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Self Cooling Mechanism in Photovoltaic Cells and Its Impact on Heat Island Effect from Very Large Scale PV Systems in Deserts

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Abstract: The share of Photovoltaic power generation is likely to increase many folds in coming decades as per projection of world energy demand by various study groups throughout the world. Deserts and arid areas have high insolation and sufficient space to house Very Large Scale Photovoltaic (VLSPV) systems. However, albedo and land cover changes are supposed to substantially increase sensible heat flux. Increase in surface heat flux, may cause local, regional and global climate changes. It is concluded on the basis of experimental observations that self cooling mechanism initiates in Photovoltaic Cell during off-sunshine hours, which can offset 'Heat Island Effect' due to high cell temperature during sunshine hours. It is also observed that the load has no effect on self-cooling mechanism.

Keywords: Climate change, Energy from desert, Heat Island Effect, Self cooling, VLSPV

1. Introduction:

New technology for economical recovery of fossil fuel resources, new reserves and nuclear energy may fulfill the energy demand in immediate future, geographical imbalances between supply and demand, as well as temporal and local supply problems would certainly worsen. Besides, the sustainable prosperity of human beings can no longer be expected if global environmental issues due to fossil fuel use are ignored. The share of electrical energy is rising more and more as secondary energy form. PV systems have unique additional values in environmental, electrical, architectural and socio-economic domain, besides main function, power generation, for example, avoidance of marginal cost of system-wide energy production and system-wide generation capacity; deferral of distribution capacity, sub-transmission capacity, transmission capacity investment; reduction of losses, value of reduced fossil emission, fuel price risk mitigation etc. There are several PV deployment projections from USA, Europe and Japan. The US Photovoltaic Industry Roadmap Steering Committee, which consists of Astropower, Idaho Power, Avista Labs, Siemens, Solar Industries, Solarex, SEIA, MIT, Spire Corporation, Trace Engineering, Purdue University, BP Solar and Stella Group, in its report aims to generate 10% of domestic peak power generation capacity by 2030 using PV technology.

Very Large Scale Photovoltaic Technology (VLSPV) is likely to be as main source of electricity generation as proposed by Kurokawa (2003). The option has become economically viable at the present state of technical development. Environmental impact analysis of atmospheric circulations due to land surface interaction and partitioning of the available energy at the surface between latent and sensible heat fluxes indicate that daily global mean temperature due to this land-use change (VLSPV installation) in Sahara, Gobi and Thar, is approximately 0.001˚C in one year as shown by Sinha et al, (2006). However, there are possibilities that changes in soil temperature due to higher module temperature may act as Heat Island Effect, adversely affecting the global climate if results obtained from Community Land Model (CLM) developed by Pielke (2002) are to be relied upon. These studies are based upon computation of large-scale synoptic patterns and mesoscale atmospheric structures. These must be offset by creating green patches - an expensive alternative.

An interesting outcome, however, of the work has been unexpected cooling effect from PV modules, which is visible during off-sunshine hours. The temperature of PV modules is 2-4˚C less than the ambient temperature when direct sun light is not falling on the modules. This is likely to reduce the heat island effect as compared to earlier computed values.

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2. Materials and Methods

The open circuit voltage , V_{oc}, of a p-n junction is related to the band gap, E_g , and is generally expressed in terms of short circuit current, I_{sc}, the dark current Io, and the junction perfection factor A_o by;

$$V_{oc} = A_o\left(\frac{KT}{q}\right)\ln\left[\left(\frac{I_{sc}}{I_o}\right)+1\right] \quad (1)$$

In the absence of light, the relationship between the flow of junction current I_j and imposed voltage V in a p-n junction is given by;

$$I_j = I_o\left[\exp\left(\frac{qV}{KT}\right)-1\right] \text{ and } I_o = \frac{qD_h p_{no}}{L_h} + \frac{qD_e n_{po}}{L_e} \quad (2)$$

Where, K is Boltzmann constant q is the electronic charge and I_o is the saturation current; D_h and D_e are diffusion constants of holes and electrons at a particular temperature (T) respectively; n_{po} and p_{no} are the thermal equilibrium densities of electrons on p-side and of holes on the n-side of the junction respectively; L_e and L_h are the electron diffusion length on p-side and hole diffusion length on n-side respectively. I_o is also called dark current.

The increase in cell temperature during day time in all seasons is observed (**Fig.1a**). It is due to recombination of hole-electron pair in presence of higher frequency of electromagnetic waves ($h\upsilon > E_g$). As it has been expected and can be explained by the above equation. The increase in cell temperature can influence the local climate. Pielke (2001) analyzed that the changes in land cover influence the climate and more specifically hydrological cycle through the partitioning of the incoming solar radiation into turbulent sensible and latent heat fluxes. The energy budgets at the surface can be written as follows,

$R_N = Q_G + H + L\,(E + T)$ (3)

$R_N = Q_S\,(1 – A) + Q_{LW}\,(\downarrow) - Q_{LW}\,(\uparrow)$ (4)

$P = E + T + RO + I$ (5)

Where *R*$_N$ is net radiative fluxes; *P* is precipitation; *E* is evaporation (conversion of liquid water into water vapor from the soil surface); *T* is transpiration (phase conversion to water vapor, through stoma on plants); Q_G is soil heat flux; *H* is turbulent sensible heat flux; *L*(*E* + *T*) is turbulent latent heat flux; *L* is latent heat of vaporization; *RO* is runoff; *I* is infiltration; *Qs* is insolation; *A* is albedo; $Q_{LW}\,(\downarrow)$ is down welling long-wave radiation; $Q_{LW}\,(\uparrow)$ is upwelling long wave radiation, which is,

$Q_{LW}\,(\uparrow) = (1 - \varepsilon)\,Q_{LW}\,(\downarrow) + \varepsilon\,\sigma\,T_s^4$ (6)

Where, ε is the surface emissivity; σ is Stefan's constant and T_s is surface temperature. Sinha *et al.* (2005) assumed that the PV system covers the land surface horizontally not inclined to any angle to the whole area of Sahara, gobi and Thar deserts. The net energy flux at the ground surface is sum of beam & diffuse solar radiation and long wavelength radiation from earth and atmosphere (Eq. 3). The sensible heat flux and latent heat flux was calculated by the following equations,

$H = \rho_{atm}\,C_p\,(\theta_{atm} – T_g)/\,r_{ah}$ (7)

Where, ρ_{atm} - air density, C_p - specific heat of air, θ_{atm} – potential temperature, T_g - ground temperature, r_{ah} - aerodynamic resistance to sensible heat flux and water vapor transfer between atmosphere at height z1. Bonan *et al.* (2002) developed CLM3.0 model which was run for one year in two cases of the assumed albedo for the whole area of Gobi desert (162.8×10^4 km^2), Sahara desert (743×10^4 km^2) and Thar desert ($44.3\text{x}10^4$ km^2). The following two cases were considered, (A) visible range radiation = 0.20, infrared radiation = 0.20 and (B) visible range radiation = 0.10, infrared radiation = 0.20. The input global data was obtained from CCM3.0 web site to run the model in offline mode for one year projections. The projected increase in daily global mean temperature due to this land-use change in Sahara, Gobi and Thar, is approximately 0.001˚C in one year. Global mean temperature rise of 0.1˚C in one century can be utmost concluded without green area patches around VLSPV (Sinha *et al*., 2006).

During sunshine hours, absorption of solar energy reduces surface albedo. The temperature of the module increases and heat dissipation from the back-sheet of the PV module is expected to increase the sensible heat flux and the ground temperature and affect land-surface interaction in long run. PV temperature (cell temperature and back sheet) is therefore monitored along with ambient temperature in all

Fig. 1a. Experimental set up at CREER, Bihar, India.

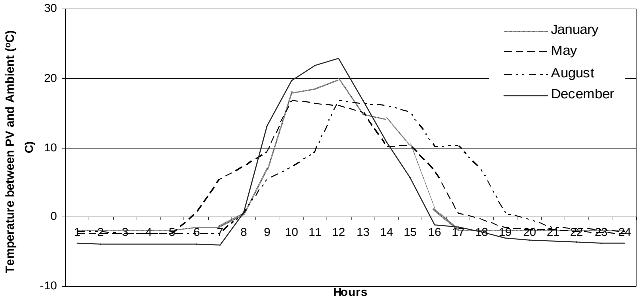

Fig. 1b. Hourly variation of temp. diff. between PV Cell and ambient in the month of January, May, August and December.

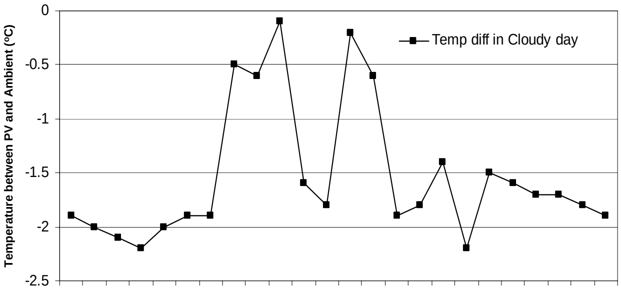

Fig. 1c. Hourly variation of temperature difference between PV Cell and ambient temperature in a typical cloudy day.

the seasons in Japan and India. Mono-crystalline and multi-crystalline solar cells of 3 W, 5 W, 10 W, 20 W, 40 W and 80 W modules from TATA BP, Kyocera and Toshiba were used for collecting data.

3. Results and Discussion

Fig. 1 (b) shows hourly difference variation of PV Cell Temperature and ambient temperature in the month of January, May, August and December on typical sunshine days. It clearly shows that during sunshine hours, cell temperature is more than the ambient temperature. The difference is as large as 23 degree Centigrade during peak sunshine hour. However, during off-sunshine hours, i.e., when direct beam is not incident, cell temperature is less than the ambient temperature. The difference is as large as 4 degree centigrade after cooling of the module stabilizes. **Fig. 1 (c)** similarly shows the same phenomenon in case of cloudy day. This indicates that diffused radiation has also cooling effect. Diffused radiation on the other hand produces electromotive force (emf) from the module but with less efficiency. Rise in cell temperature due to recombination process during day time can be explained theoretically by Eq. (1) but the cooling of cell during off sunshine hours can not be explained by this equation.

The two results collectively indicate that emf or load has no effect on cell temperature. It is direct sunlight, which increases the cell temperature due to high rate of production of electron-hole pair and their recombination consequently. The effect of cooling during off-sunshine hours can be compared to evaporation from water surface, where ambient temperature is used for creation of electron-hole pair but recombination does not take lace due to internal circuit formation in PV module. Therefore, cooling effect is observed in all types of PV modules.

Fig. 2 shows the variation of back sheet temperature of PV module, cell temperature, ambient temperature and solar intensity in the month of October during cloudy day. **Fig. 3** shows the corresponding variation of open circuit voltage of PV module and Solar Intensity. The results are identical in all cases. This shows that PV power and type has almost no effect on cooling mechanism. Results further indicate that climate has no effect on this interesting characteristic of PV panels since experiments were carried out in Tokyo and Muzaffarpur (India) had same results. The cooling mechanism can be best explained on the basis of internal loop formation which accounts for very small current and therefore no recombination takes place between thermally generated electron-hole pairs from ambient temperature.

Since deserts are quite often enveloped by dust storms, this result is of critical importance. VLSPV in diffused light would decrease overall temperature of the ambient.

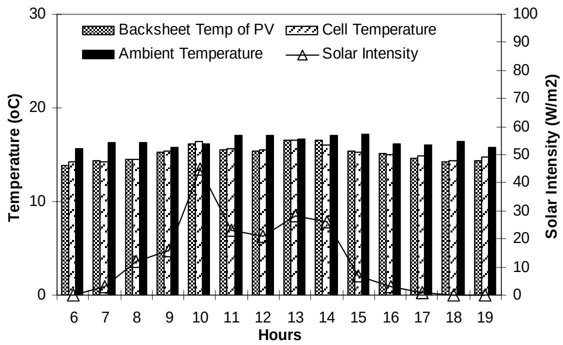

Fig. 2. Variation of Back sheet, Cell, Ambient Temperature and Solar Intensity in a typical cloudy day.

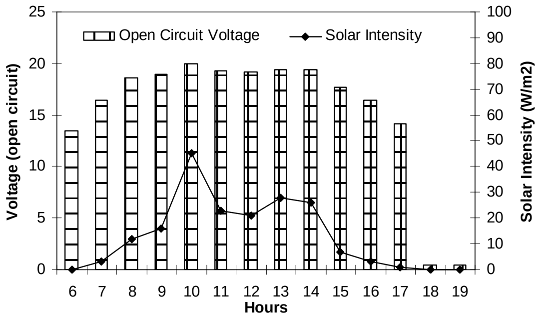

Fig. 3. Variation of Open Circuit Voltage of PV module and Solar Intensity in a typical cloudy day.

4. Conclusions

Experimental investigations and the Physics of Photovoltaic system reveals that during off-sunshine hours (absence of direct beam radiation), even if diffused sunlight is adequately available, module temperature will be always below atmospheric temperature. This phenomenon is likely to reduce Heat Island Effect from Very Large Scale Solar Photovoltaic (VLSPV) Systems if installed in major deserts.

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