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A Review-World's First Solar-Powered DEMU Train with Six Trailer Coaches

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ABSTRACT: *This Review Paper is based on newly launched the solar diesel multiple unit trains (DEMU) by The Indian Railways' are expected to save hundreds of crores for the government in fuel bills as well as reduce the carbon emissions. The Indian Railways spends a maximum amount of money on diesel to power its trains each year which, apart from the monetary impact human health, also takes an environmental toll. To solve the issue, the Railways is looking seriously at renewable energy such as a best option solar and flagged off a solar DEMU rake recently. The department has already increased the speed of installing 6 Solar panel having capacity of 6WP on rooftop solar in railway stations and railway crossings. The solar DEMUs will take the energy saving plan of the department a step further. Railways Minister Suresh Prabhu has set a target of saving the Railways Rs 41,000 crore in energy expenditure over the next 10 years. For that, the solar power project is crucial. In the 2016-17 budgets, Prabhu targeted setting up 1,000 MW solar power generation capacities to reduce the reliance on diesel. According to an energy policy report published by the Indian Railways in November 2016, the cost of energy consumed by the Railways is 24.16 per cent of its ordinary working expense which breaks into 14.72% diesel expenditure and 9.44% on electricity. The diesel bill of the Railways highly increased from Rs 7,297 crore in 2007-08 to Rs 22,716 crore in 2014-15. It is one of the largest consumers of diesel fuel in India. In 2013-14, the diesel fuel consumption of Indian Railways was around 2.6 billion liters, as per official data. So therefore in current series a solar-powered DEMU train with six trailer coaches will save about huge amount of fuel 21,000 liters of diesel, thereby saving? And also 12 lakh every year, the Railways added. Normally, DEMU trains a multiple-unit train powered by on-board engines without a separate locomotive provide power for its passenger comfort system, i.e. more-in The Railways on Current scenario launched the country's first solar-powered local train here with a battery bank facility that ensures sufficient power even in the absence of sunlight Route to be planned soon the first rake of the train will be put in commercial service over the suburban railway system of Delhi division shortly. The entire electrical equipments need of the coaches, which includes lights, fans and information display system, will be met by the energy produced by solar panels fitted atop the coaches of the DEMU (diesel electric multiple unit) train*

Keywords: Solar Panel, Battery, alternatives fuel, microprocessor, CCU.

I. INTRODUCTION

The basic disadvantage of diesel engine is that it is expensive. It expensive both in manufacturing (due to high work load) and also in maintenance. It is expensive due to ecological incompatibility of its exhaust and due to necessity to adjust its exhaust according to strict requirements of international agreements. The fuel in diesel engine is ignited by the heat of the compressed air. It results in that fact that fuel had no time to fully mix with the air and it produces CH, NOX and carbon black during the combustion process. The carbon black is particularly visible then it colors the exhaust in black. And if in the case of hydrocarbons it can be removed by catalyst, the quantity of carbon black in the exhaust is adjusted by the special exhaust filter, which is mounted between the exhaust collector and the catalyst. The exhaust filter is warming up in the flow of exhaust gas those results in carbon black afterburning. Periodically the residual carbon black should be burned up and on the command block instruction the gas temperature is raised at the end of the combustion stroke due to burning of an additional quantity of fuel. The catalyst has more complex design due to irregular chemistry of the exhaust gases.

More-in The Railways on Friday launched the country's first solar-powered local train here with a battery bank facility that ensures sufficient power even in the absence of sunlight. The entire electrical need of the coaches, which includes lights, fans and information display system, will be met by the energy produced by solar panels fitted atop the coaches of the DEMU (diesel electric multiple unit) train. Speaking at the launch at the Safdarjung railway station, Union Railway Minister Suresh Prabhu said it was a "path-breaking leap" towards making trains more environment-friendly. Referring to the Railways commitment to using cleaner fuels,



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Mr. Prabhu said it was trying to increase the use of non-conventional sources of energy. Also, the carrier is taking on several other environment-friendly measures like using bio-toilets, water-recycling, waste disposal, CNG and LNG, and harnessing wind energy. Normally, DEMU trains — a multiple-unit train powered by on-board engines without a separate locomotive — provide power for its passenger comfort system, i.e. lights and fans, from a diesel-driven generator. Route to be planned soon the first rake of the train will be put in commercial service over the suburban railway system of Delhi division shortly. A route will be decided soon, said officials. While the 1,600 horsepower train has been manufactured

at the Integral Coach Factory (ICF) in Chennai, its solar system and panels have been developed and fitted by the Indian Railways Organization of Alternative Fuel (IROAF). Twenty-four more coaches will be fitted with this system within six months. The IROAF has developed this system with a smart inverter, which optimizes power generation on a moving train to cater to full load even during night hours with the help of a battery bank that ensures sufficient electricity. The system reduces diesel consumption and the carbon signature of these commuter trains by reducing carbon dioxide generation by 9 tons per coach per year. A solar-powered DEMU train with six trailer coaches will save about 21,000 liters of diesel, thereby saving? 12 lakh every year, the Railways added.



Fig.1.Solar Panel

India's first solar powered DEMU train launched Indian Railways has launched India's first solar powered diesel multiple unit (DEMU) broad gauge train. It is 1600 Horse Power (HP) train with all solar powered coaches. The train will run from Sarai Rohilla in Delhi to Farukh Nagar in Haryana. It will replace an existing non-solar powered rake on the same route. The solar powered DEMU train has six trailer coaches, with 16 solar panels of 300 watts fitted in each of them. These solar panels have been manufactured under 'Make in India' initiative. The energy generated by these solar panels will be stored in batteries and will be used during the night.



Fig.2 Engine inside





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Fig.3.Boogie inside



Fig.4Top view of PV panel

II. SYSTEM DESCRIPTION

Solar Photovoltaic (SPV) system shall consist of mainly the following:

- i) Flexi Solar PV Panels/Modules
 - ii) Lithium-Ion Battery Bank along with Battery Management System (BMS)
 - iii) Module mounting arrangement
 - iv) Array Junction Box
 - v) Microprocessor based MPPT Solar Charge Controller (CCU)
 - vi) Cable and other accessories
- The Flexi Solar PV (Photovoltaic) Modules array converts the light energy of the sun to DC power. The module mounting arrangement shall be used to hold the module in position. The DC power shall be converted to 110 V DC by CCU to supply DC loads such as lights, fans, battery charging etc. within the DEMU. Solar Power shall be integrated with the existing auxiliary power supply system of the DEMU.
 - Array Junction Box/Combiner shall be provided in between Flexi Solar PV (Photovoltaic) Modules array and CCU. It shall have DC Disconnect or/MCCB of suitable rating for connection and disconnection of array section. Surge Arrestor shall be incorporated for surge protection. It shall have meters for measuring the array voltage and array current.
 - MPPT Solar Charge Controller shall be provided between the array junction box and DC loads, battery and auxiliary power supply (As per IEC 62305). The CCU shall convert the power generated from flexi solar panels to 110V DC which shall be used to feed the loads of the DEMU. The excess power will be used to charge the Li-Ion batteries which shall feed the load during night or non sunny days. In case of non availability of solar energy and full discharge of battery, an Auto change over switch should be provided.
 - In CCU to switch over to the hotel load supply (auxiliary power supply) of DEMU and charging of Lithium Ion battery bank through auxiliary power supply. The CCU should have integrated Energy meter, Volt Meter, Amps Meter and Data Logger.



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- Electrical storage Li-Ion batteries shall be provided. The capacity of battery should be adequate to store the energy produced during a full sunny day. Required calculations for the battery sizing shall be submitted with the Bid.
- Cables and other electrical and non electrical accessories shall be provided as per Specification. Only electron beam cables as per RDSO Specification no. ELRS/SPEC/ELC/0019 (latest version) and aluminum Conduit shall be provided.
- System shall comply with IEC 60364-7-712 and IEC 62446.

III. GENERAL REQUIREMENTS

1. Solar power generating system shall fulfill auxiliary power requirements (Lights, Fans and Charging Points) for DEMU Trailer Coaches. The Solar PV system shall reduce the electric energy units produced by auxiliary alternator through power pack (Diesel Engine) of the DEMU and thereby reduce IR's CO2 emissions.
2. Flexi Solar panels shall be installed on roof of the DEMU Trailer Coaches while the CCU and other components shall be housed inside the Trailer Coaches (TCs) of DEMU. "Site": Indian Railways will normally provide DEMU Trailer Coaches for solar array mounting at nominated Diesel Electric Multiple unit Depots of Indian Railways at Shakurbasti and Jullundur in Northern railway & Vijayawada and Maula Ali in South Central Railway. Any additional DEMU Depot may be nominated for the execution of Work at the discretion of IROAF.
3. Suitable marking shall be provided on the bus bar for easy identification of different sources of energy i.e. Solar Panels, Battery and auxiliary generator converging at bus bar.
4. Flexi Solar PV modules may be connected in series / parallel to get maximum allowed operating voltage of the CCU. Proper sealing arrangements at the points of cables entering the enclosures shall be incorporated. Although not mandatory, manufacturers are however, encouraged that the cables entering into the enclosures be sealed with modular EPDM (Ethylene Propylene Diene Monomer) based cable sealing and protection system based on multi-diameter technology. It should be made pest resistant.
5. The Renderer shall submit general arrangement lay out along with mounting arrangement for the solar system as per space constraints of DEMU coaches before design finalization. The Renderer shall also submit necessary electrical circuit's diagram, safety interlocking etc.

IV. TECHNOLOGY REQUIREMENT

The DC output from the Flexi Solar PV modules shall be fed to array junction box and the strings shall be paralleled at junction box. Then CCU shall convert DC energy produced by the solar array to 110V DC energy. The DC power output of the CCU shall be fed to the existing distribution board (metering panel & isolation panel) of the DEMU Trailer Coach. The CCU shall also house the energy meter, volt meter, amps meter and data logger. The DC output of Flexi Solar Photovoltaic (SPV) system shall be paralleled with the existing auxiliary power supply system of the DEMU using an auto change over switch. When the voltage and/or current go out of preset range of flexi panels or battery, the CCU shall automatically switch over the load on the auxiliary power supply. The CCU shall reconnect after a pre-determined set time when back in the range. For safety reasons, in case of failure of auxiliary power supply due to any reason, Battery bank should be disconnected from auxiliary power supply. Flexi Solar PV array to CCU voltage drop shall be less than 3% at the maximum power output of the array through appropriate cabling design. Adequate space and ventilation shall be provided for the charge controller.

The performance and generation data of Flexi Solar PV system shall be recorded using a data logger to monitor the actual output which may form a part of CCU. The data logger should log all the parameters such as Ampere, voltage, kWh energy generated, Temperature of array area, time, date, and year etc. round the clock. Data logging system/software shall enable automatic long-term storage of measured data from Solar Panels mounted on TC Coaches. The firm shall specify the storage capacity of data logger at the time. The capacity of data logger should be enough to store data for minimum of 06 months. It shall be possible to retrieve the data directly from the data logger through USB port or Wi-Fi connectivity.

The software / app for access/visualization of data on data logger from a laptop / Mobile shall be provided by the supplier as part of the System scope under this Work. The software / app shall provide a suitable option for generating printable reports based on flexible queries (the MIS Management information system reports (MIS)) as per requirement of IROAF.



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Sizing of Solar PV System shall be for a total of 4.5 KWp and should be installed in the available area of roof space for installation of Solar PV system on TC Coaches. The details of the size and the rating of the Solar PV System along with power load calculation have to submit at the time . Each Solar Panel shall be accompanied with OEMs performance test data.

V. FLEXI SOLAR PHOTOVOLTAIC MODULES

Flexi Solar PV Module/Array shall be of capacity as mentioned in Cl. 3.0 of this Specification conforming to IEC:61215 Ed 2 or latest – Edition II, IEC : 61730 – I :2007, IEC : 61730 – II : 2007, manufactured in a plant certified under ISO 9001 : 2008 and type tested by an accredited national/international testing laboratory. The Flexi Solar PV modules must pass all the tests as per IEC: 61215 ED 2 of latest – Edition II, IEC 61730 –I: 2007, IEC 61730 – II: 2007 including Hail test and UV Protection test. The Flexi Solar PV Module shall be made from Mono/Poly crystalline Silicon Solar Cell. The Flexi Solar PV modules used should be PID (Potential Induced Degradation) resistant and tested for PID as per IEC 62804. Solar PV Modules may be used in a highly corrosive atmosphere (coastal areas, etc.) so Solar PV modules must qualify Salt Mist Corrosion Testing as per IEC 61701. Total Flexi Solar PV array capacity should not be less than 4.5KWp per Trailer Coach of DEMU. Solar PV module should be light-weight and flexible so that they can be pasted/mounted on the rooftop of Coaches without mounting structure. The Solar Panels should be capable of withstanding body vibrations of Trailer Coach of DEMU and thermal variations without damages. The Flexi solar PV modules have suitable encapsulation and sealing arrangements to protect the Silicon Cells from the environment. The double lamination should be used at Cell level as well as Module levels.

The arrangement and material of encapsulation shall be compatible with the thermal expansion properties of the silicon cells. The encapsulation arrangement shall ensure complete moisture proofing for the entire life of the solar modules so that fast degradation of PV module can be avoided. In order to maximize solar generation under shadow effect the flexi solar panels used should have not less than 09 bypass diodes. Flexi SPV panels shall contain crystalline silicon solar cells. The solar cell shall have surface anti-reflective (AR) coating to help absorb more light in all weather conditions. The Flexi Solar Panel should have high transitivity polymer in front side of the panel for improved visibility and protection against environmental hazards (rain and hail storm) and weather proof TEDLAR/ polyester black sheet. Value of transitivity of the polymer in the front layer shall be more than 90%. An AR coating should be used to minimize reflective losses. Flexi Solar Panel fixing method on rooftop of Trailer Coaches of DEMUs should be by pasting without piercing the roof to avoid any possible leakage. Photo-electric conversion efficiency of Flexi SPV module shall not be less than 15%. Fill factor of the flexi PV modules shall not be less than 72%. Flexi PV modules shall be highly reliable, Flexible, light weight and shall have a service life of more than 25 years. SPV modules shall have a limited power loss of not more than 10% of nominal output at the end of 10 years and of not more than 20% of nominal output at the end of 25 years. PV module manufacturer should provide guaranty for the above mentioned standard of service life. Module junction box and terminal block (weather resistant) shall be designed for long life outdoor operation in harsh environment. The module junction box shall be certified as per IEC Else, they shall have the same properties as mentioned for array junction boxes. Array sub-main and main junction boxes, shall have the following properties:

It shall be dust, vermin & waterproof. The enclosure shall be double insulated with protection Class II as per IEC 61439-1. Material and the protection class shall be marked on the enclosure.

The enclosure shall have a transparent front lid for enabling easy visibility.

The enclosures shall have IP 65/66 protection in accordance with IEC 60529. Third party conformance certificate is required to be given for IP 65/ IP 66 degree of protection.

The enclosures shall have IK 08 degree of protection for mechanical load

The enclosure should be chemically resistant to acid, lye, petrol, and mineral oil & partially resistant to benzene.

The enclosures shall have a rated insulated voltage of 1000V DC and dielectric strength of 4.65 KV DC.

The enclosure shall have a usage temperature rating of 10°C to 55°C or better. The material of the enclosure shall be UV stabilized.

The material used shall be halogen, silicon free conforming to RoHS (Restriction of Hazardous Substance) directive 2002/95/EC

It shall have minimum requirements for fire protection in the event of internal faults: Glow wire test in accordance with IEC 60 695-2-11 at 960°C for box and 850°C for conducting components.

Burning Behavior: Base part of Polycarbonate Enclosure, if used, shall be UL94-V-0 compliant and Lid part of PC Enclosure shall be UL94-V-2 compliant.



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Though not mandatory, manufacturers are encouraged to provide breather glands in the array junction boxes to prevent overheating and explosions. Unless otherwise stipulated, the properties mentioned above shall be demonstrated through datasheet of the manufacturer

The junction boxes shall have suitable cable entry points with cable glands of appropriate sizes for both incoming and outgoing cables. Though not mandatory, manufacturers are encouraged to provide suitable cable entry points fitted with MC-4 connectors. m. Suitable markings shall be provided on the bus bar for easy identification, and cable ferrules shall be fitted at the cable termination points for identification.

The output of any supplied module shall not be less than the rated output. Each module, therefore, has to be tested and rating displayed.

All Solar modules shall be of the same make and design.

The flexi module shall perform satisfactorily in relative humidity up to 95% and temperature between -10°C and +85°C.

Marking on each flexi module shall carry the following clear markings which may also be provided on RFID chip additionally mounted on the Solar Panels:

- i) Name, monogram or symbol of manufacturer
- ii) Type or model number
- iii) Serial number
- iv) Polarity of terminals or leads (color coding is permissible)
- v) Open – circuit voltage
- vi) Operating voltage
- vii) Maximum system voltage for which the module is suitable
- viii) Operating current
- ix) Short circuit current
- x) Date & place of manufacture
- xi) Weight of the module
- xii) Module WP tolerance (If it is cumbersome to supply this marking, then this marking can be left out)

Insulation Resistance of the module shall not be less than 50M-ohm when measured with a 500V DC muggers.

Lithium-Ion Battery Bank and Battery Management System:

i. Lithium-Ion Rechargeable batteries shall be used.

ii. The nominal voltage of the battery bank should not be less than 110V

iii. Capacity of the battery bank should not be less than 120Ah.

iv. Charging should be done on regulated DC, Constant Current Constant Voltage (CCCV) mode.

v. Self-discharge should be less than 2.5% per month @ 25°C.

vi. The battery must have more than 2000 charge cycles at 80% DoD (Depth of Discharge) or 5 years life whichever is later.

vii. Operating conditions: Operating temperature: -10°C ~ +55°C → Cycle efficiency: 95% → Self-discharge: → < 2.5% per month at 25°C Storage time: 12 months at 25°C → Maximum relative Humidity: 90% →

viii. Battery Management System (BMS) should be provided for controlling, monitoring and protecting the Lithium Ion Battery with respect to Over Charging/ undercharging/ Short Circuiting/ over temperature/ Cell imbalance etc. The following are the details of the Battery Management System for the Lithium Ion Battery:

The BMS should be able to monitor parameters like Voltage, Current, Temperature etc of → the battery bank.

The BMS should have protections like over voltage, under voltage, Short circuit, → and Reverse polarity and over temperature. For necessary protection of lithium Ion batteries, Battery Management System (BMS) →

should be synchronized with the Charge Controller Unit (CCU) The BMS should be capable of cell balancing. →

The battery shall be charged by CCU. Whenever, the Solar Power is not generated (at night or non- sunny days), then the power to hotel load shall be fed from the battery. In case of battery being discharged, then auto change

over switch shall connect the auxiliary power supply to the Trailer Coach (TC) Electric load and shall also charge Lithium-Ion battery. In case of failure of auxiliary power supply due to any reason, Battery bank should

be disconnected from auxiliary power supply. 6.11 Module Mounting Arrangement. The mounting of Flexi Solar Panels on the roof top of Trailer Coaches (TC) of DEMU's shall be in the configuration indicated in

drawing number IROAF/Solar/DEMU/1 & Drawing No. IROAF/Solar/DEMU/2. The Flexi Panels shall be pasted on roof top of Trailer Coaches (TC) of DEMU's along with provision of proper sealing arrangement as

per following details:



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(i) The flexible solar panels shall be fixed using a combination of high strength double sided tape on the perimeter of Solar panels and polyurethane adhesive around the centre of Solar panels. The scheme should withstand the vibrations in Trailer Coach Body for the life time of the panels.

(ii) The primary bonding of the flexible solar panel shall be achieved by the double sided tape with acrylic adhesive as per minimum specifications specified below that shall ensure excellent bonding and outdoor durability properties where as the polyurethane adhesive in the centre of the flexible panel shall ensure that there is no lift up of the panel from the centre due to negative wind pressure at high speeds. The double side tape shall have a filmic liner that shall ensure proper removal of the liner during bonding which otherwise may get into the way of the bonding interface. The thickness of the doubled sided adhesive tape shall be minimum of 2 mm to ensure that the compressed thickness of polyurethane adhesive provided in the centre of the flexible solar panel is spread uniformly.

(iii) The adhesive and the tape shall be applied only after proper surface preparation that includes cleaning and abrading and primer application that will ensure proper anchorage of the bonding material to the substrate.

(iv) The flexible solar panel, thus bonded on the roof top of DEMUs in the above process shall be further sealed along the perimeter to avoid any water, hail and air ingress at operating speeds of trains. The specification of the double sided tape, polyurethane adhesive, primer and the sealing tape shall be as below. (The bidder may give any additional component in the Solar Panel mounting scheme and provide similar details for such component):

(a) Double Sided Acrylic Foam Tape

(i) The double sided acrylic foam tape with following specifications shall be applied at the perimeter of the flexible solar panels.

(ii) Acrylic foam tape shall be of minimum 1 inch wide and thickness in the range of 2 – 2.5 mm having a closed cell construction to avoid any ingress of water/air. It shall have a minimum foam density of 700 Kg/m³ for high durability and strength and a minimum Surface Resistivity (ohm/square) of 1014 to avoid any surface leakage of current.

(iii) The acrylic foam tape shall conform to ASTM D 3330 for the peel adhesion (mm 300N/100mm) and have at least 10,000 minutes static shear resistance as per ASTM D3654. The Acrylic foam tape should have been tested against sustained wind speed of a minimum of 200 kmph (ASTM E330) which has to be corroborated with third party test lab report from NABL accredited lab or international lab of repute.

(iv) Acrylic foam tape shall have been tested for its strength retention, under water submersion for a minimum of 5 years and should have 25 years of service life modeling. The underwater submersion test provides documentary evidence of the outdoor durability factor. (v) The acrylic foam tape shall display the manufacturer logo of the firm which may also be displayed in the tape core with clear mention of Lot/Batch No of the production.

(vi) Test certificates shall accompany the supplies.

(b) Elastic Adhesive Sealant

(i) The adhesive sealant of 6mm bead size shall be applied in staggered fashion at the centre of the flexible solar panels.

(ii) The adhesive sealant shall be single component moisture curing polyurethane sealant with preferably sausage pack of about 600 ml that ensures easy application with normal curing under atmospheric conditions. The adhesive shall have a shore A hardness between 55 and 60 as per ASTM C661 guidelines and elongation at break more than 300% (as per ASTM D412), The 56 service temperature of sealant shall be between 40°C to 90°C that shall ensure proper bonding under outdoor working conditions.

(iii) Test certificate shall accompany the supplies.

(c) Edge Sealing Tape

(i) After bonding, the sealing of flexible solar panels shall be 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.

(ii) This tape shall be applied on the seams and contours post priming.

(iii) Test certificate shall accompany the supplies.

(d) UV Stable Adhesion Promoter/Primer

(i) Post surface preparation and prior to the acrylic tape bonding, the UV Stable Adhesion Promoter/ Primer shall be brush/cloth applied

(ii) The UV stable promoter/primer containing acrylate polymer shall have low viscosity (< 25 cps) and fast drying properties

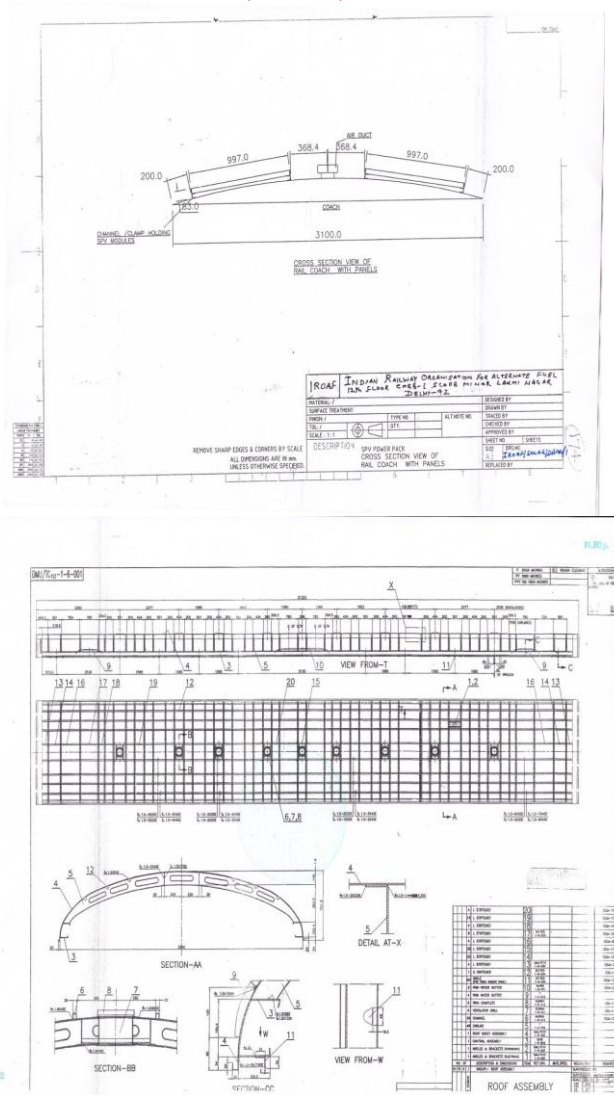


Fig.5 Graphical Representation of Solar powered train

VI. TRIAL SCHEME OF SOLAR PV SYSTEM PROVIDED ON 06 Trailer COACHES OF BG DIESEL ELECTRIC MULTIPLE UNIT (DEMU)

The first six Trailer Coaches of DEMU provided with Solar PV System shall be put on field trial for at least two (2) months and thereafter following parameters /items shall be checked and observations shall be made by the nominated DEMU.

To check the Solar Energy produced per day by each Trailing Coach of DEMU – to be measured by the energy meter provided in Charge Controller (Minimum 10 KWh on sunny day from sun rise in the morning till sun set in the evening

To check working of all parts of the Solar System and their condition as per Specifications

- a. Battery
- b. Charge controller
- c. Auto cut off and cut in of the system
- d. Working of Auto change over switch
- e. Working of data logger and Energy Meter
- f. Data Storage

To check whether there is any loose or defective part of Solar PV System in any of the Trial Trailer Coaches Condition of fixing arrangement of Solar Modules and other components.



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