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Research Article

Fabrication scheme, Instrumentation scheme and Testing of Ground Coupled Central Panel Cooling System (GC-CPCS)

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Abstract

Cooling of Photovoltaic cells is a problem of great significance,. The efficiency of wafer-based crystalline as well as Thin film Solar cells get reduced with increase of panel temperature. It is noted that the efficiency drops by about 0.4% for increase of 1° C of panel temperature. It is necessary to operate them at low temperatures in order to keep the PV module electrical efficiency at acceptable level. Therefore need for a low-cost cooling system for the Solar panels is felt. (Katkar A A et al 2011) .(Tang Y et al 2003) (Tonui J K et al, 2006) Air-cooling either by forced or natural flow, presents a non-expensive and simple method of PV cell cooling. A design for Ground-Coupled Central Panel Cooling System (GC-CPCS) has been proposed by Sahay Amit et al 2013. This plant is already installed and operational at Energy Park of Rajiv Gandhi Proudyogiki Vishwavidyalaya(RGPV), Bhopal, India. This paper presents the fabrication scheme, Instrumentation and Testing of Ground-Coupled Central Panel Cooling System (GC-CPCS).

Keywords: *Efficiency of Solar panels, Central Panel Cooling System (CPCS), Ground-Coupled Central Panel Cooling System (GC-CPCS), Smoke Flow Visualization, Analysis of Variance (ANOVA)*

1. Introduction

The I-V curve of a PV device under illumination is a strong function of temperature. An illuminated PV cell converts only a small fraction (approx. less than 20%) of irradiance into electrical energy. The balance is converted into heat, resulting into heating of the cell. As a result, the cell operates above ambient temperature. Keeping insolation level as constant, if the temperature is increased, there is a marginal increase in the cell current but a marked reduction in cell voltage. An increase in temperature causes reduction in the band gap. This in turn causes some increase in photo-generation rate and thus, a marginal increase in current. However, the reverse saturation current increases rapidly with temperature. Due to this, the cell voltage decreases by approximately 2.2 mV per °C rise in its operating temperature, depending on the resistivity of the silicon used: higher the silicon resistivity more marked is the temperature effect. (Khan B H 2006)

Therefore it is beneficial to apply artificial cooling to PV modules for the improvement in power output and optimum performance parameters. (Cruey Bryce et al 2006) Various methods have been applied for this purpose. The proposed system is referred to as *Ground Coupled Central Panel Cooling System.(GC-CPCS)* (Sahay Amit et al 2013)

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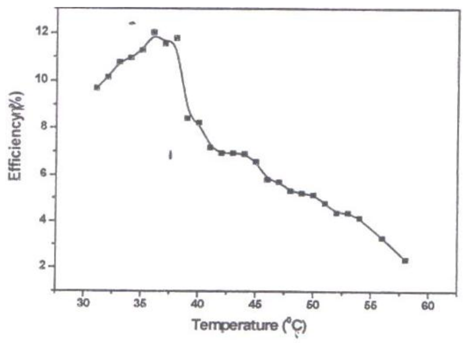

Fig 1 : Variation of Efficiency vs. Temperature (Katkar A A et al 2011)

2. Design considerations

The design considerations for cooling of PV panels draws from the pioneer work by Royne . *(Royne 2005).* The following cooling and operational requirements are considered. (Sahay Amit et al 2013)

- Cell Temperature:
- Uniformity of temperature
- Reliability & less maintenance cost:
- Pumping power:
- Minimal capital cost

3. Ground Coupled Central Panel Cooling System.(GC-CPCS) (Sahay Amit et al 2013)

The proposed method suffices to cool the Solar Panels by Forced Convection of ambient air driven by a blower. The blower is run by power provided by a separate and dedicated PV cell.

Air is passed through a ground-coupled heat exchanger to drop its temperature. The cooled air cools the Solar panels as it passes through the rear surface of the Solar Panels. To facilitate develop streamlines of flow, fibre sheets are placed towards the rear surface of the Solar panels. The air flows through the space between the fibre sheets and the rear surface of the Solar panels. (Fig 2) Natural convection is also possible in this set up.

There are nine Solar Panels of 100 W each. The air is driven by a single blower. This design is similar to Central cooling system. Hence the term *Central Panel cooling System (CPCS)*© is conceived.

The cooled air is distributed to each Solar Panels by means of a pipe. Nozzles are provided on the pipe through which the air comes out. Nozzles ensure that streamlines are developed in the desired direction.

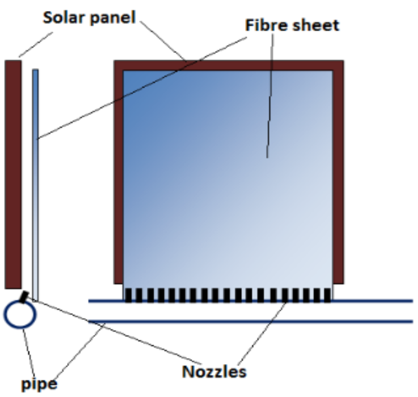

Fig 2: Arrangement of Solar panel, Fibre sheet and nozzles

3.1 Ground - Coupled heat exchanger /Earth Tubes

A Ground-Coupled heat exchanger is an underground heat exchanger that can (a) capture heat from ground and/or (b) dissipate heat to the ground. They use the Earth's near constant temperature to warm or cool air for residential or industrial use.

If building air is blown through Ground-Coupled heat exchanger for heat recovery ventilation they are called *Earth Tubes*. Earth Tubes are viable and economical alternative to conventional Central Cooling Systems since there are no compressors, chemicals or burners and only blowers are required to move the air. (http://en.wikipedia.org/wiki/ Ground-coupled_heat_ exchanger)

3.2 Central Panel Cooling System (CPCS)

Here we draw analogy from the widely used Central Air Conditioning Systems. There are two broad categories of Air conditioning systems :
(a) Centralised air conditioning systems (b) Decentralized air conditioning systems *(Bhatia A)*

Centralised air conditioning systems serve multiple spaces from one base location. *Decentralised air conditioning systems* typically serve single or small spaces from a location within or directly adjacent to the space.

Central Panel Cooling System(CPCS) is similar to Centralised air conditioning systems. In Centralised air conditioning systems chilled water is used as a cooling medium.

The Central Panel Cooling System(CPCS) proposes to use cooled air, as the working fluid, which comes through the *ground coupled heat exchanger* which makes a G*round-coupled Central Panel Cooling System (GC-CPCS)*. The schematic drawing is shown in Fig 3.

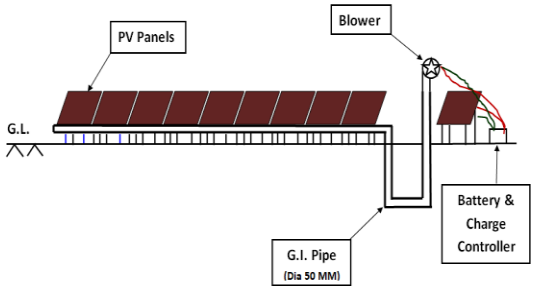

Fig 3: Schematic design of GC-CPCS

3.3 Design characteristics of GC-CPCS

Design of underground heat exchanger, pipe, nozzles, head losses, power of blower etc are made according to flow chart at fig 4.

For details please refer the pioneering work by Sahay Amit et al 2013 in which the concept of CPCS as well as GC-CPCS is developed.

The parameters are calculated taking pipe diameters as 20, 30, 40, 50, 60 mm and Total Head Losses were calculated.

Table 1: Nomenclature

Nomenclature
A_{panel} = Area of panel (m^2)
D: Diameter of pipe (mm)
g: Acceleration due to gravitation (m/s^2)
H: Total head loss (m of air column)
I : Current (A)
I_G : Global irradiance (W/m^2)
L : Length of panel (m)
Lpipe: Length of underground pipe (m)
$\dot{m}T$: Total mass flow rate (kg/s)
P : Pumping power required (W)
P_{Blower} : Power input to blower (W)
T_w : Wall temperature, oC, (under earth temp.)
T_i : Inlet air temperature of underground pipe,oC
T_o: Outlet air temperature of underground pipe, oC
T_a: Ambient temperature, oC
Tp_{avg}: Average panel temperature, oC
V : Voltage (Volt)
W: Width of panel (m)
η_o : Overall efficiency of blower
η_{panel} : Panel efficiency

The variation of Total Head Loss with Diameter is shown in Fig 5. Total Head loss is too high at D = 20 mm.

Further, we find that at D = 50 mm we are close to asymptote. Hence the *optimum diameter* for this system is D = 50 mm. Therefore at D = 50 mm the following parameters are calculated.

L_{pipe} = 4.45 m
H = 104.176 m
$\dot{m}_T$ = 7.6481 x 10^{-3} kg/s
P = 7.816 W
P_{Blower} = 15.632 W

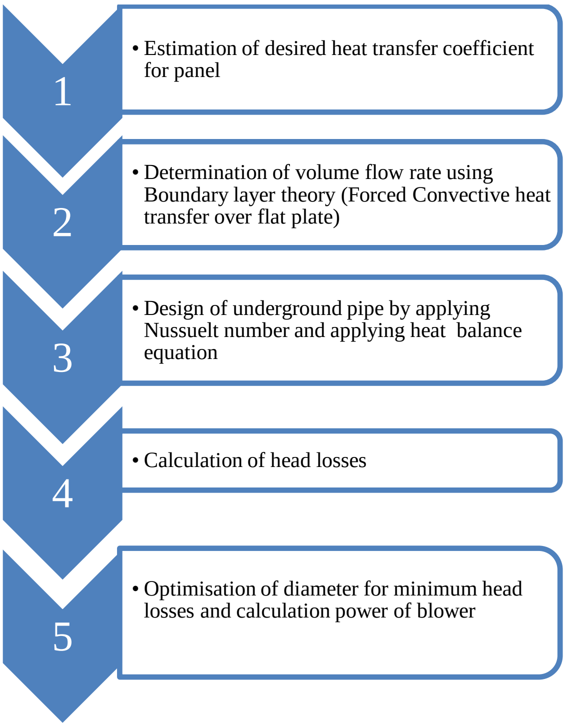

Fig 4: Flow Chart for design of GC-CPCS

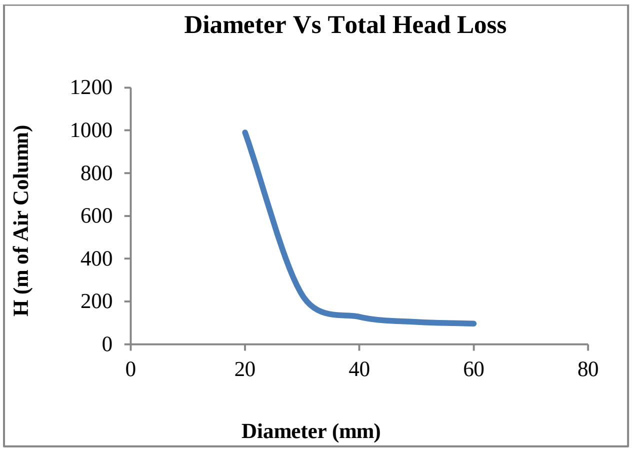

Fig 5: Variation of Total head Loss vs. Diameter

This system is installed at Thin-Film Solar PV panels at Energy Park of Rajiv Gandhi Proudyogiki Vishwavidyalaya (RGPV), Bhopal, India. (Fig 6)
Number of Solar panels = 09

Specifications of a single Solar PV panel:

Make : Schott Solar
Type : Solar Thin Film Module, Single junction a-Si/ CIGS Technology
Capacity : 122 W (Initial)
: 100 W (Stabilized)
Voltage at Nominal power : 17.5 V
Current at Nominal power : 5.71 A
Open circuit voltage : 23.8 V
Short circuit current : 6.79 A
Dimensions : 1.27 m x 1.27 m
Area : 1.6129 m^2
Thickness : 50 mm
Weight : 18 kg

Fig 6: Thin-Film PV panels at RGPV, Bhopal

4. Equipments & Fabrication

Fig 7: Thin-Film PV panels at RGPV, Bhopal after the installation of GC-CPCS

4.1 Fabrication of underground heat exchanger and pipeline

4.1.1 Diameter of pipe

Optimum diameter of pipe is calculated as 50 mm. Therefore dia. 50 mm GI pipe is used for the Pipe line.

4.1.2 Length of pipe

Length of underground heat exchanger is 4.45 m. Total length of pipe used is approximately 25 m.

4.1.3 Depth of underground heat exchanger

Temperature at 3 m below earth surface is considered near constant. Therefore optimum depth for underground heat exchanger is taken as 3 m.

4.1.4 Support frame for pipe

Sliding frame supports, 5 nos., are provided for the pipe line. The frames are designed in two halves. The two frames can slide over each other. The sliding arrangement is provided to make room for mounting and dismantling of the pipeline.

Fig 8: Arrangement of pipe line and support frames of GC-CPCS

Fig 9: Sliding design of support frames

4.2 Design and arrangement of nozzles

The nozzles are provided to direct the air at the rear surface of the Solar PV panels.(Fig 10) 20 nos. equally spaced nozzles are provided per Solar PV panel to ensure uniform distribution of air.

Internal diameter of nozzle is 4 mm and it designed as per figure 11.

Length to diameter ratio of nozzle is kept > 4 to ensure formation of streamlines.

Material used for nozzle is Copper. Tubes from air conditioning equipments are used as raw material to make the nozzles.

Holes are drilled on the pipe line at correct locations and the nozzles are brazed on the holes such that the air flowing inside the pipe line flows through the nozzles.

Fig 10 (i) : Arrangement of nozzles on the pipe line

Fig 10 (ii): Arrangement of nozzles on the pipe line

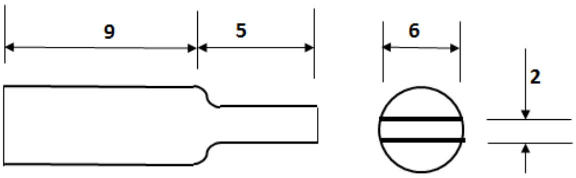

Fig 11: Design of nozzle (not to scale)

4.3 Cover at rear surface of Solar PV panels

To facilitate flow of air, passage is provided at rear surface, of photovoltaic cells by providing sheets of *Transparent PVC Flexible sheet* (fig 12) . The Sheet used is of 1 mm thickness.

Fig 12: Arrangement of fibre sheet at rear side of panels

4.4 Blower, Battery and Charge controller (fig 14)

A dedicated Solar photovoltaic cell, battery and a charge controller is provided to charge the battery which is provided to run the blower.

4.4.1 Battery (Fig 14)

Battery is used to run the blower. The battery is the most common type of storage device in Solar PV system. Batteries store the electrical energy generated by the modules during the day The battery needs DC for charging. The electricity generated from solar cells is also DC, which can be easily stored in the battery. Without involving any intermediary process. A 12 V X 150 Ah battery is used.

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Fig 13: Blower used in the experimental set up

Fig 14: Solar PV panel along with battery and charge controller, dedicated to supply power to the blower

4.4.2 Blower (Fig 13, 14)

A DC Blower is used. It is the kind of blower which is used for automotive air conditioning system.

4.4.3 Charge controller (Fig 14)

A charge controller is provided. Charge controller is a device used to control the amount of charge flowing in and out of a battery.

5. Instrumentation scheme of GC-CPCS testing

The parameters to be measured are the following

(i) Irradiance
(ii) Ambient Temperature
(iii) Temperature of output air from the underground heat exchanger
(iv) Output current
(v) Output voltage

The following measuring systems are used for the measurement of above mentioned parameters.

5.1 Weather Monitoring Station, Watch Dog (Fig 15)

Solar Irradiance and ambient temperature is measured by using a Weather Monitoring Station

Fig 15: Watch Dog (Weather Monitoring Station)

5.2 Pyranometer (Fig16)

Pyranometer is provided in the Weather Monitoring Station. It is used to measure Total Solar radiation.

Fig 16: Pyranometer installed in Weather Monitoring Station

5.3 Solar Power Conditioning unit (Fig 17)

Fig 17: Solar Power Conditioning Unit (SPCU)

Solar Power Conditioning Unit SPCU) receives DC power from Solar PV cells and converts it to 3 Phase AC power to run the Solar pump. DC Current and Voltage is measured with SPCU.

5.3 RTD arrangement for Panel temperature

RTD is provided at the rear of panel to sense panel temperature.

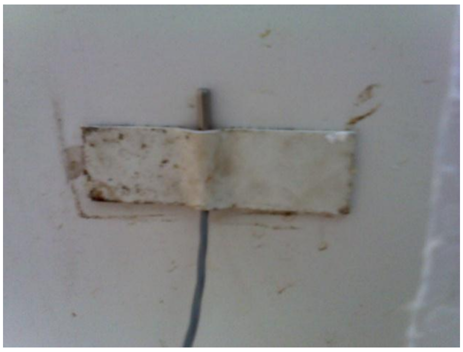

Fig 18: RTD type PT100

5.4 Thermocouple for Air temperature

Thermocouple, type J, is provided at the out let to underground heat exchanger to measure the air temperature.

Fig 19: Thermo couple arrangement

6. Testing of GC-CPCS

6.1 Smoke Flow Visualization

Flow visualization is a technique used in Fluid Mechanics to make the flow pattern visible. In the Smoke Flow Visualization technique, smoke is adverted in a real flow of gases and its temporal behaviour gives information about the flow. To perform this test incense stick (Dhoop) is used to form smoke. The smoke is then fed at the inlet of the blower which is instantly transported to all the panels. (Fig 19) The smoke comes out from the entire length of the panel assembly. This clearly indicates that GC-CPCS is able to uniformly distribute the cool air throughout the panels.

Fig 20: Smoke Flow Visualization Test

6.2 *Data collection for Statistical treatment*

The end result of this experiment is improvement in conversion efficiency of PV panels. The causal effect of convective cooling on conversion efficiency of the Solar Panels is of particular interest.

The state of existent convective cooling versus no convective cooling is distinguished by status of the blower as ON and OFF. Therefore observations are taken by keeping the blower OFF and ON alternately allowing response time of 10 minutes.

The data collected per observation are the following.

(a) Time
(b) Blower status
(c) Outlet Air temperature (from ground-coupled heat exchanger)
(d) Irradiance
(e) Current
(f) Voltage

The observations are compiled in Table 2.

Table 2: Observations

TESTING OF GC-CPCS TYPE OF TEST : TWO WAY ANOVA								
TEST SL NO. 4 DATE : 10-02-2014 AMBIENT TEMP.: 26^O C A_{panel} = 1.6129 m^2 No of panel = 9								
Time	**Time**	**Blower**	**Panel temperature**	**Outlet Air Temp.**	**Irradiance**	**Current**	**Voltage**	**Efficiency**
ABS	**STD**	**STATUS**			**G**	**I**	**V**	**η**
Minutes	**IST**	**ON/O FF**	**^{0}C**	**^{0}C**	**W/m^2**	**Ampere**	**Volt**	**%**
0	16:02	OFF	44	X	390	3.1	192.5	10.54
0	16:02	ON	X	X	X	X	X	X
10	16:12	ON	42	27	350	3.1	192.3	11.73
10	16:12	OFF	X	X	X	X	X	X
20	16:22	OFF	40	X	310	3.2	191.8	13.64
20	16:22	ON	X	X	X	X	X	X
30	16:32	ON	38	27	280	3.3	192.2	15.60
30	16:32	OFF	X	X	X	X	X	X
40	16:42	OFF	37	X	240	3.2	192.2	17.65
40	16:42	ON	X	X	X	X	X	X
50	16:52	ON	35	27	210	3.2	191.2	20.07
50	16:52	OFF	X	X	X	X	X	X
60	17:02	OFF	35	X	170	3	190.1	23.11
60	17:02	ON	X	X	X	X	X	X
70	17:12	ON	34	27	150	2.9	189.9	25.29

6.3 *Salient points of the Observations*

The following points were salient points of the observations.

(a) Solar Irradiance (radiation) is time varying.
(b) Conversion efficiency of varies with the panel temperature as well as the cooling system is not running or running ie. Blower status – OFF or ON.
(c) Therefore it is a matter of great interest to establish the causal effect of panel temperature and cooling action on the conversion efficiency. The conversion efficiency at different panel temperatures and blower status –OFF and ON, is tabulated at Table no. 3.
(d) ANOVA technique is used to study whether efficiencies differ significantly due to convective cooling or it differ significantly due to Panel temperature.

Table 3: Efficiency data at different Panel temperatures and Blower status – OFF or ON

PANEL TEMP	BLOWER STATUS - OFF	BLOWER STATUS – ON
^{0}C	Efficiency %	Efficiency %
44	10.54	11.73
40	13.64	15.60
37	17.65	20.07
35	23.11	25.29

6.4 *Two-way ANOVA analysis*

Analysis of Variance (ANOVA) is a collection of Statistical models used to analyze the differences between group means.

Table 4: ANOVA table (Two way)

	SS	DF	MS	F-Ratio	5% F-limit
COLUMN	7.51	(2- 1) = 1	7.51	52.52	F(1,3) = 10.13
ROW	190.39	(4-1) = 3	63.46	443.77	F(3,3)= 9.28
RESIDUAL	0.43	1X3 =3	0.143		

The basic principle of ANOVA is to test for difference among the means of the population by examining the amount of variation within each of these sample relative to the amount of variation between the samples. (*Kothari C R, 2008*)

Two-way ANOVA technique is used when the data are classified on the basis of two factors,

Two-way ANOVA table is made in table no. 4. We make the following inferences.

(a) It is observed that the calculated F-ratio for column, 53.74, is more than the table value of F-ration at 5% level of significance. Therefore the effect of Blower status on the efficiency is significant. This validates the efficacy of GC-CPCS.
(b) It is observed that the calculated F-ratio for row, 452.96, is more than the table value of F-ratio at 5% level of significance. Therefore the effect of Panel temperature on the efficiency is also significant.

Conclusions and future work

Experimental set up is designed and fabricated for testing of innovative panel cooling technology, *Ground-Coupled Central Panel Cooling System* (GC-CPCS). This technology is conceived, designed and fabricated at School of Energy & Environment Management, Rajiv Gandhi Proudyogiki Vishwavidyalaya RGPV), Bhopal. The conclusions are given below.

(i) GC-CPCS is tested by using Smoke Flow Visualization technique.
(ii) Further it is validated by using suitable Statistical techniques.
(iii) This is a retrofitted design. Dedicated and original design is bound to give better results.
(iv) Many technologies have been tried out to cool photovoltaic panels. We need to compare GC-CPCS with them.

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