

Effect of Dust on Solar PV Modules Efficiency

Abstract : Effect of dust and shadow of Solar Photo Voltaic panels is a natural process. The present study on dust-assimilation on the surface of solar PV panels can reduce system out-put to 16-40% in a month investigation. This paper provides current status in studying such impact on PV system performance and identifies challenges to overcome the problem. An experimental framework as designed as changing seasonally to locate diagnostic solution in this regard. If the experiment be performed in long-term basis from local to regional atmospheric conditions then the study will envisage a new paradigm in science and technology.

Solar Electricity is generated from the sunlight. The process of converting solar light into electricity is known as photovoltaic process which is rather called direct current (DC). Edmund Becquerel, a French Scientist in 1839 discovered electricity due to photovoltaic effect but efficiency was low¹. The out-put of solar cell is proportional to the Sunlight intensity and other relevant meteorological parameters in order to permit optical design of future solar power plants. The application of solar energy has become wider; with the database of solar PV industry's collaboration and case studies are being carried out to include technical evaluation as well as revenue potentials to the host country like US\$ 37 billion in 2008². The additional advantage of Solar electricity is one of the promising renewable energy options as it is direct, non-polluting, having demand of zero land and zero water and

abundant availability in nature. Recently lots of MW scale projects throughout India are being carried out with option of commercialization of solar power. Internationally (Israel, Italy, Japan, Korea, Spain, even USA) a number of MW scale power plants have already been installed maintaining Kyoto Protocol. However, in India three-four such big scale projects are launched so far including roof-canals in Gujarat plants have been installed so far recognizing the urgency of the electricity access situation in rural areas. Solar PV systems have already become headway as floating system in water bodies of West Bengal in India. The present study on roof-top PV system in 'advanced materials Solar Photo Voltaic '(AMSPV) laboratory, School of Energy Studies, Jadavpur University is to quantify losses caused by measured amount of dust accumulation and be released on PV components. As a test case, Jhapandanga, a remote village under Burdwan District, Solar Home Light (SHL) was installed by J.U. because the maximum population of the area does not have access to grid electricity to home, shop and school etc. Herein, the sunlight falls directly in summer and transversely in winter. For receiving maximum solar energy in India solar panels were tilted by 23.5° (Sun's inclination angle with respect to ground surface). West Bengal on an average receives around 4.82 – 5.43 kwh/m² (avg.) of solar irradiation out of which around 47.3% of the energy³ is received at frequencies from visible range (0.38 < λ < 0.78 mm.).

Some Salient Features : According to Hottle and Woertz⁴ were amongst the pioneers, investigating impact of dust on solar systems. They recorded maximum degradation in collector performance of 4.7% with an average loss in incident solar radiation being less than 1 per cent.

Furthermore, the study also indicated that influence of dust on PV performance would be higher in spring and summer than in autumn and winter in our hot and humid region. This experiment was conducted to investigate the effect of airborne dust concentration on the drop of PV cell performance caused by dust accumulation.

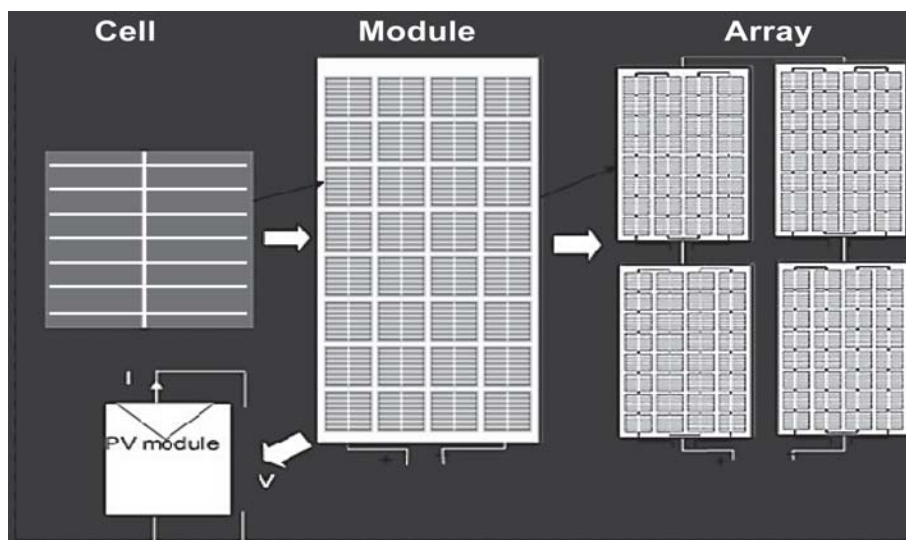


Fig.1: Solar Cell to module to array configuration

Therefore, the present study is alienated at Jadavpur University campus. The result must be independent, self-reliance, new paradigm but completely indifferent model is obtained.

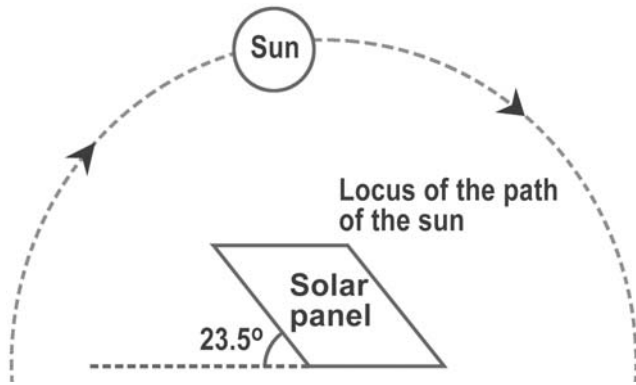


Fig.2: Sun- Earth Geometry

Owing to the Sun-earth geometry, the solar panel was kept (Fig.2) inclined at an angle 23.5° horizontal. The length of the panel was aligned along the north-south direction.

The simplest solar cell equivalent model (Fig.3) consists of diode and current source connected in parallel source current is directly proportional to the solar radiation. Diode represents PN junction of a solar cell which represents the ideal solar cell model. The current equation for a solar cell is given by the following equation [3].

$$I = I_{ph} - I_s [(e V) / (m VT)] - I \quad \dots (3)$$

Where, I_{ph} = Photo current, I_s = reverse saturation current, V = diode voltage in volt; m = diode ideality factor ($m= 1$ for ideal diode)

Experimental Setup : Photovoltaic module arrays already shows in Fig.1. It goes for field power generation, its power output drops and efficiency falls down. In the present study, analyze the effect of various environmental

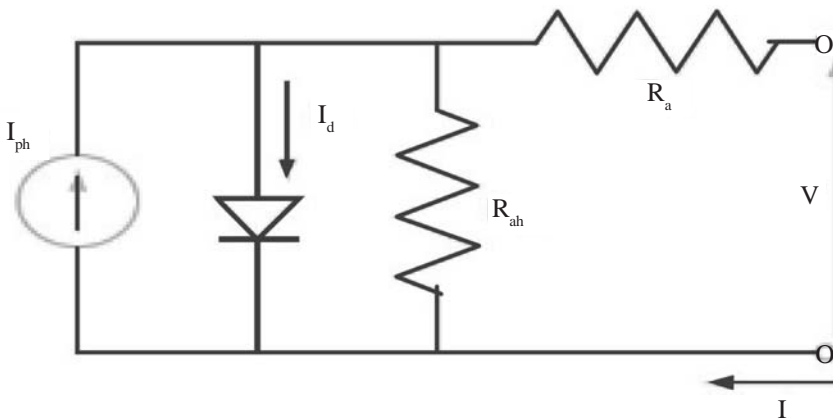


Fig.3: Solar Cell Equivalent Circuit

factors such as Temperature, Irradiance, Tilt angle of Solar plate, amount of average Solar radiation of the area, weather condition, amount of dust particle present into air, dust deposition rate , dust quality, size of dust particle, type of dust deposited on solar plate into air. Here, experimental results compare to the numerical modeling of solar cell which is performed in MATLAB SIMULINK approach.

Three types, here is used for measurement process under the present studies:

- 1st setup: Performance analysis of the solar cell at different sun irradiance and temps.
- 2nd setup: Performance analysis of solar module at different rate of dust deposition.
- 3rd setup: Measurement the amount of solar radiation is absorbed due day to day dust deposition on glass plate and correlates the data with effect to solar panel power output.

Methodologies : First experiment : The analysis about effect of Irradiation, Temperature and Humidity are measured by the 1st set-up. In this experiment, the aim is to determine the dependency of solar cell output with the parameters. A closed box is taken to put the cell inside the box and a digital meter senses and records inside temperature and humidity, By using metal wire mess filter and controlled irradiance, intensity flashing for a long time, increased temperature and flowing water vapor inside the box via a channel so that the humidity is increased (Fig. 4) solar cell by a computer software (ICS). Thus, calculation for maximum voltage, maximum current, maximum power series and shunt resistance, efficiency for various operating condition have been performed.

Second experiment : Equal amount of dust distribution on the solar panel surface, and with the help of Solar power meter observed same intensity falling onto the surface and with the help of thermocouple recorded same temperature exist in module no 5 and 6 as well as orientation of the panel was being due to same solar irradiance falling on them.

The I~V characteristic of the Photovoltaic panel was first determined under clean surface condition at different solar intensities. A variable load Resistor is used for this purpose. Second part of

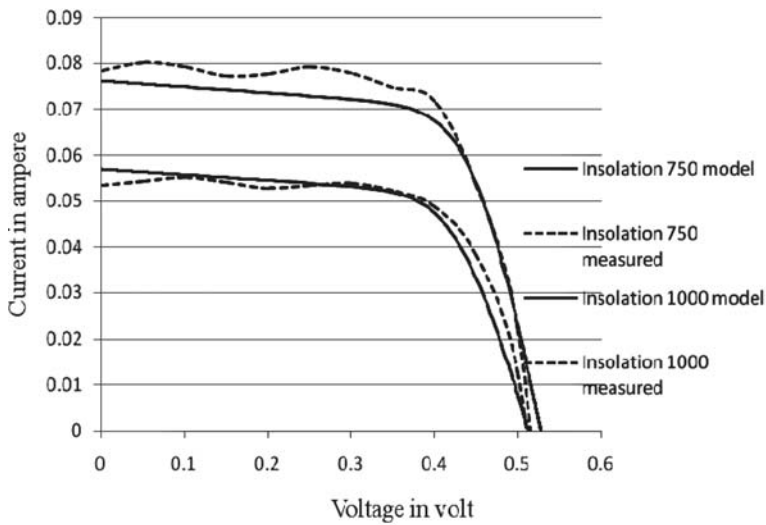


Fig. 4: V-I characteristics with change in insolation

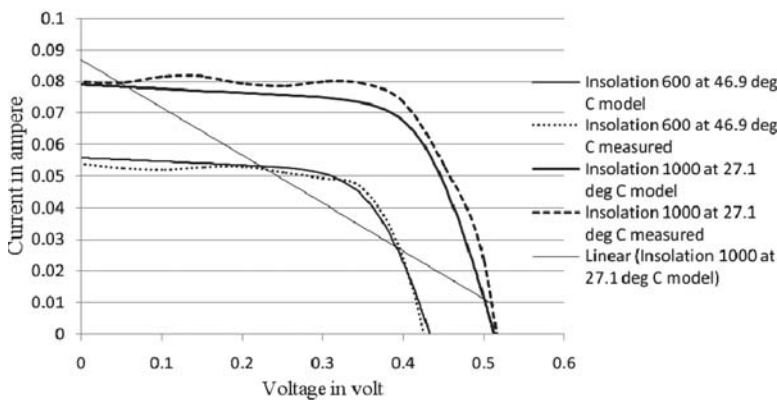


Fig. 5: V-I characteristics at various insolation and temperature

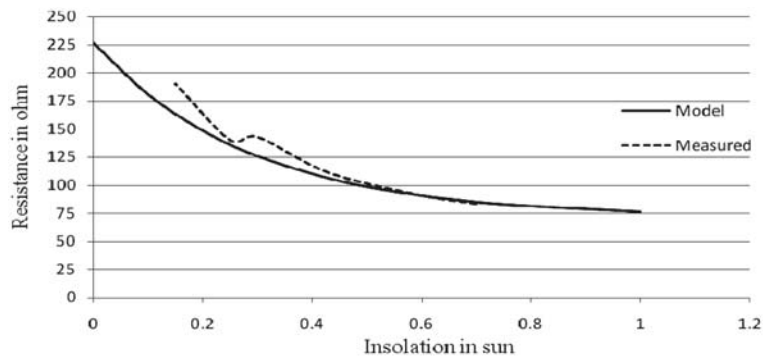


Fig. 6: Variation of shunt resistance with insolation

the experiment was then, carried out when the characteristics of the solar panel was being contaminated with natural dust varying different deposition densities (gm/m^2). The procedure followed thus: Two identical Solar Modules used here for calculating effect of natural dust of thrust areas. Each module produces 35 W p powers at standard test condition ($1000 \text{ Watt}/\text{m}^2$, 25 deg temp., 1.5 gm. air mass). Collecting very fine dust from one module

surface, taken the weight of dust while other kept clean for the period and further calculated efficiency degradation due to dust deposition onto the surface by comparing the two modules output.

Third experiment: Taken first, one glass plate about 81m^2 , cleaned and dried it by drier then taken the weight of clean and dry glass, recorded data, then to see how much solar intensity was passing through the glass plate. Next spreading natural dust, on solar surface module and observe, how the intensity was absorbed or reflected by dust particle. Putting it on the way of same intensity and measured by Surya Mapi to show degree of degradation due to day to day dust deposition.

The similar performance was done by applying artificial dusts on a layer of plastic sheet, prior to placing the set onto the Solar PV panels.

Result and Discussion : Environmental effect on various parameters : The interdependence of various environmental conditions of which solar cell parameters were computed and compared. The relations were critical, not simplistic and independent in nature as shown in details (Fig. 8 to Fig.13).

i) Short circuit current : The short circuit current of PV cell is directly proportional to solar irradiance G (W/m^2). But in actual case, found the factor, that influences not the current but the temperature also changes. To take this dependence into account, modify the previous relationship by considering equation (1) below as temperature effect.

$$\text{Therefore, } \alpha = \left(\frac{c}{c_{ref}} \right)^\alpha \left[I_{Sc_{ref}} + \mu (T - T_{ref}) \right] \quad (1)$$

Where μ = variation of I_{sc} with temperature = 0.0007.

α = variation of I_{sc} with irradiance = 1 (Fig. 4).

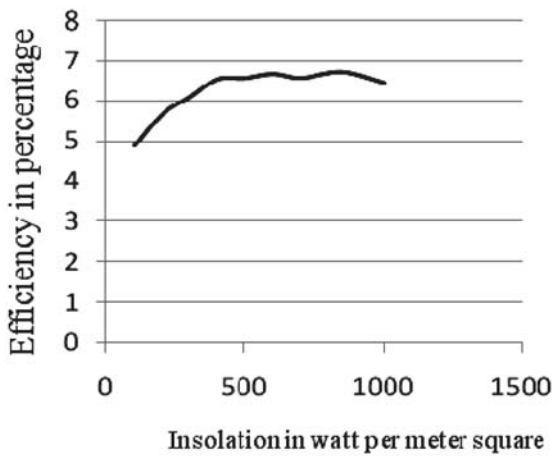


Fig. 7: PV cell efficiency with change in insolation

ii) *Open circuit voltage*

Suppose that open circuit voltage varies with temperature and insolation. Thus, it envisages that average Beta value is around 0.084 and Gama value 2 which holds satisfactory results for solar cell modeling. According to junction theory⁵, Gamma should lie between 1 and 2 ($1 \leq \gamma \leq 2$) which corresponds to ‘Tandem Technologies’ will lie between 2 and 4 and of triple junctions this Gamma (γ) will lie between 3 and 6. Thus, the value of Gamma at a given temperature appears from this model not at all sensitive. On the contrary, it significantly influences the temperature behaviour of the model.

ii) **Shunt resistance** : The characteristics of PV cell found in Fig.6 that shunt resistance changed with insolation level. Thus, this variation of resistance can be formulated by exponential relationship with insolation as shown in equation (2).

$$R_{sh} = R_{shref} + [R_{sho} - R_{shref}] e^{\left(-3.5 \cdot \left(\frac{G}{G_{ref}}\right)\right)} \quad (2)$$

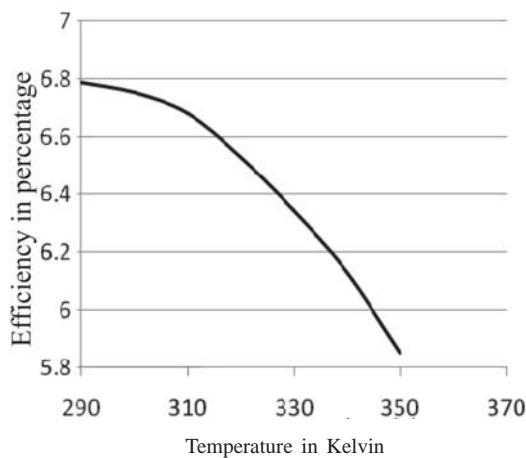


Fig. 8: PV cell efficiency with change in insolation

iii) **Series resistance** : The change in series resistance mainly depends on temperature of solar cell. But the present study includes that series resistance lays $0.8 \leq 0.7$ ohm. (Fig.8). In a specific case average value of resistance (0.75) with Gama value 2 gives satisfactory results.

iv) **Efficiency(η)** : The change in efficiency depends upon both the solar irradiance and temperature, Efficiency decreases with decreasing solar intensity, here the result reveals efficiency of solar cell in one sun intensity is about 7% and in 0.2 sun intensity is 5%.

Further, efficiency decreases with increasing temperature as V_{oc} fall due to temperature increases and the result predicts that efficiency rather decreases between 290 and 390 Kelvin temp. by 6.8% and 5.8% respectively.

v) **Fill factor (FF)** : Higher fill factor corresponds to series resistance as small as possible, and the shunt resistance will be as high as possible. As series resistance depends upon temperature, FF also changes correspondingly while temperature increases provided FF decreases (Fig. 9 and Fig. 10).

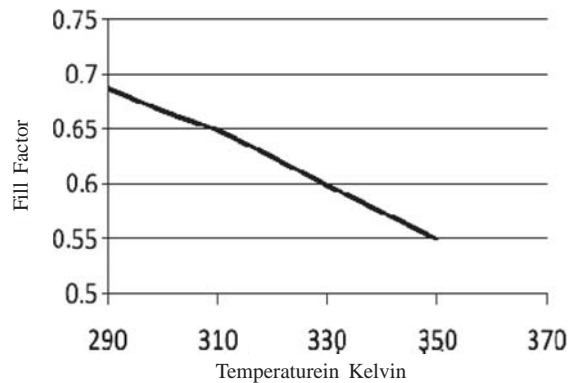


Fig. 9: PV cell variation of Form Factor with change in insolation

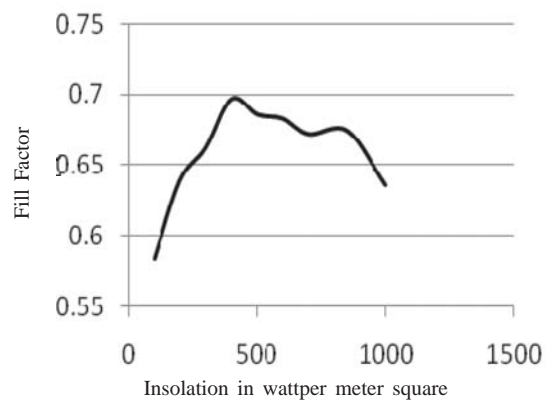


Fig. 10: PV cell Form Factor variation with change in insolation

Here, it reveals that shunt resistance goes change with insolation, obviously FF changes.

- **Effect of dust on various parameter :** The two photovoltaic modules have identical V-I characteristics, confirmed when their surfaces were clean, same irradiance were falling upon those two module surfaces. The performance of two modules was tested simultaneously for calculating the effect of dust upon the panels as output.

- **Effect of dust on solar panel I-V Characteristics:** It is shown below how Solar panel V - I curves (Fig. 14 to 16) fall down by varying different amount of dust, reveal maximum power goes degraded by dust deposition.

- **Effect on generation of maximum power of solar panel by dust deposition :** The power output of solar panel and the effect of 2 gm, 4 gm, 6 gm dust deposition are shown (Fig. 14 – Fig.16) which accounts for qualitative behavior of power losses during the day. Hence, Power is to be calculated by assuming the formula:-

$$P=V*I \text{ that includes}$$

Power degradation by 2 gram dust accumulation on solar panel surface: 16.26%;

Power degradation by 4 gram dust accumulation on solar panel surface: 28.85%;

Power degradation by 6 gram dust accumulation on solar panel surface: 39.98%.

- **Efficiency loss for dust deposition on solar PV panel surface :** The loss of conversion efficiency can be calculated using the formula:

$$\eta_{\text{loss}} = 1 - P_d / P_{n d}$$

Where P_d = maximum power output of photovoltaic panel with dust accumulation and

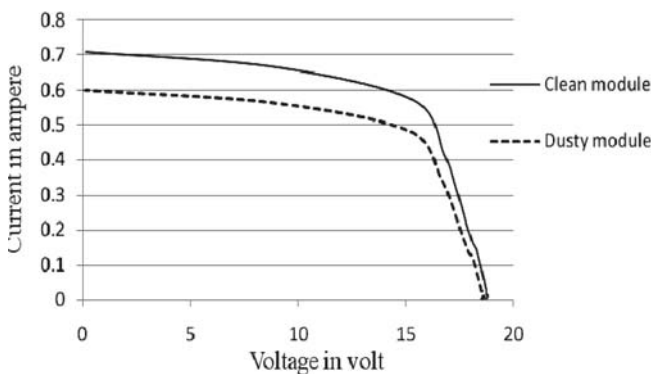


Fig. 11: V-I characteristics of PV module for 2 gm. Dust deposition

$P_{n d}$ = maximum power output with no dust accumulation on the panel;

In the experiment, loss of energy conversion efficiency for 2 gm, 4 gm, 6 gm dust accumulation observed 16.2%, 29%, 40.1% respectively. The similar study was performed using artificial mud dust under a constant irradiance conducted in a village home-let at Jhapandanga which locates between residential surrounded by open fields with shrubs and trees. Dust has an effect on the performance of solar PV panel. The reduction in the peak power generated can be found up to 18% both in summer in the case of village home-let and the roof-top of the university lab. Hence, presence of dust wherever be the location, must be removed from solar PV panel surface in order to ensure the highest performance, given the fact that is still costly form of energy source.

- **Degradation of solar panel power output by day to day dust deposition :** On the very first day study on glass plate where dust was accumulated cleaned properly and dried. Weight of glass plate was taken into account for 64.2762 gm; area of the glass is 81cm².

- **Effect of dust on solar irradiance :** Solar intensity gets absorbed and reflected by accumulation of natural dust to the photovoltaic p-n junction module reduces strongly the energy received. The influence of wind speed or its direction is not considered for probably loss, because high relative humidity contributes to the adherence of dust particles on the module surface. Thus, Solar irradiance is degraded to 23.59% by 15 days dust deposition.

Similar test on 3rd and 4th, 10th and 11th day irradiance include high because of high wind speed which corresponds to dust flown (Fig. 16) then gradual degradation occur.

- **Effect of dust on solar panel short circuit current :** Solar irradiance gets degraded day to day dust deposition, as short circuit current (I_{sc}) is proportional to solar irradiance which affects to dust deposition on panel surface.

Short circuit current (I_{sc}) degraded by 15 days of dust deposition: 23.68% (Fig.17).

Effect on power by dust deposition on solar panel surface:

As power is the algebraic multiplication of current and voltage, then current corresponds to change by dust deposition obviously power is affected by the dust deposition.

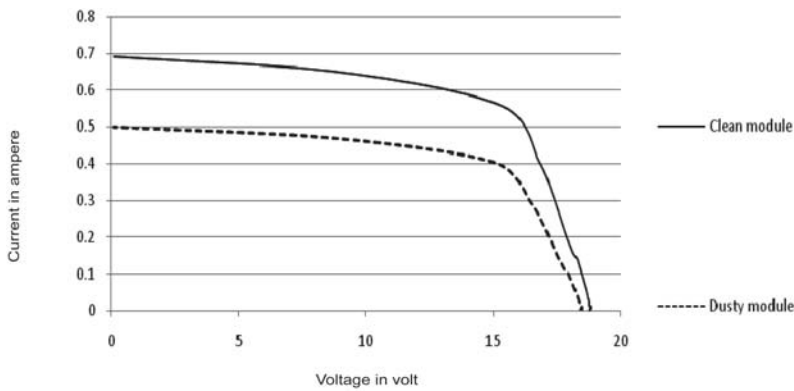


Fig. 12: V-I characteristics of PV module for 4 gm. Dust deposition

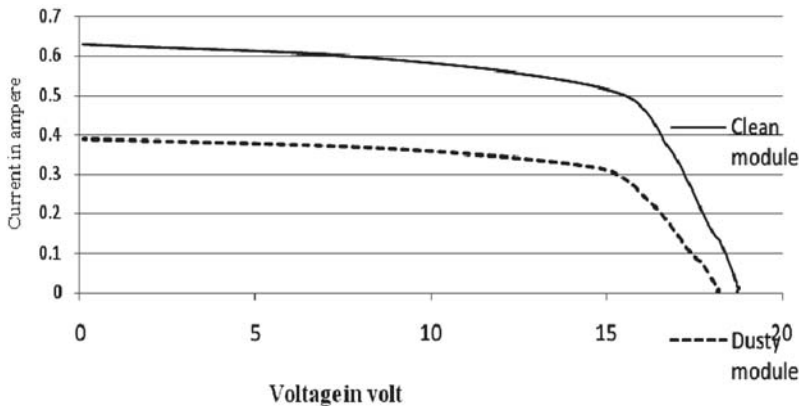


Fig. 13: V-I characteristics of PV module for 6 gm. Dust deposition

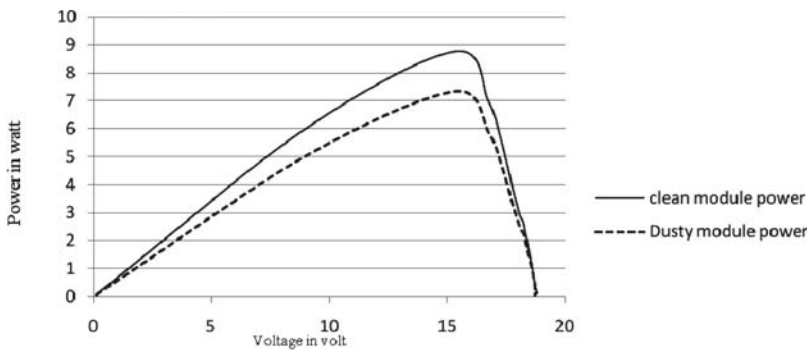


Fig. 14: Variation of power due to 2 gm. Dust deposition

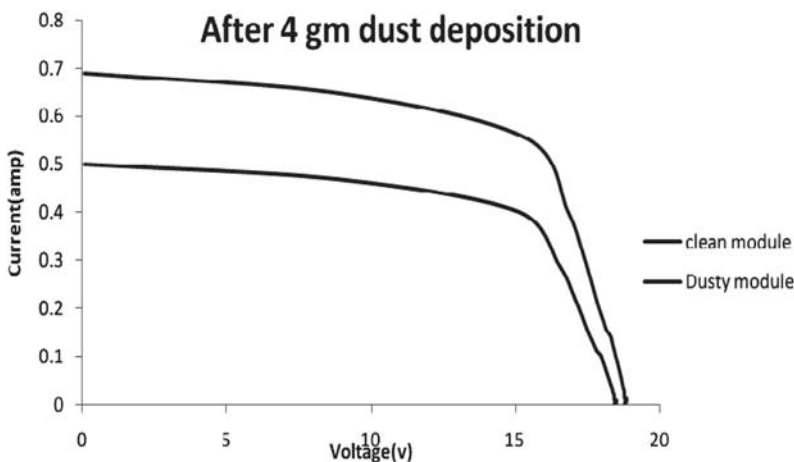


Fig. 15: Variation of Power due to 4 gm. dust deposition

Solar panel output power gets degraded by 15 days dust deposition is 24.01%. We further observed within 28 days about 6.4 gm dust was being deposited on a panel surface having area 2592 cm² while that of power degradation was ~40%. Thus, comparing those two sets of result, it reveals that power degradation will be more or less same. Based on these results a considerable reduction of PVs energy performance strongly depends on the dust composition.

Possible Solutions : The adaptation of self-cleaning technology is an efficient solution to minimize power loss which can't be any happy way to force into practice. The self-cleaning technology involves applying of a transparent, electrically sensitive material deposited on glassed or transparent plastic sheet covering the panels. Sensors monitor⁶ dust levels on the surface of panel and energize the material when dust concentration reaches a critical level. The electric charge sends a dust repelling wave cascading over the surface of the material, lifting away the dust and transporting it off the screen's edges within two minutes, process removes about 90 per cent of the dust deposited on the solar panels⁷. Release of any toxic materials from solid state inverters is also unlikely provided appropriate electrical and installation requirements are formed¹⁰. A comparison of these results with those obtained in this noted region with an annual average rain fall of 100 mm. suggests that rainfall may play an important role in atmospheric washing and relatively more particles are deposited in sites of lighter rainfall¹¹.

Conclusions : India is blessed with an abundance of sunlight⁸ at least 300 sunny days in a year. The solar cell I-V characteristic is non linear nature due to its diode property (Fig. 7 and Fig. 8). The simulation represents this COSMOL Multi-physics show the fact, when a cell is converted by a deposition its internal temp. rises and thus it leads to the occurrence of losses. Thus, the present studies of the

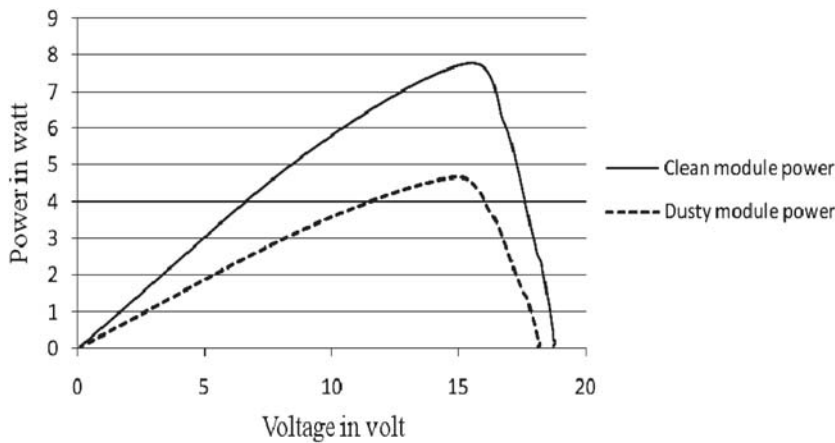


Fig. 16: Variation of power due to 6 gm. Dust deposition

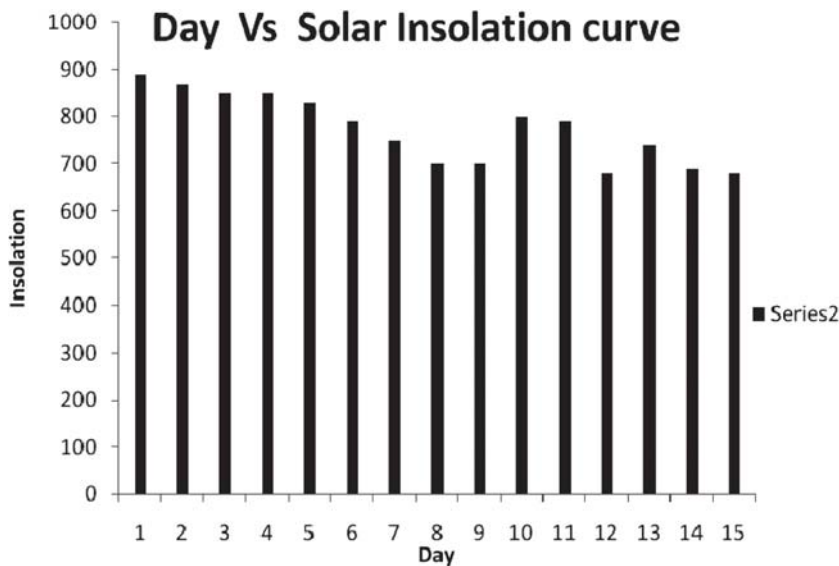


Fig. 17: Day-wise dust accumulation -Vs- Solar insolation

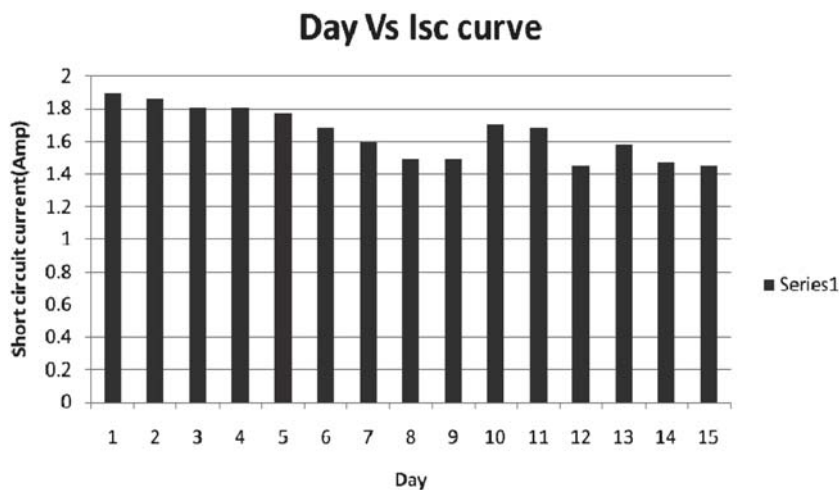


Fig. 18: Day-wise dust accumulation -Vs- Short circuit current

behavior of PV Cells are covered by impurities show that situations should be avoided as much as possible, inevitable losses occur in the system. Sometimes the losses can represent half or even more of energy that should be produced by the system operating in normal conditions.

The photovoltaic panels are thus; affected by the deposits, behave especially in locations where such phenomenon is impossible. Besides automatic cleaning of modules with specialized devices, covering them with layers that can reject dust particles seems more effective and a hand solution until now.

Appropriate installation design (orientation, exposure, Sun-tracers) maximizes solar insolation potentially ensure sustained yield. However, question of vulnerability, often overlooks, on site omnipresent of dust deposition, bird dropping and water-salts can significantly degrade the efficiency of solar thermal installations.. Current research into characterizing deposition of dust and their impact on PV system performance is limited owing to the fact that dust deposition is a complex phenomenon and is influenced by diverse site specific environmental and weather conditions.

Here, the single diode equation model with shunt resistance exponential behavior with insolation, series resistance and gamma as a combination selection of the circuit shows for determining maximum power point of photovoltaic panel. The maximum power gain speaks the load at which panel outputs its maximum power.

Now, I_{SC} of clean panel reveals greater than I_{SC} of dust panel (Fig. 9) when the sun intensity is lower at 8 a.m. to 9 a.m. while large amount decrement of I_{SC} occurs round about 40 %. Even at midday such decrement is around 20%. This model thus validates on the basis of present studies conducted in urban environment. The problem of dry deposition by means of Sensor's electric

Day Vs Power curve

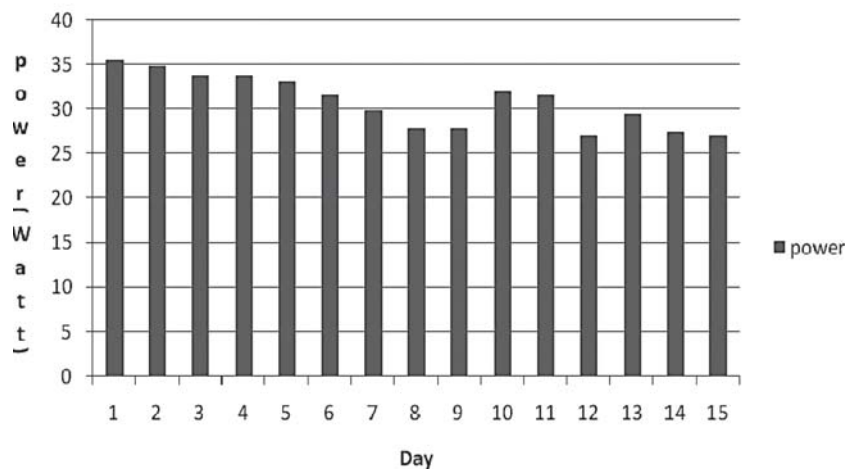


Fig. 19: Day-wise dust deposition –Vs– Effect open Power

fields which protect surfaces from airborne dust, clean them. The method is used for cleaning large collector areas. We are now addressing the problem of preventing dust from gathering on wetted surfaces under condition of high relative humidity.¹²

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