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Original Research Article

Design and Construction of an Automatic Solar Panel Cleaning System

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Abstract

PV panels are installed in an open-spaced setting and then exposed to dust, dirt, and debris which significantly reduce their power output, making regular cleaning essential. Therefore, this research developed an automatic cleaning system for solar panels to enhance their efficiency and performance. The developed system utilizes an Arduino microcontroller, a lead screw mechanism, and a cleaning arm to automate the cleaning process. The system is designed to automatically control the cleaning system wirelessly using a Wi-Fi module that has been integrated on the Arduino board, and when the solar panels require cleaning, it activates the cleaning arm to remove the accumulated dirt. This research project involves the design, development, and implementation of the automatic cleaning system. The components used in the system include a PC817 optocoupler, C815 limit switch, Nodemcu microcontroller, DC wiper motor (12V), screw mechanism, metallic frame, solar panels, and a DC power supply (12V). These components are carefully selected to ensure efficient and reliable operation of the cleaning system. The system performance for both cleaning and dusty panels has been evaluated and it was found that the efficiency for the cleaning system is higher with output power of 53.69W. The developed system can be used to enhance the PV module performance areas where the weather can be classified as dusty and the pollutants are increasing day by day as a result of smokes, industrial work and new building construction.

Keywords: Climatic Condition, Solar Panel, Power Output, Design, Performance Evaluation.

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1.0 INTRODUCTION

The increase in demand for renewable energy resources, as opposed to burning of hydrocarbon fossil fuels, is understandable because it is inexhaustible, cleaner, better and produces virtually no pollution (Carrasco *et al.*, 2006; Blaabjerg *et al.*, 2004). The basic principle of this renewable energy is to extract energy from sustainable sources via mechanical or reaction methods. Research in renewable energy is focused particularly on geothermal, wind, marine, and solar energy, with the aim of developing improved methods of generating electricity and its integration into the existing grid infrastructure for distribution to users. Among these renewable energy options, solar energy has garnered significant attention due to its abundant availability. Solar energy serves as the driving force behind several forms of renewable energy (Bolaji *et al.*, 2007). By harnessing solar energy, it is possible to generate clean and sustainable electricity for users, mitigating the reliance on fossil fuel-based generators and reducing both costs and environmental impact, but the major concern about solar system is the negative effect of dust and soil accumulation, which adversely reduce the performance of PV system.

Various studies have been carried out on the impact of dust and soil accumulation on the performance of solar PV systems. Mohamed and Hassan (2012) discovered that dust can make solar panels lose 36 % efficiency in just one month, 60% efficiency in two months, and after one year, it would be left with no efficiency at all. Mohamed and Hasan (2012) studied the effect of dust accumulation on the performance of photovoltaic solar modules in Sahara environment. They investigated a framework of weekly cleaning on PV modules array throughout the period from February to May. The results indicated a significant gradual decrease of power, with weekly water washing maintaining performance losses between 2 to 2.5%. Ali *et al.*, (2017) studied the impact of dust on solar photovoltaic (PV) performance. They found that the dust factor significantly influences the performance of the PV installations and they recommended a minimum weekly cleaning for PV.

Cleaning PV panels with pure water has significant advantages; it completely removes the contaminating particulate matter on the surfaces and does not leave residue, which increases panel output voltage (Myenerjisolar, 2021; Kursun, 2019). Although dry cleaning methods are not as effective as wet cleaning technologies, they do not require as much labor and water, but dust particles can still scratch the panel surface in dry conditions (Shehri *et al*., 2016; Memon, 2016; Mondal and Bansal, 2015). Chen *et al*., (2018) showed that the cleaning efficiency of dry dust particles was independent of the applied load. In rainy dusty areas, PV panels are covered with a layer of mud, which requires excessive cleaning. In areas with little rainfall, the dry-cleaning method proves to be a cost-effective and self-sufficient process that does not require a water supply (Aly *et al*., 2015; Alagöz and Apak, 2020).

PV cleaning can also be done by automatic system. Automatic cleaning machine can reduce the amount of water used and increase the efficiency of the panel and it is more effective than wet and dry cleaning as it provides an efficient and cost effective solution for maintaining the performance of solar panel arrays. It helps reduce manual labour, improves energy production and ensures the longevity of the panels by keeping them clean and free from obstruction (Aly *et al.*, 2015; Chailoet and Pengwang, 2019; Ba *et al.*, 2017). Because of these advantages, this research therefore develops solar panel automatic cleaning system.

2.0 MATERIAL AND METHOD

2.1 Design Consideration

The selection of materials for the automatic solar cleaning system was based on various factors such as durability, reliability, and efficiency. The PC817 optocouplers were chosen because of their ability to isolate the microcontroller from the high voltage of the electric motor, ensuring that the microcontroller is not damaged. The C815 limit switches were selected because of their high precision, which ensures accurate positioning of the cleaning arm. The electric motor was chosen based on its high torque and efficiency, which ensures that the cleaning arm moves smoothly across the surface of the solar panel. The screw mechanism was selected because of its ability to convert the rotational motion of the motor into linear motion, which is required for the movement of the cleaning arm. The NodeMCU microcontroller was chosen because of its low power consumption and ability to connect to the internet, which allows remote control of the system. The solar panel was selected based on its size and efficiency, which ensures maximum power generation. The motor use to move the control system for this is DC wiper motor with its specifications shown in Table 1.

Table 1: Specification of the DC Wiper Motor Selected in This Study

Specifications	Values
Current Limit Setting	2A
Duty Cycle	0 to 99.9%
PMW switching rate	15 KHz
Digital Voltage Input(low)	0 to 0.8V
Digital Voltage Input(High)	3.5 to 5V
Speed	55rpm
Rotational degrees	360 degrees
Positional Resolution	10bits
Operating Voltage	12V
Stall torque	10A
Motor Power	120W

2.1.1 Solar Panel Specifications

The panel used in this research could generate an output power comparing to close size approximately. The data given in Table 2 summarized the technical specifications of the selected panel. The inclination angle of the solar panel must be specified firstly because it is important to optimize the output energy from the panels by applying the solar beam perpendicular to the surface.

Table 2: Selected Solar Panel Specification

Maximum Power	**50W**
Module Dimensions	750 × 500 × 30 mm
Module Weight	20kg
Current at $P_{max}(I_{mp})$	2.86A
Voltage at P_{max} (V_{mP})	17.5V

2.1.2 Design Assumption and Parameters

The automatic system will move horizontally with a speed of 0.007 m/s. The cleaning time is assumed to be 100 seconds and the distance travelled to be 0.7 meters. This design was chosen because it is cheaper in terms of maintenance, and it is more applicable for several PV panels. Unlike the other designs where the cleaning is too low. The mass of the selected panel is 10 kg. The ultimate strength of Aluminum 6061-T6 is approximately 276 MPa (40,000 psi). This value represents the maximum stress the material can withstand before failure. The design stress depends on the specific application and safety requirements. Common design stress values for Aluminum 6061-T6 range between 50% and 75% of the ultimate strength, therefore, design stress is assumed to be 50% of ultimate stress. The weight of the wiper is 3 kg

2.1.3 Design of the Automatic Cleaning System

The equations used for the design of the automatic cleaning machine are as shown in equations 1 to 18 respectively as extracted from the studies of Budynas and Nisbett, (2011); Akyazi *et al*., (2019).

$$\sigma_c = \frac{W}{A} = \frac{W}{A_h + A_v} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\sigma_c \leq \frac{S_y}{FoS} \quad (2)$$

$$FoS = Ultimate\ Strength/ Design\ Stress \quad (3)$$

$$F_{Euler} = P_{cr} \geq F_{acting} \quad (4)$$

$$P_{cr} = \pi^2 EI / L_{eff}^2 \quad (5)$$

$$I = I_v + I_h = \frac{1}{12}(bh^3 + bh^3) \quad (6)$$

$$L_{eff} = K^2 L^2 \quad (7)$$

$$T = F \times r \quad (8)$$

$$\omega = \frac{2\pi n}{60} \quad (9)$$

$$P = T \times \omega \quad (10)$$

$$F_f = W \times g \times \mu \quad (11)$$

$$F_b = f_b \left(d_r^4 / L^2 \right) \times 10^4 \quad (12)$$

$$N_c = f_c \left(\frac{d_r}{L^2}\right) \times 10^7 \quad (13)$$

$$P = \frac{F_A}{A} \quad (14)$$

$$P = \frac{4F_A}{\pi d_r^2} \quad (15)$$

$$V = l_{hr}.N\ (16) \quad (16)$$

$$T_b = F \times P \times \frac{\eta_2}{2\pi} \quad (17)$$

Where: σ_c is the compression stress on the column (Pa), W is the weight or compressive load on the column (N), A is the area of the column (m^2), A_h is the horizontal cross section area of the column (m^2), A_v is the vertical cross section area of the column (m^2), S_y is the minimum yield stress (Pa), FoS is the factor of safety, P_{cr} is the critical load (kg), E is the modulus of elasticity (GPa), I is the area moment of inertia (m^4), L_{eff} is the length of the column (m), k is fixed end factor, I_h is the horizontal area moment of inertia (m^4), I_v is the vertical area moment of inertia (m^4), h is the height of the column (m), b is the breadth of the column (m), T is the torque of the motor (Nm), F is the weight of the load to be moved (N), r is the radius of the screw (m), $\boldsymbol{\omega}$ **is** the rotational speed of the motor (rad/s), P is the power (Watts), F_f is the wiper frictional force (N), W is the weight of the wiper (kg), g is the acceleration due to gravity (m/s), μ is the coefficient of friction, F_b is the maximum compressive buckling load (N), d_r is the root diameter of crew (m), N_c is the critical speed (rpm), f_c is the end fixity factor, N is the speed at which screw rotate (rpm), v is the linear velocity (m/s), l_{hr} is the helix length per screw revolution (m), F_A is the axial load on nut (N).

The developed system and the circuit diagram are as shown in Figures 1, 2 and 3 respectively.

Figure 1: Isometric diagram of automatic cleaning of solar panel

Figure 2: Automated Solar Panel Cleaning System in operation

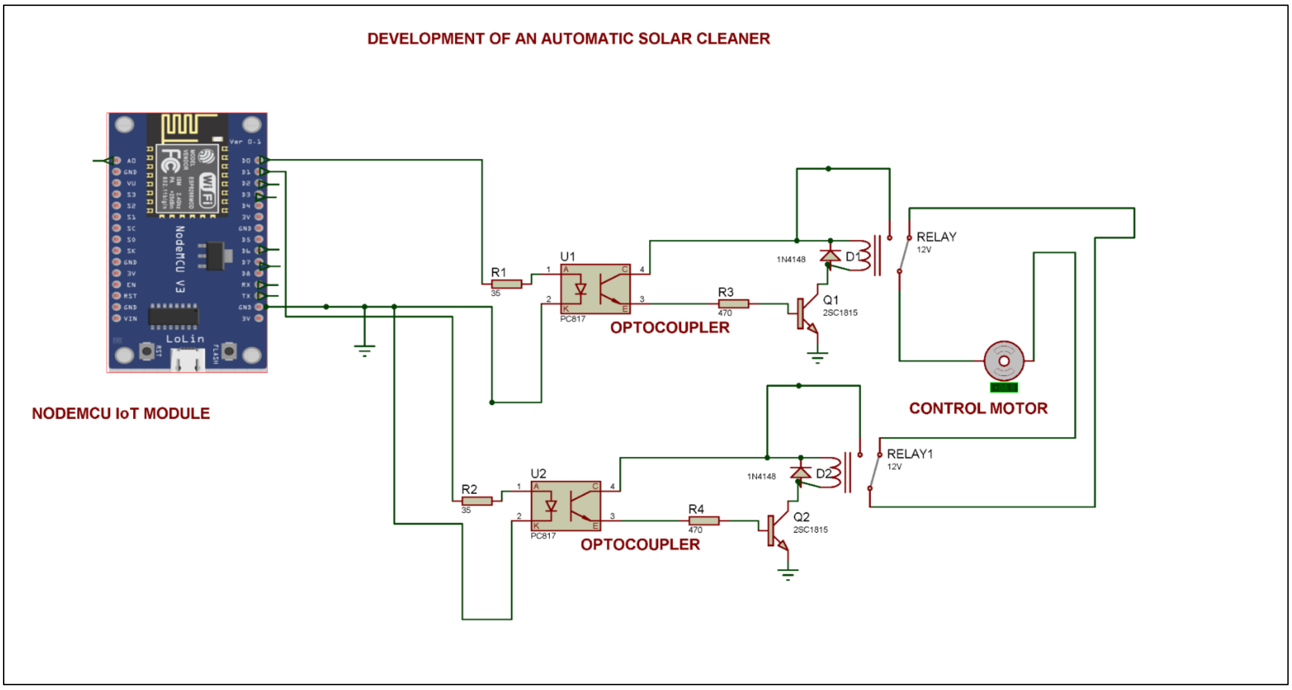

Figure 3: Hardware Schematic Circuit Representation for Cleaning

2.1.5 Description and operational procedure of the developed automated solar panel cleaning system

The automatic solar cleaning system is designed to clean solar panels automatically using a cleaning arm that moves across the surface of the panel. The cleaning arm is connected to an electric motor (DC Wiper Motor) via a screw mechanism. The system is controlled by a Nodemcu microcontroller, which is connected to PC817 optocouplers and limit switches. The PC817 optocouplers are used to isolate the microcontroller from the high voltage of the electric motor, while the limit switches are used to control the position of the cleaning arm. When the nodemcu microcontroller receives a signal from the limit switch, it activates the PC817 optocoupler, which in turn activates the electric motor. The motor drives the screw mechanism, which moves the cleaning arm across the solar panel. The limit switches control the position of the cleaning arm, ensuring that it moves in a straight line and does not overshoot the edges of the panel. The automatic cleaning device cleaner made from Aluminum, the brush made from a high-quality nylon which used to clean a solar panel surface, it used one DC Wiper motor and Nodemcu microcontroller to control the operation. Lead screw or screw mechanism is located beneath the mechanism and the solar for control mechanism. This lead screw is attached with DC wiper motor and receives power from it. With this, the automatic cleaning system can propagate over solar panel surface. For the cleaning process to start, the start button must be pressed and the system will be controlled wirelessly using Wi-Fi module on the Nodemcu microcontroller, then the motor starts moving and the lead screw moves forward. As the motor starts, the cleaning mechanism also starts. The cleaning mechanism moves forward and cleans the surface of the solar panel. When the cleaning system reaches the end of the panel, the limit detects the edge of the edge of the panel and stops the motor. Then the cleaning system changes its direction by rotating the screw backward. Once the direction is changed, the cleaning system continues the cleaning process and moves forward further. The process continues and the entire surface of solar panel is cleaned. The cleaning system operates from the 12V lead acid battery.

The control circuit consists of a Nodemcu microcontroller, PC817 optocouplers, C815 limit switches, an electric motor, and a screw mechanism. The PC817 optocouplers are used to isolate the high voltage of the electric motor from the NodeMCU microcontroller. The C815 limit switches are used to control the position of the cleaning arm. The Nodemcu microcontroller is connected to the PC817 optocouplers via jumper wires. The PC817 optocouplers are connected to the electric motor via a breadboard, which also contains a resistor and capacitor for noise reduction. The C815 limit switches are connected to the Nodemcu microcontroller via jumper wires. In operation, when a limit switch is triggered, it sends a signal to the Nodemcu microcontroller, which activates the PC817 optocoupler, which in turn activates the electric motor. The motor drives the screw mechanism, which moves the cleaning arm across the solar panel. The limit switches control the position of the cleaning arm, ensuring that it moves in a straight line and does not overshoot the edges of the solar panel. The Nodemcu microcontroller is programmed using the Arduino IDE software. The program controls the sequence of operations for the system, which includes turning on the motor, moving the cleaning arm across the solar panel, and stopping the motor when the cleaning arm reaches the end of the panel. The program also includes features such as remote control via a hotspot, scheduling of cleaning cycles, and monitoring of the cleaning process. The nodemcu microcontroller is connected to the internet via Wi-Fi, which allows remote access and control of the system from any location. The automated solar panel cleaning working cycle flow chart is as shown in Figure 4.

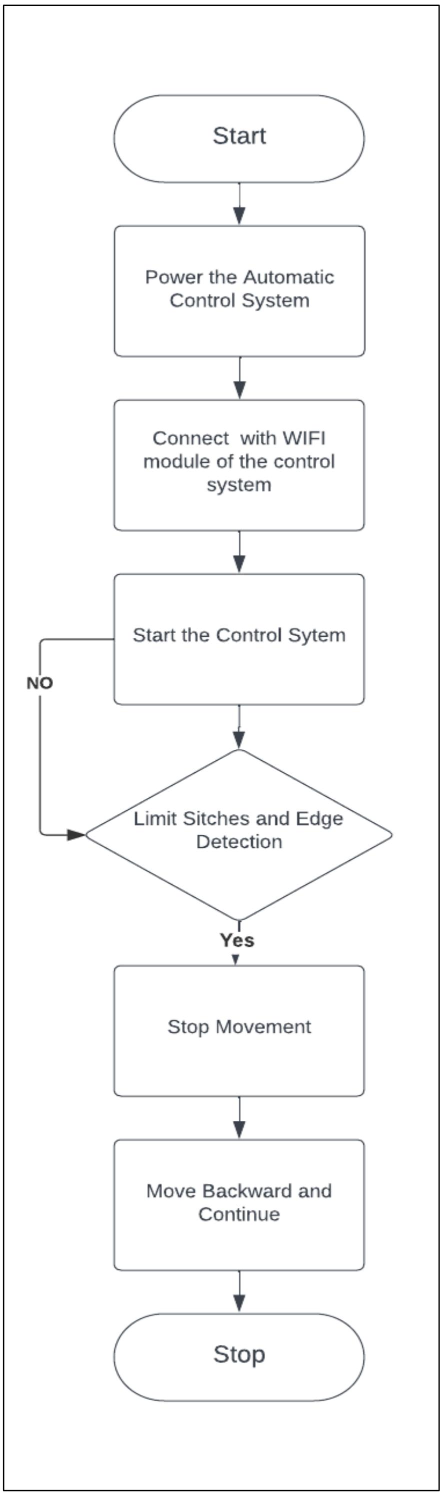

Figure 4: Automated Solar Panel Cleaning working cycle Flow Chart

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3.0 RESULTS AND DISCUSSION

3.1 Results

Performance evaluation of the developed automatic solar panel cleaning system was carried out to determine its efficiency considering two modes: evaluation of the PV modules before cleaning and evaluation of the PV modules after cleaning. The solar PV system is integrated with a dust cleaning system to attain the high amount of solar insolation for performance improvement. The measurement of peak values of voltage, current, and power of solar PV module is taken before and after cleaning the panel over a period of 5 days. Comparison between the performance of cleaning and dusty PV panels was conducted in Akure, Ondo State at 12 noon, considering high intensity of sunlight. The system inputs and outputs were measure and recorded using Multimeter (DT9205A) as measuring instrument. The measuring instrument allows measurement of current and voltage with the help of variable resistance. The obtained data for both the PV modules before cleaning and after cleaning are presented in Tables 3 and 4 respectively. From these Tables one can recognize the effect of dust and other dirt on the performance of the module where the significant reduction in the system output can be observed. It can be seen that the dust and deposits accumulation has a significant effect on the performance of the PV module and thus reduce the output power that can be generated from the system. It should also be highlighted that the obtained result of the cleaning system is the efficient cleaning of the solar panel to remove the dirt and dust accumulated over the surface of the panel, thereby improves the output performance of the PV system.

Table 3: Performance of PV Module before Cleaning

DAY	VOLTAGE (V)	CURRENT (Amps)
1	28.9	1.7
2	28.8	1.69
3	29.0	1.7
4	28.5	1.66
5	28.7	1.69

Table 4: Performance of PV Module after Cleaning

DAY	VOLTAGE (V)	CURRENT (Amps)
1	29.3	1.8
2	29.0	1.7
3	29.2	1.73
4	29.1	1.71
5	29.5	1.82

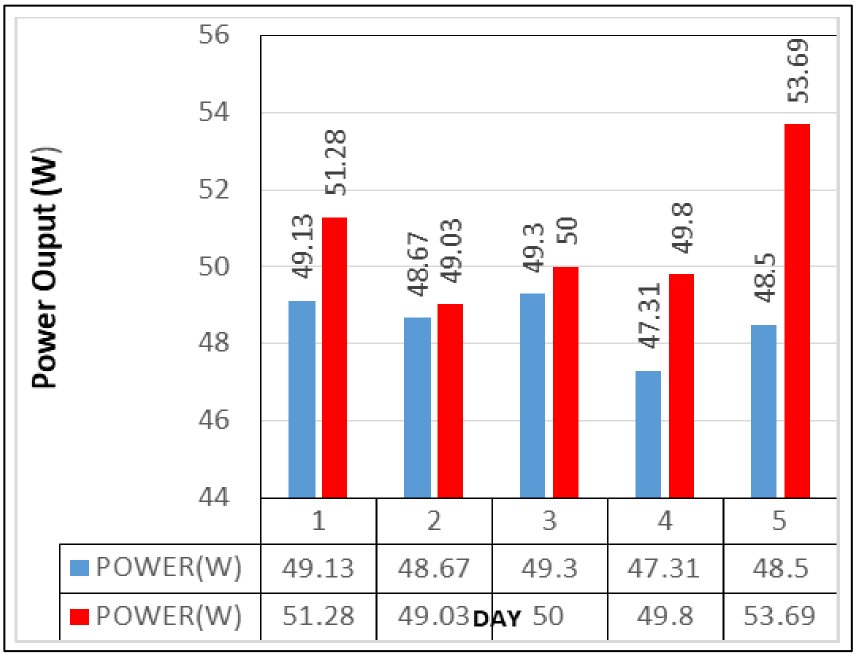

Figure 5: Power Output of the System Before and After Cleaning

4.2 Discussion

Figure 5 represents the power output of a solar panel system before and after cleaning over a period of five days. The power output is measured in watts (W). From the data presented in Figure 5, it was observed that the power output of the solar panel system generally increased after each cleaning session. This suggests that cleaning the solar panels had a positive impact on their efficiency and performance.

On Day 5, there was a particularly significant increase in power output after cleaning, with the power output reaching 53.69 W compared to the initial 48.5 W. This indicates that the accumulated dirt or debris on the panels was affecting their ability to capture sunlight radiation effectively, and cleaning them resulted in a substantial improvement in power generation. It is important to note that these results may be influenced by various factors such as weather conditions, time of year, and the specific characteristics of the solar panel system. Additionally, the power output could also be influenced by factors other than cleanliness, such as shading or changes in sunlight intensity.

4.0 CONCLUSON

Design and fabrication of an automatic solar panel cleaning system has been carried out in this research. The system will help to maintain the efficiency of PV cells by cleaning the dust film and other deposits on the panel surface that could block the sunrays from the semiconductor material within the PV panel. The system is designed to work periodically, and controlled by a mechanism that works automatically under all conditions. The system is applicable for households, companies, and can be used easily for any PV arrays. The cleaning system checked from strength point of view for all structure such as frame, wheels, coupling and connected link are found to be safe and stable. The system was evaluated for performance and it gave an output power of 53.69 W. It can be concluded that this design is a promising method to enhance the PV module performance in areas where the weather can be classified as dusty and the pollutants are increased day by day as a results of smokes, industrial work and new building construction.

REFERENCES

- Akyazi, Ö., Şahin, E., Özsoy, T., & Algül, M. (2019). A Solar Panel Cleaning Robot Design and Application. *Avrupa Bilim ve Teknoloji Dergisi*, pp. 343-348.
- AI Shehri, A., Parrott, B., Carrasco, P., Al Saiari, H., & Taie, I. (2016). Impact of dust deposition and brush-based dry cleaning on glass transmittance for PV modules applications. *Solar Energy*, *135*, 317-324.
- Alagöz, S., & Apak, Y. (2020). Removal of spoiling materials from solar panel surfaces by applying surface acoustic waves. *J Clean Prod*, *253*, pp. 1-11.
- Ali, H. M., Zafar, M. A., Bashir, M. A., Nasir, M. A., Ali, M., & Siddiqui, A. M. (2017). Effect of dust deposition on the performance of photovoltaic modules in Taxila, Pakistan. *Thermal Science*, *21*(2), 915-923.
- Aly, S., Gandhidasan, P., Barth, N., & Ahzi, S. (2015). "Novel dry cleaning machine for photovoltaic and solar panels," *2015 3rd International Renewable and Sustainable Energy Conference (IRSEC), 2015*, pp. 1-6, doi: 10.1109/IRSEC.2015.7455112.
- Ba, H. T., Cholette, M. E., Wang, R., Borghesani, P., Ma, L., & Steinberg, T. A. (2017). Optimal condition-based cleaning of solar power collectors. *Solar Energy*, *157*, 762-777.
- Blaabjerg, F., Chen, Z., & Soeren, B. K. (2004). Power electronics as efficient interface in dispersed power generation systems. *IEEE Transactions on Power Electronics*, *19*(5), 1184-1194.
- Bolaji, B. O., & Adu M. R. (2007). Design analysis of photovoltaic pumping system for rural application in Nigeria. *Int J Agric Sci Sci Environ Technol*, *6*(2), 120-130.
- Budynas, R. G., & Nisbett, J. K. (2011). *Shigley's mechanical engineering design* (Vol. 9). McGraw-Hill New York.
- Carrasco, J. M., Franquelo, L. G., Bialasiewicz, J. T., Galván, E., PortilloGuisado, R. C., Prats, M. M., & Moreno-Alfonso, N. (2006). Power-electronic systems for the grid integration of renewable energy sources: A survey. *IEEE Transactions on industrial electronics*, *53*(4), 1002-1016.
- Chailoet, K., & Pengwang, E. (2019). Assembly of Modular Robot for Cleaning Various Length of Solar Panels. *IOP Conference Series: Materials Science and Engineering*, *639*(1).
- Chen, E., Ma, L., Yue, Y. G. B., & Liang, H., (2018). Measurement of dust sweeping force for cleaning solar panels. *Sol Energy Mater Sol Cells*, *179*, pp. 247-253.
- Kurşun, M. (2019). *The Effect of Natural Dust Accumulation on the Efficiency of Solar Panels in Samsun Climate Conditions*, Turkey: University of Ondokuz Mayıs.
- Memon, N. (2016). *Autonomous vehicles for cleaning solar panels*.. Marrakech, Morocco., s.n., pp. 633-637.
- Mohamed, A., & Hasan, A. (2012). Effect of Dust Accumulation on Performance of Photovoltaic Solar Modules in Sahara Environment. *Journal of Basic and Applied Scientific Research*, *2*, pp. 11030-11036.
- Mondal, A., & Bansal, K. (2015). A brief history and future aspects in automatic cleaning systems for solar photovoltaic panels. *Adv Robot.*, 29, p. 515–524.
- Myenerjisolar. (2021). *What is Solar Energy Panel Cleaning?How is it done?*. [Online] Available at: https://www.myenerjisolar.com/gunes-enerjisi-panel-temizligi/ [Accessed 2 January 2022].