Temperature Regulation and Thermal Energy Storage Potential of Phase Change Materials Layer Contained at the Back of a Building Integrated Photovoltaic Panel

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ABSTRACT

Photovoltaics (PV) deployed in high solar radiation high ambient temperature climate suffer huge loss in efficiency and degrade faster due to higher panel temperature. In order to overcome the temperature induced loss of power and life, s paraffin wax based solid-liquid phase change material (PCM) integrated at the back of PV is investigated in high temperature climate of UAE. The temperature drop on the PV panels due to inclusion of the PCM is recorded and compared to a reference panels without PCM. The associated voltage gain caused by temperature drop of PV due to PCM also recorded to evaluate the effectiveness of PCM in temperature regulation and electrical performance enhancement of PV. A temperature drop of 12 °C and and associated voltage gain of is observed which shows such systems are effective in even mild weather condition of a hot climate

INTRODUCTION

Silicon photovoltaics (PV) show a power drop above 25 °C with a temperature coefficient of up to -0.65 %-K-1 depending on type of the PV cell and the manufacturing technology [1]. The operating temperature reached by PV panels and associated power drop largely depends on the climate of the site. In Germany 50 % of the solar radiation incident on a PV panel is above 600 W/m2 while in Sudan this value reaches 80 % resulting different operating temperatures and associated power drop [2] urging a strong need for PV temperature regulation to maximize both panel lifetime and power output. Different passive and active heat removal techniques have been used to maintain PV at lower temperatures. Passive heat removal in free standing PV relies on the buoyancy driven air flow in a duct behind the PV [3]. Heat removal depends on ratio of length to internal diameter (L/D) of the duct [4] with the maximum heat removal obtainable at an L/D of 20 [5]. Passive heat removal in building integrated photovoltaics (BIPV) relies on buoyant circulation of air in an opening or air channel, instead of a duct, behind the PV [6] Active cooling of PV relies mostly on air or water flow on the front or back of the PV surface. Effect of air flow at different inlet velocities and air gaps on front side and back side of PV temperature was modelled and a maximum 34.2 °C temperature decrease was predicted at air inlet velocity of 1 ms-1 and front and back air gap of 20 mm [7] .Water flow on the front surface of a free standing PV has a decreased cell temperature of up to 22 °C along with decreasing reflection losses from PV surface yielding an 8-9 % increase in electrical power output [8]. Water flow on the back of a façade integrated PV has theoretically shown optimum electrical and thermal performance at a water flow rate of 0.05 kgs-1 for a particular system in the weather conditions of Hefei, China at insolations of 405 W-m-2 and 432 Wm-2 [9] .

Passive cooling of BIPV with solid-liquid PCMs were experimentally and numerically evaluated using a paraffin wax as PCM and an a rectangular aluminum container with internal dimension of (300

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mm x 132 mm x 40 mm) having selectively coated front surface to mimic a PV cell [10]. Temperature distributions on the front surface and inside the PCM were measured experimentally and predicted numerically with 2D and 3D finite volume heat transfer models which showed good agreement between experimental and numerical results [11,12]. Building on this work, Hasan et al., fabricated and characterised 4 different cell size PV-PCM systems to investigate performance of 5 different types of PCM to find out the optimum PCM and the PV-PCM system for this application. Two PCM, a eutectic mixture of capric-acid-palmitic acid, PCM1 and a salt hydrate CaCl2.6H2O, PCM2 were found promising in an aluminum based PV-PCM system [13]. In current work larger PV panels are integrated with in an aluminum based PV-PCM system containing PCM fitted internally with back to back vertical aluminum fins. The devised system is deployed outdoors in UAE climate during a mild season to observe the effectiveness of such PV-PCM systems.

METHODOLOGY

EXPERIMENTAL SETUP

Two 30W polycrystalline EVA encapsulated PV panels with dimensions of 500 mm x 400mm (PTL-Solar) were used in the experiments where one served as a reference and the other contained PCM. The calibrated t-type copper-constantan thermocouples with a measurement error of ±0.2 °C were installed on all and a National Instruments Compact- Rio data acquisition system was used to record the weather data on site for solar radiation intensity, wind speed and ambient temperature shown in figure 1. Rectangular PCM containers of internal dimensions 480 mm x 380 mm x 50 mm were fabricated from a 5 mm thickness aluminum alloy (1050A) and fitted with straight vertical back to back fins of the same alloy with 60 mm horizontal spacing. A 1 mm thin layer of silicon based glue was applied at the interface of the PV panel and the PCM container and kept under pressure for two days until the glue settled and a strong bond was realized between the aluminum container and the PV panel. The reference PV and PV-PCM were installed at the latitude angle in Al Ain, UAE between 23/03/2014 and 02/04/2014. The data acquisition measured temperatures on front and back surface for the reference PV and on front and back surface and in the middle of the PCM slab contained at PV back for the PV-PCM system. The open circuit voltage and short circuit currents were also measured for both the reference PV and PV-PCM system.

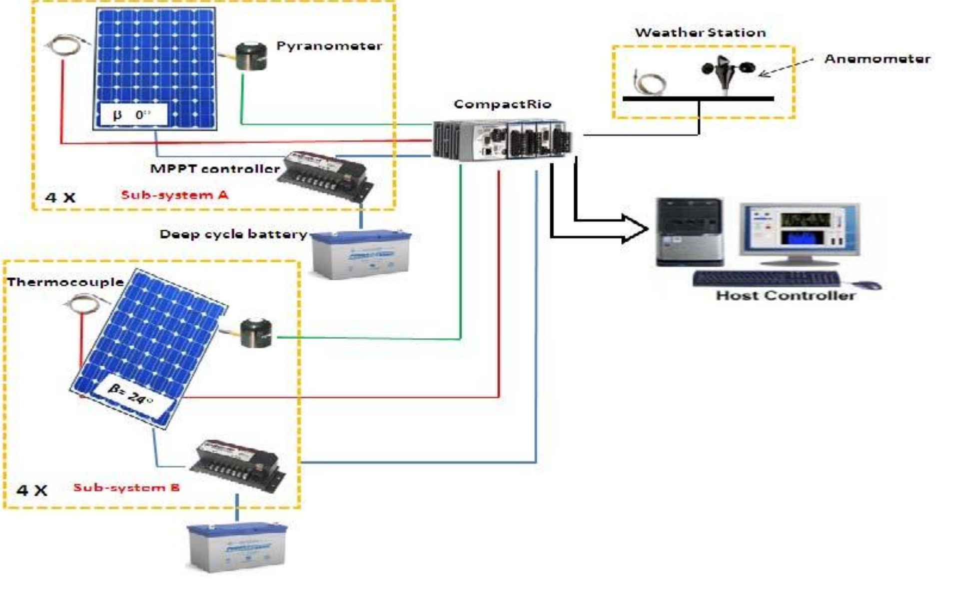

Figure 1- Schematics of the experimental setup

DATA ACQUISITION

Data acquisition system was built to record readings of the panel's voltage, current, temperature, and solar insolation. Besides, the site ambient temperature and wind speed were included in the data-logging architecture. CompactRIO 9073 was used as a real time data-logging device, while the data can be remotely monitored on a LabVIEW interface program. The developed LabVIEW program stores the PV panels' electrical and environmental variables during the daily sun hours. The data acquisition setup consists of the following components:

-CompactRIO 9073 : a reconfigurable real time controller and data acquisition chassis. The used model comprises 8 slots for I/O modules, 2 M gate embedded FPGA core, and a 266 MHz real time controller.

-NI 9227 : 4 channel differential analog current input module with nominal current rating of 5 A and maximum rating of 14 A. Two NI 9227 modules were used in this project, since 8 current measurements are required to be stored from the 8 PV panels.

-NI 9229: 4 channel differential analog voltage input module with maximum voltage range of -60 to 60 V. Two NI 9229 modules were used in this project to carry out 8 voltage measurements for the 8 PV panels.

-NI 9205: 32 single-ended channels or 16 differential channels analog voltage input module with maximum voltage range of -10 to 10 V. One NI 9205 module was used in this project, where 9 input ports were deployed to read measurements from weather sensors (8 pyranometers & 1 anemometer).

-NI 9213: 16 channel thermocouple input module. Only one module was used in this project, since only 9 channels were required, 8 to measure the 8 PV panels temperature and 1 was dedicated to measure the ambient temperature.

-Ethernet cable: Category 5 cable to establish the network between the host computer and the real time target (CompactRIO).

-NI LabVIEW development software: this includes the standard LabVIEW modules, the LabVIEW FPGA Module, the LabVIEW Real-Time Module, and the NI-RIO driver.

First, the NI CompactRIO system was assembled by installing the NI analog input modules, connecting the system to the host PC via an Ethernet cable, and powering up the device with its corresponding DC power supply. Then the network setting was configured to establish a communication between the CompactRIO and the host computer. Finally, an FPGA program was built on the LabVIEW development software and then stored in the real-time target. A host VI was built along with the FPGA VI to monitor the captured signals and represent them in plots and indicators.

RESULTS AND DISCUSSION

Figure 2, 3 and 4 shows the solar radiation intensity, ambient temperature and wind speed for the duration of experiment. Figure 2 shows that the day time peak ambient temperature varied between 29 °C to 37 °C which is a mild temperature for UAE weather conditions offers a peak day time summer temperature of upto 50 °C. Figure 3 shows that the peak time wind speed varied between 7km/h to 23 km/h. Figure 4 shows that peak time solar radiation intensity varied between 480W/m_2 on a cloudy day to 1240 W/m_2 on a very clear day. This weather caused the PV panel to heat resulting peak time reference PV temperature between 45 °C to 58 °C owing to the cloudy and sky respectively shown in Figure 5. The inclusion of PCM into PV resulted in a drop in PV temperature which reduced peak time PV temperature down to between 44 °C and 47°C shown on cloudy and sunny day respectively shown in Figure 5. The cooling effect produced by the PCM contained at the back of PV resulted in a peak time temperature drop of 5 °C to 11 °C on cloudy and clear sky conditions respectively shown in Figure 6. The temperature drop shown in Figure 6 reduced PV temperature resulted a higher open circuit voltage on PV containing PCM compared to PV without PCM shown in Figure 6 and yielded a voltage improvement peaked at 1.3 volts to 1.7 volts. The results shown in figure 6 explain that the PCM demonstrated a temperature regulation effect which was lower early in the morning for every day and increased as the PV reference temperature increased. Temperature results plotted over several days (Figure 5) also show that the PV with PCM showed a consistently lower temperature than PV without PCM which explains that the PCM regenerated every night to produce cooling for the next day. It is important to note that the PCM showed lower temperature regulation earlier in the morning while the reference PV panel temperature is below 40 °C, above this temperature during noon time, PCM showed higher temperature regulation. Figure 5 shows that the PCM achieved temperature regulation ranging from 8 °C in the modest temperature day compared to 11 °C on the hot day. It also points out that the PCM is expected to achieve higher temperature regulation in the higher temperature peak summer days which will be tested in coming months. From Figure 5 and Figure 6 it can be observed that the decreased temperature on the PV panel yielded an increase in PV voltage to enhance electrical power output from the PV.

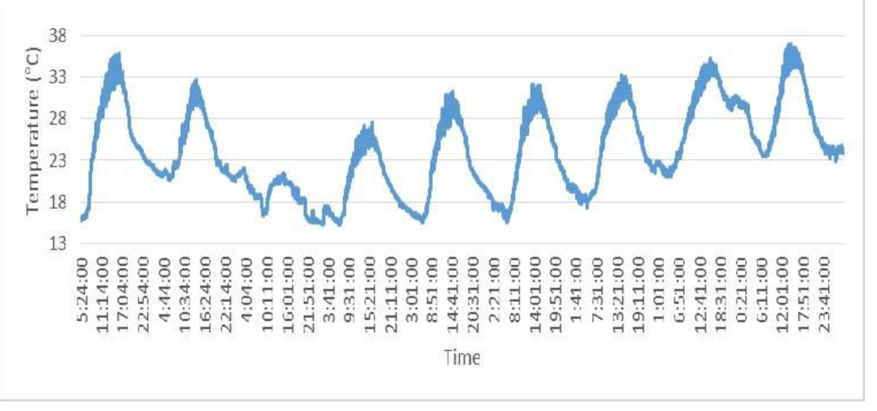

Figure 2: Ambient Temperature measured in Al Ain UAE, between 23/03/2014 and 02/04/2014

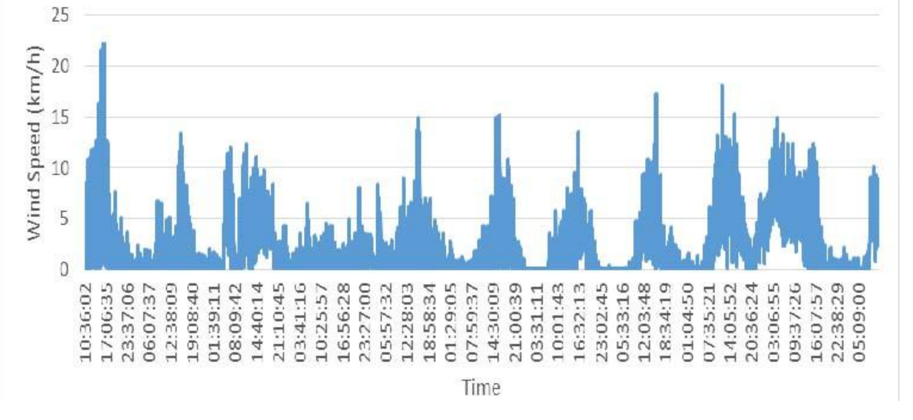

Figure 3: Wind speed measured in Al Ain UAE, between 23/03/2014 and 02/04/2014

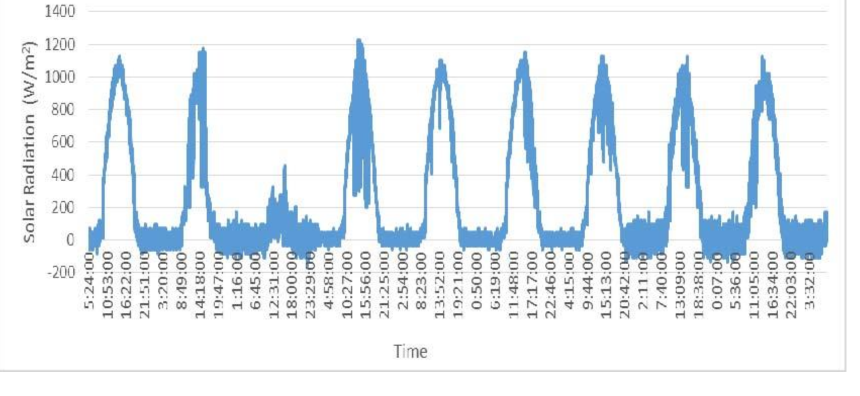

Figure 4: Solar radiation measured in Al Ain UAE, between 23/03/2014 till 02/04/2014.

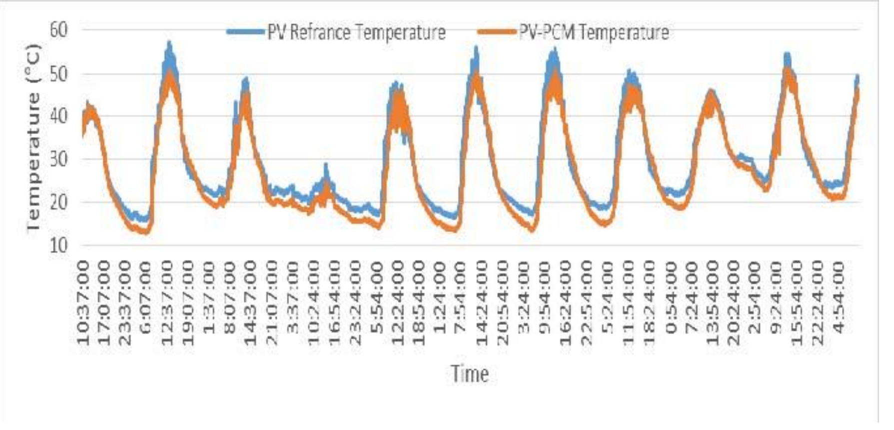

Figure 5: Reference PV and PV-PCM temperatures measured in Al Ain UAE, between 23/03/2014 till 02/04/2014

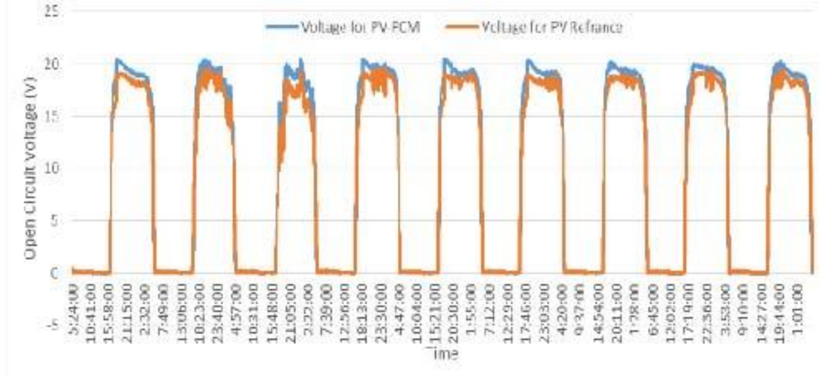

Figure 6: Reference PV and PV-PCM open circuit voltage measured in Al Ain UAE, between 23/03/2014 till 02/04/2014.

ECONOMIC EFFECTIVENESS

Authors have evaluated the use of PCM for lowering of PV temperature and extra power produced for Vehari, Pakistan which has very similar climate to the current site on experiments, Al Ain UAE. In the previous research, the PCM have been found cost effective with a return on investment about two years considering mass produced PV-PCM systems. Similiar results are expected for the current research which will be a subject of future publication for a year around testing of such systems [14]. The stored heat can be used for space or water heating. In case of UAE, the space heating demand is rare therefore Authors are currently conducting experiments for the extraction of stored heat for water heating applications in UAE and will soon publish the results. The hot water produced have larger demand in hospital buildings in UAE compared to residential developments.

CONCLUSION

The results obtained for testing PCM in higher temperature climate shows a promise for PV temperature regulation and power enhancement in the mild season of February where it always get back to solid. It needs still to be tested in the peak summer whether the PCM regenerates and gets back to solid at night by natural convection or it needs forced coolant flow to remove the heat contained in PCM.

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NOMENCLATURE

AHU = Air handling unit

EER = Energy efficiency rating

R-value = Thermal resistance value

VFD = Variable frequency drive

WWR = Window to wall ratio

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