International Journal of Engineering and Technical Research (IJETR)
ISSN: 2321-0869 (O) 2454-4698 (P), Volume-5, Issue-2, June 2016

Impact of Dust& Dirt Accumulation on the Performance of PV Panels

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Abstract— **The depletion of fossil fuel and the crisis thereon compelled the scientists to search for such alternatives of the electricity generation so as not to affect and deteriorate the environment anymore, because due to large amount of pollution emancipating from various sources the environment is becoming unhealthy for the living ones. The sun being the centre of the enormous energy encourages and experimentally proven to be the best source of Photo-voltaic transformation directly into the electricity without proving a hazard to the environment [1], but the influence of dust and other pollutants on the performance of the solar PV panels has not been given much attention. Research and development in photovoltaic (PV) systems has usually been concentrated on metrological parameters, radiation availability, locations, efficient operating approach, design, size and optimal use of the generated power. The meteorological parameters such as humidity, dust, temperature, wind speed; etc has considerable effect on its efficiency [2]. The effects on the performance of the solar cell/panel/PV system because of the dust deposition is investigated in this paper, practically, electrical performances of Photo-voltaic panels are studied experimentally and found that the energy efficiency and power output of the PV panels, reduces significantly with the accumulation of dirt and dust.**

Index Terms— **Metrological parameters, Dust, performance of Solar PV panel, Effects of Dust.**

I. INTRODUCTION

Searching for an alternative of source of electricity generation is considerably consolidated by the renewable sources, especially the solar PV application. The sun provides an incredible resource for generating clean and sustainable electricity without venomous pollution or global warming emissions. The innovations relating to the efficient photovoltaic solar cells have come up with high efficiency and the demand side management of the use of energy, the efficient electrical appliances has further improved the possibilities of an excellent solution [3], but the high installation cost, in spite of reducing the market price has the subjective consideration which is further diminishing their adoptability because of the deposition of ill products of environmental hazards. The research and development activity in the field of solar system has mainly so far focused on the solar radiation analysis, efficient managing and operating strategies, designing and sizing of the system.

The PV cell manufacturing process includes hazardous materials to clean and purify the semiconductor surface, which includes hydrochloric acid, sulphuric acid, nitric acid, hydrogen fluoride, acetone etc. Though, there are no global warming emissions associated with generating electricity from solar energy, but the emissions associated with other stages of the solar life-cycle, including manufacturing, materials transportation, installation, maintenance, decommissioning and dismantling cannot be ignored and are ranging between 0.07 and 0.18 pounds of carbon dioxide equivalent per kilowatt-hour [5,6].

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The PV output is rated and given by the manufacturers under Standard Test Conditions (STC), i.e. temperature 25^{o}C; solar irradiance intensity 1000 W/m^{2}, and solar spectrum as by passing through 1.5 thickness of atmosphere but the adoptability stresses to analyze the effects of the active meteorological parameters such as humidity, dust, temperature, wind speed; etc on its performance. This paper investigates the effect of dust on PV system performance on three parameters: effect of dust properties, effect of PV system parameters and effects of environmental parameters.

II. EFFECTS OF DUST

Nowadays energy related aspects are paid much attention, the environmental relating impact and pollutants emission holds a worldwide interest, hence the analysis becomes more significant. The dust is lesser acknowledged but significantly influence the PV performance [7]. The PV performance is affected by the deposition of dust particles; this could be analyzed in two ways: dust accumulation, and dust pollutant.

III. DUST ACCUMULATION

The accumulation of the sand particles exponentially reduces the available area for the incident photons. The available free area on the glass slide decreases with increasing amounts of sand particles both before and after a gentle disturbance caused the sand structures to settle and the subsequent particles will not allow further incident photons to pear the cluster hence reducing the efficiency of the PV cell. This causes the evolution of the free surface area to deviate from the linear behaviour described by Al-Hasan [8].

The total area of particles deposited as a fraction of the total area of the slide is N, and is directly proportional to their mass. The free fractional area A is not simply (1-N) because particles overlap. This behaviour can be represented mathematically taking into account the probability that small particles lands on free surface area is (1-A), such that

$\frac{dA}{dN}$ = 1- A or A = 1 - e^{-N} ………….. (i)

Where

A = the total area,

N = the area of particles deposited as a function of the total area of the slide. This N is directly proportional to their mass,

F_1, F_2 = filling fractions,

α = the random close packing fraction tending to $\approx$ 0.8

The evolution of the layers is described as;

$\alpha \frac{dF_1}{dN}$ And $\alpha \frac{dF_2}{dN}$ …………….. (ii)

The total area is given by

$A = 1 - \alpha F_1 - (1 - \alpha) F_2$ ……………… (iii) with laboratory investigations of particle accumulation on a glass slide [9].

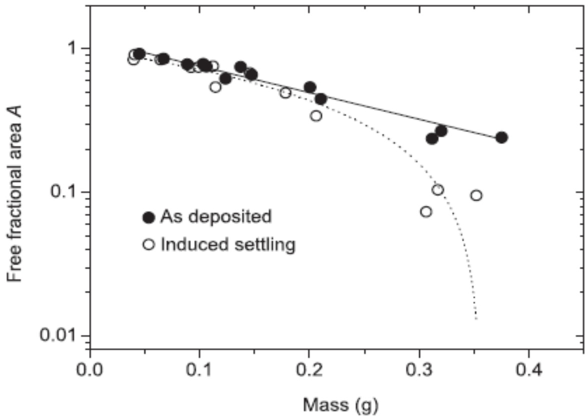

Fig.1 Reduction in the free fractional area of a glass slide with increasing quantities of sand,

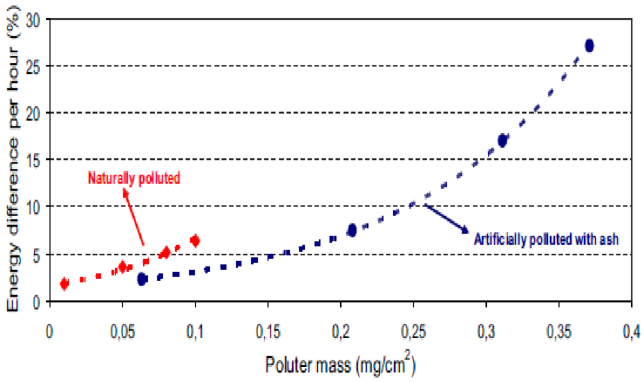

Fig.2 Clean and polluted PV panels Energy differences, normally and artificially both.

IV. DUST POLLUTANT

When the analysis carried over on the two identical pairs of panels, the first being cleaned and the second being artificially polluted with ash from thermal power stations and vehicular exhausts the air pollution causes a degradation of PV performance as a result of accumulation of solid particles varying in type, composition and shape. The performance of the clean and polluted panels varying between 2.3% and 27% as recorded with time period of one hour [10].

Table-1 Pollutant and PV output % reduction

S No	Pollutant		% η Reduction	PV Power Availability	
	Name	Deposition density		Cleaned	Polluted
1	Red soil	0.35g/m^2	7.5%	100%	92.5%
2	Lime stone	0.33g/m^2	4%	100%	96%
3	Fly ash	0.63 g/m^2	2.3%	100%	97.7%

It is observed that the red soil causing the PV panels to operate with lower performance in comparison of the Lime stone and fly-ash [11].

The hypothesis to validate the proposed theoretical model can be understood;

Let,

P_{out} = Power produced.

P_{Solar} = Incident solar power.

A_c = Collector surface.

The efficiency of the conversion will be

$$\eta = \frac{Pout}{Psolar} = \frac{Pout}{Ac \times GT}$$

$$= \frac{\text{Voltage Output} \times \text{Current drawn}}{\text{Collector surface} \times \text{Corresponding total solar Radiation}}$$

Let the total mass of deposition of the sand/dust particle on the surface of PV collector be Δm, the dust deposition ΔM is expressed in term of g/m^2, while the P V collector area is A_c,

$$\Delta M = \frac{\Delta m}{Ac} \ \text{g/m}^2$$

Here Pp is the peak power. The energy yield reduction in percentage between the clean and polluted PV panel surface can be determined, i.e.

$$\Delta CF = \frac{(CF_0 - CF)}{CF_0} \times 100$$

The experiment conducted and the electrical parameters measured [12], let

P_0 = the power output ($P_o = V_{sc} \times I_{sc} \times FF$) watts

V_{oc} = the voltage produced in volts

I_{sc} = the short circuit current in Amps,

FF = the fill factor,

A = the area of the solar panel in m^2,

I = the Intensity of the solar Radiation (W/m^2)

The Solar Panel Efficiency of the panel;

$$\eta = \frac{Vsc \times Isc \times FF}{A \times I} \times 100$$

Reduction in power in percentage

= ($P_{Clean} - P_{with\ dust}$) × 100 / P_{Clean}

Reduction in efficiency in percentage

= (η_{clean} - $\eta_{with\ dust}$) ×100/ η_{clean}

Table-2 Specifications for Crystalline Modules

S No	Particulars	Specifications
1	Maximum power, P_{max}	250W_p
2	Open circuit voltage	37.5V
3	Short circuit current	8.38A
4	Number of cells	10
5	Dimensions	950×425×35 mm^3
6	Weight	6 kg
7	Fill factor	0.85
8	Efficiency	>14%

V. PARAMETERS OF INVESTIGATION

The evaluation for the variation depending on the dust of electrical characteristics such as I-V and P-V curves, open-circuit voltage (V_{oc}), short-circuit current (I_{sc}), maximum output current (I_{max}), maximum output voltage (V_{max}), maximum power output (P_{max}) and fill factor (FF) carried out [13]. The variation in power output (P_{max}) is seen from 18 to 78%, I_{max} losses from 23 to 80% and fill factor from 2% to 17% respectively for the polycrystalline module (pc-Si) and mono-crystalline module (mc-si), but voltage output (V_{max}) and the open-circuit voltage (V_{oc}) are not affected by dust accumulation for both technologies [14].

I-V AND P-V CURVES

The current-voltage (I-V) curve of a PV module describes its energy conversion capability at the prevailing conditions of irradiance (light level) and temperature at site. Hence, the curve represents the combinations of current and voltage at which the module is operated or 'loaded', if the irradiance and cell temperature are constant. This curve witness the parameters like short circuit current (Isc) at Zero volt, similarly the open circuit voltage (V_{oc}) at Zero current. This curve also reflects the maximum power point (I_{mp}, V_{mp}), the point where the array will generate the maximum power.

SHORT CIRCUIT CURRENT (I_{sc})

The short-circuit current can be considered equivalent to the photocurrent I_{ph}, that is, proportional to the solar irradiance G (W/m^2) and is given by the expression,

$I_{sc} = I_{sc\,o} (G/G_o)^{\alpha}$

Where;

I_{sc} = the short circuit current of the PV module,

$I_{sc\,o}$ = the short circuit current of the module under standard solar irradiance (G_o),

G = Solar irradiance at the site,

G_o = Solar irradiance under standard condition and

α = the exponent responsible for non-linear effects that the photocurrent depends on.

OPEN CIRCUIT VOLTAGE (V_{oc})

It is the open circuit voltage under the standard solar irradiance and solar irradiance available at location of performing the experiment.

THE MAXIMUM POWER OUTPUT (P_{max})

It is the power output of the module, and can be given as;

$P_{max} = V_{oc}. I_{sc} .FF$

Where V_{oc} = the open circuit voltage, I_{sc} = the short circuit current and FF = the fill factor.

FILL FACTOR

It is an important performance indicator of the PV module, as it is the ratio so merely a number, and can be given as;

$FF = (V_{mp}.I_{mp}) / (V_{oc} . I_{sc})$.

FACTORS AFFECTING PV SYSTEM GENERATION

(a) PV Technology

The technology used for the production and the composition used as the material for production of PV cells plays an important role for their costing/price. There was a considerable improvement in both the parameters and a huge reduction in price with improved efficiency is obtained, and adoptability is acknowledged globally. PV modules are classified as silicon crystalline and thin film type. The types of silicon crystalline are mono-crystalline, polycrystalline; hybrid silicon, emitter wrap through cell and silicon crystalline investment while amorphous silicon, cadmium sulphide or telluride and copper indium disellenide or copper gallium are the types of thin film. It is experienced that a-Si performs best in dirt and dusty environment [15].

(b) Tilt angle

The tilt angle plays a leading role on the conversion efficiency of the PV panels. Different researchers experienced a decrease due to the dusty glass plate, the degree of solar transmittance is directly proportional to the tilt angle and this degradation depends upon the season, weather condition, temperature, humidity, deposition type, mass, size and their density. It is different at different places, conditions and type of pollution.

(c) Maximum Power Point Tracking

Though the efficiency of conversion of solar irradiation into electricity by the use of PV cell is yet to establish its landmark, but it is improved in recent era up to 21.8% and even more say up to 40.1% [ ].**Dr. Martin AUS**. The higher efficiency is appreciably supported by the use of Maximum Power Point Tracking (MPPT) system which enables the possibility of maximum solar irradiation at every instant. The MPPT operates with the DC to DC high efficiency convertor for optimal and suitable power output. The main function of the MPPT is to facilitate the working of the PV array on maximum power when the temperature and radiant intensity are changing [ ].

(d) Cleaning methods

Cleaned transparent surface plays an important role for the generated output of the PV module. Dust and dirt used to stick the surface of the panel and causes the shadow characteristics thus reducing the performance of the panel or module. Generally different methods of cleanings are adopted depending upon the accessibility and adoptability, namely natural, mechanical, electro-mechanical and electrostatic.

(e)Temperature

Generally the PV characteristics are supplied at the STC (Standard Test Conditions, temperature = 25ºC, solar irradiance (intensity) = 1000 W/m^2, and solar spectrum as filtered by passing through 1.5 thickness of atmosphere). The efficiency of PV cell usually decreases with high ambient temperature, the electric power generated from the cell decreases with the increase in temperature. The I_{SC} increases slightly with the increase in temperature. The investigations found that PV output power is affected by ambient temperature by approximately an increase of 6% A per °C for 1 cm^2 of cell and voltage decrease by 2.3 mV per °C per cell, simultaneously can be concluded that clean and cool PV Panel has optimum generated power and better efficiency [14]-[16].

(f) Humidity

The humidity itself decline the performance of the PV cells but if associated with dust particles than form a hard layer to restrict the solar irradiation on the solar PV glass surface to transform the energy conversion a difficult one and low efficiency phenomenon. In case of the solar radiation and humidity, it defers in refraction, reflection or diffraction and consequently the decline in the conversion efficiency of the PV panel. The hard layer of the dust restricts the penetration of the photons and simultaneously makes the cleaning difficult.

VI. CONCLUSION AND FUTURE SCOPE

This paper analyses the effect of dust on the performance and efficiency of PV panels. The evaluation based on the effects of dust properties, PV system parameters and environment parameters. Some points are deeply investigated and some are still needed more to investigate like size, geometry, electrostatic deposition behaviour, biological and electro-chemical properties of dust, optimization study, for various locations like geographical/climatic considering factor of optimal tilt angle, orientation for solar gain, wind patterns and geometrical structure of dust particles, deposition behaviour, electrostatic behaviour, aging degradation of the PV panels on their performance.

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