Solar photovoltaic assistance for LHB rail coaches

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Awareness for the need of sustainable and eco-friendly mobility has been increasing and various innovations are taking place in this regard. A study was carried out to assess the feasibility of installing solar photovoltaic (PV) modules atop train coaches. Most long-distance trains having LHB coaches do not have self-generating systems, thus making power cars mandatory to supply the required power for lighting loads. Feasibility of supplementing diesel generator sets with power from solar PV modules installed on coach rooftops has been reported in this communication. Not only is there a conservation of fuel, there is also a significant reduction in CO_2 emissions. This work has shown that the area available on coach rooftops is more than sufficient to generate the required power, during sunlight hours, for the electrical loads of a non-A/C coach even during winter. All calculations were done keeping a standard route as the reference. Taking the cost of diesel to be Rs 66/litre, it was estimated that there will be annual savings of Rs 5,900,000 corresponding to 90,800 litres diesel per rake per year by implementing this scheme. The installation cost of solar modules would be recovered within 2–3 years. Implementation of this scheme would also amount to an annual reduction of 239 tonnes of CO_2 emissions.

Keywords: Carbon dioxide emissions, diesel, rail coaches, solar modules.

IN recent times, much research is being carried out to develop sustainable forms of transportation. This is necessary because transportation sector is a source of CO_2 emissions and is a cause of global warming. Solar power cannot be relied upon to completely replace conventional fossil-fuel engines. It can only supplement the power generated by the engine and subsequently reduce CO_2 emissions[1]. Buses and cars have been retro-fitted with solar panels on the roofs, hoods as well as the boot lids. The Adelaide City Council has introduced all-electric buses, with batteries being charged by solar panels mounted on top of the charging stations. Its operating cost is found to be less than conventional diesel powered buses[2]. Since the hybrid automobiles with solar technology have been realized, it would be logical to extend this idea to train coaches. The train coaches have a large roof area available for generation of energy using solar photovoltaic (PV) modules. The energy generated from this scheme in excess of the requirement in the coaches can be stored in batteries and used to supply electrical lighting loads even during night, thereby reducing the fossil-fuel consumption. Prototype experimental airplanes have been made to fly on stored solar energy during the night[3].

The coaching stock of Indian Railways includes three versions, namely ICF (Integral Coach Factory), RCF (Rail Coach Factory) and LHB (Linke Hofman Busch, Germany)[4]. The LHB coaches have a longer span-length to accommodate higher number of passengers and provide superior travelling comfort. They are also suitable for higher running speeds compared to ICF and RCF coaches. Hence, all the ICF and RCF coaches across the country will be replaced by LHB coaches in the near future. Therefore, the LHB coaches would be the focus of this work. These coaches are not self-generating (alternators driven by the moving wheels and axles), but have power cars which provide the required power for the electrical load in the coaches[5]. In this study, the power that can be harnessed on the train rooftop using solar PV modules is computed in order to conserve the consumption of fuel (diesel). The feasibility of installing solar PV modules of suitable characteristics to supplement the present power generation system is reported. A train that consists of 5 A/C coaches, 13 non-A/C coaches, a pantry car and two power cars, one at each end, is termed as a train-set (commonly referred to as rake) and this train-set has been considered for calculations in the present study. Though the study is carried out considering Indian subcontinent, the findings hold good for any location in the world with similar solar radiation.

Across India, the global horizontal irradiance (GHI) is high all through the year, with May having the highest GHI of 6.8 kWh/m^2 and the lowest of 4.2 kWh/m^2 in December (Figure 1)[6]. There are over 11,000 trains on tracks plying between 6900 railway stations in India every day. This indicates the amount of energy that can be generated during the day on top of the coaches of trains during all seasons. Having this scheme implemented in all the trains would result in considerable fuel savings as well as reduction of CO_2 emissions.

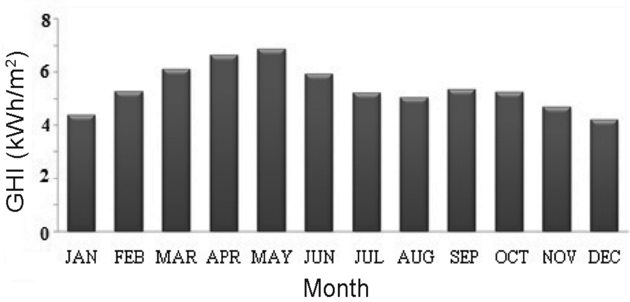

Figure 1. Plot representing the daily average global horizontal irradiance across India during various months of the year[6].

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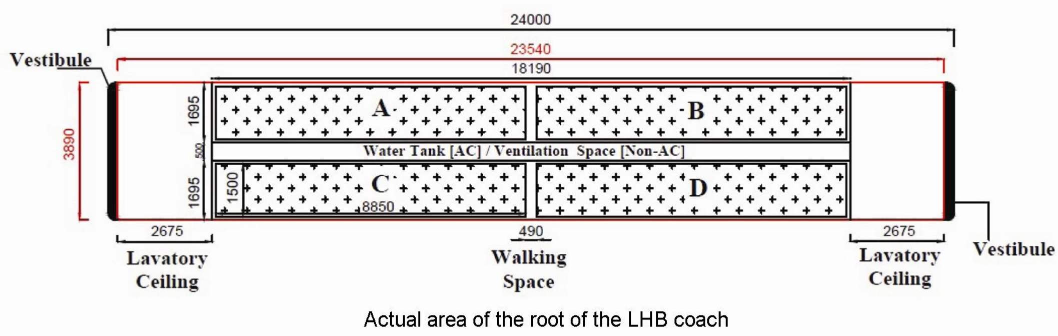

Figure 2. Schematic of the top view of a coach with the proposed design.

Figure 3. Graphical representation of a LHB coach mounted with solar PV modules.

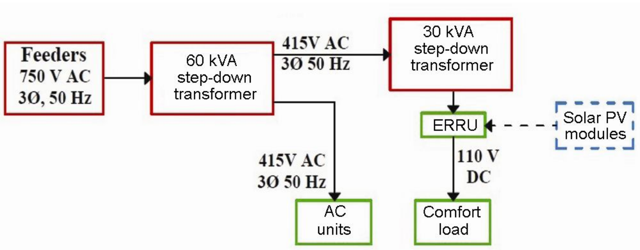

Figure 4. Power flow diagram of the existing system with proposed modifications.

Table 1. Calculation of solar power that can be harnessed

Solar power that can be harnessed in 1 m^2	154 W_P (ref. 8)
Area available on the roof of one coach	52.8 m^2
Thus, the capacity of the solar plant proposed on one coach	$52.8 \times 154 = 8.1$ kW_P
Considering system efficiency as 80%, the capacity of the solar plant that can be installed on one coach	6.5 kW_P
Capacity of the solar plant that can be installed on the rake (19 coaches)	123.5 kW_P

To mount solar PV modules on the rooftops, it is vital to consider the dimensions of the coach. The entire area of roof surface cannot be used for installing solar PV modules; there have to be clearances that allow personnel to access the top easily for various purposes and associated auxiliary equipment on the rooftop. This would mean that the actual area that is available for fixing solar PV modules is much less than the total surface area of the roof. For the convenience of calculation, the entire area on the roof of a coach shall be divided into four equal parts separated by walkways, as shown in Figure 2.

The power generation from solar modules in sections A–D may not be the same because it would depend on the direction and time of travel. Since the roof of the coach is curved, installing modules of standard sizes available in the market may not be feasible and would remain a constructional challenge. The power that can be generated from PV modules mounted in the area available on the rooftops is shown in Table 1. The installation of solar PV modules atop the roof of the LHB coaches would be similar to the representation in Figure 3.

A LHB rake consists of two power cars at either end which supply the required power for the entire rake. Each power car has two 400 kVA diesel generator sets (DG-sets). The power cars have two output terminals emerging from the two DG-sets, each providing 750 V AC. A 60 kVA transformer installed in every coach steps down the 750 V AC to 415 V AC. The AC units work on three-phase 415 V AC. However, for the lighting loads in the coach, a 30 kVA transformer is used to step down the voltage level to 110 V DC, through an ERRU (electronic regulator and rectifier unit). It is intended to divert the power from the solar PV modules to the ERRU which will in turn cater to the electrical loads, as shown in Figure 4. The ERRU regulates the uniform charging and discharging of a battery bank consisting of nine units of 70 Ah, 12 V valve regulated lead-acid (VRLA) batteries[7].

In Tables 2 and 3, various equipment that consume power in the cabin of a LHB coach for A/C, non-A/C and pantry car are listed along with their power usage. The data give an indication of the total power consumed in different types of coaches of the rake.

We now present calculations showing the feasibility of the scheme during both summer and winter season. The LHB rake considered makes one trip in 40 h and covers a

Table 2. Electrical loads in variants of LHB coach[9–11]

Equipment	Wattage (W)	No. of units	Net wattage (W)	A/C coach	Non-A/C coach	Pantry car
AC units	11,500	2	23,000	✓		
Tubelight	25	5	125	✓	✓	✓
	40	10	400	✓	✓	✓
Fan	60	30	1,800		✓	✓
Night lamp	15	5	75	✓	✓	✓
Lavatory lamp	20	4	80	✓	✓	✓
Emergency lamp	20	6	120	✓	✓	✓
Vacuum flush	50	4	200	✓	✓	✓
Reservation chart lamps	15	4	60	✓	✓	✓
Other loads	100	1	100	✓	✓	
Power sockets for mobile phones and laptops	100	18	1,800	✓	✓	
15 litres water boiler	2,000	1	2,000			✓
11 litres soup warmer	500	1	1,500			✓
Hot cases	500	3	1,500			✓
Water cooler	700	1	700			✓
Refrigerator	500	1	500			✓
Deep freezer	500	1	500			✓

Table 3. Summary of electrical loads in the rake

Connected electrical load in the AC coaches	26 kW
Connected electrical load in the non-AC coaches	4.6 kW
Connected electrical load in the pantry car	10 kW
Net electrical load in the rake	212.14 kW
Net lighting load in the rake (considering 19 coaches, including pantry car)	90 kW*

*Lighting loads include lights, fans, night lamps, lavatory lamps, reservation charts and other passenger comfort equipment.

Table 4. Comparison of global horizontal irradiance (GHI) required to sustain the lighting load of the rake and the GHI available

Number of sunshine hours in the trip	15
From Table 3, net electrical lighting load of the entire rake	90 kW
Energy consumption by the lighting load during the sunshine hours of the trip	$90 \times 15 = 1350$ kWh
Area available on the entire rake	1003.2 m^2
Energy that can be generated during summer months (GHI: 6.8 kWh/m^2)	$6.8 \times 1003.2 = 6{,}821.7$ kWh
Energy that can be generated during winter months (GHI: 4.2 kWh/m^2)	$4.2 \times 1003.2 = 4{,}213.4$ kWh

distance of 1800 km. The number of sunshine hours during the span of the trip is taken to be 15. Table 4 gives a comparison of GHI needed to generate the power requirement of the lighting load of the entire rake consisting of 19 coaches to the available GHI.

From Table 4, it is clear that the energy that can be harnessed during sunshine hours is much more than the requirements of the train even during shorter days of winter season. Even if half the panels are under shade, there is enough power to meet the lighting load requirements. The excess energy can be stored in batteries for consumption during non-sunshine hours.

The present scheme of operation of the power cars is as follows:

- Only one power car out of the two is put into service and the other is used as a standby.
- The power generated by one alternator is enough to cater to the electrical load in the entire rake. However, when the load is higher, say in summers due to usage of ACs, the second DG-set of the same power car comes into operation.
- Both the power cars have a diesel tank capacity of 3000 litres each and during the start of the journey both the tanks are completely filled.

Indian Railways, being the largest and most dense railway systems in the world, implementation of this design would lead to a significant move in conserving fossil fuels. However, it must incorporate a smart control system which operates depending on the availability of the solar power. At instances where solar power is insufficient, the control system should latch on to the conventional power supply scheme.

Assuming that the rake makes 188 trips in a year and 3000 litres of diesel is consumed per trip, it is shown from our calculations that 90,804 litres of diesel can be conserved every year with a saving of Rs 5,993,064. Table 5 shows details of the calculation. Taking the cost prescribed by the Ministry of New and Renewable Energy (MNRE), Government of India for setting up solar panels as Rs 90 per watt, it is shown that the investment is economically viable. The Indian railways would reap the benefits of saving diesel fuel for the lifetime of the solar PV modules after around 2–3 years when the initial investment is paid back.

For an efficient performance of this scheme, it is advisable to link the PV systems to the loads through a smart

Table 5. Definitions, calculations for fuel conservation and return of investment for the entire rake

Cost of H-type diesel purchased by Indian Railways	Rs 66/litre
Considering the POH (periodic overhaul) period of each coach as 30 days, the total number of trips made by the rake in a year	188
Volume of diesel consumed per trip	3000 litres
Capacity of the solar plant that can be installed on the rake	123.5 kW_p
Lighting load amounts to 43% of the total electrical load on the power cars; implying the diesel fuel consumed by the DG-sets to supply for the lighting load is approximately 43%.	
The 40 h travel consumes 1290 litres of diesel for electrical lighting loads, which implies that during 15 h of sunshine when solar energy can be harnessed, this scheme would save 483 litres of diesel.	
Volume of diesel consumed by lighting loads	1290 litres
Annual conservation of diesel due to solar power generated on the rake	483 × 188 = 90,804 litres
Cost of fuel that would be saved by the implementation of this system	90,804 × Rs 66 = Rs 5,993,064
Investment to be done to implement this design on the entire rake (price per watt prescribed by MNRE, GoI: Rs 90)[12]	Rs 11,115,000
Investment required for special mounting structures on curved surfaces (roof) for the entire rake*	Rs 3,334,500
Considering the investment for 19 coaches on which solar PV modules would be mounted, the overall investment for the entire rake	Rs 14,449,500
Annual O&M cost for a solar plant of 1 kW** (ref. 13)	Rs 1,163
Annual O&M cost for the entire rake	Rs 1,163 × 19 × 6.5 = Rs 143,630
Net cash flow per year	Rs 5,993,064 – Rs 143,630 = Rs 5,849,433
ROI (return of investment)	Rs 14,449,500/5,849,433 = 2.47 years

*Since the solar PV modules are required to be mounted on a curved surface, special mounting structures are to be fabricated. The price per watt for mounting the modules on a curved surface has been assumed to be 30% higher than the rate prescribed by MNRE.
**It has been stated by Central Electricity Regulatory Commission that the O&M cost of a solar power plant is approximately Rs 1,163,000/MW.

Table 6. Calculation of CO_2 emissions that may be mitigated

CO_2 emissions per litre of diesel as a rule of thumb[14]	2.66 kg
Total CO_2 emissions avoided per year considering 15 h of sunshine	2.66 × 90,804 = 241.53 tonne
Considering factor of combustion of 0.99, the effective reduction in CO_2 per year per train	241.53 × 0.99 = 239.12 tonne

grid on the train. These grids would consist of circuits which can regulate the source of charging the batteries, either from the DG-sets or the PV modules, depending on the loads in the rake and the time of the day.

The above computations have proved that there would be significant reduction in emissions. Table 6 shows that 239 tonnes of carbon dioxide emissions may be avoided per year per train by the implementation of this scheme. The calculations are done for one particular train; if the scheme is implemented on all trains across the world, it would further contribute to combating climate change.

The calculations demonstrate the feasibility and scope of using solar PV modules atop trains. This design would therefore benefit the Indian Railways by saving significantly on diesel fuel. Wide application of this design would enable usage of the power saved to supply for other creature comforts of the passengers. Modifications and replacements of the PV modules may be done without too much down time. Also, the operation of the electrical load management systems currently being used in the trains would continue to function with minor modifications. This work shows that the investment put into this project shall be recovered within a short duration. There are certainly challenges involved in this scheme, but it is necessary to underline the benefits and on a larger scale its impact would be tremendous. Installation of this system on any train, especially in the tropical regions, may be considered as a wise investment. The seasonal variations will not be a major hindrance as it has been proven that even during winter sufficient power can be generated on the rake.

The estimated price of the LHB rail coach consisting of solar power generation system would be 4% higher than the price of the present LHB coaches. It is to be noted that the investment on this scheme would be recovered within 2–3 years. Considerable subsidy/funding together with research and developmental support would further optimize this scheme.

Since the saving on annual diesel consumption of the rake would be about 90,804 litres and taking into account the total number trains running in the country, the amount of diesel conserved is large. Not only will this reduce the import of foreign oil, it will also be a welcome measure to mitigate global CO_2 emissions. The emissions that would be prevented annually amount to around 239.12 tonnes per rake.

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Effect of vitamin D_3 on antimicrobial peptide gene expression in the neutrophils of pulmonary tuberculosis patients

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We studied the effect of 1α 25 dihydroxy vitamin D_3 (1α,25$(OH)_2D_3$), the active form of vitamin D_3, on the expression of cathelicidin (CAMP), defensin-α3 (DEF-α3) and vitamin D receptor (VDR) genes in neutrophils cultured with or without *Mycobacterium tuberculosis* (*Mtb*) from pulmonary tuberculosis patients and healthy controls. Vitamin D_3 significantly enhanced the CAMP, DEF-α3 and VDR mRNA expression in the neutrophils of both the study groups ($P < 0.05$). Moreover, significantly upregulated CAMP expression was observed in vitamin D_3-treated neutrophils infected with *Mtb* ($P < 0.05$) in both the study groups. These findings suggest that vitamin D_3 enhances innate immunity by increasing the expression of the CAMP gene, which might inhibit the growth of *Mtb* at the site of infection.

Keywords: Antimicrobial peptide genes, cathelicidin, neutrophils, tuberculosis, vitamin D_3.

TUBERCULOSIS (TB) is a granulomatous disease caused by *Mycobacterium tuberculosis* (*Mtb*). During mycobacterial infection, polymorphonuclear cells (PMNs) or neutrophils leave the blood vessels and infiltrate the site of infection and get involved actively in the inflammatory response[1]. Neutrophils have different types of granules and secrete an array of antimicrobial peptides that play an important role in innate immunity. They express four alpha defensins, also known as human neutrophil peptides (HNPs1-4), that can attract the monocytes and help macrophages kill intracellular pathogens[2,3]. Moreover, human neutrophils also express cathelicidin antimicrobial peptide (hCAP-18/CAMP)[4], which undergoes further cleavage by protease-3 to form LL37, the active form of CAMP[5].

Adequate serum concentration of vitamin D_3 is critical for optimal innate immune response. Rapid sputum clearance of mycobacteria and radiological improvement were observed in Indonesian pulmonary tuberculosis (PTB) patients, who received vitamin D supplementation[6]. Several studies have shown that 1,25-dihydroxyvitamin

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