SolarPACES

Proceedings of the
10th SolarPACES International Symposium
on Solar Thermal
Concentrating Technologies

"Solar Thermal 2000"

Sydney, Australia

8 - 10 March 2000

part of the
Renewable Energy
for the
New Millennium
conference

ESAA
Electricity Supply Association of Australia Limited
ACN 052 416 083

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THE STAND-ALONE HELIOSTAT FIRST OPERATION RESULTS

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Abstract - The first Stand-alone Heliostat has been developed by CIEMAT and tested at the PSA facilities in Almería. This heliostat is an innovative approach to reducing the civil work costs in heliostat fields. Trenching, cables and other electric elements have been eliminated in the new heliostat. Thus, one $70m^2$, classical "T" glass/metal heliostat has been adapted to include all the new stand-alone concept components. A PV system is able to drive two sun-tracking DC motors between 5 and 24Vdc, 0 and 15A. The heliostat communicates with the control room at 400m distance by using a radio-modem working at 9600 baud. One anemometer, a wind switcher, irradiance and ambient temperature sensors have been installed on the heliostat for self-protection decision-making. A PV panel integrated within heliostat reflecting surface eliminates cabling and other elements required to conventional power supply. Cabling for communications between master control and local control has been substituted by radio-modem.

1. INTRODUCTION

Trenching, cabling and other land conditioning operations in large heliostat fields are a non-negligible economical factor to be analyzed during the design phase of Solar Thermal Tower Power Plants. A 10 MW tower plant with approximately 1000 heliostats (90 m^2 each) like the recent PS10 initiative in Spain is estimating an added cost of 1 million dollars due to heliostat cabling (Fernández, 2000), or in other words $\$11.1/m^2$.
As a new approach to minimize the problem, CIEMAT engineers have developed and tested a stand-alone heliostat prototype at the Plataforma Solar de Almería facilities (García, 1995; García, Egea and Gázquez, 1996; García, Egea and Gázquez, 1999). The solution applied with success may be used in the next generation of Solar Thermal Tower Power Plants (STTPP) and can be a definitive breakthrough to reduce civil works costs and remove all the existing grids of channels and wiring for power supply to the mechanical drives, signals and communications (Monterreal et al., 1997).
A number of autonomy concepts have been identified for the prototype:

Physical autonomy: Removal of canalizations and cabling that unbind the heliostat from physical restrictions.
Autonomy for solar vector calculation: Determination of solar vector and axes positioning during sun tracking unbinding the heliostat from the master control.
Autonomy for alarms and self-protection: Receiving some autonomous information on weather conditions and being able to handle self-protection and diagnosis.
Operational autonomy: Capability to perform pre-assigned operational cycles or accepting remote instructions.

2. HELIOSTAT DESCRIPTION

For the purpose of the first stand-alone tests, the COLON heliostat prototype developed by the Spanish company INABENSA has been used (Silva, Blanco and Ruiz, 1999), being representative of the already mature glass/metal technology ready for the first generation of commercial STTPP. The heliostat consists of a 70m^2 reflectant surface with two-axis Winsmith tracking system. A customized local control box has been designed to handle the two 240 W engines. The original 110 V engines have been replaced by 24 Vdc units fed by a PV panel and battery.

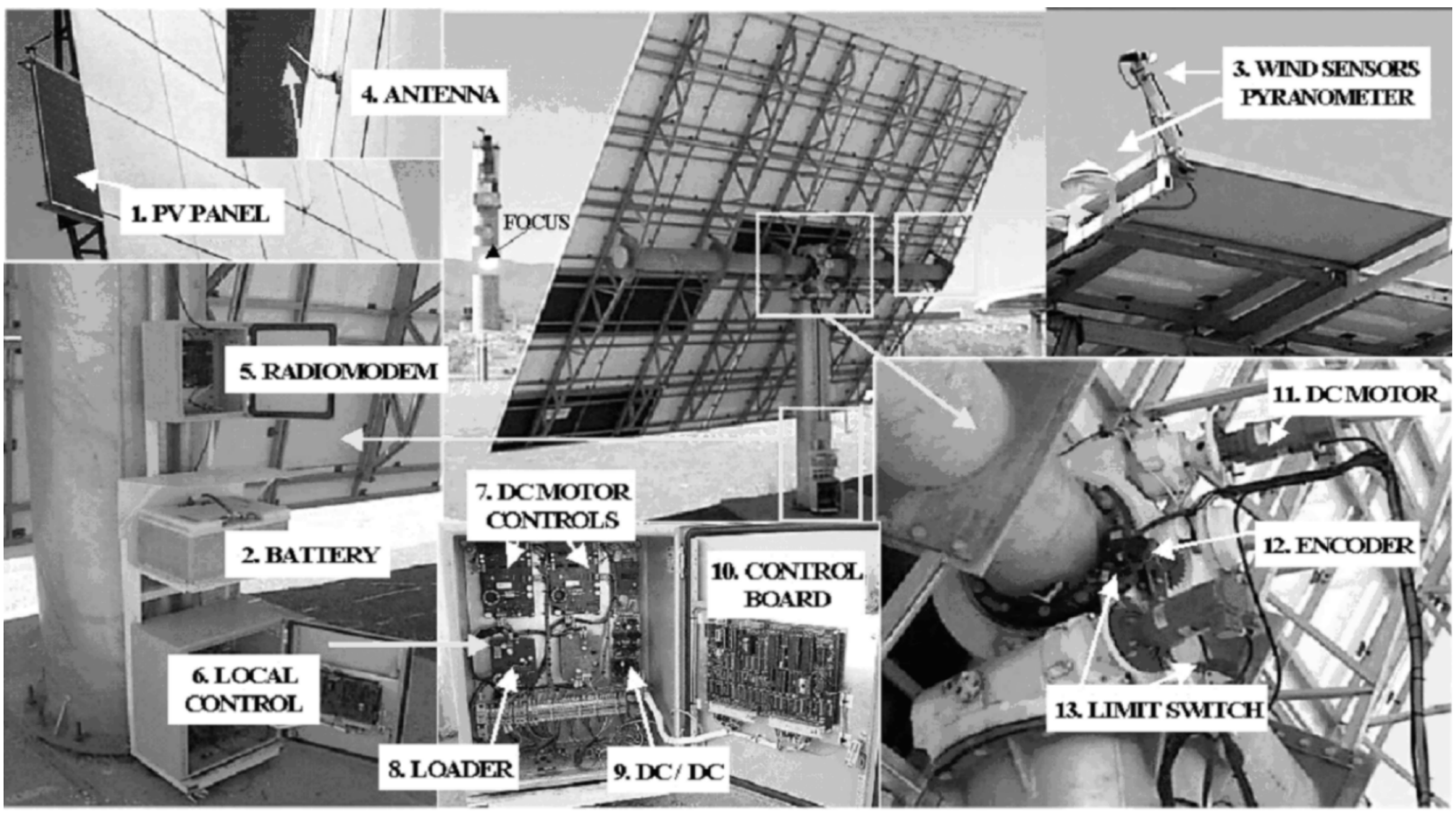

Fig. 1. Stand-alone heliostat photocomposition.

➤ Motors:	24Vdc, 10A, 3000rpm
➤ Geardrives ratio:	28000 / 1 azimuth&elevation
➤ Speed axis:	High: 7.2°min & Low: 2° min
➤ Encoders:	incremental type 3600x4 (14400bits
➤ Angular resolution:	0.025° in each axis
➤ Photovoltaic panel:	polySi, 24Vdc, 110Wp
➤ Battery:	2x12Vdc, 55AH
➤ Radiomodem:	400-470Mhz, messages encrypted 9600baud, a lot frequencies
➤ Wind sensor:	special magnetic switch
➤ Additional sensors:	anemometer, PT100, pyranometer
➤ Solar vector calc.:	PSA hybrid algorithm, error<0.5min

Figure 1 shows the PV panel (1) located in the same plane and attached to the reflectant surface leading to an additional improvement in PV efficiency and common washing operation. Heliostat stow position is vertical and facing South therefore PV loading is taking place overnight and during cloudy periods and outages. Batteries (2) are located at pedestal bottom and protected by its shadow and a small cover. As can be observed, a small anemometer and wind switch system have been installed over the PV panel (3) to increment diagnosis information for self-protection protocols. A pyranometer has been also installed for testing purposes. Another relevant element is the small antenna (4) located at the center of the mirrors surface. The antenna and the radiomodem (5) allow wireless communication to the control room at 400 m distance. Local control (6) has been assembled into a metallic box located at the pedestal bottom and includes the different electronic cards (7, 8, 9 and 10) namely DC motors control cards, motor drivers and modem card. The rest of elements are fully traditional like motors (11), encoders (12) and limit switches.

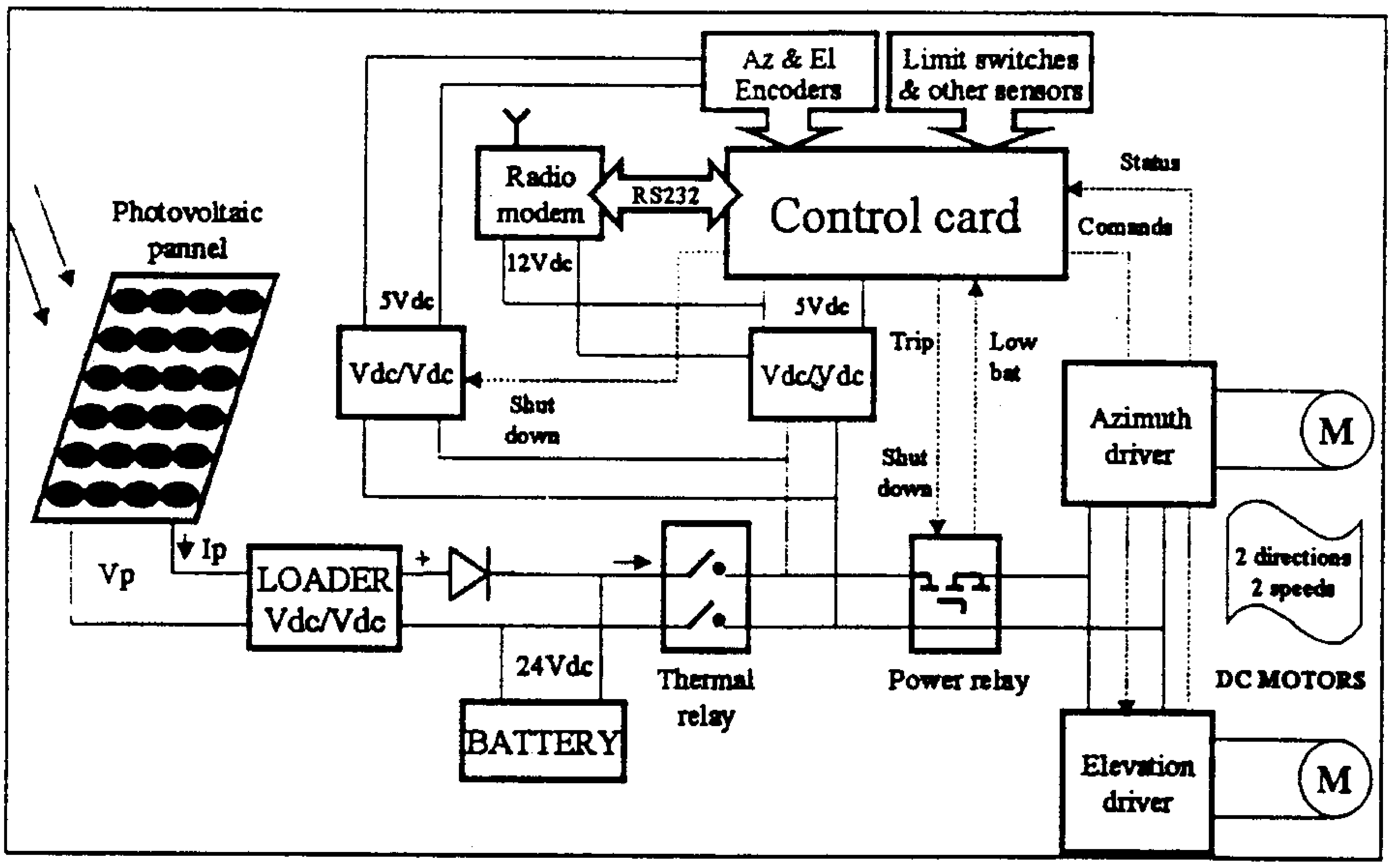

Fig. 2. Stand-alone heliostat block diagram

3. EVALUATION

A thorough testing campaign has been carried out during September 1999 (autumn equinox). The main objective was to validate the technical feasibility of the prototype and to quantify the efficiencies of new elements like the loader, servos and radiomodem. Real consumption data were processed for a correct dimensioning of PV power supply.

3.1 Parasitics and power consumption

The heliostat has been programmed to perform three different operation modes:

- Inactive periods (days 3 to 12 September) to determine minimum consumption and parasitics.
- Repetitive cycles from sunrise to sunset (days 13 to 27 September) to determine real consumption during routine operation.
- Cycles with automatic overnight disconnecting of unnecessary loads referred to as **lethargy** (days 3 to 20 September) to determine the corresponding energy saving.

Two lead-acid batteries Hoppecke-Energy of 12V and 55Ah each have been selected. A monthly discharge percentage of 10 % and a charge/discharge efficiency of 94% have been assumed. Figure 3 represents the average distribution of consumption for inactive (right) and routine (left) operation. Fixed parasitics from the electronics and independent from the type of operation of the heliostat were measured as 91.4 Wh per day with overnight lethargy and 110.2 Wh per day without lethargy (**20.5%** energy saving).

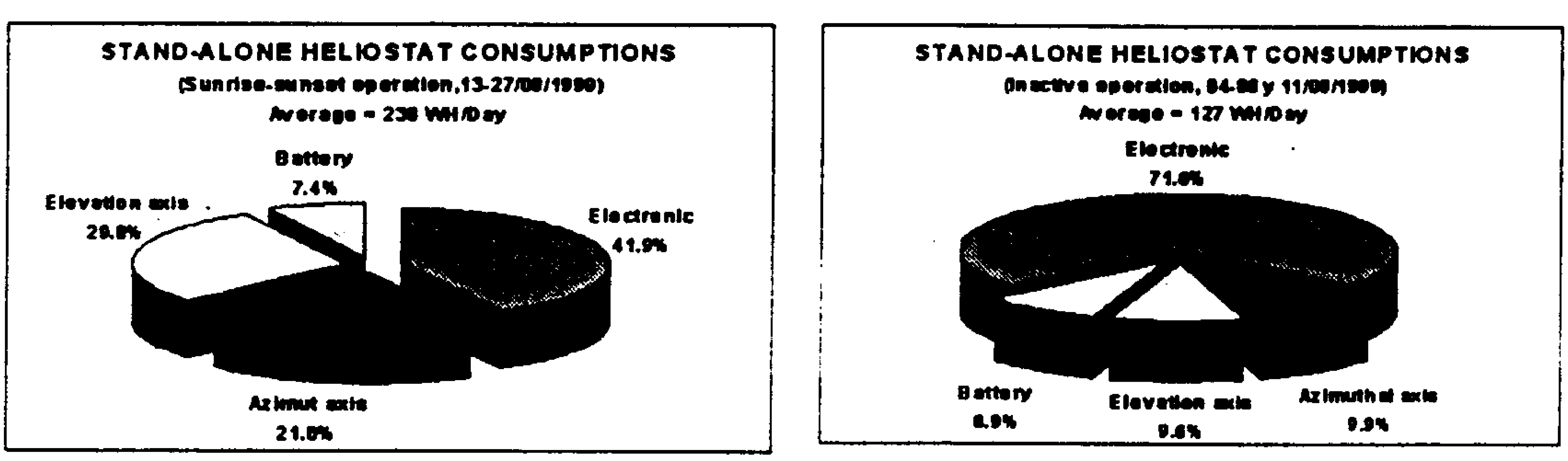

Fig. 3 Average distribution of Stand-alone heliostat comsumptions

3.2 Electric efficiency

Several components of the stand-alone heliostat have been designed to achieve high efficiencies during operation, basically the two servos necessary to operate the DC motors and the battery charger. Because of that during the testing period special attention has been paid to their evaluation. Measured consumptions during abatement operations at nominal speeds (fast speed) are listed in Table 1.

Table 1 Servos efficiency

	Servo_AZ	Motor_AZ	µ_AZ %	Servo_EL	Motor_EL	µ_EL %
13/09/99	14.528	12.854	0.885	20.713	19.005	0.918
14/09/99	15.646	13.606	0.870	21.768	19.590	0.900
15/09/99	14.842	12.900	0.869	21.622	19.326	0.894
16/09/99	14.007	12.318	0.879	20.375	18.940	0.930
	59.023	51.678	**0.876**	84.478	76.861	**0.910**

As can be observed a good performance is obtained in the elevation axis with an average efficiency of 91%. Since both servos are identical, the lower efficiency of the azimuthal axis is motivated by constructional and adjustment reasons. Both servos achieve a parasitic consumption higher than 12 Wh per day due to their electronics. Those consumptions might be eliminated by disconnecting the servos during lethargy periods.

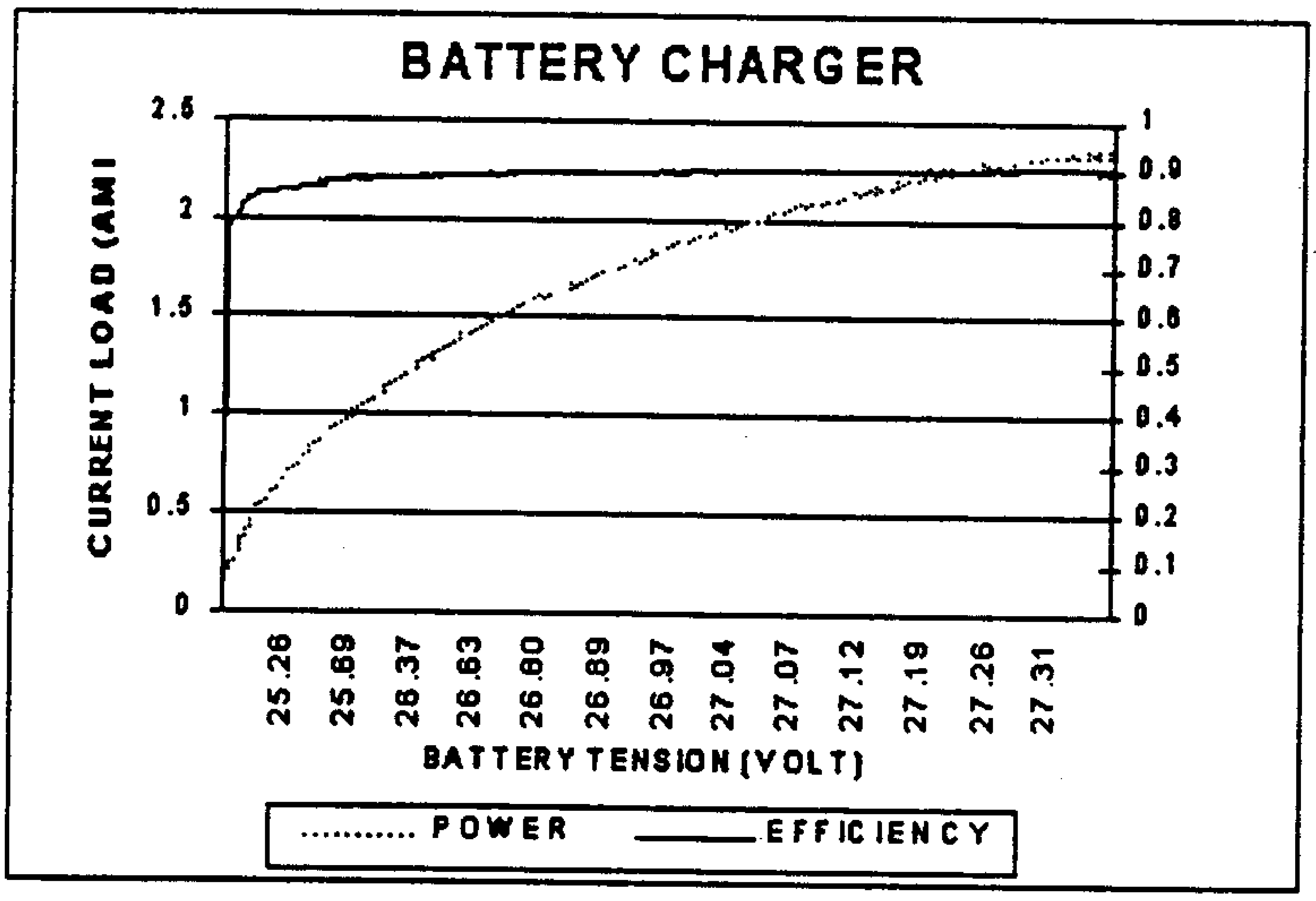

Fig. 4 Battery charger efficiency

The battery charger efficiency established at 27.3 V, moves between **85 - 90.5%.** The charger has been designed to load the battery even at rather low irradiances with the aim to make use of high number of cloudy days. The threshold to start the positive charge of the battery has been measured **25W/m²** for a battery voltage of 25.2 V.

Specific test campaigns to compare PV panel collection between two-axis tracking mode during typical sunrise-sunset operation and horizontal position led to 110.1 kWday/m² versus 78.7 kWday/m².

3.3 Security systems

The day 19th September, the stand-alone heliostat, following its self-protection routines, decided automatic abatement after detecting high winds above 45Km/h. Wind switch has revealed as a simple and reliable element for high winds detection and its low cost makes it useful for solar fields in isolated areas. It encompasses a steel strip and a small magnetic switch.

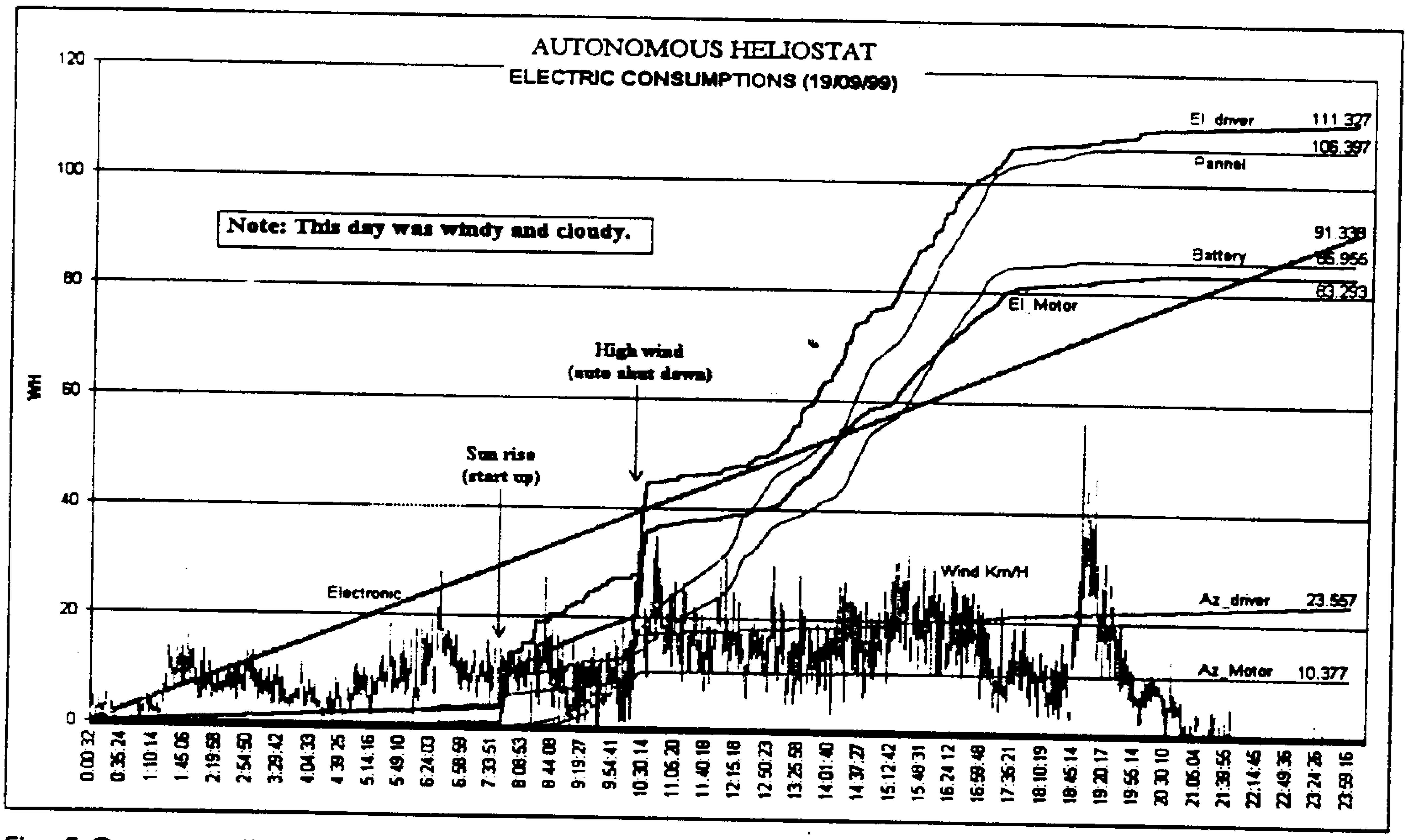

Fig. 5 Consumptions in a windy and cloudy day

3.4 Optimized PV supply design

Once electric consumptions of the heliostat were evaluated, a suitable sizing of the PV system was undertaken. PV panel power has been sized considering a range of two operation scenarios. The first one considering the energy collected in horizontal angle and second the energy collected in sunrise-sunset operation. Then the capacity of the batteries has been sized under two scenarios: operation sunrise-sunset with 5 days autonomy and no solar input and the same for 2 days autonomy.

Table 2. Autonomy days for different battery options

	Design interval		Current design	
Power Panel = Average daily consump./Hours peak average Sun	**45.4**	**32.4**	110	Wp
Working voltage	24			V
Capac. Bat = Daily ave. consump.* Autonomy days/ voltage	**49.6**	**19.8**	55	Ah
DAYS OF AUTONOMY FOR ROUTINE OPERATION SUNRISE-SUNSET (or number of up-down movements in both axes)				
Without solar contribution (reference case)	5	2	**5.5**	
Cloudy days with operation (R_diffuse average = $100 W/m^2$)	**5.8**	**2.2**	**8.2**	
DAYS OF AUTONOMY FOR INACTIVE DAYS				
Without solar contribution	**9.4**	**3.7**	**10.4**	
Cloudy days (R_diffuse average = $100 W/m^2$)	**23.5**	**4.6**	**26.0**	

100W/m2	PV 110Wp	PV 45Wp	PV 32Wp
Intensity (A)	0.25	0.103	0.075
Voltage (V)	25.5	25.5	25.5
Power (W)	6.4	2.6	1.9
E.Bat(12h)	**76.5**	31.5	22.9

As it can be observed at the table, autonomy days are noticeably increasing by considering the electricity produced during cloudy days. Therefore, with the existing 110 Wp panel as much as 76.5 Wh/day could be charged in a cloudy day with a typical average radiation $100 W/m^2$.

3.5 Radiomodem

The radiomodem is a system specifically developed for this application allowing a semiduplex communication with transmission velocities of 9600 or 4800 baud at 400-434 Mhz band or 868-870 Mhz. This system has been not fully evaluated during the reported period and will be subject of specific tests during the year 2000 with a group of 20 stand-alone heliostats. It can be however stated that the single radiomodem has operated with success during the whole test campaign communicating with the control room located at 400 m distance.

4. COSTS

The extra costs produced by the autonomy of the heliostat are related to the PV panel, batteries, radiomodem and wind switch. Those costs are making sense for a stand-alone heliostat only in the case that they can compete versus the subtracted costs like:

- Civil works (trenching, channels, small chests, earth leveling, ducts, etc.)
- Electric material (electric cables, communication wires, amplifiers, electric protections, computers, distribution boxes, interconnecting boxes, etc.)
- Security costs (lightning protections, UPS, absolute encoders, permanent supervision,...)

Table 3. Breakdown of stand-alone extra costs.

	Price per unit	Quantity	Total 70 m2
PV panel	\$4.5/Wp	0.5Wp/m^2 mirror	\$157.2
Battery and charger (24V)	\$2.7/Ah	25Ah	\$67.4
Radiomodem and antenna	\$329.3	1	\$329.3
Wind switch	\$15.0	1	\$15.0
			\$568.9

The investment cost for a "wired" 10 MW plant with 1000 heliostats is \$11.1/m2 as estimated for the PS10 plant versus the cost of \$8.1/m2 as conservatively estimated for the autonomous units.

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