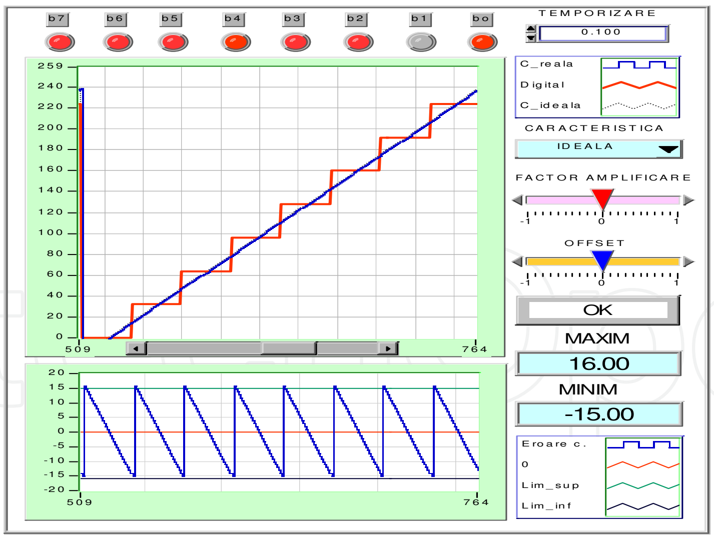


Fig. 8. Quantization of signal

	8-bit	12-bit	16-bit	18-bit	24-bit
Distinct Levels	256	4.096	65.536	262.144	16.777.216
Resolution, ±10 V scale	78.4 mV	4.88 mV	305 µV	76.4 µV	1.192 µV

Table 1. Common Analog-Digital-Converter Resolution

From the point of view of the method of conversion there is a variety of different types of A/D converters used in data acquisition. The most commonly used A/D converters in today's data acquisition products are divided into:

- Dual Slope/Integrating - with a good attenuation of interferences during the integration process
- Successive approximation - provides resolutions in the 10 to18-bit range, and depending on the resolution, offers sample rates up to tens of Megasamples per second.
- Flash – characterized by the shortest conversion time
- Sigma Delta provides very high resolution, especially in converting continuous signals.

Most multi-channel data acquisition systems are based upon a single A/D converter. A multiplexer is then used between the input channels and the A/D converter. The multiplexer connects a particular input to the A/D, allowing it to sample that channel. Figure 9 depicts a typical, multiplexed input configuration.

The primary disadvantage of this system is that even if the switching and sampling are very fast, the samples are actually taken at different times. The ability to sample inputs at the same instant in time is typically referred to as simultaneous sampling.

There are two ways to achieve simultaneous sampling. The first is to place a separate A/D converter on each channel. They may all be triggered by the same signal and will thus sample the channels simultaneously. The second is to place a device called a sample & hold (S/H) on each input. When commanded to "hold", the S/H effectively freezes its output at that instant and maintains that output voltage until released back into sample mode. Once the inputs have been placed into hold mode, the multiplexed A/D system samples the desired channels. The signal to be sampled will all have been "held" at the same time and so the A/D readings will be of simultaneous samples. The simultaneous sampling configurations are shown in Figure 10.

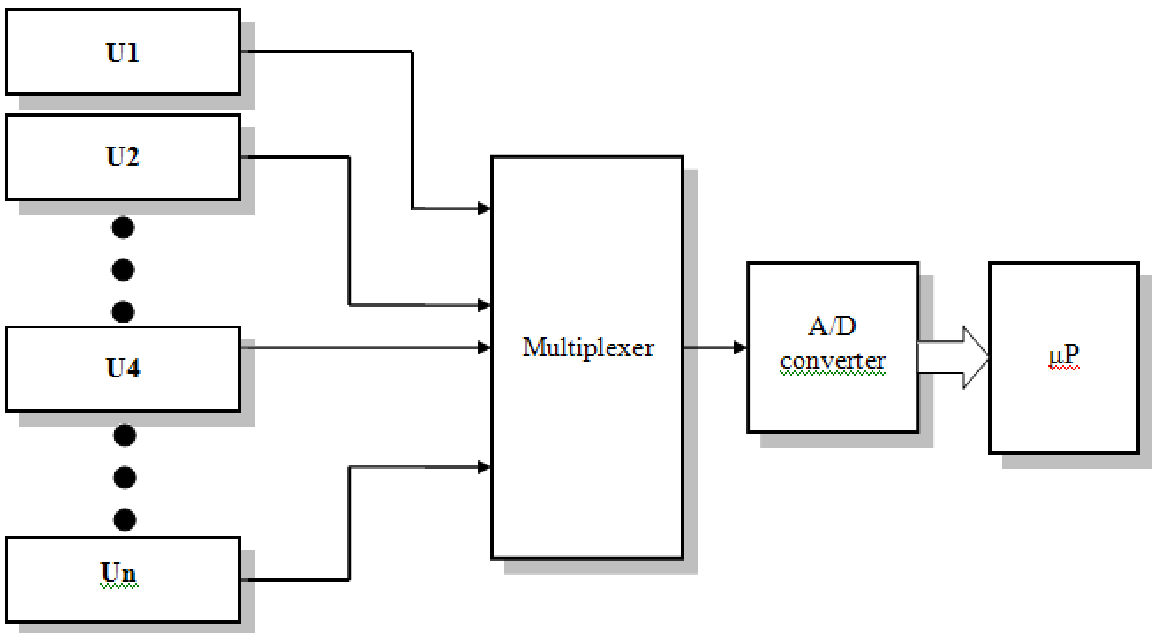
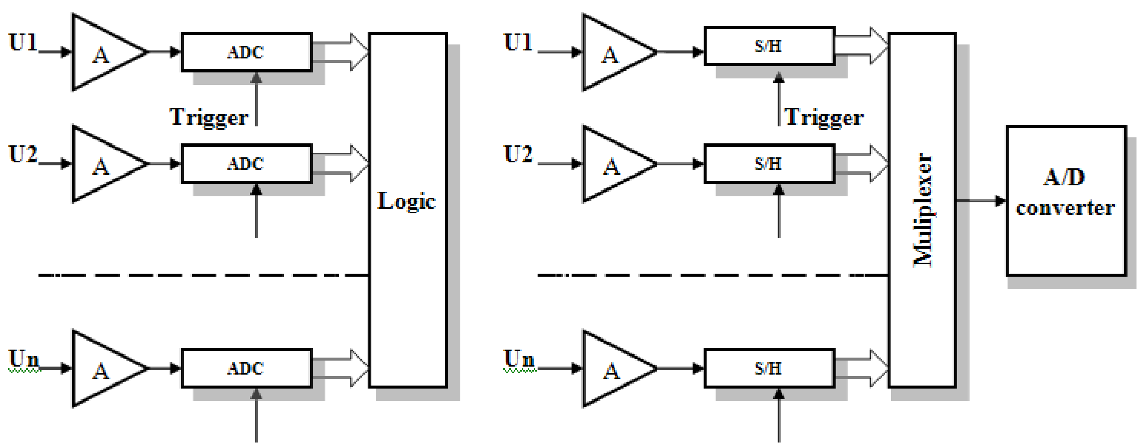


Fig. 9. Typical Multiplexer/ADC DAQ System



a. using individual ADCs on each input b. using Sample-Hold, MUX, and a single ADC

Fig. 10. Simultaneous Sampling Techniques

A criterion applied to classify data acquisition systems is the transmission type of digital announcements (data, addresses, commands): serial transmission or parallel transmission.

The interface system assures equipment and adjustments of devices attached to the bus. The original PC-bus, ISA-bus, is a simple, robust, and inexpensive interface that has certainly stood the test of time. However, most of today's plug-in board business is based on the PCI bus (or variants such as cPCI and PXI). The external box vendors now have Ethernet and USB standards to work with as well as some less used, but very viable, interfaces such as Firewire, CAN, and perhaps the oldest standard in computing, RS-232.

Software has progressed from the original DOS-based version to hyghly complex applications such as MATLAB and LabVIEW™ that are both easy to use and able to take advantage of today's powerful computers.

Currently, most data acquisition companies provide hardware either at board level or external box and software. PC-based DAQ systems are available with a wide variety of interfaces. Ethernet, PCI, USB, PXI, PCI Express, Firewire, Compact Flash and even the venerable GPIB, RS-232/485, and ISA bus are all popular (Manea & Cepisca, 2007).

RS-232 is by far the simplest and least expensive interface. Every PC shipped today can communicate over an RS-232 line. Only a compatible cable and a terminal program are required. RS-232 is limited to about 50 feet, but it can operate over huge distances with a little help from a modem. Only one device can be connected to a single RS-232 port. This interface is typically not electrically isolated from the host computer. For example, if a power line were inadvertently dropped across the RS-232 line, the host computer most likely would be destroyed. As a result, RS-232 may be appropriate for situations in which very few remote I/O systems are needed and where the likelihood of electrical transients is low.

RS-485 allows multiple devices (up to 32) to communicate at half-duplex on a single pair of wires, plus a ground wire (more on that later), at distances up to 1200 meters (4000 feet). Both the length of the network and the number of nodes can easily be extended using a variety of repeater products on the market. Many RS-422/485 protocols were developed in the 1980s for such applications. Profibus, Interbus and CAN are a few. These were designed with proprietary interests in mind, and each subsequently received backing from several vendors in an attempt to develop an open international standard with widespread support.

Ethernet has been around for more than 20 years and has become a commodity in modern business environments. Ethernet also has many characteristics that make it suitable for industrial networked and remote-sensor I/O applications. It combines the low cost of RS-232 with the multidrop capability of RS-422/485 and provides a clear standard for communications. Ethernet has become the medium of choice to communicate management data throughout the enterprise. Interoperability of Ethernet based data acquisition devices from multiple vendors has not always been stellar. However, most Ethernet based data acquisition systems are single vendor and this has not been a major issue in the acquisition space. The LXI Consortium has developed a specification that ensures simple and seamless multi-vendor interoperability.

Gigabit Ethernet is a version of Ethernet that supports 1 Gigabit per second data transfer rates. Boasting the same speed capability as standard Ethernet, the fiber optic implementation extends the range of the system to 2 kilometers. Fiber also provides virtually absolute electrical isolation and has immunity to electrical and magnetic interference.

Firewire is a high speed serial interface. However, at approximately the same time Firewire was being promoted, USB interface was coming on line. At this time, there are a wide variety of data acquisition vendors and products actively promoting USB devices, Firewire success has been confined to the original target market of audio and video.

USB's simple plug-and-play installation, combined with its 480 Mbps data transfer rate, makes it an ideal interface for many data acquisition applications. Also, the popularity of USB in the consumer market has made USB components very inexpensive. USB's 5-meter range is perhaps its largest detraction as it limits the ability to implement remote and distributed I/O systems based on USB.

Today, board level solutions offering 24-bit resolution are now available as, e.g. 6.5 digit DMM boards. On the box side, USB 2.0 is capable of delivering 30 million 16-bit conversions per second and Gigabit Ethernet will handle more than twice that. The internal plug-in slot data transfer rates have increased 10 fold in recent years.
The market of data acquisition equipment is very large, different companies propose new solutions. National Instruments offers several hardware platforms for data acquisition. The most readily available platform is the desktop computer, with PCI DAQ boards that plug into any desktop computer. For distributed measurements, the Compact FieldPoint platform delivers modular I/O, embedded operation, and Ethernet communication. For portable or handheld measurements, National Instruments DAQ devices for USB and PCMCIA work with laptops or Windows Mobile PDAs. In addition, National Instruments has launched DAQ devices for PCI Express, the next-generation PC I/O bus, and for PXI Express, the high-performance PXI bus.

4. Simulations and experimental acquisitions

To determine the operation characteristics of the photovoltaic panels and the panel arrays, the built data acquisition system allows to measure the values of current and voltage, to simultaneously trace characteristics (current-voltage, power-voltage, power-charge resistance) - see figures 11 and 12, to present the measured parameters (during the data acquisition) in tables, to save data into files for future processing.

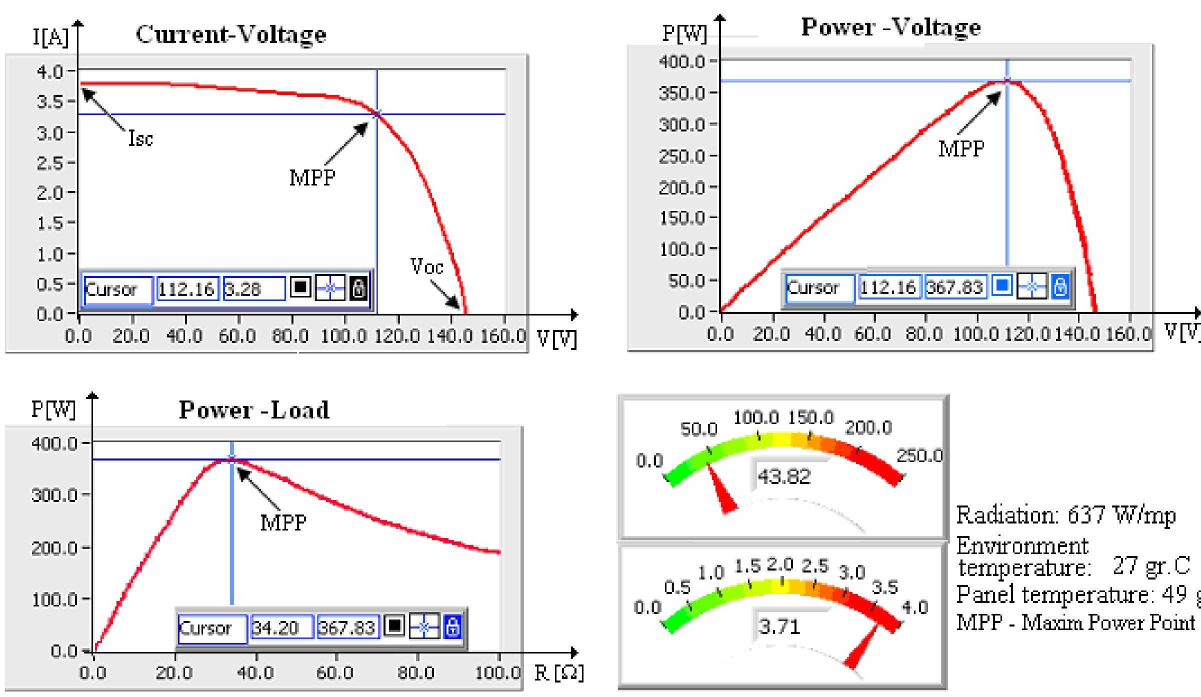


Fig. 11. DC characteristics

For alternative current systems it is necessary to obtain signals with volt-range amplitude to be applied to the input of the data acquisition board. For phase/line voltages there can be used voltage dividers (which do not ensure galvanic isolation) or voltage measurement transformers (ensure galvanic separation). Shunts (current-voltage converters) or current measurement transformers can be used for currents. The use of both voltage dividers and shunts must be done by taking into account the current through the voltage divider, the voltage drop on the shunt, the power dissipation, parasite resistances, self-heating effects and dynamic effects. The use of voltage-current measurement transformers guarantees galvanic isolation of the measuring system but it introduces ratio and angle errors and inadequate perturbation transfer.

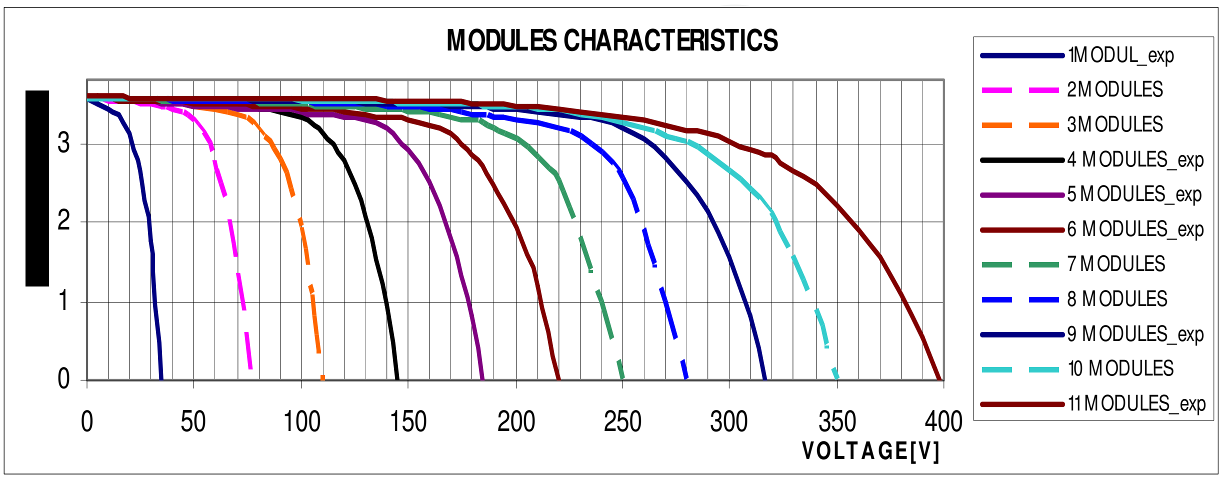


Fig. 12. Current –voltage characteristics. Experimental acquisition (1,4,5,6,9,11 modules) and simulation (2,3,7,8,10 modules)

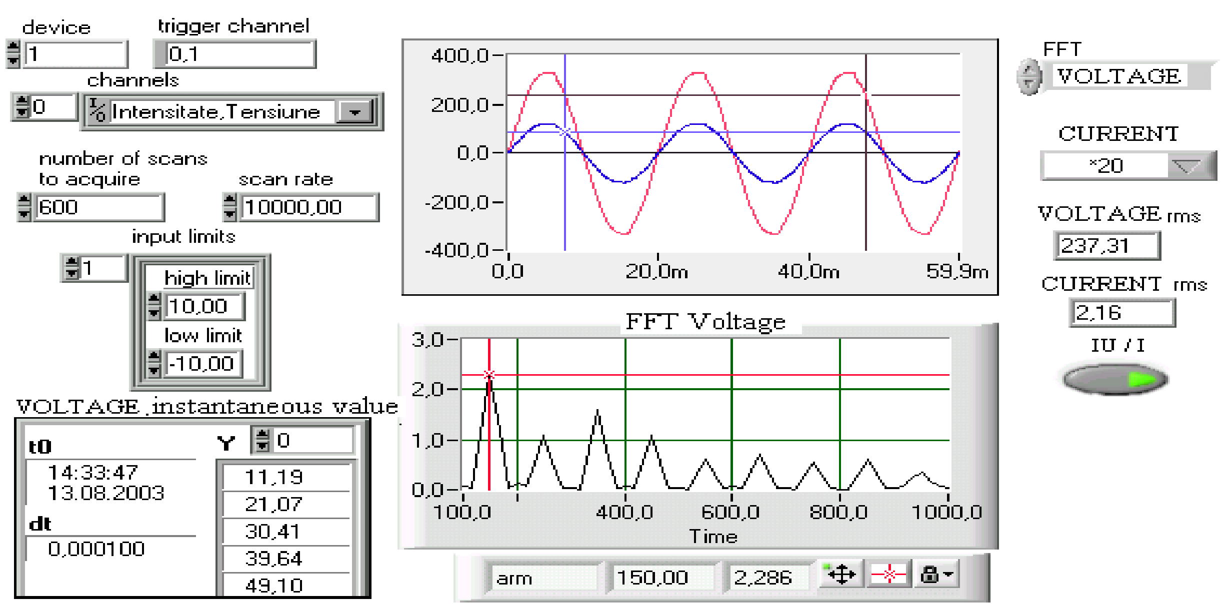


Fig. 13. AC Acquisition Instrument (Phase B)

The solution adopted was to use current and voltage transducers based on the Hall Effect. To obtain a good magnetic sensor the magnetic field is concentrated around the transducer, by using a circular core (used as a flux concentrator and made of a material with high magnetic permeability), which ensures both an increase of the magnetic field in the area of the sensor and the independence from the position of the conductor inside the core. Non-linear behavior of the flux concentrator can be obtained by using an operational amplifier,

which injects a compensation current through the reaction loop. Figure 13 presents the front panel of the LabVIEW™ application which acquires and processes data in the AC circuit from the output of the phase B connected inverters.
Figure 14 shows a LabVIEW™ application (Ertugrul, 2002) to determine the characteristics of PV panels, with the possibility of remote monitoring.

4.1 Experimental results in PV system

The following results are obtained with data acquisition system Sunny Data Control. Totally, around 90 channels are recorded permanently. All channels are stored in SBC+ memory for maximum 8 days; after exceeding this interval the data will be lost if not transferred to the computer. Depending on the connected sensors the Sunny Boy Control+ can monitor all inverters and PV panels to ensure an even higher performance and more sophisticated system diagnosis.

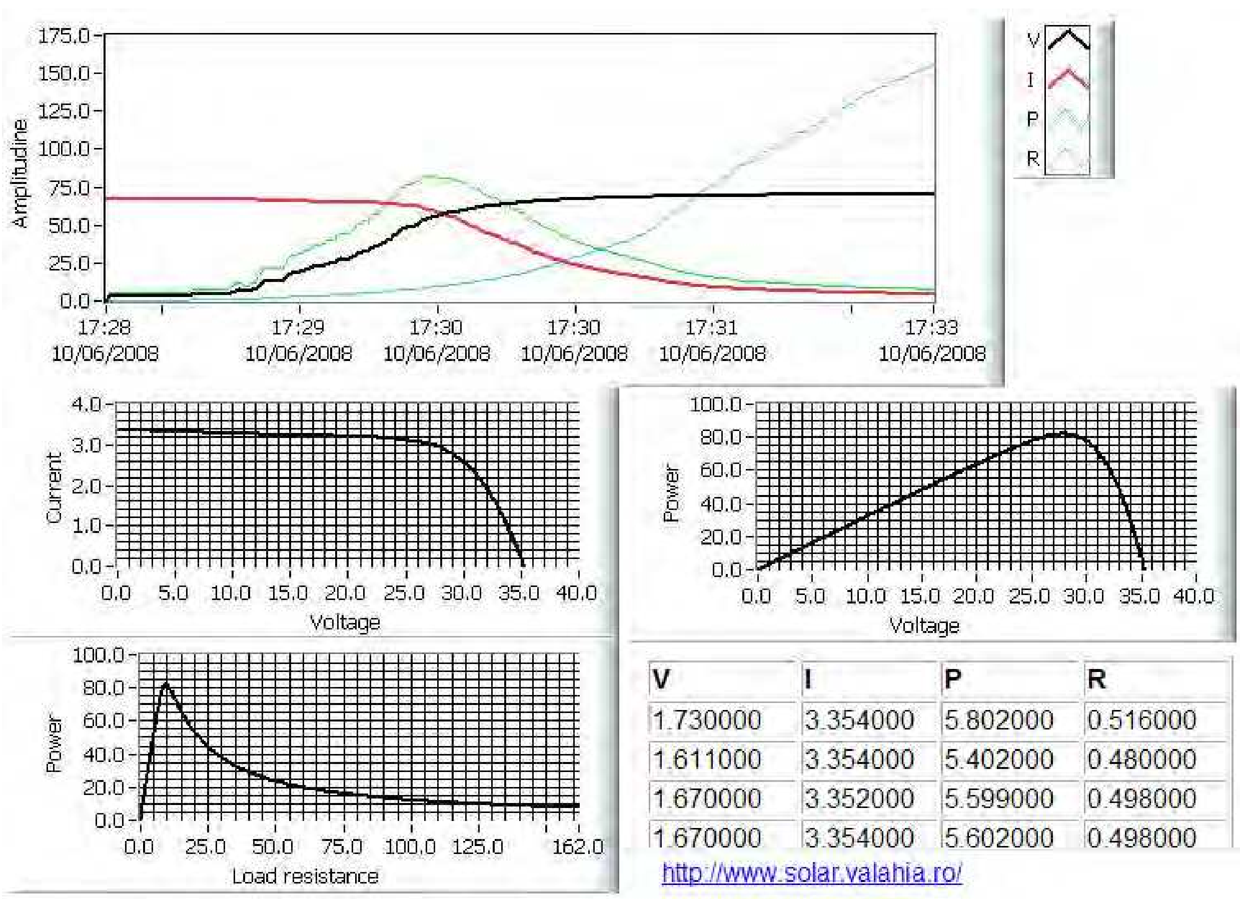
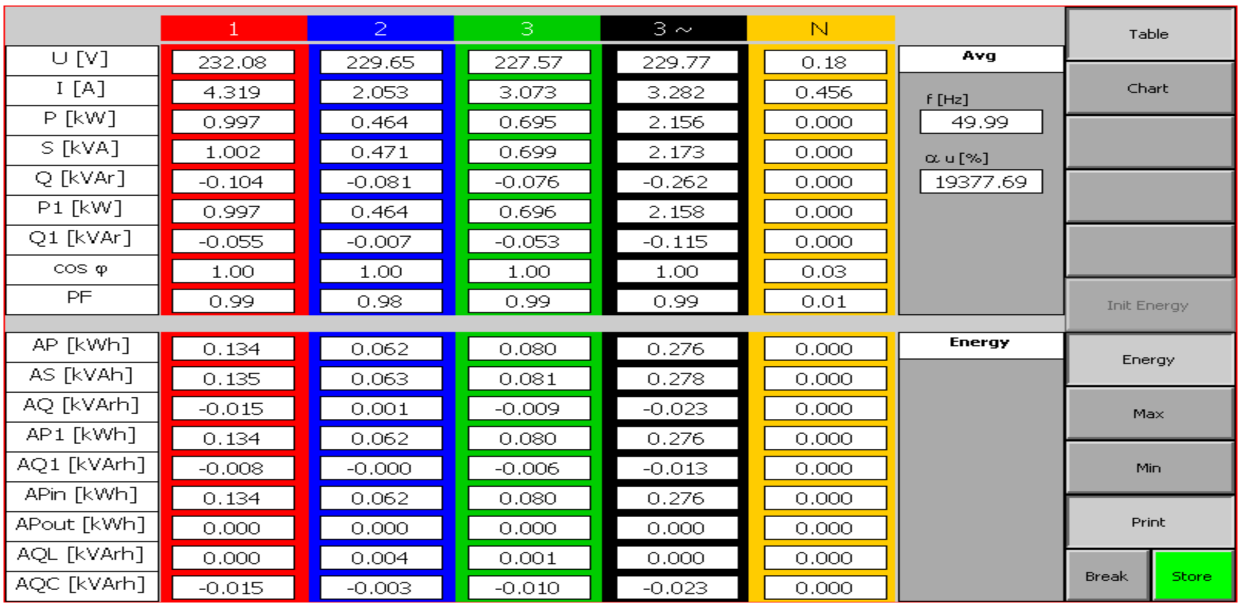


Fig. 14. Remote monitoring of PV system



	1	2	3	3 ~	N
U [V]	232.08	229.65	227.57	229.77	0.18
I [A]	4.319	2.053	3.073	3.282	0.456
P [kW]	0.997	0.464	0.695	2.156	0.000
S [kVA]	1.002	0.471	0.699	2.173	0.000
Q [kVAr]	-0.104	-0.081	-0.076	-0.262	0.000
P1 [kW]	0.997	0.464	0.696	2.158	0.000
Q1 [kVAr]	-0.055	-0.007	-0.053	-0.115	0.000
cos φ	1.00	1.00	1.00	1.00	0.03
PF	0.99	0.98	0.99	0.99	0.01
AP [kWh]	0.134	0.062	0.080	0.276	0.000
AS [kVAh]	0.135	0.063	0.081	0.278	0.000
AQ [kVArh]	-0.015	0.001	-0.009	-0.023	0.000
AP1 [kWh]	0.134	0.062	0.080	0.276	0.000
AQ1 [kVArh]	-0.008	-0.000	-0.006	-0.013	0.000
APin [kWh]	0.134	0.062	0.080	0.276	0.000
APout [kWh]	0.000	0.000	0.000	0.000	0.000
AQL [kVArh]	0.000	0.004	0.001	0.000	0.000
AQC [kVArh]	-0.015	-0.003	-0.010	-0.023	0.000

Fig. 15. Electrical quantities monitored

Figure 15 shows the LabVIEW™ application for the visualization of quantities monitored and the results are presented in Figure 16 (Andrei et al. 2010).

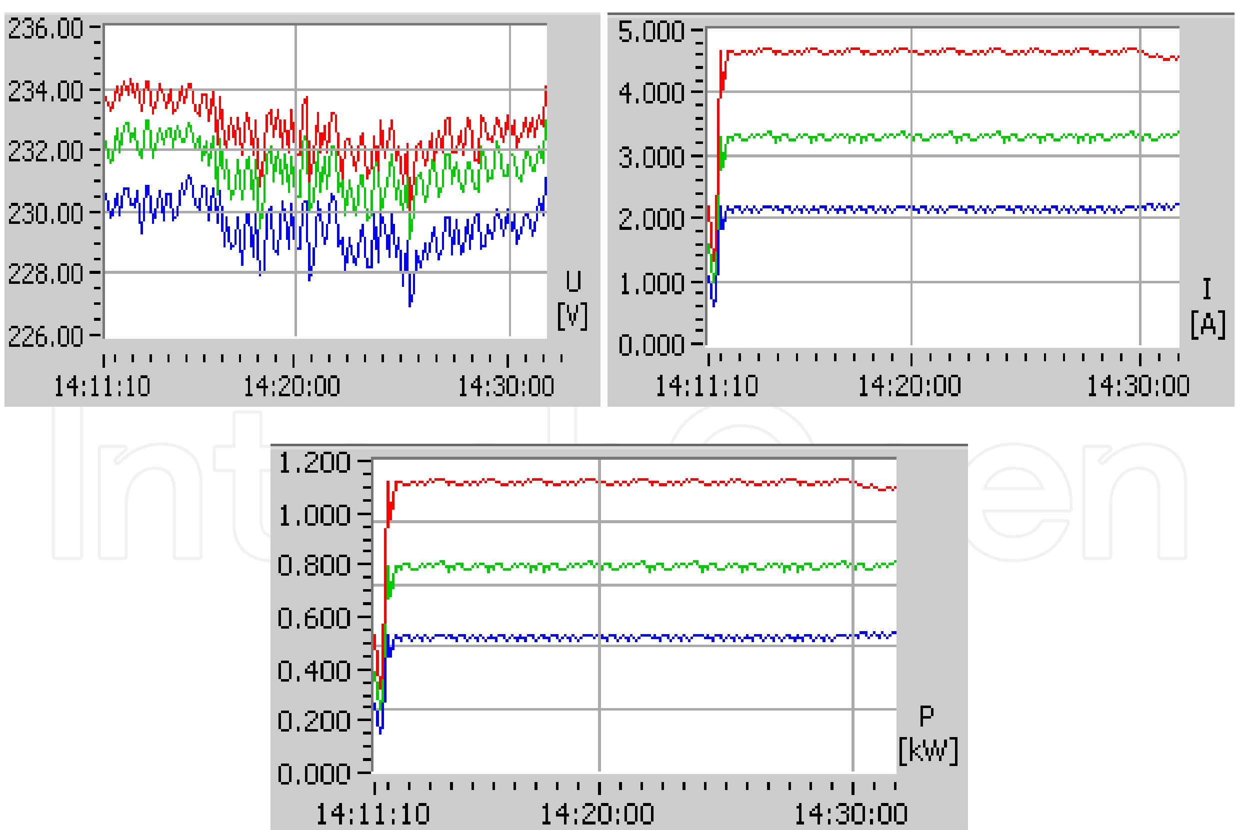


Fig. 16. Results of acquisition

The application allows visualising the phase diagram – Figure 17 - and obtains information on the quality of electricity produced by PV system – Figure 18.

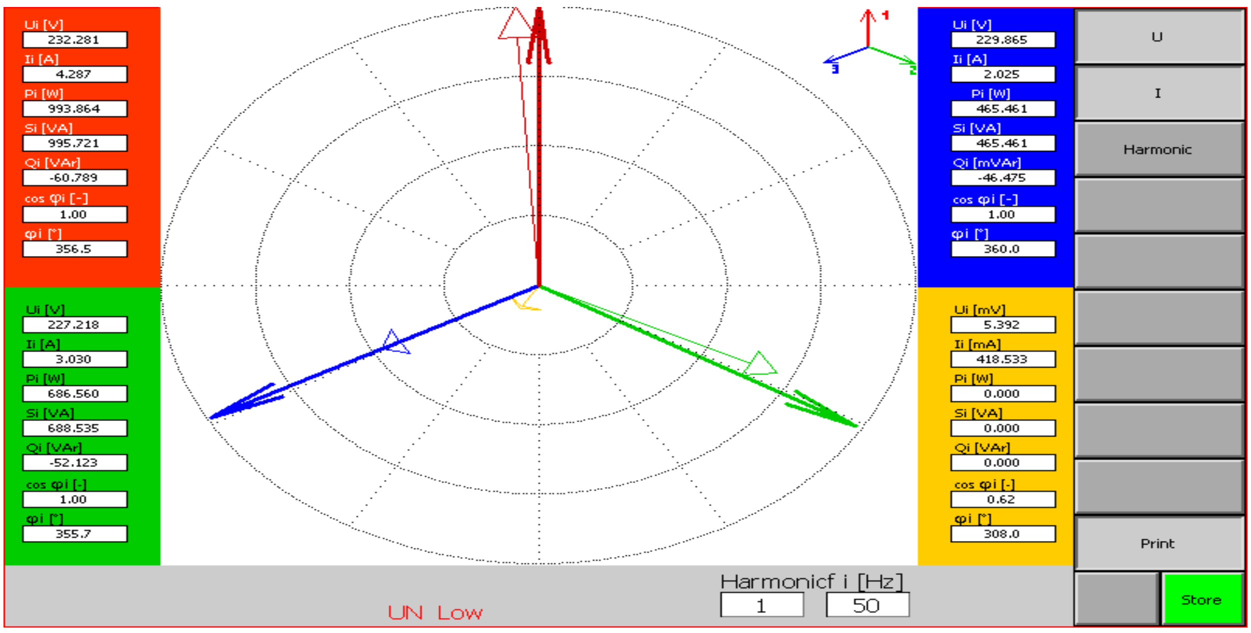


Fig. 17. Phase diagram

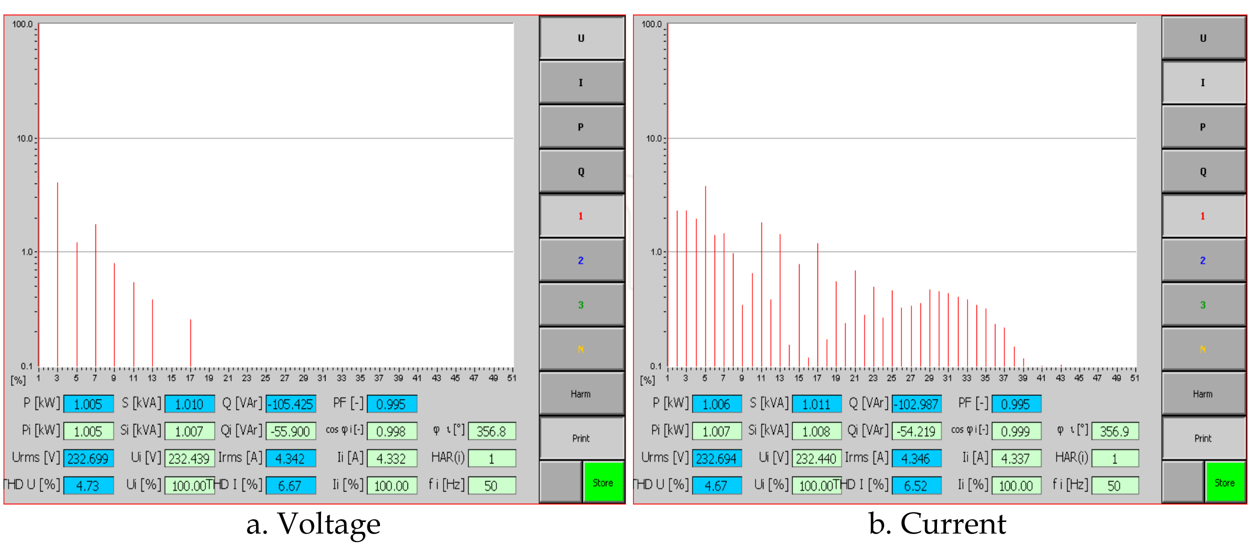


Fig. 18. Harmonics (Phase A)

After processing the data obtained with Sunny Data Control software following characteristics were obtained.

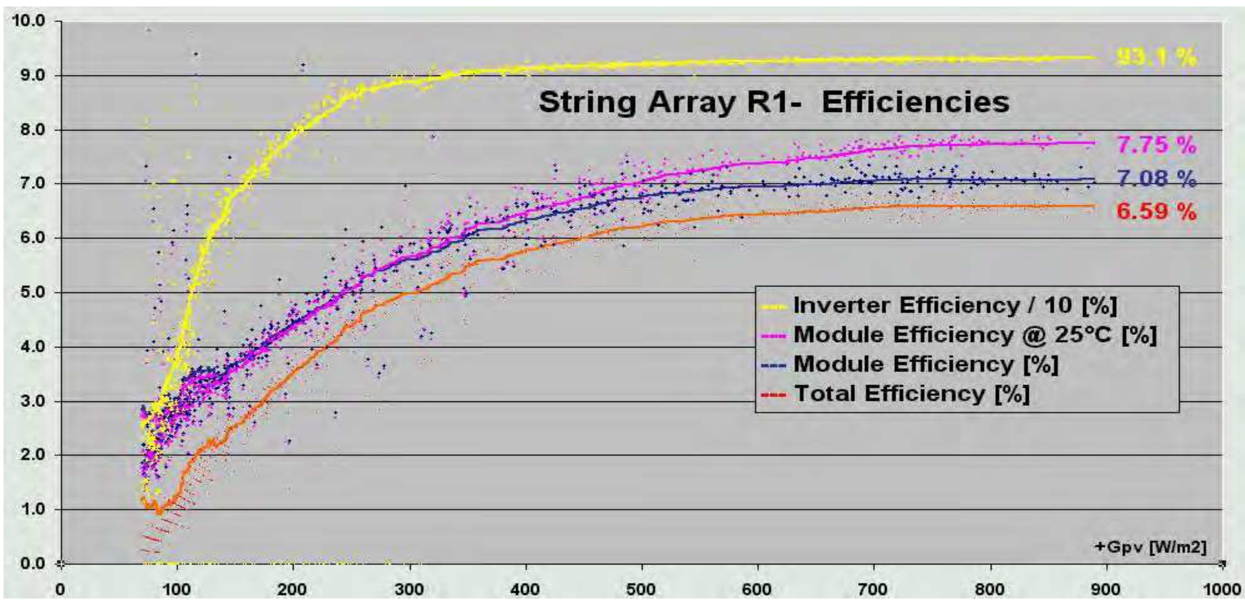


Fig. 19. Efficiency of a panel no.1 according to solar radiation

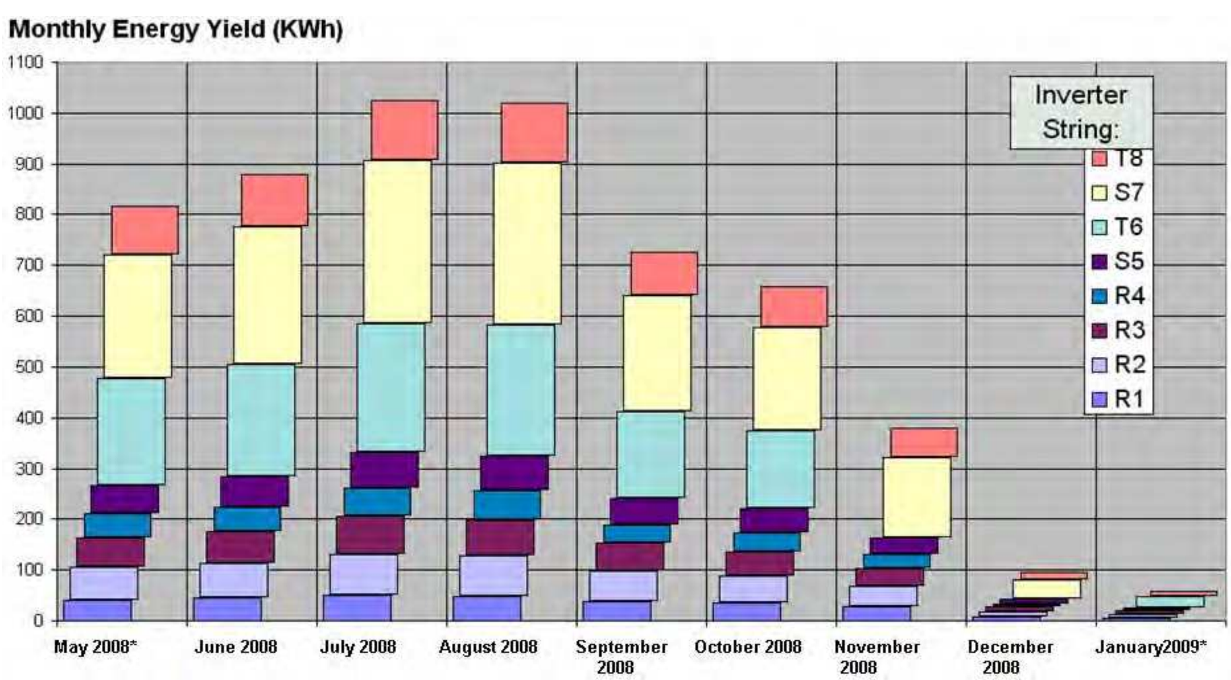


Fig. 20. Monthly electrical energy produced by each rows of modules

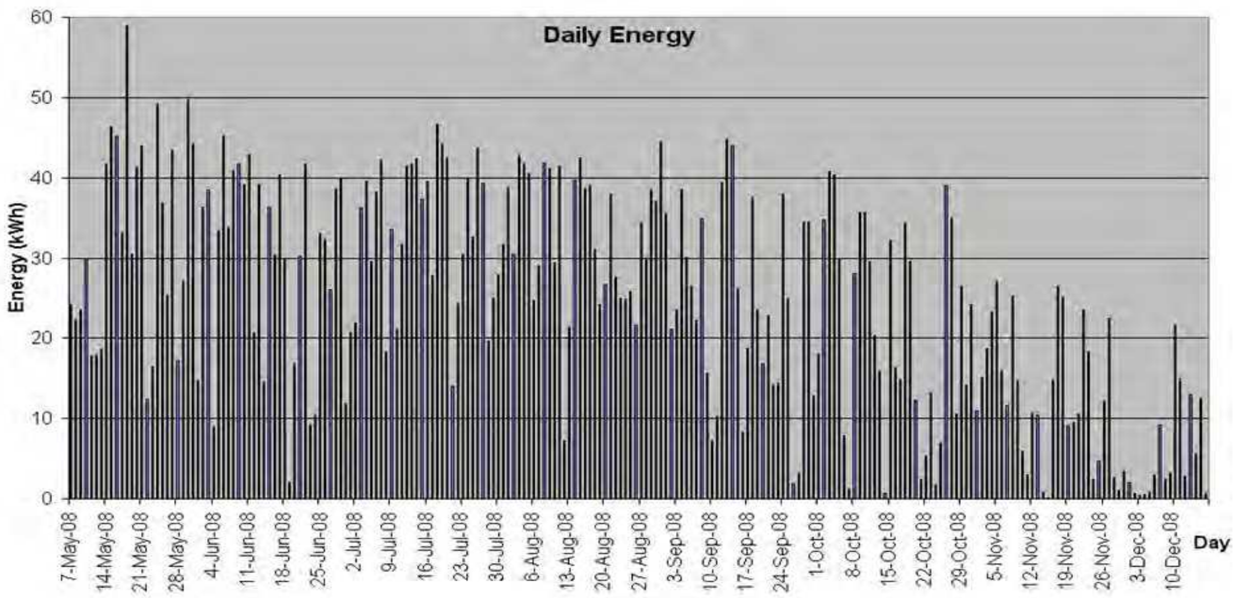


Fig. 21. Total electricity produced by PV system

The data acquisition system allows observation of the link between solar radiation, temperature and solar conversion result – Figures 22 , 23 and 24 .

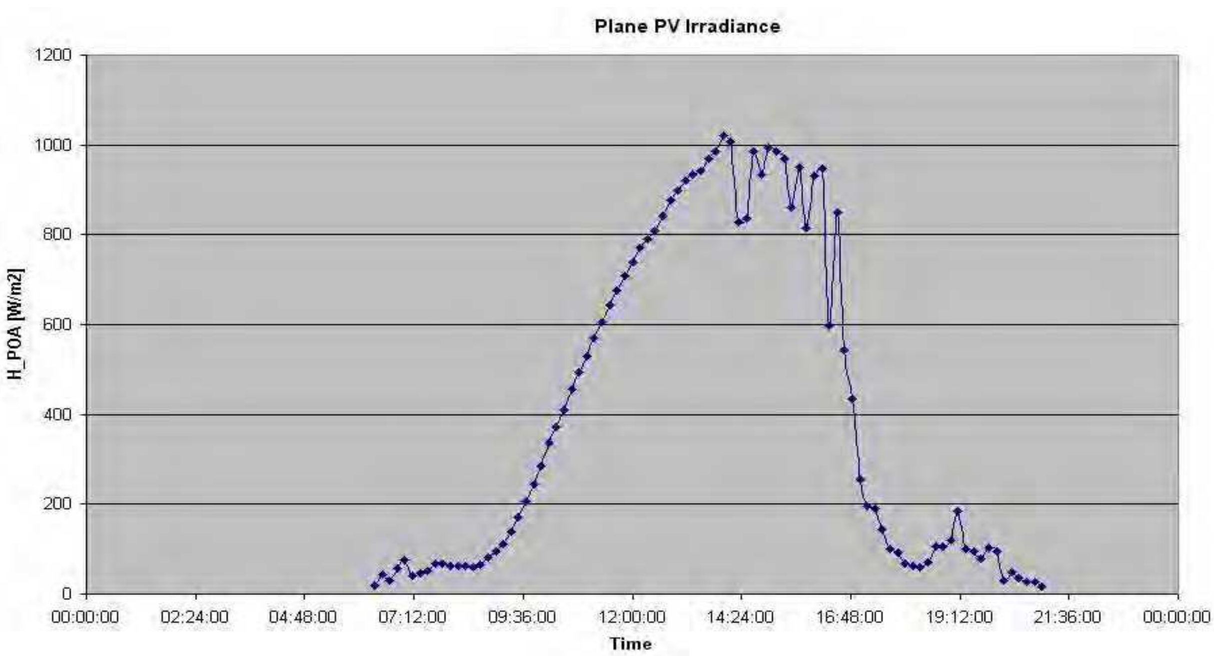


Fig. 22. Solar radiation

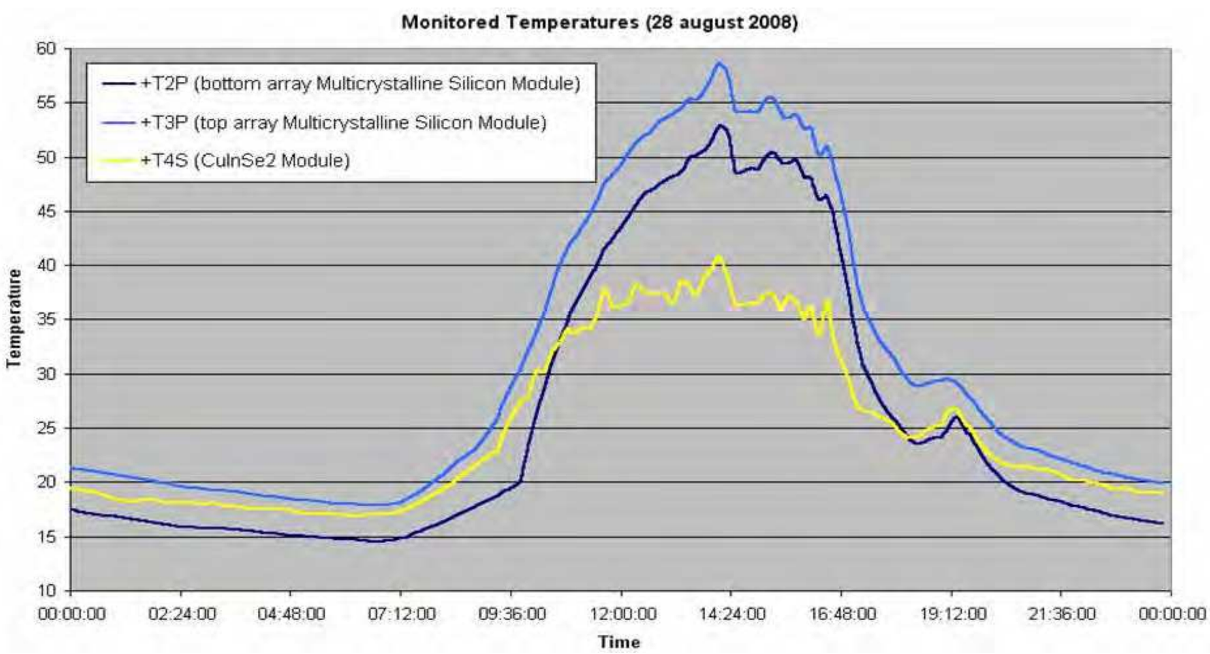


Fig. 23. Temperature evolution of the 3 types of PV modules

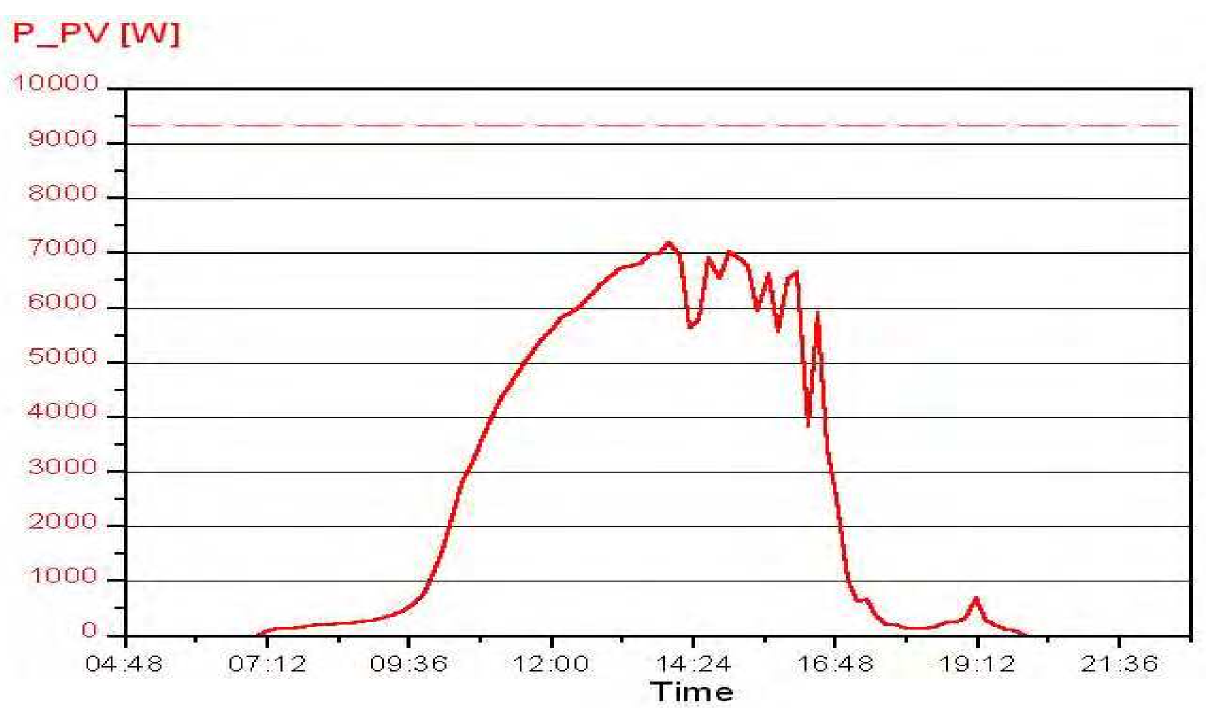


Fig. 24. Variation of total power

5. Conclusion

Even though the costs of installations producing electric energy with PV panels are high compared to the costs of conventional installations, the number of such systems is continuously increasing. It is very important to determine the output characteristics of the PV panels in order to achieve an accurate connection and operation of the device and reduce energy losses.

Monitoring activities follow the operation analysis by periodical reports, papers, synthesis, with the precise aim to make the most accurate decisions to produce electric energy using unconventional sources.

To quantify the potential for performance improvement of a PV system, data acquisition systems has been installed. The importance of this chapter consists in the presentation of a dedicated DAQ used in PV system analysis and real data measurements. The operation is performed by simulations using LabVIEW™.

The information obtained by monitoring parameters, such as voltage, current, power and energies are fed to the PC via the DAQ for analysis. The control interface has been developed by utilizing LabVIEW™ software. The system has been in operation during the last five years and all its units have functioned well.

6. References

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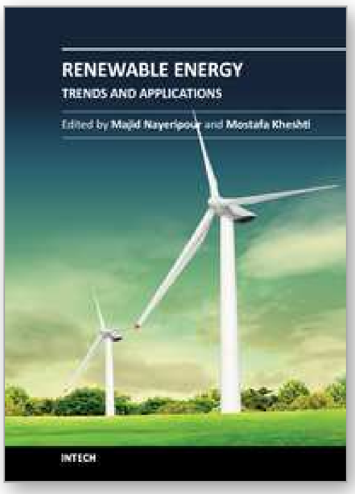

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Increase in electricity demand and environmental issues resulted in fast development of energy production from renewable resources. In the long term, application of RES can guarantee the ecologically sustainable energy supply. This book indicates recent trends and developments of renewable energy resources that organized in 11 chapters. It can be a source of information and basis for discussion for readers with different backgrounds.

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