New equipment for cleaning solar panels

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Abstract. This article presents the results of solving an urgent problem of creating new equipment designed to solve the problem of operating solar panels, such as pollution of their front surfaces. The authors have developed an autonomous and reliable cleaning method with low energy consumption and the absence of the possibility of panel shading. An automated system was created with a short payback period in connection with the noted criteria. The article describes the developed device that is used for cleaning solar panels. The using of such device will minimize the share of human participation in the cleaning of PVP.

1. Problem statement

Renewable energy has now become a global trend. According to Energy Strategy of Russia for the period up to 2030, the involvement of renewable energy sources (RES) in the fuel and energy complex of our country will remain an urgent task. This is evidenced by the adoption of a federal law of Federal Law 471, dated 27 Dec. 2019, «On Amendments to the Federal Law On Electric Power Industry regarding the development of microgeneration». According to the International Energy Agency (IEA) solar photovoltaic energy is in third place in the world among RES but solar panels have taken the first place since 2016 in terms of volume among commissioned capacities based on RES [1]. Support for the development of renewable energy sources in Russia is currently based on cost compensation under Capacity Supply Contracts (CSC). Competitive selection of RES projects for 2020-2024 is carried out taking into account the targets approved by order of the Government of the Russian Federation No. 1-r of January 8, 2009 (changes approved on April 18, 2020). According to the targets for commissioning the generated capacities on the basis of RES in Russia until 2024, the share of solar stations will take the second place (Figure 1.) Besides, solar energy is one of the most promising areas for households. Many countries have adopted new strategies and developed roadmaps to attract prosumers on renewable energy sources [2]. Installation of solar panels in Russian households is also only a matter of time. With the active use of solar panels by households the share of solar energy in the balance of RES of Russia will increase even more.
The introduction of any technology is followed by a complex of difficulties. Solar energy, as one of the most promising areas of renewable energy, has great potential for Russia. However, during operation, the solar panel may lose its declared power due to pollution of the front surfaces of the PVP modules. The urgent task of solar energy is the issue associated with cleaning the front surfaces of panels. The problem leads to enormous economic losses. According to the analysis for Russia, the figure is about 15 million per year [3]. This is associated with a reduction of output power in the absence of cleaning. The goal of the authors’ study was to design fundamentally new equipment that will allow timely cleaning of solar panels.

2. Analysis of existing PVP cleaning methods

We have analyzed advantages and disadvantages of various PVP cleaning methods from pollution. The analysis presented in Table 1.

Table 1. Front surface cleaning methods of PVP.

| №  | Method name | Principle of operation | Advantages                                      | Disadvantages                                 |
|----|-------------|------------------------|------------------------------------------------|-----------------------------------------------|
| 1  | Manual cleaning | Cleaning PVP surface with brushes | Work with any kind of pollution | High cost; Chance of accidents among workers |
| 2  | Greenbotics robot [4] | Automated Panel Cleaning System; Robot moves along a panel and cleans the surfaces of PVP with microfiber | Protection against any pollution; Autonomy | High cost; Covers a large area; Complexity of execution; Requires electricity |
| 3  | Venturi method [5] | Principle of operation is based on the laws of aerodynamics. Differential pressure creates a directed air flow that blows loose snow. | Autonomy; Simplicity | Dimming; Suitable for windy places; Defence not from all type of pollution |
| 4  | SCROBBBY [5] | Automated Panel Cleaning System; Robot is hung on a cable and when it receives a signal comes into action. | Autonomy | Dimming with hanging cables and the robot itself; Unreliable power supply |
| 5  | Cleaning system based on the principle of Ampere's law [6] | Alternating current is passed through the wires in different directions and as a vibrations result cleaning occurs. | Snow cleansing; Autonomy | Requires electricity; Dimming |
| 6  | Device based on a mechanical thrust film [7] | If PVP dims then part of the film is rewound | Autonomy; Cheapness; Simplicity | Risk of frequent repairs because of choice of low-quality film; Chance of dimming part of PVP surface |
None of the methods analyzed was widely used in the energy sector because each method was designed by developers to solve a local problem. In this regard, for example, the advantage of the Venturi method where the wind rose has a pronounced character becomes a disadvantage in geographical areas where winds are a rare. The application of cleaning based on the occurrence of Ampère force remains relevant for cleaning snow from a module located in the steppe but such a system is not suitable for cleaning dust in the desert.

The conclusion that should be drawn from this table is that the main advantage that they strive for is the autonomy of a device.

3. Description of operation principle of the automated PVP cleaning system

As part of this work we have launched a project to develop a system for cleaning front surfaces of solar modules. The work was divided into four main tasks: designing the measuring part, the logical part, the executive part and also device’s power system (Figure 2).

Work of the system can be divided into three stages. At the first stage, the sensors of the measuring part convert the analog signal into a digital signal and send it to the Arduino Uno microcontroller [8]. At the second stage, the signal is compared with the values that were originally set in the program. If the triggering condition is satisfied, then a control signal is generated, which is goes to the engine driver. The third stage is the work of the executive part. The principle of operation of a linear actuator.

![Figure 2. The structure of the panel cleaning system based on the Arduino Uno R3 microcontroller.](image)

3.1. Solar Panel Cleaning System Requirements

The operation of a solar panel cleaning system should be possible in various climatic conditions. In this regard, one of the requirements for the installation is the stability of the construction to external influences. It is possible to use methods that protect the main equipment to fulfill this requirement. For example, to reduce the influence of external factors it is possible to use - protective boxes for microcontrollers, trays for wires. The main equipment of the construction must be attached to the edges of the solar module in order to work with various types of precipitation and ambient temperatures and not obscure the solar cells.

The next requirement is simplicity. For mass application of the device, the principle of operation must be understood, and materials for the design accessible and not deficient. It is difficult to design a system that provides continuous reliable cleaning in the case of the Venturi method. For this reason, the method does not find wide application even in places with a pronounced nature of the wind rose. The method based on Ampere’s law will probably remain laboratory because it requires additional equipment - an inverter, a large number of wires that obscure the front surface of the panel.

The economic factor that may limit the use of the system is the cost of the structure. If the device has electricity consumption for its own needs, then it should be less than the electricity saved as a result of
cleaning, otherwise the use of such a system is not economically feasible, because in this case the system will never pay off.

Another installation requirement is reliable control. Structure control technology may be different. There are two methods which can be considered - complete autonomy of the device and telecontrol. In the case of complete autonomy, human control is minimized. Autonomous work can be carried out periodically through to the algorithm, or depending on the presence of contamination. Also, the installation has as a “vision” - various sensors that detect the presence of snow or dust on the front surface of the solar module. In the case of telecontrol, cleaning can be carried out as the solar panel becomes dirty, which significantly reduces the cost of electricity consumed by the installation in case of operation according to the algorithm.

3.2. Construction of a solar panel cleaning system based on a linear actuator

A cleaning system based on a linear actuator involves the use of a helical gear, which allows to convert the rotational motion of the engine into the translational motion of the carriage. Cleaning is produced by using a brush which can be fixed to the carriage. There are six metric screw holes for mounting. The holes are located two opposite each other. This makes it possible to adjust the brush height in increments of 5 mm. The carriage can move along the plane of the solar panel along two guides one of which is a threaded rod and the second is an aluminum cylinder. The operability of the entire system depends on the choice of guides. Characteristics of the motor used must be considered in process of choosing a threaded rod. It is necessary that the thread pitch of the rod was as large as possible so the carriage quickly passes the specified distance. However as the larger the thread pitch the larger the diameter and mass of the rod made of the same material. This leads to an increase effort which the motor needs to overcome. This means it increases currents which in turn leads to a large heating of the controller. We have not yet done any experiments on choosing the optimal threaded rod but so far we have preferred the M8 thread.

When the motor shaft rotates then a rod which is connected to the shaft by an adapter sleeve also starts to rotate. Because of an aluminum guide the carriage does not turn but moves linearly. The brush mounted on the carriage removes dust, dirt and snow.

3.3. Construction of a solar panel cleaning system based on a belt drive

Using a linear actuator will not ensure the rapid passage of a length of the solar panel. This will lead to prolonged engine operation and the heating of the microcontroller. In order to solve the problem, it is possible to change the type of mechanical transmission from helical to belt. This will eliminate some of the disadvantages that arise during the operation of the linear actuator. Firstly, the cleaning time will be reduced due to the possibility of the belt working at high angular speeds. This will lead to less operation of the electric motor and, accordingly, to lower consumption for own needs. Secondly, there will be no vibration that occurs when the helical gear rotates.

The main requirements for belts are a high coefficient of friction during movement along the pulley and high wear resistance.

On the site of construction, a belt drive system can be implemented in the same way as a linear actuator. But instead of a threaded helix it needs to install a belt. Also, it's required to fix the carriage with an aluminum guide and one side of the belt. When the engine rotates, the shaft will pull the belt and thereby entraining the carriage.

3.4. The power system

Electricity for shaft rotation can be obtained from a battery connected to the solar module through a charge controller (Figure 3).
Figure 3. Motor power system.

For the SMD-50 silicon polycrystalline solar panel, the useful power generation for each month was calculated.

\[ E_{\text{tech}} = E_{\text{gr}} \cdot F_{\text{sm}} \cdot m \cdot \tau \cdot \eta_{\text{SM0}} \cdot K_{\text{fil}} \cdot K_{\text{t}} \cdot \eta_{\Delta N} \cdot \eta_{\Delta P} \]  

- \( E_{\text{gr}} \) – gross specific arrival of solar radiation on the considered site, kWh/(m²·month). Monthly average values of the parameter were taken for \( \phi = 57,5^\circ \text{NL}, \psi = 43^\circ \text{EL}; \)
- \( j = 1...12 \) – month number;
- \( F_{\text{sm}} \) – solar module square, m²;
- \( m \) – number of solar modules;
- \( \tau \) – transmittance coefficient of a protective coating of a module;
- \( \eta_{\text{SM0}} \) – nominal efficiency of the solar module for calculated conditions;
- \( K_{\text{fil}} \) – coefficient of filling entire area of the module by solar cells;
- \( K_{\text{t}} \) – coefficient which is taking into account the influence of the temperature of the solar module on its efficiency;
- \( \eta_{\Delta N} \) – coefficient determining the power loss during series connection of modules;
- \( \eta_{\Delta P} \) – coefficient determining the energy loss during transmission to the consumer [9].

Figure 4. The dependence of the useful generation of SMD-50 from pollution.
The average annual consumption for own needs of the system will be approximately 14.25%. The calculation was carried out with the assumption that the selected Nema 17 electric motor will operate according to the algorithm daily for 0.25 hours.

A wide range of storage devices is presented on the market of batteries which differ not only in parameters but also in technology embedded in operation principle. This mean that the choice of batteries should be treated responsibly.

We have analyzed 221 projects using chemical energy storage devices that have been either implemented or are being implemented in the world in the last decade (the main source is The DOE Global Energy Storage Database, as well as other sources). Since 2015 more interest has been shown in lithium-ion batteries in renewable energy projects. In this regard, our project also plans to use a drive with a similar technology in the further development of the cleaner.

4. Conclusion

The analysis of scientific and technical literature and practical experiments revealed the following
- It’s possible to assemble a cleaning system based on the operation principle of a linear actuator;
- Batteries of various technologies can be used as a power source for an electric motor with a rated voltage of 12 volts. Lithium-ion batteries are in great demand given the experience of cases over the past 5 years;
  - The battery can be powered by a solar battery through a charge controller.
- The method of cleaning solar panels, based on a linear actuator, combines several advantages over the analyzed methods. Firstly there is no dimming of the solar panel as when using the SCROBBY robot. Secondly, it is not necessary to equip with additional bulky equipment as in the Venturi method. Thirdly, the system does not require much power consumption, like the Greenbotics robot.

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