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Cleaning Solar Panels using Portable Robot System

V. Selvaganesh* P.S. Manoharan and V. Seetharaman*****

Abstract : Dust and dirt particles accumulating on Photovoltaic (PV) panels decrease the solar energy reaching the cells and thereby reducing their overall power output. Hence, cleaning the PV panels is a problem of great practical engineering interest in solar PV power generation. In this paper, the problem is reviewed and methods for dust removal are discussed. In this paper the microcontroller based robot is proposed to clean the solar panels. Initial testing of the robot has provided favourable results and shows that such a system is viable. It is found that robotic cleaning process can help to clean PV panel efficiency.

Keywords : Photovoltaic (PV), Return on investment (ROI), Concentrated PV (CPV), Standard test condition (STC).

1. INTRODUCTION

The soiling effect depends on both the soil type and the washing technique [1]. Cleaning methods for solar panels are used to keep solar panels efficient [2]. The effect of dust accumulation on PV cells performance varies with respect to different factors such as: differences in PV surface material, tilt angle, surrounding atmospheric, pollution and variation in weather condition. The dirt particles affect the performance of PV cell because soiling is site-specific [3]. Dirty panels are reduce the ability of the solar Soiling of PV cells can result from dust which includes sand, pollen, and other air-born particles, bird droppings, and the growth of lichen near the lower edge of the module frame. Leaves, bird poop and airborne particles (from dirt and pollen) all dirty our solar panel investment [4]. Nowadays Energy loss could reach 25 percent to 30 percent for the consumers. Having dirty solar panels can severely increase the return on investment (ROI) time. For concentrated PV (CPV) modules, the soiling effect shows efficiency. After one year of exposure without cleaning, the systems were cleaned using pressurized distilled water spray with brushing for one of the plant that showed 6.9% losses [5]. To improve the PV cell efficiency by incremental digits, dust particles accumulating on the surface reduce the efficiency and it takes long time to clean PV panel economically and effectively. The various methods for dirt and dust removal from PV panels are passive self-cleaning by natural removal of dust includes wind, gravity, rain, and dew, and active (manual or automated) cleaning. The robotic system for cleaning photovoltaic panel arrays for large scale solar PV plants was developed. There are two factors reducing the PV applications such as the cost of PV cell, PV modules voltage variations. The designed robot is a portable automated system for solar panel cleaning where energy loss minimized to 20 percent for the consumers. The testing results in Improvement of PV efficiency by their overall power output a portable robotic cleaning device is developed and features a versatile platform which travels the entire length of a panel.

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2. PROBLEM DESCRIPTION

The proposed robot is tested with solar panels which installed in BSNL tower located in Silarpatti village, Madurai district, TamilNadu. It is situated 7 km away from sub-district headquarter Peraiyur and 53 km away from district headquarter Madurai. Solar panels are used as a distributed generation to meet out the load. The photo of BSNL tower is shown in Fig.1 and PV panels are shown in Fig. 2. **DIMENSION:** 1652 x 982 mm **THICKNESS:** 40 mm 60 CELLS MODULE which help in satisfying the load and each panel is of 250 W.

Figure 1: BSNL Tower in Silarpatti village

Figure 2: PV panels as distributed generation

A. Problem Identification

Figure 3: Soiling condition

The PV panel accumulated with dust particles as shown in Fig.3 is taken for testing, the soiling condition which drastically reduces PV panel efficiency as compared with standard test conditions given by the manufacturer of PV panel under various irradiance condition as given in Table 1.

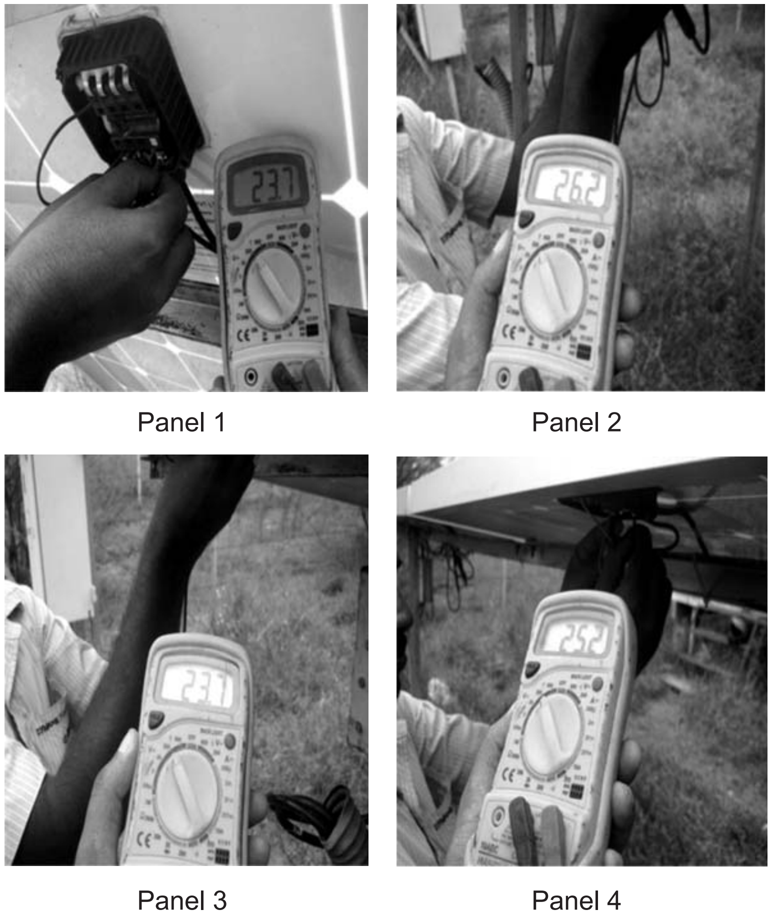

Figure 4: Measurement in each panel

Under soiling condition, various readings are taken in four numbers of 250 Watts solar panel as shown in Fig. 4 at 200W/m^2 irradiance. When comparing the results between standard test conditions from plant data sheet and soiling condition it shows that (25-30)% losses as shown in Table 1. So it is necessary to clean the PV panels to increase the solar power generation capacity.

Power generated in PV module $P = VAP_r$

Where, P_r = Performance Ratio

= 0.73 (from plant data sheet)

Table 1

Comparison between standard test condition (STC) and soiling condition

Panel	*STC Condition*			*Soiling condition*			*Dif.*
	Voltage (V)	*Current (A)*	*Power (W)*	*Voltage (V)*	*Current (A)*	*Power (W)*	
1.	31.9	1.9	44.7	23.7	1.22	19.4	25.3
2.	31.9	1.9	44.7	26.2	1.44	27.6	17.1
3.	31.9	1.9	44.7	23.7	1.22	19.4	25.3
4.	31.9	1.9	44.7	25.2	1.26	23.2	21.5

3. CLEANING METHODOLOGY

The cleaning methodology, as shown in Fig.5 the robot travels the entire area of a solar panel. In this paper a microcontroller based robot is proposed to clean the solar panels which a robot is fixed to the solar panel and moves on the panel while cleaning it. This robot utilizes a dry system of brushes to clean the solar panels, and no water is wasted in the process. Once the cleaning process is done the robot is transferred to the next track of solar panels in the farm in an automated setup.

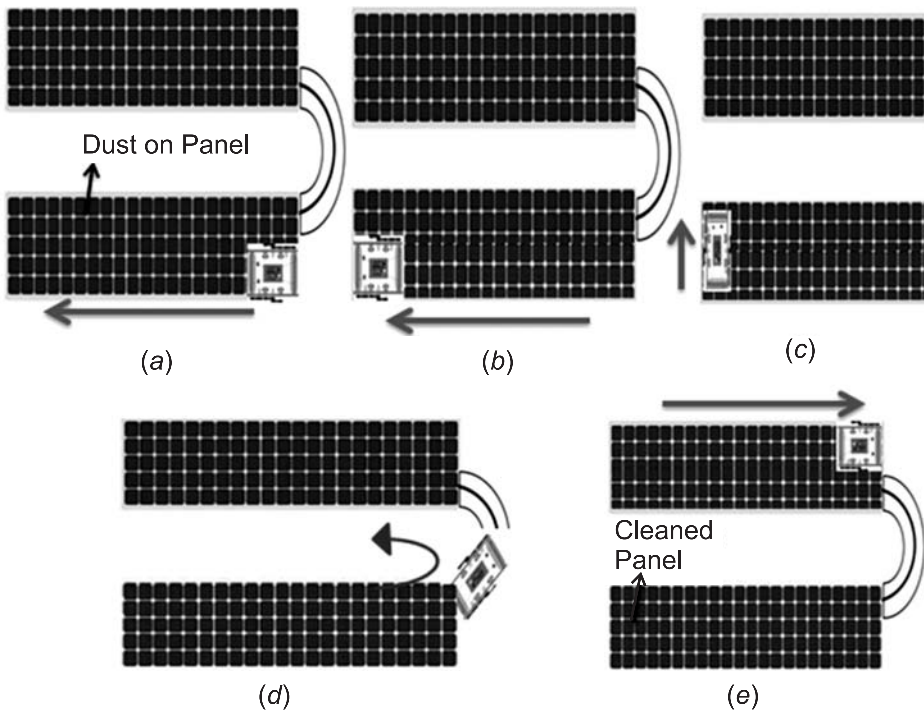

Figure 5: The proposed system operation sequence

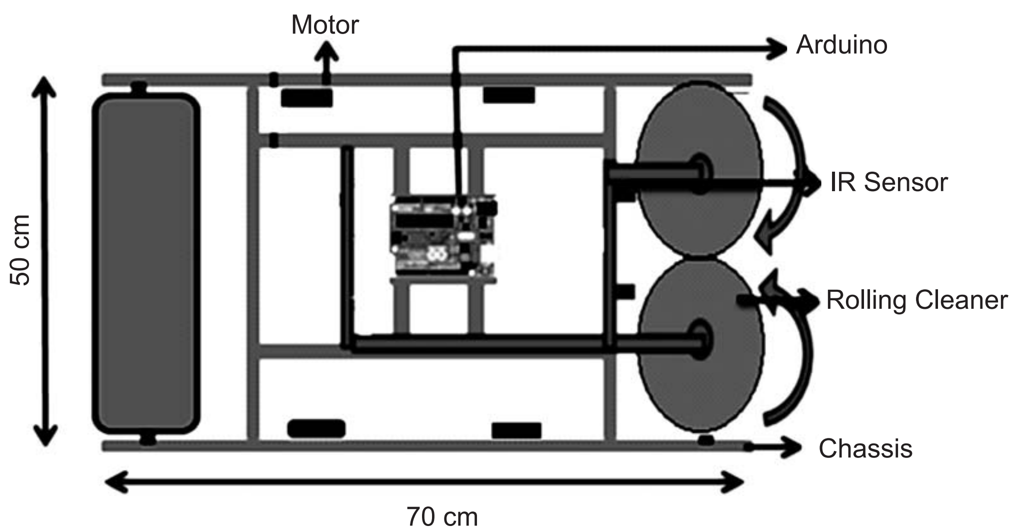

Figure 6: The proposed Robot scheme

The cleaning system designs have the capability to clean multiple panels in a solar plant using a single robot. In order to use multiple robots single robot performs multiple operations. To move the robot from one panel to another, the system has two main Parts that is cleaning robot and the automated carrier track, the robot which moves on a semi circular platform which connects the neighbour panel. The track transfers the robot from one panel to the next. That is, the carrier track aligns itself with the solar panel at which point the robot leaves the track to clean the panel through forward and backward directions as shown in Fig. 5(*a*) – 5(*c*) and returns to the track which transports the robot to the next panel as shown in Fig. 5(*d*). Then, the robot performs the cleaning as repeating the process from first as shown in Fig. 5(*a*). The proposed system operation sequence of the cleaning robot is shown in Fig.6, travels the entire length of a solar panel. The robot has water sprayer sector and three brushes with motors on the extreme ends, four wheels - four motors, sensors and controller subsystem. Two motors are installed on each side of the robot frame. Four motors are used to drive special wheels and the other three motor is used to drive each brushes at front and back to increase the stability of the robot.

4. MODELLING OF ROBOT

Proper design of the system and its components starts with mathematical modelling. The movement of the robot is modelled as illustrated in Fig.7. The model assumes that there is no slip between the wheels and the panel. The movement along the solar panel is in *x* direction.

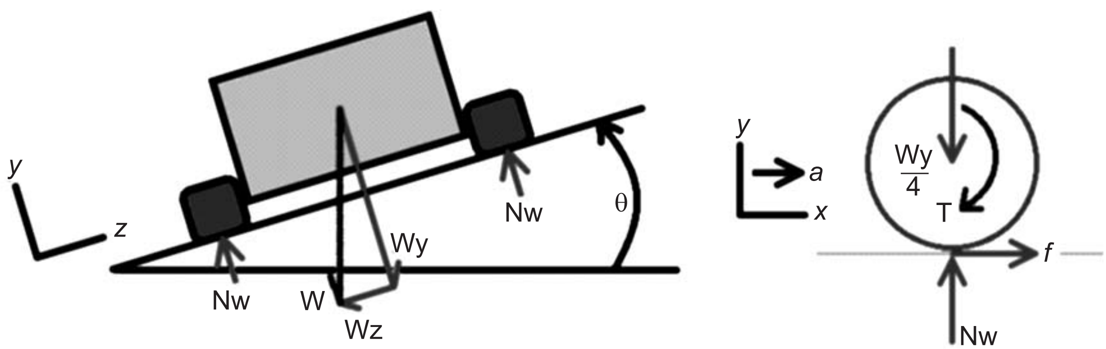

Figure 7: Movement of robot

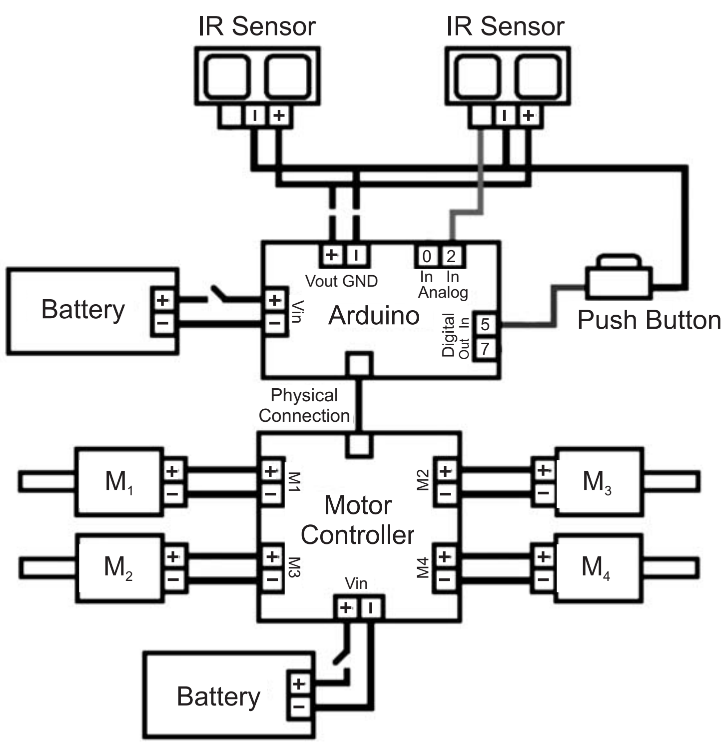

Figure 8: Control system schematic

Here, W is the robot weight, Nw is the normal force acting on each wheel, T is the driving torque, *f* is the friction force, and *a* is the robot linear acceleration. Also, the wheel mass, radius, and moment of inertia are denoted by *mw*, *r*, and I, respectively.

Applying the equations of motion, the relationship between the robot's acceleration and the applied torque to the wheel is:

$$a_x = \frac{\times}{(1 + m \quad \times r \quad)} \tag{1}$$

A. Connection Diagram

The schematic diagram of robot control system as shown in Fig.8.On-off control scheme depends on Arduino microcontroller, a motor controller; infrared sensors were used to check the PV panel boundaries. Once the sensor senses the panel edge the robot stop before reaching the edge of the panel. The microcontroller and sensors are interconnected in same battery and the driver circuit were connected with another separate battery for efficient, error free operations .The four motors plays vital role in movement of robot. Separate push button is provided for ON/OFF purposes.

B. Robot Operation

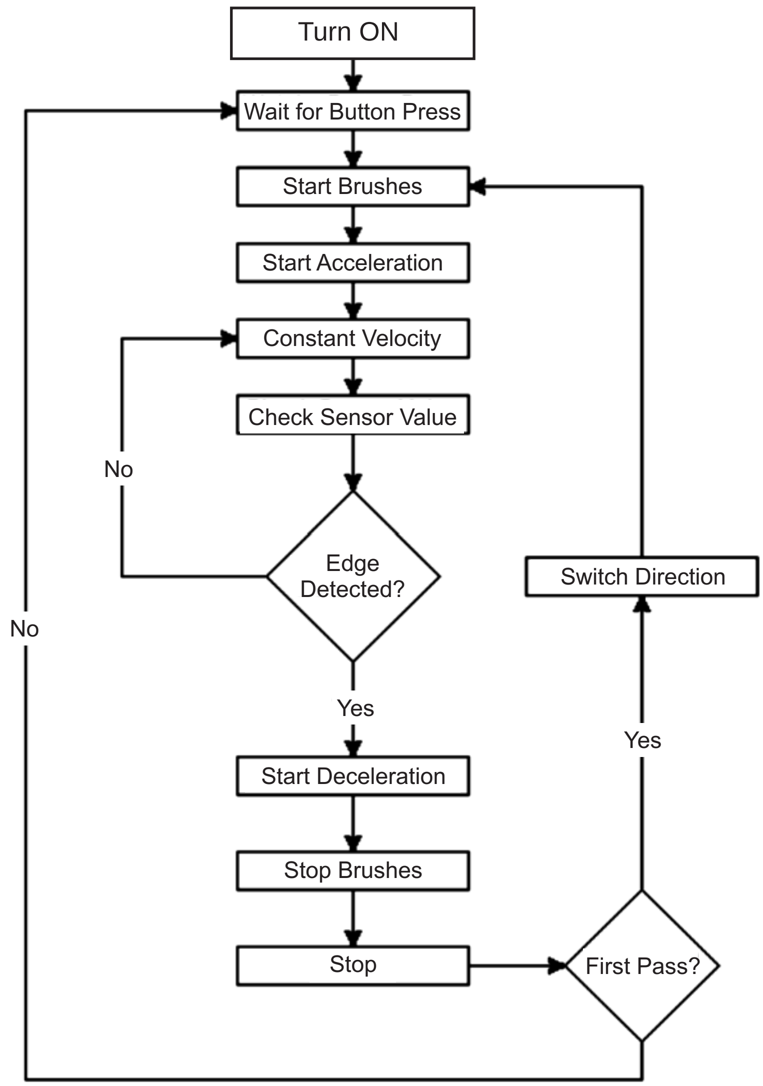

Figure 9: Robot operation flowchart

The flow diagram of robot cleaning system operation is shown in Fig.9. After receiving the command, the robot starts moving in one direction while cleaning the panel. At maximum tilt angle the robot remains effective. The robot was placed on a panel with a sensor while the robot was operating and the angle was measured It was found that the robot can be used to clean solar panel at tilt angles between 0° and 40°. During the operation, the robot keeps moving at constant speed until the sensors signal to reach the panel edge at which point the robot slows down and stops. If this is the robots first pass on the panel, and then it moves backwards until it reaches the edge again where the carrier subsystem is located. The board in the middle contains the microcontroller and the battery to run the motors. Sensors are connected in both sides of the robot signal the reach of panel edge at which point the robot returns back to the starting position, making a second cleaning pass. The several experimental testing scenarios were conducted and analyze the performance of the robot in both static and dynamic modes. The rotors may be arranged such that their downwash will enhance the system cleaning operations.

C. Hardware Requirements

The prototype model developed using the hardware materials as shown in Table 2. The Arduino kit which plays a vital role in controlling the robot using Arduino programming, there is a physical connection which connects both the sensors and motor controller circuit to the Arduino board. Motors $M_1 – M_4$ is controlled by the motor driver circuit which is programmed according to the sensor actions whether to move front or backward directions.Lithium ion battery which acts as energy source to both the controllers as shown in Fig. 4.

Table 2
Specifications

S.No	*Components*	*Quantity*	*Specification*
1.	Arduino kit	1	ATMEGA 328, 16Mhz, 2kb
2.	DC geared motors	4	12V, 60RPM
		3	12V, 100RPM
3.	Voltage Regulator	1	12V, IC7812
4.	Relay/Driver circuit	1	7A/240V, AC (or) 7A/24V, DC
5.	Super polymer Lithium ion battery	2	12V/3000 mAh
6.	IR sensors	2	5V
7.	Solar panel	–	Required
8.	Special wheels	4	–
9.	Cleaning brush	3	–
10.	Other Accessories	–	Required

Special wheels are installed for the purpose of gripping actions in tilted solar panels. And the cleaning brushes located in front and back as shown in Fig.10 and Fig.11 wipes out the dust and dirt particles.

5. RESULTS AND DISCUSSION

A. Prototype Model

The fully integrated robot cleaning system is launched to clean the panel surface is shown in Fig. 10 and Fig. 11. During cleaning, the robot moves along the length of the panel. In-between, the board contains the microcontroller and the battery to run the motors. Sensors installed at front side of the robot where signals the reach of panel edge after that the robot returns back to the starting position, making a second cleaning pass. The several experimental testing scenarios were conducted and analyze the performance of the robot in both static and dynamic modes.

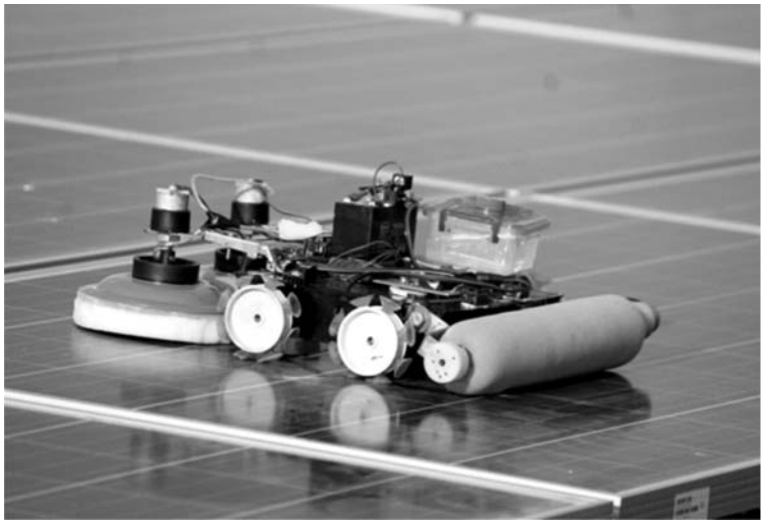

Figure 10: The panel integrated robot cleaning system

Figure 11: Robot functionality test on tilted solar panel

B. Result

Under soiling condition, various readings are taken in four numbers of 250Watts solar panel at 200W/m^2 irradiance. When comparing the results between standard test conditions from plant data sheet and soiling condition it shows that (25-30)% losses as shown in Table 1.

Table 3

Comparison between soiling condition and cleaned condition

Panel	*Soiling Condition*			*cleaned condition*			*Dif.*
	Voltage (V)	*Current (A)*	*Power (W)*	*Voltage (V)*	*Current (A)*	*Power (W)*	
1.	23.7	1.12	19.4	27.9	1.74	35.5	16.1
2.	26.2	1.44	27.6	29.6	1.83	39.6	12.0
3.	23.7	1.22	19.4	27.9	1.74	35.4	16.0
4.	25.2	1.26	23.2	28.7	1.80	37.8	14.6

After cleaning the panels using portable robot, various readings are taken in four numbers of 250Watts solar panel at 200W/m^2 irradiance. During STC condition each panel output is 44.7W respectively, where in soiling condition it is found that 19.4W to 27.6W power drop, after cleaning the panels using portable robot it has been concluded that improvement in power output up to 35.4W to 39.6W. When comparing the results cleaned condition and soiling condition it shows that 93% Improvement in power output shown in Table 3.

6. CONCLUSION

In this work a robotic system is designed to tackle the soiling challenge on PV panels efficiently. Although promising results are obtained from the prototype design, to validate the efficiency of the proposed robot is tested on a PV panel installed in BSNL plant, Silarpatti village, Madurai. The test results show that the efficiency of the PV panel is improved to 93% by robot cleaning, On the other hand, instead of doing expensive processes to minimise the effect of soiling, this cleaning method can be implemented for an economical operation optimised to improving electricity production.

7. ACKNOWLEDGMENT

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