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Improving automatic control of a solar heating system for increasing its efficiency

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Abstract. The control scheme for the operation of a solar circuit pump with a bypass and photovoltaic batteries during the period of solar insolation is considered. At the same time, optimal modes of functioning are provided by thermal processes in the heat supply system. Are shown results of experimental researches by energy efficiency for developed technical solutions.

1. Introduction

The variety of types of solar heat supply system (SHS) predetermines the need to develop and apply a large number of options for methods and schemes for their automation [1,2]. When choosing options, the following classification features of systems are taken into account [3]:
i) types of heat load - seasonal hot water supply, year-round hot water supply, process load, heat supply;
ii) types of systems - autonomous (without a backup source of thermal energy, with a peak fossil fuel boiler, with an electric boiler); centralized (solar installations associated with the heat supply system from the boilerhouse, also from the district boiler house);
iii) types of coolant and the number of circulation circuits - water single-circuit systems, liquid double-circuit and multi-circuit systems;
iv) heat carrier circulation methods - thermosyphon (with natural circulation), with forced circulation;
v) types of solar collectors - flat solar collectors focusing solar collectors without a tracking mechanism, also with a tracking mechanism, tanks - solar water heaters, jet solar collectors;
vi) types of accumulation - daily, seasonal (in accumulator tanks).

The properties of the technological process in SHS [4] are characterized by such physical quantities as pressure, level, flow rate and temperature of the coolant. Parameters are divided into qualitative (level or volume of fluid for a hydraulic tank, its pressure, temperature, etc.) and quantitative (coolant inflow into the tank, coolant flow rate). The parameters are in close functional relationship and by changing one of them, you can control the change in the second. The task of controlling the technological process of the SHS system includes the management of all simple single circuits of this process and their interconnection [6,7].

Various dynamic influences on the processes occurring in the automated objects of the SHS systems are caused by a relatively small number of factors: continuous and discrete. The first include changes in pressure, flow rate, level, amount of heat, etc.; to the second - the state of the actuators and equipment [8,9].

The main general features of SHS systems are as follows [10]:
- the dependence of the operating mode of the system on constantly changing technological and climatic parameters, namely: on the intensity of solar radiation, changes in the angle of inclination of the solstice in relation to the solar collector, meteorological conditions;
- the dependence of the operating mode of the system on the heat load of consumers changing during the day (hot water supply, heating);
- the need to ensure the most economical processes for collecting, accumulating and distributing solar energy;
- the need to ensure the most effective regulation of heat extraction by the SHS system from a backup source (electric heating).

The above features of the SHS operation show that for optimal control it is not enough to have qualified service personnel, and it is necessary to use modern means of automatic control and management, which provide the best technical and economic indicators for the selection and establishment of operating modes in these conditions.

The tasks of automatic control [11,12] for the SHS in general form can be formulated as follows:
i) regardless of the mode of radiation heat input, the required values of the controlled parameters (water temperature in the hot water supply system) at the heat consumption facility must be maintained;
ii) energy losses during the conversion of solar energy into thermal energy, during transport and storage of generated heat should be minimal;
iii) the operation of solar systems must be organized in such a way that the costs of fuel and energy resources in the production of heat by a duplicate source, as well as damage from environmental pollution, are minimized;
iv) protection of solar collectors, as well as other elements of solar systems from freezing, overheating and mechanical damage must be provided.

The task of maintaining the required parameters is solved by controlling the flow distribution through solar collectors and heat accumulators, as well as by changing the included power of the backup source [13].

The minimization of costs in the production of solar collectors, transportation and storage of thermal energy is achieved by stopping the circulation of the coolant during periods of absence of solar irradiation, by changing the orientation of the solar collector in space, which ensures the maximum efficiency of the collector when absorbing solar rays and reducing losses in the absence of irradiation [14].

Minimization of the costs of fuel and energy resources during the operation of combined systems is ensured by solar installations covering the base part of the annual (daily) load schedule and operation of the backup source in peak mode, as well as by seasonal heat accumulation. The protection of solar systems equipment is carried out using special automatic devices [15].

The solution to the first problem can be represented as

$$\min \sum_{i=1}^{N} [\Delta t_i(\tau)]^2 \qquad (1)$$

provided that

$$\Delta t_i(\tau) \leq \Delta t_{\mathrm{norm}} \qquad (2)$$

where □- moment of time; *t* is the studied time period of the system operation (year, heating season, month, day, etc.); N is the number of measurements carried out over a period of time; Δt_i - deviation of the value of the controlled temperature at the time □□ from a given value; Δt_{norm} - normalized (maximum allowable) deviation of the controlled temperature from the set value.

Minimization of heat losses in the solar heating system takes place under the condition

$$\min \int_0^T [Q_{l.solar}(\tau) + Q_{l.\mathrm{tr}}(\tau) + Q_{l.a}(\tau) + Q_{l.\mathrm{other}}(\tau)]\, d\tau \qquad (3)$$

where $Q_{l.solar}(\tau)$- energy losses when capturing solar radiation, converting it into heat and transferring (dissipating) the generated heat energy from the solar collector to the surrounding harm; $Q_{l.\mathrm{tr}}(\tau)$- losses of the received energy during transportation in the solar system; $Q_{l.a}(\tau)$ - losses of

thermal energy in the accumulator; $Q_{l.\text{other}}(\tau)$ - losses of thermal energy in other elements of the solar heat supply system.
The minimization of the cost of fuel and energy resources will be ensured when

$$\max \frac{\int_0^T Q_{\text{solar}}(\tau)d\tau}{Q_{\text{total}}(\tau)d\tau} \quad (4)$$

here $Q_{\text{solar}}(\tau)$- the amount of energy generated in the solar collector at a time τ; $Q_{\text{total}}(\tau)$ - the total amount of energy generated by all types of heat sources.
At the same time, economic conditions must also be

$$\min \int_0^T Z_{dam}(\tau)\, d\tau \quad (5)$$

$$\int_0^T Z_{\text{solar}}(\tau)\, d\tau \leq \int_0^T Z_a(\tau)\, d\tau \quad (6)$$

here $Z_{dam}(\tau)$ - cost characteristic of environmental damage from the operation of the combined system, $Z_{\text{solar}}(\tau)$- the cost of operating a solar energy system; $Z_a(\tau)$ - the cost of operating an alternative heat source, provided that the same amount of energy is generated for the same period of time.

2. Methodology

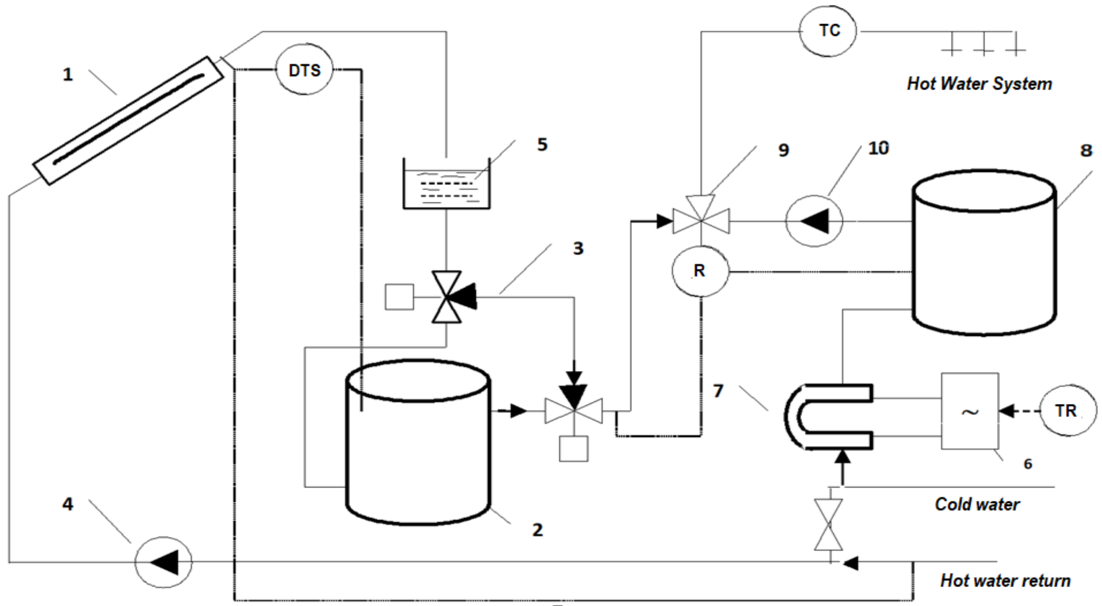

Figure 1. The proposed scheme of a solar hot water supply system with an electric backup: TC - temperature controller; TR - time relay; DTS - differential thermal switch; R - ratiometer

Figure 1 shows the proposed scheme of a solar hot water supply system with an electric backup, developed taking into account the above conclusions. When the temperature in collector 1 is higher than in storage tank 2, water circulates in the collector-accumulator circuit.
When the temperature of the water in the collector falls below the temperature in the accumulator, it is directed to the consumer through the bypass channel 3. A further decrease to values below the temperature of the return hot water leads to the fact that it becomes impossible to heat it in the collector.
In this case, the circulation pump 4 in the solar circuit is switched off and the bypass valves return to their normal position. After that, the water from the collector is drained into the reservoir 5 and the heat is removed only from the accumulator. When the sun rises again, and the temperature in the collector becomes higher than the temperature in the accumulator, the circulation of water through it resumes when the circulation pump 4 is turned on by the differential thermal switch. The electric

backup 6 is switched on by the signal of the timer-time relay in off-peak mode. The incoming cold water is heated through a high-speed heat exchanger 7. As a result, the tank 8 is filled with hot water, which is then used to heat up the water going to the consumer. This occurs by a signal from the temperature controller located at the supply to the consumer, pump 10.

If the output signal of the regulator reaches the limit value and remains so for a certain time, indicating a lack of solar heat to maintain the water at the set temperature, then the position of the mixing valve 9 is adjusted by the ratiometer so that proportional mixing of water from the solar circuit and from the backup circuit takes place, depending on their temperatures.

3. Results

The above SHS scheme allows the use of methods for storing heat and electrical energy, which is very important from an economic point of view for the successful implementation of solar hot water supply systems.

To create an energy-saving mode, the SHS automation unit must be supplemented with a solar insolation sensor, i.e. a device - a pyranometer, which will allow to exclude the supply of coolant from solar collectors to the hot water storage tank during the period when the supply of solar energy becomes insufficient.

In existing circuits, a malfunction of the SHS often occurs due to a malfunction of the differential thermal switch control unit (wire breakage from the sensors, contact failure), as a result of which the solar circulation pump does not turn off / turn on at the required time.

Thus, the task of finding technical solutions that can significantly improve the reliability of the automation of such an important unit of the solar system becomes urgent, providing the most optimal energy-saving mode of operation of the SHS.

Such a solution could be the replacement of an asynchronous motor in the circulating pump drive with a DC motor, the electric current of which will be supplied from photovoltaic batteries.

The advantages of such a solution will be:

1.improving the control accuracy, since solar insolation will directly affect the actuator, and not through an intermediate automation unit in the form of a differential thermal switch;

2. simplification of the pump drive and thereby increasing its reliability by eliminating the violation of operating modes due to failures in automation;

3. no need to install a backup pump in the solar circuit;

4. saving electricity from the network, because power comes from autonomous photovoltaic batteries.

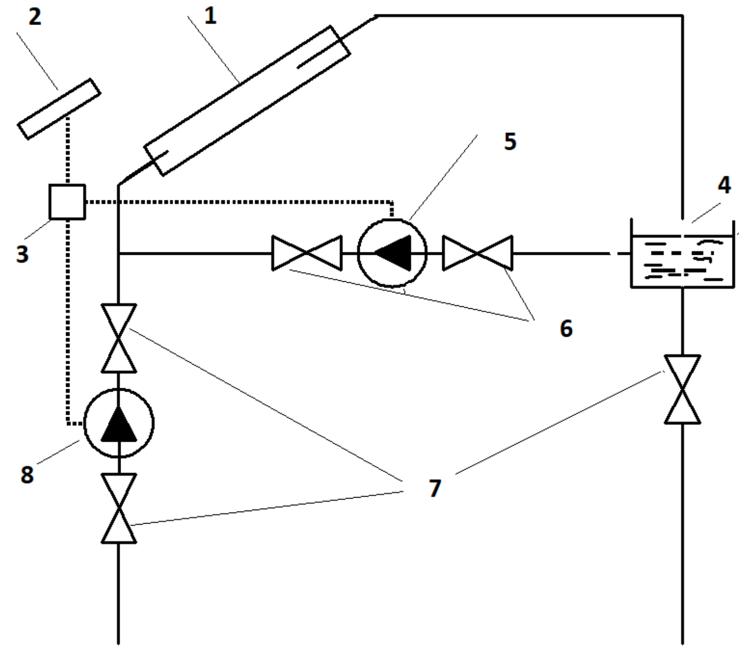

Figure 2. Adding the SHS solar circuit to the SHS circuit (Figure 1): - bypass circuit; - power supply of circulation and bypass pumps from photovoltaic batteries

The power of the photovoltaic batteries can be selected in such a way that the circulation pump is switched on during the period of solar insolation, when useful work of solar collectors is possible to heat water and at the same time the necessary pressure of the coolant in the solar circuit is provided. It is possible to simplify this task due to the bypass circuit, which will significantly reduce the required installed power of the pump drive motors in the solar circuit of the system shown in Figure 2.

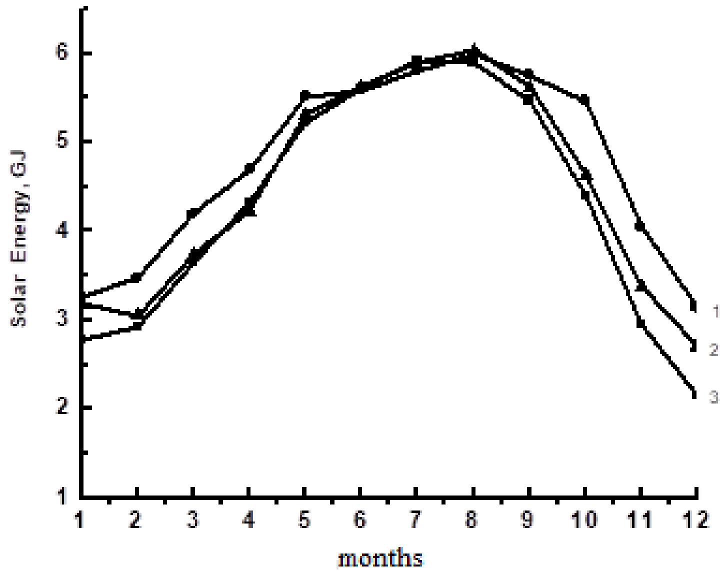

Figure 3. Monthly coverage of the heat load due to solar energy for the climatic conditions of Tashkent city at the variants: *1*- traditional scheme; *2*-technical solution in Figure 1; *3* - technical solution in Figure 2

The operation of the solar circuit with bypass and photovoltaic batteries shown in Figure 2 is as follows. In the drainage system, with sufficient solar radiation, the controller 3 of the photovoltaic batteries 2 turns on the pump of the bypass circuit 5 and, due to the shorter length of the pipes, it is possible to provide a quick supply of water to the collectors 1 from the tank-reservoir 4 and to intensify the process of its heating. When the set value is reached, pump 5 is turned off, valves 6 are closed, valves 7 are opened and the main circulation pump 8 is turned on, distilling already heated water through the solar circuit into the storage tank. Further work of the SHW occurs according to the schematic diagram shown in Figure 1.

To verify the conclusions, experimental studies of SHW technical solutions for the conditions of Tashkent were carried out in 2018. The CST solar plant consists of four panels of solar collectors, the area of each of which is 1.93 m^2. The measurement results during year monitoring are shown in Figure 3.

4. Conclusions

Based on the analysis of existing solar heat supply systems, the following conclusions can be drawn:

I. For systems using liquid solar collectors, frost protection is required; in some cases, filling the solar circuit with antifreeze becomes economically unprofitable for the following reasons:

a) With significant required storage volumes, the high cost of antifreeze prevents its use [16];

b) This protection method can only be used in double-circuit systems, when the heating medium circulating through the solar collectors is separated by a heat exchanger installed in the storage tank from the heat storage water. The cost of the heat exchanger constitutes a significant part of the total capital cost of the system and, in addition, reduces its efficiency, as shown in [17], each degree of temperature difference in the heat exchanger reduces the efficiency of the collector by 1-2% due to the fact that at high temperatures of the collector, solar absorption decreases. energy and heat losses increase.

c) The use of storage tanks in the form of high-capacity heaters is associated with an increase in the surface of the heat exchanger several times compared to two-tube high-speed heat exchangers and necessitates an increase in the area of solar collectors [18].

A more preferable method is to prevent the coolant from freezing when the collector is placed above the accumulator, as a result of which water can freely drain from the collector, after the circulation pump is stopped, into the tank with thermal insulation protection. This can be easily achieved by installing solar collectors on the roofs of buildings [19].

In this case, the pump must have a higher head, but the energy consumption for pumping is so small compared to the heat generation in the system, which does not lead to a noticeable increase in costs. In this case, it is possible to provide the necessary protection without using a heat exchanger in the solar circuit.

II. Differentiation of electricity tariffs, which implies its reduction in price during gaps in the power system's electrical load schedules, makes it possible to develop a solar system scheme that allows obtaining hot water for technological and household needs, using solar energy in combination with off-peak electricity, which will significantly reduce the payback period for these SHS installations [20].

III. Carrying out experimental researches demonstrated increasing performance of proposed SHW up to 16% in perods of winter, spring, autumn.

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