Data Acquisition Systems for Monitoring and Control of Photovoltaic Generators

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Abstract

This paper aims to describe two intelligent systems, microprocessor based, capable of monitoring, both locally o remotely, more photovoltaic strings. In particular, the electronic board called CS097 helps to detect environmental parameters such as temperature and solar radiation and to calculate average power and energy produced by the solar system, in order to monitor the efficiency and electricity production of the photovoltaic field. It can control up to four photovoltaic strings, acquiring voltage and current values for each string. Transducers, installed on the same board, detect currents lower than 20 amps and voltages lower than 1000 V. The acquired data have a maximum error of 1% compared to true current and voltage values generated by the strings. It's also provided a galvanic isolation between the measuring circuits and the acquisition ones. The CS083 and CS088 electrical boards, instead, work as an alarm system which indicates a critical condition in case of an electrical continuity loss or a not-justified rapid variation of the voltage read on each string. This system has a dual operation mode that makes it capable of auto-adapting itself to the operation of the photovoltaic system distinguishing between day and night. The dual mode operation is ensured by the presence of a microcontroller installed on the CS083 electronic board, expressly programmed, which defines the temporal condition in which the system works – day or night – by monitoring the voltage value read on the photovoltaic string and comparing it with a predetermined threshold value. On the CS088 board there are two voltage dividers, properly sized to read voltages from 0 to 1000V and to take this range into the range 0-0,2 V, adapting it to optocouplers whose ensure galvanic isolation between the voltage dividers and the CS088 electronic board. Both the remote control system (CS097) and the anti-tampering system (CS083 and CS088), have the possibility to communicate with a personal computer via the RS485 interface or other remote stations by adding new communication modules.

Keywords: telecontrol, data acquisition, photovoltaic, RS485 interface, RS232 interface, current transducer

1 Introduction

Technicians and engineers which manage plants, not only photovoltaic power plants but also, i.e. lighting plants are increasingly geared towards the improvement of customer service. New technologies and telecontrol systems contribute significantly to achieve this goal. In addiction to get an effective solution in the prevention of faults and their quick correction, these new electronic system constitute an excellent tool for cost control: plants monitoring and control systems must however be easy to use, quick to install and efficient.

In the world of alternative energies, the need for a careful management of security and remote control of plants is becoming more pressing, especially when it concerns large photovoltaic systems, often characterized by a lack of control. In addition, a photovoltaic system is remunerated according to the actual energy production, whereby is fundamental to keep the monitoring of the plant by a telecontrol system:

1. To keep the plant safe from thefts;
2. To be promptly advised as soon as there is an unjustified loss of production;
3. To easily view acquired data on the Internet in an area dedicated to under-control plant;

Telecontrol systems of photovoltaic plants use a monitoring software, and integrate the capabilities of remote monitoring and fault reporting or tampering with user-friendly technologies (sms, email, web).

All acquired information is stored locally on memory device and periodically sent to a server. Data and statistics can be easily available in graphic form on a web portal or directly accessible on site.

Usually, various functional alarms are also implemented, which are managed by sms to promptly initiate maintenance.

2 Remote monitoring and control of photovoltaic systems

The heart of a telecontrol system is a local management device which, once installed on the plant, using special sensors and RS232/RS485

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connections and/or radio waves, watches to ensure the highest efficiency and functionality with the possibility of communication from/to a supervision centre. The supervision centre can be located on the plant (system's local management) or remote location (system's web management).

Given the continuous growth of photovoltaic installations in Apulia, but not only, thanks primarily to government intervention in terms of financing, it has been identified the need to design and implement an intelligent system, microprocessor based, able to acquire voltage and current from many photovoltaic strings, to measure environmental parameters such as temperature and solar radiation and to calculate average power and energy produced by the plant, so that the power production of the photovoltaic field can be monitored, both locally and remotely.

Therefore, it has been made the electronic system of local management, also called CS097. This board, despite having all the current and voltage transducers installed on itself, was designed with the smallest size possible so it can be mounted near the inverters that are part of already existing photovoltaic plants.

The functions of acquisition, power calculation and communication to external devices, unlike other commercial systems, where the power calculation is done using a wattmeter, are managed and executed by a microcontroller on the board. Acquired data by the plant, once processed, are transmitted to a personal computer connected to the board via the RS485 interface, or other remote stations by adding new communication modules.

Parallel to the development of the photovoltaic market, has also grown the annoying problem of theft of solar panels, mainly because of their relatively high cost and location of these plants, usually placed in remote and poorly protected sites. To prevent the theft of solar panels many companies have stepped forward on the anti-tampering systems market, proposing many alternatives.

The proposed system, composed of CS083 and CS088 electronic boards, is an alarm system which indicates a dangerous situation when electrical continuity between the modules is interrupted or string voltage present not-justified rapid variation due to by-passed solar panels. Such system provides control over string voltage both at day, distinguishing in this case the conditions of maximum solar radiation from the conditions of partial or full shading, and at night during which there is no exposure to light.

Evaluating the voltage value, the system must be able to establish, with the help of a suitable programmed microprocessor, if there is a critical situation due to a sudden drop of electrical potential, thus generating a possible alarm condition, or if the lowering of string's voltage was caused by a decrease of solar radiation. In this situation, it was observed that the shape of the string's voltage curve is characterized by a progressive, and not sudden, reduction, index of a correct operation of the plant and not a critical condition of theft.

3 Block diagrams of data acquisition systems

As shown in Figure 1, the CS097 board is capable of controlling up to four photovoltaic strings, acquiring current and voltage for each string. Current and voltage transducers are installed on the same CS097 electric board and detect currents not exceeding 20 amperes and voltages lower than 1000 V. Since this electronic board is not a real measuring instrument but only a device to control the trend of electrical parameters, it shall not require great accuracy for data acquisition, however, acquired data have a maximum error of 1% compared to the real values of voltage and current generated by the strings.

Galvanic isolation is provided between the signal measure and transmission circuits and the signal acquisition circuits.

The CS097 electronic board also operates two signals from a temperature sensor and a pyranometer positioned near the photovoltaic field, so that it may also be able to evaluate the expected energy from a photovoltaic system, starting from the information on panel temperature and solar energy that actually reaches the solar panel.

Since, as mentioned above, the supervision centre can be located on the plant or in remote location, the CS097 is equipped with RS232-RS485 outputs so that is possible to connect a personal computer directly to the electronic board (local system management) and/or a GSM/GPRS (web system management).

Remote telecontrol units, in fact, may be connected to the system using any communication protocol tunnelled over GSM/GPRS network. Aside from connection in real time, in fact, it's always possible to consult the historical archives of monitored data on a daily, weekly, montly basis.

Alternately to the system of acquisition and processing of electrical and environmental parameters, it's possible to install the anti-tampering system, consisting of CS083 and CS088 electronic boards, on the photovoltaic system.

The CS083 board is the basic element for acquisition, processing and generation of any alarm signal in presence of a critical condition. The powerful microcontroller installed on this board runs a set of inputs, including signals from the CS088 acquisition board connected to the photovoltaic string. This board has the function of transduction: the voltage signal from the photovoltaic string is translated and adapted into a voltage signal that can be interpreted and processed by the CS083 board.

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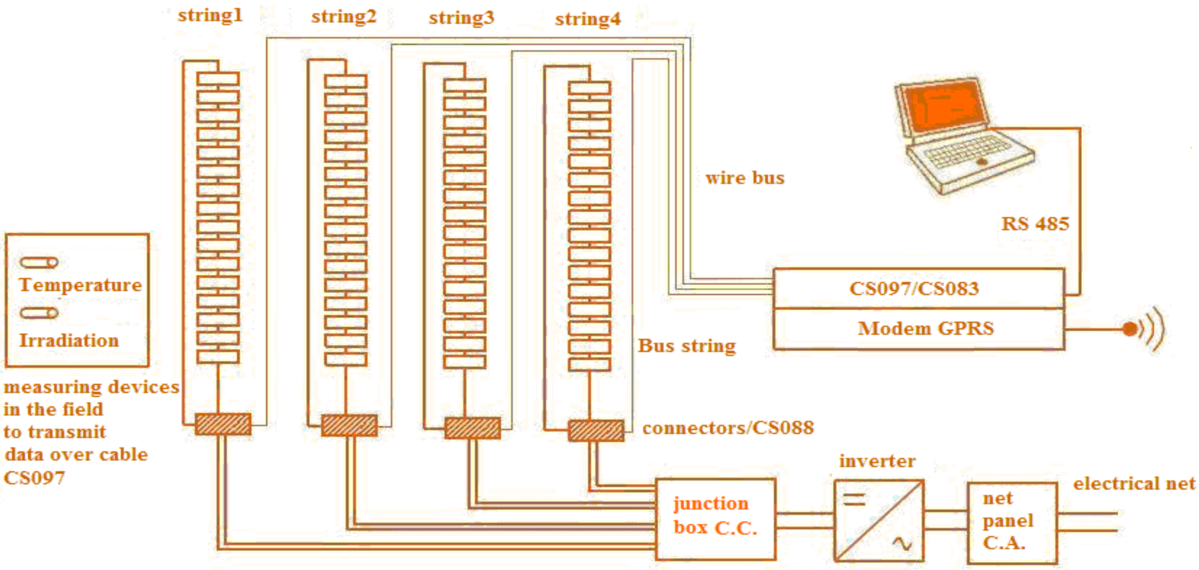

Figure 1: bus-communications net between photovoltaic plant and CS097 data acquisition board or CS083-CS088 alarm system.

3.1 Block diagram of data acquisition boards

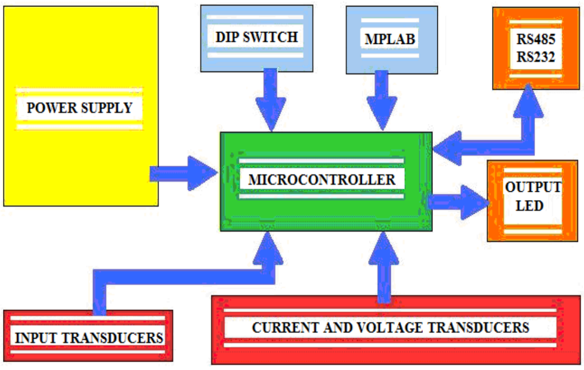

Figure 2: Block diagram of data acquisition board CS097.

Figure 2 shows the block diagram of CS097 board. The heart of the electronic board is the powerful microcontroller (MCU Microcontroller Unit), the Microchip ® PICmicro ™ PIC16F887A model which, suitably programmed, can perform different tasks independently. Essentially, it manages input and output lines according to the program (firmware) implemented in it. Inside it can be found a real microprocessor with CPU, RAM, Timer and many input/output lines [1]. CS097 board is also provided for the presence of an interfacing with RS-485, RS-232 ports and with the communication port with the MPLAB REAL ICE, respectively to transfer out of the board the outgoing data from PIC16F887A and to program it. The powerful microcontroller will handle two inputs that correspond to signals from temperature and radiation sensors, and the outputs of the four current transducers and four voltage transducers installed on the same board.

Note also the presence of a DIP switch that will allow the technician, when the board will be installed in the photovoltaic field, to configure the CS097 with the right parameters related to the plant on which the board is installed. Two leds, however, will show the execution of any particular instruction by the microcontroller.

The CS083 block diagram is similar to that of the CS097 electronic board.

3.2 Block diagram of transduction board

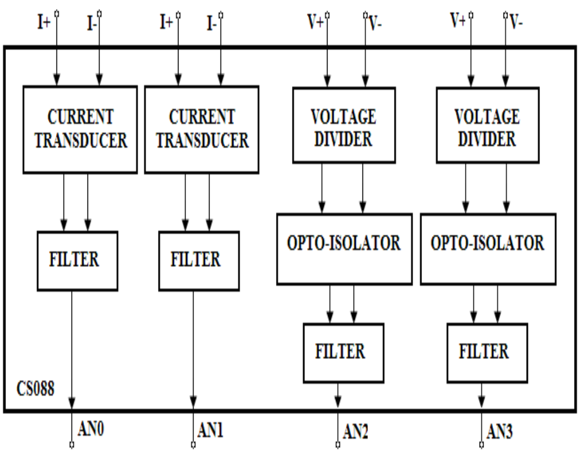

Figure 3: Block diagram of transduction board CS088.

The CS088 electronic board was designed and built for voltage and current reading present on two photovoltaic strings. On the CS088 are present therefore two current transducers and two voltage dividers, suitably sized to receive input voltages from 0 to 1000V (maximum voltage range produced by a photovoltaic string) and to place this range into the voltage range 0 ÷ 0,2 V. Downstream of the dividers are in fact installed optocouplers for which the input voltage range is -0,2 ÷ 0,2 V [2]. The output signals of the CS088, before being sent to the microcontroller of

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the CS083 board, are filtered by RC circuits specifically designed to reduce the noise.

4 Electrical circuits of data acquisition board

As shown in figure 4, voltage transducers are simply linear optocuplers connected downstream of voltage dividers.

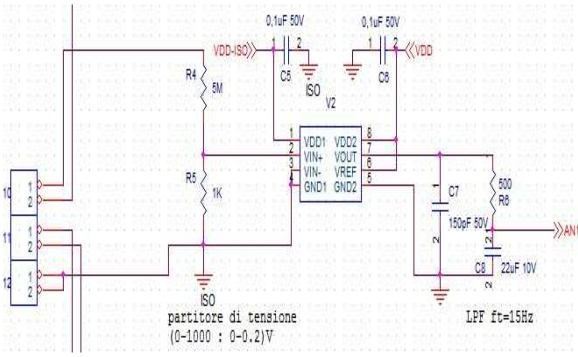

Figure 4: circuit diagram of voltage transducers.

The voltage dividers have been designed to relate the maximum range in input voltage (0 to 1000V) to the input range of CS00V optocoupler (0 ÷ 0,2 V). The resistors R4 and R5, then, were calculated taking into account the amount of power to dissipate, given the wide range of transduction, from 1000 V to 0.2 V.

The other side of the optocoupler is galvanically isolated from the voltage supplied by the photovoltaic string and is connected to an input (AN1) of the A/D converter, through a low pass filter. The low pass filter, whose task is to eliminate any fast changes of the signal forming noise superimposed on the useful signal, is designed to have a cutoff frequency of 15 Hz, according to the following formulas [3]:

$$f = \frac{1}{SC} \times \left(\frac{1}{SC} + R \right) = \frac{1}{2\pi RC} \Rightarrow \quad (1)$$

$$\Rightarrow RC = \frac{1}{2\pi f} = \frac{1}{2\pi 15} Hz^{-1} = 1 \times 10^{-2} Hz^{-1}$$

Then, choosing R and C with values closer to commercial ones, we get:

$$RC = 500\Omega \times 22\mu F = 0{,}011\ Hz^{-1} \quad (2)$$

Also output signals from the four current transducers pass through low pass filters with a cutoff frequency of approximately 15 Hz (Figure 5).

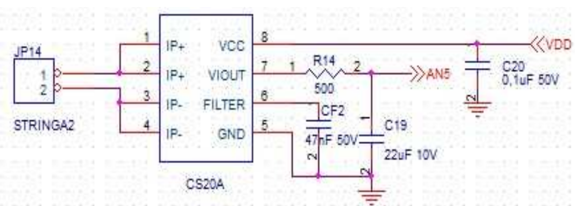

Figure 5: circuit diagram related to the interfacing between the current transducer and the PIC.

JP7-CH0 and JP6-CH1 inputs in Figure 6 are used to interface the CS097 board with any other device, such as temperature sensors and pyranometer.

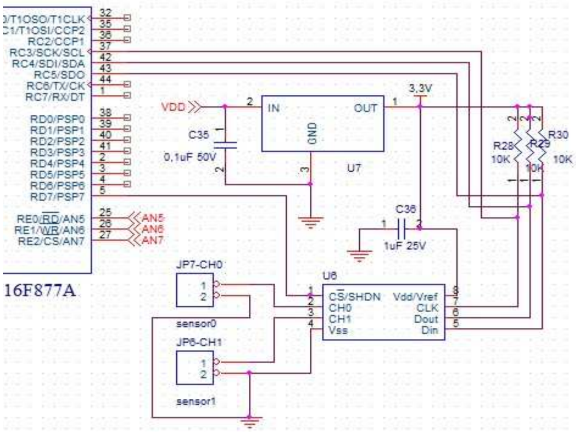

Figure 6: circuit diagram related to interfacing the temperature sensor and pyranometer to the PIC.

The analogue signals from sensors are converted into digital signals by the U6 integrated circuit. Communication between the A/D converter and the microcontroller on the CS097 board is implemented through the PIC16F887 SPI serial interface.

To develop the firmware we used the C language and the software development environment Microchip's MPLAB IDE. The tool used for programming and debugging microcontroller's firmware is Microchip's MPLAB Real ICE In-Circuit Debugger and Programmer.

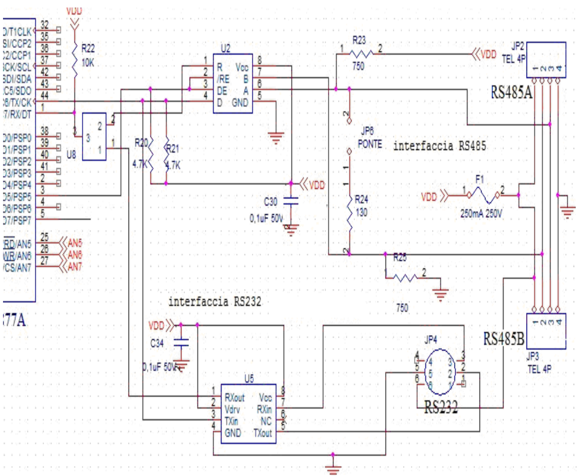

Figure 7: Circuit diagram of RS232 and RS485 interfacing.

Figure 7 shows the circuit diagram of RS-485 and RS-232 ports interfacing with the CS097 board [3]. The bridge JP6 is used to adjust the impedance of the transmission line depending of the application.

5 Development of firmware

In this section we analyze the firmware algorithm implemented in the CS097 data acquisition board, and in the CS083 alarm electronic board.

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5.1 Development of firmware of the data acquisition board CS097

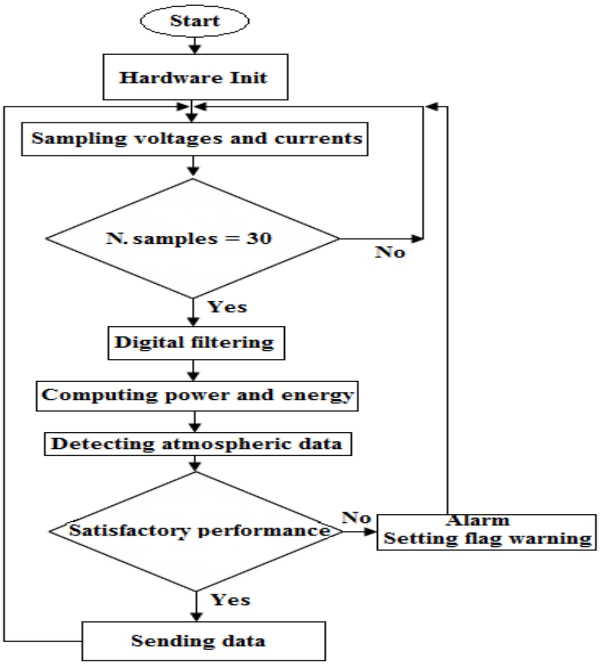

Figure 8: Block diagram of firmware of the data acquisition board CS097.

Figure 8 shows the block diagram of the firmware implemented in the data acquisition board for telecontrol of a photovoltaic system. As soon as power is supplied to the board, the firmware initializes the state variables and prepares the device for the acquisition and transmission of signals with the outside world. After this operation, through a loop, signals are read from voltage and current transducers, that are connected to analogue inputs of the microcontroller. This signal are filtered though a digital filter F.I.R. (Finite Impulse Response) designed specially, by Matlab software, to reduce the noise present on the electrical signals.

Once that 30 samples of current and voltage are acquired, with a given sample rate, and filtered, we proceed with the calculation of power and energy produced by the plant. Subsequently, the solar radiation and panel temperature parameters are detected to check if the system is working properly. If the plant performance is satisfactory, the acquired and processed data are sent to a remote station, otherwise a warning signal is generated and sent.

5.2 Development of firmware of the alarm system CS083-CS088

Figure 9 shows the block diagram of the firmware implemented in the CS083 electronic board microcontroller. The microprocessor reads the voltage on the photovoltaic string under control and compares it with Vthr which is the predetermined threshold value.

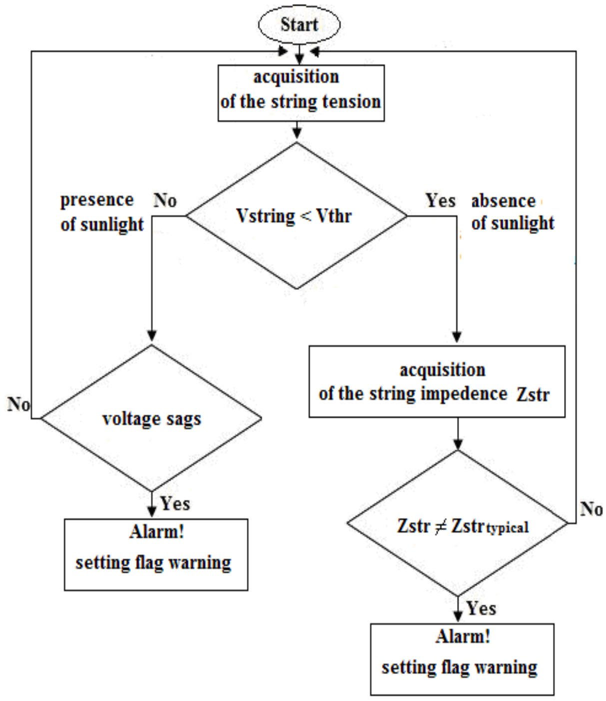

Figure 9: Block diagram of firmware of the alarm system CS083-CS088.

Then the different control and discrimination night/day can start; if the read value is below the voltage Vthr, the system interprets this as a condition of absence of solar radiation, activating the nightly mode of analysis and action. Then the microprocessor reads the Zstr string impedence and compares it with the $Zstr_{typical}$ typical string impedence. Consequently, if the Zstr impedence is different of the $Zstr_{typical}$ impedence value, the microcontroller generates a signal that enables the alarm output.

If the comparison performed by the microcontroller indicates a value above the threshold voltage, the modules surely work in lighting conditions, even partial, so it is possible to initialize the part of program that manages the day operating mode. In this case, the microcontroller runs an algorithm that evaluates the rate of change in string tension rather than its lowering, as the tensions during the hours of irradiation are very high (hundreds of Volts) and the deactivation of just a single module would result in a negligible voltage drop and thus not easy to identify.

6 Experimental testing and result

In this section we present the experimental results of testings with the two designed and manifactured electronic systems.

Figure 10 shows the electronic board CS097, whose electrical schematic is designed with the software OrCAD Capture. The Printed Circuit Board (PCB), instead, was designed using OrCAD Layout.

The C097 is composed specially of surface mount electronic components. To install these components was used Pick and Place machine.

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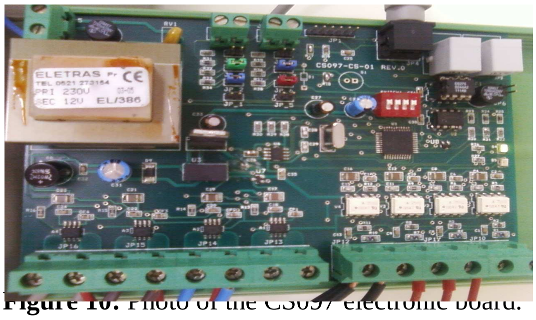

Figure 10: Photo of the CS097 electronic board.

6.1 CS097 experimental testing results

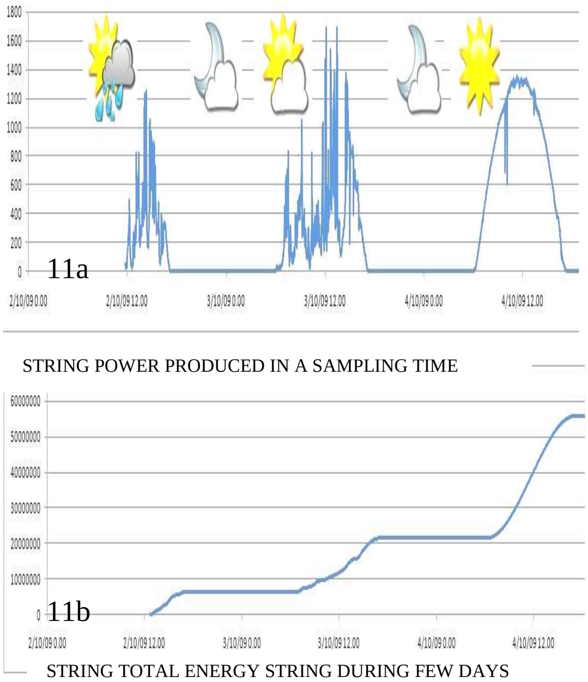

Figure 11: instantaneous power and total energy produced by a photovoltaic string and acquired by CS097 electronic board.

Figure 11 shows the trends of the instantaneous power and total energy detected on a photovoltaic string, during three days with different climatic conditions, using the CS097 data acquisition board. The continuos variations of the graph in figure 11a are due to the slow changes in the weather conditions, while the nighttime is obviously characterized by no energy production. As it can be seen from the second graph (figure 11b), the total energy produced by the string during the course of a day is greater in a day characterized by an almost always clear sky.

6.2 CS083-CS088 experimental testing results

Figure 12 shows the results of an experimental test of the CS083-CS088 alarm system. The aim of this test was to verify whether the board was able to identify the critical condition, typical of theft of one or more modules. In this way the test was conducted mainly during the nearly dark hours, whereas these are the most critical hours for thefts. To verify that the system was able to notice the critical condition of alarm, the condition of a theft has been recreated, first shorting only one module, then two modules. Thus the reaction of the system was detected on the PC. From acquired samples we noted that during the first "attempted theft" of the module, there is a voltage lowering, measured by the board, then the return to normal operation when the short circuit is removed. The difference between the voltage level before and after the theft is even more pronounced during the second test, with the short circuit of two modules.

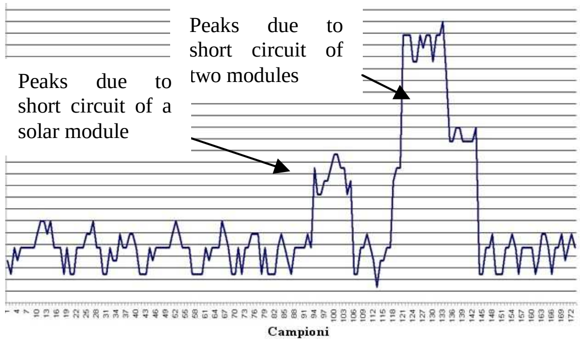

Figure 12: Testing of the alarm system CS083-CS088, string tension developed during the simulation of a robbery.

7 Conclusion

Two different applications of remote control of a photovoltaic system were presented in this paper. In one case, an electronic board, CS097, acquires electrical and environmental parameters and allows to control the production of the plant from a remote station. With the application of the system composed of the CS083 and CS088 electronic boards, instead, an alarm mechanism [anti theft mechanism] is implemented, it is active both during the daylight hours and the nighttime, and able to detect possible false alarms, resulting from changes in weather conditions and therefore brightness.

8 Acknowledgements

The development of the data acquisition system, and of the alarm system for photovoltaic generators is supported by Cavalera Sistemi S.r.l., Galatone (LE).

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