Performance Evaluation of Solar PV Panel by Micro Pulsating Heat Pipe as Cooling Device

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Abstract— In photovoltaic solar panels, a large amount of heat must be dissipated through all areas. The above purpose is met by making use of micro pulsating heat pipes. Micro pulsating heat pipes are of different geometries depending, upon practical applications. In this work we would like to investigate the effect of Micro Pulsating Heat Pipe on heat transfer. The MPHP where designed and manufactured from the data collected from literature survey. Model is fabricated to determine the heat transfer rate and efficiency. Then the results of readings and calculations are plotted. The observations give the amount of heat transfer and increase the efficiency of PV panels.

Key words: Solar, PV Panel, Heat Pipe

I. Introduction

Energy is the quantitative property that required to do work or to heat the object. There are different forms of Energies, i.e. mechanical energy, electrical energy, magnetic energy, gravitational energy, nuclear energy, thermal energy and solar energy etc. These forms of energies having different sources, mainly divided into two types non-renewable and renewable. Non-renewable sources are finite resources and renewable sources which can be used repeatedly. In renewable sources the main source is Solar Energy because large amount of energy is incident on Earth surface (3.5–7.0 kWh/m² per day approx. 3,850,000 exajoules (EJ) per year). This much amount of energy we lost every day. By using photovoltaic panel, we can convert solar energy into electrical energy and use it. There are different types of PV panels as follows:

Solar Cell Type	Efficiency-Rate	Disadvantages
Monocrystalline Solar Panels (Mono-SI)	~20%	Expensive
Polycrystalline Solar Panels (p-Si)	~15%	Lower price
Thin-Film: Amorphous Silicon Solar Panels (A-SI)	~7-10%	Relatively low costs; easy to produce & flexible
Concentrated PV Cell (CVP)	~41%	Very high performance & efficiency rate

Table. Type of solar panels and their efficiency

The efficiency of solar PV cells gets reduced with increase in panel temperature. It is noted that efficiency drops by about 0.5% for increase of 1-degree Celsius of panel temperature. It is necessary to operate them at low temperature. In order to keep the PV module electrical efficiency at acceptable level. Therefore, need for a low-cost cooling system for the solar panel is felt. The cooling of solar PV panel is a problem of great practical significance.

A. *Cooling techniques for PV panel:*

Efficiency of PV panel is increased by cooling the PV panel. As the PV panel cools, higher will be the electrical outputs. There are mainly two types of cooling techniques

1) *active cooling techniques: -*

active cooling techniques consumes the energy. It consists of:

- pumping water (pump)
- blowing air (blower, fan)

2) *passive cooling techniques: -*

In passive cooling techniques heat extraction enabled by using natural convection/conduction.

- Heat pipe
- Pulsating heat pipe

In water spraying and Air blowing cooling techniques the energy is required to run the motor, pump, fans, blowers, etc.

Heat pipe cooling technique have limitations in becoming thinner and more flexible as a result of their weak structure.

All the above cooling system having the problem of flexibility of design, high weight and increase in size.

All above problems are overcome in the pulsating heat pipe that’s why we selected the pulsating heat pipe as a cooling device.

B. *Factors affecting the performance of PHP's:*

1) *Tube material:*

Copper having high thermal conductivity that’s why we use copper material for PHP.

2) *Tube diameter:*

The internal diameter of the PHP influences the thermal performance. This is directly related to the surface tension of fluid with the PHP material and gravity. Design of a PHP has some constraints which the basic criteria are to induce the pulsating flow inside the tube. This criterion is defined by Bond number (Bo). From the equation:

$D \le D_{cr} = 2[\sigma/g(\rho_f - \rho_g)]^{0.5}$

where, D is the allowable diameter of PHP, Dcr is the critical diameter, σ is the surface tension, g is the gravity, and ρf and ρg are the densities of working fluid at liquid and gaseous phase.

$D_{critical} = 2 x \sqrt{\sigma}/(\rho_{liq} - \rho_{vap}) x g$

For Water

$= 2 x \sqrt{19.09} x 10^{-3}/(748.5 - 2.123) x 9.81$

$= 2 x 2.72 x 10^{-3}$

$\boxed{D_{critical} = 5.44 x 10^{-3} m}$

Eotvos Number (Eö): - $g x D^2 x (\rho_{liq} - \rho_{vap})/\sigma$

For Water

$= 9.81 x (0.5x10^{-3})^2 x (1000 - 0.554)/72.75 x 10^{-3}$

$\boxed{Eö = 0.033}$

3) *Cross-section:*

Circular cross-section also reduces the flow drag resistance which in turn improves the flow characteristics by assisting oscillation. Thus, PHP with cross-section other than circular are bound to miss these advantages. However, reducing the influence of gravity and inclination of modification in design will definitely affect the performance of PHP in constructive manner.

4) Inclination:

Latitude and longitude for India.
Latitude: 20” 00’N
Longitude :76” 00’E
Latitude and longitude for Lonavala
Latitude: 18” 44’N
Longitude :73”28’E
Therefore, we select angle between 15 to 19 degrees

5) Filling Ratio: (70% of volume)

Volume of MPHP, $V = \frac{\pi}{4} * D^2 * L$

$$V = \frac{\pi}{4} * (0.5 * 10^{-3})^2 * 33$$
$$V = 6.48 * 10^{-6}\ m^3$$
$$V = 6.48 * 10^{-3}\ litre$$

II. CALCULATIONS:

A. Fill Factor: -

Fill factor is the figure of merit for the PV panel, it tells how good or how bad is the PV panel.

a. If the value of fill factor is more than 0.7, the PV panel is in good condition.
b. If the value of fill factor is less than 0.7, the PV panel is in bad condition.

$$FF = \frac{V_{mp} * I_{mp}}{V_{oc} * I_{sc}}$$
$$FF = \frac{17.8 * 2.25}{21.95 * 2.44}$$
$$\boxed{FF = 0.7477}$$

Therefore, our panel is in good condition.

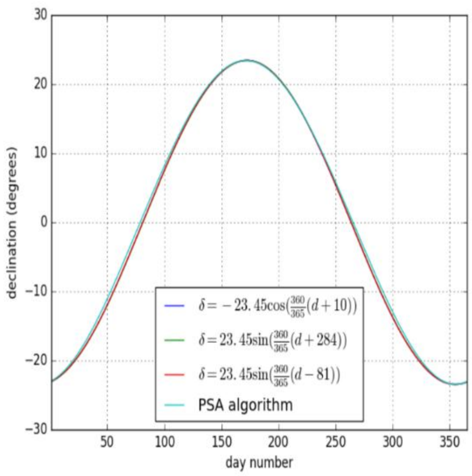

Fig. A graph of declination vs day number

B. Daily Energy Incident on Horizontal Flat Plate is,

$$H_O = \frac{24 * K * L_{SC}}{\pi}[cos\phi * cos\delta * sin\omega_{sr} + \omega_{sr} * sin\phi * sin\delta]$$

Where,

$$K = 1 + 0.033 * \cos\left(\frac{360 * N}{365}\right)$$

$$\rightarrow \left\{\begin{matrix} N\ is\ day\ number \\ = 1\ is\ for\ JAN\ first \\ = 365\ is\ for\ DEC\ 31st \end{matrix}\right\}$$

$$\boxed{L_{sc} = 1.37\ KW/m^2}$$

$\omega_{sr} = cos^{-1}(-tan\phi * tan\delta)\ rad$
$\phi = Lattitude\ of\ the\ place$
$\rightarrow \{for\ \ Lonavala\ 18.76^0\ N, 73.41^0\ E\}$
$\delta = Declination$
$\left\{\delta = -23.45 * cos\left(\frac{360}{365}(d + 10)\right)\right\}$

Then,

$$K = 1 + .033 * \cos\left(\frac{360 * N}{365}\right) \quad \rightarrow \begin{bmatrix} JAN = 31 \\ FEB = 28 \\ MARCH = 31 \\ APRIL = 12 \end{bmatrix}$$

$$K = 1 + .033 * \cos\left(\frac{360 * 102}{365}\right)$$
$$\boxed{K = 0.9939}$$

$\omega_{sr} = cos^{-1}(-tan\phi * tan\delta)\ radian$
$\delta = -23.45 * cos\left(\frac{360}{365} * (d + 10)\right)$
$\delta = -23.45 * cos\left(\frac{360}{365} * (102 + 10)\right)$
$$\boxed{\delta = 8.1992^0}$$

$\omega_{sr} = cos^{-1}(-tan\phi * tan\delta)$
$\omega_{sr} = cos^{-1}(-tan18.76^0 * tan8.1992^0)$
$$\omega_{sr} = 92.80$$

$$H_O = \frac{24 * K * L_{SC}}{\pi}[cos\phi * cos\delta * sin\omega_{sr} + \omega_{sr} * sin\phi * sin\delta]$$
$$H_O = \frac{24 * 0.9939 * 1.37}{\pi}[cos18.76 * cos8.1992 * sin92.80 + 92.80 * sin18.76 * sin8.1992]$$
$$\boxed{H_O = 54\ KWhr/m^2/\text{day}}$$

C. Daily Energy Incident On a tilted Flat Plate is,

1) $H_{Ot} = \frac{24 * K * L_{SC}}{\pi}[cos(\phi - \beta) * cos\delta * sin\omega_{srt} + \omega_{srt} * sin(\Phi - \beta) * sin\delta]$
 $\omega_{sr} = cos^{-1}(-tan\phi * tan\delta)$
 $\omega_{sr} = cos^{-1}(-tan18.76 * tan8.1992)$
 $\omega_{sr} = 92.80$
2) $\omega_{sr\beta} = cos^{-1}(-tan(\Phi - \beta) * tan\delta)$
 $\omega_{sr\beta} = cos^{-1}(-tan(18.76 - 15) * tan8.1992)$
 $\omega_{sr\beta} = 90.54$
3) $K = 1 + .033 * cos\left(\frac{360 * N}{365}\right)$
 $K = 1 + .033 * \cos\left(\frac{360 * 102}{365}\right)$
 $K = 0.9939$
4) $L_{SC} = 1.37\ KW/m^2$ $\delta = 8.1992$
$\Phi = 18.76$
$H_{Ot} = \frac{24 * K * L_{SC}}{\pi}[cos(\phi - \beta) * cos\delta * sin\omega_{srt} + \omega_{srt} * sin(\Phi - \beta) * sin\delta]$
$H_{Ot} = \frac{24 * 0.9939 * 1.37}{\pi}[cos(18.76 - 15) * cos8.1992 * sin90.54 + 90.54 * sin(18.76 - 15) * sin8.1992]$
$H_{Ot} = 19.0680\ \ KWhr/m^2/\text{day}$

D. *Ideal Calculation: -*

1) *Effect of Temperature on current*$(25^0\text{c} - 55^0\text{c})$:-

$$I_{SC}\ per\ 55^0c = I_{SC}\ per\ 25^0c\ + \frac{\alpha I * I_{SC}\ per\ 25^0c*\Delta T}{100}$$

$$I_{SC}\ per\ 55^0c = I_{SC}\ per\ 25^0c * \left(1 + \frac{\alpha I*\Delta T}{100}\right)$$

$$I_{SC}\ per\ 55^0c = 2.44 * \left(1 + \frac{0.045*(55-25)}{100}\right)$$

$$I_{SC}\ per\ 55^0c = 2.4829\ A$$

2) *Effect of temperature on voltage*$(25^0\text{c} - 55^0\text{c})$:-

$$V_{oc}per\ 55^0 = V_{oc}per\ 25^0 + \Delta V$$

$$V_{oc}per\ 55^0 = V_{oc}per\ 25^0 * \left(\frac{\alpha V * V_{oc}per\ 25^0*\Delta T}{100}\right)$$

$$V_{oc}per\ 55^0 = V_{oc}per\ 25^0 * \left(1 + \frac{\alpha V*\Delta T}{100}\right)$$

$$V_{oc}per\ 55^0 = 21.8 * \left(1 + \frac{-0.34*(55-25)}{100}\right)$$

$$\boxed{V_{oc}per\ 55^0 = 19.5764V}$$

3) *Effect of temperature on Power:* For $(25^0\text{c} - 55^0\text{c})$

$$P_m per\ 55^0 = P_m per\ 25^0 + \Delta V$$

$$P_m per\ 55^0 = P_m per\ 25^0 + \left(\frac{\alpha P*P_m per\ 25^0*\Delta T}{100}\right)$$

$$P_m per\ 55^0 = P_m per\ 25^0 * \left(1 + \frac{\alpha P*\Delta T}{100}\right)$$

$$P_m per\ 55^0 = 40 * (1 + (-0.47 * (55 - 25))/100)$$

$$P_m per\ 55^0 = 34.36\ W$$

III. OBSERVATIONS: -

Readings For 5 Hours

A. *Without MPHP*

Starting Voltage= 22.4 V
Starting Current= 2.2 A
Ending Voltage= 20.6 V
Ending Current= 2.228 A

1) *Observation Table: - (observation taken in 5hrs)*

Table Observation table without MPHP

Time(min)	Voltage(V)
1	22.4
2	22.3
3	22.2
5	22.1
7	22.0
9	21.9
13	21.8
17	21.7
23	21.6
28	21.5
34	21.4
39	21.3
51	21.2
63	21.1
72	21.0
81	20.9
91	20.8
114	20.7
240	20.6

B. *With MPHP*

Readings for 5hrs
Starting Voltage= 22.4 V
Starting current= 2.2 A
Ending Voltage= 20.7 V
Ending Current= 2.228 A

1) *Observation Table: - (observation taken in 5hrs)*

Table Observation table with MPHP

Time(min)	Voltage(V)
1	22.4
2	22.3
3	22.2
5	22.1
7	22.0
10	21.9
13	21.8
18	21.7
25	21.6
29	21.5
37	21.4
48	21.3
59	21.2
78	21.1
89	21.0
105	20.9
123	20.8
240	20.7

C. *ACTUAL CALCULATION*

1) $I_{at\ 55^oc} = I_{at\ 25^oc}(1 + \frac{\alpha\Delta T}{100})$

$$= 2.2(1 + \frac{0.045*(55-25)}{100})$$

$$I_{at\ 55^oc} = 2.2297A$$

2) $V_{at\ 55^oc} = V_{at\ 25^oc}\left(1 + \frac{\alpha\Delta T}{100}\right)$

$20.6 = 22.4(1 + \frac{-0.34*(55-25)}{100})$

$V_{at\ 55^oc}$=20.1152V

3) $P_{m\ at\ 55^oc} = P_{m\ at\ 25^oc}(1 + \frac{\alpha\Delta T}{100})$

$= 49.28(1 + \frac{-0.47*(55-25)}{100})$

$P_{m\ at\ 55^oc} = 42.33W$

By temperature changes the value of current, voltage and power are changes.

The maximum change in values is as follows

1) I will increase from 2.2 to 2.2297A.
2) V will decrease from 22.4 to 20.1152V.
3) P will decrease from 49.28 to 42.33 W.

D. *Efficiency Calculations*

1) $\eta_{ideal} = \frac{V_{oc}*I_{sc}}{L*A}$

$$= \frac{V_{oc} * I_{sc}}{L * (l * b)}$$

$$= \frac{21.95 * 2.44}{1 * 270}$$

$$\eta_{ideal} = 19.83$$

2) $\eta_{actual} = \frac{V_{oc}*I_{sc}}{L*A}$

$$= \frac{V_{oc} * I_{sc}}{L * (l * b)}$$

$$= \frac{22.4 * 2.2}{1 * 270}$$

$\eta_{actual} = 18.25$

3) $\eta_{actual\ when\ temp.\ increase} = \frac{V_{oc} * I_{sc}}{L * A}$

$$= \frac{V_{oc} * I_{sc}}{L * (l * b)}$$

$$= \frac{20.6 * 2.228}{1 * 270}$$

$\eta_{actual\ when\ temp.\ increase} = 16.99\%$

4) $\eta_{actual\ PHP\ connected} = \frac{V_{oc} * I_{sc}}{L * A}$

$$= \frac{V_{oc} * I_{sc}}{L * (l * b)}$$

$$= \frac{20.8 * 2.228}{1 * 270}$$

$\eta_{actual\ PHP\ connected} = 17.16\%$

E. Increase temperature:

1) Without MPHP:

$$V_{at\ 55^o c} = V_{at\ 25^o c}\left(1 + \frac{\alpha \Delta T}{100}\right)$$

$$20.6 = 22.4\left(1 + \frac{-0.34 * \Delta T}{100}\right)$$

$23.63 = \Delta T$

$23.63 = T_{increase} - 25$

$T_{increase} = 48.63^o c$

2) With MPHP:

$$V_{at\ 55^o c} = V_{at\ 25^o c}\left(1 + \frac{\alpha \Delta T}{100}\right) \quad 20.8 = 22.4\left(1 + \frac{-0.34 * \Delta T}{100}\right)$$

$\Delta T = 21$

$T_{increased} - 25 = 21$

$T_{increased} = 46^o c$

IV. Conclusion

1) 1.By using MPHP the efficiency is increased by 0.17%.
2) By using MPHP the temperature of solar panel is decreased by $2.63^o c$.
3) The increase in efficiency and decrease in temperature of panel is very less.
4) The selection of micro pulsating heat pipe for cooling of solar panel is not right. We must use different cooling process for panel or select the different dimension of MPHP (Do not select the MPHP of 0.5 mm diameter of circular cross section which of closed end type).

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