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Development of a control system for automatic surface cleaning device for solar photoelectric panels

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Abstract

The article presents the current state and development prospects of the use of photovoltaic solar panels in the world and in Uzbekistan, as well as an analysis of foreign researchers' scientific studies on cleaning the surfaces of photovoltaic solar panels and the factors affecting their efficiency. It provides information about photovoltaic solar power plants installed in Uzbekistan and the innovative scientific research carried out by the "Green Energy" Scientific Innovation Center under Bukhara State Technical University, where reliable cleaning devices for removing various types of contamination from photovoltaic solar panel surfaces under continental climate conditions have been developed. Automatic control systems for cleaning devices, water-based and waterless cleaning methods are proposed. Over the course of one month, the output power of two contaminated and two daily cleaned photovoltaic solar panels was compared. According to the experimental results, when the dust density varied from 0 to 22 g/m^2, efficiency was found to decrease by up to 26%. The article also presents the general structure of the proposed device, information about the DC motors installed in the device, as well as the schematic diagram, algorithm, and operating principle of the automatic control system.

Keywords: Photovoltaic Solar Panels; Photovoltaic Solar Cells; Solar Radiation; Ambient Temperature; Dust Concentration; Automatic Cleaning Device; Control System and Algorithm.

1. Introduction

In the world, renewable energy sources are taking a leading role in saving fuel-energy resources and improving the continuity and reliability of energy supply. Considering the global plan to "reduce greenhouse gas emissions and waste by at least 40%, increase the share of renewable energy sources to 32%, and improve energy efficiency by 32.5% during the period from 2021 to 2030" [1], the use of photovoltaic solar panels that enhance energy reliability and continuity becomes essential. In this regard, the utilization of both large- and small-scale photovoltaic solar power plants is of great significance.

Globally, the use of renewable energy sources, in particular solar energy for electricity generation, has been expanding rapidly. In 2024, a total of 600 GW of photovoltaic solar panels were installed, and this figure is expected to reach 1 TW by 2030. According to calculations by Germany's Solar Power Europe, in 2024 the installed photovoltaic solar capacity reached 597 GW worldwide, representing a 33% increase compared to 2023. The top ten countries installing photovoltaic solar panels in 2024 were: China (54%), the USA (8%), India (5%), Brazil (3%), Germany (3%), Spain (2%), Turkey (2%), Italy (2%), Japan (1%), and France (1%), while other countries accounted for 19% [2].

Scientific research on cleaning the surface of photovoltaic panels has been carried out by foreign scholars. These studies propose various automatic cleaning devices, including water-based and waterless systems.

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South African researchers Benjamin O. Olorunfemi and Nnamdi I. Nwulu proposed an automatic cleaning device for photovoltaic panel surfaces. Their system was designed for a 30 W photovoltaic panel and consisted of two DC motors, a cleaning brush, a TCS3200 color sensor, a battery, and an Arduino Uno Rev3 controller [3]. Similarly, researchers from South Africa and Nigeria, Khairiya M. Nkinyam and Chika O. Ujah, developed a prototype device for waterless cleaning technology of photovoltaic panels. The proposed device included the following components: DC motor, battery, fan, cleaning brush, relay, RTC, Arduino Uno, IR receiver, and remote controller. Signals were sent remotely to the Arduino Uno, which then activated relays and motors, initiating the cleaning process [4].

Korean researcher Paenggeom Choi Byeong-sam obtained a patent (KR102328972B1) for an automatic photovoltaic panel cleaning device. The system included a cleaning brush, moving roller, balancing axle, brush-driving motor, roller-driving motor, water pipe, sprayer, water tank, water pump, battery, an additional battery charger, and docking stations. The device automatically returned to its docking station, where it recharged and refilled the water tank before the next cleaning cycle. It was remotely controlled and operated for 6–7 hours per day [5].

South Korean researcher Soojin Song obtained a patent (KR20230101550A) for another automatic photovoltaic panel cleaning device. This system comprised a driving motor, mechanical movement block, automatic control system, solar cells, monitor, battery, moving wheels, cleaning brush, contamination detection sensor, handle, and stopping mechanism. The device was designed for photovoltaic power plants, automatically controlled, self-charging, and capable of operating for 6–8 hours per day. Importantly, this system performed waterless (dry) cleaning [6].

The aim of this research is to study the control system of an automatic cleaning device for photovoltaic solar panel surfaces.

2. Material and methods

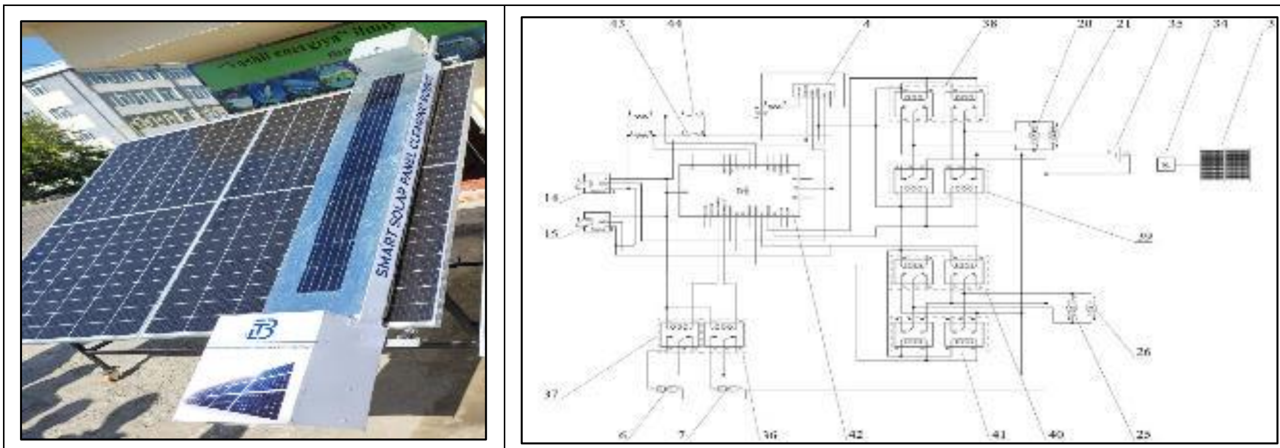
According to the Presidential Decree of the Republic of Uzbekistan No. PQ-190 dated June 14, 2023, measures were adopted for the implementation of the investment project "Construction of a 500 MW photovoltaic solar power plant in Karaulbazar district of Bukhara region" by the company *China Gezhouba Group Overseas Investment Co. LTD* (People's Republic of China). The project is valued at USD 350 million, with the solar power plant installed on 997 hectares of land. Longi photovoltaic solar panels manufactured in China were installed, each with a capacity of 575 W, output voltage of 43.11 V, output current of 13.34 A, operating temperature range of −40 °C to +85 °C, and dimensions of 113.3 mm × 227.8 mm. Nearly 1 million solar panels and 57 inverters were installed [7]. At this photovoltaic plant, cleaning devices produced by China's *Sunpure* company are used for surface maintenance of solar panels. The device parameters are: nominal power 180 W, nominal voltage 24 V DC motor, nominal current 7.5 A, maximum movement speed 10–20 m/min, operating temperature −20 °C to +60 °C, weight 55 kg, charging panel capacity 105 W, brush thickness 6 cm, cleaning capacity 180–220 m^2 per day. The cleaning process is conducted remotely after 18:00 [8].

At the *Green Energy Scientific-Innovation Center* established under Bukhara State Technical University, research is being carried out on the factors affecting the efficiency of photovoltaic solar panels, including temperature, dust accumulation, wind flow speed, and humidity. During one month, two uncleaned panels and two daily-cleaned panels were monitored. Longi panels (575 W, 43.11 V, 13.34 A, −40 °C to +85 °C, 113.3 mm × 227.8 mm) were used. Dust concentration was measured using GP2Y1010AU0F sensors. The experiments revealed that as dust density increased from 0 to 22 g/m^2, efficiency decreased by up to 26%.

For continental climatic conditions, reliable devices for cleaning photovoltaic solar panels from various types of contamination were developed. The device operates as follows: GP2Y1010AU0F sensors measure the dust concentration on the panel surface. When dust concentration reaches 10 g/m^2, the dust sensor transmits a signal to the A2 port of the control unit (42). The controller then sends signals through output ports D8 and D9 to servo motors (14, 15), rotating them by 90° to activate the brush-type (16) and soft rubber (18) cleaning mechanisms. Next, through port D10, the controller activates relay (36), which starts the circulation water pump (7) connected to the water tank (5) and pipes (9). Water is sprayed across the panel surface through sprinklers (11, 12). After 5 seconds, the controller sends a signal through port D2 to relay (39), activating DC motors (20, 21) connected to brush mechanisms (23, 24), which rotate at 120 rpm. Simultaneously, through port D5, the controller activates relay (41), starting DC motors (25, 26) connected to the main wheels (28, 29), moving the device at 40 rpm. The auxiliary wheels (31), linked to the main wheels, ensure back-and-forth movement depending on the panel layout. Both sets of wheels are supported with springs (27, 30). Once cleaning is completed, the device automatically stops at the base frame (46) using the stopper (33) and contact (44). Additional solar cells (3) mounted on the device supply power to charge/discharge controllers (34) and batteries (35). The device is powered by the batteries (35).

3. Result and Discussion

A patent has been obtained in Uzbekistan for the proposed device (Patent No. IAP 8065) [9]. Figure 1(a) shows the overall appearance of the proposed device, and Figure 1(b) illustrates its control system schematic.



a b

Figure 1 General view of the proposed device (a), control system schematic of the device (b)

The energy parameters of the proposed device's battery are 12 V, 20 Ah, equipped with a charge and discharge controller. For charging, two photovoltaic modules of 65 W each, with dimensions of 330 × 1040 mm, are used. The driving rollers have a diameter of 120 mm, powered by a 30 W motor with a speed of 1800 rpm, reduced to 40 rpm through a gearbox. Each cleaning brush is driven by a 45 W motor operating at 3000 rpm, with a reduction speed of 120 rpm. Water pumps installed in the tank have a capacity of 5 W. The 25 W DC servo motors rotate 90° to activate the soft rubber and brush cleaning mechanisms. The device is capable of both dry (waterless) and wet cleaning modes.

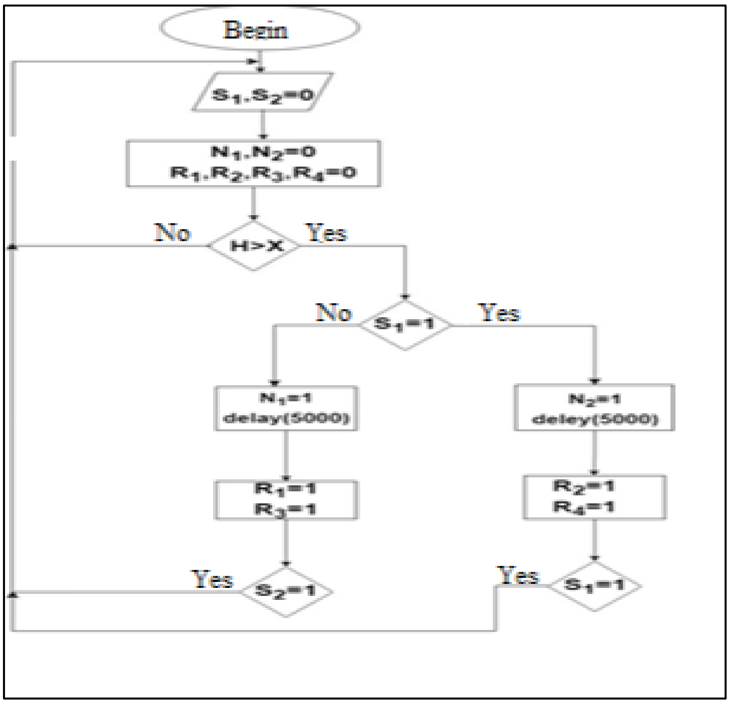


Figure 2 Algorithm of the automatic control system of the proposed device

In the algorithm of the cleaning device, starting from Begin, the data is updated every 10 minutes. When S1, S2 = 0 (corresponding to 44, 43 in Figure 1(b)) and R1, R2, R3, R4 = 0 (corresponding to 38, 39, 40, 41 in Figure 1(b)), if the dust concentration X is less than the set threshold of 10 g/m^2, the condition is evaluated as *No*, and the device does not operate. If X is greater than 10 g/m^2, the condition is evaluated as *Yes* and a signal is sent to S1 = 1.

When S1 = 1 and the output is *No*, then N1 = 1, i.e., the water pump (37 in Figure 1(b)) starts spraying water. After 5 seconds, signals are sent to R1 = 1 and R3 = 1, activating the DC motors connected through relays, initiating movement. Once the process is completed, a signal is sent to S2 = 1, which then evaluates as *Yes*, and information is sent to the Begin stage confirming the completion of the task.

Again, every 10 minutes the data is refreshed. If X is greater than 10 g/m^2, the condition is evaluated as *Yes*, and a signal is sent to S1 = 1. When S1 = 1 and the output is *Yes*, then N1 = 2, i.e., the water pump (36 in Figure 1(b)) starts spraying water. After 5 seconds, signals are sent to R2 = 1 and R4 = 1, activating the DC motors connected through relays, initiating movement. Once the cleaning is finished, a signal is sent to S1 = 1, which evaluates as *Yes*, and information is again transmitted to Begin indicating the task is complete. Thus, the algorithm operates in this way, continuously updating the data every 10 minutes.

4. Conclusion

The effect of surface contamination on the energy performance of photovoltaic solar panels was investigated. It was found that as the amount of dust increased, the efficiency of the panels decreased significantly. Experimental results showed that when dust density increased from 0 to 22 g/m^2, the efficiency decreased by up to 26%.

A reliable cleaning device was developed to remove various types of contamination from photovoltaic panel surfaces under continental climate conditions. The proposed device is capable of both dry (waterless) and wet cleaning without causing damage to the panel surface. It does not require additional energy, as it is self-charging and can operate for 6–8 hours a day. Compared to the cleaning devices manufactured by China's *Sunpure* company, the developed automatic cleaning system demonstrated 1–2% higher efficiency.

The article presented the general design of the proposed device, technical specifications of the installed DC motors, cleaning brushes, dust detection sensors, as well as the schematic diagram, algorithm, operating principle, and the features of both automatic and remote control capabilities.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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