on market requirements for energy trade. Long-term forecasting is necessary for grid development planning and economic analysis, and performed in seasonal and annual time horizons.

The physical approach to predicting deal with solar and photovoltaic energy behaviors, and statistical approach based primarily on historical data to identify trends. If the forecast concerning a large number of areas, some objects are modeled and methods of extrapolation or interpolation are used.

Images of the sky are using with the methods of tracking the movement of clouds in the sky photographs. For satellite imagery a similar approach is used for longer time horizon because the spatial and temporal resolution. For deterministic approach a certain level of solar energy is predicted, the stochastic indicates additional level of uncertainty. The combination of techniques provides better accuracy of forecasts. To assess the accuracy of prediction the average deviation, mean square error, mean absolute error, standard deviation are used. The accuracy of the forecast is affected by the local climate, the amount of area or number of areas, forecasting horizon, precision of the measuring equipment. The emergence of intelligent networks and power systems management forms its own requirements for predictability, and encourages new developments in forecasting.

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Design and implementation of the unified control module for a sustainable operation of the combined renewable energy system

Unified modular solar collector monitoring and control system with balancing capabilities and stagnation protection has been developed. The automated control module performs continuous monitoring of operational modes and temperature parameters of the system, as well as switches the mode in the case of certain edge conditions are reached. Stagnation protection has been implemented as a special emergency operational mode where surplus heat is transferred to the high-capacity heating circuit that will protect collector and improve sustainability of the system. It was shown that proposed system is capable to utilize any type of heat sources without replacing the control module while modular architecture allows easy upscaling for building complex smart systems. Ref. 2, fig. 1, tab.1.

Keywords**:** *smart home, solar collector, automated control module, stagnation protection.*

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Introduction. The wide application of renewable energy systems [1] require the development of smart monitoring and control systems that are capable to achieve and maintain the optimal operational mode, maximize the efficiency and ensure durability of the equipment. Furthermore, such systems should meet the requirements of scalability, interoperability, and must be compatible with wide range of equipment, including solar collectors, heat pumps and PV modules [2].

In present report, unified modular microcontroller-based (MCU-based) solar collector monitoring and control system with balancing capabilities and stagnation protection is demonstrated.

Results and discussion. The generic structure of the module (fig. 1) includes three independent heat sources – solar collector, the boiler of any type, and electric heater.

The proposed scheme includes separated heating and hot water supply circuits that may be conditionally connected only via dedicated heat exchanger. When the amount of solar energy is insufficient for both heating and hot water supply, heating circuit may be completely detached from solar collector and rely solely on boiler.

Temperature measurements are carried out using four sensors that provide temperature data for solar collector input ($t_{c\text{-}c}$) and output ($t_{c\text{-}h}$), storage tank (t_t), and temperature in the room (t_r). Room temperature is calculated as an averaged data from multiple installed sensors.

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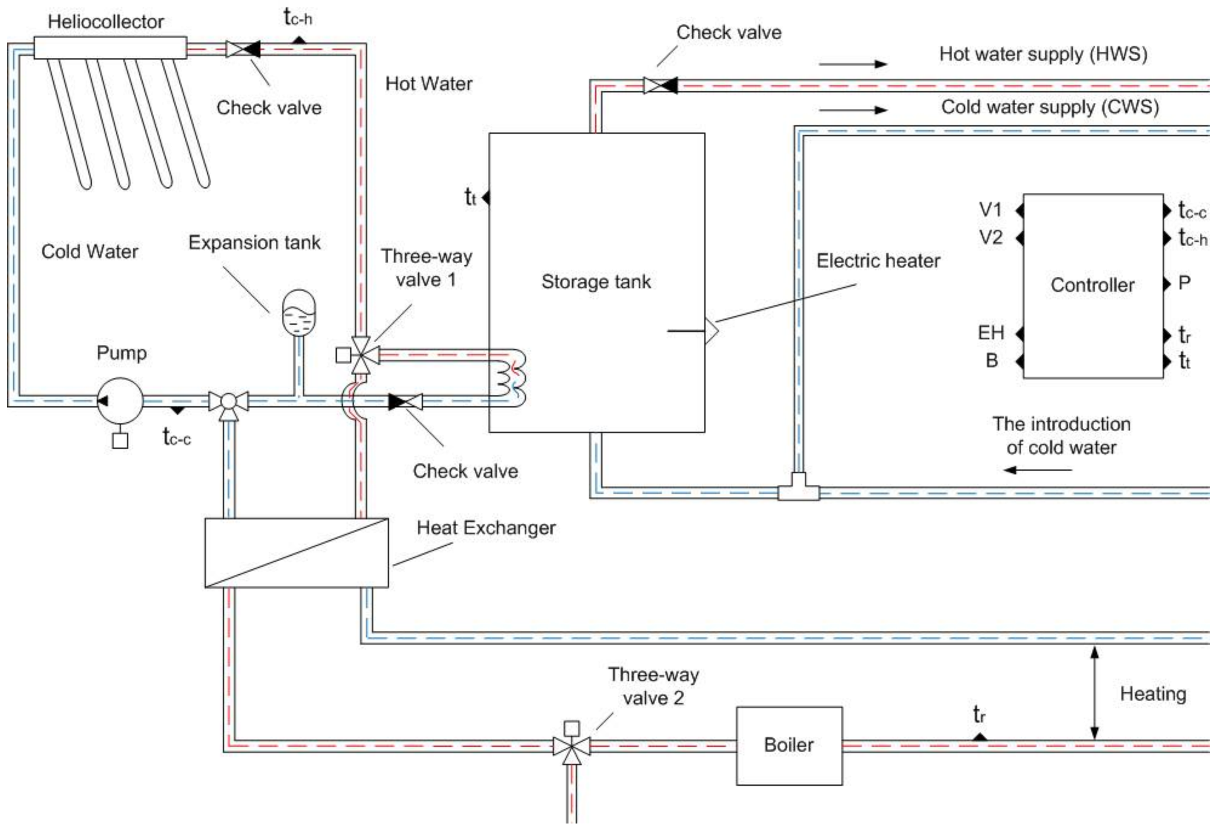

Fig. 1. Generic structure of the unified MCU-based solar collector monitoring and control module.

The automated control module performs continuous monitoring of operational modes and temperature parameters of the system, as well as switches the mode in the case of certain edge conditions are reached. The implemented state machine uses the three-temperature model that represents logical temperature ranges – minimal (min), nominal (nom), and maximum (max) with associated parameters that together define the operational mode. Temperature ranges may be adjusted for a particular system as well as associated operational parameters may be redefined according to equipment setup.

For the purpose of operational mode switching, the control module continuously measures three key temperatures: temperature of hot water, produced by solar collector, temperature in storage tank, and air temperature in the room. The module implements 7 operational modes that are listed in table 1.

Table 1. Operational modes

Operational mode	t_t	$t_{c\text{-}h}$	t_r	**Relay**				
				1	2	3	4	5
1 (idle)	nom	nom	nom					
2 (active: solar collector)	min	nom	nom	■				
3 (active: el. heater)	min	min	nom		■			
4 (active: solar coll, boiler)	nom	nom	min	■		■		■
5 (active: boiler)	nom	min	min					■
6 (active: el.heater, boiler)	min	min	min		■			■
7 (stagnation protection)	max	max	max	■		■	■	

Relay key: 1 – pump; 2 – electric heater; 3 – three-way valve 1; 4 – three-way valve 2; 5 – boiler.

In the idle mode, system is found in an equilibrium state when temperatures in solar collector, storage tank and in the room lie in a nominal range. In this mode none of the control relays are engaged.

If the temperature in storage tank drops below nominal value while other temperatures remain in nominal range the system switches to operational mode #2 by activating the pump in a solar collector circuit. Circulation of heat medium will rise temperature in a storage tank that in the case of sufficient insolation will eventually reach nominal range.

Operational mode #3 is being activated when temperatures in storage tank and solar collector output both fall below nominal value, while the room temperature is still in the optimal range. In this mode, the electric heater is switched on by engaging relay #2. Controller will maintain the storage tank temperature in the range between t_{nom0} and $(t_{nom0}+t_{nom1})/2$, leaving some capacity for heat energy that may come from the solar collector. Such situation may occur in the case of improvement in weather conditions.

Operational mode #4 is activated when temperatures at solar collector output and storage tank lays in the nominal range, while room temperature drops below its lower point. The boiler and pump are switched on, while three-way valve 1 is engaged to attach solar collector to heating circuit. This mode allows the solar collector to assist boiler as a secondary source of heat and reduce the amount of energy required to for heating in the case of sufficient insolation.

Operational mode #5 corresponds to the scenario where temperature in storage tank remains in nominal range, while both solar collector and room temperatures fall below their minimal value. In this case insolation is insufficient to assist heating that is performed solely using boiler.

One of the critical problems that should be efficiently solved in order to ensure durability and sustainability of such system is the stagnation of the solar thermal collector. Stagnation will damage equipment if the temperature reaches critical value (200°C for flat collectors, and 300°C – for vacuum ones). Such situation may occur in the case of high insolation and low consumption of hot water.

The stagnation may be divided into number of stages, for this reason the multilevel stagnation protection is implemented in the proposed design that includes active and passive components. Among passive measures there are expansion tank that prevents the development of the stagnation process and the high temperature flap valve that helps to reduce temperature and pressure in the case of critical overheating. Both of these measures help to reduce the negative impact of overheating while still not capable to prevent it entirely.

As an active measure, the control module implements special emergency operational mode #7 to protect solar collector against stagnation. For this purpose, the pump will be switched on to reduce temperature inside the collector while three-way valve 1 will be engaged to attach solar collector to heating circuit via heat exchanger. Thus, the surplus heat will be transferred to the high-capacity heating circuit that will protect collector and improve sustainability of the system. Furthermore, the proposed approach reduces the maintenance cost for remove/refill the heat agent.

Conclusions. The proposed design is capable to utilize any type of the heat sources such as a heat pump without replacing the control module or changing the operational logic, while modular architecture allows easy upscaling for building complex smart systems.

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Розробка і реалізація уніфікованого модуля керування для забезпечення сталого функціонування комбінованої системи на базі відновлюваних джерел енергії

Розроблено уніфіковану модульну систему моніторингу і контролю сонячного колектора з можливостями балансування *та захисту від стагнації. Автоматизований модуль керування здійснює постійний моніторинг температурних параметрів системи, а також перемикання режимів роботи у випадку настання граничних умов. Захист від стагнації реалізований як спеціальний аварійний режим роботи, коли надлишкове тепло передається на контур опалення, що дає змогу захистити колектор та продовжити термін експлуатації обладнання. Показано, що запропонована система здатна використовувати будь-яке джерело теплової енергії без заміни модуля керування, тоді як модульна архітектура спрощує задачу масштабування для побудови комплексних інтелектуальних систем енергопостачання. Бібл. 2, рис. 1, табл.1.*

Ключові слова: *"розумний дім", сонячний колектор, автоматизований модуль керування, захист від стагнації.*

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Разработка и реализация унифицированного модуля управления для обеспечения устойчивого функционирования комбинированной системы на базе возобновляемых источников энергии

Разработана унифицированная модульная система мониторинга и контроля солнечного коллектора с возможностями балансировки и защиты от стагнации. Автоматизированный модуль управления совершает постоянный мониторинг температурных параметров системы, а также переключение режимов работы в случае наступления граничных условий. Защита от стагнации реализована как специальный аварийный режим работы, когда избыточное тепло передается на контур отопления, что дает возможность защитить коллектор и продлить срок эксплуатации оборудования. Показано, что предложенная система способна использовать любой источник тепловой энергии без изменения модуля управления, тогда как модульная архитектура упрощает задачу масштабирования для построения комплексных интеллектуальных систем энергоснабжения. Библ. 2, рис. 1, табл.1.

Ключевые слова: *"умный дом", солнечный коллектор, автоматизированный модуль управления, защита от стагнации.*

SYNOPSES

Automated monitoring and control systems becoming an integral part of modern renewable energy systems to optimize efficiency, reduce maintenance cost and improve their sustainability. In addition to the traditional passive measures, the overheating and stagnation issues in the solar collector systems may be addressed with MCU-based control system. The emergency stagnation protection mechanism has been developed and automated control module with balancing capabilities and active stagnation protection has been implemented. The system uses abstract three temperature range state-machine that provides compatibility with various heat sources without requirement of replacing control module or changing operational logic. In the case of critical overheating the solar collector may be attached to heating circuit via dedicated heat exchanger to prevent irreversible degradation of equipment. The implemented control module performs continuous monitoring of the temperature and operational parameters optimizing utilization of renewable energy sources and ensuring safe and sustainable operation of the system.

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