A Comparative Review on Cooling Techniques to Develop Hybrid PV/T Panel

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***Abstract*— Renewable energy will be the leading source of power on the upcoming days. Solar irradiation is one of the most convenient sources due to abundance in nature. Right now scientist are facing challenges to mitigate the heat induced by the solar panel during the conversion process. Excessive heat degrades the electrical property of photovoltaic panel thus resulting in reduced efficiency. To improve the efficiency different cooling techniques have been introduced namely active and passive cooling. It is really important to select the right cooling technique while developing the PV panel. It is found that, passive cooling technique is more preferable in-terms of operating cost, ease of use and reliability.**

Keywords*— *Hybrid PV/T panel, PCM, active cooling techniques.

I. INTRODUCTION

Day by day the demand for electricity is increasing to meet the demand of increased population of this world. We can not think of a single moment without electricity. The electric power generation system is mostly dependent on fossil fuel till date. But this source will not able to meet the future demand if the consumption is continued in the same way or more. Scientist are working day and night to find some alternative sources of energy. Right now all the researchers are focusing on renewable energy which is considered as the ultimate source of eco-friendly energy. The main benefit of solar energy is- it is abundant in nature and completely free in terms of cost. Although challenges are there to store the solar energy. Solar irradiation is converted into power with the help of photovoltaic (PV) solar panel which is the intermediate medium of the whole conversion process. There exist some limitations as well. It is not capable of converting the whole irradiation into power. Till now the maximum efficiency of a panel reached around 25.6% [1] which is very low. The main reason behind this is the solar irradiation does not fall into the solar panel uniformly throughout the day as the incident angle varies during the whole period. Apart from that, the peak time when solar irradiation is in parallel with the panel- it produces a lot of heat as well on the panel which decreases the electrical property of the panel thus resulting in reduced power generation. By thumb of rule for the increase of each 10°C the efficiency of the panel decreases by 5% [2]. Scientist are working day and night to increase the efficiency of the panel by introducing new manufacturing materials, techniques and off-course by optimizing the existing available methods. It is found that- we can keep the existing panel in a stable condition during the peak hour when the conversion is hampered due to additional heat by applying some cooling techniques. Cooling techniques are divided into two types namely: active cooling technique and passive cooling technique. Here we will be comparing both of the techniques with their possible advantage and disadvantage to implement a photovoltaic thermal (PVT) solar panel. The whole paper will be focused on the improvement of thermal panel.

II. BACKGROUND STUDY

As we discussed earlier, there are two types of cooling technique [3] involved while dealing the thermal PV panel system. The active cooling technique [4] requires external power to reduce the heat level by spraying fluids on the surface, blowing air through the panel or passing through fluids on the back side of the panel using motor pump. On the other hand passive technique [5] does not require any external power. It is always on the first choice of the researchers due to low operational cost, eco-friendliness followed by high reliability. Here all the techniques involved for active and passive cooling will be discussed with their possible pros and cons.

Active cooling techniques

In general the cooling process related with thermal panel can be categorized in the following way shown in Fig.1:

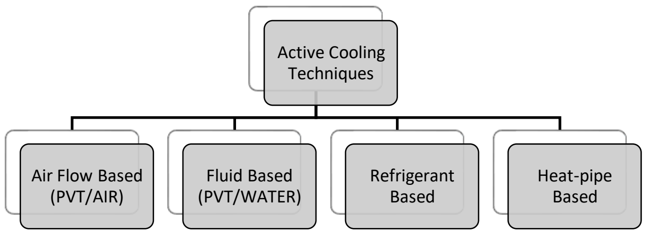

Fig. 1. Different cooling techniques

Air based cooling technique: It is one of the most popular non-expensive technique used in thermal PV panel to reduce the heat. The main concept is to create a channel between the solar cell and the back wall via which air can pass through [6]. While designing the air based cooling system two parameter should be taken into consideration namely channel depth and mass flow rate. Channel depth should be at 10 cm to obtain the optimum results. Although it is considered that for efficient heat extractions use of thin (flat) metallic sheet (TMS) in the middle of the channel or adding fins at the back wall of the channel could be more effective for faster heat dissipation comparing with the traditional one which is shown in Fig 2. The energy performance of any PV panel can be determined from the following Eq. (1):

$$Electrical\ Efficiency,\ \eta_{mu} = \eta_{ref}\left(1-\beta\left(T_{pv}-T_{ref}\right)\right) \quad \text{Eq. (1)}$$

Here,

η_{ref} = reference efficiency

β = cell efficiency temperature coefficient

T_{ref} = Standard Temperature (25°C)

T_{pv} = Operating temperature of the module

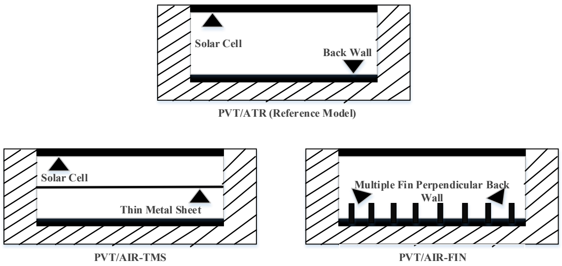

Fig. 2. Different cross sectional view of PVT/AIR model

For any weather condition η_{ref} can be determined with temperature ranging from 20°C to 70°C from the relation curve between electrical efficiency and panel temperature.

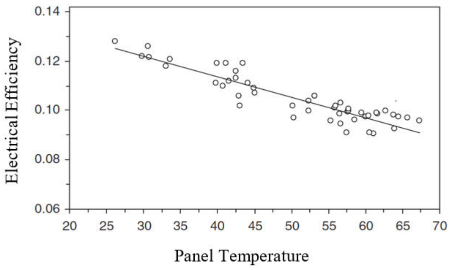

Fig. 3. Relation between electrical efficiency and panel temperature

In a natural air flow condition a maximum efficiency of 12.5% is achieved [7].

Fluid based cooling technique: Till now fluid based cooling technique is considereds the most efficient way which includes regular water and different kinds of concentrated fluids (combination of different chemical composition) as it has high capability of heat absorption. For example, by spraying water on top of the surface panel using nozzle- a reduction of temperature between 10 -15°C is achieved [8]. In addition to that, the above mentioned method cleans the panel surface thus resulting in 2-3.5% reduced reflection loss. Water trickling method is applied on top of the surface which increases the system output almost 15% as the heat is dissipated due to convection process between the water and panel [9]. This method is capable of reducing the operating temperature upto 50% which is really promising. Recently a technology is widely accepted which is based functionally graded materials (FGM's). This cooling technique involves, a gradation of materials from metal dominated layer to other material layer (polymer). Water tubes are included on top part of the panel which have high thermal conductivity for heat dissipation in all direction [10] which is shown in Fig 4. In this way higher efficiency of 12.3% is achieved at lower temperature like 35°C.

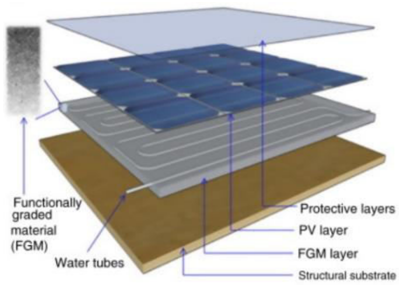

Fig. 4. FGM layer [10]

As we can see from the picture that FGM layer functions as an intermediate layer for heat dissipation and suitable for domestic use with rooftop solar system.

Refrigerant based cooling technique: This method is still under test and not suggested as it has some technical limitations. The main concept is to pass the refrigerant through pipes beneath the solar cell where the additional heat will be evaporated which is shown in Fig 5. In this case a very well maintained control system is required to ensure the pressure level of the system. In general it is very expensive with high probability of getting damage due to leakages. This technique along with heat pipe based method is not recommended due to their limitations.

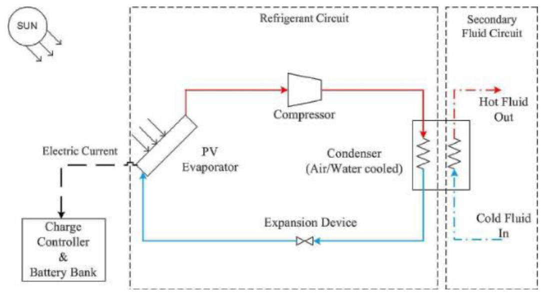

Fig. 5. Refrigerant circuit [11]

Passive cooling techniques

Passive cooling technique [12] does not involve any external sources like active cooling technique thus resulting in low operating cost, low maintenance, high reliability and more eco-friendly in nature. There are different ways to apply passive cooling on the panel. Major technique involves - i) submerged water cooling, ii) heat sink, iii) phase changed materials (PCM), iv) cotton wick cooling, v) evaporative cooling and vi) using dielectric medium.

Submerged water cooling: In this method the flat PV panel is submerged in shallow water. The performance is studied by setting different levels (0-10 cm) of water. Although challenges are there as the solar spectrum is different in water. This method results in an increase of power upto 15%.

From the final result- it is found that maximum conversion efficiency is achieved at a depth of 4 cm. The performance of the panel varies a lot during different season of the year as the ambient temperature is not same all the time [13].
Heat sink: In this method some fins (mostly aluminum plated) are attached on the back side of PV panel with the help of adhesive. This technique functions well when there is a significant difference in temperature between the sink and ambient air to transfer the heat. With the help of this technique a decrease of minimum 25-30°C in temperature is achieved. Although proper steps are required to increase the natural convection heat transfer by attaining higher Rayleigh numbers at the heat sink [14].

Phase changed materials (PCM): Phase changed materials is very popular now-a-days due to it's wide applications. It is already recognized as one of the most promising materials to store the excessive temperature in a form of latent heat [15]. Paraffin wax is one of the available materials which can be easily attached on the back side of the panel using turning pack as it has some low thermal conductivity. This material works very well in higher temperature condition as the wax starts melting properly. Cooling system using PCM decreases the operating temperature by almost 30°C with an overall power gain of 55% [16]. In addition to that, the reduction of temperature more than 30°C is also possible by adding fins on the back panel instead of flat aluminum plate. A typical schematic diagram of PV panel with PCM is shown in Fig 6 below:

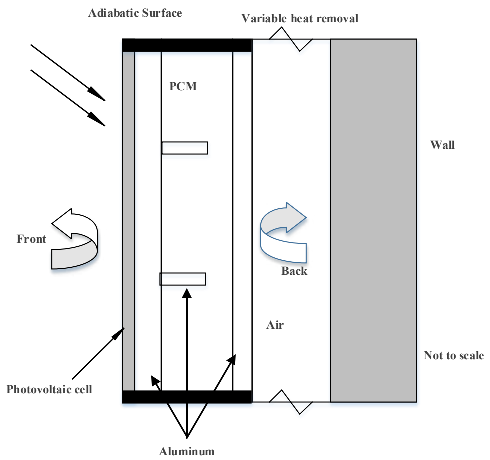

Fig. 6. PV Panel with PCM [11]

Cotton wick cooling: In this method, layer of wet cotton is attached on the back side of the panel which creates a moist environment. Usually this layer of cotton is connected with some water reservoir. It can decrease the temperature almost by 30% with a maximum efficiency of 10.2% while producing power [17].

Evaporative cooling technique: This cooling method [18] is also promising as it does not suffer from any on site parasitic effect like other passive cooling technique. In real life we also have application of evaporative cooling where air motion is not desired. For example: recording studio, dark room for film development or places like hospital. Usually evaporation occurs when small portion of working fluid changes it's phase and withdraw the latent heat in a form of vapor. This system is developed which is made of copper and covered with synthetic clay to allow indirect evaporation. A clay layer with thickness of 2 mm performs best for evaporation process with maximum 19.1% enhancement in power generation [19].
Using dielectric medium: In this cooling method, the complete panel is immersed into the dielectric medium to reduce the heat. The solution could be of any combination but the efficiency is not that much promising so far [20] [21]. Earlier different techniques have been used individually to improve the PV panel efficiency. But in this moment the best method is hybrid approach where couple of cooling techniques are applied together to get the best PV panel efficiency.

III. ANALYSIS OF DIFFERENT METHODS

It is of utmost importance to choose the right cooling technique while developing the hybrid thermal PV panel where the prime concern is to maximize the power generation by making the system as efficient as possible. To achieve the goal an appropriate cooling method must be selected from the vast options of active and passive techniques. The main goal is to choose a technique which is less expensive, eco-friendly and requires less operating cost. Here all the cooling techniques along with their possible limitations are described in Table I:

TABLE I. ANALYSIS OF DIFFERENT COOLING METHODS

Cooling Type	Method Name	Main mechanism	Limitations
Active	Air flow based (PVT/AIR-REF)	Create a flat channel between solar cell and back wall for air flow	Not beneficial for area with very nominal air flow and channel depth should be minimum 10 cm in general
Active	Air flow based (PVT/AIR-TMS)	Create a channel with thin metal sheet in between cell and back wall	Metal shit must be placed in such way that there is enough spacing with the cell and back wall
Active	Air flow based (PVT/AIR-FIN)	Create a channel with multiple fins attached with back wall	Lack of proper attachment to the back wall could degrade the performance
Active	Fluid based (PVT/WATER-Nozzle)	Spraying water with nozzle by using motor	An array of nozzles required to ensure uniform distribution of temperature
Active	Fluid based (PVT/WATER-Trickling)	Dripping water from external sources throughout the front panel surface	Recycling the water for continuous usage.
Active	Fluid based (PVT/WATER-FGM)	A heat sink is created by adding graded materials	Required efficient design with proper use of graded material
Active	Refrigerant based	Refrigerant or coolant is pumped though a channel	It is very expensive and need to maintain different pressure

			levels throughout the system
Active	Heat pipe	Additional pipes are attached with the panel to pass the heat	Overheating of heat pipe may have an adverse effect
Passive	Submerged water cooling	Large amount of heat is dissipated by putting the panel into water	Leak proof design is mandatory to avoid liquid admission
Passive	Heat sink	Aluminum fins are attached on the back side of the panel to absorb the heat	Significant difference in temperature is required between the fins and ambient air to transfer the heat
Passive	Phase changed materials (PCM)	Materials like paraffin wax is used to store the latent heat	Works well only on high temperature condition due to it's higher melting point.
Passive	Cotton wick	Wet cotton is added on the rear side of the panel to create a moist condition due to capillary action	Highly depends on the wet capability of the cotton.
Passive	Evaporative	Latent heat is transferred via evaporation	Continuous supply of water required, under dry condition there could be crack on the clay.
Passive	Dielectric medium	This method involves immersing the front and back panel inside dimethyl-silicon oil	The percentage of temperature reduction is very nominal.

IV. RESULT ANALYSIS

Different techniques related with PV panel cooling techniques have been discussed thoroughly. Each and every technique has some advantage along with some limitations. Here in the Fig. 7 a comparison based on efficiency of different methods are summarize where the value ranges from 2-55%.

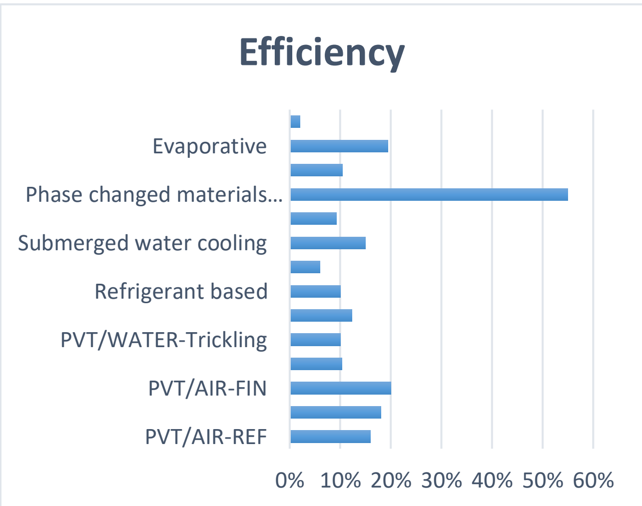

Fig. 7. Comparison of efficiency for different cooling technique

Using different cooling techniques, the efficiency increased almost around 20%. But PCM based technique is capable of increasing the efficiency up-to 55% which is very significant number.

V. CONCLUSION AND LIMITATIONS

In most cases active cooling and passive cooling techniques performs equally. But active cooling technique has some limitations like requirements of additional power sources to operate the cooling system. Not only that-to some extent it is not eco-friendly at all. In contrast with active cooling technique- passive cooling technique is more preferred as it does not require any kind external power sources to operate which also ensures the low operational cost of the system. Not only that the passive cooling system is more eco-friendly as well and free from all kind of parasitic effects. So the applicable cooling technique solely depends on the application but passive cooling will be dominating on the coming days. Hybrid approaches are also considered as the future of PV panel efficiency enhancement.

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