Automated system for cleaning solar panels based on a linear actuator

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Abstract. High volatility in the hydrocarbon market in tandem with an increase in anthropogenic impact on the environment has become one of the main reasons for the accelerated transformation of the global energy industry. Today we have witnessed a gradual increase in the share of renewable energy sources (RES) in the energy industry structure of leading economically developed countries. Solar energy is a promising area of renewable energy for most economies because of its availability and ease of use. Not only for commercial companies but also for the private sector. Pollution of a front surface of a module has become a pressing problem of generating electrical energy by using photovoltaic panels (PVP). For a solution to the problem of timely panels cleaning developers proposed several options of systems none of which were widely used. We started the development of the panel cleaning system which is based on the linear actuator operation principle. The system is planned to be controlled by using the Arduino UNO R3 microcontroller which will allow us to minimize the share of human participation in the cleaning of PVP.

1. Problem statement
Over the past few years, many countries have begun to change their attitude towards energy resources which is used. One of the essential prerequisites for this was the adoption of the Paris Climate Agreement in 2015 which combined the efforts of world powers to curb climate change on the planet. Many countries have adopted new strategies and developed roadmaps to attract prosumers on renewable energy sources. According to the International Energy Agency (IEA) [1], Europe expects an annual increase in electricity consumption by 1.4% until 2030. Roadmap of 2050 developed by them aimed at reducing greenhouse gases through the integration of distributed and renewable energy sources [2].

Russia follows a similar path as evidenced by the adoption 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 which prosumers with a microgeneration facility such as a solar panel can sell surplus generated electricity. Solar energy is one of the most promising areas for households. However, 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.
2. Analysis of existing PVP cleaning methods
We have analyzed the advantages and disadvantages of various PVP cleaning methods from pollution. The analysis presented in table 1.

| No | 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  | SCROBBY [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 |

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 the operation principle of the automated PVP cleaning system
As part of this work, we have launched a project to develop a system for cleaning the 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 1).

Figure 1. The structure of the panel cleaning system based on the Arduino Uno R3 microcontroller.
3.1. The executive part
The main component of the executive part is the Nema 17 stepper motor. Motors of Nema series have high torque and with the help of special drivers A4988, it is possible to rotate their shaft in both directions [8].

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 the 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 increased effort which the motor needs to overcome. This means it increases currents which in turn leads to 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.

The executive part is based on the operation principle of a linear actuator (figure 2).

![Figure 2. Linear actuator for PVP.](image)

Control signals are sent to the motor through the A4988 driver. When the motor shaft rotates then a rod that 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.

The carriage is supposed to move in one direction in order to save energy. After that, it is planned to check the surface of the PVP and if the pollution has not been eliminated then reverse the movement to the place of the initial start. If the pollution has been eliminated after the first passage of the carriage then in order to save energy it is left it alone until the next command.

3.2. The logical part
The logical part includes the software package which contains all operation settings and cycles for canceling the false operation of the executive part at dusk. Programs for the microcontroller are written in C ++ in the Arduino IDE development environment.

3.3. The measuring part
At this stage of development, the motor is switched on by using an IR (infrared) remote control and an IR receiver. The control involves three buttons. The first is responsible for the rotation of the shaft “to the right,” the second - “to the left,” the third - “stop.” It is planned to use measuring sensors in the future.

Sensors for measuring the wavelength of solar radiation:
- Photoresistor;
- Light sensor;
- UV sensor;

Sensors for measuring the distance to an object:
- Ultrasonic distance sensor;
- Infrared barrier;
- Dust sensor.

Each element that can be used in the measuring part of the solar panel cleaning device has both advantages and disadvantages that limit the scope of application of certain sensors. Photoresistor - resistor whose resistance depends on the intensity of incident light. Its parameter is the nominal resistance. It may be equal to 200 kohms. In complete darkness, the resistance of such a resistor is 200 kohm, and in bright light it drops to almost zero. This effect can be used in a solar panel cleaning device. The Arduino Uno R3 microcontroller must be programmed that when the resistance of the photoresistor increases which may be caused by ingress of snow dirt or dust the executive part works and cleans the front surface of the panel and photoresistor. However, it should be noted that at night the resistance can reach the response value which will lead to a false switching on of the executive part. This fact limits the use of these components and it is a significant disadvantage. It's supposed to use a cycle in the microcontroller program that increases the response resistance depending on the time of day or use LED backlight in order to eliminate this effect.

The fraction of UV radiation in the solar spectrum is only 9% [9] but this does not exclude the possibility of using a UV radiation sensor as the measuring part. The principle of operation is the same as the photoresistor. But unlike photoresistors, most of these sensors have a larger measurement range. For example, the measuring range of the GYML8511 sensor from 400 to 280 nm and for photoresistors the range is from 450 to 600 nm. In turn, it is possible to combine two types of analog sensors to improve the measuring part.

The next example of a measuring device is an ultrasonic distance sensor. It could be HC - SR04. Important components of the sensor are two piezoelectric elements. One of them emits an ultrasonic wave when 15 microseconds pulse is applied, and the other piezoelectric element receives the same reflected wave from an obstacle. Then the delay time from transmission to the reception of the wave is measured and the distance is calculated. The frequency of the sound wave is within the ultrasound frequency which provides a concentrated direction of the wave because sound with a high frequency is less scattered in the environment.

The signal may reflect off drops when it rains or snows and resulting in a spurious echo. This phenomenon can be used as a logical unit for the device of the executive part. However, it will not be possible to build an automatic system that monitors the accumulation of dust on a solar panel using an ultrasonic distance sensor.

The next group of measuring devices is based on the use of infrared radiation. It includes an IR barrier and a dust sensor.

IR barrier is widely used in security systems. It is a sensor consisting of an infrared light source and an infrared receiver. When the beam path intersects the signal enters the logical element of the system. IR LED is used as a light source and an IR phototransistor as a receiver. This technology has a third element - the environment. The environment is a source of aerosol attenuation, resonance absorption and the presence of barriers in the form of precipitation.

A special case is a barrier in the form of snowfall. This environment is still poorly formalized and the action of IR channels is estimated on the basis of experimental data.

Using the IR barrier is perfect for protection from snow on the front of PVP.
Another infrared technology is a dust sensor. It uses optical sensing to detect dust. A photosensor and infrared LED as known as an IR LED, are optically located in the dust sensor module. A photosensor detects reflected infrared rays from LEDs that are reflected from dust particles in the air.

One of the most common dust sensors on the market is the GP2Y1010AU0F sensor. The GP2Y1010AU0F module can detect the smallest particles in the air, which makes it possible to detect even cigarette smoke. The high output pulse from the sensor is triggered when the dust is detected.

3.4. The power system
It is necessary to provide a reliable power supply for the drive to operate the motor in a linear actuator system. Electricity for the microcontroller can be obtained from a 9-volt crown battery (figure 3).

![Figure 3. Microcontroller power system.](image)

Electricity for shaft rotation can be obtained from a battery connected to the solar module through a charge controller (figure 4).

![Figure 4. Motor power system.](image)

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:
• Pollution of the solar panels surface causing economic damage to the energy industry is a task that can be solved in the near future;
• It’s possible to assemble a cleaning system based on the operation principle of a linear actuator;
• It is possible to use the Arduino Uno R3 microcontroller as a system control;
• 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.

References
[1] International Energy Agency 2018 Renewables 2018 Analysys and Forecasts to 2023 (Paris: International Energy Agency)
[2] Sumper A Micro and Local Power Markets 2019 (Hoboken, NJ: John Wiley & Sons, Inc) p 272
[3] Zacarinnaja Ju N, Amirov D I, Zemskova L V and Rahmatullin R R 2019 Study of the solar panel efficiency with the influence of pollutants on it Transactions of Academenergo 1 81-92
[4] SunPower Cleans Up Solar With Acquisition of Greenbotics available at - URL: https://www.greentechmedia.com/articles/read/sunpower-cleans-up-solar-with-acquisition-of-greenbotics (accessed: 20.01.2020)
[5] Sanarov S V and Lebedev R I 2016 Methods for Cleaning the Solar Battery. Introduction to Energy p 148
[6] Ismagilov F R, Vavilov V E and Nurgalieva R A 2018 Method for automated cleaning of solar panels Patent RF no. 2018104009
[7] Vaskovskay T, Thakurta P G and Bialek J 2018 Contribution of transmission and voltage constraints to the formation of locational marginal prices Int. J. Elec. Power 101 491-9
[8] 2013 Exploring Arduino: Tools and Techniques for Engineering Wizardy ISBN 978 – 1 – 118 – 54936 – 0 (John Wiley & Sons, Inc)
[9] Vissarionov V I, Derjugina G V, Kuznecova V A and Malinin N K 2008 Solar Energy: A Study Guide for Universities ed V I Vissarionova (Moscow: MPEI Publishing House) p 317