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Environmental Effect on Performance of Solar Cell

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ABSTRACT: Solar power is future of our planet due to the depletion of non-renewable sources of energy. The renewable sources of energy are responsible for 80% of world's power and we all are directly dependent on non-renewable source which will only last for 1 or 2 decades. Due to increase in power demands new development in renewable sources of energy are going on due to which on commercial level solar cell achieved an efficiency of 15-20% and improving day by day. Some factors affects the performance of solar cell and decreases its output while some factors improves the efficiency of solar cell and improves its performance. These factors includes temperature of solar cell, humidity, and wind velocity, light intensity, altitude and air pressure along with many other factors.

The world is at the verge of depletion of non-renewable energy sources, 80% power is supplied by oil, coal and gases while only 20% is supplied by renewable sources of energy which includes solar power, wind power, hydro power, and many more. The non-renewable sources are biggest contributor of environmental pollution. In all renewable sources of energy solar power is fastest growing source of energy. With the development of new methods and technologies efficiency of solar cell is improved in past years and cost of manufacturing is also improved. Despite all the development many environmental factors affects the performance of solar cell, these includes temperature, humidity, wind velocity, light intensity, altitude and air pressure. Some of these improves the performance of solar cell and some factors deteriorates the performance of solar cell.

KEYWORDS: solar cell, power, performance, humidity, light, wind, altitude, hydro, temperature, air, factors

I. INTRODUCTION

The use of conventional sources of energy like wood, coal etc pollutes the environment and give rise to global warming. Sun is a renewable source of energy and is safe for the environment. Solar energy is one of the popular and efficient source of energy. It is obtained from the sun by collecting and converting the solar radiations into electrical energy. Solar energy is being utilized in several sectors like engineering, irrigation, medical etc and raising the overall efficiency of power generation. About 4-7kWh/m² and 5x10¹⁵kWh/m solar energy falls in India in a day and in a year respectively. About 3.6x10²⁴ Joules/year total radiations are received by earth and environment. A solar cell is the smallest component in solar cells that changes the radiated solar energy into electrical energy. These solar cells are installed in an open atmosphere and subjected to the environment directly. This direct contact of solar cells towards the environment develop certain defects in solar photo-voltaic cells. These defects are degradation, discoloration of solar cells, depositions effects like bird deposition, dirt and dust deposits on cell surface, shading effects, fault in solar cell components etc. Inspection of solar cells improves the health condition as well as the overall performance of solar cell and improve power generation. Thermographical techniques give best results for performance analysis of environmental conditions in terms of temperature analysis using thermal imaging camera.[1]

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A Worker inspects solar cells at a solar Dunhuang, 950km (590 miles) northwest of Lanzhou, Gansu Province September 16, 2013. China is pumping investment into wind power, which is more cost-competitive than solar energy and partly able to compete with coal and gas. China is the world's biggest producer of CO2 emissions, but is also the world's leading generator of renewable electricity. Environmental issues will be under the spotlight during a working group of the Intergovernmental Cell on Climate Change, which will meet in Stockholm from September 23-26. REUTERS/Carlos Barria (CHINA - Tags: ENERGY BUSINESS ENVIRONMENT) - RTX13UEF

Solar cell is the basic element in solar photo-voltaic cell. When solar radiations fall on a solar cell, it absorbs the solar radiations and convert the absorbed solar radiations into the electrical energy. The figure 1 shows the equivalent circuit diagram of a solar cell.

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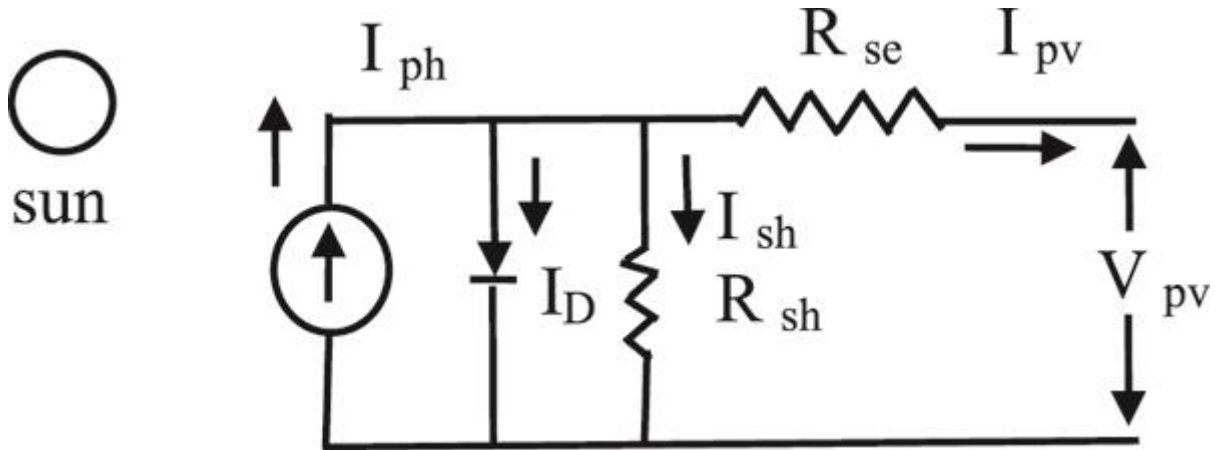


Figure 1: Equivalent circuit diagram of a solar cell

The output current I_{pv} of a solar cell can be written as:

Where, V_{pv} is output voltage of photo-voltaic cell, I_{ph} is photo-voltaic generated current/ photon current/ Insolation current/ current produced by Incident light, I_0 is diode reverse saturation current/ leakage current of diode, I_D is diode current/ Shockley diode equation, V_D is voltage drop across diode, R_{se} is series resistance, R_{sh} is shunt resistance, V_T is thermal voltage and is equal to (KT/q) , K is Boltzmann constant, T is cell's operating temperature in kelvin, q is charge of an electron, η is Ideality factor of diode/ cell quality factor. The solar cells may be different types depending upon the photo-voltaic technologies used. These photo-voltaic technologies may be divided into the two types namely Crystalline silicon type and Thin film type. The Crystalline Silicon PV cells can be Mono-Crystalline and Poly-Crystalline PV Cells. Thin film PV cell consists of Cd Te (Cadmium Telluride), CIGS (Copper Indium Gallium Selenide), and a-Si (Amorphous Silicon). The fig. 2 shows a complete diagram of 72 cell Mono crystalline solar photo-voltaic module.[2]

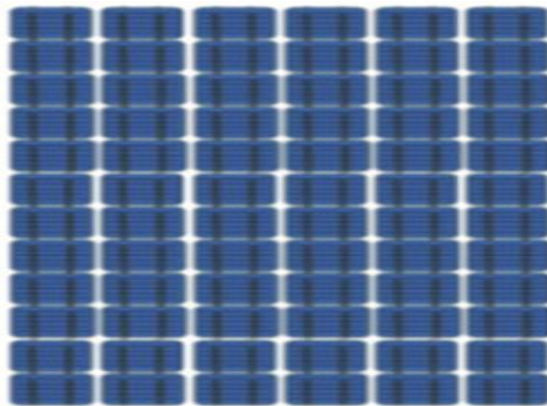


Figure 2: Monocrystalline solar photo-voltaic module

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Method of Thermography

Infrared radiations were first discovered in 1800 by Frederick William Herschel, a German Astronomer. A thermal camera can detect the energy emitted as heat from any object, whose temperature is above absolute zero (-273°C). Thermography is a technique of converting infrared radiations into thermal images known as thermogram. It uses a thermal camera which captures thermal images without making a physical contact to the object. These thermal images known as thermograms, are the colourful patterns of the object representing the temperature.

II. DISCUSSION

Table 1: Visually identified environmental defects in solar panels

Components of solar panel	Defects in solar panel	Possible reasons	Effect of defects
Frame	Corrosion of frame and interconnect, deframing	Subject to open atmospheric effects(moisture, dust, detachment of sealing and adhesive between frame and panel parts.	Risk electric shock, reduced expected life
Glass surface	Cracking of transparent glass, soil deposition on panel glass surface	Mishandling, lack in maintenance, dusty and soily environment	Degradation of ARC (discoloration, delamination), corrosion of cells, possibility of electric shock, reduced power generation
EVA encapsulant	Yellowing	Degradation of adhesive material between glass and cell due to high temperature, UV and water exposure	Change in transmittance of light falling on solar cell cause reduction in power generation
Solar cells and bus bars	Discoloration (blue from purple), burn marks in bus bars	Poor EVA quality, high temperature, oxidation of ARC, heating of module parts to show burn mark	Reduction in energy generation due to less absorption of solar irradiance by discolored cell, discolor encapsulant by burn marks
Backsheet of solar module surface	Bubbles, rupture, chalking of back sheet	Release heat dissipation of cells from back surface at high temp., transportation or heating due to temp., due to thermal degradation and poor quality material of back sheet	Reduce life of cell, formation of hotspots, reduce performance of heated portion, less reduction in generated power, moister and risk of electrical shock
Junction box	Corrosion	Moisture due to loose sealing contact	Reduce life of junction box components

Table terms: ARC (Anti-reflective coating), EVA (Ethylene vinyl acetate)

The experimental work performed to study the condition of solar cells in practical environmental conditions include two sections. First Section was to identify the environmental defects in solar cells using visual inspection i.e., the defects clearly visible by naked eye. The visual inspection involve physical identification of the environmental defects and capturing the normal camera photographs. The Second Section involves effect of shading of tree on solar cells power generation using a thermal imaging camera. Electrical measurements for power generation under no shade and under shade of tree are also done.[3]

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1. Visual Identification of Environmental Defects in Solar Cells

The visually inspected defects in solar cells are shown from fig. 3(a) to fig. 3(b). Fig. 10(b).



Figure 3(a): Corrosion on the interconnecting joints of solar modules



Figure 3(b): Deframing of solar module

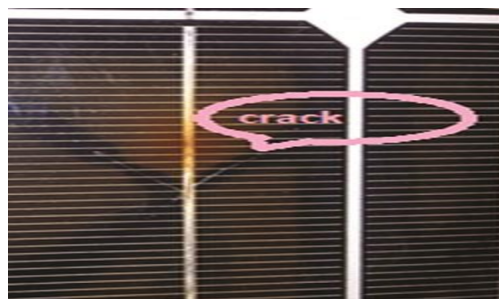


Figure 4(a): Crack on a small part of glass surface

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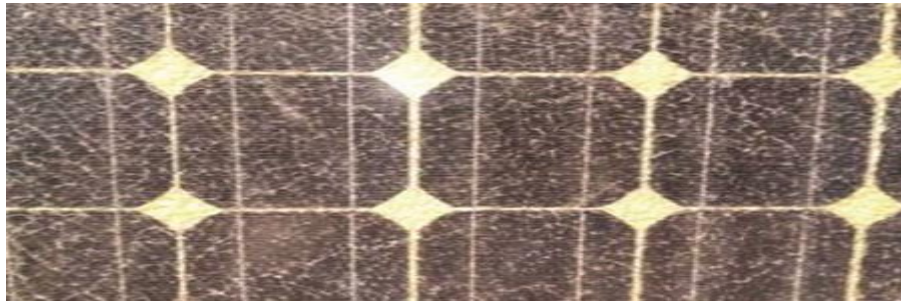


Figure 4(b): Cracking of the complete glass

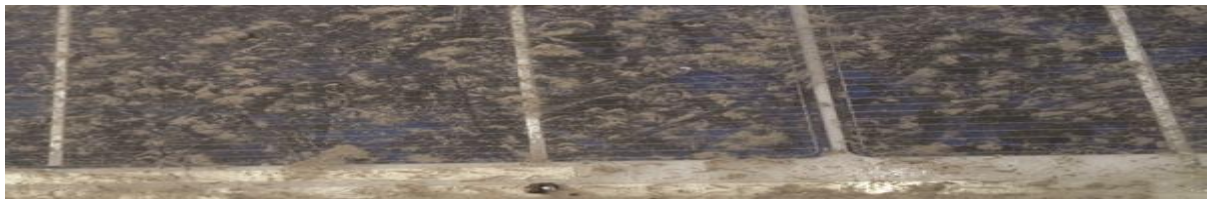


Figure 4(c): Soil deposition on the solar module surface

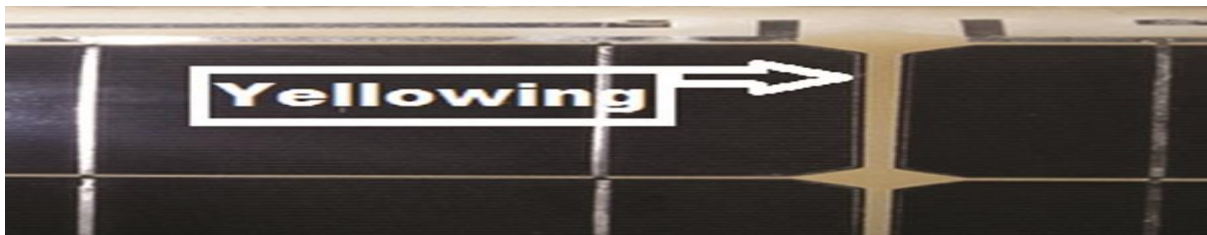


Figure 5: Yellowing of solar cell surface

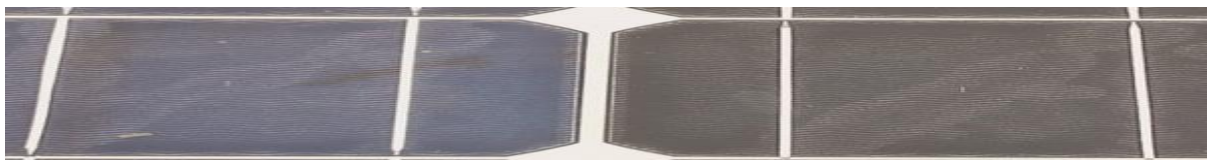


Figure 6: Discoloration of solar cell

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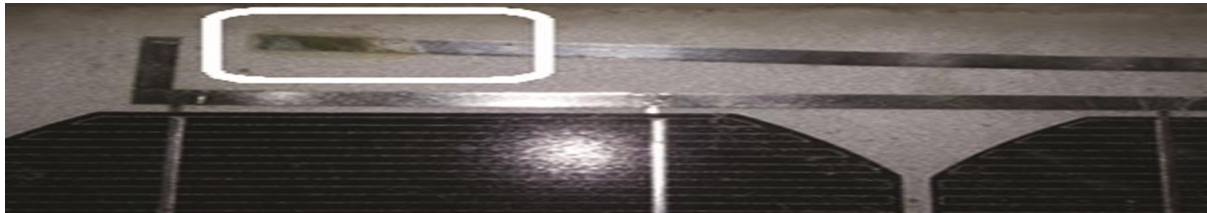


Figure 7: Burn marks on the bus bars



Figure 8(a): Bubbles on the back sheet of solar module surface

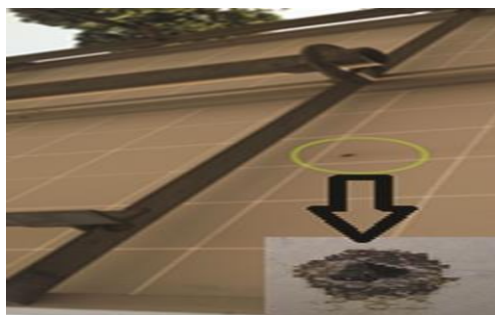


Figure 8(b): Rupture on the back of solar module surface



Figure 9: Chalking at back surface of unlaminated solar cell

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Figure 10(a): Corrosion in junction box



Figure 10(b): Moisture over the cover of junction box

The Fig 3(a) shows the corrosion on the joints used for connecting one solar module to another. Fig 3(b) shows deframing of solar cell frame. Deframing can occur due to ageing effect when solar cells are exposed to open atmospheric conditions. Cracks of glass surface can affect the solar cell as well as bus bars. The glass surface defects are shown in the fig 4(a) and fig 4(b). The effect of a small crack at glass surface on solar cell can be seen in fig 4(a). The fig 4(b) shows the cracking of the complete glass surface. The soil deposition on solar cell surface can also be visualized easily. The fig 4(c) represents a heavy soil deposits on the solar module surface. Yellowing is a common problem in solar cells. The Fig 5 shows yellowing of the cells due to the degradation of EVA (ethylene vinyl acetate).[4]

The discoloration of solar cell is also one of the mostly occurred problem in solar cells. It is basically due to high temperature and oxidation of ARC (anti-reflective coating). The color of the solar cell changes from purple to blue. The change in color of solar cell allows to fall less amount of solar irradiance on solar cell, as a result less amount of energy is generated. Fig 6 shows the discoloration of the solar cell. The color of the left solar cell became less blue than the right solar cell which is dark blue.

When the temperature of a particular part becomes very high, then the hot area produce burn marks. Such burn marks on the bus bars can be seen in fig 7. It can affect the life of encapsulant if neglected or even not treated with a proper care.

There may be visual defects at the back sheet of solar modules. As the module back sheet allows to dissipate the heat of the solar cells, there may be a possibility of the emergence of bubbles. It occurs when some gases are released during the chemical reaction of encapsulant and creating an air chamber. The temperature of cell above the bubble becomes high because of less dissipation of heat. Rupture is another defect exists in back sheet of solar module surface. It can be due to high temperature, mishandling of modules during transportation. Both bubbles as well as rupture affect the generation of power by a small amount. Fig 8(a) shows two bubbles on the back sheet of solar module surface and fig 8(b) shows a rupture on the back of solar module surface.

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Generally, the back sheet of solar cells are laminated to get good finish, durability and safety against any other degradation defects. When the quality of back sheet material is poor or the back surface is rough, deposition of chalking is observed. Chalking is a white powder at the back sheet of solar cells commonly occurs due to thermal degradation or poor quality materials used at the back sheet of solar cells. It fails back sheet insulation and cause electrical shock also. The fig 9 shows two solar cells with un laminated and laminated back surface along with chalking observed from un laminated back surface. There may be corrosion in the junction box, situated at the back surface of solar module. The main reason of the corrosion of the junction box is the moisture. If the closing cover of the junction box is not fixed tightly then there are chances of corrosion. Fig 10(a) and fig 10(b) shows the photograph of the corrosion present in the junction box components and moisture on the outer cover of junction box. The corrosion may lead to reduce the life of the junction box components.[5]

Effect of Shading on Solar Cells using Thermal Imaging Camera

Shading of tree, bird deposits, cement deposits, soiling are some of the environmental factors which cause reduction in power generation from solar cells in heat form. The heating of solar cells due to shade is not be visualized by naked human eye and can damage the affected area. Therefore, thermographical techniques are like thermography is used.

Effect of shading of tree: When shade of tree falls on solar cells, the solar cells under shade attain less solar irradiance as compared to unshaded solar cells therefore unshaded solar cells act as a load and draw power instead of supplying. This causes formation of hotspots on shaded areas of solar cell surface and release heat. The temperature of hotspot area becomes more which may damage the solar cell. The second important issue is regarding loss of power which is wasted during shading of solar cell. A lot of generated power is radiated in heat form when hotspots are formed during shading effect.

The measurements were performed on 25.04.17 at the roof of a library building in faculty of engineering of Dayalbagh Educational Institute Campus over which solar array was installed with facing towards south. The library building is surrounded by trees in plenty on eastern side and few on western side, there was a building on north side. The table 2 shows detailed configuration of complete solar array consisting of four strings of solar cells.

Table 2: Configuration of solar array

No. of Strings (S1, S2, S3, S4)	No. of Solar Modules
String 1(a+b+c)	6+6+6=18
String 2	18
String 3	18
String 4	18
Solar Array (4 strings connected together)	72

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The shade of tree falls on solar cells after 2.00 pm, so two cases were formed:
Case 1: Thermal method with no shade of tree on solar cells
Case 2: Thermal method with shade of tree on solar cells

III. RESULTS

For case 1, the measurements were performed at 10.30 am when there was no shade on solar cell surface. Normal camera photographs and thermal images were captured along with other thermal and electrical parameters. For case 2, measurements were performed after 2.30 pm when shade of tree covers almost half portions of solar cell string 1, string 2 and string 3. String 4 is free from shade. Therefore, solar irradiance of string 1 and string 2 is low as compared to string 3 and string 4. Normal camera photographs and thermal images were captured with electrical parameters. The fig. 11(a) to fig. 11(h) and fig. 12(a) to fig. 12(h) show normal camera photographs and thermal images of solar cells for two cases considered above. The thermal images show areas of heating with maximum temperature, minimum temperatures on scale.[6]

Fig. 11(a) to fig. 11(h) shows normally captured photographs for string 1, 2, 3, 4 respectively under no shade of tree, fig 12(a) to 12(h) show normally captured photographs for string 1, 2, 3, 4 respectively under shade of tree.

The fig 11(a), fig 11(b), fig 11(c), fig 11(d) are the normal photographs of string 1, string 2, string 3, string 4 respectively under no shade of tree i.e., for case 1. The fig 12(e), fig 12(f), fig 12(g), fig 12(h) are the corresponding thermal images showing high temperature represented by bright color. The fig 12(a), fig 12(b), fig 12(c), fig 12(d) are the normal photographs of string 1, string 2, string 3, string 4 respectively under shade of tree i.e., for case 2. The fig 12(e), fig 12(f), fig 12(g), fig 12(h) are the corresponding thermal images showing low temperature represented by dark color with hotspots clearly visible.

Electrical measurements for shading effect of tree

To study the effects of shade of tree on solar cells more precisely the corresponding electrical parameters were measured along with thermal measurements, which include output current, output voltage and output power of complete solar array. Table 3 shows electrical parameters for case 1 and case 2.

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Table 3 Electrical parameters under no shade and under shade of tree for solar array

Parameters		Case 1: With no shade on solar panels	Case 2: With shade on solar panels
Date & Time		25.04.17, 10.30 am	25.04.17, 02.30 pm
I Output (A)		16.24	3.76
V Output (V)		440	497
P Output (kw)		7.14	1.86
T Ambient (°C)		35	39
Solar string operating Temp (°C)	T1	45	40
	T2	46	41
	T3	48	40
	T4	47	40
Solar Irradiance (W/m ²)	I1	161	74.8
	I2	151.3	84.6
	I3	158.5	117.4
	I4	163.2	116.8
Humidity (%)		25	25
Pressure (K Pa)		100.8	100.6
Wind speed (m/s)		NW 4.6	W 5.7
UV		9	8
Visibility (km)		6	6
Shade status		No shade on solar panels	Shade of tree on solar panels
Hot spots observed		No	Yes
Weather status (dry/ wet/rain)		Clear sky	Cloudy sky

Table 3 shows that the output current as well as output power of solar photo-voltaic array reduces as solar cells come under the shade of tree. It also shows individual temperature, solar irradiance of solar strings with atmospheric parameters. Hotspots were noticed for solar cells which are shaded by tree showing loss of generated solar power in heat form

The fig 13 and fig 14 show the bar chart for operating temperatures, solar irradiance for four string with no shade of tree and with shade of tree respectively. The fig 15 shows bar chart of the output current and output power of solar array with no shade of tree and with shade of tree respectively showing reduction in output current and output power of solar array due to shading effect of tree.

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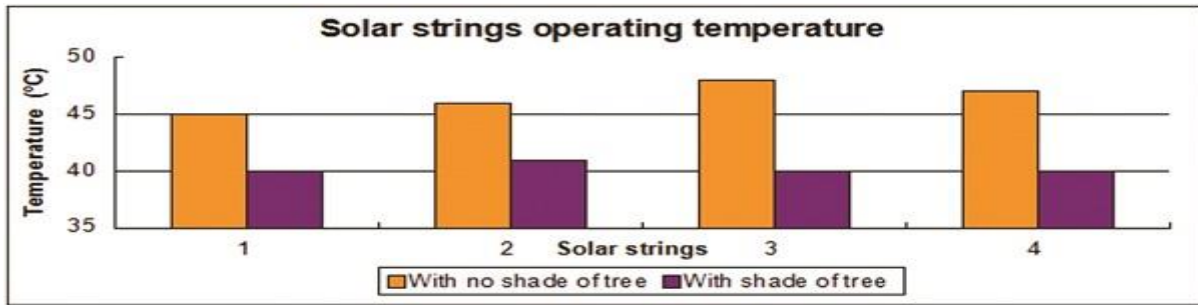


Figure 13: Operating temperatures of four solar strings with no shade of tree and with shade of tree

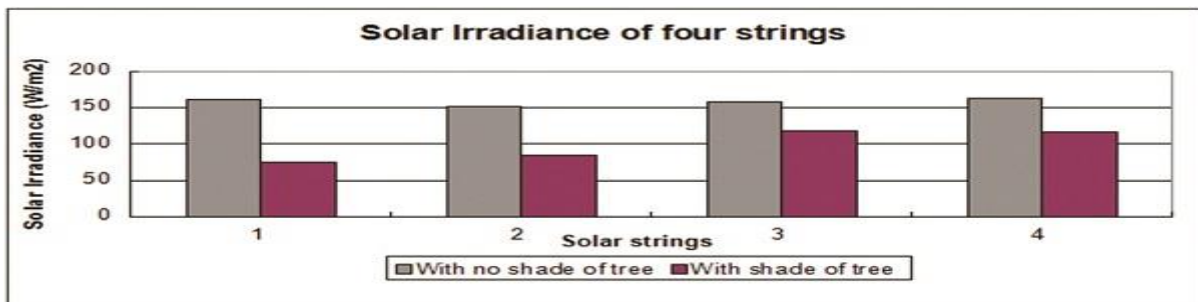


Figure 14: Solar irradiance of four solar strings with no shade of tree and with shade of tree

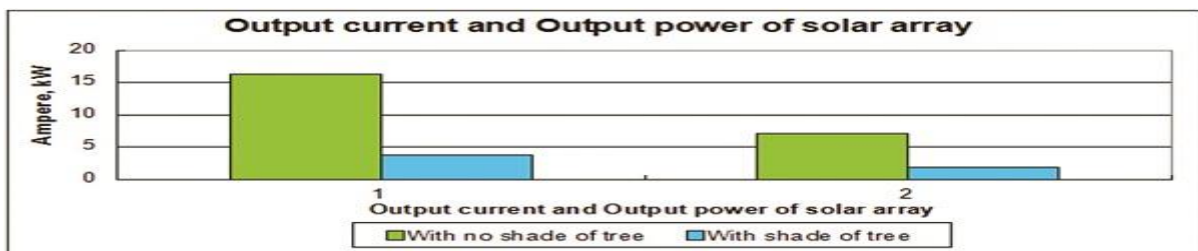


Figure 15: Output current and output power of solar array with no shade of tree and with shade of tree[7]

IV. CONCLUSIONS

This paper shows a study of environmental effects generally occur in solar cells/cells due to different causes.[8] Some open environmental defects are visible by naked eye can be identified by visual inspection. The effect of shading is one of the important factor considered in the condition monitoring of solar cells.[9] The shading of tree on solar cells increase the temperature of solar cell surface, which is not visible in the photographs captured by normal camera. Such heat effects can be detected by thermal imaging camera easily. The shading of tree on solar cells affect the power generation of solar cells, therefore, thermal analysis of solar cells with no shading and with shading is also included by

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formulating two cases.[10] So a comparison is obtained between case 1 and case 2 with the help of normally captured photographs and thermal images to show how shadow of tree affects the generating power of solar cells. The bar charts shown in fig 13 and fig 14 represent variation of operating temperature, variation of solar irradiance for solar cell strings 1, string 2, string 3 and string 4 respectively. [11,12] The shading of tree give rise to hotspots and causes heat and reduction of generated power as shown in fig. 15.

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