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Low Carbon Emission Initiative by Indian Railway: A Case Study

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Abstract: ***Global warming is one of the biggest problems of 21st century for the world. It is imperative for Transportation sector to reduce environmental pollution,*** create ***energy security and mitigate the severity of the climate change. Indian Govt has already planned to be Green transporter within 2030 by reducing the carbon footprint in Indian railway. Being the fourth largest rail network the initiative of decarbonization will not only impact India but take a predominant role in the world. One of the initiatives of decarbonizing is solar installation on narrow gauge Kalka-Shimla line trains have been depicted here in detail. The study not only reveals the amount of energy saving potential in a train after solar installation but also gives a clear idea on carbon emission reduction per year and carbon credit earned by the initiative. The description of minute details of the solar system, comment on installation benefit on various types of coaches and more over the payback calculation will give a clear planning route map for other countries also who want to address the burning issues of the era like global warming and energy dependency.***

Key words: Flexible Solar PV, Railway Rooftop, Energy Saving, Carbon Credit, Payback Period

I. INTRODUCTION

Decarbonization of the transportation sector is essential to address issues like environmental pollution, global warming, and energy dependency. According to US Energy Information Administration (EIA) (EIA, 2020b) [2], about 28% of total U.S. energy consumption in 2019 was used in the transportation sector and almost 92% of the energy was harnessed from fossil fuel-based sources. Indian Railways, the fourth largest railways in the world by network, has envisioned to become a Green Transporter by reducing its carbon footprint. The energy consumption of Indian Railways in FY 2020 was around 18, 410 Million Units for traction and 2,338 Million Units for non-traction load (Green Railway,2020). Indian Railways has taken significant strides to reduce its carbon footprint & fuel cost and is committed to become a 'net-zero' carbon emissions organization by 2030. Some of its key initiatives towards decarbonization are 100% electrification of Railways broad gauge network, reduction in energy consumption and meeting energy demand through renewable energy (RE).

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Indian Railways already has 220-Megawatt (MW) capacity of RE power, with nearly 3,450 MW capacity in the pipeline. It is also anticipated by researchers that with the use of renewable energy (RE) in transportation, almost 40% of greenhouse gas emissions can be subsided (Andersen, Mathews and Rask, 2009). Owing to Asia's largest railway network with 115,000 track kilometers, 8500 stations, and operating approximately 12,000 trains every day (Shravanth Vasisht et al., 2017) [7], the Indian Railways (IR) is considered one of the largest consumers of fossil fuels in India [8]. On average, approximately 2.7 billion litters of diesel are consumed by IR every year (Gangwar and Sharma, 2014). The study (Rohollahi, Abdolzadeh and Mehrabian, 2015) [3] carried out in the railway network of Iran showed that around 74% and 25% of power requirements of rail coaches can be generated from rooftop SPV systems during summer and winter seasons respectively [9]. They have also presented the statistics on CO2 mitigation and green energy generation [10]. A notion of SPV integration on locomotive rooftops for the South African Railway industry was presented by Lencwe et al. (Lencwe, Chowdhury and Elgohary, 2016) [5]. Parallel adoption of e-transportation and large-scale integration of RE sources into the transportation system will eventually decarbonize the transportation sector [11]. Similar to Italy (Trentini, 1991) [6], France, USA, etc, India initiated the use of train rooftops to generate electrical power using solar photovoltaic (SPV) panels in 2011 (RMI, 2011). India has initiated the Solar PV installation in Patankot, Punjab in 2011 and Kalka Shimla line in 2019 [12]. Though the experiments were successful but no scientific data available in public domain for further development. (Vasisht et. Al, 2017)

Here we have presented a case study on solar powered Kalka Simla (KLK-SML) railway coaches to find the impact of energy saving and feasibility studies of solar coach installation.

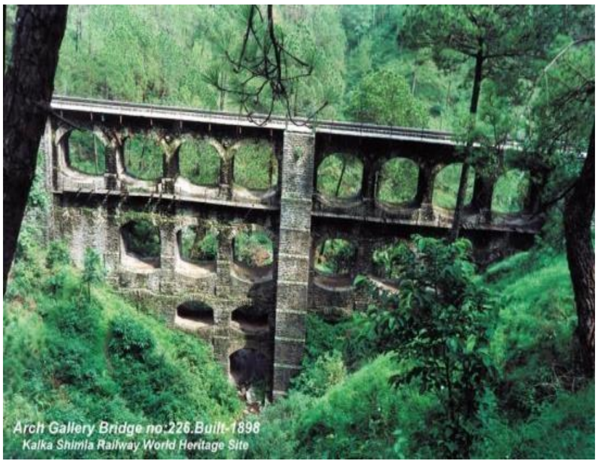
II. CASE STUDY DESCRIPTION

A. Heritage

Approximately 111 years back KLK-SML Railway, Himachal Pradesh line was opened for public on 9th Nov.1903(FIG 1). It was also known as "Mountain Railways of India" and declared as World Heritage Railway line by UNESCO on 10th July 2008. It is believed that a local saint Baba Bhalkhu helped the British engineers in laying down this track. In dedication to his services, Railway has named a Museum as BABA BHALKHU RAIL MUSEUM at SML.

The narrow-gauge line has 96.57 km length. Multi Arched Galleries, like ancient Roman Aqueduct were very commonly used to carry the lines carrying the lines over a deep narrow valley with steep sides on the hills. Some of the bridges are unique, specially Bridge No 226 & 541 remained most spectacular bridges of this section throughout this period (Fig 2). Initially there were 103 tunnels, but 102 exist, as tunnel number 46 does not exist now. Out of these 102 tunnels, Barog Tunnel (No 33) is 3752 feet long. It is the longest Tunnels of Kalka Shimla Railway Line. The first two steam locomotives approved on Kalka Shimla Railway were from Sharp Stewart and Company Limited of Glasgow, built in 1900 & 1902 respectively. Diesel Traction was introduced in 1956 in KLK-SML railway track. No doubt this exotic Railway section is stunningly beautiful. Sometimes it faces whim of nature also. Peak winter season and rainy season are the worst period for KLK-SML line. The snowfall of moderate intensity is very common on this section, in December and January.

[Fig.1: KLK-SML Railway in 1903]



[Fig.2: Arch Gallery Bridge]

B. Railway coaches of KLK-SML line-

The coaching stock of Indian Railways includes three versions, namely ICF (Integral Coach Factory), RCF (Rail Coach Factory) and LHB (Linke Hofman Busch, Germany). Though Govt of India has taken the initiative to replace all ICF coaches to LHB due to less weight and more speed for LHB trains but as the KLK Shimla railway trains are old the uses the ICF coaches. Unlike the LHB coaches the ICF coaches has alternators and power backup system. Due to which it does not require any additional provisional power from the Locomotives or the EOG (End on Generation) to provide uninterrupted supply of electricity to the coaches. Moreover, in ICF coaches there are battery backup boxes and alternator system present near the axle of the wheels, this system helps in providing supply, without any external sources, as like LHB has.

Before installation of Solar PV, the KLK-Shimla trains also have also Body Mounted Flat Belt type Alternator with Rectifier cum Regulator Unit (RRU) (Fig 3). The specification of alternator uses here is 3kW, 30V, 100 Amp and weight is approx. 200 kg.

[Fig.3: Alternator Connected with ICF coach in KLK-Shimla Trains]

ICF coaches uses Self Generating (SG) scheme of power supply, the power required to cater the electrical load in the coach is generated by coupling an alternator to the wheel and axle system of the rail coach by means of a V-belt. The wheel and axle set up acts as the prime mover for the alternator. The output of the alternator is used to charge the battery bank which supplies for the electrical load in the rail coach. The batteries get charged as long as the rail coach is in motion. Here twelve numbers of 2V lead acid batteries have been used. The batteries provide the lighting load.

In KLK-SML line the trains are charged by electricity to provide the hauling and lighting power.

The electrical charging arrangement snapshot has been depicted in Fig 4.

[Fig.4: Electrical Charging for ICF coaches at KALKA]

C. Solar PV installation of Railway coaches:

In 2011, The Indian Railway installed 1 kWp capacity SPV modules on rooftop of trains at Pathankot, Punjab, India.

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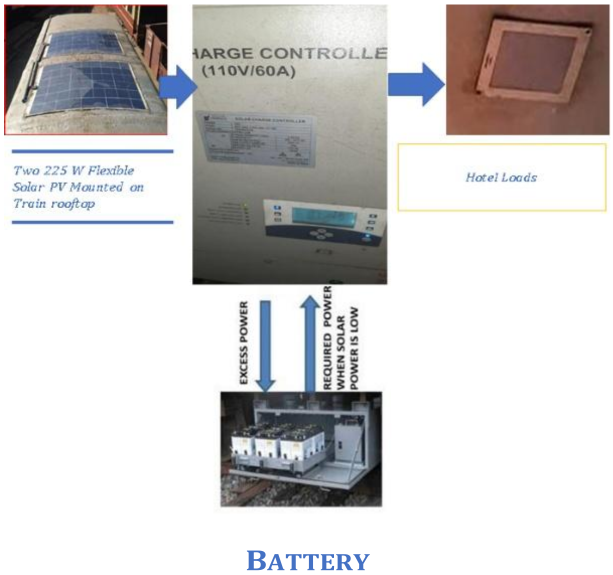
The SPV modules power 420 W. Similar attempts were made by KLK-SML railway, to supply hotel loads each. These experiments were done for narrow gauge rail coaches, which run at a maximum speed of 40km/h. The coaches of KLK-SML line are mainly charged by Electricality now. The total charging time is 6 hrs (Kalka 4hrs and for Shimla 2 hrs). In October 2019, as a zero- carbon initiative in some coaches of KLK-SML trains solar PVs have been installed. On the solar PV installation main challenge was standard dimension. The PV modules and the mounting structure has to abide the Maximum Moving Dimension (MMD) guidelines as mentioned by Research Design and standard Organisation. Since the roof is curved so two Polycrystalline Solar PV each of 225 W have been installed (Fig 5). One of the first initiative also done here with flexi solar panels. To install conventional/rigid solar panels the MS frame have to be installed by puncturing the railway coaches. The mounting lead to additional weight on coach and also increase the height of coach. The increase height and weight will lead to more Fuel/Electricity consumption due to increase in hauling loads. The flexible solar panels can be bent up to 30^{o} and it is about 80% lighter than conventional Solar PV. Thereby flexible solar panel to cover the roof of the railway coach with specialized pasting technologies is considered a better option than conventional solar PV. The adhesive sealant with suitable bead size shall be applied as to Flexible solar panels. The sealing of Flexible solar panels is carried out on its periphery with a minimum of 2 inch wide and 2mm thick translucent, single side coated pressure sensitive acrylic adhesive tape with Ionomer backing, having an elongation of 530% at break when tested as per ASTM D3759.

[Fig.5: Solar Panel on Roof of NG Coach/KSR]

D. Solar System Design

Combination of several solar panels with supporting structure is known as solar array. Here two 225 W polycrystalline solar panels are connected with mounting structure will be referred as solar array. Array Junction Boxes are provided in between Flexi Solar PV (Photovoltaic) Module's array and CCU (Current Control Unit). DC Disconnect or MCCB of suitable rating for connection and disconnection of array section are provided. Surge Arrestor is also incorporated for surge protection. Meters are provided for measuring the array voltage and array current. An array junction box is used to combine the DC cables of the Flexible solar panel arrays with DC HRC fuse protection or DC PV fuse protection for the outgoing DC cables to the CCU. The Junction Box is mounted close to the CCU. The output of solar power plant is connected with Direct Current Distribution Box (DCDB) through solar charge controller output. DCDB have Miniature Circuit Breaker for short circuit and Over current protection.

Maximum Power Point Tracking (MPPT) Solar Charge Controller is provided between the array junction box and DC loads, battery and auxiliary power supply. The CCU (Charge controller Unit) converts the power generated from Flexible Solar Panels to 110V DC which is used to feed the hotel loads of the Train. The excess power is used to charge the batteries which are feed the load during night or non-sunny days. In case of non-availability of solar energy of solar energy and full discharge of battery, an Auto Change Over switch is provided in suitable location to switch over the hotel load supply through auxiliary power supply of train. CCU also control the amount of charge flowing in and out of the battery. It acts like a voltage regulator. Primary function of a charge controller is to manage rate and amount of charging the battery. The CCU is also integrated with Voltmeter & Ammeter through LCD display with adequate protection to show the charging conditions. The details of Solar system installed in the trains of KLK-SML line is depicted in Fig 6.



[Fig.6: Block Diagram of Solar System Configuration for NON-AC coach at KLK-SML line]

III. FIELD STUDY AND FINDINGS

Across India the Global Horizontal Irradiance (GHI) is high all through the year with having the highest GHI of 6.8 kWh/m^2 and the lowest of 4.2 kWh/m^2 in December (Arsie, I et. al., 2008). A data logger has been set up to measure the peak power, irradiance and energy generation through the solar PV. The solar data has been collected throughout the year from July 2021 to June 2022 [1]. The battery voltage also been checked time to time through clamp meter during field study. The online solar energy datalogger and field measurement snapshots have

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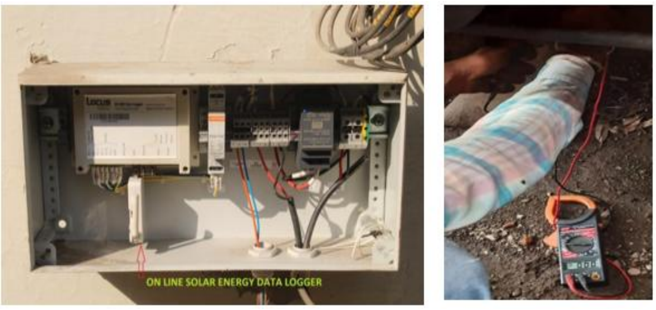
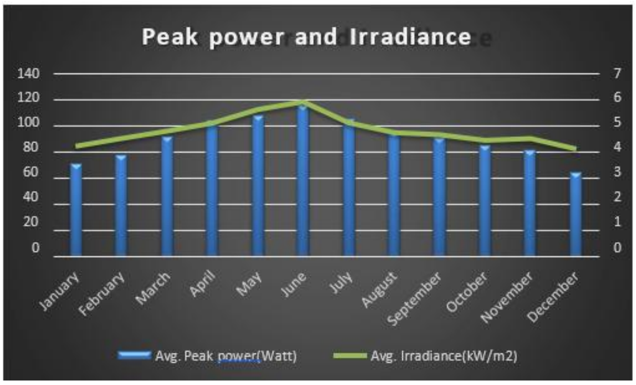
been depicted in Fig 7.



[Fig.7: Energy Data Logger and Field Measurement Snapshot]

A. Findings

The average peak power and average irradiance on monthly basis has been jotted down for review. Maximum and Minimum average peak power generated from solar system in the month of June and December respectively. Through Kalka-SML zone, the month with the most daily hours of sunshine is May with an average of 12.11 hours of sunshine. In total there are 375.51 hours of sunshine throughout June. The month with the fewest daily hours of sunshine in KLK-SML zone is December with an average of 8.89 hours of sunshine a day. In total there are 275.66 hours of sunshine in December. The maximum average solar irradiance occurs in the month of June, which is 5.9 kW/m^2 and lowest irradiance observed in the month of December i.e., 4.1kW/m^2. The average solar irradiance and average solar peak output power on monthly basis has been depicted in Fig. 8.



[Fig.8: Average Peak Power and Average Irradiance on Monthly Basis]

After the solar PV installation, the electrical charging required for hotel loads is not required. The Indian railway put its step forward to low carbon transition through this initiative. Solar PV installation on train rooftop not only cater the hotel loads but the requirement of Alternator and Lead Acid battery also abolished. It creates another opportunity to remove the train load around 500 kg or 0.5 Ton. The Alternator and lead acid battery weight has been measured of 200 kg and 300 kg respectively. In cascading effect, the hauling power reduction also results to less electrical charging than previous. Moreover, the lead acid battery is considered as hazardous waste. Reduction of hazardous waste is treated as very good initiative because in addition to human risks, hazardous waste mismanagement is also very harmful for the environment. Pollution, contamination, and leachate are all negative impacts that hazardous waste can have on the environment if not handled properly.

The benefits observed after installation the solar PV on the train rooftop of KLK-SML line has been depicted in Table 1

Table-1: Electrical Energy Requirement Per Day/Per Coach of KLK-SML Line Trains

Electrical Energy Requirements Per Day Per Coach	
Charging Time: - At Shimla Station	4 hours
Charging Time: - At Kalka Station	2 hours
Total Charging Time	6 hours
Hotel Load / Coach	13 nos. Lights @ 7W = 91 W 5nos mobile charging unit@20W=100 W 4nos fan @45 W each = 180 W - - - - - - - - - - - - - - - - Total Hotel load = 371 W
Energy requirements for hotel load	371 W X 5.5* Hrs. = 2040 Wh (2kWh approx)
Hotel Energy Required for To and FRO journey per coach	2 X 2 = 4 kWh

* KLK-SML train normally takes 5.5 hours to travel from Kalka to Shimla

Around six trains travel in KLK-SML narrow gauge line per day and every train has 8 coaches. If solar system has been installed in each consecutive coach, then four coaches of each train is powered by green energy. Here consecutive coach has been chosen to give more margin of safety so that in any case there is a failure of solar system then the coach can take power from other coach which is charged by conventional electrical power [Fig.9]. The train time required to travel from KLK to Shimla is around 5 hours and most of the time it travels in day time. The lights will be turned on only when there is fog or daylight is not available. The average speed of trains has been maintained 20km/hour. So, we have taken that around 3hours the hotel loads are on for calculation taking sufficient margin of safety.

From table 1 it is seen that for Solar installation there is an electrical energy saving 4kWh/per coach. Not only that there is around 500 kg weight (i.e., 200 kg for alternator and 300 kg for battery) reduction after solar installation as solar system weight is negligible.

[Fig.9: Solar System Installed in Consecutive Coaches]

Hauling power for a train also directly proportional to weight exerted on each driving axle as depicted in

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equation 1.

Hauling Power of train = Number of Pairs of Driving Wheels x Weight exerted on Each Driving Axle x Coefficient of friction …. (1)

The weight of each train in KLK-SML line is 20,000 kg (RDSO, April 2017) [4]. After solar installation the coach tare weight reduced by 500 kg. The solar system weight in comparison with the alternator and battery weight is negligible so we can conclude that for four coaches around 2000kg weight (@ 500 kg per coach) will be reduced which is around 10% of total weight of train. The 10% weight saving will result 10% of energy saving for hauling power.

Though a point here has to be considered that the energy required for hotel loads is generated through Self Generating Scheme, so we can't directly claim that 4 kWh electrical charging per coach has been saved for solar installation but in view of hauling power reduction due to decrease of weight of Alternator and Battery it has been assumed that 4kWh has been saved per coach for further calculation.

The electricity saving, carbon emission reduction, payback period for solar installation has been depicted in table 2.

Table-II: Benefits of Solar Installation in KLK-SML Line Trains

Benefits of Solar Installation on Coach Rooftop	
Hotel load energy consumption/coach	4kWh/per day
Hotel load energy consumption for solar installed coaches	4x4= 16kWh
Energy Saving per year/train after solar installation	16x 365= 5,840 kWh
CO2 emission saving per train per year	4.84 tonnes (@0.00083 tCO2e/kWh)
Carbon Credit per train per year	4.8 tonnes
Initial Investment after deducting the scrap (Alternator and Battery)	1960 $ (@490$ per coach)
Monetary saving for Electricity purchased	642$ (0.11$ per kWh)
Payback period	3 year 6 months

It has been seen that the fist initiative of solar installation in KLK-SML trains has saved 5,840 kWh per year per train and which is equivalent to 4.84 tonnes CO_2 saving. After solar installation the coach tare weight has been reduced 0.5 tonnes per coach among that hazardous waste material(battery) is 0.3 tonnes/coach. The payback period calculated based on energy saving which is only 3 years 6 months. It will be again reduced if we consider the Carbon Credit trading. Carbon credits are certificates representing quantities of greenhouse gases that have been kept out of the air or removed from a process. While carbon credits have been in use for decades, the voluntary market for carbon credits has grown significantly in recent years. Indian Govt. is all set to launch a domestic carbon market very soon to achieve the ambitious pledge of became net zero country within 2070.

IV. CONCLUSION

Indian Railways, the fourth largest railways in the world by network. has envisioned to become a Green Transporter by reducing its carbon footprint. The energy consumption of Indian Railways in FY 2020 was around 18, 410 Million Units for traction and 2,338 Million Units for non-traction load. Indian Railways has taken significant initiatives to reduce its carbon footprint & fuel cost. One of the first initiative they have taken by installing solar in a heritage root train i.e., KLK-SML line. Though the program was successful but till date there is no information in scientific domain for further research. In this paper we have documented not only all the details of solar system installed in coach rooftop but also collected the peak power generation, solar irradiance etc. through out the year.

There are six trains in the narrow-gauge route and one train consists of 8 coaches. Two 225w flexible solar panel has been installed in the consecutive coaches of each trains. Here consecutive coach has been chosen to give more margin of safety so that in any case there is a failure of solar system then the coach can take power from other coach which is charged by conventional electrical power. The trains are charged by the electric supply at Kalka and Shimla station around for 4 hour and 2 hours. The solar system mainly installed to supply the hotel loads of the coach. The successful installation of flexible solar cell in coach rooftop will open a new opportunity for further research in broad-gauge trains. Another importance of this study is that before it was believed that the project will not be so much successful because of cold climate and fog prevailing in this route. Our study proves that this assumption is not correct. All the trains here use ICF coaches and the hotel loads mainly supplied by Self Generation (SG) scheme so directly the energy saving can't be claimed but one interesting point come out that due to the removal of battery and alternator the tare weight per coach is reduced around0.5 tonnes among that hazardous waste is 0.3 tonne. This will result to decrease the hauling power around 10% and so the energy saving for hotel loads can be assumed after solar installation. In case of LHB coaches the saving can be directly calculated as it uses direct power to run hotel loads. India has already taken the initiative to shift to LHB coaches from ICF due to its light weight and other advantages. So, one of the conclusions from this study can be drawn that it is much profitable to install solar in LHB coaches than ICF.

It has been recorded that Maximum and Minimum average peak power generated from solar system in the month of June and December respectively. The average monthly irradiance prevails in the range of 4.1 kW/m^2 to 5.9 kW/m^2. The study also depicted that the energy saving per year per train is around 5,840 kWh per year per train and which is equivalent to 4.84 tonnes CO_2 saving. At the time of initial investment, the railway authority has sold the scrap alternator and hazardous waste material i.e., LED Acid Battery.

This not only reduce the initial investment but also eliminate the ill effects of hazardous waste mismanagement like human risk pollution, contamination and leachate. The payback period calculated based on energy saving which is only 3 years 6 months which is quite lucrative investment option. The payback will again be reduced if we consider the Carbon Credit trading because this projects also earns 4.8 tonnes carbon credit per train per year. This study proves that India's initiative to became a green transporter is in right path. High solar irradiance throughout the country and the successful implementation of solar projects in railway coach rooftop will play a dominant role to make the ambitious pledge to became carbon neutral with 2070.

DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

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- **Ethical Approval and Consent to Participate:** The content of this article does not necessitate ethical approval or consent to participate with supporting documentation.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Authors Contributions:** The authorship of this article is contributed equally to all participating individuals.

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