COST REDUCTION AND INCREASE OF RELIABILITY FOR REMOTE PV-SYSTEMS BY SATELLITE

S.C.W. Krauter & T. Depping
Universidade Estadual de Ceará, Departamento de Física, Grupo de Energias Alternativas
Av. Parajana 1700, Fortaleza 60740-000 CE, Brazil
Tel/fax: +55-85-2992804, E-mail: krauter@uece.br

ABSTRACT: A majority of autonomous PV systems are used to supply electricity in regions with no grid, no phone coverage, and limited accessibility. Commonly, systems in such regions are supervised by 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. From the PV system site the most relevant data—such as irradiance, PV generation, state of the battery and load—is collected and sent to the ARGOS-SCD satellite. The satellite data is transferred from the receiving ground station to the Internet, providing worldwide access via WWW. The advantages are manifold: sponsors (NGOs, foundations, public, etc.) have an immediate access to the projects, manufacturers can use the data to improve products, and the online monitoring system enables more public interest in the PV area
Keywords: Monitoring, Rural Electrification, Reliability.

1 INTRODCTION

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. 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 h. Over the 20 year period that constitutes the minimum lifetime of a system, this results in an expenditure of12,000 h

For a biannual read-out, as done in many projects, these costs even double. These high service costs often inhibit installation of new systems. Response time for maintenance, repair and product improvements is very long, necessitating the constant monitoring of PV-systems.

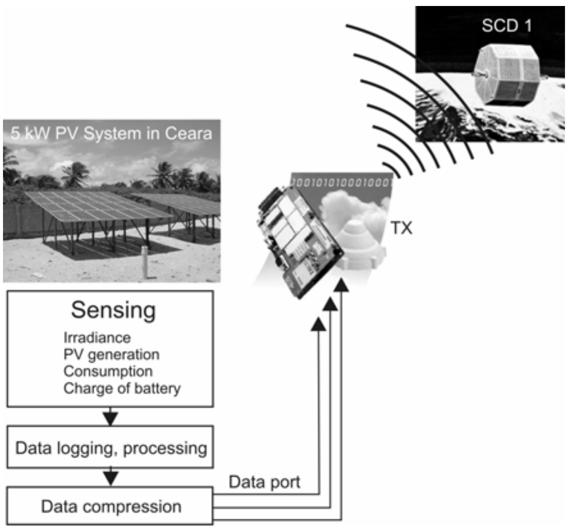

Figure 1: Scheme of PV Satellite Monitoring System: Uplink with data acquisition, Satellite-Data-Collection- System ARGOS-SCD.

Satellites have facilitated the transmission of this data over long distances, and the first such project which monitors PV-power plants via satellite is located in a remote fishing village called Apiques near Baleia, 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 on the internet are given in Figure 2

2 PV-MONITORING VIA SATELLITE

2.1 Selection of the system

The first step is to compare the different satellite transmission systems and select the one best suited for monitoring remote PV-systems. An ideal satellite transmission system should have the following properties:

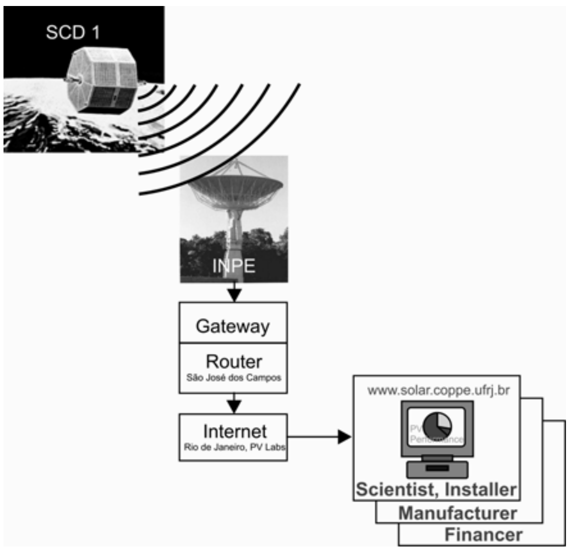

Figure 2::Scheme of PV Satellite Monitoring System: Downlink with SCD, ground station at INPE, worldwide publication via WWW.

1. The satellite system should work well over the ‘‘sun-belt’’ region around the equator. Unfortunately, due to present commercial viability, most systems are not capable of functioning in this region because they are set on orbits plus or minus 30 degree of the equator.

2. The total system cost (including hardware, energy costs, monthly fees and transmission costs) should be as low as possible. Often systems have a relatively low initial cost, but have high monthly expenditure or offer obligatory features (e.g. bidirectional communication, high bandwidth, etc.) which have to be paid for. Beware, over the projected lifetime of the PV-system these features can become very costly.

3. Provider should enable internet publication of the transmitted data.

With these parameters in mind a Brazilian version of the advanced research and global observation satellite (ARGOS) system was selected. The Brazilian ARGOS (called ARGOS-SCD) features two satellites in equatorial orbit, free data transmission, touts wide use and is reliable. Other systems such as Orbcom and Globalstar are more modern but have fixed costs of at least 10–15 h/month and occasionally have poor equatorial coverage. Since the future of the Iridium system and TUBSAT [3] is uncertain they were not taken into consideration.

2.2. The ARGOS system

ARGOS was first used for maritime research and animal tracking. ARGOS is a unidirectional system and uses platform transmitters (PTT) that are very small and can be interfaced with sensors to collect data [4].

Energy consumption is relatively low due to sensitive receivers located on the satellite and pulse transmission (2 s followed by a break of 3 min). HF-power output is below 1W. The PTTs continuously send data-messages (identified by the unique PTT address) and do not receive feedback from the satellites. By calculating the Doppler-shift PPT devices can be located with an accuracy of 130 m. This option is a helpful deterrent to theft [4, 5]. The system works in conjunction with low orbiting satellites at an altitude of 850km. Their orbital planes rotate about the earth from north to south at the original ARGOS. 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 min 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 four times during 24 h.

2.3. ARGOS-SCD

The Brazilian ARGOS-SCD system is compatible to the original ARGOS, but the satellites are on different orbital planes. Brazil uses two satellites (SCD-1, SCD-2), which fly in parallel to the equator and cover the whole of Brazil. The system permits up to 14 contacts/day. The satellites send the collected data directly to the ground-stations; the main ground-station is in S*ao Jos!e dos Campos near Sao Paulo. From there the data containing a reception-time log stamp is distributed via internet to the users. For this project, the use of the Brazilian ARGOS-SCD system has been made available for free. The ARGOS-SCD system is controlled by the national space research institute INPE (Instituto Nacional de Pesquisas Espaciais).

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

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/contact and address, it is possible to use multiple addresses (multi-ID), with a maximum of four IDs. In Brazil the satellites send the received data directly to the ground-station, consuming very little time, making it possible to send more than 32 bytes via one address by using small repetition periods which allow for several transmissions during one contact period (e.g. 60 s). This allows our transmission system to send two different 32-byte-data-packages (coded with an address in the data to differentiate the package) during one contact. But in general it is safer to use multiple addresses to transmit packages containing more than 32 bytes, as the transfer of the PTT-ID has a higher reliability than the data.

2.4 Transmission

Our system collects approximately 10 bytes of measured data every 15 min. The analogue sensor signals are digitalized, averaged over 15 min, processed and then sent to the send-buffer of the transmitter. The transmitter sends the content of the buffer, independent of the measuring time, every 30–40 s. 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 Sao Jose dos Campos to the server, and is published from there worldwide via WWW (see Fig. 2). The system permits 12–14 satellite contacts/day, at a transmission rate of 32 bytes/contact.

2.5 Data processing

The poor data-transmission of 32 bytes every 100 min (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. Fig. 3 (see also Figs. 1, 2) shows the configuration scheme using a multiplexer for the selection of the signal and a microcontroller for processing. The nonlinear conversion characteristics enable the more relevant range of the values to be coded with a relatively high resolution, while other parts are coded with less resolution. For example, in the case of the battery voltage (nominal voltage: 24 V), the value range between 22V and 30V is the most relevant, while the ranges o22V and >30V 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 have a high rate of change, 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 loosing accuracy while carrying out an energy analysis.

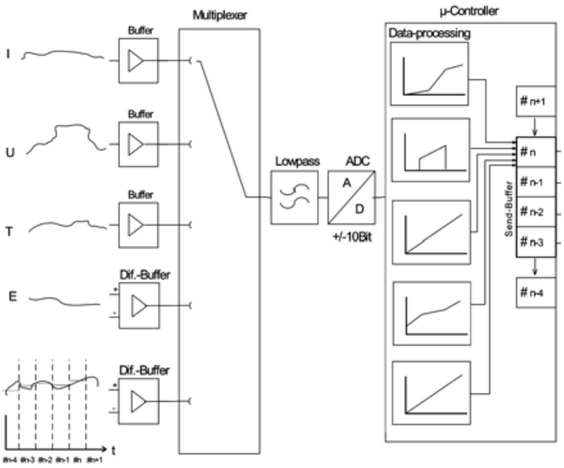

Figure 3: Schematic of sensing and processing unit of the satellite transmission system (I: currents, U: voltages, T: temperature, E: irradiance).

The device is designed to facilitate monitoring of different kinds of renewable energy systems. It consists of a microcontroller 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. 3). Therefore just one amplifier and one filter are 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 voltage 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. true RMS 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 microcontroller handles all analog inputs and also serves to combine measurements to measure power (*I* x *U*).

2.6 Specifications

Analog inputs

6 differential, 3 single-ended inputs
1 isolated, single ended, ±12 V
Voltage range: max. ±12V
Resolution 1: max. 10 bit/70 ms 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 230V AC/DC
Isolation: 500V AC

Supply 18–36 V DC
Consumption: max. 3 W
Satellite-transmitter:
ARGOS-PTT ULT-01, 2 W, max. 4 addresses

3. PROJECT SITE

The first project using the satellite monitoring system is a remote 5 kW_p PV-system close to Baleia (Federal State of Ceará), in the Northeast of Brazil. The system feeds an ice-making unit used to cool fish and works autonomously. It consists of two PV panels (2.5 kW_p each, see Fig. 4), four charge controllers (24 V, 50A each, see Fig. 5), a 24V battery system, and a DC–AC sine inverter (5 kW nominal).

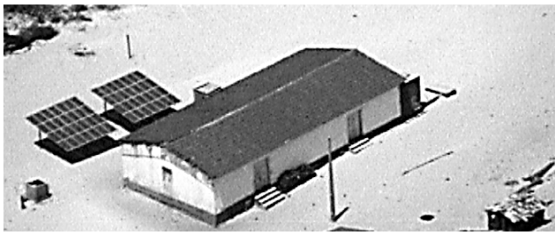

Figure 4: Installation site at the coast of Apiques, close to Baleia, NE-Brazil: building of the PV-powered ice manufacture and the two PV panels (2.5 kW_p each).

Figure 5: Charge controllers with the Hall-effect current sensors (center), enabling a current-balance for the batteries, and at the satellite transmission device (on the right) during installation.

The measured data ranges for this project are:

Irradiance:	0–1200 W/m^2
PV-panel 1 power outp.:	3.0 kW (30 V, 100 A)
PV-panel 2 power outp.:	3.0 kW (30 V, 100 A)
Battery voltage:	22–30V
Battery power max:	9 kW (30 V, 300 A)
Inverter output max:	6.25kW (250V_{AC}, 25A_{rms})

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

4. MONITORING RESULTS

Fig. 6 shows the plot of the voltage of the battery bank (nominal voltage: 24 V) during a typical day of operation transmitted via satellite. Fig. 7 also shows the transmitted records of global irradiance (measured by a CM 3 pyranometer in the plane of the PV-panel), together with the battery output power and AC power output (true RMS) of the inverter of that day. Not all data transmissions have been successful, but the remaining are sufficient to check the proper operation of the system. If the charge controllers used would enable Maximum–Power–Point–Tracking, which they do not do, studies of PV conversion efficiencies could be carried out, using the records of the actual irradiance on the plane of the PV panel. The transmitted records of the battery voltage allow to oversee the actual state-of-charge of the battery; the data of the inverter's DC input along with its AC output facilitates to study real-operating-condition conversion efficiencies. From Fig. 7 a DC to AC conversion efficiency of barely 81% can be derived, this is probably due to the high reactance (cos ρ = 0.7-0.8) of compressor engine in the ice machine.

5. COST COMPARISON

Initial costs for the transmitter (ca. 1,000 h) and the pre-processing unit (ca. 500 h) are realized after 2 years of usage by savings in travel expenses for the yearly supervision of the systems. Table 1 gives a cost comparison between the conventional approach via data logger versus satellite monitoring.

Table I Cost comparison of conventional monitoring (data logger) with satellite monitoring over a period of 20vyears 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 €**

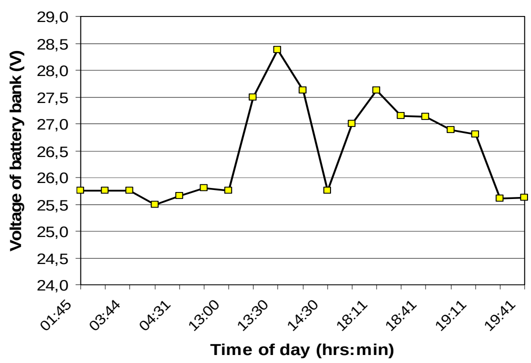

Figure 6: Satellite transmission record of battery voltage during a typical day of operation (13th of January 2003).

Cost savings over the system's lifetime are more than 10,000 h. Data transmission costs are not applied to a limited number of monitored systems, due to an agreement with INPE. For future projects these costs have to be taken into account. While the investment for the equipment is considerable, it is - aside from the scientific concern - more recommendable for bigger systems or for micro-grids while the benefits outweigh the costs within a shorter period of time. A further application of the system is the energy metering and billing.

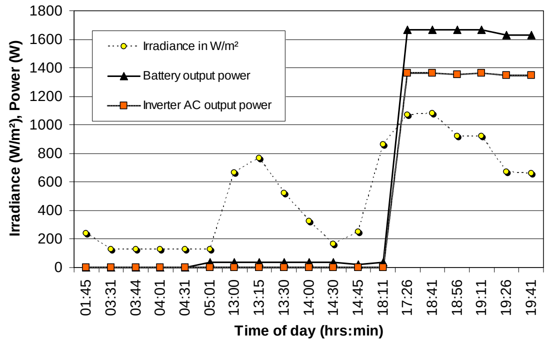

Figure 7: Satellite transmission record of irradiance, battery output and AC output of the inverter during a day of operation (1/13/2003).

6. 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 PV 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 an ample rate of transfer 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 actual operating conditions. Sponsors (NGOs, World Bank, foundations, public, etc.) have immediate access to the projects, which creates more confidence in the way such projects are implemented. Also, the online satellite monitoring system helps to attract more public interest in the PV area by promoting its usefulness via the WWW.

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