

7P-B3-02

## MONITORING OF REMOTE PV-SYSTEMS VIA SATELLITE

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### ABSTRACT

A vast majority of autonomous PV systems are used to supply electricity in regions with no grid, no telephone coverage, and often with difficult accessibility. Commonly systems in such regions are supervised by yearly visits in conjunction with a data logger. Over the lifetime of a PV system costs for supervision often exceed the cost of the system itself. Response time for failures is very poor. To overcome these disadvantages a data satellite transmission system was set up. It is compatible to the ARGOS protocol, facilitates small transmitters and has full equatorial coverage. The satellite data is transferred from the ground station to the Internet, providing worldwide access via WWW. The advantages are manifold: Sponsors (NGOs, foundations, World Bank, public etc.) have an immediate access to the projects, manufacturers can use the data to improve their products, and the online monitoring system may provoke more public interest in the PV area.

During the lifetime of a system the costs for that type of supervision significantly exceeds the cost of the system (e.g. monitoring for NE Brazil). Travel expenses and personnel for each yearly read-out of the data logger costs 600 €. Over 20 years this results in 12,000 € just for the minimum of a system's lifetime. For a read-out every 6 months, as done in many projects, these costs even double. These high service costs often inhibit installation of new systems. Also response time for maintenance, repair and product improvements is very long. So the necessity to constantly monitor PV-systems is evident. To transmit the data over long distances from remote sites the use of satellites is beneficial. The first project which monitors PV-power-stations via satellite is located in a remote fishing village called Apiques near Beleia, in the Northeastern state of Ceará, Brazil. The scheme of transmission from that site to the satellite (uplink) is shown in Figure 1, the scheme of transmission from the satellite to the ground station (downlink) and the publication are given in Fig. 2.

### 1 INTRODUCTION

A major part of PV applications are autonomous electrical supplies in regions with no grid, no telephone lines, no cellular phone coverage, and often with difficult accessibility by common transport. Commonly in such regions PV systems are supervised by yearly visits in conjunction with a data logger.

### 2 MONITORING BY SATELLITE

#### 2.1 The ARGOS system

The satellite system has to transmit approximately 10 bytes of measured data every 15 minutes. For this purpose a common telemetry-satellite-system called ARGOS is used.

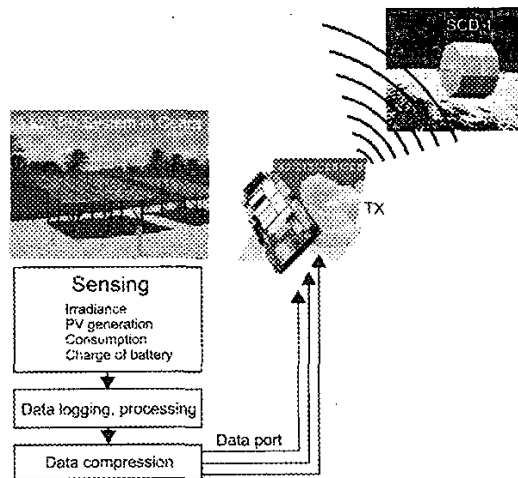


Fig. 1 Scheme of PV Satellite Monitoring System: Uplink with data acquisition, Satellite-Data-Collection-System ARGOS-SCD.

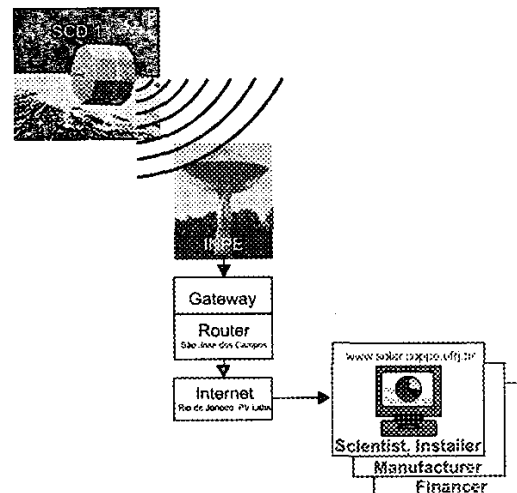


Fig. 2 Scheme of PV Satellite Monitoring System: Downlink with SCD, ground station at INPE, worldwide publication via WWW.

ARGOS was set up in the Seventies for scientific purposes to collect environmental data and is used for atmospheric and oceanic measurements and is even applied for telemetric purposes in zoology. The transmitters, called PTT (platform transmitter), are very small and can be interfaced with sensors to collect data (see Fig. 3).

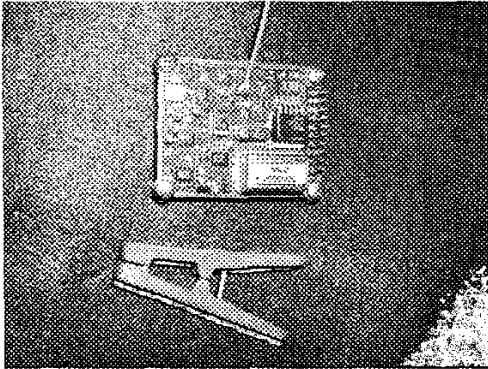


Fig. 3 ARGOS Platform-Transmitter (PTT).

The devices can also be localized up to an accuracy of 130 m by calculating the Doppler shift - for example to observe the movements of animals. They permanently send their data-messages (identified by the unique PTT address) without feed back from the satellites.

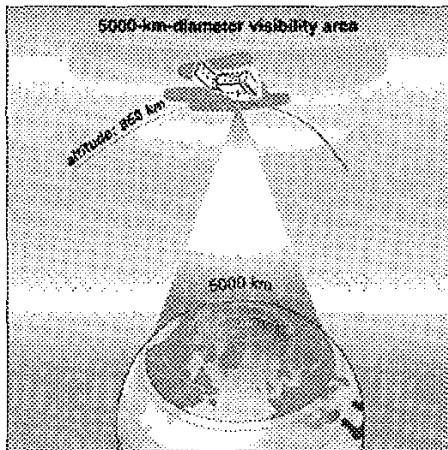


Fig. 4 ARGOS low orbit satellite system, polar orbit version.

The system works together with low orbiting satellites at an altitude of 850 km (see Fig. 4). Their orbital planes rotate about the earth from north to south. One complete earth-revolution takes about 100 min. Although there are 14 original ARGOS satellites in orbit, only two or three are applied to perform monitoring functions. Data collected by these satellites is transported to France (Toulouse) or the United States (Wallops and Fairbanks) for processing. The satellites have a visibility circle of about 5000 km diameter, which covers the whole of Brazil. Contact time is between 8 and 12 minutes with a

transmission-rate about 32 bytes. Because of the near-polar orbit, the number of daily passes over a transmitter increases with latitude. At the poles, each satellite passes about 14 times, at the equator about 4 times during 24 hours.

## 2.2 ARGOS-SCD

The Brazilian ARGOS-SCD system is compatible to ARGOS, but the satellites have a different orbital plane. Brazil uses two satellites (SCD-1, SCD-2), which fly equator-parallel and cover the whole of Brazil. The system permits up to 14 contacts per day. The satellites send the collected data directly to the ground-stations; the main ground station is in São José dos Campos near São Paulo. From there the data which contains a receiving-time time stamp will be distributed via internet to the user. For this project, the use of the Brazilian ARGOS-SCD-System is for free. The ARGOS-SCD system is controlled by INPE (Instituto Nacional de Pesquisas Espaciais).

Nominal uplink frequency:	401.65 MHz
Message length:	up to 32 bytes
Repetition period:	45 s to 200 s
Transmission time:	360 to 920 ms
Transmission power:	1 up to 2 W

The quality of transmission depends on the location; often the transmitter-data interferes with other transmitters. To avoid errors, redundancy is necessary. The rate of transmission repetition required varies and depends on the location. To overcome the limit of 32 bytes per contact it is possible to use more than one address (multi-ID), maximal up to 4 simultaneously. In Brazil the satellites are sending the received data directly to the ground-station, which consumes very little time. This makes it possible to send more than 32 bytes via one address by using small repetition times which allows for several transmissions during one contact period (e.g. 60 s). This allows our transmission system to send two different 32 byte-data-packets (coded with an address in the data to differentiate the packets) during one contact. But in general it is safer to use more addresses to transmit packages containing more than 32 bytes because the transfer of the PTT-ID has a higher reliability than the data.

## 2.3 Transmission

The analogue sensor signals are digitalized, averaged over 15 minutes, processed (see 2.4) and then sent to the send-buffer of the transmitter. The transmitter sends the content of the buffer, independent of the measuring time, every 30 to 40 seconds. When the measuring-time is over, the new measured data will replace the oldest measuring data sets (see Fig. 1). The satellite data is transferred via ftp from the ground station in São Jose dos Campos to the server of the PV-Labs at UFRJ in Rio, and is published from there worldwide via WWW (see Fig. 2). The system permits 12 to 14 satellite contacts per day, at the transmission rate of 32 bytes per contact.

## 2.4 Processing

The poor data-transmission of 32 bytes every 100 minutes (in average) can be overcome by using more than one transmission-channel (Multi-ID) and by using smart

data pre-processing (e.g. nonlinear ADC-characteristics) which extracts the information needed to supervise a PV system in terms of yield, usage, and battery state. Figure 5 (see also Figures 1, 2) shows the configuration scheme using a multiplexer for the selection of the signal and a micro controller for processing. The nonlinear conversion characteristics means that the more relevant range of the values are coded with a relatively high resolution, while other parts are coded with less resolution. E.g. in the case of the battery voltage, the value range between 22 V and 30 V is the most relevant, while the ranges < 22 V and > 30 V are less relevant. Thus the resolution of the analog to digital coding can be reduced for operational points that are farther away from standard. Also the battery voltage does not change very fast so a lower temporal resolution can be utilized. Other values, such as the load current, can change very rapidly, which requires a higher temporal resolution in order to avoid losing accuracy while carrying out energy analysis.

**2.5 Device Description**

The device is designed to facilitate monitoring of different kinds of renewable energy systems. It consists of a micro-controller including an EEPROM, an integrated A-D-converter, and an extra high resolution A-D-converter. It is configured by a serial port and provides several analog inputs. All analog inputs pass the input-multiplexer before being conditioned by the differential amplifier and a low-pass-filter (see Fig. 5). Therefore just one amplifier and one filter is necessary - the adjustment for each input is carried out by software. The main A-D converter is a quad-slope high-resolution A-D converter (17 bit plus sign), so for the maximum resolution used (11 bit) it is not necessary to adapt each channel for the demanded input-range by additional hardware (e.g. potentiometer) - if they do not exceed the maximum input of 12 V. The integrated A-D converter has just a 10 bit resolution and assists the main-converter for fast sampling demands (e.g. AC measurements). It is also utilized for redundancy and to control the power supply of the device. The controller manages the measurements and controls the transmitter; during a sending period the measurements have to be interrupted. The micro-controller handles all analog inputs and also serves to combine measurements to measure power ( $I \cdot U$ ).

**2.6 Specifications**

Analog inputs

- 6 differential, 3 single-ended inputs
- 1 isolated, single ended, +/- 12Volt
- Voltage Range: max. ±12V
- Resolution 1: max. 10 bit / 70 µs or ±9 bit each channel
- Resolution 2: max. 17 bit / 133 ms each channel

Digital inputs

- 2 positive polarities, 2 inverted polarity
- Range: up to 220 V AC/DC
- Isolation: 500 V AC

- Supply 18 to 36 V DC
- Consumption: max. 3 Watt

Satellite-Transmitter

ARGOS-PTT ULT-01, 2 Watt, max. 4 addresses

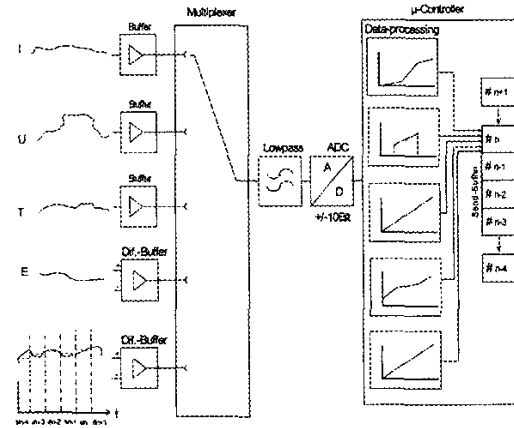


Fig. 5 Schematic of sensing and processing unit.

**3 PROJECT SITE**

The first project using the satellite monitoring system is a 5 kW<sub>p</sub> PV-System close to Baleia (Federal State of Ceará), in the North of Brazil. The system feeds a ice making unit used to cool fish and works autonomously. It consists of two PV panels (2.5 kW<sub>p</sub> each, see Fig. 6), four charge controllers (24 V, 50 A each, see Fig. 7), a 24 V battery system, and a DC-AC inverter (5 kW nominal).

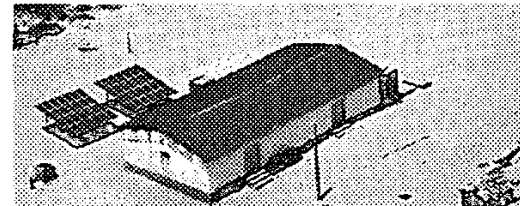


Fig. 6 Installation site at Apiques, close Baleia, NE-Brazil: building of the PV powered ice manufacture and the two PV panels (2.5 kW<sub>p</sub> each).

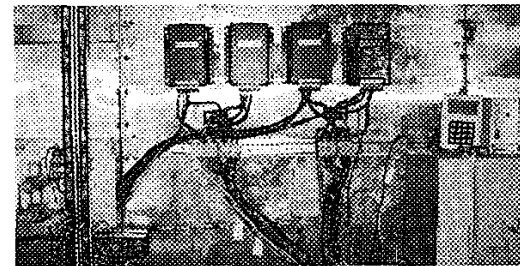


Fig. 7 Charge controllers with the Hall-effect current sensors (center) and at the satellite device (on the right) during installation.

The measured data ranges for this project are:

Irradiance:	0 - 1200 W/m <sup>2</sup>
PV-panel 1 power output:	3.0 kW (30 V, 100 A)
PV-panel 2 power output:	3.0 kW (30 V, 100 A)
Battery voltage:	22 - 30 V
Battery power max:	9 kW (30 V, 300 A)
Inverter output max:	6.25 kW (250 V <sub>AC</sub> , 25 A <sub>rms</sub> )

The resolutions of the measurements are set to 8 and 10 bits, the transmitted temporal resolution used is 15 minutes, requiring two ARGOS transmitter addresses simultaneously.

#### 4 COST COMPARISON

Initial costs for the transmitter (ca. 1,000 €) and the pre-processing unit (ca. 500 €) are realized after two years of usage by savings in travel expenses for the yearly supervision of the systems. Table I gives a cost comparison between the conventional approach via data logger versus satellite monitoring. Cost savings over the system's lifetime are more than 10,000 €.

**Table I:** Cost comparison of conventional monitoring (data logger) with satellite monitoring over a period of 20 years for a remote PV system in Brazil (without development costs).

Type of cost	Conventional data logger	Satellite monitoring
Equipment	1 · 1,000 €	1 · 1,500 €
Transportation	20 · 500 €	1 · 500 €
Personnel	20 · 50 €	1 · 200 €
Accommodation	20 · 50 €	1 · 150 €
Total costs	13,000 €	2,350 €

Data transmission costs are not applied to a limited number of monitored systems, due to an agreement between INPE and UFRJ-COPPE. While the investment for the equipment is considerable, it is – aside from the scientific concern - more recommendable for bigger systems or for micro grids. A further application of the system is the energy metering and billing.

#### 5 CONCLUSION

Monitoring renewable energy systems in remote areas is essential in order to guarantee reliable operation. A lack of infrastructure in these remote areas does not allow telephone or radio transmission of measured data. Periodic visits of the power plants or SHS are prohibitively expensive or in many cases not practicable.

Transmission of data for remote PV systems via satellite is a feasible and efficient way to monitor renewable energy systems. The transmission system presented has a

sufficient transfer rate that allows for hourly monitoring. Early recognition of failures saves money and improves the reliability and reputation of renewable energy power supplies. Manufacturers can use the data to improve their products by adapting them to real operating conditions. Sponsors (NGOs, World Bank, foundations, public etc.) have immediate access to the projects ("*Where did my money go?*"), which creates more confidence in the carrying out of projects. Also, the online satellite monitoring system helps to attract more public interest in the PV area by promoting its usefulness via the WWW.

#### 6 ACKNOWLEDGMENTS

The authors are expressing their sincere thanks for the support from INPE, Brazil and Würth Solar Ltd., Germany. Thanks also to Keith Parsons for text revisions.