Automated Solar Panel Cleaning System

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***Abstract*— Solar panels have a significant impact on our world by providing an environmentally friendly alternative to traditional power generation plants that can harm the environment. However, it is crucial to recognize that solar power plants require regular cleaning. When solar panels are not cleaned regularly, environmental dust accumulates on their surfaces and transforms into a sticky layer due to morning dew. This dust accumulation leads to a decrease in the efficiency of the solar panel. In our research, we have developed an automated cleaning system for solar panels. This system eliminates the need for manual cleaning efforts and ensures that solar panels remain clean and efficient. This system reduces human efforts, which saves time, and works automatically, resulting in increasing the efficiency of the solar panel. The cleaning is achieved using a water-based Roller brush. Two ac motors with inverters are used for the brush and the system's assembly motions. A control unit based on Arduino is built to perform the cleaning task with the aid of limit switches, relays, electric valves, and other electrical and electronic tools. The brush is attached to the movable assembly of the system. This brush remains in contact with the panel. When the assembly of the system moves, water flows through sprinkles on panels and brush move on the surface of the panel and removes the dust. The proposed system is tested and evaluated by comparing the electrical parameters (maximum power, voltage, and current) for the solar panel before and after cleaning. Results show that the efficiency is increased when the solar panel is regularly cleaned.**

Keywords— Solar Panel, Cleaning system, PV.

I. INTRODUCTION

Abundant solar radiation is accessible worldwide, surpassing the requirements of solar power systems. The fraction of sunlight that reaches Earth's surface is more than sufficient to meet global energy demands by a factor of 10,000 [1], [2]. On average, each square meter of land is exposed to enough sunlight to produce 1360 kWh of energy every year [3], [4]. Solar Panel has a huge effect on the world, which also helps the environment to be better without using other power generation plants that can harm the environment, but solar power plants need to be cleaned at least every 3 days. The frequency of cleaning depends on the country. For example, in the Middle East, which should be cleaned daily resulting in increasing the cost significantly. In this chapter, the problem statement, the objectives of the project, expected results, feasibility, and design methodology is described. A comprehensive literature review is be highlighted also [5], [6].

The measured performance of solar panel is found to be less than designed condition due to dust and other contaminants such as leaves and bugs on solar panel. If there is dirt on the surface of the solar panel, it can reduce how much light is absorbed by that area, reducing efficiency [6]–[8]. A solution to this problem is proposed with automated solar cleaning mechanism in such a way that reduce manpower requirement and increase the efficiency [9]–[12].

The electrical energy produced by photovoltaic (PV) cells depends on the amount of sunlight they receive. To maximize sunlight exposure, PV cells are typically installed outdoors. However, this also makes them susceptible to dust, bird droppings, ice, and salt accumulation, which can reduce their efficiency. Automatic PV cleaning systems can help to address this issue. These systems use a variety of methods to remove dirt and debris from the surface of PV panels, such as water-based brushes, compressed air, and ultrasonic waves. This can help to improve the efficiency of PV panels and increase their energy output [13]–[15].

In [16], the authors extensively explored various solar panel cleaning methods, with a notable focus on the rising technology of autonomous cleaning robots. These robots are designed to glide effortlessly across the solar panel surfaces, employing gentle brushes to ensure no damage or scratches occur. These robotic cleaners are typically affixed to motorized trolleys, facilitating horizontal movement, while vertical motion is commonly regulated through a belt-driven system.

Authors of [17], [18] have also conducted a comprehensive survey of diverse solar cleaning projects and technologies. Their analysis encompassed the operation of the solar brush UAV robot, the Ecoppia E4 system, and the NOMAD wash panel cleaning system.

Our objectives in this study are summarized as follows:

- Design solar panel cleaning system that can increase the efficiency of solar panels.
- Make a simple and automated cleaning system
- Minimize human intervention.
- Design a system that does not affect the quality of the original solar panel or cause any damage to it

The expected results from this study are increased energy production from solar panels, reduced cleaning costs, and reduced need for human intervention.

II. Methodology

A block diagram for the project implementation methodology is shown in Fig. 1.

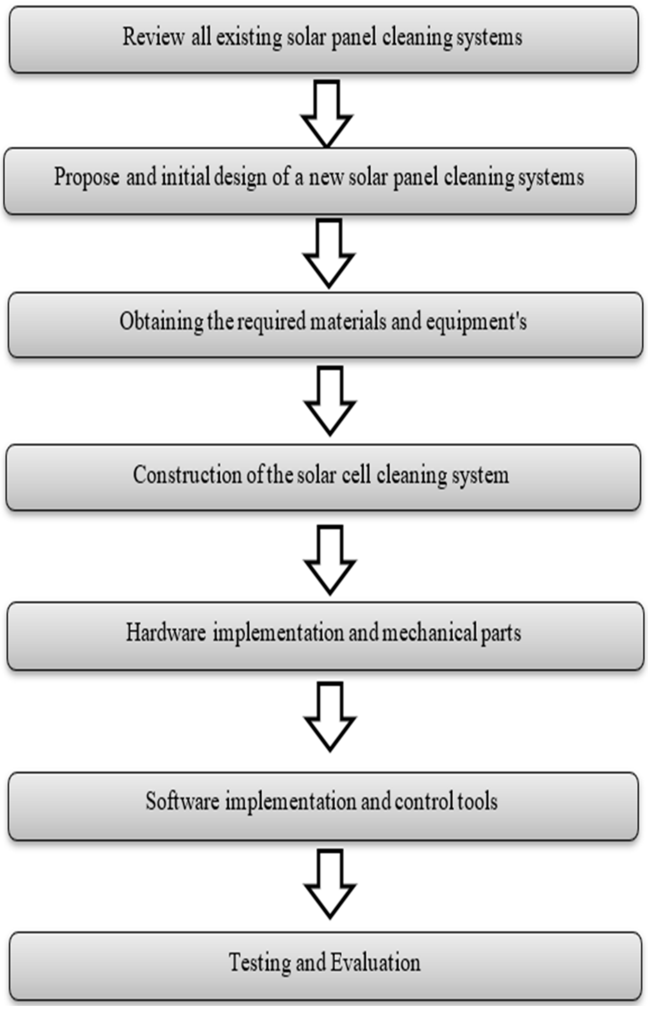

Fig. 1. Block diagram for the project implementation methodology

The main goal of the study is to design a smart device system that cleans solar panel modules automatically. To achieve this goal and meet all the requirements of the project, it is divided into several stages.

- Stage 1: System Structure and Assembly

After looking into the existing solar panel cleaning systems technologies, this project was started by making an initial sketch of the proposed system as shown in Fig. 2. The system assembly is a trolley moving on a rail using four wheels and carrying the bush with all the mechanical and electrical equipment.

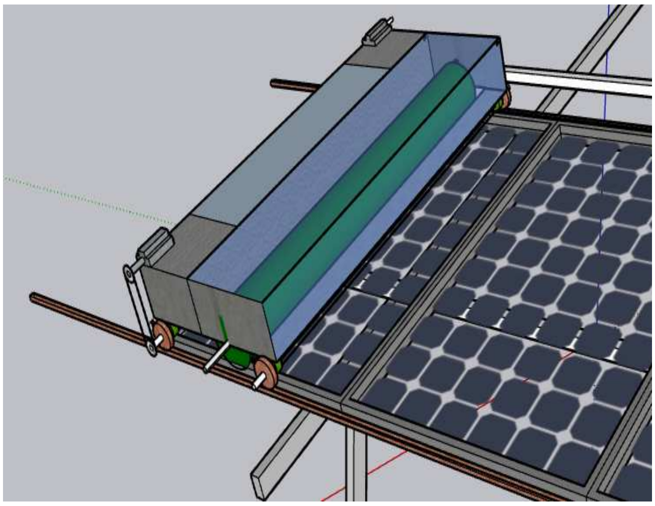

Fig. 2. Initial sketch of the project.

- Stage 2: System Control

The control unit is based on Arduino Uno. The system is based on two AC motors, Invertors, and water electrical valves. A relay module along with Arduino is used to control the operation of these equipment's. Furthermore, speed and direction control (Forward / Backward) of the three phase AC motors was achieved. Similarly, the water electrical valve control (ON/OFF) was designed using a relay.

After finishing the construction stage of the system assembly, the system was installed on an actual solar panel system to move on a rail using four wheels as shown in Fig. 3.

Fig. 3. The system assembly was installed on a real solar panel system

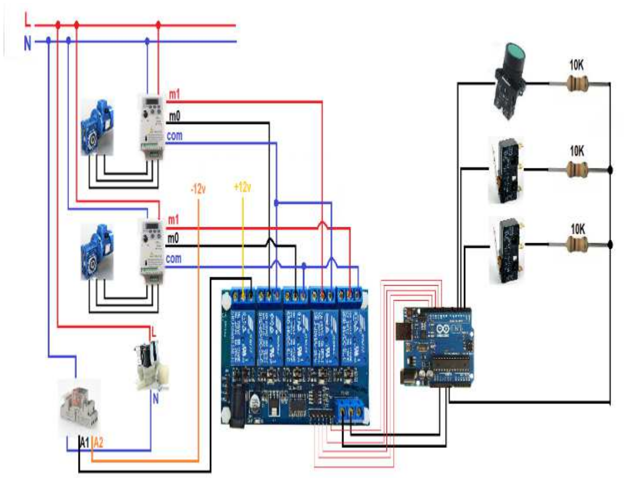

Fig. 4. Control Circuit Unit.

The system function diagram is presented in Fig. 5.

III. RESULTS

In this section, the testing and evaluations of the proposed solar panel cleaning system is described.

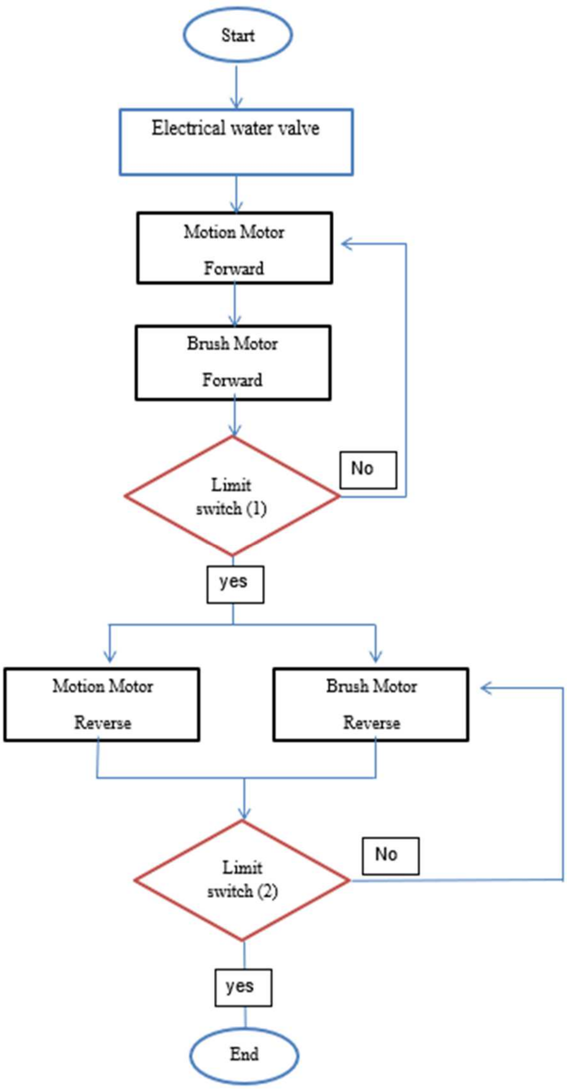

Fig. 5. System working block diagram.

- Case 1: Module Measurements Without Load

A basic module measurement using a multimeter was conducted. To measure the complete power output of a solar module, it needs a load. Nonetheless, as an initial step, a basic multimeter to measure the open-circuit voltage (V_{OC}) and short-circuit current (I_{SC}) without applying a load can be used.

When working with large outdoor solar modules, any multimeter equipped with a current scale reaching up to 10 A (amps) and a voltage scale of 50 V (volts) is enough as it is crucial to choose a sunny day for these measurements and ensure that none of the module is shaded. Even partial shading of one corner can result in a significant loss of output.

To measure the open-circuit voltage (VOC), follow these steps:

1. Set the multimeter to a DC voltage scale that exceeds the expected module voltage.
2. Connect the multimeter leads to the solar panel leads, making sure to match power to power and ground to ground.
3. Record the voltage reading.

For measuring the short-circuit current (ISC), which is important to follow these steps:

1. Disconnect the multimeter from the module before changing its settings.
2. Set the multimeter to a DC current scale that exceeds the expected module current.
3. Reconnect the multimeter leads to the solar panel leads.
4. Record the current reading.

These measurements are essential for assessing the performance of the solar module and ensuring its optimal functioning under varying conditions.

In Table 1, the module measurements without load that were obtained from solar panels with dust and from cleaned solar panels were tabulated. Even though a clear change in the VOC measurements between cleaned and not cleaned solar panels was not shown, a drastic change in the ISC values was observed.

This is the first indication of the efficiency improvement that occurs in the solar panel when cleaned from the dust by the proposed system.

TABLE I. MPPT DISTRIBUTION.

Solar Panel	Voc (V)	Isc (A)
Not Cleaned	35.5	7.76
Cleaned	35.3	10.5

- Case 2: Module Measurements with Load

This module measurement method uses the variable of resistance. By changing the resistance of the module load, voltage, current and power for a specific panel can be measured. This method allows the user of the module to compare these parameters before and after the cleaning process. For this purpose, an electric load device as shown in Fig. 6 was used.

Fig. 6. Electric load.

These loads find extensive applications across various industries, including production lines for cell phone chargers, cell phone batteries, electronic vehicle batteries, switching power supplies, linear power supplies, and LED drivers. They are also used in research institutes, automotive electronics, aeronautics and astronautics, maritime technology, and in sectors like solar cell and fuel cell development. Furthermore, they play a crucial role in test and measurement applications.

TABLE II. MODULE MEASUREMENTS WITH LOAD AT DIFFERENT TIME PERIODS

Time 1:27am				
Solar Panel	**Load (Ω)**	**Power (W)**	**Voltage (V)**	**Current(A)**
Not Cleaned	3.6	218	28	7.8
Cleaned	3.3	231	28	8.4
Time 2:40 am				
Solar Panel	**Load (Ω)**	**Power (W)**	**Voltage (V)**	**Current(A)**
Not Cleaned	3.9	209	28.6	7.3
Cleaned	3.3	225	27.3	8.3
Time 2:50 am				
Solar Panel	**Load (Ω)**	**Power (W)**	**Voltage (V)**	**Current(A)**
Not Cleaned	4	208	29	7.2
Cleaned	3.4	223	27.5	8.1

For the comparison purpose, a sunny day was chosen and measurements were conducted around noon time. These measurements were repeated three times and summarized in Table.2. It was noticed that at the maximum power point recorded for the panel before and after cleaning, the measured voltage is slightly change. However, a noticeable difference in the measured current of about 1 A is obtained. Thus, an enhancement in the maximum power that ranges from 13 W to 16 W is obtained for a single solar panel before and after cleaning.

Based on practical calculations, it was found that the cleaning one solar panel takes one minute; So, it was assumed the system would clean 60 solar panels and that it was should be cleaned them twice a month.

- Cleaning cost via specialized company:

Cleaning cost per time: 60 panel * 1.35 NIS = 81 NIS

Annual cleaning cost = 16 times * 81 NIS = 1296 NIS

- Cleaning cost using the proposed system:

Cleaning cost per time (electricity + water) = 1.139 kwh * 0.56 NIS/kwh +1 NIS = 1.63 NIS

Annual cleaning cost = 16 times * 1.63NIS = 21.76 NIS

- Savings:

Amount of savings per each cleaning time = 81-1.63= 79.37 NIS

Amount of savings annually = 1296-21.76= 1274.24 NIS

The project cost= 5000 NIS

Time required to return the initial cost = 5000NIS/1274.24 NIS = 4 Years

IV. CONCLUSIONS AND RECOMMENDATIONS

In this study, a solar panel automated cleaning system with minimal human intervention is designed. The cleaning is achieved using a water-based Roller brush. The project assembly and the brush motion are achieved by ac motors. A control unit based on Arduino is built to perform the cleaning task with the aid of limit switches, relays, electric valves, and other electrical and electronic tools. The proposed system is tested and evaluated by comparing the electrical parameters (maximum power, voltage, and current) for the solar panel before and after cleaning. Two testing methods were used. The first method is the module measurements without load where an enhancement is observed in the ISC measurements for the cleaned solar panel indicating the efficiency enhancement. The second method is the module measurements with load where the maximum power point becomes better in the cleaned solar panel by 13 W to 16 W. These results show that the efficiency is increased when the solar panel is regularly cleaned. The economic feasibility analysis show that the cleaning cost of the solar panel is drastically reduced. The project fulfilled the desired design with the planned control and mechanism.

A future modification of the project can be achieved by adding the followings:

- Victron Solar Charge Controller complete termination and setup
- Remote device control using wi-fi
- A pressure and temperature sensor can be added

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