Automatic Versus Manual Solar Panel Cleaning for Remote Locations

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Abstract: Photovoltaic solar technology is now being widely investigated for implementation in the UAE as a possible renewable energy source. Currently the main emphasis is on the accessible areas but remote locations are now being explored for the possibility of large scale deployment. However due to the environment and location certain measures such as regular cleaning must be considered to ensure the efficient operation of the PV panels. This paper investigates the cost of current developed cleaning technologies available in the Gulf region, highlights their advantages and disadvantages and the time needed to recoup initial investment.

Keywords: Solar Energy, Photovoltaic, Renewable Energy, Electricity Generation.

INTRODUCTION

Many companies in the Gulf region are looking for solutions to the problem of power in remote locations and have implemented photovoltaic (PV) technology with secondary batteries to secure this since it was found to be the most suitable solution for these areas [1]. Nevertheless such technology suffers today with lower efficiency as well as other issues which traditional electricity generation techniques do not see; hence it is vitally important to keep these modules running at their maximum output [2]. It has been widely proven in test systems that the accumulation of dust particles on the surface of the PV panels affects the output power generated in the same manner as clouds would [3-5]. PV outputs in various applications have been reduced due to two main factors which are dust and hard and soft particle shading which can come from bird droppings which can significantly reduce the PV output power, if not removed, hence causing a negative impact on the system's performance which is a critical issue for remote power generation.

Currently, one of the implemented methods to clean the panel and retrieve the maximum power generated by the panel is to implement manual cleaning but depending on the remoteness this can be expensive. Therefore, a proactive, cost effective solution is required to ensure cost efficiency for deploying this cleaning technology. In designing such a solution several factors need to be taken into consideration such as i) lack of distilled water, ii) power source accessibility due to the location, iii) space availability and iv) maintenance. To resolve some of these issues, the cleaning system should consume low power and require minimal maintenance. In this paper two alternative solutions to manual cleaning are presented and a cost comparison is completed.

SOLAR ENERGY

PVs are considered to be an environmentally friendly option and when operating do not produce CO_2 emissions or any other pollutants making them a suitable technology for cutting carbon footprint and provides power to locations which otherwise would use a diesel generator. Such systems are suitable for basic electrical supplies for low power requirement and remote locations such as the Gulf desert which provides its own unique challenges.

However, no system is perfect and an issue with PVs is its degradation due to prolonged exposure to ultraviolet (UV) radiation which is a concern for long term operation [6]. Unfortunately, this is not the only problem, the effects of dust [7, 8] and loads on the system [9] are factors which should also be considered. A major issue that is currently being considered more often in the renewable energy field is the energy loss or panel damage which can occur due to natural staining or shading. Some suggested solutions to reduce the impact of the above mentioned concerns have been presented in the following references keeping in mind that the proposed methods are for large scale installations rather than single panels [10-14]. Currently in the Gulf region PV installations are formed by small numbers of modules, thus a small amount of shading can result in the whole supply being disabled. To ensure a reliable system, the designer must have an

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extended knowledge of photovoltaic theory and the possible issues and ensure they are addressed.

PHOTOVOLTAIC MODULES

A photovoltaic module is a combination of small solar cells which are the basic power conversion units. A photovoltaic system is the series/parallel connection of several PV modules in order to meet the current and voltage requirements. Photovoltaic energy conversion relies on the quantum nature of light where a flux of photons carries the energy

$$E_{ph}(\Lambda) = \frac{hc}{\lambda} \quad (1)$$

h is the Planck constant, c is the speed of light, and λ is the wavelength of the earth's surface every second. "Because photovoltaic cells mainly convert to electricity photons of visible, ultraviolet and infrared light, i.e. photons of lower energy than X-rays, the external photo effect is not applicable to photovoltaic cells [15]."

Solar cells are p-n junctions which consist of doped semi-conductor material. Energy is transferred by photons falling within the junction, creating a current flow. Internal electric field at the junction causes voltage drop which is required in order for the PV cell to generate power. Photovoltaic systems offer substantial advantages over common power sources due to their reliability, durability, low maintenance cost, no fuel cost, modularity, safety and independence. However, they have some disadvantages including high initial cost, variability of available solar radiation, efficiency improvement and energy storage.

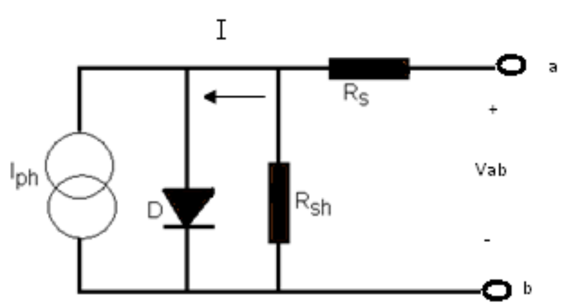


Figure 1: Standard model for photovoltaic cells.

PV modules are cells connected in series with two bypass diodes [16], with each solar cell represented by its equivalent circuit model, as illustrated in Figure **1** where, I_{ph} is the photocurrent source, D is a diode, R_{sh} is a shunt resistance (normally large), R_s is the series resistance (normally small) and K is Boltzmann's constant.

$$I = I_{ph} - I_S\left[[e]\frac{\frac{V_{ab}+IR_S}{nkT}}{q} - 1 \right] - \frac{V_{ab}+IR_S}{R_{Sh}} \quad (2)$$

I_{ph}, the current source, produces a current which is proportional to the level of solar radiation landing on the cell.

$$I_{ph} = C_0 . E \quad (3)$$

E is the irradiance level and c_0 is a reflection coefficient [15]. When no load is connected, the current flows through the diode D determining the solar cell's open voltage V_{OC} [17]. The amount of irradiation colliding with the PV surface determines the short circuit current (I_{sc}), and from the model shown above it is simply the light generated.

Due to the mismatching in PV modules in addition to the impact of non-uniform irradiation, cloud, cell damaging, partial shading and soiling, the output power generated by the PV system decreases extensively [10]. A solar cell can also be characterized by its maximum power point where the product V_{mp} x I_{mp} is at its maximum, where

$$V_{mp} = V_{oc} - \frac{nkT}{q}\ln\left[\frac{Vmp}{\left(nkT/q\right)} + 1\right] \quad (4)$$

The maximum device power which is noted as P_{max} can be obtained from highest point on the P-V curve. This power under strong sunlight (1 kW/m^2) is known as the peak power of the cell. Hence, solar cells are rated in terms of their peak watts (W_p).

Moreover, in order to measure the junction quality and series resistance of the cell, a fill factor (FF) can be defined by:

$$FF = \frac{V_{mp}I_{mp}}{I_{SC}V_{OC}} = \frac{P_{max}}{I_{SC}V_{OC}} \quad (5)$$

Obviously, the nearer the FF to unity, the higher the quality of the cell is. However, as the fill factor determines the output power of the cell, when considering the series resistance of the cell, the maximum power can be described by:

$$P_{max} = P_{mp}\left(1 - \frac{I_{SC}}{V_{OC}}R_s\right) \quad (6)$$

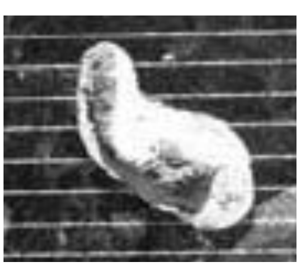
As mentioned earlier regarding the direct relationship between light available and amount of current produced, shading or staining may have a severe effect on the performance of the system by reducing the output power as much as 50% when the panel is shaded by as small an amount as 5% [10, 14, 16, 18, 19]. Shading, which depends on the area and surroundings, can be classified into two types – Soft and Hard. Soft shading, which can block as much as 10% of the diffuse radiation from being captured by the cell, can be caused by local structures, telephone/electric poles, snow and fallen tree leaves. However, hard shading presents a more problematic issue as it prevents the cell absorbing either direct or diffuse light. When shading occurs, a significant reduction of the output power is noticed and two maxima appear on the PV curve. The first maximum is located very far from the normal maximum power point region and it is independent of the shaded area and irradiance while the second maximum depends on the shading scenario. In this case, the number of shaded cells determines the global maximum power of the panel.

Bird droppings are a prime example of natural hard shading. Not only does it block the solar radiation, it also stains the PV [20]. Both soft and hard shading will provide minimum current hence making the PV act as a resistive load. Dust accumulation, water stains (salt) or bird droppings can drastically affect the efficiency of the solar system by 10 to 25% [21, 22] with the PV surface being either partially or fully shaded (Figure **2**). In either case, uneven illumination and reduction of sunlight reaching the PV cells is taking place, hence shading must then be eliminated or reduced. In addition, research has shown that deposition of various particles may negatively influence the "rate of heat transfer between the PV and the environment" [23].

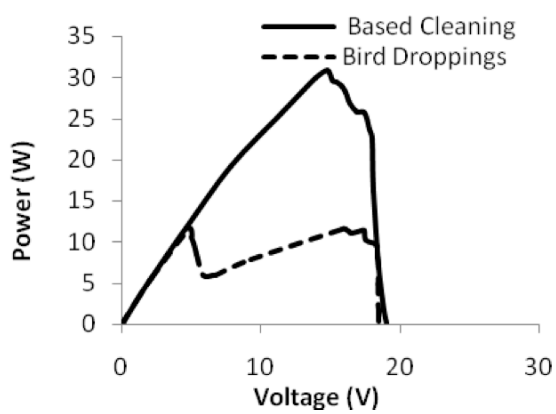
CURRENT SOLUTIONS

In order to enhance the performance of the PV system, cleaning is required. Several methods have been discussed to eliminate the effect of solid particles accumulating on the surfaces of the PV's in order to maximize the solar radiation absorption by the panels. Various techniques have been considered and summarized in [24] but many more have been developed since this publication such as robotic devices [2, 25], coated glass [26, 27], oversizing [28] and manual [29]. Currently there are three viable solutions for the offshore environment of the United Arab Emirates (UAE):- manual cleaning which is traditionally used, PIC (Programmable Integrated Circuit) Microcontroller based cleaning [30] and PLC (Programmable Logic Controller) based cleaning [31]. The basic function of the two automated devices is shown in Figure **3**.

Manual cleaning, which involves manpower, a pure water source and cleaning supplies, although a reasonable option in accessible locations due to the cheap labour and low initial costs, is a non-effective solution for remote areas mainly due to the transportation costs and time to travel to remote locations. Therefore, more automated systems such as the PIC or PLC based cleaning which requires less human intervention is more environmentally and economically favoured. These automated systems (Figure **3**), although using different types of controllers for the cleaning, use the same principle to clean the PV panels. The main features of the process of these



(**a**)



(**b**)

Figure 2: (**a**) Birds dropping on PV panel (**b**) Power-Voltage characteristics showing effect of shading due to droppings (measured by the authors).

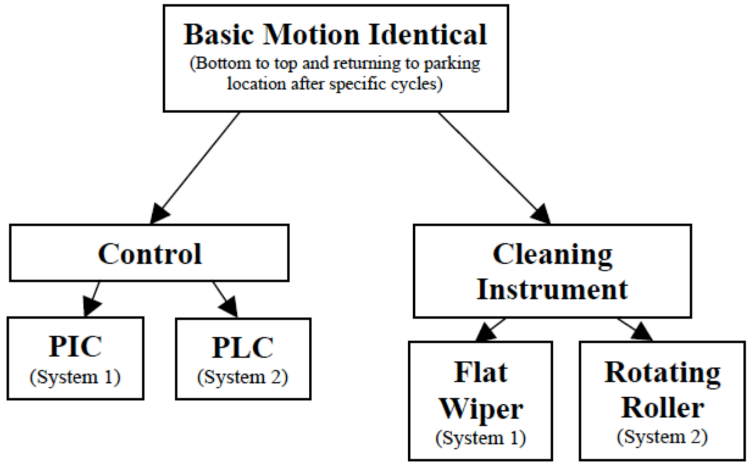


Figure 3: System description of PIC and PLC based cleaning systems.

cleaning systems are as follows but are further described in references [30, 31].

PIC based cleaning main features:-

- A solar powered water desalination
- Minimal cost with simple operation
- Daily cleaning initiated by means of a photodetector (detecting daylight)
- Water to wet the panel was provided by a desalination water system
- Wipers move in two rounds of movement from their initial position at the bottom of the panel

PLC based cleaning main features:-

- Cleaning is started by a 24 hour timer – time specified by the user
- Water storage tank is used for the desalinated water
- Roller blade is used to clean the panel not only moving up and down but also rotating
- Water from the tank is sprayed before the three cycles begin for cleaning

A detailed list of advantages and disadvantages of all options are summarized in Table **1**.

Reference [32] interestly noted that for a PV panel automatic cleaning generates more output power than without an integrated mechanical cleaning system.

RESULTS

Initially, economics is one of the major constraints that is closely examined when designing and installing PV systems [28]. In addition to the initial capital cost, maintenance cost, system's lifetime, and salvage value, cleaning of PV systems is a primary issue to consider. The breakdown of the financial cost of the three possible cleaning systems is outlined in Tables **2** to **4**. As the manual cleaning does not require any installation the only cost incurred is the maintenance

Table 1: Current Cleaning Solutions

Cleaning Type	Manual cleaning	PIC based cleaning [30]	PLC based cleaning [31]
Advantage	No moving parts	Low cost compared to PLC Automated Daily cleaning 24 hours bird deterring	Automated Daily cleaning 24 hours bird deterring
Disadvantage	Cost varies, depending on location and manpower Time consuming Inefficient water usage No feedback about specific time for cleaning	Inefficient water usage Moving parts	Higher initial cost compared to PIC Moving parts Inefficient water usage

Table 2: Costing for Manual Cleaning

Description of Maintenance (6 times a year)	Quantity	Cost ($) per part
Labours	12	150
Materials	6	275
Total Maintenance per year		**3,450**

Table 3: Costing for PIC Based Cleaning

Description of Installation	Quantity	Cost ($) per part
Labours	4	150
Engineer	1	550
Total - Initial Installation		**1,150**
Description of Design Cost	**Quantity**	**Cost ($) per part**
Water header and wiper	1	30
Nozzles	2	4
Pipes	5 meters	2
Solar Heater	1	68
Pumps	2	19
Limit switches	2	2
DC motor and wires	1	60
Light sensor and motion sensor	1	4
Rail	2	2.75
LED's	2	3.5
Tank	1	27
Buzzer	1	12.25
PIC 18 and motor driver	1	15
Aluminum Structure	1	82
Total - Initial Investment		**370.75**
Description of Maintenance (2 times a year)	**Quantity**	**Cost ($) per part**
Labours	4	150
Materials	2	150
Total Maintenance per year		**900**

and as with Table **3** and **4** it is the summation of the cost ($) per part times the quantity to provide the total maintenance per year. Table **3** and **4** not only include the maintenance per year they also include the total initial installation and the total initial investment both of which are calculated in the same manner as explained previously.

Table **5** incorporates not only the maintenance per year but also the initial outlay which is the total of the initial installation and the initial investment hence the total for 1 year is the summation of all these factors. It is evident from the calculations presented that the two automated systems would have a payback period of less than 1 year. Other factors should be considered with any cleaning mechanism specifically in a remote location. These concerns are related to the amount of water used as well as sustaining the maximum power generated. Determining solutions to these issues will have an impact on the system's economics. Since the efficiency as well as the electrical output decrease at high temperature [33], it is normally desirable to sustain

Table 4: Costing for PLC Based Cleaning

Description of Installation	Quantity	Cost ($) per part
Labours	4	150
Engineer	1	550
Total - Initial Installation		**1,150**
Description of Design Cost	**Quantity**	**Cost ($) per part**
Wood Structure	1	125
PLC Controllers	1	520
Metal Chain	1	8
Pulleys	2	7
Wiper and pump	1	28.5
Buzzer	1	16.5
Motion Sensor	2	4
Limit Switch	4	12.25
Nozzles	2	4
Universal Motor	1	49
Pipes	1	14
Water Tank	1	63
Wooden Tank Support	1	14
Motor Driver and wires	1	22
Total - Initial Investment		**939**
Description of Maintenance (2 times a year)	**Quantity**	**Cost ($) per part**
Labours	4	150
Materials	2	150
Total Maintenance per year		**900**

Table 5: Comparison Over a 1 Year Period

Cleaning Type	Initial Outlay	Maintenance per year	Total for 1 year
Manual cleaning	0	3,450.00	3,450.00
PIC based cleaning	1,520.75	900.00	2,420.75
PLC based cleaning	2,089.00	900.00	2,989.00

a low system temperature which is difficult in the UAE due to high peaks reached during summer months. Frequent cleaning could be a solution to maintain preferred temperature and this could definitely be achieved by the proposed automated cleaning mechanisms where a timer or command is used to clean the panels' surface. Pure water in the Gulf is expensive so the amount used with automated systems can be controlled compared with manual cleaning where limited control only is possible.

CONCLUSION

This paper presented a detailed cost comparative study for PV cleaning systems in the remote locations of the UAE region. It is well noted that an automated system is an important solution to overcome the problem of dust accumulation which was found to have a negative impact on the PV performance, hence effecting the efficient operation. The cost comparison proved that over an extended duration the automated system is more cost effective than the manual cleaning that is currently undertaken. However implementing such technology will require a high initial cost from the company.

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