Investigation of the working condition of large power solar panel cleaning device

E. Saitov¹*, G. Khushakov², U. Masharipova³, O. Mamasaliyev¹, and S. Rasulova¹

¹Tashkent State Technical University, Street University, 2A, 100095 Tashkent, Uzbekistan
²Jizzakh Polytechnic Institute, Islam Karimov avenue (former Khalklar Dustligi), 4, 130100 Jizzakh, Uzbekistan
³Tashkent State Pedagogical University, Bunyodkor avenue, 27, 100070 Tashkent, Uzbekistan

Abstract. Solar energy is becoming a key resource of electrical energy in the modern world. Therefore, it is necessary to use it rationally and profitably. The article deals with the issues of efficient use of solar panels due to automatic cleaning devices in winter. The proposed device allows you to use solar energy in maximum quantities, regardless of weather conditions and seasons. This device can be used in the construction of new solar power plants, as well as in the modernization of existing ones. The development and modernization of solar energy will improve the economic side of the energy situation in our country in the future.

1 Introduction

A pressing issue in the modern world is the problem of reducing fossil fuel reserves and the transition to alternative fuels. This is primarily due to the depletion of natural resources and environmental pollution. Of the existing directions for the development of alternative energy, the most promising is solar energy. Its potential has been estimated for centuries, and the harmful effects on the environment are minimal [1, 2].

The purpose of using solar energy is to convert solar radiation into various types of energy. Many developing countries of the world interested in solar energy are looking for various ways to reduce the cost of maintenance and operation of solar panels.

It should be noted that in accordance with the Program of measures to reduce energy intensity, the introduction of energy-saving technologies and systems in the sectors of the economy and the social sphere for 2015-2019, approved by the Decree of the President of the Republic of Uzbekistan dated May 5, 2015 No. Presidential Decree -2343, in the republic in recent years a wide range of measures is being implemented to ensure energy saving in the sectors of the economy and the social sphere [3, 4].

By 2026, an increase in the share of renewable energy sources in a number of regions of the country up to 25% will save about 3 billion cubic meters of natural gas per year. It will also reduce the amount of harmful gases emitted by 8 million tons.

* Corresponding author: gelyor.saitov@gmail.com

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Planned work will be carried out in accordance with the program for expanding and supporting the use of renewable energy sources, approved by the relevant presidential decree.

From this:

a) Construction of 4 GW of additional capacity through the construction of at least 8 wind farms (WPPs), including:
   - In 2023 in the Beruni and Karauzak regions of the Republic of Karakalpakstan and in the Gijduvan and Peshkun regions of the Bukhara region (1.1 GWh);
   - 1 (0.5 GW) in the Tomdinsky district of the Bukhara region in 2024;
   - Launch of at least 4 (2.4 GW) HPPs in the Republic of Karakalpakstan and other regions in 2025-2026

   These works cost 4.7 billion dollars. will be financed by attracting foreign direct investment in the amount of

b) At least 10 solar power plants will be put into operation to increase the capacity of solar photovoltaic installations (PV plants) up to 4 GW, including:
   - Completion of the selection of investors in 2022, 5 in Bukhara, Namangan, Khorezm, Kashkadarya and Fergana regions with a total capacity of 0.9 GW in 2024;
   - 4 1.1 GW in Navoi, Jizzakh, Samarkand and Surkhandarya regions in 2023;
   - commissioning of PPPs with a total capacity of 1.8 GW in the Republic of Karakalpakstan and other regions in 2025-2026.

   These works cost $1.5 billion. by attracting foreign direct investment in the amount

c) The construction of 15 new hydroelectric power plants (HPPs) and the modernization of 5 existing HPPs will generate an additional 868 MW of electricity per year.
   Including:
   - 7 to create an additional 173 MW in Samarkand, Surkhandarya and Tashkent regions in 2022;
   - Completion of the modernization of 1 HPP in the Tashkent region in 2023 and 2 in the Kashkadarya and Andijan regions with a total capacity of 29 MW;
   - Completion of the modernization of 1 HPP in Andijan, Namangan, Surkhandarya and Tashkent regions in 2024 and 4 with a total capacity of 122 MW;
   - Commissioning of 4 HPPs with a total capacity of 544 MW in Kashkadarya and Tashkent regions in 2025-2026.

   In total, 1.6 billion dollars were spent on these works. JSC "Uzbekhydroenergo" and other sources provided by the legislation.

In this regard, there is a need to increase the efficiency of solar panels. Timely detection of dirt, foreign objects on the surface of the panel and their quick removal will make it possible. It is the degree of pollution that determines the efficiency and service life of solar panels [5, 6].

According to long-term average data, a stable snow cover is formed in Ufa in mid-November (sometimes even the first ten days of April) and remains until the end of March. On average, there are about 164 days with snow cover per year, i.e. more than five months [7]. Undoubtedly, the presence of snow cover affects the efficiency of solar panels and their efficiency.

To assess the impact of weather conditions on the generation of energy by solar panels, a SPP was chosen, installed at the Department of Alternative Energy Sources of the Tashkent State Technical University named after Islam Karimov. 10 kW photovoltaic stations manufactured by Chint Electric LLC are used (microamorphous module with a nominal power of 125 W and a crystalline module with an area of 1.286 m2, the rated power of the crystalline module is 223 W, the installation angle of photovoltaic modules is
39 degrees). Four days were chosen for the study: two clear days and two cloudy ones. At the same time, snow sticking to solar panels was observed on one of two days [8, 9].

Table 1. Energy indicators of the SES crystalline module.

<table>
<thead>
<tr>
<th></th>
<th>It's a nasty day</th>
<th>Clear day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without snow coverage (November 12)</td>
<td>With snowy coated (November 20)</td>
</tr>
<tr>
<td>Maximum intensity of solar radiation</td>
<td>25</td>
<td>32</td>
</tr>
<tr>
<td>Maximum generated power</td>
<td>2.8</td>
<td>0.9</td>
</tr>
<tr>
<td>Electricity generated per day</td>
<td>thirteen</td>
<td>2</td>
</tr>
</tbody>
</table>

The average duration of these days was 8 hours and 30 minutes. At the same time, the level of solar radiation intensity in the compared days is approximately the same.

The studies carried out made it possible to obtain results that can be used to evaluate the effect of snow cover on the efficiency of energy generation by solar panels (Tables 1, 2). The presence of snow cover leads to a decrease in the power of the crystalline module by 2 times, and that of the micromorphic module by 10%. That is, the generated electric power is affected by bad weather conditions and the presence of snow cover, but transparent ice is practically not affected [10, 11].

It is necessary that the surface of solar panels periodically be able to self-clean from snow, fallen leaves and dust, since solar power plants are usually installed in remote areas and constant monitoring of their cleanliness by personnel is impossible [12, 13]. Monitoring and constant maintenance increases the cost of construction, and reducing the cost of building and maintaining solar power plants is a key factor in further development.

2 Evaluation of the effectiveness of solar panels

A number of options have been proposed that allow autonomous and independent cleaning of the panels. For example, the application of a special composition, the installation of a protective panel, the use of automated robots, the use of flexible modules, the use of the phenomenon of vibration [14]. Each proposed concept has its own advantages and disadvantages. Our initiative group has developed a model with improved cleaning technology, devoid of key shortcomings. In the future, such technologies will completely eliminate the dependence of electricity production on weather conditions and the availability of maintenance personnel [15, 16].

The purpose of this work was to automate the cleaning processes of solar panels in order to increase their efficiency and performance. An important point is the use of solar
panels regardless of temperature and weather conditions, as well as the lack of maintenance personnel and the possibility of installing this system on existing solar panels. [17, 18]

This goal is achieved by the fact that in the upper part of the photovoltaic battery two elastic hoses are installed, turned in the form of an arc, and in the direction perpendicular to the plane of the photovoltaic battery, using springs, and united by a common tube along which nozzles are installed directed towards the surface at an angle of 45° to the front surfaces, and on the back side are united by a common pipe in the central part, a pipe is connected, directed downward and part of which is underground, where an electromagnetic hydraulic valve is installed in the intermediate part, the pipe is connected to an electric pump with a collector electric motor, closed in a thermal insulation box and connected to a phase-pulse control circuit, including a power trinistor, the anode output of which is connected to an electric motor and photodiodes, the second output of which is connected to the zener diode and the anode of the low-power trinistor and the capacitor, the second output of the zener diode is connected to the control output, the cathode output of the low-power trinistor is connected to the control electrode of the powerful trinistor, the cathode output of which is connected in parallel to the resistor to the second output of the capacitor and the rectifier bridge, the other output of the diode of the bridge is connected to the second output of the electric motor, two outputs of which are behind - in parallel with a series-connected resistor and a capacitor, photodiodes are combined with LEDs forming an optocoupler, the latter are connected to a multivibrator with adjustable frequency, an electromagnetic hydraulic valve is connected in parallel to the rectifier bridge through a resistor and a parallel-connected capacitor, through a push-button switch, a second short pipe with a tap is connected to the pump [19 - 22].

Fig. 1. General view of automatic cleaning of solar photocells.  
Fig. 2. Front side photovoltaic array with washing unit

The essence of the proposed device is illustrated by drawings where, in Fig. 1. shows a general view, from the front side of a photovoltaic battery with a washing unit, in Fig. 2. the same side view, in Fig. 3. view from the rear (rear) part, in Fig. 4. shows the connection diagram of the conduit (hose) to the pump and its installation; the electrical circuit of the pump motor control and connection is shown in Fig. 5., in Fig. 6. fragments of water flows (jets) coming out of the nozzles are shown depending on the change in the supplied water pressure, angles of incidence (angles of attack) on the surface of the photovoltaic array, in the form of an oblique projection and in Fig. 7. the nozzle is shown in section [23, 24].
The essence of the proposed device is illustrated by drawings where, in general view, from the front side of a photovoltaic battery with a washing unit, in the plane of the photovoltaic battery, using springs, and united by a common tube along the surface, and on the back side are united by a common pipe in the central part, a pipe is connected to the pump 10 with a collector electric motor, closed in a thermal insulation box and connected to a horizontal level of the pump 11 and tube 14 with a tap 15 should be below the entry point (level) of pipe 9 into the ground. The collector motor 11 of the pump 10 and the valve mechanism 12 are connected to the electrical circuit 16 with a phase-pulse controller, [24] consisting of a powerful control SCR 17 Figure5, connected by an anode to one of the outputs of the electric motor 11 of the pump 10, the other end of which is connected to an analog of a dinistor, composed of a low-power trinistor 18 and a zener diode 19.

![Fig. 3. View from the rear (rear) part of the automatic cleaning of solar photovoltaic cells.](image1)

![Fig. 4. A diagram of connecting a conduit (hose) to a pump and its installation is shown.](image2)

![Fig. 5. Electric circuit for pump motor control and connection.](image3)

![Fig. 6. Fragments of water flows (jets) emerging from nozzles.](image4)
The choice of the collector electric motor 11 of the pump is due to the fact that the voltage control is much simpler than with an asynchronous electric motor, the operating time in the water injection mode is not a long time interval (hours, for example, 1 time in 2-4 weeks), so the limited resource of work is not the main obstacle to its application [25, 26].

The frequency of the multivibrator can be adjusted in the range of 0.1 - 1.0 Hz. those. (from 10 secs to 1 sec) depending on the specified conditions. Power supply regulator. Sequential connection of LEDs 35 and photodetectors 36 (optocoupler) is necessary to ensure the maximum change in resistance (up to 35 - 40 kOhm) from the minimum [27, 28].

The operation of the proposed device is as follows. In the initial state, nozzles - nozzles 4 are at the smallest angle to the surface of the photobatteries 1 and the smallest distance, due to the attracting springs 6, the stiffness of which is selected depending on the elasticity of the hoses 5, the maximum water pressure, the diameters of the hoses 5, the size of the photobatteries and 1, etc.

To carry out the cleaning process with the switch 37, the voltage drops on the diode bridge 22, from which the capacitor 20 is charged through the photodetectors 36, with current from the diode bridge, 22 when the voltage across the capacitor 20 becomes equal to the turn-on voltage, the zener diode 19 opens, followed by the tristor 18, the capacitor 20 is rarefied through the control transition of the tristor 17, as a result, it opens, and the electric motor 11 is energized for the time remaining until the end of the half-cycle of the mains voltage [29, 30]. At the end of its tristor 17 is closed because. the current through it decreases to zero, after which the cycle repeats. With the help of a multivibrator on the logic elements 28, 29, 30, the frequency is set i.e. increasing or decreasing the voltage to the electric motor 11, which is regulated by a variable resistor 32.

At the minimum speed of the electric motor 11, the water pressure will also be minimal, while the nozzles 4 are directed at an angle of approximately 450, and the water flows will wash the uppermost part of the photobatteries 1, the voltage increase signal from the multivibrator and, accordingly, the increasing light flux from the LEDs 35 hitting the photodetectors 36 will lead to a decrease in resistance and the electric motor 11 will begin to increase the water pressure, while the pressure inside the sections of the hoses 5 will begin to rise, the hoses will begin to straighten and the angle of attack of the water flows will increase, (Figure6) i.e. flows will now (smoothly) go to the middle, and then to the lower part (the travel time is determined by a variable resistor 32), then the light flux from the LEDs 35 will begin to decrease, the hoses will begin to bend again (inward).

If necessary (heavy pollution or ingress of sticky particles), the flushing process can be carried out in a pulsed mode, for which the push-button switch 27 is turned on, while the water flow will be closed due to the voltage from the diode bridge 22, from it through the limiting resistor 26 and the capacitor 25, solenoid valve 12, the closing frequency (closing -

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Fig. 7. Nozzle in section.
opening time) will be determined depending on the given conditions and the level of pollution.

After the end of the washing process, the switch 37 turns off the water flow, while the residual water from the upper hoses 5, nozzles 4 and vertically installed hose 9 will begin to flow down the pipe through the open tap 15. This is necessary to prevent freezing of water in winter (below 0°C) which will exclude a break in the expansion of the supply part and blockage of the metal pipe 9 in the area outside the ground. The water remaining in the lower (underground part of the pipe 9 is protected from freezing. To restart the device, it is necessary to close the valve 13.

The impulse cleaning mode is more efficient in comparison with a uniform supply under pressure of water, due to the fact that at the initial moment the speed of the water in the closed state, after opening, has a maximum value with a certain mass (impulse m × v) and therefore this cleaning method should be used in cases where increased efficiency is required [30].

To simplify the design, instead of conventional springs, flat arcuate springs can be used, which will somewhat simplify the fastening parts of springs 6.

The washing process in the middle and lower parts will also be effective. the angle of attack of the water flows is much greater than in the upper part of the photovoltaic arrays 1. The pulse mode is different in that the direction of the water flow also changes. In the closed state by the solenoid valve 12, the angle of the nozzle 4 will be minimal, when opened it will increase i.e. water supply is not only shock, but also with a change in angle [31].

Thus, the increase in cleaning efficiency is increased by using the flow of water, in contrast to the closest analogue with, and thereby energy efficiency is increased, the design of the mechanical part is simplified, bulkiness; the convenience of operation is increased, due to the introduction of an electric pump with an electronic control circuit, where the cleaning process is provided without an additional electric drive. It is the process of cleaning the manufacturer without human participation in photovoltaic batteries, reducing weight, cost and simplifying the design [32]. The proposed device provides for the exclusion of water freezing in pipes, which increases the reliability of operation in winter and the possibility of intensive cleaning due to the possibility of pulsed water supply under pressure.

Numerically, the Ampere force acting on a length of wire is equal to:

$$dF_A = \frac{\mu_0 \mu_2 I_1 I_2}{4\pi R} dl$$

Where \(dF_A\) is the Ampere force acting on section of wire length \(dl\), N; \(dl\) is the length of the wire section, m; \(I_1\) - current flowing in the first wire, A; \(I_2\) - current flowing in the second wire, A; \(R\) is the distance between the wires, m; \(\mu_0\) is the magnetic constant equal to \(4\pi \times 10^{-7}\) N/A²; \(\mu\) is the relative magnetic permeability. When passing alternating current pulses through two wires, the wires will perform mechanical oscillations under the action of the periodically appearing and disappearing Ampère force. Due to these vibrations, the wires are in contact with each other, and the snow cover formed on the wires will eventually fall off [33].

To improve the efficiency of the proposed method and reduce energy consumption, it is necessary that the frequency of the current pulses passing through the wires be equal to the natural frequency of oscillations of the iced wires fixed on the solar panel. In this case, a resonance phenomenon occurs, leading to a destructive effect on the ice.

The proposed development should reduce the energy consumption for wire cleaning. Since the mechanical destruction of ice is produced, the time spent on cleaning will be significantly less than the time spent on melting. In addition, the energy costs for cleaning...
will be lower than for melting, even with a higher instantaneous power required to create vibrations.

The device works as follows:
- battery pack as storage energy;
- the inverter converts the direct current from the batteries into alternating current;
- wire tension sensors, allow you to signal the presence of icing on the wires;
- controller of the state of the wires and the inclusion of the cleaning system.

When ice or a heavy layer of dirt accumulates on the wires, tension sensors are triggered, which transmit data to the controller. The controller allows you to evaluate the condition of the wires and, if necessary, start the mechanism for supplying alternating current with a frequency of 50 Hz to the wires. After the current is applied, the wires begin to gradually oscillate for a certain time. Further, the sensors either work or not, depending on the tension of the wires [34].

The obvious requirement for such devices is the relative ease of implementation, relatively low cost and high reliability [35].

For example, if we take two parallel wires 1 m long and pass a current of the same value of 5 A through them, but in the opposite direction, while changing the distance between the wires, we will get a graph of the dependence of the interaction force between the wires on the distance between them (Fig. 4):

- at $d = 5$ cm.
  
  \[
  F_{A1} = \frac{\mu_0 I^2 l}{2\pi d} = \frac{4\pi \times 10^{-7} \times 5^2 \times 10^3}{2\pi \times 50} = 10^{-4} H;
  \]

- at $d = 10$ cm.
  
  \[
  F_{A2} = \frac{\mu_0 I^2 l}{2\pi d} = \frac{4\pi \times 10^{-7} \times 5^2 \times 10^3}{2\pi \times 100} = 10^{-4} H;
  \]

- at $d = 15$ cm.
  
  \[
  F_{A3} = \frac{\mu_0 I^2 l}{2\pi d} = \frac{4\pi \times 10^{-7} \times 5^2 \times 10^3}{2\pi \times 150} = 0.33^{-4} H;
  \]

- at $d = 20$ cm.
  
  \[
  F_{A4} = \frac{\mu_0 I^2 l}{2\pi d} = \frac{4\pi \times 10^{-7} \times 5^2 \times 10^3}{2\pi \times 200} = 0.25^{-4} H;
  \]

- at $d = 25$ cm.
  
  \[
  F_{A5} = \frac{\mu_0 I^2 l}{2\pi d} = \frac{4\pi \times 10^{-7} \times 5^2 \times 10^3}{2\pi \times 250} = 0.2^{-4} H;
  \]
The device works as follows:

- battery pack as storage energy;
- inverter converts the direct current from the batteries into alternating current;
- wire tension sensors, allow you to signal the presence of icing on the wires;
- controller of the state of the wires and the inclusion of the cleaning system.

When ice or a heavy layer of dirt accumulates on the wires, tension sensors are triggered, which transmit data to the controller. The controller allows you to evaluate the condition of the wires and, if necessary, start the mechanism for supplying alternating current with a frequency of 50 Hz to the wires. After the current is applied, the wires begin to gradually oscillate for a certain time. Further, the sensors either work or not, depending on the tension of the wires [3].

The obvious requirement for such devices is the relative ease of implementation, relatively low cost and high reliability [3].

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\[
F_A = \mu_0 (I \sin \omega t)^2 \frac{l}{2\pi d} = \mu_0 I l (1 - \cos 2\omega t) \frac{2}{2\pi d}
\]

It can be seen that the force pulsates with a double frequency \(\cos 2\omega t\) compared to the frequency of the current (Figure 5). That is, when an alternating current with a frequency of 50 Hz is passed through the wires, stable oscillations occur that can create mechanical vibrations of the wires. A resonance phenomenon occurs [37].

If we take into account the time of these oscillations, during which the deposited snow cover and ice will subside, then we can bring these forces as a function of time and frequency.

**Fig. 4.** The dependence of the force of interaction of wires on the distance between them.

The graph shows that the distance between the parallel wires significantly affects the strength of the interaction between them. Therefore, to achieve the maximum effect, the distance between the wires should be 5–10 cm (Table 3).

**Fig. 5.** Fluctuations in the force of interaction of wires [36].
The process of oscillations in the wires makes it possible to achieve the set goal with the help of minimal costs and maximum energy-efficient indicators. This allows us to evaluate the prospect of using both alternative energy and solar energy.

**Table 3.** The dependence of the force on the frequency and operating time of the device.

<table>
<thead>
<tr>
<th>( f, \text{ Hz} )</th>
<th>Working time, s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>300</td>
</tr>
<tr>
<td>2</td>
<td>3.069 ( 10^{-5} )</td>
</tr>
<tr>
<td>5</td>
<td>8.184 ( 10^{-4} )</td>
</tr>
<tr>
<td>ten</td>
<td>5.944 ( 10^{-4} )</td>
</tr>
<tr>
<td>fifteen</td>
<td>6.129 ( 10^{-5} )</td>
</tr>
<tr>
<td>20</td>
<td>9.643 ( 10^{-4} )</td>
</tr>
<tr>
<td>25</td>
<td>3.473 ( 10^{-4} )</td>
</tr>
<tr>
<td>fifty</td>
<td>9.068 ( 10^{-4} )</td>
</tr>
<tr>
<td>75</td>
<td>9.011 ( 10^{-4} )</td>
</tr>
<tr>
<td>100</td>
<td>3.382 ( 10^{-4} )</td>
</tr>
<tr>
<td>150</td>
<td>3.565 ( 10^{-4} )</td>
</tr>
</tbody>
</table>

**3 Conclusion**

Thus, in the upper part of the photovoltaic battery, two elastic hoses are installed, turned in the form of an arc, and in the direction perpendicular to the plane of the photovoltaic battery, with the help of springs, and united by a common tube along which nozzles are installed directed towards the surface at an angle of 45° to the front surface, and on the back side they are united by a common pipe, in the central part a pipe is connected, directed downwards and part of which is underground, where an electromagnetic hydraulic valve is installed in the intermediate part, the pipe is connected to an electric pump with a collector electric motor, closed in a thermal insulating box and connected to a phase-pulse control circuit, including a power trinistor, the anode output of which is connected to an electric motor and photodetectors, the second output of which is connected to the zener diode and the anode of the low-power trinistor and the capacitor, the second output of the zener diode is connected to the control output, the low-power trinistor, the cathode of which is connected to the control electrode of the powerful trinistor, the cathode output of which is connected in parallel to the resistor to the second output of the capacitor and the rectifier bridge, the other two output of the diode bridge is connected to the second output of the electric motor, the outputs of which are connected in parallel with a series-connected resistor and a capacitor, photodetectors are combined with LEDs forming an optocoupler, the latter are connected to a multivibrator with adjustable frequency, an electromagnetic hydraulic valve is connected in parallel to the rectifier bridge through a resistor and a capacitor connected in parallel, through button switch, a second short pipe with a tap is connected to the pump.

The use of such devices will already today make it possible to use solar energy very intensively and will make it possible to take a significant place in the fuel and energy complex of a number of countries. Also, the active adoption at the state level of laws that provide significant support for the development of solar energy will significantly increase the number of solar power plants under construction and operation, which in turn will contribute to a gradual transition from industries dependent on traditional fuel to alternative ones.
When writing this article, experiments done by R. Ismagilov, V.E. Vavilov and R.A. Nurgalieva were used and we express our gratitude to these scientists.

The work was financially supported by the Ministry of Innovative Development of the Republic of Uzbekistan within the framework of the project F-OT-2021-497 - “Development of the scientific foundations for the creation of solar cogeneration plants based on photovoltaic thermal batteries”.

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