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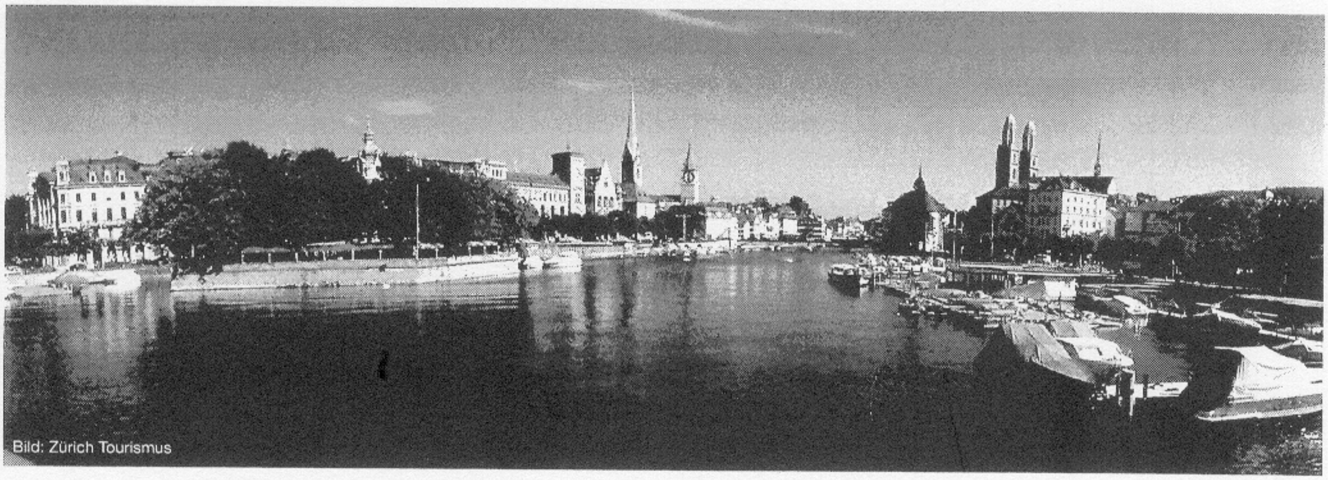

Towards Clean and Sustainable Energy Utilization

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Implementing Wireless Communication into Heliostat Fields

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Abstract – Autonomous heliostats fields are a priority objective long time pursued by PSA. Removal of all the electric cables, trenches and related components will really mean an important cost reduction in civil works and investment for future Solar Thermal Power Plants. Several previous developments have been required before making autonomous-heliostat fields an eventual reality. First, a new local control has been designed to adapt all heliostat components to work on 24Vdc supplied by a photovoltaic panel. Second, a specific radio-modem has been designed for wireless communications. In April 1999, the first autonomous heliostat was started up and main results were reported at the 10th SolarPACES International Symposium. The objective, fixed within the project SIREC funded with the FEDER European Regional Development Program, has been to scale these concepts to a mini-field to demonstrate the feasibility of the wireless communication and operation with 20 MBB heliostats located at the North side of CRS facilities of PSA. A specific radio-modem has been designed for this application thanks to the scientific cooperation agreement between the University of Almería and CIEMAT. 50% of the heliostat field has been implemented with a commercial radio-modem and the other 50% with specific radio-modems to compare the performance and capabilities. The capacities of both systems will be analysed and the main data obtained from the test campaign carried out, will be showed.

1. Introduction

Trenching, cabling and other land conditioning operations in large heliostat fields are a non-negligible economical factor to be analysed 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, [9]).

It is necessary to develop and validate new ideas to reduce, in the future, these costs by eliminations of wires, electric elements and trenches. From this point of view, the autonomous heliostat concepts were born at PSA in 1995 and they were first time described, into SolarPaces family (Ginés García,[1]). This heliostat should be supplied by a small photovoltaic system and it should be communicated to Central Control of the Solar Plant by radio. A number of autonomy concepts have been identified:

- **Physical autonomy:** Removal of trenching and cabling that unbind the heliostat from physical restrictions with a higher freedom of heliostat locations and enlargements of the solar field.
- **Power supply autonomy:** A PV panel unbinding the heliostat from conventional power grid giving it an un-interrupted power system, UPS.
- **Autonomy for calculation**: Determination of solar vector and axes positioning during sun tracking unbinding the heliostat from the master control (Manuel Blanco, [10]).
- **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.

These solutions may be applied in the next generation of Solar Thermal Tower Power Plants (STTPP) and they can be a definitive breakthrough to reduce civil works costs (Monterreal, [3]).

Six years ago, when we started this line of work (Ginés García, [2]), the commercial radio-modem had very low features and it was very expense. A low communication speed, maximum 1200baud, was usual and the price of a pair of devices was about 4000$. These circumstances advised the development

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of a new and specific radio-modem to be used in heliostat fields. Therefore, a specific radio-modem has been designed for this application thanks to the scientific cooperation agreement between the University of Almería and CIEMAT signed on 1998.

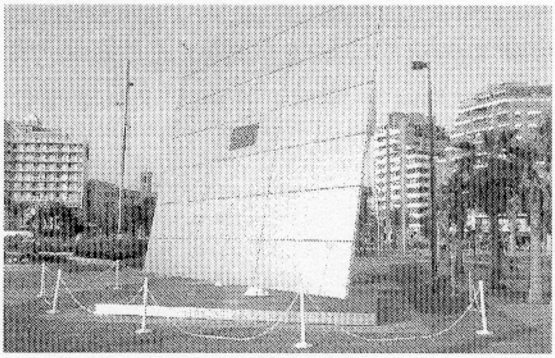

Fig. 1: Autonomous Heliostat.

In April 1999, the first autonomous heliostat was started up and main results were reported at the 10th SolarPACES International Symposium (Ginés García, [5]). Since then, this heliostat, supplied by a PV panel and communicated with a specific radio-modem, has been satisfactorily operated, without wires and the results obtained during this period have been published (Ginés García, [6], [8]).
Later, in November 2001, as shown in figure 1, this heliostat was exhibited, in Almería town Centre, as commemorations of Technologies and Science European weak.
The PV system was entirely verified on heliostat during 3 years of continuous operation. So, it was necessary to find secure and dynamic field heliostat radio communications to keep on with our objectives.
From this point of view, the objective, fixed within the project SIREC funded with the FEDER European Regional Development Program, has been to scale these concepts to a mini-field to demonstrate the feasibility of the wireless communication and operation with a significant number of units. The project aims to communicate the first heliostat field by radio, using the old MBB North heliostat field. This is composed by 20 heliostats located at the North side of the CRS facilities at Plataforma Solar de Almería, PSA.
In 2001, the radio-communications to exchange voice and data have changed a lot by the telephony industry respect to the last decade. So, several radio-modems have recently appeared in the market with very low prices offering high specifications. For this reason, during this year we decided to use also commercial radio-modem. Then the MBB field was divided into two groups of 10 heliostats each. The first group, located at west side, was equipped with ten specific radio-modems and the other group, located at east side, was equipped with ten commercial radio-modem. This configuration will permit us, within the SIREC tasks, the testing and comparing of both types of devices.
In this paper will be exposed the results and conclusions obtained from the several test campaigns done to specific and commercial radio-modems in real heliostat field operational conditions.
The results of this study will help to find the better solution to heliostat field radio-communication. The final conclusions of this study will be implemented next year in CRS field composed by 92 heliostats, located at PSA facilities.

2. Implementation

20 heliostats of the German Company MBB[1], located at north side of CRS facilities of PSA, have been used to this project. The communication lines of these heliostats were broken by sodium fire happened at PSA in 1986. Since then, these heliostats have been out of service.
The decision to use these heliostats takes into count the following considerations:

- Recover the normal operational conditions of 20 old heliostats increasing the PSA facilities.
- The number of these heliostats, 20, was ideal, as first step, to test the heliostat field radio communications.
- The distance, about 400 meters, was ideal to test and simulate real operational condition of the solar field with 1000 heliostats.

[1] Messerschmitt-Bolkow-Blöhm, MBB. GAST project, 1985.

- We had developed a new local control to these heliostats. This new electronic card permitted us modifying the functionality of these heliostats to implement the radio communications concepts. This electronic development was done in 2000 to PSA Solar Furnace MBB heliostats.

To get all the project objectives, the following tasks were necessary:

- Manufacturing of 25 new electronic cards to replace the old local control cards.
- Manufacturing of 15 specific radio-modem developed by CIEMAT
- Selections of commercial radio-modem types.
- Repairing of heliostats.
- Implementing and assembling of new components and star-up.

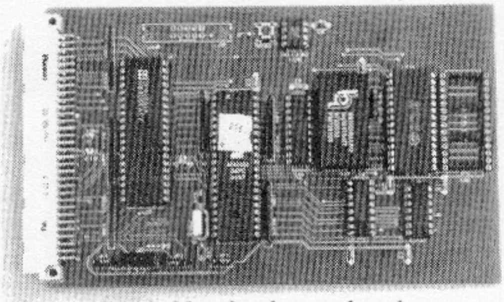

Fig. 2: New local control card.

2.1 Manufacturing of local control cards.

The development done in 1999 to PSA Solar Furnace heliostats is used in this project. (Ginés García, [7]).

The developed electronic card has been employed to get fully control of these heliostats. This development has permitted us to optimise the firmware of the card to implement the new radio communication protocols and the autonomous functionality.

The new card is fully compatible with all hardware elements of heliostat and implements a micro-controller and a real time clock and calendar. These elements execute solar vectors and axes position calculations and implement all autonomous concepts.

PSA electronic technicians manufactured 25 cards and these were equipped with a new firmware.

2.2 Manufacturing specific radio-modems.

The development done in 1999 as result of the scientific cooperation agreement between the University of Almería and CIEMAT (Gázquez, [4]) is used to this project. A specific radio-modem was developed to implement the following conditions:

- Low price (less than 350$)
- Data transfer rate of 9600baud.
- Messages coded and discriminated. Tele-configuration.
- 433KHz band, according to UN30 Spanish regulation.
- Can use many 433MHz-channels with 12.5KHz spacing.
- Two radio-channels implemented.
- 250mW of RF power. Licences are necessary.
- 5Km of communication range.
- Ambient enclosed protections, IP55.

This equipment was optimised on the Autonomous Heliostat during the years 2000 and 2001.

15 radio-modems were manufactured and adjusted to be used on the west group of MBB field composed by 10 heliostats.

2.3 Selection of commercial radio-modem.

Different manufacturers of radio-modems were consulted to choose the better equipment to be used to heliostat field application. After a detailed study the S433MCLight of FARELL Company was chosen. The price of this radio-modem was very attractive and it was at the same rate of specific radio-modem, about 350$. This device will offer the following characteristics:

- High data transfer speed established on 36800baud maximum.
- Transparent protocol with coded messages. Tele-configuration

- 433MHz band, UN32 and I-ETS 300-220 European regulation.
- Maximum 10 channels with 175KHz spacing.
- 10mW of RF power. Licences are not necessary
- Communication range: 1000 m high at sight.

15 commercial radio-modems were acquired to be used on the East group of MBB field composed by other 10 heliostats.

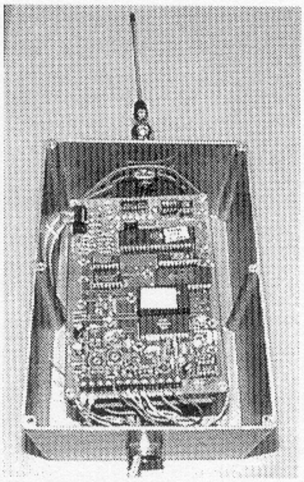

Fig.3: Specific radio-modem.

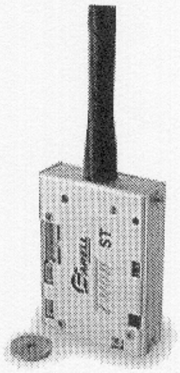

Fig.4: Radio-modem S433MCLight.

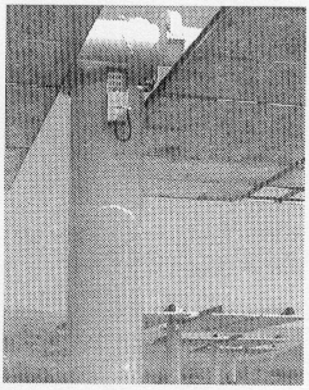

Fig. 5: Assembly of specific radio-modem.

2.4 Components repairing and implementing.

All the heliostats were checked and repaired. The substitution of the limit switches was necessary because these elements were oxidized by water actions during the large inactivity period. Mechanical elements were checked and several power supply units and servo cards were repaired at PSA electronic laboratory.

The new cards substituted the old control cards and the radio-modems were assembled on the structure of heliostats. As shown in figure 5, special supports were manufactured and additional wiring was done.

The commercial radio-modems were installed inside a metallic and watertight box to get enough ambient protections.

The master radio-modems were mounted on flat roof of CRS building at about 12 m of height.

3. Test campaign and results

During February of 2002, a lot of tests were done to study and compare both types of radio-modems. The main objectives of this study are:

- Know the percentage of erroneous radio contacts between heliostats and Central Control during routine interrogatory at different conditions to determinate the optimum operational conditions.
- Determinate how many heliostats are possible to contact every second.
- Validate simultaneous interrogatories employing several radio-channels.
- Compare the results and get final conclusions.

All tests have been performed using specific software made especially to this application. From this Central Control application, located in the CRS control room, all heliostats are interrogated with different dynamics and conditions. The Central Control uses the master radio-modems, see figure 6, to ask for the status to one heliostat and waits for its answer. Immediately after receiving the answer it asks to the following heliostat. This interrogatory is running continuously to refresh the status of all heliostats at least possible time. Each asking/answering process is named as "contact".

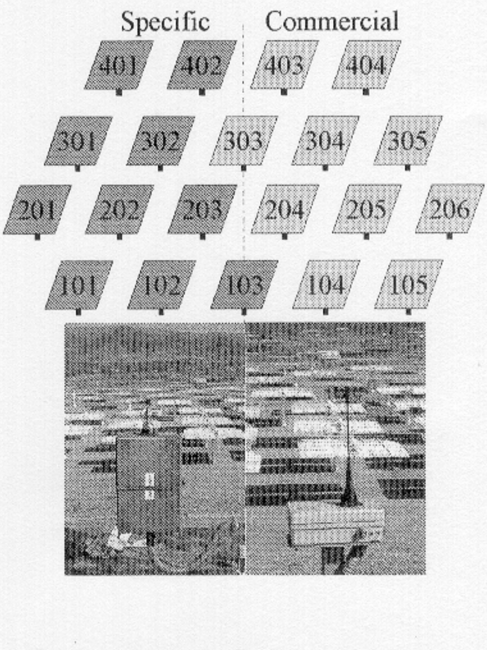

Figure 6. Heliostat field organizations

60 different tests have been done in this test campaign and a total of 8.7Mbytes have been transferred by radio establishing 265000 contacts.

This traffic by radio has been stored and analysed to determinate the faults percentage and the dynamic results in both types of radio-modems.

These tests have been done taking into count:

- **Data transfer speed**. In the specific radio-modem this variable depends directly on the synchronism bytes number. Increasing this number, the communication is more secure but it is slower. In this study will be analysed the percentage of faults with 6, 8, 10 and 12 bytes of synchronism. In the commercial radio-modems, this variable depends on the speed rate on radio-modems cables with heliostat and Central Control. Fixing 40Kb/s in radio speed, we have studied five cases. These are (heliostat/Central Control): 9.6/9.6, 9.6/19.2, 9.6/36.8, 19.2/19.2 and 19.2/36.8Kb/s.
- **Length of messages.** Two different levels are studied: level 0 with answers composed by 16 bytes and level 1 with 38 bytes answers.
- **Repetition of tests.** All types of tests have been performed three times at least in different days.

3.1 Faults rate.

When Central Control transmits the asking message, the heliostat receives it, interprets it and sends its answer. A contact will be correct when the Central Control receives the answer properly. If something faults during this process the contact will not be produced. These faults have been counted for all tests and, after this analysis; the optimum data transfer speed for an acceptable fault rate has been determined as follows:

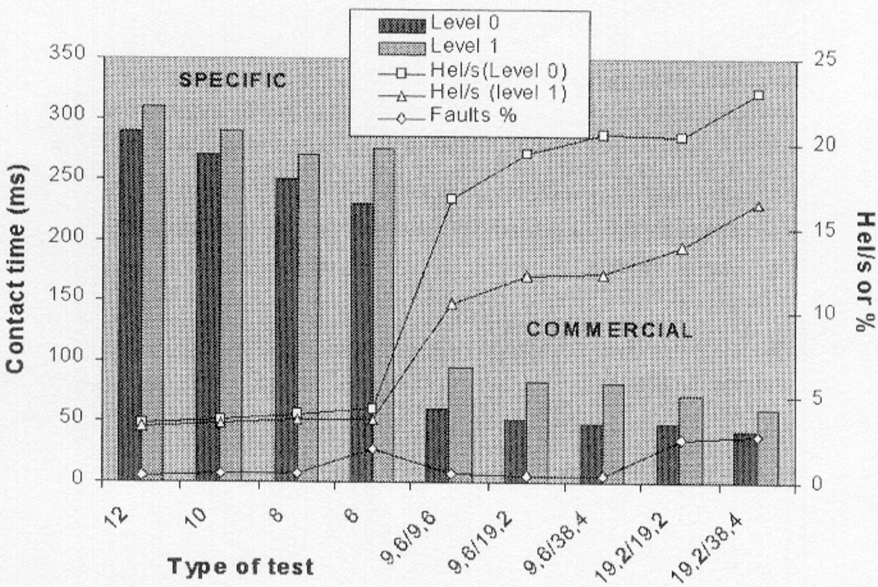

Fig. 7: Results of radio communications.

- Specific radio-modem: 8 bits of synchronism for 0.52% faults rate.
- Commercial radio-modem. 9.6/36.8Kb/s speeds for 0.44% fault rate.

The 0.5% faults rate means that we will have one erroneous contact every 200. This result is assumable for a heliostat field interrogatory because this data-lose will be refreshed a few seconds later. The messages sent to heliostat as commands have, fortunately, less than 0.2% fault rate because the length of these messages is smaller and they only travel in one direction.

The faults percentage increases with data transfer speed as shown in figure 7.

3.2 Communication dynamism.

An accurate oscilloscope has been used to measure the time to do a contact. This time will determine the number of heliostats that it possible to contact every second with both types of radio-modems.

For the optimum data transfer speed, the dynamism of both radio-modem is very different. While a specific radio-modem can contact with 4 heliostats every second for messages of level 0, with 0.52% of faults and using 8 bytes of synchronism, a commercial radio-modem can do it with 20.
This ratio of 5:1 decreases when the messages are longer. So, for level 1, the ratio caps down to 3,3:1.

Other tests have been done to demonstrate that the simultaneous interrogatories using different channels are possible. According to the manufacture's recommendations, to use simultaneous interrogatories it is necessary to leave at least a channel free between two operational channels. This recommendation is to avoid noises and interference between next channels. As commercial radio-modem supports 10 channels maximum, with 175KHz of spacing, only five simultaneous interrogatories will be possible. The specific radio-modem has not this channel restriction because the spacing between channels is very low, only 12.5KHz. So, with the appropriate elements such as antenna duplexers and others, they should use a lot of simultaneous interrogatories.

4. Conclusions

Both types of radio-modems should be employed to implement the wireless communication into the heliostat fields. Table 1 shows the main conclusion of this study.
The traditional time to interrogate all heliostats in solar fields is about 10 seconds. So, the specific option will need 25 simultaneous interrogatories to refresh the status of 1000 heliostats (4 Hel/s x 25 channels x 10s) while the commercial option will need only 5 (20Hel/s x 5 channels x 10s). This means that commercial option is ideal to medium heliostat fields with 1000 heliostats maximum.
The specific option offers the possibility of wireless communication to large heliostats fields but with a higher complexity because it is necessary to solve the problems appeared when using a lot of simultaneous channels (interferences between channels, separation of antennas, using more master radio-modems and special equipments such as duplexers...).

Table 1: Suitability conclusions.

		Specific	Commercial
Side	Large heliostat fields (>1000 heliostats)	X	
	Medium heliostat field (≤ 1000 heliostats)		X
Simplicity	N° of channels and master equipments		X
	Cabling and additional equipments		X
Flexibility	Powerful of tele-configuration		X
	Functionality open (firmware)	X	
	Dynamic change of all of channels		X
Reliability	Faults rate	X	X
	Simultaneous interrogatories		X
Protocol suitability	Short control data flow		X
	Short messages with variable length		X
Specific deliveries	Coding	X	X
	Special codification with time codes	X	
	Discrimination of messages	X	
	Private (restrict use bands)	X	
Cost effective	Projects and licences		X
	Radio-communication canon		X
	Saving of equipments and cablings		X
	Endorsement		X

While the commercial option implements all its 10 channels in the same device and offers the dynamic change of them by a powerful tele-configuration, the specific option only implements, on hardware, two dynamic channels. Hardware modifications on the device will be necessary to change the used channels. Only the specific option offers a functionality open to future firmware modifications.
The results obtained tell us that the commercial option is more suitable to short and variable messages length while the specific option has better capacities to transferring few and larger messages as files.
The special characteristics implemented in specific radio-modem as the employing of special and advanced coding and the messages discrimination, are not offered by the commercial option.

Finally, the commercial option offers ten channels to be used for industrial, scientific and medical applications. These channels are free of canon, projects and licenses according to UN32 and I-ETS 300-220 European regulation. The specific option gives us the possibility to use private bands but to do it will be necessary to pay.

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