

INSTALLED SOLAR PANEL PERFORMANCE ENHANCEMENT: DUST CLEANING ROBOT

Audu, A. I. and Hena, A. K.

Department of Computer Engineering, University of Maiduguri, Nigeria

*Corresponding email: abdulkadir.iyyaka@gmail.com

ABSTRACT

Dirt and dust accumulation on the surface of the solar panel can reduce the amount of solar energy that can be absorbed and converted to electricity, hence reducing its efficiency. To increase the efficiency of the solar cells, the solar panel must be kept clean at all times, so as to provide a wide surface area for absorption of energy from the sun. This paper explores the use of dust sensor, rotating cylindrical brush, which is driven by DC motor, and microcontroller programmed for automatic and reliable cleaning of the solar panel to reduce the effect of dirt and dust accumulation. It proposes to develop a prototype solar panel cleaning system, which can move front and back across the surface of the solar panel. Water is the solvent used during the cleaning process. The performance of the solar is assessed for two situations: dust and no-dust. Comparison of the solar panel performances is made in order to gauge the working of the robot cleaning system.

Keywords: Renewable energy; concentrated solar power; Photovoltaic; Efficiency; Microcontroller.

1 INTRODUCTION

The need to use technologies to process clean and renewable energies for electricity generation has become inevitable. These renewable energies can be obtained from sources such as sunlight, wind, rain, tides, waves, and geothermal heat [1, 2]. Most renewable energy sources feature sustainability with the exception of few such as biomass source. In contrast, fossil fuels from which fossil-based energies are obtained from are being used far more quickly than they are being replenished [2]. They are also, responsible for environmental concerns such as global warming, greenhouse harmful gas emissions, and ozone depletion that threaten the security of human beings and the future of the world [1]. The report of [3] mentions that renewable energy often provides energy in four important areas: electricity generation, air and water heating/cooling, transportation, and rural (off-grid) energy services. About 20% of human global energy consumption is renewable, including almost 30% of electricity as shown in Figure 1 [4]. A considerably huge amount of solar energy is received on earth surface the sun. "The amount of solar radiation striking the earth over a three-day period is equivalent to the energy stored in all fossil energy sources." It is further stated that solar energy is a free, inexhaustible resource; yet harnessing it is a relatively new idea [5]. Despite, the fact that the amount of solar energy depends on factors such as geographical location, time of day, ambient temperature, and dust accumulation season and clouds: electrical power is generated in order to drive development in towns and cities. Concentrator photovoltaics (CPV), solar heating, photovoltaics (PV), concentrated solar power (CSP), solar architecture and artificial photosynthesis [6, 7], low-concentration (LCPV) and high concentration (HCPV) [5], are some of the ever-evolving technologies used in harnessing solar energy. Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert, and distribute solar energy.

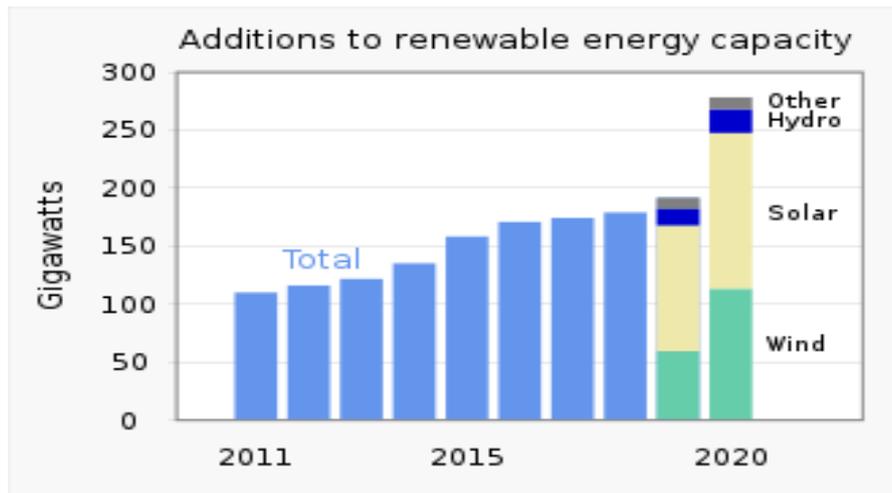


Figure 1. Renewable energy capacity [4]

In practice, solar energy is mostly harnessed by using PV panel. It is a module of solar cells, made from different chemistry and physics of semiconductor materials and technologies that converts the energy of the sun directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon [5, 7]. There are several advantages of photovoltaic solar power that make it "one of the most promising renewable energy sources in the world". It is non-polluting, has no moving parts that could break down, requires little maintenance and no supervision, and has a life of 20-30 years with low running costs. It is especially unique because no large-scale installation is required [5]. However, the accumulation of dust particles reduces the efficiency of solar cells and results in appreciable losses in the generated power due to the solar irradiance scattering effects on the surface of the solar panel. Higher temperatures can severely reduce the solar panel's production of power. Higher temperature increases the conductivity of the semiconductor, resulting in balanced charges within the material thereby reducing the magnitude of the electric field, which inhibits the charge separation and lowers the voltage across the cell. Depending on the location, heat can reduce the efficiency by 10% to 25% [8, 9]. Constant and effective cleaning of the PV panel surface, which is one of the maintenance requirement strategies, can minimize the effect of dust accumulation, which is an external factor, on performance of PV panels. This is because dust accumulation can reduce the absorption of light and generation of either electron-hole pairs or exactions. Considering the importance of the use of PV panels and efficient use of solar energy, this paper focuses on the prototype development robot that can remove dust from PV panel in order to reduce the effect of dust accumulation on PV panel, consequently improving its efficiency. To circumvent the aforementioned problem, a system is proposed to improve the performance of PV panel through cleaning.

2. LITERATURE REVIEW

A study by [7] in Iran, investigates the effect of air pollution result from local industries on the efficiency of PV systems, in their experiment several PV modules were installed with different tilt angles. The Investigation shows that the output of the system varies with the season due to the amount of dust that exists in the air in different seasons. They observed the variation in output during winter, spring and summer. They observed that the power output of a PV system decreases by more than 60% because of air pollution that covered the surface of the PV panel. The authors in [10] investigate the impact of dust on solar panel. The test carried out on the performance of three set of solar panels reveals an average of 1% loss of incident solar radiation due to dust or dirt accumulation on the surface of the panel with a tilt angle of 300. The maximum degradation in the output power was found to be 4.7%, a correlation factor of 0.99 for a glass plate inclined at 45°. In [11], the effect of dust accumulation on the performance of solar modules in Sahara environment was carried out. They investigated a framework of weekly cleaning on modules and found that dirt accumulation on solar module have a significant impact on output power and system efficiency. They reported that once a week cleaning and rinsing every three days during sand and dust storm months (February-May) and once a month cleaning in other months will maintain a 2 to 2.5% loss in performance. A simple model

was developed by [12, 13], for the typical behavior of the relative transmittance losses due to the presence of dust on the solar cell. Their result shows 4.4% mean daily energy loss caused by dust deposition on the surface of the PV module. They report that in long period without rain, daily energy losses can be higher than 2%. In Norway, a study by [14] reported that the effect of soiling can be accurately determined by a combination of optical measurement and high precision balance measurement, combining the quantitative dust measurement and the optical characterization, an approximately linear correlation between the increase in soil density and the reduced transmittance is observed. The reduction in transmission per unit of soiling density of 2.8% for every 10 mg/m² is found.

3 THEORETICAL BACKGROUND

3.1 Hardware Components of the robotic cleaner

3.1.1 Pulley system

A pulley is a wheel on an axle or shaft that is designed to support movement and change of direction of a taut cable or belt, or transfer of power between the shaft and cable or belt [15]. In the case of a pulley supported by a frame or shell that does not transfer power to a shaft, but is used to guide the cable or exert a force, the supporting shaft is called a block, and the pulley may be called a sheave. In this design, a pulley is used to move the locomotive and cleaning unit to and fro the across the length of the panel. Rack (geared thread) and pinion is used to convert a rotary motion into translating motion or vice versa (either the pinion drives the rack or the rack drives the pinion). Rack can be imagined as a spur gear having an infinitely larger diameter. Therefore, the rack has an infinite number of teeth and a base circle, which is infinite distance from the pitch point.

3.1.2 Worm gear

Worm gear teeth resemble screw thread, which mate with helical gear, except that it is made to envelop the worm as seen along the worm's axis (Figure 2). Operation of worm gears is analogous to a screw. The relative motion between these gears is sliding rather than rolling. The uniform distribution of teeth pressures on these gears enables use of metals with inherently low coefficients of friction.

3.1.3 Spur gear

Spur gears are the common types used (Figure 2). They consist of a cylinder with teeth projecting radially. Looking down the length of the shaft, a tooth's cross-section is usually not triangular. Instead of being straight, the sides of the cross section have a curved form to achieve a constant drive ratio. Spur gears mesh together correctly only if fitted to parallel shafts. Spur gear can be classified into two pressure angles, 20° being the current industry standard and 14½° being the former.



Figure 2. Worm and Spur gear configuration: Source: www.hobbytronics.co.uk

$$\text{Gear ratio of worm wheel} = \frac{\text{Number of teeth on worm wheel}}{\text{Number of teeth on worm}} \quad (1)$$

3.1.4 Motor Driver

A motor driver is an integrated circuit chip, which is usually used to control motors in autonomous robots and many applications. It acts as an interface between microcontroller and the motor. This dual bi-directional motor driver is based on the very popular L298 Dual H-Bridge Motor Driver Integrated Circuit. The circuit will allow you to easily and independently control two motors of up to 2A each in both directions. It is ideal for robotic applications and well suited for connection to a microcontroller requiring just a couple of control lines per motor.

3.1.5 Dust Sensor

DSM501A is a dust sensor that detects dust particle concentration by using optical sensing method. In this method an infrared light emitting diode (IR LED) and a photo-sensor are optically arranged in the device. The photo sensor detects the reflected IR LED light. The dust sensor module can detect large house dust by pulse pattern of signal output.

3.1.6 Microcontroller

The microcontroller [16], unit consist of peripheral interface controller (PIC), amongst is the PIC16F877A manufactured by Microchip Company. It is very efficient and at the same time it is economical. It is an 8-bit microcontroller, 40 pins dual-in-line package. It is based on reduced instruction set computer (RISC) architecture. Therefore, it has a smaller number of instructions (35 instruction). It has 5 input/output ports (A through E), port A has 6 pins, port B has 8 pins, port C has 8 pins, port D has 8 pins and port E has 3pins, making a total 33 input/output pins, 2 pins each for VDD, VSS and oscillator. Support for multiple memory types, interrupt, direct, indirect and relative addressing mode is sufficient. Amongst the memory types are; 8K x 14 words of flash program memory (write-erase possibility). 368 x 8 bytes of data memory (RAM). 256 x 8 bytes of EEPROM data memory. It consumes less power, operating voltage and frequency 5VDC/20MHz respectively.

4 METHODOLOGY

4.1 Block Diagram of the System

The work presented in this paper is implemented based on the block diagram and flow chart shown in Figures 3 and 4. This section describes the design process as well as the implementation of microcontroller based solar panel dust cleaning system. It consists of the following units; Power supply unit; Microcontroller unit; Sensor unit; Water pump unit; Motor driver unit; Display unit and Brush and rail motor unit. A polycrystalline PV panel is used for this project; the specifications of the module are presented in Table 1. The photovoltaic module is fixed at 35° inclinations, for maximum solar energy harvest as suggested by [7], and at a location devoid of overcasts from nearby trees and buildings.

Table 1. Solar Module Specifications

S/N	Parameter	Value
1	Type	Polycrystalline
2	Manufacturer	Man-Tech. Solar
3	Model	KL-SP-20W
4	Surface Area (L x W x B)	(470 × 320 x 43 46.99mm)
5	Power Rating (pmax)	20 Watts
6	Maximum Power Voltage VMP	17.5 V
7	Maximum Power Current IMP	1.14 A
8	Open Circuit Voltage VOC	22.05 V
9	Short Circuit Current ISC	1.28 A

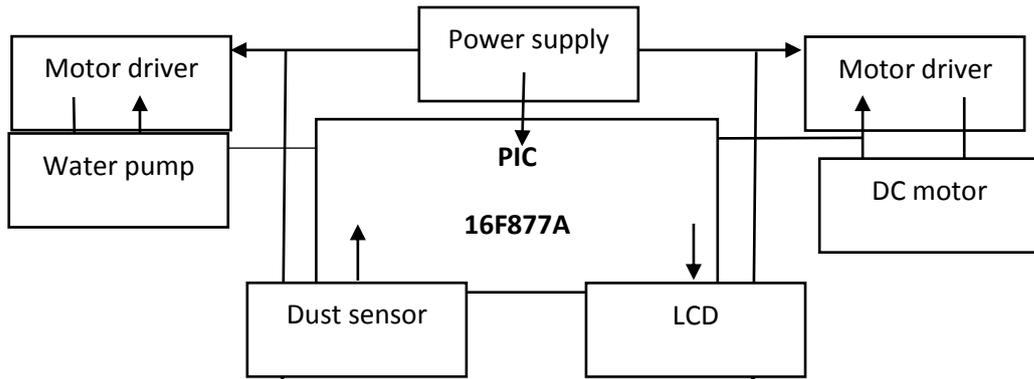


Figure 3. Block diagram of the robotic cleaner

4.2 Flow chart

After initialization of each unit, the output of the sensor is read and if dust is detected is up to the predetermined amount, the cleaning unit together with the locomotive unit is activated. The cleaning is done twice once (to and fro) dust is detected.

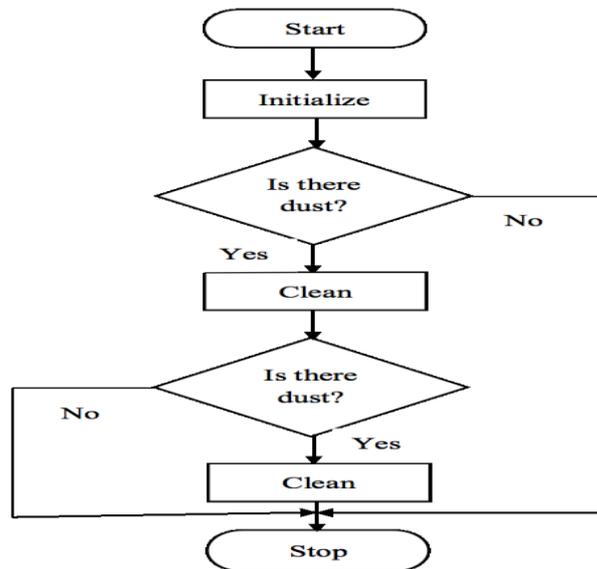


Figure 4. Flowchart of the system

To find the efficiency of the solar panel;

$$\text{Efficiency} = \frac{\text{output power}}{\text{input power}} \times 100\% \quad (2)$$

$$\text{Output power} = \text{voltage}(v) \times \text{current}(i) \quad (3)$$

$$\text{Input power} = \text{solar radiation} \times \text{area of PV panel} \quad (4)$$

$$\text{Increased efficiency} = \text{Avg. efficiency without dust} - \text{Avg. efficiency with dust} \quad (5)$$

$$\text{Average efficiency without dust} = \frac{60.62}{6} = 10.1\%$$

$$\text{Average efficiency with dust} = \frac{43.83}{6} = 7.31\%$$

$$\text{Increased efficiency} = 10.1 - 7.31 = 2.80\%$$

Where PV panel area is in m²; Output power in watt/m²; Input power in watt/m²

To summarize, the contribution of this paper are as follows:

- A dust sensor module (DSM 501A) is interfaced with PIC16F877A microcontroller in order to measure the concentration of dust accumulation on the surface of the PV panel.
- A motor driver module is interfaced to control the to-and-fro movement of the cleaning unit and as well to ensure smooth rotation of the brush.
- A solar panel is interfaced with microcontroller in order to measure the output voltage with and without dust for efficiency calculation. The measurement is done using voltage divider technique.

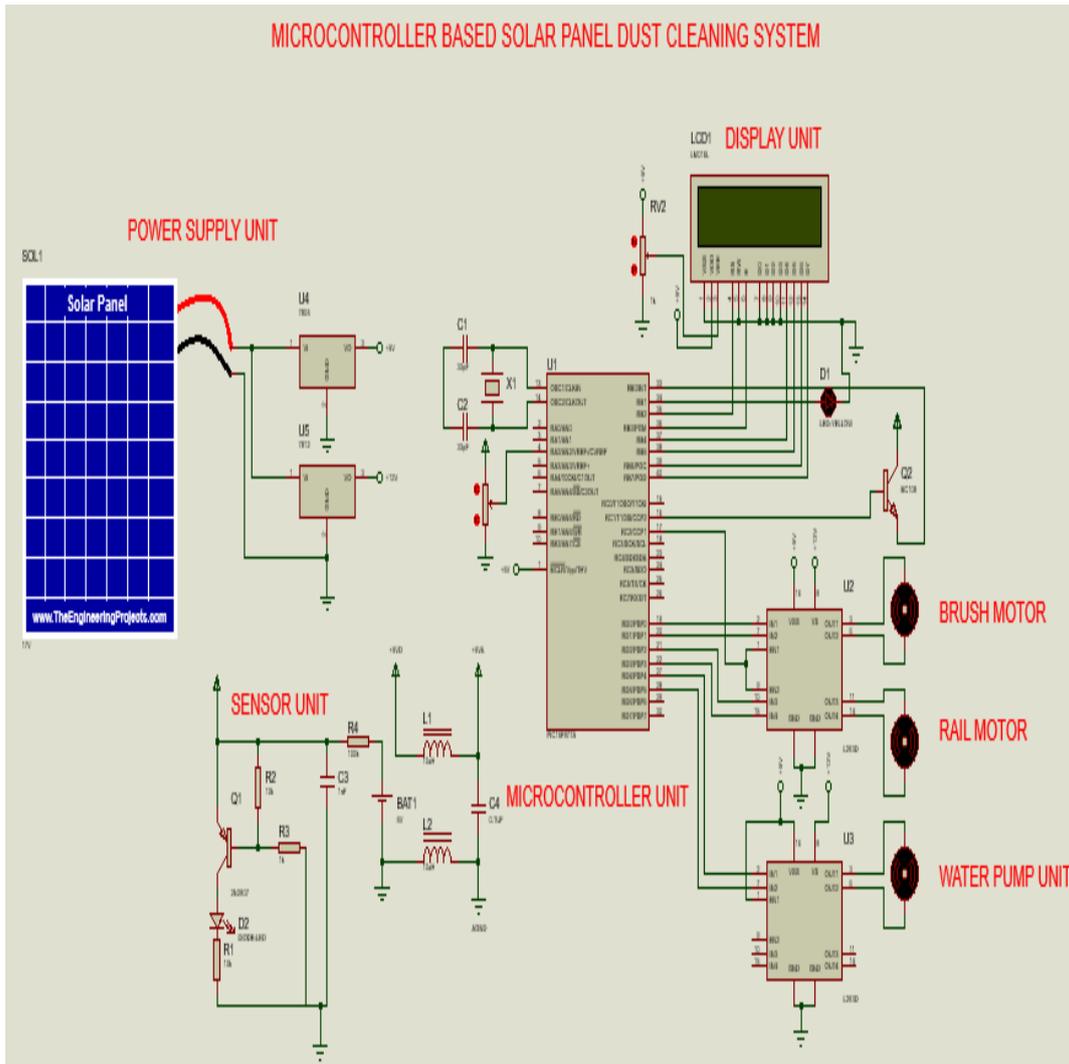


Figure 5. Circuit implementation of the system

5 RESULTS AND DISCUSSION

5.1 The prototype setup

The circuit of Figure 5 is implemented and results in the prototype shown in figure 6. The automatic cleaning system is used to clean the accumulated dust on the solar panel. In the system, a dust sensor is used to sense the presence of dust; the output from the sensor and solar panel is fed to the microcontroller. Since the output of the sensor is analog, the analog to digital converter (ADC) circuit within the microcontroller takes care of the conversion process. A voltage divider circuit is constructed to handle the panel output. The output of the microcontroller is put across Dual H-bridge motor driver integrated circuit (L298) in order to create enough current drive for the motor. Based on programmed instructions, the cleaning and locomotive unit is activated.



Figure 6. Constructed solar cleaning system

5.2 The cleaning unit

The cleaning unit consists of a brush, which is cylindrical in shape and the material is tiny hairy rubber in nature, which is used to clean the surface of the panel. The brush is attached to a 5VDC motor for its continuous rotation. The gearing induction helps provide the motor with enough torque to overcome the friction. The brush unit has 5 induced spur gears. Ordinary brush cannot clean dust off the surface of the module completely, hence the need for foam (duster), which can be used to clean the remaining dust that could not be wiped by the brush. Research have shown that keeping the module at lower temperature increase the rate at which the panel converts sun rays to electricity. A water pump is employed to sprinkle water on the surface of the module to reduce the temperature.

5.3 Performance

The data obtained for solar radiation versus time characteristics, PV panel efficiency versus Time analysis with dust, PV panel efficiency versus time analysis without dust, voltage and current versus time with and without dust and composite graph showing difference in efficiency for the PV panel under investigation are shown in Figure 7, 8 and 9 respectively. In the raining season, the sun appears not brighter in the sky, which reduces the duration of sunlight seen in a day than it appears in the dry season when the sun is the highest in sky on. The maximum and minimum solar radiation intensity was found to vary between 985 and 210 W/m². The effect of the deposition of dust on the solar panel is considerable due to the fact that power is a complex phenomenon that is influenced by different environmental and weather conditions. From the study so far conducted, cleaning the solar PV Panel regularly can maximize the number of radiations received and increases output power up to the maximum limit. Table 2 shows the Output parameters of the PV panel with dust accumulated on it. Concentration of 60grams dust is spread over the surface of the module. The efficiency is depicted in Figure 7.

Table 2. Efficiency of PV Panel with dust and without cleaning system

S/N	TIME HH:MM	INTENSITY (LUX)	VOLTAGE (VOLTS)	CURRENT (AMP)	POWER (WATT)	EFFICIENCY (%)
1	06:00AM	965	11.39	0.63	7.18	4.52
2	08:00AM	983	15.34	0.69	10.58	6.54
3	10:00AM	1001	16.98	0.71	12.06	7.32
4	12:00PM	1023	19.23	0.79	15.19	9.02
5	02:00PM	1019	18.89	0.75	14.17	8.45
6	04:00PM	1011	18.43	0.72	13.27	7.98

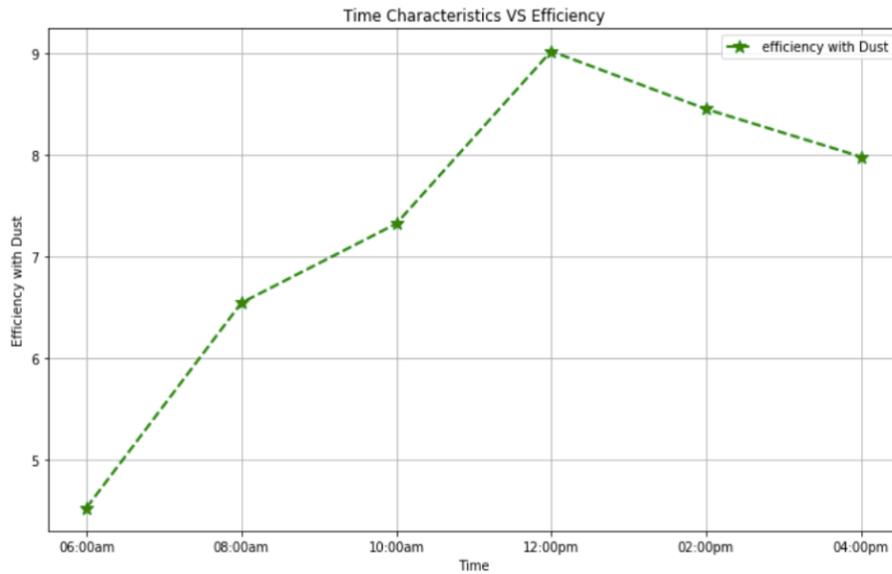


Figure 7. Graph of PV panel efficiency with dust and without cleaning mechanism

Table 3 shows the output parameters of the PV panel without dust accumulation on it.

Table 3. Efficiency of PV Panel without dust and with cleaning system

S/N	TIME HH:MM	INTENSITY (LUX)	VOLTAGE (VOLTS)	CURRENT (AMP)	POWER (WATT)	EFFICIENCY (%)
1	06:00AM	965	15.47	0.74	11.44	7.21
2	08:00AM	983	17.62	0.82	14.44	8.93
3	10:00AM	1001	19.58	0.81	15.85	9.62
4	12:00PM	1023	21.01	0.99	20.79	12.35
5	02:00PM	1019	20.56	0.98	20.14	12.01
6	04:00PM	1011	20.08	0.87	17.47	10.50

Table 3 shows clearly the increase in values of the PV panel output parameters. The increased efficiency is depicted in Figure 8 and 9.

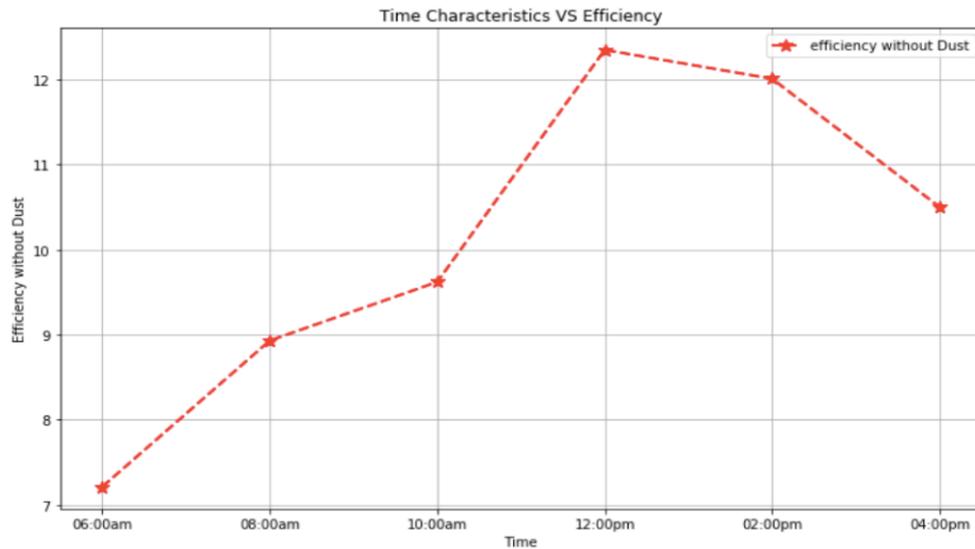


Figure 8. Graph of PV panel efficiency without dust and with cleaning mechanism

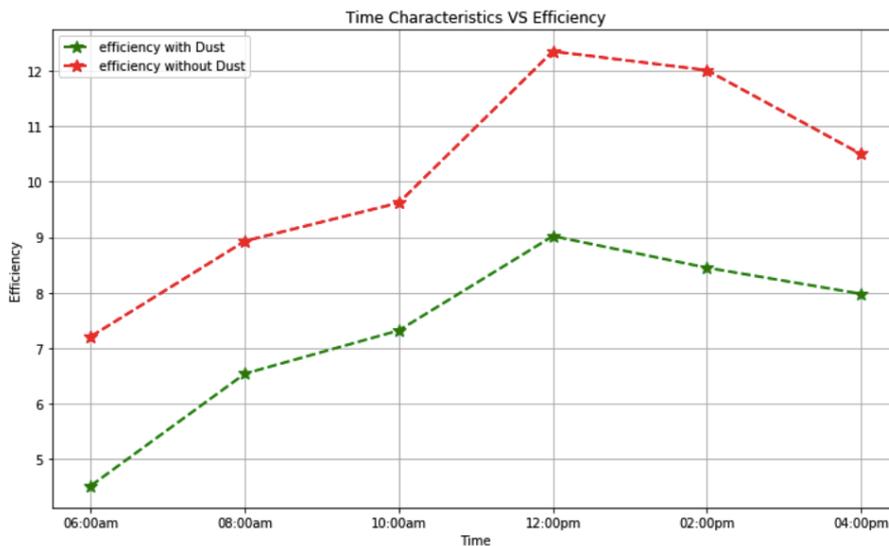


Figure 9. Difference in efficiency of PV panel.

6 CONCLUSIONS

The conclusions can be summarized as: The losses of the output power of the fixed PV panel at a tilt angle of 35° is about 25% of the rated yield and can be higher depending on the dust form. The dirt and bird drop make a hotspot on the panel, and it can make temporary fail in the panel. Dry cleaning cannot remove all the dirt on the surface of the PV panel. However, cleaning PV panel with water increases the cleaning efficiency by removing majority of the dirt deposited on the panel. No external powers are required as the self- cleaning system takes its power from the battery of the PV panel. This device is made up of lightweight material. Comparing the costs of cleaning by manual operation and automatic operation, the cost for automatic cleaning has proved to be more economic and significantly less cumbersome particularly in systems having large number of PV panels.

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