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An Electronic Emulator of Combined Photovoltaic and Solar Thermal Systems

Pietro Calò, Giuseppe Fiscelli, Francesco Lo Bue, Antonio Di Stefano, Costantino Giaconia
Dipartimento di Ingegneria Elettrica, Elettronica e delle Telecomunicazioni (DIEET),
University of Palermo, Italy Parco d'Orleans, Viale delle Scienze s.n.c.– 90128 Palermo (Italia)
distefano@dieet.unipa.it, giuseppe.fiscelli@dieet.unipa.it, francesco.lobue@dieet.unipa.it,
costantino.giaconia@unipa.it

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Abstract: *An emulator of combined Photovoltaic and Solar Thermal (CPS) systems is presented. In order to carry out early testing on the design of such systems, a - microcontrolled based - hardware board has been designed, implemented and tested. This emulator is able run several typical daily solar irradiation patterns as a function of the seasons and a complete solar thermal and photovoltaic model that depends on a very flexible set of parameters characterizing the real CPS behaviour.*

By properly varying these parameters many different CPS models can easily be created and tailored to the energy performance needed for a predefined target application. Beside these functionalities, the CPS emulator is also capable to produce a set of output signals whose characteristics match the ones produced by a real CPS system. Moreover the CPS emulator can easily accelerate the real time clock up to 60 times faster, so speeding up the logging phases during tests.

Keywords: Renewable Energies, Energy Efficiency, Microcontroller, Digital Systems, Embedded Systems.

1. Introduction and Motivations

CPS systems have been spotted as having a serious potential impact on lowering the daily energy consumption monitored at house level [1, 2]. Simulation results on the effect of this locally produced thermal and electric energy at house level have been already carried out showing very promising preliminary outcomes [3]. However these studies also demonstrate that the CPS contribution of its renewable energy production is much more efficient when it matches the energy requests made by the different loads present within a selected house.

From the above consideration it can be figured out that a single apartment must be seen as an integrated entity, owing intelligent power loads and generators, capable to exchange information about their daily behaviours through a residential gateway. It can also actively control their profiles by moving their requests, according to a set of general rules imposed by the user, in order to optimize the total net daily energy consumption and/or power peaks. In order to implement such architecture the authors are already involved in the European project, called Beywatch, and many others US and EC projects, working on the optimization of energy efficiency based on the integration of ICT techniques with the energy control, clearly show how much interest is focussing around this research field [4]. One of the most significant steps of this scenario is the capability to form a house network in which the domestic appliances (comprising a CPS seen as an energy generator entity) can be monitored and their characteristic parameters can be downloaded by the house residential gateway through a suitable data logger.

Since a logging station will collect the data coming from the appliances after a suitable transduction, it will effectively read voltages or current loops whose values are proportional to the sensed parameters. From the above considerations it can be pointed out that an important tool to be designed and implemented is a low cost emulator of an appliance, in order to make early and easy tests by substituting the real loads with the emulated ones.

This is especially true in the case of CPS systems; in fact they are usually expensive and the choice of their main parameters in term of occupied area, energy production and storage, tailored with the house needs, is not an easy task.

The main purpose of the designed and implemented CPS emulator is the to realize a pin to pin compatibility with a real CPS, thus dramatically facilitating all the R&D prototyping steps of a CPS design phase, significantly boosting the early testing and optimization of the whole systems while keeping their costs at a very low level.

The paper will then describe the CPS emulator characteristics and subsequently some experimental results will be sown; lastly some conclusion will be summarized.

2. CPS Emulator Design and Implementation

The main goals to reach in the design of a CPS emulator must cover several aspects. Figure 1 shows the main component forming a CPS system: as for the electric generator, an inverter will convert the DC current generated by the Photovoltaic panel in the AC counterpart, capable to be delivered to the house loads. The solar collector will instead warm up a thermal fluid located within a pipe that will exchange its thermal energy with a hot water tank (or boiler). But the first aspect to be covered by the CPS emulator is the generation of a simulated solar irradiation pattern, keeping into account its dependencies upon the time of the day and the various seasons too. A simplified yet effective model of the radiation pattern has been realized within the emulator by introducing the incident radiation upon the emulated panels, the wind speed, the air temperature and the water temperature, as delivered by the public network. These atmospheric inputs allow the generation of a radiation pattern for a generic day of the year when matched with the geographical localization of the house. A final serenity index will randomly take into account the casual fogginess always present and, by emulating several different days, it will be possible to collect an average behaviour of the solar radiation. Besides this model however a constant radiation can always be simulated, this representing a work condition far from the real situation, yet useful in order to compare different CPS emulated models starting from a default solar radiation pattern.

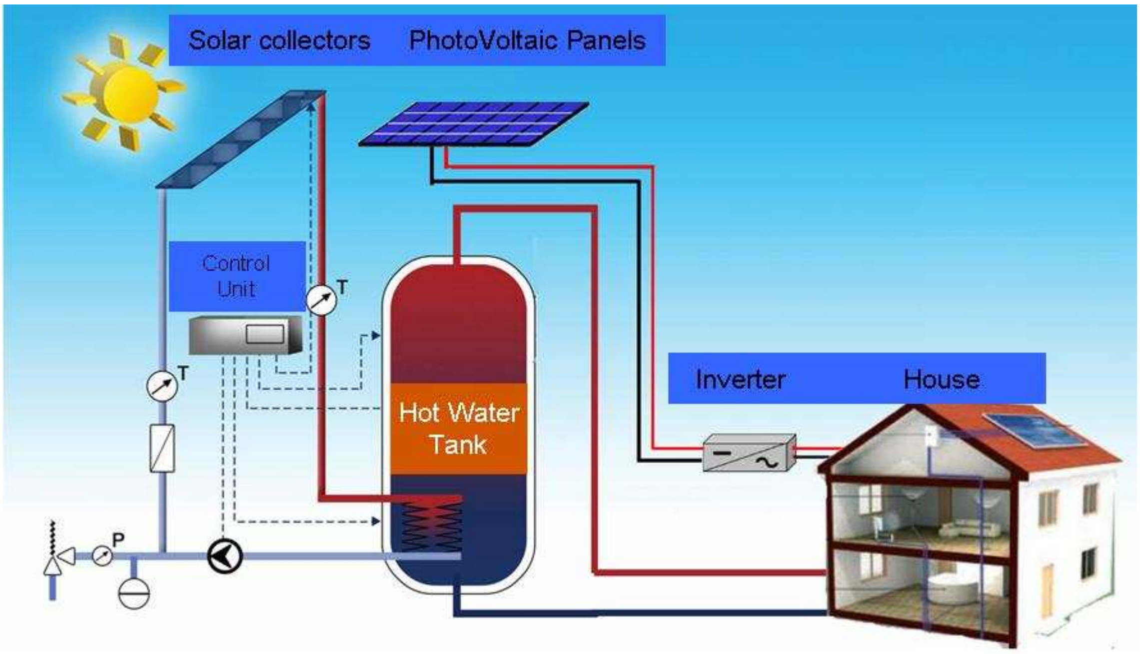

Figure 1: Layout of the typical CPS system with Solar Thermal and Photovoltaic units

Once the solar irradiation pattern has been generated, the CPS emulator receives these inputs and implements a thermodynamic model of both thermal and electric panels, and of the hot water tank. Many parameters has been kept into account and the details of these parameters are out of the purpose of this paper, but to give an idea a brief list regarding the thermal panel is given hereafter:

- Epv: emissivity coefficient of the thermal absorbing panel;
- K1: Thermal dispersion coefficient (from the back surface of the panel)
- Tau: Transmittance of the front glass cover
- Panel surface;
- Diameter, length and distance between the solar pipes of the panel
- Inclination of the panel

These among others will affect the model behaviour and all their values are usually found within the thermal panel datasheets, provided by manufacturers. The CPS emulator has been designed with the capability to store all these significant parameters within a non volatile memory, thus giving the aptitude to easily change them and tailor the model of thermal and photovoltaic panels produced by different companies. This is of paramount importance since it’s possible to quickly emulate the results produced with different systems before buying them.

The CPS emulator implementation is based on the adoption of an ATMEGA16 micro-controller, produced by ATMEL [5] and used within an electronic board whose block diagram is shown in Fig. 2.

A power supply can easily receive AC or DC energy from a standard source or from one of the photovoltaic panel and will feed two stabilized voltages: 5 V for the microcontroller unit and 12 V for the output section.

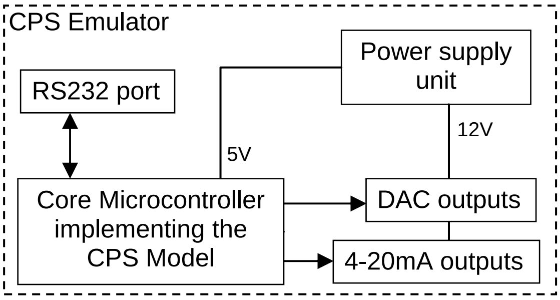

Figure 2: Main block diagram of the CPS Emulator.

In particular the DAC outputs are capable to give output signals with programmable voltage range spanning between 0-2 V and 0-5 V.

These outputs are designed to emulate all the sensors of real CPS that will give a voltage transduction of their sensing parameters. Some sensor are manufactured to transduce their relevant physical magnitudes as a current loop ranging between 4 and 20 mA. To fulfil this emulation requirement a suitable block has been added to the electronic board. An RS232 interface, integrated within the microcontroller, has been also used with a twofold meaning: as a programming port during all the development phases and as a data port while the CPS emulator is running. This always allow to read through a common RS232 serial terminal all the data generated by the emulator in a digital form.

Finally two other input parameters has been designed and implemented: the first one emulates the on/off switching of the thermal fluid pump that allows a forced circulation between the solar thermal collectors and the serpentine located within the hot water tank.

The second input is necessary to emulate the presence of hot water spillage from the boiler representing a user will or a thermal energy request made by an appliance.

3. Experimental Results and Tests

The above described hardware board has been programmed using ANSI C, compiled for the ATMEGA16. The AVR Studio (v4.0) Integrated Desktop Environment, freely available from the ATMEL website, has been adopted to the purpose. The non volatile EEPROM memory, internal to the microcontroller, has been used to host all the solar radiation and input parameters that feeds the CPS emulation program ready to produce the output signals at one per minute refresh rate, according to the minimum interval between two adjacent monitoring instants, usually set up by the data logger. The CPS emulator has also added the useful feature to speed up the update rate to one new set of values every second. It has to be noted that this x60 speed rising has also affected the solar radiation pattern, thus leading to a virtual accelerated tests.

Many tests have been carried out by trying to check the emulated results with the experimental behaviour provided by the manufacturer datasheets of different systems.

Table 1: Comparison between data coming out from standard efficiency certificate and emulated data

Gc[W/m2]	TfiP [C°]	TfuP [C°]	Ta [C°]	TfuP[C°] Em	TfuP[C]Em- TfuP [C°]
804,7	24,1	27,7	25,9	27,786777	0,086777
803,9	24	27,6	25,9	27,68621	0,08621
804,2	40,9	44,2	25,9	44,020596	-0,179404
802,9	40,95	44,1	25,9	44,012755	-0,087245
800,7	60,9	63,6	26,1	63,340016	-0,259984
801,6	60,95	63,6	26,1	63,342429	-0,257571
802,2	80,92	83	26	82,667441	-0,332559
802,2	80,94	83	26	82,666286	-0,333714
802	80,96	83,1	26	82,667307	-0,432693
800,9	80,98	83	26	82,661084	-0,338916
802,7	60,9	63,7	25,8	63,336964	-0,363036
802,4	60,9	63,7	25,8	63,335627	-0,364373
807,6	41,3	44,6	25,6	44,410254	-0,189746
807,8	41,3	44,5	25,7	44,413539	-0,086461
805,1	23,9	27,6	25,9	27,602578	0,002578
805,1	23,9	27,6	25,9	27,602578	0,002578

Table 1 reports a data comparison of a thermal collector, called EasySun II, between the one coming out from the CPS emulator and those provided by ENEA (National Institute for Alternative Energy) following the measurement protocol procedure stated in the standard EN 12975 [6]. In particular these trials have been carried out at constant solar radiation (Gc = 800 [W/m2]) and 25°C of ambient temperature. TfiP and TfuP are the input and output temperature of the thermal fluid flowing within the solar collector pipes, while TfuPEm stands for the emulated output fluid temperature. As it is clear from the last column the difference between experimental and emulated values are always significantly low, reaching a maximum value of about 0.5%.

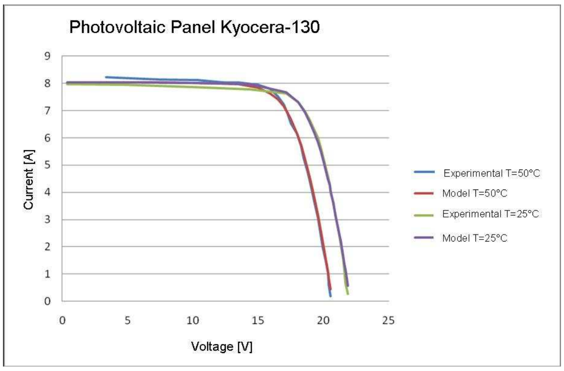

Figure 3: Real and emulated characteristics of Kyocera -130 Photovoltaic Panel.

Fig.3 instead shows the high level of fidelity when the CPS emulator tries to model the voltage current characteristic of a Photovoltaic panel. In this case the experimental data has been directly provided by the manufacturer and the percentage error is limited to a few percent even considering the relatively large variation of the panel temperature.

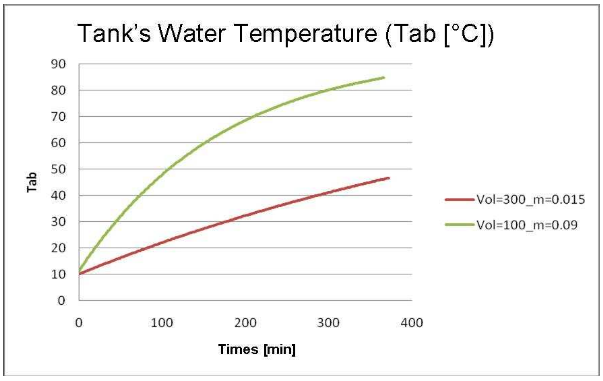

Figure 4: Emulated Tank Temperature Behaviour

Finally the tank temperature behaviour is visible in Fig.4, where two storage volumes (100 and 300 Litres) are considered. Clearly it is quite straightforward to change between them and see what is the hot water temperature evolution when a constant radiation level is heating the solar collectors. It's visible the higher raise speed of the Tab within a smaller boiler, even if a bigger value of the thermal fluid flux is asserted (m = 0.09 Kg/s); hence it can be argued that it is not always convenient to have large storage tank, but they must instead tailored to the effective user needs, otherwise leading to an unwanted slow response to the thermal loads.

4. Conclusion

The paper described a microcontroller based emulator of CPS systems. The main aim was the early stages capturing of the principal suitable characteristics and dimensions of a local energy generator. Some interesting experimental results was also described, showing the high potential that the method can deliver in the optimization phase and by increasing the speed of the experimental tests up to 60 times.

Acknowledgement

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