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Monitoring System for a Solar Photovoltaic and Thermal Concentrator Plant

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***Abstract* – A practical demonstration of a monitoring system for PV/T concentrating system is presented in this paper. The solar module under test is a PV/T double axis concentrating system using a primary spherical reflector and a secondary parabolic reflector. The overall system can provide both electrical and thermal energy. The concentrating system and the monitoring system have been developed under the European Community grant of UPPSol (Urban Photovoltaics: Polygeneration with Solar Energy). The presented monitoring system, based on a main central processor, is able to monitor both electrical and thermal characteristics acquired from the solar and thermal plant.**

I. INTRODUCTION

In recent years, many solar concentrating systems have been developed to reduce of silicon needed when compared to the traditional linear photovoltaic modules [1]. The concentrating unit used as device under test is devoted to actually provide simultaneous thermal and electrical power production from solar energy. This device has been developed and built by SHAP, a partner of European project UPPSol (Urban Photovoltaics, Polygeneration with solar energy). The hybrid energy generation implies a tradeoff between the electrical and the thermal production.

The main idea on concentrating systems is based on generation of electric energy at a lower cost than a linear solar module. This can be actually experimentally compared and verified if the behavior of the concentrating module during actual operating condition is well known.

Monitoring system for linear solar photovoltaic plants have been widely developed [2]. Some data on concentrating photovoltaic tested in laboratories [3] are available, but experimental data on concentrating plants are nearly missing. Only a few concentrating systems have been experimentally tested under practical operating condition for a relatively long time operation [4].

One more need of “liquid” cooled concentrators, and therefore, hybrid electrical and thermal modules, is that a cooling system malfunctioning can result in solar cells damage due to an excessive operating temperature. This is avoided if the solar collector is moved out of the focus, once cooling system fault occurs. This operation is known as module defocusing.

The significance of the paper is that a modular and general purpose monitoring system architecture developed for a concentrating system is presented. This system provides an overall knowledge of the plants operation and also provides plant safety; a defocusing procedure has been included on control procedure.

The system presented in this paper is able to monitor many single devices independently. The data acquired from the monitoring system are storaged in a central workstation remotely connected to the monitoring system.

The developed system allows a dual mode data storage access: the first one is the “real-time” mode, the second one is a “deferred” mode. These two modes allow the users to analyze the energy production and plant behavior instantaneously or analyze the recorded data, respectively. The main unit of the monitoring system can handle the two presented modes for all the sensors and connected devices.

High power production is mandatory for renewable energy power plants; therefore, the monitoring system power consumption is a crucial aspect [5-7]. Particular attention has been given to the sensors used to acquire the data. The use of triple junction PV Cells [8] working in the concentrating field requires a constant and reliable measurement of the cell temperature. Particular attention has also been given to the sensors positioning inside the solar concentrating module.

The collecting data are stored in a relational database that can provide different analysis to the data. The monitoring system is also required to control the solar plant and to move the solar collector in a safe state in case of fault or dangerous situations. When dangerous

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situations occur, the monitoring system is able to generate email and SMS alert message to the administrators to prevent damages for the collectors and, especially for the photovoltaic cells.

II. SOLAR MODULE AND SAFETY AND MONITORING SYSTEM

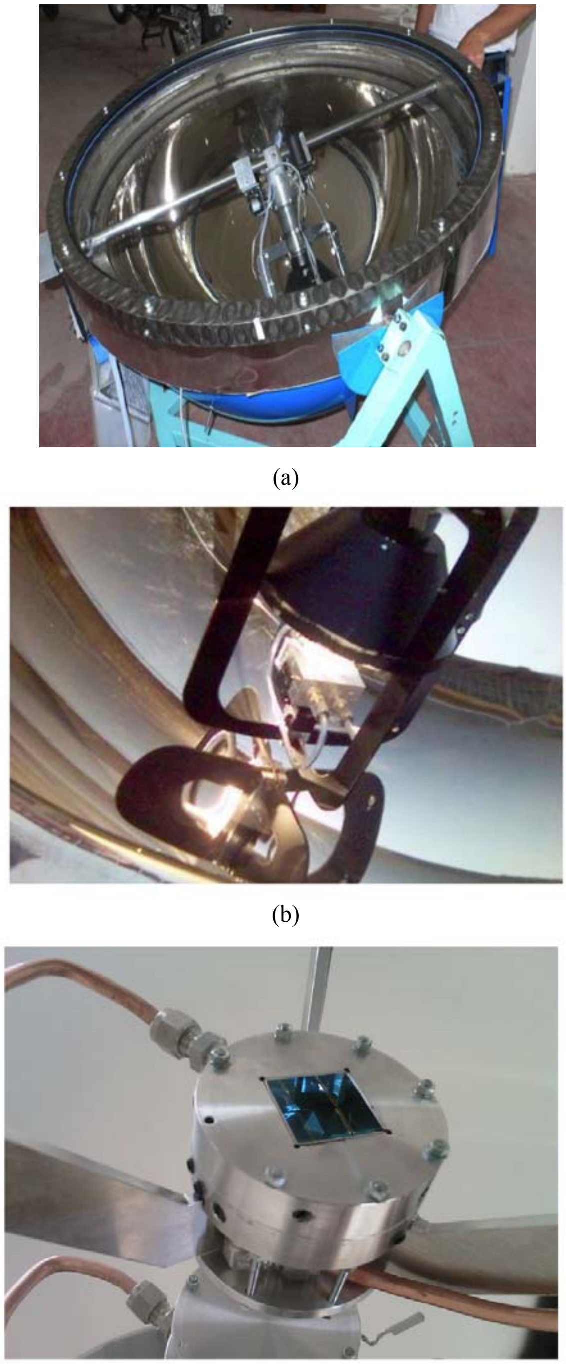
A. Solar Concentrator

The concentrating called Building Integrated Spherical Collector (B.I.S.C.) shown in Fig. 1 (a) has been developed under the EU project UPP-SOL to be integrated beyond a house roof. The B.I.S.C. is a 300x concentrating system is a double axis tracking, double reflection, concentrating PV/T system, which uses a primary spherical reflector that concentrates the sun radiation to a secondary parabolic reflector (Fig. 1(b)). The solar receiver (Fig. 1(c)) consists of the homogenizer used to recover the thermal energy and a a matrix of 9 (3x3) 14x14 mm triple-junction (Ge-I-GaAs) photovoltaic cells are produced by CESI (Centro Elettrotecnico Sperimentale Italiano). These cells are mounted on an aluminum nitride substrate. This substrate is mounted on an aluminum heat exchanger that allows a high thermal transfer from the PV cells to the thermal fluid. The single collector technical data are shown in Table I.

Table I. Collector Characteristics

Primary Optic Diameter	1000mm
PV cells area	9 cm^2
Collector Area	0.785 m^2
Rim Angle	43°
Shadows	7%
Collector active area	0.31 m^2
Reflection Efficiency	75%
Incident Power	232W
Electrical Efficiency	27%
Electric Power	62 We
Thermal Power	136 Wt

High thermal energy is produced and recovered by a proper thermal fluid that flows under the PV cells. The thermal fluid is regulated with a pump and monitored with a mass flow sensor. During overheating case, the monitoring system is able to grow the flow rate of the thermal fluid to decrease the operating temperature of the solar cells by acting on the pump. If the overheating exceeds the permitted working temperature of the triple junction cells, the monitoring system brings the fault of the solar module, or entire solar string, in a safe state to prevent solar cell's damage. During fault case (for example if sensors are disconnected), the monitoring system generates error messages using module channels scanning operation, so the monitoring system can generate warning messages in order to prevent any future dangerous situation.



(a)

(b)

(c)

Fig. 1. B.I.S.C. Solar concentrator. (a) Prototype. (b) Secondary Reflector. (c) Receiver.

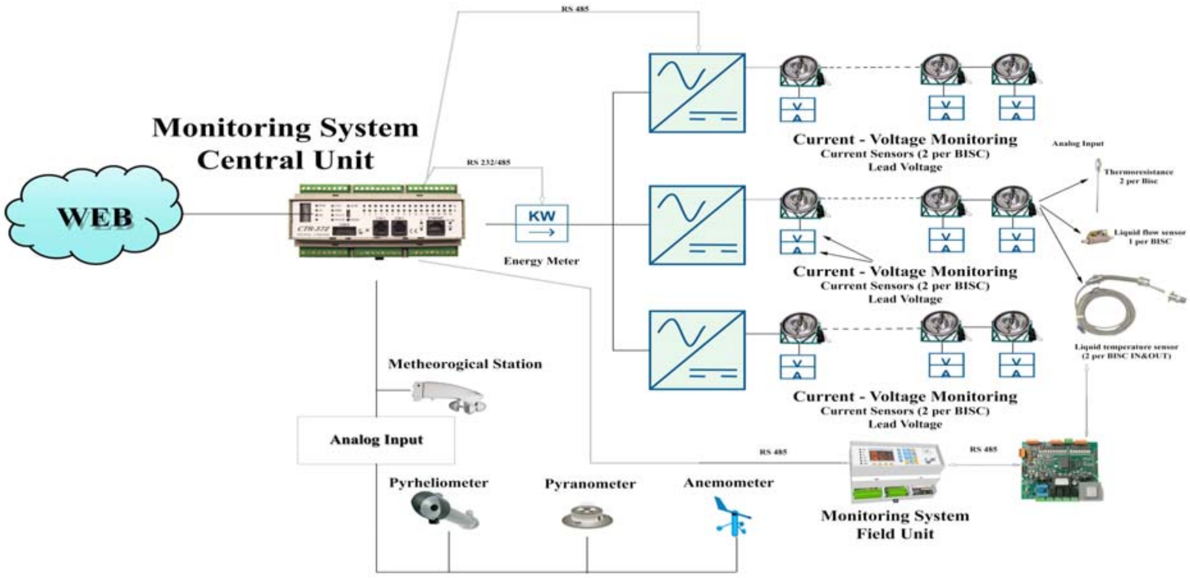


Fig. 2. Data acquisition scheme.

B. Monitoring System

An overall view o the monitoring system is given in Fig. 2. This system has been designed to provide information on each solar concentrator operation and compare them with environment parameters such as solar radiation, temperature, wind speed etc. This requires a large amount of signals to be acquired but can provide a high number of information from the solar plant. Each module voltages and currents, temperatures and inlet-outlet thermal fluid temperatures are acquired. The temperature of the thermal fluid used to recover the thermal energy is controlled with a pump monitored by a flow meter. The comparison between electrical power produced from the solar concentrators and the effective energy delivered to the grid is monitored acquiring data from commercial inverters. As shown in Fig. 2, the environmental data are also monitored and acquired by the monitoring system; a pyranometer and a pyroheliometer are installed to monitor the global and direct sun radiation, respectively.

The sensors used in the monitoring system are:

a) Thermoresistances: used to monitor the cell temperatures.
b) Two thermocouples are used to monitor inlet and outlet thermal fluid temperature of each solar module.
c) Flow meters are used to sense the small volumetric flow rates of fluid. These sensors have 0-5 V_{DC} analog output. The operative range is 1 to 10 ml/min, and the accuracy is ± 3% of full scale;
d) Hall effect based current sensors are used to achieve contactless current measurements. The CSLH series sensor characteristics are:

Sensed current range accuracy: ± 9 %
Response: 3 µs

The solar module power output is monitored by a programmable converter working in the 4-20 mA range. The monitoring system acquires current values by an Analog to Digital converter.

All acquisition modules and sensors has been calibrated and tested to reduce the measure errors.

C. System Monitoring System Hardware and Architecture

The main operations that the monitoring system must provide are:

a) Acquiring data from the plant;
b) Make plant data available as a website.
c) Monitoring the electrical and thermal performances of the solar plant, its power generation and the building energy consumption;
d) Controlling the solar collectors to prevent collectors damages.

The monitoring system architecture is based on a PLC processor unit handling the field signals and the secondary field signals. Sensors and environmental devices installed on solar and thermal plant allow data acquisition and a database setting-up. Specific software tools and PLC programming have been developed to store the data acquired, to make the data readable also by remote sites, and to get a plant representation as a web site where acquired data are available. The access to the website is allowed by user authentication.

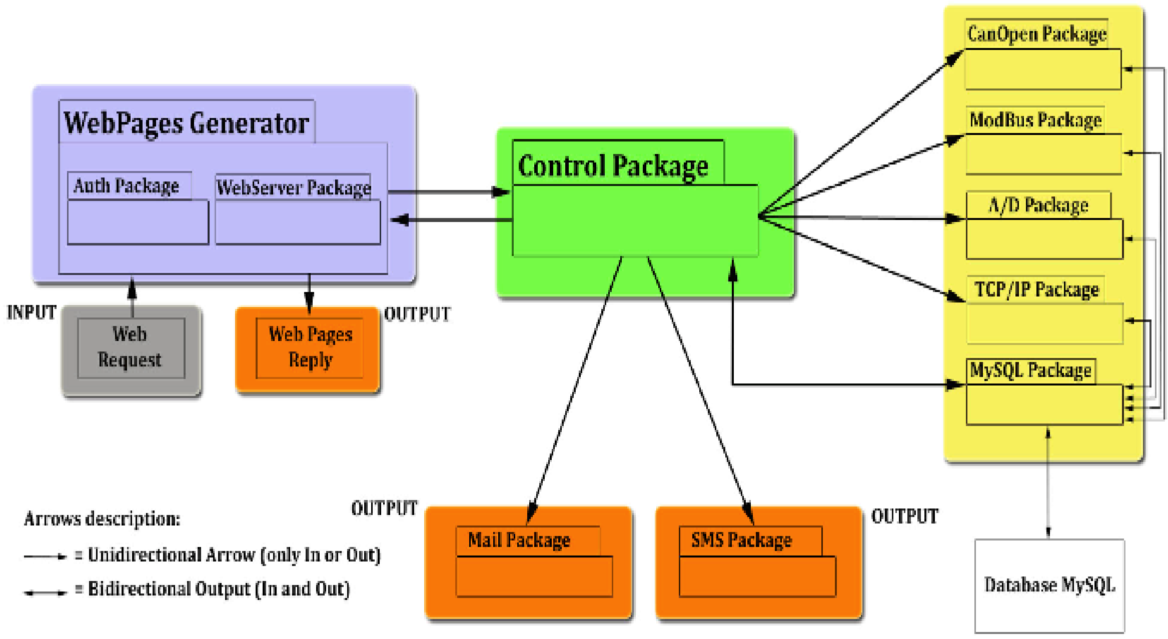


Fig. 3. Monitoring system logical architecture.

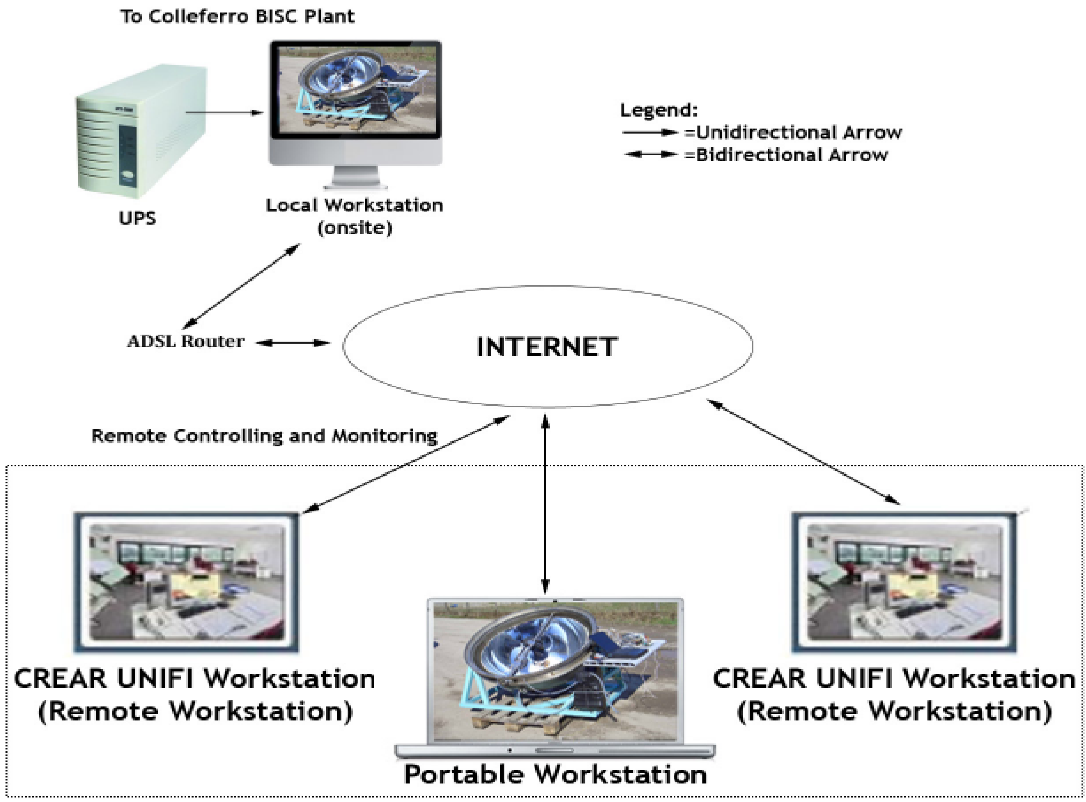


Fig. 4. Monitoring system layout

Fig. 3 shows the monitoring system web access and interrogation request. When a web request is established, the user authorization package is activated. Only authorized users can access the monitoring system website. Once the web request is established, the user authorization package is activated. The user authorization allows the access to the control package through the Web server package. The entire monitoring system request is forwarded through the control package at the monitoring system, and the results are shown to the relative web page. The control package manages all the monitoring system instructions and if some fault occurs, an error message is sent to the system administrators by e-mail or by SMS.

The control package is interfaced with the MySQL package recording all the data obtained by the control package instructions into the MySQL database. The access to the MySQL database could be done by the control package activated by the WebPages Generator.

The packages are:

a) CanOpen Package: All the devices connected with the Canopen Protocol;
b) Modbus Package: All the devices connected with the Modbus communication protocol;
c) A/D Package: All the analog and digital sensors that are connected to the PLC;
d) TCP/IP Package: Package that manage all the signals with a TCP/IP communication protocol;
e) MySQL Package: With MySQL package

The interaction between monitoring system and local/remote workstation is shown in Fig. 4.

The local workstations installed on site are directly connected to the monitoring system hardware. Here bidirectional arrows represent the two directional communications between two devices, (e.g., each remote workstations can be connected to local workstation and exchange data with this, the same operations can be done in the opposite direction). Both remote and local website access are allowed to authorized users to the monitoring system plants. The local workstations are directly connected to the PLC rack. By using a ADSL router, the interface between monitoring system local workstations and remote user is ste-up. The UPS system connected to the local workstations prevents power off state, and eventually disconnected state of the monitoring system to the remote users. The UPS indicated on Fig. 4 and the UPS connected to the rack PLC are different, the UPS shown in Fig. 4 is embedded for the local workstation. Only few query instructions are programmed on the monitoring system hardware devices in order to reduce occupied space on internal memory. The acquired data are sent to the data storage (recorded on the remote workstation) and all the analyzed instructions are demanded to the local and remote workstation. By using this solution a very large amount of data can be acquired, recorded and analyzed. The monitoring system hardware is programmed to acquire signals and to monitor any system faults or errors. Fig. 5 shows some output displayed by the monitoring system.

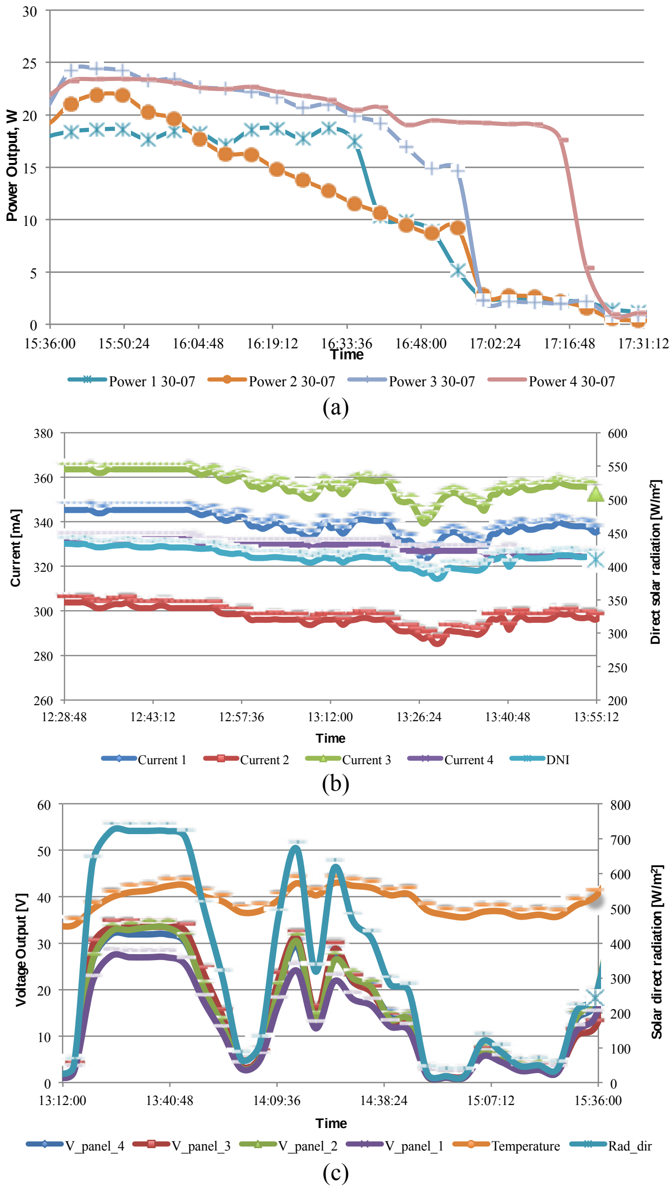


Fig. 5. Monitoring System Output. (a) Power output of each collector around sunset time. (b) Collector currents and Direct Solar Radiation. (c) Collector voltages, solar radiation and temperature

Fig. 5(a) shows the plot of each solar concentrator electrical output power over several days. Fig. 5(b) shows the plot of several concentrator unit output current along with the solar irradiation monitored over some hours time period. As expected, the concentrator unit output currents are proportional to instantaneous solar radiation. Fig. 5(c) shows the plot of the concentrator units output voltages along with solar radiation over some hour time period. Actually a solar cell output voltage highly depends on its operating temperature and cell shadowing and it is nearly independent from solar radiation. This explains the plot shown in Fig. 5(c).

III. CONCLUSIONS

A monitoring system architecture used to monitor PV/T solar plant performances has been presented in this paper. The proposed monitoring system permits the analysis of both thermal and electrical signals acquired from the solar and thermal plant. All sensors needed to monitor performances of solar plants have been chose. The analogical signals are acquired by the analog –to-digital converter modules and sent to the database. The data are stored on relational database, which permits different and related analysis. The access to the stored data is allowed from a website and can be done "on Site" (using local workstation installed on power plant site) or "remotely" by connection to the website of the monitoring system. The hardware used allows upgrading and extending the dimensions of number of signals acquired from the solar field.

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