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Design, construction, testing and performance of split power solar source using mirror photovoltaic glass for electric vehicles

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ABSTRACT

Solar photovoltaic panels are prominently integrated into electric vehicle rooftop to charge the battery bank. In this paper, the performance of the conventional solar power source architecture employed in electric vehicles is analyzed using PVsyst real-time simulator. The limitations with solar photovoltaic panels and conventional solar power source are addressed through a novel mirror photovoltaic glass and split power solar source architecture. The design, manufacturing and structural merits of split power solar source are presented. The operational behavior of split power solar source is validated using Matlab. The performance of the mirror photovoltaic glass is analyzed at standard test conditions and various combinations of irradiation and temperatures using climate chamber solar simulator. The performance of mirror photovoltaic glass at on-site conditions is analyzed by comparing with climate chamber solar simulator results. Further, the analysis is validated through a convection analysis carried out using ANSYS. Subsequently, the performance of the split power solar source is studied using PVsyst real-time simulator. The split power source architecture is obtained as the best feasible solar power source design for an electric vehicle in terms of material requirement, replacement cost, withstanding capability, space utilization, power loss, tracking mechanism feasibility and performance through the comparative study.

1. Introduction

Technicalities associated with manufacturing and electrical power generation using conventional solar PV panels are pre-eminent [1]. The solar PV panels espoused with static and dynamic tracking mechanisms deliver enhanced power output [2]. Hitherto, EV charging stations either on-grid or off-grid is deployed with solar panels to minimize the Co_2 emission and tariff of charging [3]. Architects are incorporating EV charging stations in the parking lots of the buildings by making use of solar power to support EV users [4]. Three level fast charging mechanisms are being deployed in these EV charging stations to minimize the time of charging [5]. Solar powered charging stations are connected to the grid during low and medium loads, in order to ensure profits to the entrepreneurs of charging stations [6]. Further, studies are being carried out to integrate hybrid solar-wind technologies with EV charging station through vehicle-to-grid technology [7]. In recent years to minimize the grid dependency and to maximize the usage of green energy technologies, solar PV panels are integrated on the rooftops of EVs for charging the battery bank in conjunction with plug-in charging [8]. Collegial racing teams customize their EV design to accommodate 1000 W peak rated power to meet the premeditated power demand [9]. Conversely, the mainstream vehicles possess limited surface area hence higher wattage solar PV panels are generally used owing to their better space utilization and efficiency [10].

The most common on-site issue faced by the solar PV panels apart from yearly deration is the partial shading. This occurs either due to physical obstacles or due to discoloration of the EVA encapsulate instigated by exposing to UV wavelength and water at temperatures above 50 °C [11]. The hotspots ensued under partial shading conditions results in very high temperatures capable of damaging PV cell [12]. The degradation of the bus bar connecting PV cells becomes obvious in the solar panel during multiple hotspots because the high temperature is aided by the high voltage electrical architecture [13]. Moreover, unequal expansions in the Tedlar sheet are observed frequently in the solar panels due to these recurring hotspots and moisture absorption [14]. The instabilities in the light transmittance are apparent at on-site due to the accumulation of dust on the glass resulting in declined

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Abbreviations

PV	photovoltaic
EVA	Ethylene Vinyl Acetate
MPVG	Mirror Photo Voltaic Glass
EV	Electric Vehicle
AFIR	Automatic Fault Identification and Rectification
STC	Standard Test Conditions
CSPS	Conventional solar power source
SPSS	Split power solar source
USD	United states dollar

performance [15]. The heat developed by the photovoltaic effect is trapped within the solar panel due to its poor thermal conductivity hence high internal operating temperatures are maintained in the panel resulting in efficiency drop [16]. Additionally, absorption of IR spectrum by the encapsulation materials increase the solar panel operating temperature over 65 °C causing precipitous efficiency drops during midday [17]. The high operating temperatures and moisture absorption in solar panels result in the formation of micro-cracks in the PV cells [18]. Besides, loosening of panel junction box is more often due to drying out of silicon gel [19].

The adverse soiled EV environment contains high moisture and dust. In addition to this, multiple shades on EV roof are induced by the routine obstacles such as trees and buildings. Due to these conditions in EV, the above issues in solar panels occur at faster rates, resulting in higher structural deration, frequent damages and reduced performance of solar power source. Moreover, practical observations carried out on an EV with solar rooftop parked under the sun exhibits an increment in the internal temperature of the vehicle due to low thermal conductivity and absorption of IR light spectrum. Recently, flexible thin-film modules have been manufactured for EV [20]. However, they are unable to address the power loss due to multiple hotspots, replacement cost and internal temperature gain in EV.

In this paper a detailed analysis has been carried out on the performance and limitations of the CSPS architecture universally employed in EV, using PVsyst real-time simulator. The analysis is further extended to observe the feasibility of implementing tracking mechanism. The limiting factors preventing from achieving the best yields in CSPS provided necessary motivation to develop a novel SPSS architecture. The structural impediments faced by conventional solar panels are addressed through a novel technology named as MPVG. The issues related to the source architecture such as power accommodation, power loss, replacement cost and internal temperature gain in EV are addressed through SPSS architecture. The operational mechanism of SPSS under fault conditions is validated through dynamic simulation using MATLAB. The developed MPVG is tested for its performance at STC and under various combinations of irradiation and temperature using climate chamber solar simulator. Subsequently, the on-site performance of MPVG is tested and analyzed. Further, the performance of MPVG is validated numerically using ANSYS fluent. The obtained outputs of MPVG are used to study the performance of SPSS architecture using PVsyst real-time simulator. Finally, the SPSS structural and performance superiority over CSPS is analyzed through a comparative study in terms of material requirement, replacement cost, withstanding capability, space utilization, power loss and tracking mechanism feasibility.

The paper is organized as follows: the section.2 of the paper provides the architecture of CSPS, its performance and limitations. The manufacturing process of MPVG, the architecture, structural merits and operational behavior of SPSS are presented in section.3. The performance of MPVG at STC, on-site conditions and under various combinations of irradiation and temperature and its validation through numerical approach are furnished in section.4. Subsequently, the performance of SPSS under various modes of alignments and its advantages are also presented in section.4. The SPSS superiority over CSPS is highlighted in section.5 through a comparative study.

2. Conventional architecture of solar power source in electric vehicle

The vehicle rooftop area and the battery bank voltage are the deciding factors in sizing the solar power source and its connection arrangements. The aerodynamics of the vehicle is the major factor that decides the mode of solar panel integration on the rooftop of EV.

The arrangement and electrical architecture of the CSPS followed in EV with 8 m^2 rooftop area, with 1200 W rated power capacity is shown in Fig. 1 (a) and Fig. 1 (b) respectively. The solar power source is divided into four subsections of 300 W capacity. Two subsections are connected in series to produce a required voltage of 58 V to charge the battery bank of 48 V. A bypass diode is connected across each solar cell string to minimize the power loss under fault conditions. To stop the reverse currents from entering the solar power source, a blocking diode is provided in between the solar power source and the battery. The performance of the CSPS architecture shown in Fig. 1 (a) is analyzed in the following section.

2.1. Performance of conventional solar power source design

The CSPS architecture annual yield is studied using PVsyst real-time simulator for the location with co-ordinates 13.1°N and 80.2°E. Conventional solar panels rated 300 W available from Canadian solar company [21] are used in the simulation. The furnished results in the Table 1 show that the CSPS configuration generates 1624 kWh/year in the given area of 8 m^2. The effective power generating area observed in this configuration is 7 m^2. The rest area of 1 m^2 is lost in spacing between solar cell strings and subsections.

The study is further extended to observe the annual yield improvement from the solar power source by employing various tracking modes. The obtained results furnished in the Table 2 shows that the yield from the CSPS is improved upon employing the tracking mechanism.

Based on the structural design of solar panels [21], dynamic simulation and performance study carried out on CSPS architecture, the limitations associated with the design are listed as follows.

- The adverse soiled vehicle conditions induce multiple partial shades on the solar panels resulting in the generation of multiple hotspots. This increases the de-rating factor of the solar panel that leads to reduced power output and faster wear and tear.
- The occurrence of surface damages, moisture deposition, discoloration and hotspots in single solar cell results in a power loss of 60 W. This is due to the present electrical architecture in solar panels.
- The occurrence of four hotspots in multiple solar cell strings results in a power loss of 600 W.
- Failure of odd or even pair of subsections results in the failure of the entire source due to source voltage drop. Hence charging of battery bank is terminated when two subsections are under faulty mode.