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Design and Development of Polycrystalline Silica Solar Concentrator for Power Generation

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Abstract - *Demand for energy is increasing in the recent years and this lead to exhaust of conventional energy. This focuses to find alternate solution for energy crisis to use the enormous amount of renewable energy sources which is available in the nature. Clean and pollution free solar-renewable energy is the never exhausting energy that can be exploited for human needs using various energy harvesting engineering methods. Transparent solar concentrator (TSC) is a Photovoltaic system used to generate some portion of solar power using solar cells fixed at various positions of the window panels of the buildings. This research work focuses to tap the solar thermal energy to generate electricity using PV cells fixing at the vertical edges of the windows. Generation of power is investigated in outdoor condition of the building window panel with solar Polycrystalline Photovoltaic (PPV) cell for their performances. The polycrystalline cells used in the model with glass was verified for possibility of power as well as heat generation. The maximum possible efficiency of the PPV model is analyzed by placing the model in flat and at 45^0 orientations towards west direction.*

Key Words*: *Solar energy, Polycrystalline PV cell, Glass, Window, Efficiency

1. INTRODUCTION

As conventional energy sources are depleting, energy demand is increasing rapidly. Large amount of CO_2 of about 20×10^{12} kg is put into the atmosphere every year, mainly by burning fossil fuels and coal. Due to global warming sea level has already risen by 10-25 cm and continuously natural disasters are happening in environment affecting on human being and other forms of life in different parts of the earth [1] [2]. The harnessing of alternate energy resources is the state-of-the-art for demanding nature of present earth. Some of the renewable energy sources such as wind, solar, tidal, geothermal, biomass, etc., are the solution for the demanding nature of this world. India is the fourth largest energy consumer in the world comes after US, China and Russia [3]. The 49% of world total generated power is consumed by US, China, Japan, and Russia. Energy consumption rate of India is increasing at a higher rate due to population growth, rapid urbanization, growing economic development. Generating energy from the solar is an alternative solution to meet urban and rural needs in a reliable, affordable and environmentally sustainable way. Annually, the earth receives about 1.6×10^{18} units of energy from the sun, which is 2000 times the energy required for mankind on the earth [5]. Solar energy is the promising renewable energy resource which can meet the increasing output efficiencies and ability to install in various locations in developing countries [6]. Solar energy has the potential to generate virtually unlimited, clean and carbon free electricity.

Fig.1. shows the total installed capacity of renewable energy in India as per Ministry of Non-renewable Energy, India, dated 31st March 2017 [4].

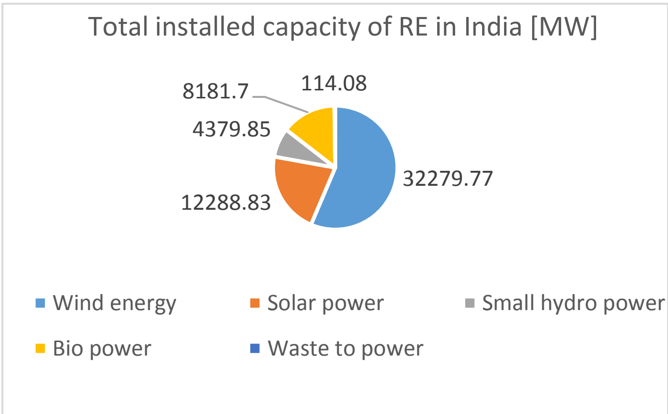

Fig.1. Total installed capacity of renewable energy in India in MW

In India, most parts of the country receive large amount of solar radiation ranging from 4 to 6hours a day for over a period of 300 days in a year. Photovoltaic cells are the power generating materials used to harvest solar energy for power generation. Crystalline silica is the common PV cell material used because of its semiconducting properties [7]. Crystalline cells are used in PV cells which are occupied nearly 93% of the solar panels installed worldwide. Amorphous or non-crystalline silica make up 4.2% of global solar panel requirements. In the recent years, solar energy is made as integrated part of the construction building to save energy. Along with this large energy consumers are industry, transportation, and households. Therefore saving of energy consumed in building, plays an important role for national energy conservation strategies. Solar thermal, photovoltaic and optical technolgy are relevent applicable solar energy tools for building integration technology in residential buildings.

Building integrated PV (BIPV) systems with phase change materials (PCM) are widely used for energy production [8]. PV windows are replaced by glass window for transmiting light and heat into indoor space. This radiated energy goes waste due to improper design of window and use of right materials. Present research focuses to see the possibility of usage of Polycrystalline PV cell with traditional Sodalime glass fixed at various position of the window panel. This produces a small amount of electricity in day light therby it works as an efficient sun shading window and it gives potential solution to reduce the investments for cooling equipments and savings on cooling energy demand.

PV cells act as luminescent solar concentrators potentially offer the lower cost per unit of power compared to conventional solar cells. This effort include the application of selective mirrors which allow sunlight by reflecting emitted light on to different edges of window panel. The study is conducted in terms of total heat gain, output power, and daylight illuminance to calculate its total energy performance [9][10].

2. MATERIALS AND METHODS

2.1 Materials

The materials used for the model is listed in Table.1. The polycrystalline silica PV (PPV) cell is used in the model of 0.5 volts. Sodalime glass with the refractive index of 1.523 is used in the model.

Table.1. Materials used for PPV model

Type of glass	Soda lime glass
PV cell used	Polycrystalline silica
Dimensions of PV cell	115(L)×12(B)×0.8(t) mm
Voltage of PV cell	0.5 Volts
Dimensions of glass	115(L)×115(B) ×3(t) mm
Refractive index of glass	1.523
Dimensions of mirror used with PV cell	115(L)×20(B)×3(t) mm
Dimensions of mirror used without PV cell	115(L)×26(B)×3(t) mm
Other materials are used	Connecting wires, gum, UV light, etc.

Mirrors are used to hold the PV cell as well as to close the edges of the model. Other materials used in the model is connecting wires, glue, UV light, etc.

2.2. FABRICATION OF THE MODEL

PV cells are placed at vertical edges of the model as shown in Fig.2 and remaining two edges are closed with the help of mirrors. Initially PV cells are soldered using leads of the wires for connection. These are pasted on to the mirrors in order to have stiffness in the model. Gap is created between two glasses for placing the solar cell of 20 mm width. A hole is drilled on the top glass to monitor and measure the inside temperature of the setup. 3-D model with PV cell at two vertical edges is shown in Fig.3.

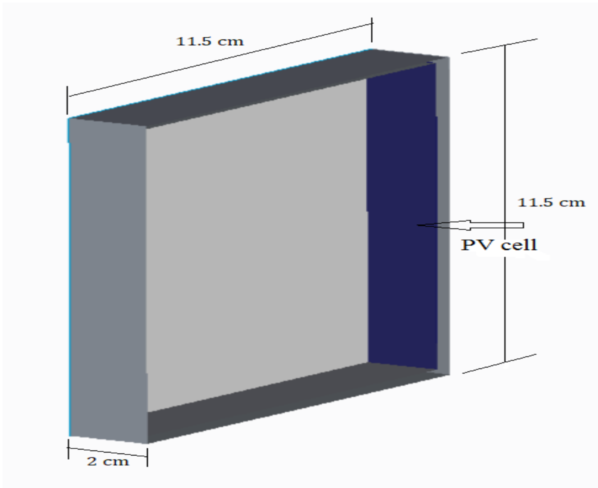

Fig.2. 3-D model with PV cell at two vertical edges

In this work, Polycrystalline silica of 0.5 volts PV solar cell having dimensions $115 \times 12 \times 0.8$ mm^3 is used to investigate the power generation in outdoor conditions. These PV cells units are further embedded

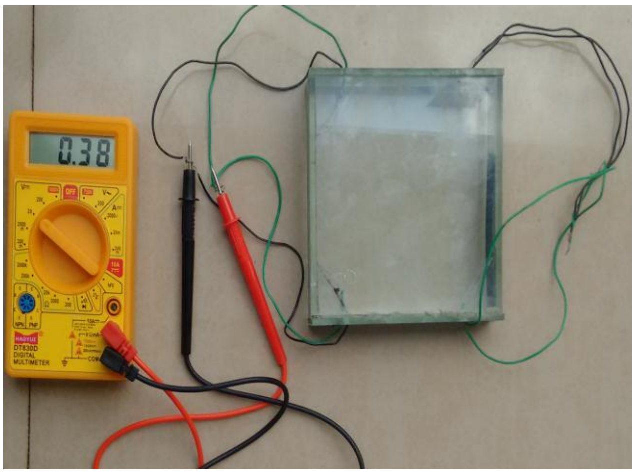

Fig.3. Final model with PV cell at two vertical edges

on mirror maintaining 20 mm gap between each other. PPV cell generates power by using sunlight incident on it through a glass and also absorbs reflected (scattered) rays from mirrors. Recording of the generated current and voltage is carried by digital multimeter for every alternative hour. The values are recorded for the model at 45^0 towards the west direction and also flat position. Temperature inside the model is measured using thermocouples which were fixed in the hole provided in the top glass.

3. RESULTS AND DISCUSSION

3.1. Solar radiation data on hourly basis

The solar radiation is recorded for 5 days during sunny days and observed from 9:00 AM to 17:00 PM. The variation of solar radiation is as shown in Fig.4. The solar radiation is lower in morning and maximum during afternoon time in between 12:00 PM to 14:00 PM due to increased thermal radiation. Further it decreases parabollically after 14:00 PM until the sunset. Solar radiation passes through the atmosphere before reaching the earth gets reflected, absorbed, scattered, or transmitted resulting in reduction of the energy flux density. The solar flux density reduces by an amount 30% compared to extraterrestrial radiation flux on a sunny day and is 90% in a cloudy day. Main losses of 10-30% by particles absorption and molecules, 2-11% by way of reflected and scattered back to the space and 5-26% scattered to earth [11].

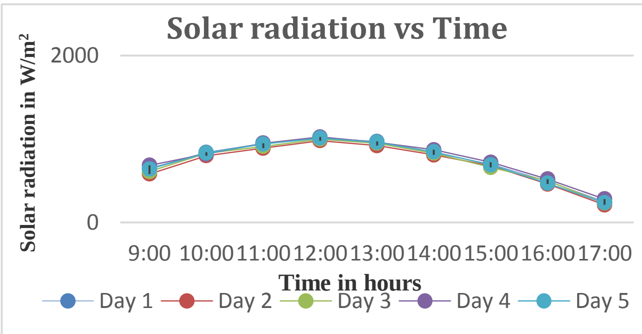

Fig.4. Solar radiation in different intervals of time

3.2. Temperature variation with time

The average temperature is recorded for both model inside and ambient temperature for 5 days at different intervals of time from 9:00 AM to 17:00 PM. The model average temperature is little higher than the ambient temperature because of the reflected rays, absorption, and conduction as shown in Fig.5. Hence it is observed that high temperature is obtained at peak hours that is from 12:00 PM to 14:00 PM may be due to increased thermal gradient in a restricted volume of the model and humidity.

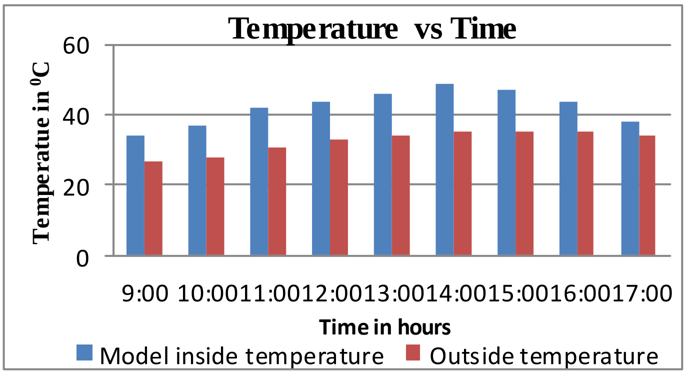

Fig.5. Variation of temperature with time

At peak hours the model temperature is higher as compared to ambient temperature. When the ambient temperature is more, in turn the model temperature is also high. As the day is in closing hours the model temperature decreases from peak hours as shown in Fig.5.

3.3. Efficiencies of a model in hourly basis:

The solar cell is placed directly in outdoor sunlight; maximum solar radiation gives the efficiency of ≥ 15% during 12:00 PM to 14:00 PM. The plot is drawn between efficiency versus time as shown in Fig.6. The model with PV cells at vertical edges gives the less efficiency in both 45^0 and flat position at morning.

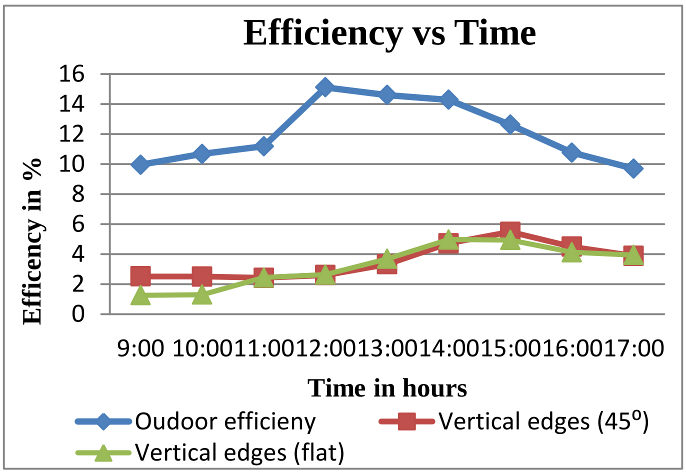

Fig.6. Efficiency of PV cell embedded model.

Efficiency of PPV cell in outdoor condition embedded along with mirror model has yielded efficiency of ≥5% in the afternoon hours [12]. Outdoor efficiency of the PV cell is 10% at the beginning sunny day and at the closing hours of the sun. It is 15% during noon showing the actual performance of the PV cell [13]. The same PV cell embedded in the fabricated model at the flat edge and at 45^0 is 3% at the beginning hours of the day and 4% during the closing hours the day. The indirect exposure of the PV cell to sunlight fixed in the window panel yield ≥5% indicates that an average of 40±2% performance of the model. Since the model is symmetric concentrators type efficiency of 60-80% is possible due to wide range of angle of solar incidence [14]. This efficiency of the fabricated model at vertical edges receives less solar radiation from the sun leading to that amount of power generation [15]. Therefore, PPV cell can be used as window panel material for saving energy cost by harvesting the solar energy.

4. CONCLUSIONS

The heat and power generation from polycrystalline PV cell model with mirror fixed in vertical edges of the window panel was fabricated. The conditions adopted during the evaluation are solar radiation, fabricated model, ambient temperature, and solar cell area. The polycrystalline PV solar cell yielded an efficiency of >15% at an outdoor condition whereas efficiency of the model at vertical edges is ≥5% and it is almost same in 45^0 orientations and flat conditions. There is improvement in efficiency at 45^0 inclinations towards west direction. The maximum inside temperature in PPV model observed is $51^0 \pm 2^0$ C which is more compared with ambient temperature.

Incorporating of PPV cell for roofing materials, windows provide the opportunity for newer building materials at marginal costs. In the near future, we can envisage more on luminescent solar concentrator either by present PV cell, or by organic or dye synthesized or by nano-coatings attaching to the edges of the window for tapping solar energy for power generation and to have thermal balance in the building.

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