Solar Assisted Power Supply for Rail Coaches

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Abstract
We have examined the feasibility of installing solar photovoltaic modules atop train coaches in India. Most long distance trains of Indian Railways consist of Alstom-LHB (Linke Hofmann Busch) coaches that do not have self-generating systems, making diesel generator cars mandatory to supply the required power for the electrical loads of the coaches. The feasibility of supplementing the diesel generator sets with power from solar photovoltaic modules installed on the coach rooftops has been studied. The area available on the roof of the coach was found to be more than sufficient to meet the electrical lighting load through photovoltaic modules.

For the case study, a typical railway route that covers a distance of 1,800 km has been considered. The saving of diesel was around 90,000 litre per year per train-set. The analysis indicates that the return on investment is around 4 years. In addition, this scheme will reduce the CO_2 emission by 239 tons per year per train. Indian Railways being the largest railway network of the world, operates 160 LHB trains in a day. Hence a significant savings in Diesel and reduction in CO_2 emissions can be achieved.

Keywords: Railway, Solar, Renewable, Energy, Transportation, Sustainable

Introduction

The transportation sector is a major contributor to the global CO_2 emission and global warming. Solar power can be used to reduce the CO_2 emissions in buses and trains. The Adelaide City Council introduced all-electric buses in which its batteries were charged by a roof-mounted solar photovoltaic(SPV) system erected at charging stations and has concluded that its cost of operation is far less than diesel powered buses(Adelaide City Council, 2007). In Italy, amorphous silicon modules were installed on five passenger coaches, two locomotives and three freight coaches. (Alessandro Basili, 2005). In 2010, TER-SCNF (Transport Express Régional Société Nationale des Chemins defer Français), the state-owned railway of France tested a DMU (Diesel Multiple Unit) fitted with Thin-film CIGS (Copper Indium Gallium Selenide) SPV modules. The SPV system of capacity 990W_p mounted on the rooftop partially supplied power for electrical lighting system inside the DMU (Disasolar, 2012). In 2011, Indian Railways, rail coach at Pathankot was fitted with SPV modules of net capacity of 1 kW_p to power an electrical load of 420W. Similar attempts were made in Kalka-Simla Mountain Railway (toy-train) to supply power for six LED bulbs of 6W each(Ministry of New and Renewable Energy, 2012).The experiments that were done by Indian Railways was for narrow gauge rail coaches run at a maximum speed of 40 km/h. This paper discusses the feasibility of providing solar power for broad gauge (1,676 mm) LHB coaches being used by the long distance trains of Indian Railways, which generally run up to a maximum speed of 160 km/h.

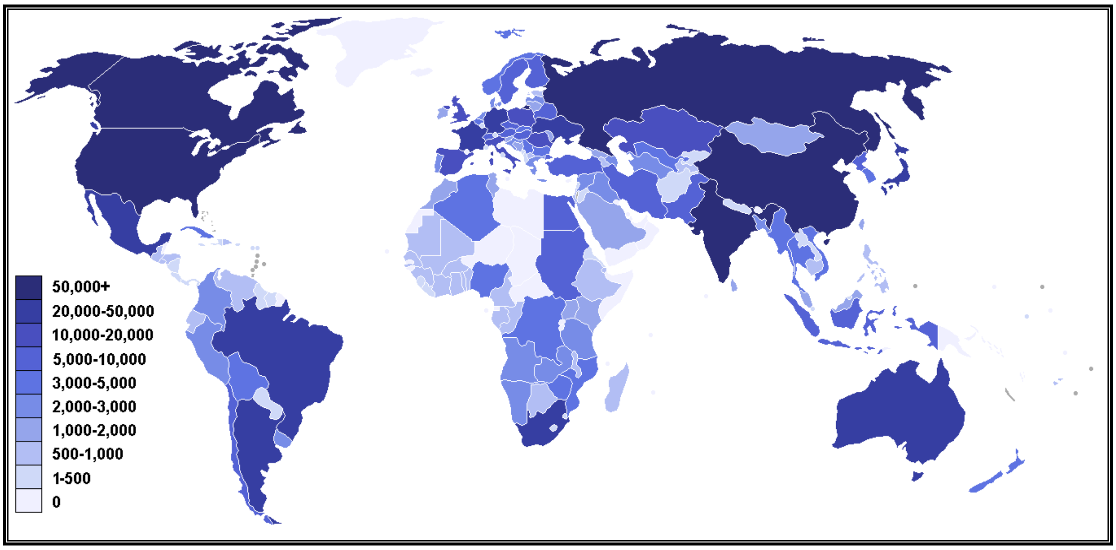

Figure 1: Map describing the length of various railway networks in the world (Wikipedia, 2013)

Figure 1 shows the lengths of railway networks of different countries. It can be seen that United States of America, China, Russia, India and Canada have the longest railway lines. India has the 5th largest railway network of the world with a total length of 65,436 km and has been operational since 161 years. It carries 23 million passengers per day scattered over 12,617 trains and remains as the most preferred mode of transportation (Mali, 2014). Figure 2 shows the spotting of various trains of India Railways in which blue and red arrows represent the trains in transit and trains at stations, respectively.

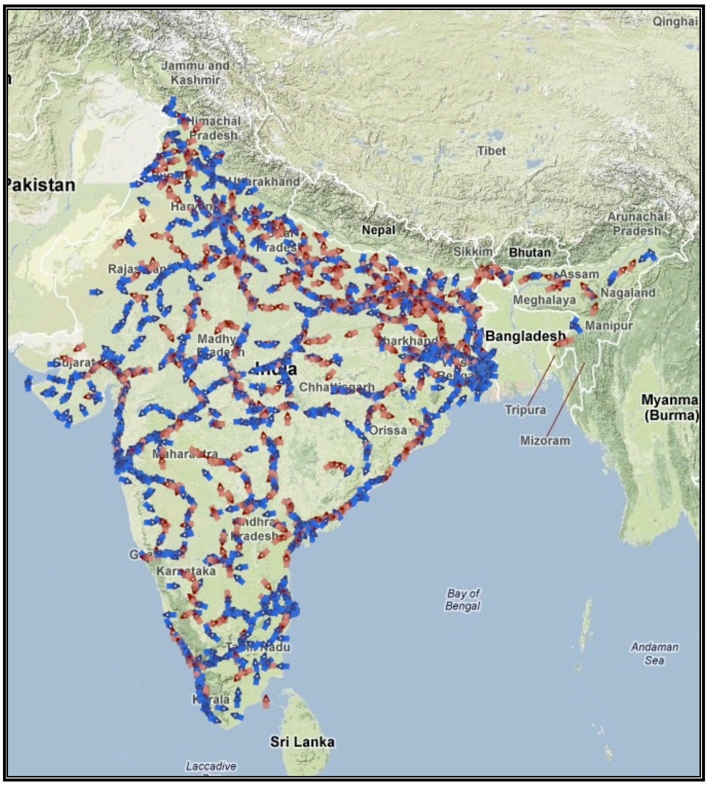

Figure 2: Train spotting of Indian Railways (Ministry of Railways, 2013)

Diesel has been the major source of energy for most of the rolling stock of Indian railways. As shown in figure 3, 70 % of diesel is being consumed in the transportation sector of India, where Indian Railways consume 3.24 % (Ministry of Petroleum & Natural Gas, 2014).

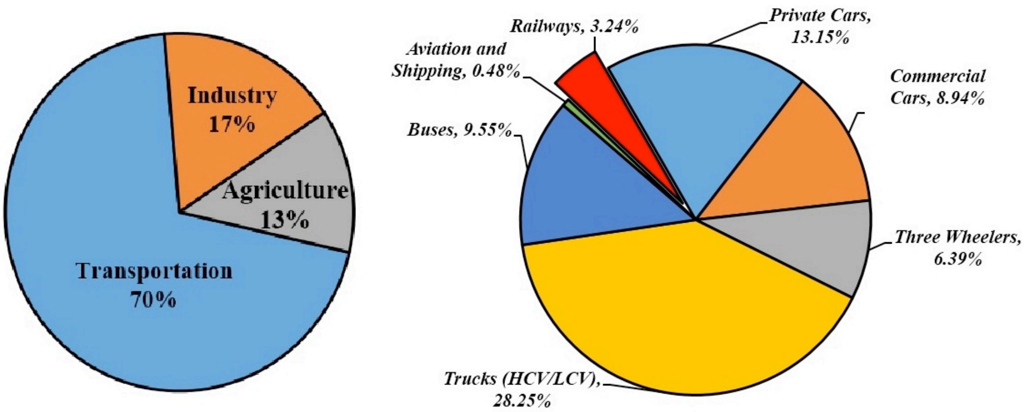

Figure 3: Sectorial Consumption of Diesel in India

Coaching stock of Indian Railways and its power supply schemes

The coaching stock of Indian Railways includes three versions classified based on the manufacturing units, namely ICF (Integral Coach Factory), RCF (Rail Coach Factory) and LHB (manufacturing license by Linke Hofmann Busch, Germany)(Shravanth Vasisht, Sridhar, & Dhanyavathi, 2011).The total number of passenger coaches being operated in India adds up to 62,924 out of which 5,000 coaches are variants of LHB (Wikipedia, 2014). Since the LHB coaches possess benefits like higher carrying capacity, lesser weight, low corrosion, low maintenance, good aesthetics, better passenger comfort and safety than the conventional coaches, Indian Railways is slowly migrating from conventional coaches to LHB coaches (Ministry of Railways, 2012).

There are two significant schemes of power supply for the coaching stock of Indian Railways, namely Self-Generation (SG) and End-On Generation (EOG)(Shravanth Vasisht, Sridhar, & Dhanyavathi, 2011), which are adopted by the utility based on the requirement of variants of the coaching stock.

Self-Generation (SG) Scheme

In 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, as shown in figure 4. 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.

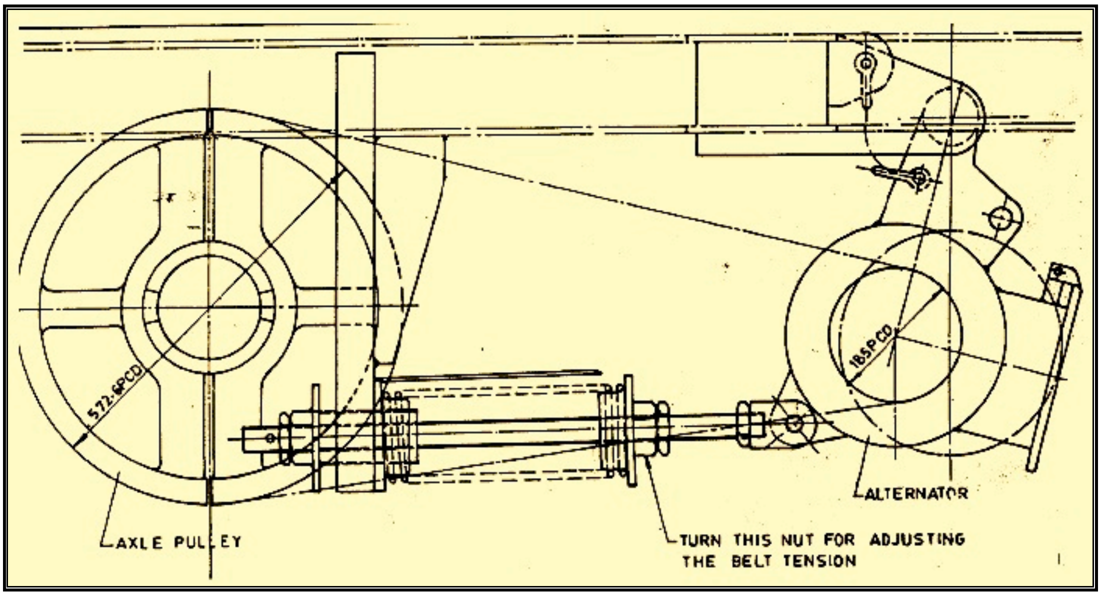

Figure 4: Schematic representation of SG scheme (Shravanth Vasisht, Sridhar, & Dhanyavathi, 2011)

SG system is being used in the conventional rail coaches of Indian Railways and stands as the most environment friendly sources of energy for the rail coaches. In case of outage in the SG system, the required power can be drawn from the adjacent coaches of the rake with the help of the terminals provided on either ends of each coach.

End-On Generation (EOG) Scheme

EOG scheme of power supply employs two diesel generator sets (DG-Sets) installed in a wagon. This wagon is known as generator car or power car and is coupled on either ends of the rake, as shown in figure 5 (a). The generator cars provide the energy required for supplying for the electrical load of the entire rake, as shown in figure 5(b).

Figure 5(a): Generator Car or Power Car

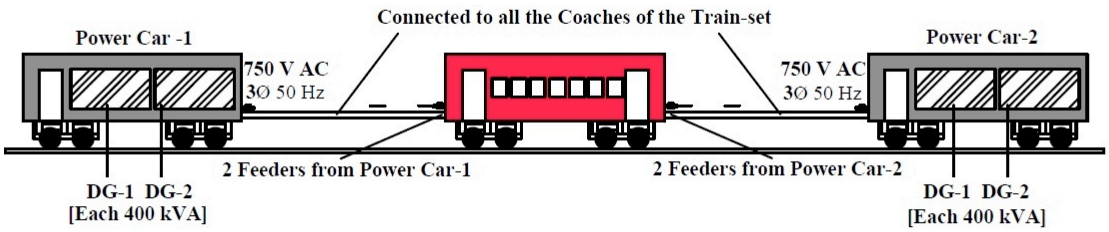

Figure 5(b): Schematic diagram of a rake with EOG scheme of power supply

EOG scheme has been adopted in the LHB variants of coaching stock of Indian Railways. The only demerit of LHB coaches is the consumption of huge volume of diesel for supplying the electrical load. In addition to this, the generator cars produce loud noise which is audible upto a distance of more than 1 km. There is a need to adopt solar power for the coaches in order to reduce the diesel consumption by the LHB coaches, at least for supplementing the electrical power required for the lighting load (Vasisht, Vishal, Srinivasan, & Sheela, 2014). Providing solar power assistance for the LHB rakes would not only reduce the diesel fuel consumption but reduces the CO_2 emission which is one of the major greenhouse gases.

A Case Study

To check the feasibility of providing solar power assistance for LHB coaches, it is required to know, analyze and evaluate the performance of a train consisting of LHB coaches. For this, one of the first few mixed rake LHB trains (a train with rake composition of both air-conditioned and non-air-conditioned coaches) of the country was selected and details about various types of electrical loads (both heating and lighting circuits), diesel consumptions of the generator cars, fuelling schedules of generator cars and area of roof-top available for installation of SPV modules were collected. The transition from source to destination has been termed as 1 trip. The route taken by the train and other details of the train are as shown in figure 6 and table 1, respectively. It was calculated that the lighting load in the entire rake amounts to

43% of the net electrical load. However, the main focus of this work was to supplement the power source for the electrical lighting circuit in the rake.

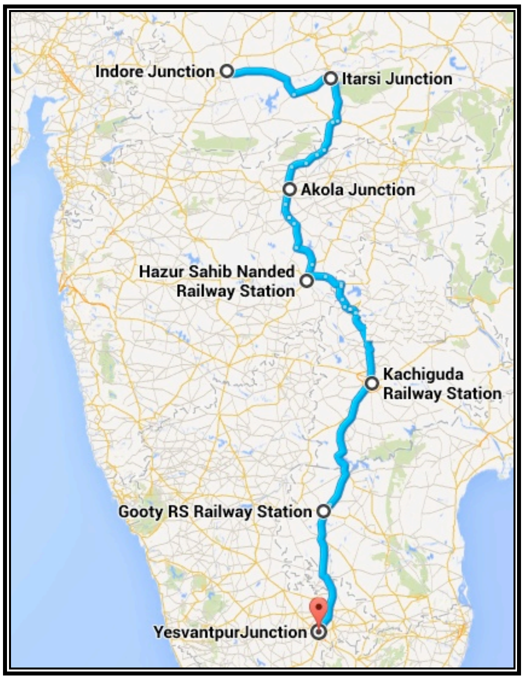

Figure 6: Route map of the train considered for case study

Table 1: Details of the LHB train considered
(Vasisht, Vishal, Srinivasan, & Sheela, 2014)

Name of the train	**Indore – Yeswantpur LHB Express**
Rake composition (19 coaches) **i. No. of air-conditioned coaches** **ii. No. of non-air-conditioned coaches** **iii. No. of pantry cars** **iv. No. of generator cars**	 5 13 1 2
Distance from source to destination	1,800 km
Duration of 1 Trip (source to destination)	40 hours
Total sunshine period during the trip	15 hours
Electrical load (lighting circuit only) **i. Total lighting load per coach** **ii. Net lighting load of the rake**	 4.6 kW 90 kW
Details of the fuel used for generator cars **i. Type of fuel used** **ii. Price per litre of fuel**	 Hi-Speed Diesel (HSD) US$ 1.07 (Rs. 66)
Fuel consumption by generator cars for 1 trip **i. by the net electrical load of the rake** **ii. by the lighting load of the rake** **(43% of the net electrical load of the rake)**	 793 gallons (3,000 litre) 341 gallons (1,290 litre)

iii. Expenditure on fuel for supplying for electrical lighting load during the trip	US$ 1,385 (Rs. 85,140)

It was observed that the train is exposed to sunshine for 15 hours during the trip. This is indeed a good opportunity to harness the solar energy incident on its roof-top. The roof-top layout of the LHB coach along with the region available for placing the SPV modules is shown in figure 7 and calculation for evaluating the feasibility of erecting the SPV modules within the space available is shown in table 2.

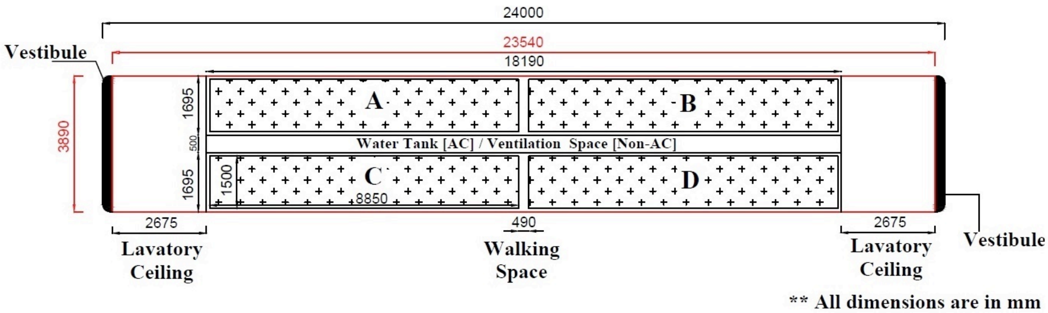

Figure 7: Proposed layout of the roof-top of an LHB coach (Vasisht, Vishal, Srinivasan, & Sheela, 2014)

Table 2: Roof-top area available for the installation of SPV system on one LHB coach

Roof-top area of the LHB coach i. Roof-top area available on an LHB coach ii. Area occupied by air-conditioning units, lavatory ceilings, water tanks. walkways and ventilation vents iii. Total available area for mounting SPV modules	 93.36 m^2 31.567 m^2 61.793 m^2
Solar power potential in an area of 1 m^2	154 W_p
Thus, solar power potential in the area available on the roof-top of an coach	61.793 m^2 X 154 W_p = 9.5 kW_p
Net solar power potential assuming system efficiency to be 80% and shaded region as 15%	6.5 kW_p

From tables 1 and 2, it is clear that the solar power potential on the roof-top of one LHB coach is significantly higher than the electrical lighting load of the coach. In order to check the feasibility of installation of SPV system for catering the lighting load, the average daily Global Horizontal Irradiance (GHI) is required to be taken into consideration. Figure 8 describes the trend of daily GHI averaged over different months of the year (Ministry of New and Renewable Energy, 2013). It can be observed that GHI is maximum and minimum during the months March and December, respectively. The estimation of the energy that can be generated from the SPV system and its comparison with the energy consumed by the electrical lighting load of the rake is given in table 3.

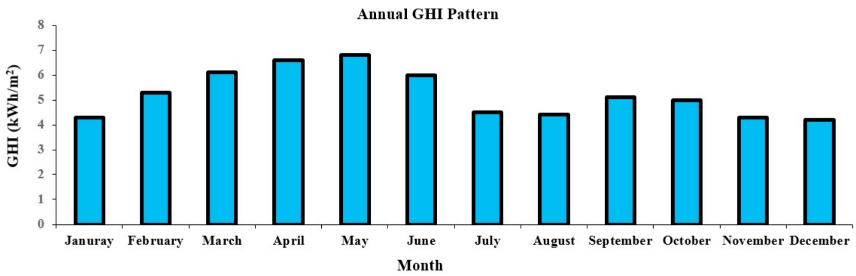

Figure 8: Monthly average daily GHI pattern

Table 3: Solar power electrical generation by SPV system

From table 2, total area available on the roof-top of all the coaches in the rake	1,174 m^2
Net capacity of SPV system that can be installed on the roof of the rake	6.5 kW_p X 19 = 123.5 kW_p
From figure 8, yield of the SPV system when the monthly average daily GHI is i. maximum (March) ii. minimum (December)	6.8 kWh/m^2 X 1,174 m^2 = 7,983 kWh 4.2 kWh/m^2 X 1,174 m^2 = 4,930 kWh
Lowest daily GHI measured in India(Ramachandra, Jaina, & Krishnadas, 2011) Estimated yield of the SPV system for the lowest daily GHI measured	2.5 kWh/m^2 2.5 kWh/m^2 X 1,174 m^2 = 2,935 kWh
From table 1, energy consumed by the net electrical lighting load of the rake during the sunshine period (15 hours) of 1 trip	90 kW X 15 hours = 1,350 kWh
From table 1, volume of diesel consumed by the electrical lighting load of the rake during the sunshine hours of 1 trip	128 gallons (483 litre)

From table 3, it is clear that the energy that is actually required to supply for the electrical lighting load in the rake can be the comfortably generated from the SPV system even on the days with GHI as low as 2.5 kWh/m^2. It is also clear from table 3 that the SPV system can support the electrical lighting load in the rake even if 50% of the roof-tops are shaded, thus providing sufficient yield even with diffuse radiation. Hence, seasonal variation would not be a major hindrance.

Impact of this scheme

The train considered is assumed to undergo a periodic over-haul (POH) stretching up to a maximum duration of 30 days, the train makes upto 188 trips in a year. The utility can reap benefits mentioned in table 4 along with a large reduction in CO_2 emission.

Table 4: Benefits of implementation of this scheme
(Vasisht, Vishal, Srinivasan, & Sheela, 2014)

From table 1, the maximum number of trips the train can make in an year	188
Volume of diesel that can be annually conserved due to this scheme	23,988 gallons (90,804 litre)
Return on Investment (ROI)	3.38 years
Annual reduction in the CO_2 emitted by one train, considering the amount of CO_2 emitted per litre of diesel burnt as 2.66 kg and factor of combustion as 0.99	239 tonnes

Requirements for implementation of this scheme

Solar assisted power supply for rail coaches can be implemented if the following requirements are satisfied.

1. SPV modules that are required to be mounted must suit the dimensions of the coach and should be flexible or semi-flexible. These SPV modules can be selected from the models available in the market and arranged suitably to attain the required voltage.A better option would be to manufacture the SPV modules based on the dimensions of the rail coach. In either case, the system voltage of 110 V has to be achieved.
2. A smart central processing unit (CPU) consisting of a power conditioning unit (PCU) is required to be designed. This equipment must be integrated to all the power sources and electrical loads as shown in figure 9 and must be able to
    a. switch the power source for lighting circuit between EOG and SPV system based on the availability of sunshine
    b. regulate the charging required for the battery bank depending on the availability of sunshine and previous data recorded by the system
    c. provide uninterrupted power supply for the net electrical load in the rake by coordinating with all the power sources available and efficiently shift to default (conventional) power supply during faults
    d. provide real time data of the system to the control room from where the system can be controlled or monitored.
3. The SPV modules are required to be mounted on the structures which can withstand random vibrations and high wind speeds, which would otherwise reflect on the performance of the system.

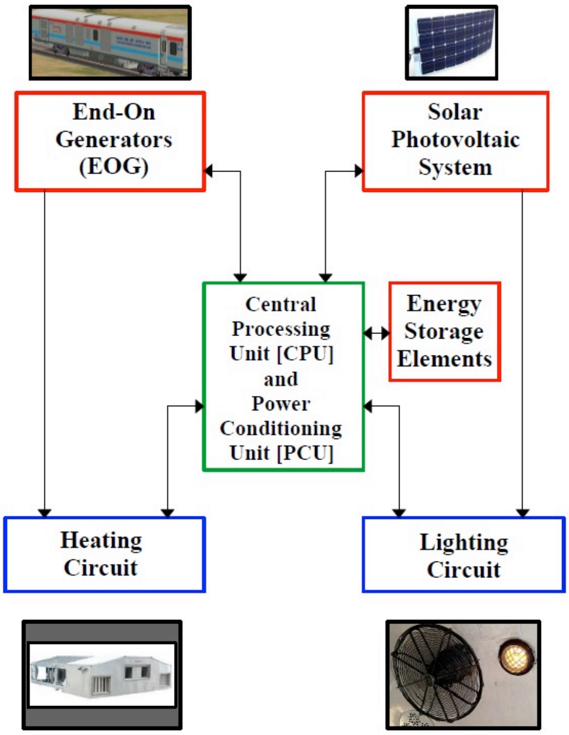

Figure 9: Single line diagram representing the control and coordination required to be done between various power sources and loads

Conclusion

Indian Railways, being one of the biggest railway networks of the world, operates 160 daily trains consisting of LHB coaches (Ministry of Railways, 2014). It has been calculated that the volume of diesel conserved per year per train is around 23,988 gallons causing a reduction of 239 tonnes of CO_2 being emitted into the atmosphere. These benefits would become significant if all the 160 LHB trains operated in the country are retrofitted with SPV systems on their roof-tops. The approximate annual reduction in the diesel fuel consumption by Indian Railways would amount to 3.8 million gallons leading to a reduction of 38,240 tonnes of CO_2. This would reduce the overall diesel consumption of Indian Railways along with a reduction in the oil imports by the country. SPV assistance for the existing power supply system would also enable the utility to increase the creature comforts and facilities for the passengers by utilizing the excess energy generated. Estimated return on investment would reach a maximum of 4 years, which would further decrease with the increase in the number of trains fitted with SPV system. The implementation of this scheme on any train can be considered as a wise investment, especially in tropical countries.

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