Efficiency Improvement of Solar PV Panels Using Active Cooling

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Abstract— **Huge amount of Solar radiation reaching the earth can be harnessed to provide electricity through Photo voltaic (PV) panels. The solar PV is an exciting technology but suffers from low efficiency. A study on low efficiency in multi MW solar power plants reveals that the electric yield of the PV modules is reduced due to reflection of the irradiation from the sun and when a module's temperature is elevated, as there is decrease in the voltage and efficiency. We intend to improve the efficiency of the Solar Photo Voltaic Panels by active cooling to reduce the temperature losses considerably and decrease reflection losses to some extent. We deploy natural resources at the plant site to cool the panels which further results in efficient operation.**

Keywords— **PV panels; efficiency improvement; active cooling; soil temperature model; ground water tunnelling**

I. INTRODUCTION

Solar irradiance is a key driving force of the Earth. Ultimately it is the source of all energy supplies except for nuclear energy. Hydroelectric, wind and wave energies are linked to climate, which are also driven by the sun through uneven heating on the Earth. Direct conversion of solar irradiance through solar energy systems is obviously linked to the sun as well and is of much interest to researchers.

There are several solar energy systems that harness solar irradiance directly. Passive solar heating systems absorb heat directly into a building. Another type of solar energy systems is active heat generation, which includes solar water heaters. Producing electricity as well as heat, solar thermal engines, which can be made with Sterling engines, are another type of system. However, photovoltaic (PV) arrays convert solar irradiance directly into electricity through a solid-state system. The main focus of this paper is on efficiency improvement of solar PV panels. We are running out of fossil fuels and are confronting climate change. The only solution being clean energy and there is an urgent need to make it cheaper and efficient. This work is a innovative approach which is a one among many solutions to the problem posed above.

The paper is organised as follows : section II presents different types of photovoltaic losses, section III deals with methods to reduce losses, section IV discusses the idea of active cooling system, section V gives thermal modelling of PV panels, section VI elaborates on the soil temperature modelling, section VII presents practical calculations and section VIII design of underground tunnels followed by a conclusion.

II. PHOTO VOLTAIC LOSSES

A study made on the losses that occur in a multi MW solar power plants reveals that the electric yield of the PV modules are reduced by 8-15% due to reflection of the irradiation from the sun. In facade applications located in the tropics, about 42% of the drop in yield due to flat incident angles is observed. Although there are other losses, optical losses and temperature losses are considered primary.

A. Optical loss

As is often mentioned in literature, solar radiation hitting a glass encapsulated or laminated PV-module at a perpendicular incidence angle yields a reflection loss in the range of 4–5%. Yet for most applications the incidence angles do differ from zero and thus result in an increased reflection loss as according to Fresnel's laws. The accumulated reflection loss over one day for a fixed tilt angle of the module depends on the latitude, clearness index (diffuse-direct ratio), surface treatment and the match of refractive indices within the layers of module encapsulation.

B. Thermal loss

A crystalline silicon solar cell's electrical power generation depends on its operating temperature. While the short circuit current (I_{sc}) increases slightly with increasing temperature, the open circuit voltage (V_{oc}) decreases significantly (about 2.3mV/°C) with increasing temperature. This results in a reduction of electrical power output (and electrical yield) of 0.4%/°C to 0.5%/°C for mono and multicrystalline silicon solar cells (which are used in most power applications).

When a module's temperature is elevated, there is decrease in the voltage and efficiency which is expressed by the relation,

$$\eta_{electricity} = \eta_{ref}\,[1-\beta\,(T_{panel}-T_{ref}) + \Phi_{log}\Phi_{ref}] \qquad \text{(i)}$$

Where η_{ref} is the reference efficiency of the panel at T_{ref},
T_{panel} is the surface temperature of the panel.
Φ is the solar irradiation at the location.
Φ_{ref} is the reference solar irradiation of 1000W/m².

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Also, for some panels, it can be observed that the fall in efficiency per centigrade rise in panel temperature above 25^0C is 0.25 %.

A brief illustration give below explains the temperature losses. The temperature of the cell when kept in air is given by the following generalized expression.

$$T_{cell} = T_{air} + ((NOCT-20)/80)*S \quad (2)$$

Here T_{cell} is the temperature of the cell surface

T_{air} is the temperature of air surrounding the panel

NOCT = Normal Operating cell temperature

S is the irradiation in mW/Cm2

For a sample case: let us assume 1000W/m2 of irradiation and let us assume air temperature to be 35^0C and NOCT for a practical solar panel (Thin film FS-380 by first solar) is 45^0C. If we substitute these values, we find that cell temperature is 66^0C. For the same panel, fall in efficiency per centigrade rise in panel temperature above 25^0C is 0.25 %. So now fall in the efficiency in this case is (66-25)*0.25 = 10.25 %. This is very significant and we are working on reducing such losses. In the case of other types of solar PV these losses are even higher

III. PRELIMINARY STUDY TO REDUCE LOSSES

We are proposing to use front water cooling of panels to reduce temperature losses. This method is advantageous in two aspects which are explained below

A. Improved matching of the refractive indices of the module encapsulation layers

By using certain optical models, an optical system consisting of front glass, EVA (ethylene vinyl acetate), anti-reflective coating and silicon solar cells, a variation of parameters led to the following result: an improved optical match between the two upper layers (glass and EVA) and an increased optical transmittance of 3.2% for materials with ideal properties of n_1=1.33 and n_2=1.73. Unfortunately, these ideal properties for the top layer cannot be achieved with solid materials. Yet water, with a refractive index of 1.3, returned an increased yield in the vicinity of 3% for both optical transmittance and electrical generation [1].

Other methods for reducing reflection also work, but have disadvantages. Anti-reflective coating of glass is often not durable and structured surfaces are costly, have a tendency to accumulate dust and are thus difficult to clean.

B. Active cooling of the cell surface

Because efficiency and electrical yield decrease with increased operating temperatures it is preferable to maintain low system temperatures. By mounting the PV module on a water-filled tank and due to the high thermal capacity of water in the tank, the operating temperatures can be kept at low levels during most parts of the day.

IV. PROPOSED IDEA

We plan to use active cooling to reduce the cell temperature. For analysis purpose, we have developed an accurate thermal model for the solar panels considering that the panels lose heat by conduction, convection and radiation phenomenon taking place on the surface of the panels. In our proposes model and also in [1], we are making a very thin layer of water to flow on the surface of the solar panel, this is explained further in the latter part.

Figure 1: Water cooling of panels [1]

A few ideas to reduce reflection have been proposed but many have drawbacks; anti-reflective coatings are not durable and structured surfaces are expensive, accumulate dust and are difficult to clean. Yet water with a refractive index of 1.3 is most viable interface between glass (η=1.5) and air (η=1). Also a thin layer of water flowing on the surface of the PV cell would increase the convective heat transfer from the surface of the water hence further increases the efficiency by controlling the surface temperature of the PV cell. However one choice which is to be made for this design is deciding the mode of flow employed for the flow of cooling water namely, closed circuit flow or an open circuit flow. In this project we intend to follow a closed circuit water circulation system. The above figure obtained from [1] gives a overview of the idea.

A. Our Idea-Novelty

Closed circuit flow should involve some mechanism for cooling of water that has absorbed heat from the surface of the PV cell. For this a novel “Ground water tunneling” mechanism is being proposed in which the hot water is made to flow through underground pipes which are made of highly conductive materials. These pipes are present where the temperature of the earth remains constant (say around 2-3m below the surface, depending on the thermal conductivity of the soil composition at the local location).

One practical idea which has been implemented regarding earth air cooling is at Tata Energy Research Institute , Delhi. The campus air conditioning system uses similar technique where air is circulated below the earth at 4 meters depth. They found and reported that temperature is pretty stable at that point and is at 26^0C [7] . This sounds interesting if implemented in the case of water cooling for solar panels also.

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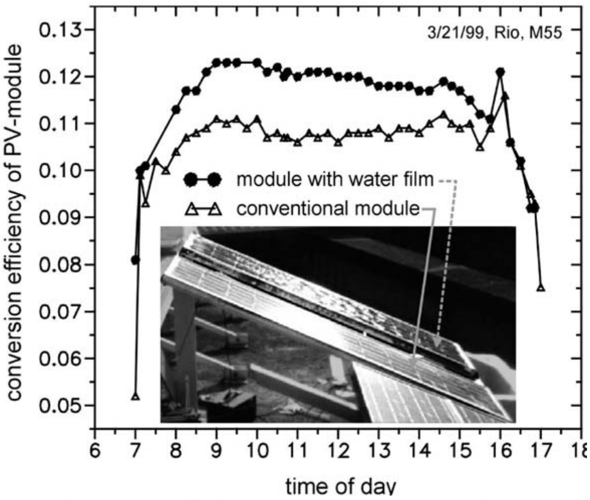

Figure 2 : Efficiency Improvement Graph [1]

This idea can bring about a major revolution in the solar power generation using PV cells, as it considerably increases the efficiency of the electricity production with no additional cost involved in cooling. The only thing we require here is a pump to circulate water which takes negligible power in case of multi MW plants. This increase in efficiency results in the net increase in the Energy production. This, when compared to other present techniques was estimated to be feasible from both economic and energy point of view. We would also like to mention that this would result in cheaper solar power, a field in which India is advancing rather at a rapid pace. Since the clean energy becomes more efficient costs come down and more people go for clean energy. Thus a lot of carbon foot print is saved. At present rate, Solar power is brought at 15 Rs/KWh by government of Gujarat and this work will have huge impact in savings also.

V. THERMAL MODELLING OF PV PANELS

Three modes of heat transfer are involved with a PV array. The input energy to the array is in the form of solar irradiation in the form of short wave radiation. The panel undergoes heat removal by conduction, convection and radiation. However, the heat lost due to conduction is very negligible because of the small contact area between the solar panel array and its framework. The heat removed from the panel is in the form of long wave radiation due to much colder temperature of the panel, compared to the surface of the sun. In the present proposed idea, the thin layer of water helps in decreasing the reflection losses and the loss of heat due to convection is enhanced by the higher convection heat transfer coefficient of the fluid, thus increasing the efficiency in both the cases.

A. *Thermal modelling*

The heat balance model of the heat accumulating in a system is equal to the heat in(q_{in}) minus heat out (q_{out}) plus internal heat generation (q''') [1]

$$\rho C_p \frac{dT}{dt} = q_{in} - q_{out} + q''' \qquad (3)$$

Where ρ is the density, Cp is the heat capacity and T is the temperature and the first term determines the accumulation of heat. The term q_{in} in the equation denotes the inflow of heat into the PV system, q_{out} denotes the heat lost, it is denoted into several components, namely heat lost to long wave radiation, convection and as electricity and q''' is zero as there is no internal heat generation.

$$C_p \frac{dT}{dt} = q_{lw} + q_{sw} + q_{conv} - P_{out} \qquad (4)$$

the long wave component can be calculated by modifying the Stefen-Boltzman constant law to include a component radiated to sky, the ground and the panel.

$$q_{lw} = A\sigma\{(1+\cos\theta)/2\}*\varepsilon_{sky} * T_{sky}^4 + \{(1+\cos\theta)/2\}*\varepsilon_{ground} T_{ground}^4 - \varepsilon_{sky} * T_{sky}^4] \qquad (5)$$

where σ is the boltzman constant, ε is the emissivity and θ is the angle of inclination of the panel with respect to the ground.

$$q_{conv} = -A(h_c,\text{forced})(T_{panel} - T_{water}) \qquad (6)$$

where h_c is the convective heat transfer coefficient of the forced convection process.

So based on the above equations, if the various values of the constants and the required temperatures of the panel surface are substituted, calculation of the flow rate of water and also the temperature of the water that is to be flown over the panel can be found out and the design of the active cooling can be accomplished.

VI. SOIL TEMPERATURE MODELLING

The hot water is made to flow through underground pipes which are made of highly conductive materials. These pipes are present where the temperature of the earth remains constant (say around 2-3m below the surface, depending on the thermal conductivity of the soil composition at the local location). Soil temperature fluctuates annually and daily affected mainly by variations in air temperature and solar radiation. The annual variation of daily average soil temperature at different depths can be estimated using a sinusoidal function Suitable soil temperature models were developed completely by us, considering the variation of temperature in different periods of year and also different periods of a particular day.

The sinusoidal temperature variation of the soil can be derived by solving the equation

$$\frac{dT(x,t)}{dt} = \alpha \frac{d^2T(x,t)}{dx^2} \qquad (7)$$

Where T(x,t) is the soil temperature at time t (days) and depth z (m) α is the temperature diffusivity.

Solving the above equation, we obtain a relation between the temperature at a certain depth from the surface and a particular time, T(x,t) . This model helps in estimating the depth where the hot water pipes must be flowing underground.

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$$\frac{T(x,t)}{T_{sx}} = \cos\left[\frac{2\pi t}{t^{\circ}} - x\sqrt{\frac{\pi}{\alpha t^{\circ}}}\right] \qquad (8)$$

And $T_{sx} = T_a\, e^{-x\sqrt{\pi/\alpha t^{\circ}}}$ (9)

where T(x,t) is the soil temperature at time t (days) and depth x(m), T_a is the average atmospheric temperature during a particular period (°C), t° is the duration of period (days), t is the particular time from the start of the period(days).

Based on the estimated values of the constants, the value of the depth, x where there is no variation of temperature or the sinusoidal variation of temperature is obtained as 3 to 4 m. So if the pipes are laid at a depth of 3 to 4 m, we can obtain the best results.

VII. PRACTICAL CALCULATION

A. Estimate of Energy savings

To prove the efficiency of the system, we have taken a panel FS-380 by first solar as indicated in previous section and calculated the possible values for it. The panels have a dimension of 1200mm * 600 mm and rated power output of 80W . We take 32 of these panels and combine into a module to produce a square shape of 4800 mm side which can be mountable. This module produces 2.56KW rated power.

Now, we calculate the power required for the motor to pump the water with flow rate such that water is continuous over the panel. We assumed the diameters of pipes are 0.05m. The module is placed at 1m above the surface. The pump is assumed to be at lowest point of panel. The depth of tunnel to be dug in soil is assumed to be 4m. With this values and assumptions, we found that power required to pump the water for the module is 36W.

After this, we calculate the gain in energy. As given in section two, the panels reach a temperature of 66^0C. Also from our soil modelling , we obtained that the soil temperatures will be 25^0C for sub tropical climate at 2.16 m. But, to be practical , we assumed values observed at TERI[7]. The coolant in [7] is air but here we use water which has better heat transfer capabilities. So, we justify assuming [7] values. Now, water reaches 25^0C when circulated in a network underneath. The network length should be adjusted accordingly. The next section clearly describes the same. Now, water at 25^0C is circulated and it is flown on panels. Now, as the flow is continuous, panels should turn to a steady state temperature. We assume this steady state temperature to be air temperature (35^0C). This is most pessimistic assumption. Hence, if we assume panel temperature is operated at 35^0C, then temperature losses will be only 2.5%. Net savings in reduction of losses is 7.75% (previous losses: 10.25%). This, for the module turns out to be 200 watts. Also it is reported in [1] that, the effect of a layer of water (μ=1.3) between air (μ=1.0) and glass (μ=1.5) improves light penetration and decreases reflection losses. They are reported to have 3.5 % savings but here we assume only 1 % which adds 25 watts savings. Thus if we spend 36 watts in water circulation , we obtain 225 watts savings. Net savings is around 7.5% which is very significant value.

All assumptions are taken from practical scenarios and in cases of choice, pessimistic values are taken. Also, maintaining a constant layer of water on panels is a practical issue to be considered. If width of module is increased by adding more panels (one below the other) less energy will be required to pump the water because the water pumped for the above panel is used by this panel also. But the flow uniformity may be disturbed. Also, water gets heated up after travelling a critical distance. Thus more width of panel is boon in reducing the water pumping but bane in case of cooling and flow effects. Both should be carefully balanced and modules should be designed.

B. Cost savings

Solar plants typically operate at plant capacity factor of 20 %. For a 1 MW plant and tariff of 15 INR/KWh this would amount to net savings of 8 Lakhs INR for one month. This is equivalent to 1 crore INR for one year. All this infrastructure would not cost more than 1 Crore INR. We assume about 20 Lakhs for the equipment and it can be recovered within 3 months, If not 3 months, it is 6 moths, but definitely this option is innovative and viable one. Extensive research for better design and improvement of this idea can be done and can be implemented in plants.

VIII. DESIGN OF UNDERGROUND TUNNELS

The underground tunnels are designed aiming at a maximum rate of heat transfer from a unit length of the pipe underground. To facilitate it, the design should involve an optimal way of accommodating a greater length of the pipe and hence greater surface area of the pipe must be in a minimum liner length (measured parallel to the surface of the earth). Also to increase the rate of heat transfer and hence the amount of heat transferred from the hot water to the pipe, the thermal conductivity of the pipe must be high and also a layer of insulation of a critical radius is laid onto the outer surface of the pipe and also the vertical section of the pipe inside the ground is spiraled and the surface of the ground is made in a zig zag manner so that the length to surface area ratio is high.

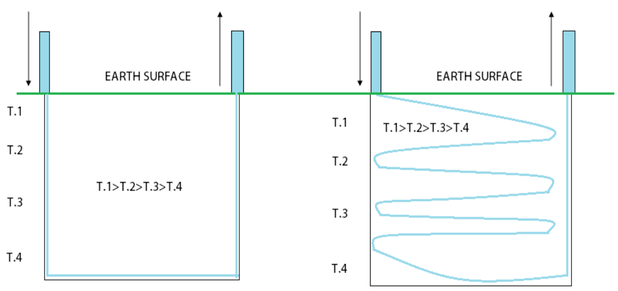

Figure 3. Design of underground structure

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IX. CONCLUSION

In this paper, we proposed an active cooling of PV panels that ensures increased efficiency of operation, thermal modelling of PV panels, soil modelling, design of underground tunnels. A practical calculation is also carried put based on proposed modelling and a net 7.75% improvement in efficiency of the system is made.

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