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Cell (module) temperature regulated performance of a building integrated photovoltaic system in tropical conditions

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ABSTRACT

The performance of a building integrated photovoltaic system (BIPV) has to be commendable, not only on the electrical front but also on the thermal comfort front, thereby fulfilling the true responsibility of an energy providing shelter. Given the low thermal mass of BIPV systems, unintended and undesired outcomes of harnessing solar energy – such as heat gain into the building, especially in tropical regions – have to be adequately addressed. Cell (module) temperature is one critical factor that affects both the electrical and the thermal performance of such installations. The current paper discusses the impact of cell (module) temperature on both the electrical efficiency and thermal comfort by investigating the holistic performance of one such system (5.25 kW_p) installed at the Centre for Sustainable Technologies in the Indian Institute of Science, Bangalore. Some recommendations (passive techniques) for improving the performance and making BIPV structures thermally comfortable have been listed out.

1. Introduction

Building integrated photovoltaic (BIPV) systems are slowly gaining recognition as a novel means of harnessing solar energy. As the name suggests, BIPV systems are components of a building in the form of a building envelope such as roof, façade, shading device or architectural accessory. When PV is added to the existing envelope it is called as Building Applied PV (BAPV). As sustainable power generators, they tend to reduce the overall greenhouse gas emissions. BIPV systems can be easily adapted on both new and existing buildings, and thereby save up on land requirements. According to a recent BCC Research report [1], BIPV make up a small but noticeable part of the world PV market; BIPV roofing is considered to be one of the largest market segments with a compound annual growth rate of 51%. Most regions in India receive good solar insolation throughout the year. On an average, the country has 250 sunny days per year (also translates to 5000 trillion kWh per year) and receives an average hourly radiation of 200 MW/km^2. It is also estimated that around 12.5% of the land mass in India could be used for harnessing solar energy, which could be further increased by the use of building integrated PV [2].

Despite the advantages offered by BIPV, their widespread utilization is hindered by complex intertwined factors. To be an energy-efficient building envelope, the BIPV system would need to passively regulate its responsiveness to the external environment and also maximize the electrical yield. However, the requirements for climate-responsive building design may infringe upon those required for optimal PV performance [3]. The generation of electricity is by harnessing maximum solar energy – this depends on (a) unalterable factors: location (latitude, longitude and altitude) and type of climate, and (b) alterable factors: system configuration (solar exposure, slope, orientation and sizing), wind patterns, dust conditions and maintenance. A major issue of concern here is the efficiency of the solar PV array systems. Apart from the inherent material-related losses in the efficiency of commercially-available photovoltaic panels, there is further decline in efficiency in the working atmosphere mainly due to cell (module) temperature and dust settlement [4] on the modules (Fig. 1).

The temperature of a solar cell (module) in operation increases phenomenally (especially true in tropical regions), resulting in a decrease in the output. The working of a solar cell is based on the photoelectric effect wherein electrons are emitted from the surface of a material as a consequence of absorption of energy from short wavelength electromagnetic radiation. The current generated is directly dependant on the solar radiation and decreases as the temperature of the cell (module) increases. The voltage,

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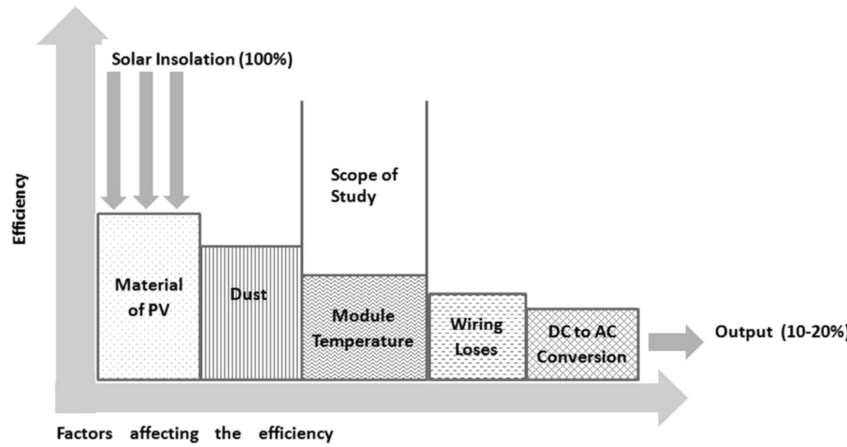

Fig. 1. Losses during the conversion of solar insolation to electricity.

however, is practically constant even at low solar radiation levels but drops with increasing temperatures. Thus, the current and voltage from a solar cell (module) have to be optimized for maximum output. Tropical regions are characterized by high ambient temperatures; the consequence of this is outlined in Fig. 2. This rise in temperature in BIPV systems, which have low thermal mass, may result in thermal discomfort of the occupants and also increase the cooling load of the dwelling. It is, therefore, necessary to optimize both the electrical and the thermal comfort-related performance of BIPV systems to make them attractive energy solutions. Here, temperature is the quintessential and common factor determining the effectiveness of these structures. Most of the temperature based studies have been carried out on the basis of simulations and have dealt with the performance issues of BIPV [5–8,12]. This current study is a real-time experimental investigation with a holistic and unique approach through electrical and thermal comfort performance of the BIPV system.

A study was carried out on the overall performance of a 5.25 kW_p BIPV system installed at the Center for Sustainable Technologies (CST) in the Indian Institute of Science, Bangalore with a focus on the consequence of cell (module) temperature regulation. Since a cell (module) temperature is difficult to be measured the temperature of the back-side of a PV panel is measured in this study. Module (back-side) temperature is not equivalent to the cell temperature; however, the maximum error due to this measurement is around 5 °C under-estimation as suggested in Ref. [9]. The range of temperature is more important in this study compared to the accuracy of it, module temperature is loosely considered as the cell temperature. The observations along with some strategies to reduce the cell (module) temperature (and eventually improve performance) are discussed in this paper.

2. BIPV system under study

The BIPV system (Fig. 3) is installed as the roof (with no false ceiling, in the second floor) of the experimental laboratory at CST (12° 58′N, 77° 38′E, 921 m above MSL). The specifications for the building and the PV system are given in Tables 1, 2 and 3. The authors have given a detailed description of the same case in a recent publication [10].

3. Appraisal of the installed system

The performance of the BIPV system – electrical and thermal comfort-related – has been studied based on data collected from May 2011–April 2012. A summary of the electrical performance [5] and details of thermal comfort-related performance are presented.

3.1. Performance: electrical

For a critical assessment of the system, the efficiency, performance ratio and losses were calculated. Data related to the power generated (both AC and DC) were retrieved from the grid export conditioner. A cumulative energy of ~4000 units was supplied to the grid during the study period. It was observed that the system output increases during months of good solar insolation even though efficiencies are low.

3.1.1. Efficiency

Efficiency is the fraction of solar energy falling on the panels that is converted into electricity. The system efficiency is considered as the ratio of final AC energy to the solar energy falling on the surface for the given time period. The installed system has an average efficiency of 6%. An interesting observation is that the

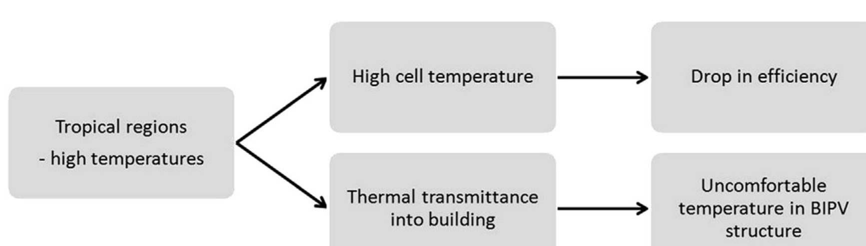

Fig. 2. Consequences on BIPV performance due to high ambient temperatures.