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A NOVEL APPROACH TO THE DESIGN OF MODULAR CONTROLLERS FOR SOLAR THERMAL SYSTEMS

NOWE PODEJŚCIE DO PROJEKTOWANIA MODULARNYCH STEROWNIKÓW SYSTEMÓW SOLARNYCH

A b s t r a c t

The paper presents a new approach to the design of the solar thermal system controller which is characterized by modular arrangement. The proposed solution enables the integration of controller functions that significantly improve user comfort and the overall reliability of the system. These functions may include both security operations (control of blinds for solar collector, emergency power supply) as well as system monitoring (heat meter, data logger with memory card, Internet-based monitoring, weather station).

Keywords: solar thermal system, modular solar controller, plant monitoring

S t r e s z c z e n i e

W pracy przedstawiono koncepcję nowego, charakteryzującego się budową modułową, rozwiązania sterownika do systemów solarnych. Zaproponowane rozwiązanie umożliwia integrację w sterowniku solarnym funkcji znacząco poprawiających komfort i niezawodność eksploatacji układu. Do funkcji tych można zaliczyć zarówno zabezpieczenia (sterowanie roletami osłaniającymi kolektor, zasilanie awaryjne), jak również monitoring (ciepłomierz, rejestracja pracy układu na karcie pamięci, nadzór przez Internet, stacja pogodowa).

Słowa kluczowe: *kolektory słoneczne, modułowy sterownik solarny, monitoring instalacji*

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1. Introduction

Continuous increase in energy demand together with the emphasis on increase of participation of environment-friendly technologies foster the dissemination of the use of renewable energy sources. One of the most common ways to use this energy is the photothermal conversion in solar thermal systems [1, 2]. The need to provide appropriate operating parameters of the system enforces the use of properly selected and configured controllers. Solar thermal controllers are manufactured by many companies, both in Poland [3, 4] and abroad [5, 6]. Despite of the wide range of available solutions the controllers are still mostly closed-structure devices with virtually none expansion capabilities. On the other hand the flexible solutions, based on the programmable controllers (PLC Programmable Logic Controller), are applicable only in larger systems due to very high cost of PLC [7].

Simple controllers, representing the vast majority of the current market offer are dedicated to handle only basic types of solar installations. Usually their functionality is limited to controlling the pump charging the hot water tank. Depending on the category of the controller additional functions might be available: charging of the 2–3 hot water storage tanks, controlling the collectors located on different parts of the roof or controlling the hot water circulation pump. However, recently one may notice the growing demand for modular controllers, fully programmable that allow the integration of multiple systems into a complete operational system. Not less important for users appears to be implementing a number of additional functions such as control and monitoring system over the Internet [9] or utilize the power supply with the photovoltaic panels [10, 11]. Until now such systems implementations have relied only on PLCs, however, due to their high cost, they are rarely used in residential installations. Although the modularity and expandability are already offered by a few manufacturers of solar controllers, e.g. [5] however, software of these devices is still closed. With the spread of low-cost microcontroller platforms, such as Arduino [8], it became possible to design controllers in a small series and fit their software to the needs of a specific customer. It is also worth noting that such controllers can be easily upgraded when the supported system will be expanded. Regardless of design, solar controllers for custom, bespoke installations must meet the requirements defined by the standard PN-EN 12977 [12, 13].

2. Functionality of the solar thermal controller

The primary function of each solar controller is to control of the solar circuit pump based on temperature difference between a collector and a hot water tank [1]. In larger systems the groups of collectors that are located on different parts of the roof are supported. Such systems often support a group of hot water tanks, swimming pool or underfloor heating. Simple controllers only allow to generate on/off control signal for the pumps. More sophisticated controllers also allow the control of variable-speed pumps using PWM (Pulse Width Modulation) signal, which allows to improve the quality of control, as well as help to reduce electricity consumption. The efficiency of the differential thermostat has been studied in detail in the 80's and 90's of the twentieth century [14]. Several studies, e.g. [15] point out the significant relationship between energy yield and the differential thermostat setting. It has been shown that the use of variable hysteresis of the controller, adapted to current system conditions, allows to increase of solar energy yield and furthermore, the reduction of electricity consumption. However, virtually all commercially available solar thermal controllers provide the pump control based on a constant hysteresis. It may be noted that the introduction of a differential thermostat with variable hysteresis depending on the actual operating conditions of the solar system is easy to realize with programmable controller. A prototype of the controller described in this paper allows to both control of the pumps using on-off signal as well as variable speed utilizing the PWM signal.

An important addition to the differential thermostat is to provide the additional control and protective functions. The most common may include the following: control of the hot water circulation pump, anti-frost protection or periodic overheating of the hot water tank in order to prevent the Legionella growth. However, there are a number of functions which significantly support the solar system operation, that are rarely implemented in the solar controllers. For example, a rarity among controllers is the protection of solar collectors from excessive temperature increase in case of insufficient heat reception (eg. in the holiday season). Many providers offer blinds for obscuring collectors but very often they require a separate controller. The modular solar controller can implement such a function in the central unit or provide as an additional expansion module.

A reliable power supply is a basic requirement for the proper operation of all HVAC systems (Heating, Ventilation, Air Conditioning). A loss of power supply in solar thermal collectors causes interruption of the heat reception which consequently results in a very rapid increase of the collector temperature. An increase of fluid volume should be compensated by the expansion vessel in a well-designed system but design or realization weakness, as well as the expansion vessel defect may lead to system damage. For this reason, a considerable number of solar system users decide for the investment in emergency power source [10] or even a total power system using photovoltaic panels [11]. This all is more legitimate that the highest power demand, associated with the circulation pump at maximum capacity, coincides with the highest power generated from photovoltaic cells. As stated in the previously mentioned papers [10, 11], the power supply control should be connected with solar thermal system controller because it improves the overall system reliability.

A common feature of all solar controllers is to provide the information about the operation of the supported system. The basic controllers provide only readings from 3–4 temperature sensors in the hot water tanks and collectors. More sophisticated devices allow to use up to 5–7 temperature sensors. In many solar systems even this number of sensors may not be sufficient. Valuable information about the efficiency of the solar system can be provided by the use of the heat meter, especially in combination with solar radiation meter. Unfortunately, this feature is only available in very few controllers and the use of an external heat meter, designed for solar installations, is a substantial investment. Likewise, there may be other useful additional features to help the monitoring of solar thermal system operation, e.g.: data logger with memory card, solar system visualization over the Internet or the weather station.

3. Prototype of the modular controller for solar thermal system

As stated above, the controllers designed to control the solar thermal installations, in particular uncommon or complex ones, should be characterized by modular structure. This allows update of the controller functionality with further development of the installation. This chapter presents the exemplary prototype of the modular solar controller, based on the freely programmable Arduino platform [8]. A block diagram of the controller is shown in the the drawing (Fig. 1). The prototype of the controller consists of a central unit, implementing all the main control functions, and three major expansion modules: system monitoring, backup power supply and the weather station.

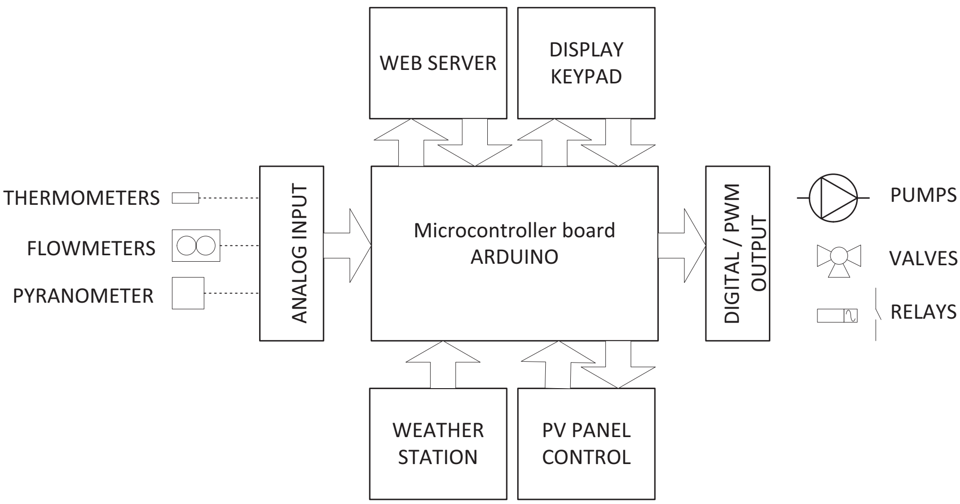

Fig. 1. The block diagram of the modular solar controller prototype

3.1. The central unit

The central unit of the solar controller is based on the Arduino Ethernet platform (Fig. 2). This system utilizes the Atmel ATmega328 microcontroller running at 16 MHz clock frequency. Equipped with communication interfaces such as SPI, I2C [16] and Ethernet allows to attach multiple additional modules. In order to provide the elementary local service, the controller is equipped with a small (1.8” diagonal, 160 × 128 pixel resolution) graphic display that communicates with the microcontroller through the SPI bus. In addition to communication interfaces, the central unit is equipped with 6 analog inputs (e.g. for temperature sensors) and 9 available digital inputs/outputs (including 4 PWM for pump speed control). This number of I/O channels allows the customization of the software for supported installation. The microcontroller is programmed in a language similar to C, using the development environment Arduino IDE software.

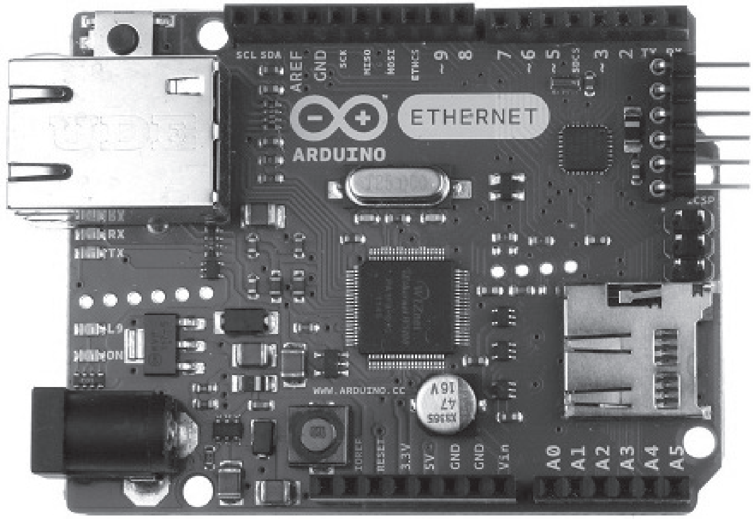

Fig. 2. The central unit board – Arduino Ethernet module

3.2. Solar thermal system monitoring

In the presented controller there are a number of monitoring features provided for solar installation. The use of a micro-SD memory card slot that is built-in Arduino system enables the implementation of a data logger recording selected data on plant operation. The diagram (Fig. 3) shows a sample logged data of the selected parameters of the solar installation operation.

A large number of measuring channels enables to add additional temperature sensors inlet end the outlet of solar collector as well as and the flowmeter. The use of these sensors makes it possible to implement a heat meter which can be used when analyzing the efficiency of solar energy. Common access to the Internet gives the opportunity for many contemporary systems to be monitored through the web [9]. The prototype controller provides a simple web server software that allows monitoring of the plant operation on the computer (or mobile devices such as smartphones) in a home network. For safety reasons those data should not be published on the Internet. The notification of events through SMS in the prototype system was not implemented, although it is a useful feature. However, it is possible to further expand the system using additional GSM communication module. For servicing a relatively small solar installations it appears to be unprofitable because it requires additional fees for data transfer. Notification by e-mail using the built-in Ethernet module seems to a better solution for such a system.

3.3. Control of photovoltaic power supply

Regardless of the method of use of photovoltaic panels (system powered only with PV panels or just a backup power supply) it is essential to control the voltage and load current

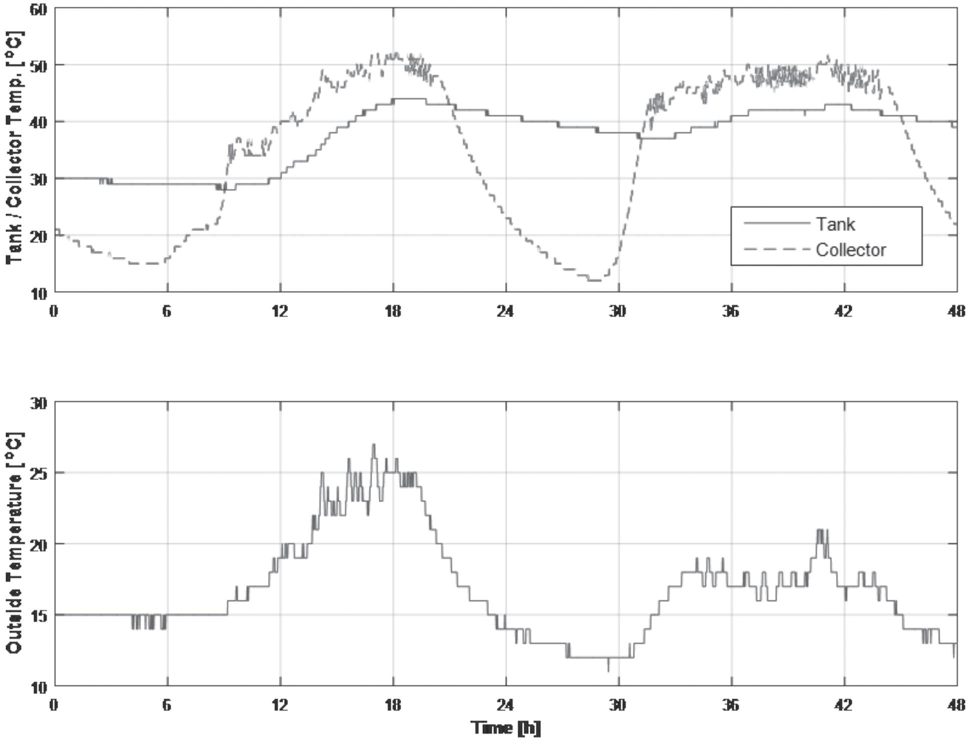

Fig. 3. The sample logged data of the selected parameters of the solar installation operation

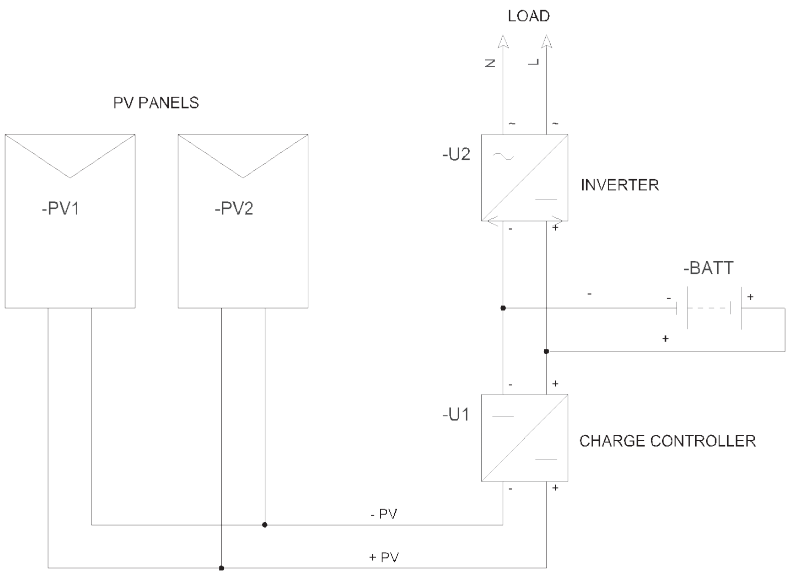

Fig. 4. Diagram of the photovoltaic power supply for the laboratory solar thermal installation

of the panels, as well as battery charging system (if used). The drawing (Fig. 4) shows a diagram of the photovoltaic power supply for the laboratory solar thermal installation. Further details of the applied solution and the experimental results of the obtained effectiveness are presented in [10].

3.4. The weather station

The module of the simple weather station is based on digital sensors: air temperature and humidity (Sensirion SHT11), as well as barometric pressure (Xtrinsic MPL3115A2). The sensors communicate with the microcontroller through an I2C serial bus [16]. Measurement of solar radiation in the presented prototype was carried out using LAB-EL LB-900 pyranometer [17]. This solution, although it provides high accuracy, may be disproportionately expensive compared to the needs. Probably a better solution would be to apply a small standard photovoltaic cell [5].

4. Conclusions

In this paper the limitations of a typical, commercially available, solar controllers were presented in detail. It has been shown that in unusual or complex solar systems the improved results can be achieved with the modular controllers. Such controllers can be better adapted for the plant through dedicated both the hardware modules and the software functionality. Obviously, the features listed above will not be necessary for every user, but with the further development of the installation (or an increase in customer needs) the controller functionality can be updated. Of course, preparing software for described controller (using language similar to C) is far more complicated than simple configuration of a typical, commercially available controller. However, the advantages of this solution in many cases may prevail outlay of work.

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