Energy xxx (2016) 1–8

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

# Rail coaches with rooftop solar photovoltaic systems: A feasibility study

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A R T I C L E I N F O

*Article history:*
Received 13 May 2016
Received in revised form
19 September 2016
Accepted 24 October 2016
Available online xxx

*Keywords:*
Solar rail coach
Solar train
Photovoltaics
Indian Railways

A B S T R A C T

The performance of solar photovoltaic modules mounted on the rooftop of a rail coach of The Indian Railways is reported here. The focus of this experiment was to quantify the reduction in diesel consumption of the end-on generation system that powers the electrical load in the new generation coaches. A coach retrofitted with two flexible solar photovoltaic modules was run at speeds up to 120 km/h by coupling it to three popular trains of south India. Based on the experimental results, the benefits of operating solar rail coaches is projected. It is estimated that one solar rail coach can generate atleast 18 kWh of electricity in a day, leading to an annual diesel saving of 1700 litre. The Indian Railways operates 63,511 coaches and hence, under ideal conditions, can save around 108.5 million litre of diesel annually. This would help to control environmental pollution and mitigate climate change, as it reduces the carbon dioxide emission by 2.9 million tonnes in a year. A statistical model was developed to estimate the power output per unit rooftop area of the coach, to enable The Indian Railways to calculate the benefits of operating solar rail coaches on various routes.



## 1. Introduction

Few countries have successfully commissioned and operated trains fitted with solar photovoltaic (SPV) system on its rooftop. In Italy, amorphous silicon modules were installed on five passenger coaches, two locomotives and three freight coaches [1]. In 2010, TER-SCNF (Transport Express Régional Société Nationale des Chemins defer Français), the state-owned railway of France tested a Diesel Multiple Unit (DMU) fitted with thin-film CIGS (Copper Indium Gallium Selenide) SPV modules. The SPV system of capacity 990 $W_p$ mounted on the rooftop partially supplied power for electrical lighting system inside the DMU [2]. In 2011, the Indian Railways installed 1 $kW_p$ capacity SPV modules on the rooftop of trains at Pathankot, Punjab, India. The SPV modules power an electrical load of 420 W. Similar attempts were made by Kalka-Simla Mountain Railway, Himachal Pradesh, India to supply power for six LED bulbs of 6 W each [3]. These experiments were done for narrow gauge rail coaches, which run at a maximum speed of 40 km/h. Although the experiments of installing SPV system on trains were successful, no scientific data is available in the public domain for further research and development of Solar Rail Coaches. In 2013, a similar study carried out in Iran, showed that 74% of the power requirement of a coach can be supplied by SPV system during hot months and 25% during cold months. The maximum yield of the SPV system was 63.7 kWh, with an annual reduction of 37 tonnes of $CO_2$ emission [4]. The Indian Railways being one of the largest railway networks in the world operates around 12,000 trains per day [5]. It is also one of the largest consumers of diesel in the country, with an annual consumption of 2.7 billion litre, which includes locomotion and power supply for coaching stock [6]. Hence, efforts are being made by the Indian Railways to reduce fossil fuel consumption and to adopt eco-friendly technologies [7]. Solar energy can find wide application in the railways sector, especially in tropical countries. The Indian Railways operates 63,511 coaches which include both conventional coaches and Linke Hofmann Busch (LHB) coaches [8]. Most of these coaches remain exposed to sunlight throughout the year. This provides an opportunity for the Indian Railways to explore the possibility of operating Solar Rail Coaches across the country. This would reduce the diesel consumption of End-on Generation (EOG) system which is the power supply for the electrical load in LHB coaches [9]. In this connection, the project 'Solar Rail Coach' was conducted by Divecha

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http://dx.doi.org/10.1016/j.energy.2016.10.103
0360-5442/

Centre for Climate Change, Indian Institute of Science (IISc), Bangalore, in association with Integral Coach Factory (ICF), Chennai. A LWSCN Coach, which is a LHB Second Class Sleeper Coach, manufactured by ICF was retrofitted with two flexible SPV modules. This coach, named as 'Trial SPV Coach' was run at speeds up to 120 km/h by coupling it to three popular trains of the country. The trials were conducted during the onset of south-west monsoon, so that it would indicate the performance of PV system under low sunshine conditions.

## 2. The experiment

One of the important constraints considered during the design of the SPV system and module mounting structure (MMS) was the 'Standard Dimensions'. The standard dimensions are declared by Research Design and Standards Organization (RDSO), Ministry of Railways, Govt. of India. According to the guidelines of RDSO, any moving body on the rails must not exceed the Maximum Moving Dimension (MMD). Hence, the SPV modules and MMS were installed such that it doesn't violate the MMD guidelines. The front-view of the roof-arch of the coach is as shown in Fig. 1 (a). Since the roof of the coach was curved, two mono-crystalline flexible SPV modules, each of rating 190 $W_p$, were used. The modules were mounted along the axis of symmetry as shown in Fig. 1 (b). Since the roof of the coach was corrugated, a flat surface was required to be created along the profile of the roof in order to facilitate stiff and easy mounting of the modules. Hence, a 2 mm thick stainless steel sheet was welded to the crests of corrugates and MMS was mounted on it. MMS was an assembly of Z-frames, rubber sheet, rubber gasket and copper strings. The module was housed inside the module mounting structure. Rubber sheet of the same dimension as the module was placed beneath the module to arrest vibrations of the train. Silica gel was used as an adhesive between the rubber sheet and the SPV modules. Rubber gasket was used to pack the gap between the SPV module and Z-frame. In order to ensure safety of the modules, copper strings fastened across the Z-frame. Hat-shaped conduits were welded to the roof for routing the cables emerging from the modules and these cables were drawn into the coach through the vents provided on the roof for ventilation. A pyranometer was installed along with the MMS to measure the incident solar radiation. A temperature sensor was placed beneath the modules to measure the module temperature. A view of the MMS and modules mounted on the coach are as shown in Fig. 2 (a) and (b), respectively.

An Online Monitoring System (OMS) system consisting of an Embedded Data Acquisition and Control System (EDACS) was developed in order to track and analyse the performance of the SPV system. The OMS was installed inside the coach. The electrical energy generated by the modules was fed to a charge controller which regulated the charging required for the batteries and simultaneously powered the OMS, as shown in Fig. 2 (c). The functions of OMS was to measure, record and display the instantaneous values of parameters such as ambient temperature, module temperature, incident solar radiation, instantaneous power, voltage, current and daily yield. Different sensors were incorporated to measure the above mentioned parameters. The electrical signals from the sensors were directed towards EDACS and OMS. EDACS being an embedded card connected to a computer, the live data generated was being displayed on the screen of the OMS.

To evaluate the performance of the SPV system mounted on the coach, the 'Trial SPV Coach' as shown in Fig. 2 (d), was coupled to three prominent high-speed trains namely, Chennai ↔ Coimbatore Shatabdi Express, Chennai ↔ Mysore Shatabdi Express and Chennai ↔ Bangalore Double Decker Express. The schedule of trials are

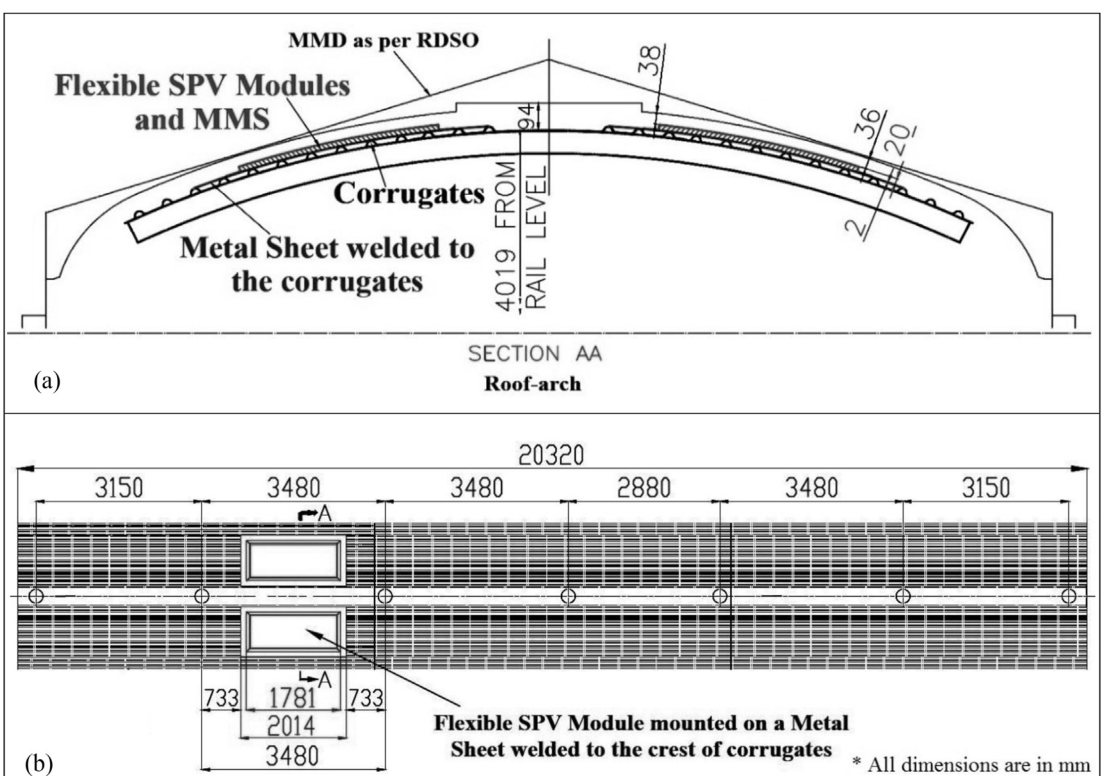


Fig. 1. Layout of Trial SPV Coach (a) Front-view of roof-arch of the coach. The module mounting structure (MMS) does not exceed the maximum moving dimension (MMD) guidelines of Research Design and Standards Organization (RDSO). (b) Top-view of the coach, showing the location of the two flexible SPV modules.

Please cite this article in press as: Shravanth Vasisht M, et al., Rail coaches with rooftop solar photovoltaic systems: A feasibility study, Energy (2016), http://dx.doi.org/10.1016/j.energy.2016.10.103