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A PC-Based Instrument for Automatic Monitoring and Control of a CPVT Power Plant

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***Abstract* – A PC-based instrument has been developed for the monitoring and control of a concentrated photovoltaic and thermal (CPVT) power plant. The instrument allows acquiring both electrical and thermal quantities. Moreover it implements the solar tracking algorithm used to optimize the power production.**

I. INTRODUCTION

The growing of global demand for energy and the contemporaneous reduction of the conventional energy sources like coal and petroleum impose the increase exploitation of renewable sources in the next future. Although the sunlight provides the Earth with more energy in one hour than it is consumed on the planet in one year, the solar electricity currently offers only a fraction of a percent of the world's power consumption. The Sun irradiance is about 63 MW/m^2, but the Sun–Earth geometry dramatically decreases the solar energy flow down to around 1 kW/m^2 on the Earth's surface [1]. On the basis of this consideration, in last years the concentrating solar power (CSP) technology has gained an increasing interest. In these systems, a solar collector is used to focus the light on high-efficiency photovoltaic (PV) cells, which are cooled by a fluid circulation system. In this way hot water and electricity are generated at the same time. Various concentration schemes can achieve a wide range of concentration ratios [2]-[3]. Parabolic trough collector technology (PTC) is the most mature concentrated solar power design. It is currently utilized by multiple operational large-scale CSP farms around the world. PTC applications are mainly industrial process heat (IPH), low-temperature heat demand with high consumption rates (domestic hot water (DHW), space heating and swimming pool heating) and heat-driven refrigeration and cooling.

A new prototype of concentrated photovoltaic and thermal (CPVT) power plant was developed by the authors in the framework of the research project named SERPICO. The developed solar collector is 10 m long and 1.05 m large. Two pictures of the developed CPVT power plant are shown in Fig. 1 and Fig. 2. An innovative interface protection system and a modern inverter were also developed. Thanks to an embedded power line communication system, the new interface device allows the electrical utility to control the inverter and thus the power plant production [4]-[5]. In this way, new smart grid functionalities can be implemented such as anti-islanding protection, production shuttering, power factor variation, remote disconnection [6]-[10].

This paper describes the design and development a PC-based instrument for automatic monitoring and control of the CPVT prototype. Firstly, the system architecture is presented. Secondly the solar tracker system is described. Finally the experimental measurement results are reported.

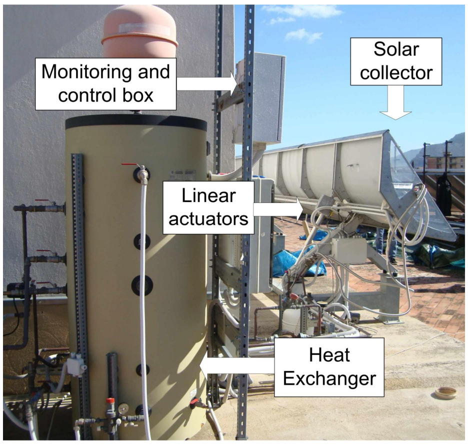

Fig. 1. CPVT power plant.

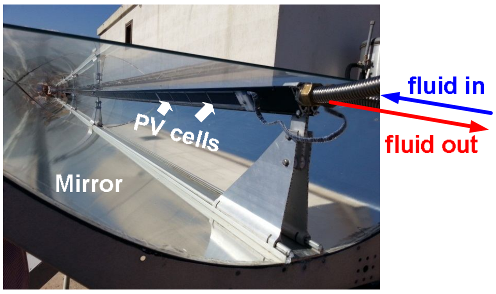

Fig. 2. CPVT solar collector detail picture.

II. PC-BASED INSTRUMENT DESCRIPTION

The designed PC-based instrument has the following tasks:

- to implement the solar tracker algorithm;
- to evaluate the power plant performances in terms of electrical and thermal energy production in dependence of the sun irradiation;
- to preserve the power plant from dangerous working condition (such as over-temperature of the cells);
- to register the power plant operation (disconnection, power factor variation, production shuttering).

The architecture of the complete CPVT power plant monitoring and control system is shown in Fig. 3. The PC-Based instrument is developed in LabVIEW environment. The front panel of the virtual instrument (VI) is shown in Fig. 4. To perform all the mentioned tasks, different quantities are monitored. They are reported in Table 1, together with the related sensors. Two data acquisition boards NI USB 6009 and proper conditioning circuits were used to acquire the sensors outputs.

More in detail, the fluid temperature is monitored both at the input and the output of the circulation system. Moreover the temperature is monitored also in three different points of the PV cell strip and in the boiler. Six PT1000 sensors are used. Each one is connected to a LM317 regulator, generating a constant current of 3 mA. The voltage drops at the PT1000 terminals are acquired to obtain the temperature values: *Tin, Tout* and Tc_i and *Tb*, respectively.

The fluid flow *G* is measured by a SM-08.15. flow sensor, which offers an output signal of 915 ppl (pulse per litre). The rectangular impulses are counted by a digital-event counter of the DAQ board.

The VI calculates the thermal energy production as follows

$$\dot{Q}_{th} = Gc_p\left(T_{out} - T_{in}\right) \qquad (1)$$

where:

- G is the fluid flow rate;
- T_{in} and T_{out} are the fluid in and out temperatures, respectively;
- c_p is the specific heat of the fluid.

A mixture of 70% of water and 30% of glycol is used as fluid. Its specific heat is c_p= 3100 J/(kg*K). When the pump is activated the fluid flow rate is G=0.17 kg/s.

The solar irradiance *Irr* is measured by a pyranometer LP PYRA 02 AV.

The solar collector angle α is measured by a MMA7361L Sparkfun accelerometer. Further details are given in the next section.

The DC current (*Idc*) and voltage (*Vdc*) are measured by the Hall Effect sensors TELCON HTP 25 and LEM LV 25-P, respectively. In this way, the DC power is calculated as *Pdc=Vdc*Idc*.

The AC current (*Iac*), voltage (*Vac*), active and reactive powers (*Pac* and *Qac,* respectively) are measured by a Janitza UMG 604 power analyser. The Virtual Instrument queries in real time the power analyzer by using a Modbus over Ethernet communication. The VI acquires also the state of the interface protection system (IPS), which connects the power plant to the grid. In this way it can obtain a registration of the power plant operation (disconnection, power factor variation, production shuttering).

Table 1. Monitored quantities and correspondent sensors.

Quantity	**Sensors**	**Brand model**	**Input**
Tin, Tout, Tc_1, Tc_2, Tc_3 *Tb*	Temperature sensors *Tin*=fluid in *Tout*=fluid out Tc_i= cell *Tb*=boiler	PT1000 Correge D 04718	6 AI
G	Flow sensor	Profimess SM-08.15.	1 Counter
irr	Pyranometer	Delta Ohm Lp Pyra 02 AV	1 AI
α	Accelerometer	MMA7361L Sparkfun	2 AI
Idc	DC Current Transducer	Telcon HTTP 50	1 AI
Vdc	DC Voltage trasducer	LEM LV 25-P	1 AI
IPS state			1 DI
Iac, Vac, Pac, Qac	Power analyzer	Janitza UMG 604	The measured values are sent to the VI via Ethernet

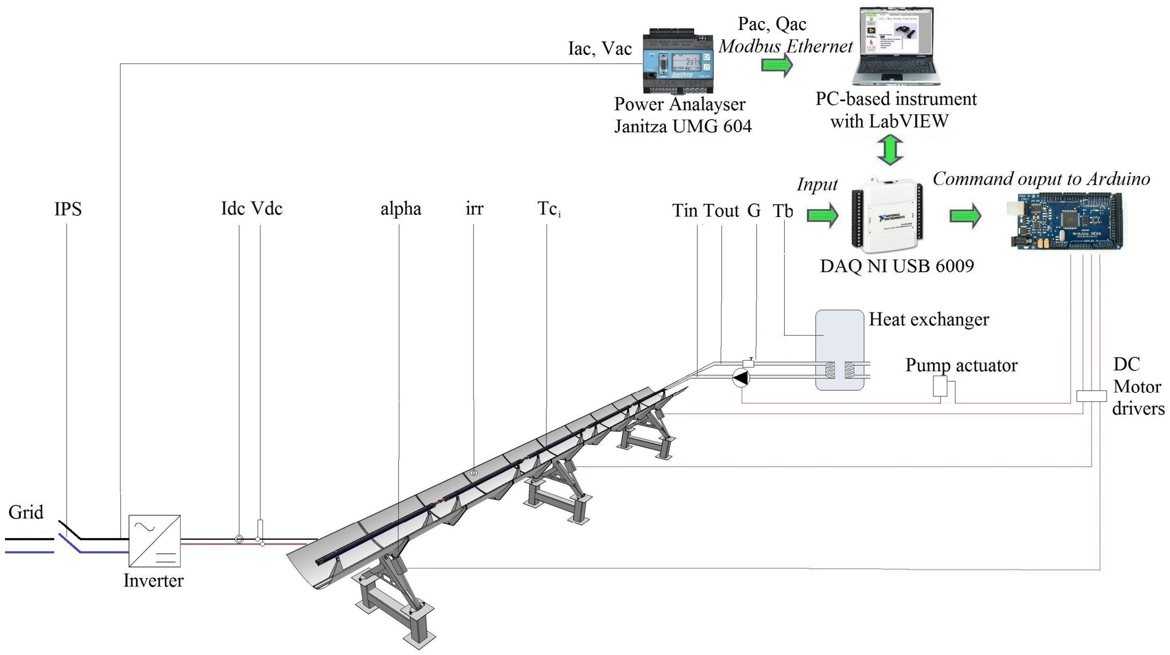

Fig. 3. Architecture of the CPVT power plant monitoring and control system.

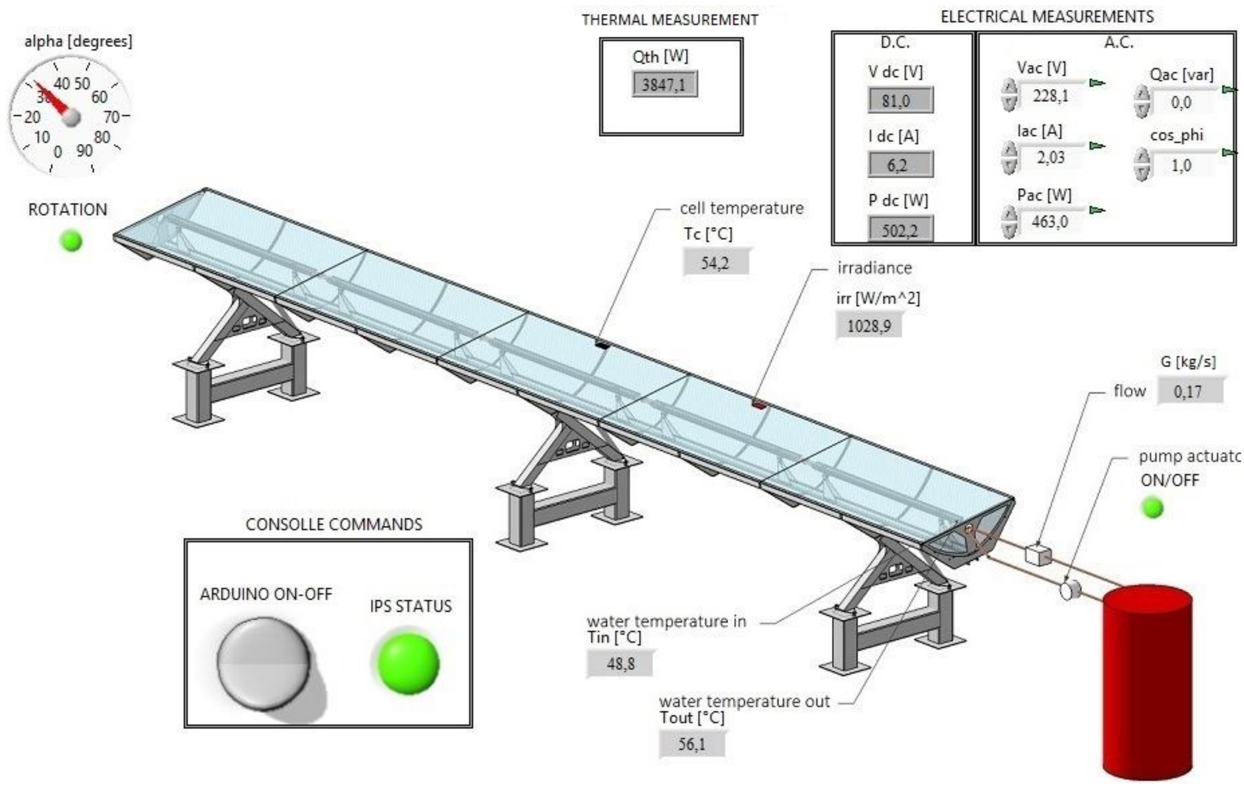

Fig. 4. Front panel of the developed PC-based instrument.

III. SOLAR TRACKER

A solar tracker is developed to orient the collector mirror, in order to concentrate the sun rays to the PV cells. In this way the maximum electrical and thermal energy production is obtained at each time of the day. To this aim, a proper algorithm is developed and implemented in the PC-based Instrument. The algorithm varies the angle α between the transversal axes of the solar collector and the horizontal plane (see Fig. 5), on the basis of the sun elevation angle and of the measured energy production. To do this, the collector longitudinal axes is connected to three linear actuators, each moved by a step by step motor. Each motor is supplied by a Pololu A4988 driver, whose control signals are given in parallel by an Arduino Mega 2560 board.

The electrical scheme of the linear actuators control system is shown in Fig. 6. The implemented algorithm changes the angle α of the concentrator in relation with the position of the sun during each day of the year. More in detail, in the Arduino memory the map has been recorded of the optimal tilt angle values, computed for every 15 minutes of each day of the year. These values can be found in literature in dependence of the installation site latitude and longitude and of other parameters. Then, every 15 minutes, the memorized value of the tilt angle is used as reference of a feedback control system, where the feedback signal is the value of the actual angle α measured by the MMA7361L accelerometer.

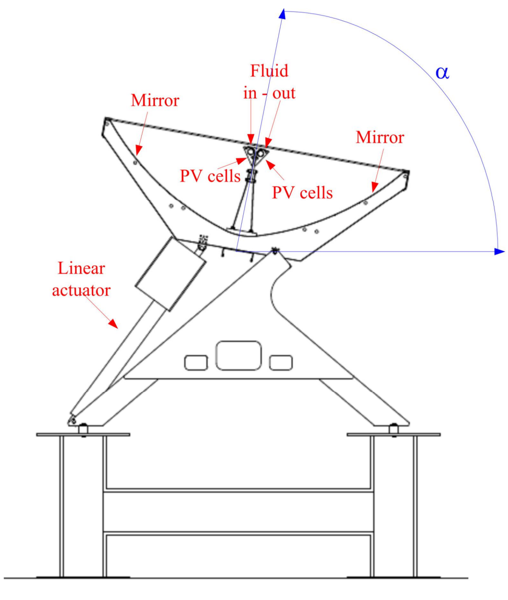

Fig. 5. CPVT solar collector side view.

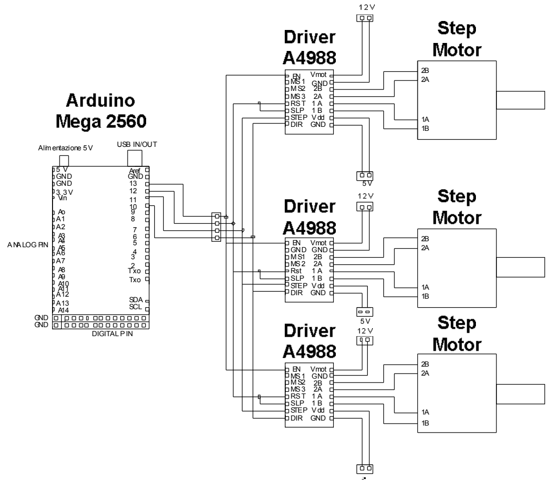

Fig. 6. Linear actuator control system.

This sensor is placed along the longitudinal axis of the concentrator. It measures the projection of the gravitational acceleration along the transversal axis y of the concentrator. In this way, the actual angle α can be computed as:

$$\alpha = \arcsin\left(\frac{g_y}{g}\right) \tag{2}$$

where g is gravitational acceleration and g_y is projection along the transversal axes y. The control algorithm computes the value of the actuator linear translation to reach the memorized optimal tilt angle starting from the measured angle α.

IV. EXPERIMENTAL RESULTS

Thanks to the developed PC-based instrument some interesting consideration could be performed on the CPVT power plant performances.

In Table 2 the thermal experimental results are reported of a test campaign performed the 9th Apr. 2014. A medium thermal power production of 3800 W was obtained. It has to be noted that the fluid temperature has been increasing during the test.

As regard the electrical production some considerations have to be done. First of all it has to be underlined that the photovoltaic cell peak power is defined in the Standard Test Conditions of radiation, temperature and air mass (1 kW/m^2, 25 °C and 1.5, respectively). On the other hand, the electrical characteristics of the pv cells change with the increase of the temperature. More in detail, the current increases while the voltage decreases. In the PV string, the current value is imposed by the coolest cell, while the voltage of each cell is proportional to its temperature. In Fig. 7 the voltage and current trend per watt/m^2 of irradiation are reported, which were found in the experimental tests. As can be seen, a high reduction of voltage per W/m^2 of irradiation (more than 20%) was found. The temperature increase mainly depends on the use of hot water from boiler. Thus in a hybrid system, the electrical production is strictly connected to the use of the thermal energy. In fact, a delayed use of thermal energy causes an increase of the temperatures in the boiler, in the thermal circuit and in the cells thus causing a decrease of the electrical production. Thus in a hybrid power plant, the monitoring of the temperature in different point of the PV string and in the boiler is essential for a correct definition of the electrical and thermal energy production and efficiency.

Table 2. Thermal power production.

Time hh:mm	T_{in} [°C]	T_{out} [°C]	irr [W/m^2]	ΔT [°C]	[W]
11:10	37,3	43,5	826,0	6,2	3267,4
11:24	38,7	45,1	860,0	6,4	3372,8
11:30	39,5	46,0	883,4	6,5	3425,5
11:45	41,4	48,3	924,9	6,9	3636,3
12:00	42,3	51,1	981,5	8,8	4637,6
12:20	45,1	52,9	1040,0	7,8	4110,6
12:30	45,6	53,6	1034,6	8,0	4216,0
12:40	47,4	54,9	1028,6	7,5	3952,5
12:50	48,8	56,1	1028,9	7,3	3847,1
13:00	49,4	56,8	1031,1	7,4	3899,8
13:10	50,6	57,7	1037,2	7,1	3741,7

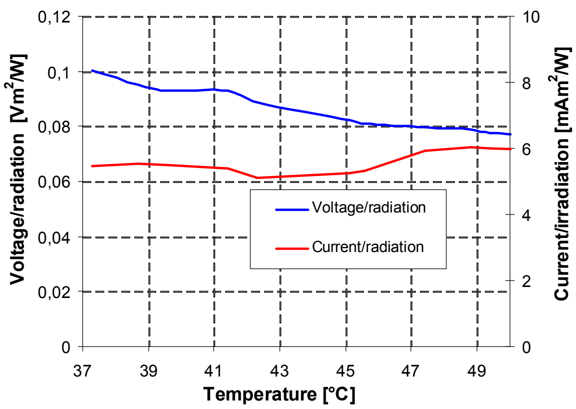

Fig. 7. Voltage and current of the PV cell.

CONCLUSIONS

A PC-based instrument has been developed for automatic monitoring and control of a prototype of CPVT power plant. The PC-based instrument allows to monitor many quantity of interests and it also implements the solar tracking algorithm.

Some interesting consideration can be obtained by the contemporaneous monitoring of thermal and electrical energy production.

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