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भारत सरकार GOVERNMENT OF INDIA
रेल मंत्रालय MINISTRY OF RAILWAYS

HANDBOOK ON SOLAR LIGHT SYSTEM

END USER: ELECTRICAL GENERAL SERVICES STAFF

CAMTECH/E/15-16/Solar Light/1.0

November 2015

Indian Railways
Centre for Advanced Maintenance Technology

महाराजपुर, ग्वालियर – 474 005
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QUALITY POLICY

"To develop safe, modern and cost effective Railway Technology complying with Statutory and Regulatory requirements, through excellence in Research, Designs and Standards and Continual improvements in Quality Management System to cater to growing demand of passenger and freight traffic on the railways".

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FOREWORD

Limited resources and growing demand of energy poses a clear need for energy generation from alternative and renewable sources of energy.

The earth is blessed with enormous amount of **solar energy** and it is an in-exhaustive, reliable & non-polluting source of power.

The solar energy can be well utilized for lighting purpose. Solar powered LED based stand alone outdoor lighting system is ideal to illuminate the surroundings of the buildings, hospitals, open platforms etc.

CAMTECH has prepared this handbook on "Solar Light System" with the objective of creating awareness and to disseminate knowledge on the subject. I am sure that this handbook will be useful to the users.

CAMTECH Gwalior — ***A.R.Tupe***
Date: 30.11.2015 — ***Executive Director***

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PREFACE

Concerns over global climate change, local air pollution & resource scarcity make the alternative and renewable sources of energy attractive. Solar energy has a wide range of applications in Indian Railways especially at remote. Solar energy based lighting applications are being used exhaustively and are also being promoted by Government.

CAMTECH has prepared this handbook on “Solar Light System” with the objective to disseminate basic knowledge on solar energy and specific information on “Stand alone solar photovoltaic LED based street lighting system”.

This handbook also comprises a chapter on “Questions and Answers” which consists of descriptive type, objective type and true false. This will be helpful for reviewing the knowledge.

It is clarified that this handbook does not supersede any existing provisions laid down by RDSO or Railway Board/Zonal Railways. This hand book is for guidance only and it is not a statutory document.

I am sincerely thankful to all field personnel who helped us in preparing this handbook. Technological up-gradation & learning is a continuous process. Please feel free to write us for any addition/ modification in this handbook.

CAMTECH, Gwalior — ***Peeyoosh Gupta***
Date: 24.11.2015 — ***Director Electrical***

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ISSUE OF CORRECTION SLIP

The correction slips to be issued in future for this handbook will be numbered as follows:

CAMTECH/E/2015-16/Solar Light/C.S. # XX date---------

Where "XX" is the serial number of the concerned correction slip (starting from 01 onwards).

CORRECTION SLIPS ISSUED

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CHAPTER 1

GENERAL

1.1 INTRODUCTION

Concerns over global climate change, local air pollution & resource scarcity make the alternative and renewable sources of energy attractive worldwide. The sources of energy that are inexhaustible as they are replaced by nature and can be replenished in short time period are known as **renewable energy resources**. **Sunlight, wind, biomass, water, geothermal,** and so on, which can be harnessed continuously, are termed as renewable energy sources.

The earth is blessed with enormous amount of **solar energy** that it receives every morning with the rise of the sun. The Sun is an in-exhaustive, reliable & non-polluting source of power. S**olar energy** experienced by us as heat and light, can be used through two routes:

(i) First, the **thermal route** uses the heat for water heating, cooking, drying, water purification, power generation, and other applications.

(ii) Second, the photovoltaic route converts the solar energy into electricity, which can then be used for a number of purposes such as lighting, pumping, communication, and power supply in un-electrified areas.

Solar energy is obtained through the use of Solar cells. The Solar cells convert sunlight into electrical energy, based on the principle of photovoltaic effect. The electricity so

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obtained can directly be used to charge the batteries used for various appliances.

Solar energy has a wide range of applications in Indian Railways especially at remote or hilly places where grid supply is not available round the clock or not available at all.

The solar energy can be well utilized for lighting purpose. Solar powered outdoor lighting system is ideal for lighting the area in remote locations where the electricity is unavailable or erratic. It can also be used to illuminate the surroundings of the buildings for security & safety.

RDSO has issued specification no. RDSO/PE/SPEC/0093-2008 (Rev.0), Amend. 3 for “Stand alone solar photovoltaic LED based street lighting system”. This street light system based on LED technology which consumes very low power, is a true replacement of normal energy saving lightings.

1.2 ADVANTAGES AND DISADVANTAGES OF SOLAR PANEL

Advantages

- Fuel source for solar panel is direct and endless so no external fuels required.
- Sunlight - free of cost.
- Long life of solar modules, fast response and high reliability.
- Can operate under high temperature and in open.
- Inherently short circuit protected and safe under any load condition.
- Pollution free.

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- Minimum maintenance
- Independent working
- Operation is simple and no electrochemical reaction and no liquid medium.
- Noise-free as there are no moving parts.
- No AC to DC conversion losses as DC is produced directly.
- No transmission losses as installed in the vicinity of the load.
- Suitable for remote, isolated and hilly places.
- Suitable for moving loads/objects.
- Since it is in modular form, provision of future expansion of capacity is available.
- It can generate powers from milli-watts to several mega watts.
- It can be used almost everywhere from small electronic device to large scale MW power generation station.
- It can be installed and mounted easily with minimum cost.

Disadvantages

- Initial cost is high.
- Dependent on sunlight.
- Additional cost for storage battery.
- Climatic condition, location, latitude, longitude, altitude, tilt angle, ageing, dent, bird dropping, etc. affect the output.
- It has no self-storage capacity.
- Manufacturing is very complicated process.
- To install solar panel large area is required.

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1.3 DEFINITIONS

The following definitions are very important in designing a solar photo voltaic system.

Solar Cell

The basic photovoltaic device, which generates electricity when exposed to sunlight, shall be called a "Solar Cell".

Solar Module

The smallest complete environmentally protected assembly of interconnected solar cells shall be called "Module".

Solar Panel

A group of modules fastened together, pre-assembled and interconnected, designed to serve as an installable unit in an Array shall be called "Panel".

Solar Array

A mechanically integrated assembly of modules or panels together with support structure, but exclusive of foundation, tracking, thermal control and other components, as required to form a dc power producing unit shall be called an "Array".

Solar irradiation

On any given day the solar radiation varies continuously from sunrise to sunset and depends on cloud cover, sun position and content and turbidity of the atmosphere.

The maximum irradiance is available at **solar noon** which is defined as the midpoint, in time, between sunrise and sunset. The total solar radiant power incident upon unit area of an inclined surface (Watt/m^2) is called total solar irradiance.

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Insolation

The actual amount of sunlight falling on a specific geographical location is known as insolation — or "incident solar radiation."

Insolation differs from irradiance because of the inclusion of time. Insolation is the amount of solar energy received on a given area over time measured in kilowatt-hours per square meter (kW-hrs/m^2) - this value is equivalent to "**peak sun hours**".

Peak Sun Hours

Peak sun hours is defined as the equivalent number of hours per day, with solar irradiance equaling 1,000 W/m^2, that gives the same energy received from sunrise to sunset.

Peak sun hours is of significance because PV panel power output is rated with a radiation level of 1,000W/m^2.

Many tables of solar data are often presented as an average daily value of peak sun hours (kW-hrs/m^2) for each month.

Conversion Efficiency

The ratio of the maximum power to the product of area and irradiance expressed as a percentage.

$$\acute{\eta} = \frac{\text{Maximum power}}{\text{Area x irradiance}} \times 100\%$$

Balance of System' (BoS)

In an SPV system, the components other than the PV module are collectively known as 'balance of system' (BoS), which includes batteries for storage of electricity, electronic charge controller, inverter, etc.

Light Emitting Diode (LED)

Light Emitting Diode (LED) is a device which emits light when an electric current passes through it.

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1.4 PHOTO VOLTAIC EFFECT

Electricity can be generated directly from sunlight, by a process called photovoltaic effect, which is defined as the generation of an electromotive force as a result of the absorption of ionizing radiation. The photo voltaic effect can be observed in almost any junction of material that have different electrical characteristics, but the best performance to date has been from solar cells made of Silicon.

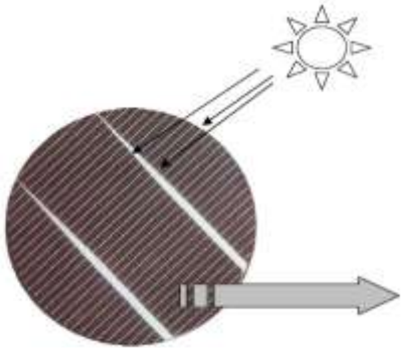

Fig.1.1: Photo Voltaic effect

1.5 SOLAR CELL: CONSTRUCTION & WORKING

The basic building block of a photovoltaic system is the Solar Cell, a semiconductor device having a simple p-n junction and which when exposed to sunlight produces DC electricity.

The solar cell is made up of “Semi-Conductor” materials that are processed to make the device photovoltaic. The solar cell is made of single crystal silicon, polycrystalline and amorphous Silicon with an area of a few sq. centimeters to 200 sq. centimeters and even more.

A thin p type silicon wafer is taken through phosphorus diffusion process and by screen-printing technology electrodes are made. The P-N junction of the solar cell gives rise to diode characteristics.

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Hence a solar cell is a PN junction device on which front and back electrical contacts are screen-printed. A sketch of typical psuedo-square solar cell is **shown in fig.1.2 (a) & (b).**

The side, which has negative polarity, is taken as front side and that which has positive polarity is taken as backside. The front or Negative side is exposed to sunlight for conduction to take place.

Two Tinned copper strips work as terminal leads for interconnection to other cells. For collection of charge from the cell and conduction to terminal leads on negative side, Silver Oxide lines are screen printed horizontally and these are joined to terminal leads at close spacing **(refer fig. 1.2a).** These lines cover only 5% of the total area of the cell, so that these do not pose any hindrance to the exposure of Sunrays.

The back or Positive side is not exposed to sunlight; hence Aluminium is coated on whole surface for better conductivity **(refer fig 1.2b).** Aluminium is coated instead of Silver Oxide as latter is expensive hence not economical.

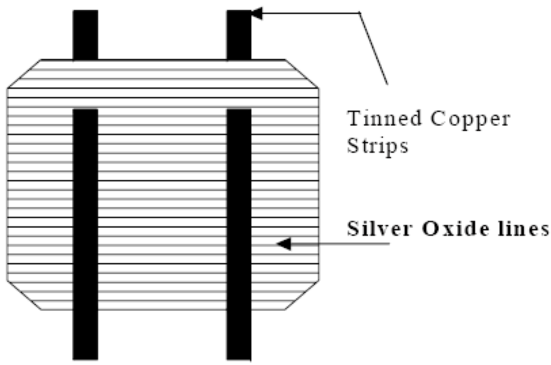

Fig 1.2 (a) Sketch showing front view of typical Pseudo square solar cell

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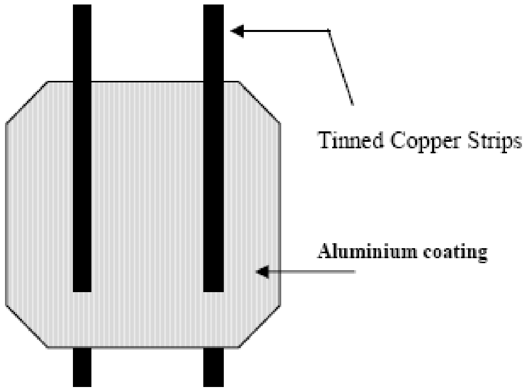

Fig 1.2 (b) Sketch showing rear view of typical Pseudo square solar cell

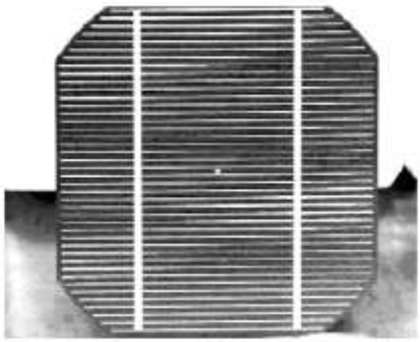

Fig. 1.2 (c): Solar Cell: Actual view

The operation of solar cells involves these major processes:

i) Absorption of sunlight into semiconductor materials

ii) Generation of charge carriers.

iii) Separation of +ve & -ve charges to different regions of the cell to produce e.m.f.

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1.6 SOLAR PHOTO VOLTAIC (SPV) MODULE

The power generated by a single cell is small and therefore several cells are interconnected in series/parallel combination to get the required voltage and current. When a number of solar cells are connected in series to get a specific voltage the unit so formed is called as Solar Module.

Charging batteries is the primary use of SPV module. Therefore normally 36 cells are joined in series to form a standard module, which is capable of charging 12 volts battery.

A terminal box is provided on the backside of the module for external connections. A Bypass diode is connected across +ve and –ve in the terminal box. Cathode of the diode will be at +ve terminal and Anode will be at –ve terminal of the module. This diode protects the module cells from overheating due to shadowing of the module or any cell breakage.

Generally the rating of bypass diode is 1.52 times of the maximum current of module. The Repetitive Reverse Peak Voltage Vrrm of the diode should be double the string open voltage.

Standard Capacity/Ratings of SPV

The wattage output of a PV module is rated in terms of **wattpeak** (Wp) units. The peak watt output power from a module is defined as the maximum power output that the module could deliver under standard test conditions (STC). The STC conditions used in a laboratory are

- 1000 watts per square metre solar radiation intensity
- Air-mass 1.5 reference spectral distribution
- 25 °C ambient temperature

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The voltage output of a PV module depends on the number of solar cells connected in series inside the module. In India, a crystalline silicon module generally contains **36** solar cells connected in **series**. The module provides a usable direct current (DC) voltage of about 16.5 V, which is normally used to charge a 12-V battery.

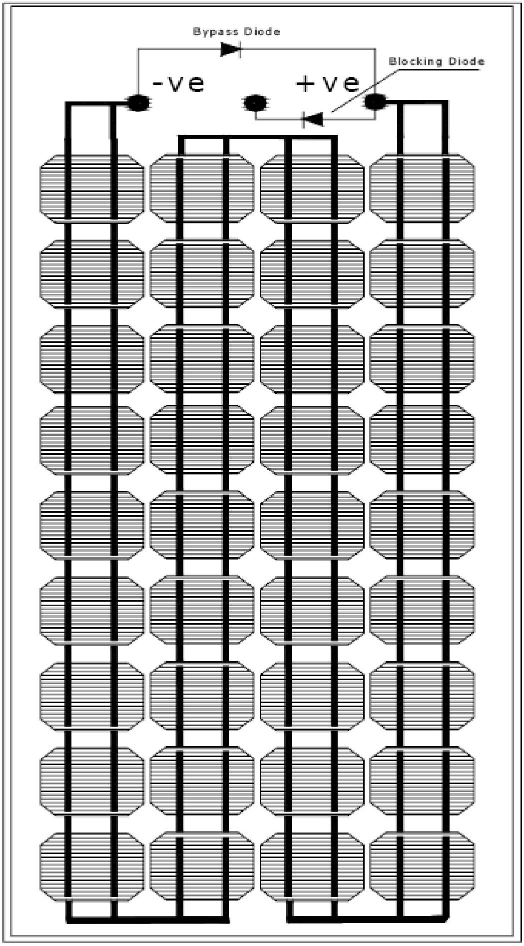

Fig.1.3: Solar Module

1.7 SOLAR PANEL

A Solar panel consists of a number of solar modules, which are connected in series and parallel configuration to provide specific voltage and current to charge a battery. A diode is connected on the +ve terminal of such string in forward bias. This is called Blocking diode.

This diode is provided so that in daytime current can flow from module to battery, but at night or in cloudy day current should not flow back from battery to module or from one string to another string drawing shown in f**ig 1.4 below** illustrates a Solar panel connected 4 in series and 4 in parallel to charge the battery bank of 48 Volt system.

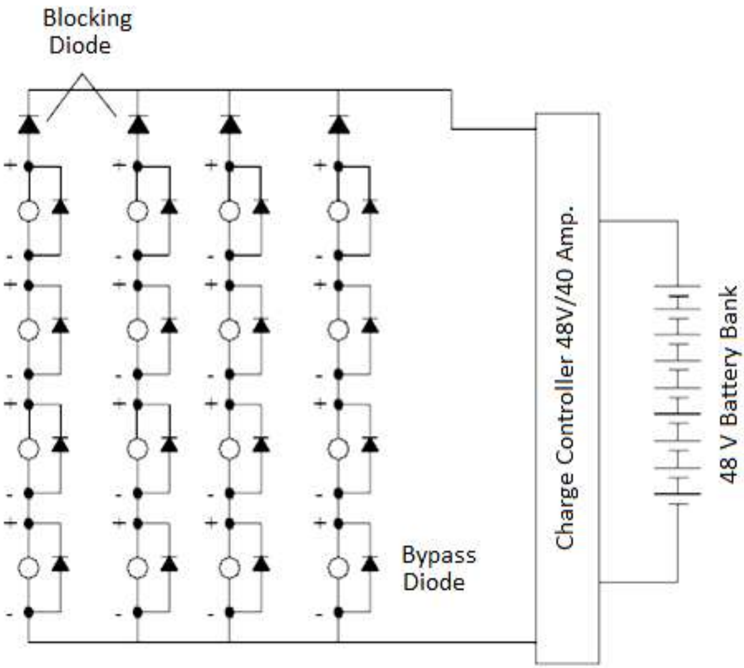

Fig.1.4: Structure of a Solar Panel

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Solar panels are classified on the basis of the following points :

1) Crystalline Silicon (Mono/Poly)
2) Different Size or Area of cells
3) Type of cells & nos. (Rectangular/Circular/Square/ Pseudo-square/Semi-circular etc.)
4) Power (High/Mid/Low range)

1.8 CHARGE CONTROLLER

Charge controller is the interface between solar panel/array and battery bank. It protects the battery from overcharging and moderate charging at finishing end of charge of battery bank. Therefore it enhances the life of the battery bank. It also indicates the charging status of batteries like battery undercharged, overcharged or deep discharged through LEDs indications. Some switches and MCBs are also provided for manual or accidental cut-off of charging. The technology adopted nowadays for manufacturing solar charge controller is MOSFET/IGBT technology.

First the controller is connected to battery bank and then it is connected to solar array/solar module for sensing the voltage from the module. When the system is put into operation, the SPV modules start charging the battery bank. Care should be taken that in no case the battery connections are removed from the controller terminals when the system is in operation, otherwise SPV voltage may damage the Charge controller, since the solar voltage is always higher than the battery voltage.

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1.9 MOUNTING THE SOLAR MODULES

While mounting the solar modules, following points should be considered for getting maximum output from the solar modules:

- Modules should be oriented south facing to receive maximum sunlight.
- The Modules produce more power at low temperature and full sun.

The Solar panels are generally installed in such a way that they can receive maximum direct sunlight without shade from any building/trees nearby falling on them at any part of the day.

As we know that the Sun rises in the East and sets in the West as a result of Earth's rotation around its own axis. Also the Earth revolves around the Sun. Due to these two movements there is variation in the angle at which the Sun's rays fall on Earth's surface over a year. At any particular place on Earth this variation in angle in one year may be up to 45 degrees. Considering these facts the following guidelines are to be kept in mind while installing solar panels:

1. Solar panels should be installed South facing in the Northern hemisphere and North facing in the Southern hemisphere. Since India is in the Northern hemisphere, Solar panels will be installed always- **South facing in our country**.
2. The rule of thumb for fixed (never adjusted) is to set them pointing south at an **angle = latitude.** If it is to be adjusted twice in a year, winter is latitude + 15 deg and summer is latitude - 15 deg.

For the angle for "now", point them so that a stick perpendicular to the panel casts no shadow at solar noon (when the sun is at it's peak -- close to noon standard time).

The directions North- South may be found with the help of Magnetic Compass. The picture given in **fig 1.5** illustrates this.

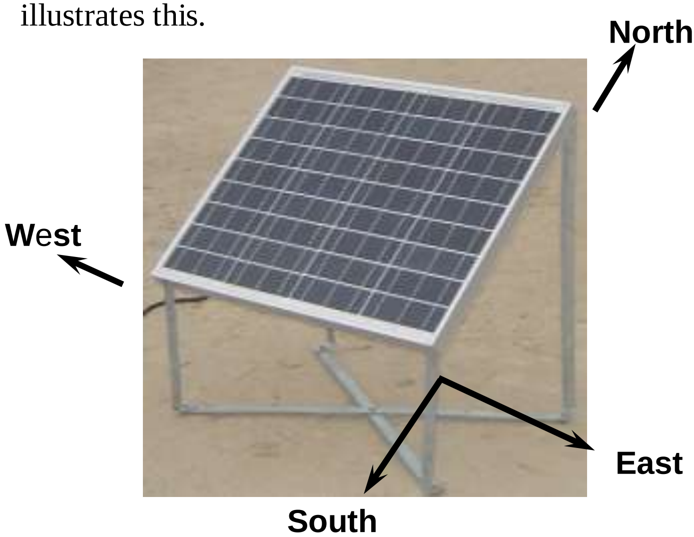

Fig.1.5: A Solar Panel installation

3. Any obstruction (such as tree or building) should be avoided in East, West or South of the place of installation. The following is the criteria:

   (i) East or West: The distance between solar panel and obstruction should be more than double the height of obstruction.

   (ii) South: The distance should be more than half the height of obstruction.

4. The support for the Solar panel need to be a robust one and should not be accessible to general public. It should be so installed that rainwater, bird dropping, leaves etc. do not accumulate and the top surface can be cleaned easily.

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Latitude

Latitude, usually denoted by the Greek letter phi (φ) gives the location of a place on Earth (or other planetary body) north or south of the equator. **Lines of Latitude** are the imaginary horizontal lines shown running east-to-west (or west to east) on maps (particularly so in the Mercator projection) that run either north or south of the equator.

Technically, latitude is an angular measurement in degrees (marked with °) ranging from 0° at the equator (low latitude) to 90° at the poles (90° N or +90° for the North Pole and 90° S or −90° for the South Pole). The latitude is approximately the angle between straight up at the surface (the zenith) and the sun at an equinox.

CHAPTER 2

STAND-ALONE SOLAR PHOTOVOLTAIC LED BASED STREET LIGHTING SYSTEM

Solar powered outdoor lighting system is ideal for lighting the area in remote locations where the electricity is unavailable or erratic. It can also be used to illuminate the surroundings of the buildings for security & safety. The street light system as per RDSO specification no. "**RDSO/PE/SPEC/0093-2008 (Rev.0), Amend. 3-Sept-2010"** is based on LED technology which consumes very low power. It is a true replacement of normal energy saving lightings.

Fig.2.1: Stand Alone LED Solar Light

2.1 MAIN COMPONENTS

This street lighting system may be used for uninterrupted illumination of the streets, pathways & surroundings of the buildings from dusk-to-dawn for security & safety. This lighting consists of the following components:

i. SPV Module to convert solar radiation directly into electricity.

ii. 6 m height MS pole painted with corrosion resistant paint with necessary accessories.

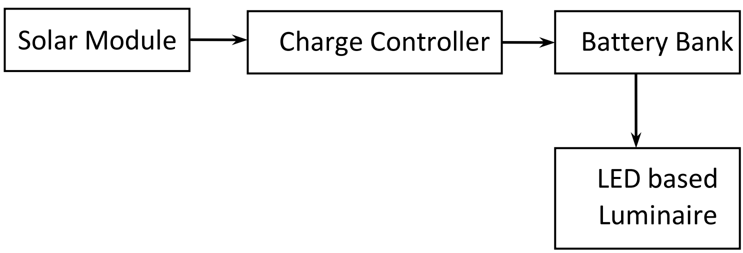
iii. Battery bank to store the electrical energy generated by SPV panel during day time.

iv. Charge controller to maintain the battery to the highest possible State of Charge (SOC) while protecting the battery from deep discharge (by the loads) or extended overcharge (by the PV array).

v. Blocking diode, preferably a Schottky diode, connected in series with solar cells and storage battery to keep the battery from discharging through the cell when there is no output or low output from the solar cell, if such diode is not provided with the module itself.

vi. 15 W, 12 V DC LED based luminaire as a light source.

vii. Interconnecting wires/cables & hardware.



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2.2 SALIENT FEATURES OF SYSTEM & ITS COMPONENTS

i. The system is designed to have 4 days autonomy (i.e. system will run for 4 consecutive days without charging from the panel).

ii. The street light pole should be mounted clear of vegetation, trees & structure so as to assure that they are free of shadow throughout day light hours during each season of the year.

iii. The entire system is designed and built to withstand the extreme environmental conditions prevailing at site.

iv. All wiring, enclosures and fixtures that are mounted outdoor are resistant to high humidity conditions, corrosion, insect and dust intrusion.

v. The **solar module** consists of the following four main components:

- An assembly of suitable inter-connected crystalline silicon solar cells.
- The solar cells are provided with surface anti-reflective coating to help to absorb more light in all weather conditions.
- Toughened, high transmissivity glass in front side of the module for improved visibility & protection against environmental hazards, such as, rain, hail & storm and weather proof TEDLAR/POLYSTER back sheet.
- The transparency of toughened glass used is > 91%, when measured in actual sunlight by placing the glass plate perpendicular to the sun's rays through an air mass of 1.5.

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- The complete solar module is provided with water-proof sealing in an anodized aluminium frame.
- A bird spike is provided at the highest point of the array/module structure to avoid bird sitting on the solar module.

Fig.2.3: Solar Module Top Side

vi. The output terminals of the module are provided on the back of the solar PV module.

vii. Terminal block is made of Nylon-6 or equivalent material with weather proof design (IP-65) and have a provision for opening for replacing the cables.

Fig.2.4: Solar Module Back Side

viii. All metal equipment cases and frames in the system should be well grounded.

ix. The Sun is not always available and it is not regular. However, lights are to be fed daily. Therefore power should be stored in a **battery bank**.

- The storage battery bank have enough capacity to keep the system going on without break down when the weather is not favorable for generation of electricity due to cloudy days and rains.
- LMLA or VRLA batteries are used for this purpose. LMLA batteries are provided with micro porous vent plugs & electrolyte level indicator.
- Suitable battery Box made of Plastic OR M.S fabricated is provided to house the battery.

Fig.2.5: Battery Box

xi. **Charge Controller** suitable for both tubular LMLA as well as VRLA battery is used. This charge controller uses PWM charging technology.

- When battery discharges more at the end of autonomy days, in such a situation charge controller automatically boost charge the battery.

- On availability of sun shine (after autonomy days), the night load energy is delivered by the battery through the solar charge controller.

2.3 TECHNICAL DETAILS

2.3.1 System Rating:

i. Normal system voltage (rated voltage):12Vdc.

ii. **System load**: 15W LED based luminaire working for 12hrs/day. (Dusk-to-Dawn)

iii. Battery Autonomy – 4 days

iv. Solar Insolation - 5 peak sun hours/day

2.3.2 SPV Module

i. The solar modules are designed to withstand the following environmental conditions normally encountered at site –
   - Extreme temperature ranging from -10 degree C to +85 degree C.
   - Wind load – 200 km/h.
   - Maximum mean hourly rainfall of 40 mm.
   - Humidity level upto 95%.

ii. The conversion efficiency of Solar PV Cells used in the module is more than 15%.

iii. The minimum module rating per LED based street light system is 80Wp (Watt peak)

2.3.3 Battery Bank

i. LMLA or VRLA battery which are specially designed to be charged & discharged frequently and can handle heavy discharges time after time with minimum charging efficiency of 90%.

ii. The minimum capacity of the battery bank shall be 12V/75 Ah @ C10.

2.3.4 Charge Controller

i. Charge controller has automatic dusk-dawn circuit for switching on/off the street light without manual intervention.

ii. It is capable of handling 120% of the module's rated current for one hour duration.

iii. The controller displays the battery status as follows using 3 LEDs : -

- Red LED - Low battery
- Green LED - Battery on charge
- Yellow LED - Battery fully charged.

2.3.5 LED Lamp & fixtures

i. Rated Power: 15 W / fixture

ii. Light intensity : 1500 Lumens (typical)

iii. LED type – White High Powered LED's 5500-6500 K temperature

iv. LED fixing arrangement - Mounted on metal core PCB fixed to aluminum heat sink.

v. Illumination: More than 15 Lux at 1 m from the ground (5 m from the Light source).

vi. LED Fixture: ABS plastic/Aluminum fixture with acrylic cover with IP 55 protection

CHAPTER 3

MAINTENANCE & TROUBLESHOOTING

3.1 MAINTENANCE

Solar panels require virtually no maintenance. However the associated equipment such as batteries and charge controller are to be maintained in good condition.

- Once in a month the surface of the panels should be wiped clean with wet rag to remove dust, fallen leaves, bird dropping etc. Only water to be used for cleaning and **no other cleaning agent**.
- Once in a month the surface of the LED light fitting should be wiped clean with wet rag to remove dust etc.
- General periodical maintenance of lead acid battery should be carried out in usual manner and as per maintenance instructions of battery manufacturer. Specially **topping up of battery** with distilled water as per requirement is essential.

3.2 PRECAUTIONS AND PREVENTIVE STEPS

For efficient working of SPV system certain precautions are to be observed as given below:

Please ensure that:

a) All connections are properly made tight and neat using the crimped Red (for +ve) and Black (for –ve) wires supplied by the manufacturer in order to avoid reverse connection.

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b) The proper rating of the fuse in the charge controller is provided.

c) The SPV panel is installed facing SOUTH and with the correct 'Angle of tilt' to get direct sunlight throughout the day.

d) There is no shadow on any part of the SPV panel at any time of the day, to get maximum power.

e) FIRST the battery, then SPV panel and then load (light fitting) is connected to charge controller and for disconnection reverse sequence is adopted.

f) Battery terminals are never to be shorted even momentarily as shorting will result in **HEAVY SPARK AND FIRE**. (To avoid the same connect the cable at charge controller end 'First' and then battery end.)

g) Never connect the load (light fitting) directly to the SPV panel as it may give higher/lower voltage than required by the load equipment and hence the equipment may be **DAMAGED** permanently.

h) Blocking diode is provided at the array output for protection against reverse polarity.

i) It is **NOT HEAT BUT LIGHT** that produces energy. So let direct sunlight to fall on the module surface without shades.

3.3 TROUBLESHOOTING

The SPV power source is reliable source of electrical energy. However, there may be rare instances, when the SPV power source is not able to supply power to the connected equipment.

The diagnosis of the problem in such situations starts with the **battery**:

Check the voltage of the battery. If the voltage of the battery is correct, there may be problem in the switch /load MCB is tripped or load fuse is blown off.

If none of the above fault is observed then check the specific gravity of the electrolyte in the secondary cells of the battery. There may be two cases:

a) If the specific gravity is above the level 1.2 (hydrometer reading 1200) value or as specified in the maintenance manual, it implies that the battery is in order and the problem would be either with the charge controller or load.

b) Disconnect the load (light) from charge controller and connect it directly to battery. If the light glows, the defect may be with the charge controller.

c) Disconnect the charge controller and check as per troubleshooting instructions given in the manual supplied with it or inform the manufacturer/supplier.

d) If the specific gravity of the electrolyte is below the specified level, the problem may be with any of the following:

   i. Light/Load: This may be drawing more current from the battery than required. In such case, battery is bound to get discharged, even if SPV

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panel is functioning properly. To avoid this, get the light/load equipment checked and replace if required.

ii. SPV Panel: The SPV panel may not be producing required power for which the power source has been designed. In that case, check the SPV panel as given below:

- Check for any loose connection/breakage of wire in SPV module interconnections.
- If there is no such loose connection, clean the SPV Modules with soft cloth. Whenever there is bright sunshine (Sun intensity 90 mW/Sq. cm), measure the voltage of module after disconnecting the wire. Open circuit voltage of module should be around 21 volts. Inform the manufacturer/supplier with module serial number along with the measurement taken, for necessary investigations.

iii. Failure of blocking diode: Blocking diode fails in short circuit and open circuit mode. If it is failed in short circuit mode, voltage across its terminal will be zero in place of 0.7 V while charging current flows through it. When it fails in open circuit mode, the current will not flow through the diode. The diode may be checked as per standard method of checking of diode by removing from the circuit.

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Apart from these some possible complaints and troubleshooting methods for **Solar modules** are listed in below table:

S.No.	Symptom	Possible Failure	Probable cause	Action
1.	No output	Cable	Conductor break	Replace cable
			Corrosion	
			Loose connection	
			Improper connection	Verify the wire connections are tight, corrosion free and of correct polarity.
		Connector	Defective connector	Replace connector
			Loose connection	
			Pin loose	
			Corrosion	
			Improper fixing	Fix the connector properly
		Charge controller	Electronic failure	Replace charge controller
		None of the above	Internal problem	Return to factory, if within warranty
2.	Output voltage OK, but no output current	Cell/interconnections	Internal damage	Return to factory, if Within warranty

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S.No.	Symptom	Possible Failure	Probable cause	Action
3.	No charging indication on the Charge controller	Solar module	Shading	Remove the shades or change the location of the module and ensure maximum sunlight to fall on the module.
			Dirt accumulation	Clear the particles on the module
		Module cable	Breakage	Replace cable
			Corrosion	
			Dry solder	
			Loose connection	
		Module	Broken module	Replace module
		Charge controller	Electronic failure	Replace Charge controller
4.	Output voltage for less duration	Solar module	Shading	Remove the shades or change the location of the module and ensure maximum sunlight to fall on the module.
			Dirt accumulation	Clear the particles on the module
			Improper installation	Place the module in such a way that direct sunlight falls on the module for more hours.

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		Module cable	Breakage	Replace cable
			Corrosion	
			Loose connection	
			Dry solder	
		Charge controller	Electronic failure	Replace Charge controller
			Corrosion	
		Battery	Insufficient charging	Charge the battery to full charge condition and check the output duration.
			Low capacity	Replace battery
			Acid leakage	
			Terminal broken	
5.	Always low battery condition	Solar module	Shading	Remove the shades or change the location of the module and ensure maximum sunlight to fall on the module.
			Dirt accumulation	Clear the particles on the module
		Battery	Insufficient charging	Charge the battery to full charge condition and check the output duration.

		Solar Module	Improper installation	Place the module in such a way that direct sunlight falls on the module for more hours.
		Module cable	Loose connection	Replace cable
			Improper fixing	Fix the cable properly and ensure that the connections are tight with correct polarity.
		Charge Controller	Electronic failure	Replace the Charge controller
			Corrosion	
6.	Front Glass broken	Breakage	Mishandling/ transportation	Un-serviceable, Replace
7.	No voltage Across blocking diode	Diode failed in short circuit mode	Random failure	Replace the diode
8.	Voltage high Across blocking diode	Diode failed in open circuit mode	Random failure	Replace the diode

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CHAPTER 4

QUESTIONS AND ANSWERS

Q. 1 What is PV?

PV is a short form which stands for **'photovoltaic'**, a way of producing electricity from light. More properly, the photovoltaic effect is an aspect of the photoelectric effect, and may be defined as the conversion of electromagnetic radiation to electrical voltage by a material.

Q.2 What is a solar cell and its construction?

A solar cell is one piece of photovoltaic material suitable for incorporation in a larger module. Normally it looks like a piece of blue plastic/stone with leads for connection in an electric circuit.

In general the solar cell is built in several layers. There needs to be at least two semiconductor layers. There may be several semiconductor layers designed to absorb light of different wavelengths. There needs to be two conductive layers to draw off the charge. Sometimes the conductive layers will be metallic; sometimes they will be transparent metallic oxide such as zinc oxide. There will likely also be an anti-reflection layer on top and a reflection layer on the bottom. There may be an encapsulating layer as well, on top, commonly glass to protect the material. It may all be sitting on a substrate which serves as a base for the device.

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Q.3 What is a PV module?

The power generated by a single cell is small and therefore several cells are interconnected in series/parallel combination to get the required voltage and current. When a number of solar cells are connected in series to get a specific voltage the unit so formed is called as Solar Module.

It is typically a group of solar cells assembled in a commercial unit ready for installation in a system. Usually the PV module has a specified power rating and guaranteed lifetime (commonly ~20 years).

Q.4 How does photovoltaic work?

At the simplest and most practical level, sun light falls on a solar cell and electricity is generated. On a slightly more sophisticated level, photons of a high enough energy are absorbed by semiconductor material creating electron-electron hole pairs which come under the influence of an electric field and are conducted through an external circuit.

Q.5 What is the photoelectric effect?

The photoelectric effect may be defined as changes in electrical characteristics of substances due to electromagnetic radiation, usually in the form of light. Radiation of a sufficiently high frequency impinging on some substances (usually metals, but not always) cause bound electrons to be released.

The photoelectric effect has two principle aspects - photoconductivity (change in conductivity due to light) and photo voltage (change in voltage due to light).

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Q.6 What is the photovoltaic effect?

The conversion of electromagnetic radiation (photons) to electrical voltage by a material.

Q.7 What is the photoconductive effect?

Photoconductivity may be defined as changes in conductivity (the inverse of resistivity) due to electromagnetic radiation (usually light). Conductivity is a measure of the ease with which electric current flows in a material.

It was the photoconductive properties of selenium which led to the discovery of its photovoltaic properties.

Q.8 What materials show the photovoltaic effect?

In general the photovoltaic effect is demonstrated by semiconductors. The first solar cells were made with selenium and gold. Nowadays a wide variety of semiconductor materials are used, as well as a few exotic which may never escape the lab.

Q.9 What does light do the material to make electricity?

The light which impinges on the photovoltaic material is a solar spectrum, ie. an approximately 6000K black body curve filtered by the atmosphere. It is composed of photons having a range of energies. A photon which has energy greater than or equal to the band gap of the PV material will move an electron from the valence shell to the conduction shell, thereby creating an electron-electron hole pair. If the electron is caught by an electric field before it has an opportunity to recombine, it will flow through an external circuit first, providing electricity, and then recombine.

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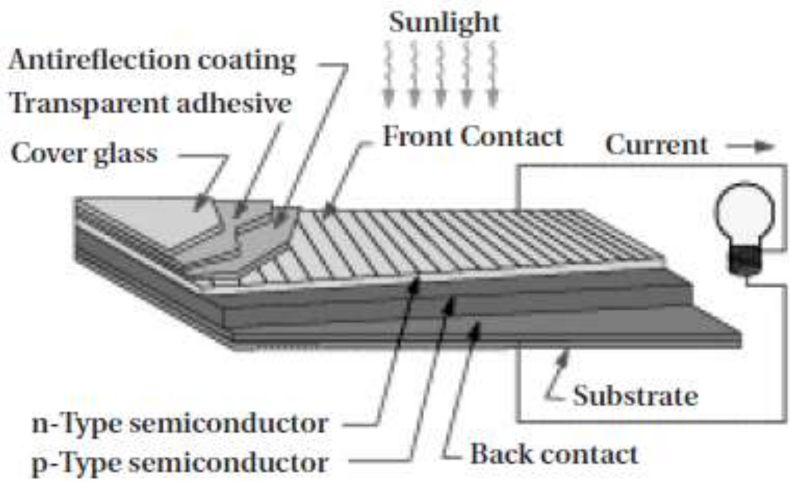
Q.10 What is the solar cells construction in general?

In general solar cells are made from semiconductor material. PV device (solar cell) usually consists of:



- an n-type semiconductor layer
- a p-type semiconductor layer
- a conductive layer on the bottom
- a partial or a transparent conductive layer on the top
- an anti-reflection coating on top
- a substrate to serve as a support
- an encapsulating layer for protection

Q.11 What is a semiconductor?

Materials, both compounds and elements, can be classified according to how well they conduct electricity. There are materials such as **metals (conductors)** which conduct electricity well and those which conduct electricity poorly, called **insulators**. There are a few materials which fall in between. They conduct electricity a little bit. These materials are called **semiconductors**.

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The Pauli Exclusion Principle applied to electrons bound to an atom defines a series of distinct energy shells which electrons can fill. These shells are filled from the lowest energy level upwards. The Periodic Table arises with each element adding a proton and the filling of each shell taking one 'period' of the table.

The semiconducting elements form a loose band on the table; not quite metals and not quite insulators. Compounds formed from various crystalline and amorphous mixtures are also semiconducting.

On top of which, the electrical characteristics of semiconductors can be changed by introducing traces of other elements in minute proportions. This is called doping and is how n-type and p-type semiconductors are constructed.

By applying voltages and bias currents, semiconductors can function as switches forming the basis of transistors. And by applying light radiation, semiconductors can function as photovoltaic devices.

Silicon is the most commonly used semiconductor.

Q.12 What types of photovoltaic devices are there?

The common types of photovoltaic devices are:

- crystalline
- polycrystalline
- amorphous
- thin film
- multi-junction

The significant difference in these different forms is the cost of production.

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Q.13 What are Thermo Photo Voltaics?

Similar to photovoltaics, Thermo Photo Voltaics (TPV) may be defined as the conversion of heat to electrical voltage by a material. The difference is the wavelength of the radiation and the corresponding band gap in the material.

Q.14 Are there PV cells that work in Ultraviolet wavelengths?

Ultraviolet tends to have destructive effects on living things, and it has likely been avoided for this reason.

"PV cells can be tuned to receive UV by using different materials. a-Si cells by Uni-Solar capture some UV. Indoor PV cells used in calculators capture UV."

Q.15 What is an anti-reflection coating?

The natural surface of many photovoltaic materials is quite reflective. Crystalline silicon for example will reflect ~35% of incident light. As far as a PV device is concerned this is energy lost, so it makes sense to apply a coating which will absorb as much light as possible.

Q.16 What are the different grades of silicon?

Silicon (Si) is the second most abundant element in the earth's crust constituting ~28% by weight.

There are at least three commercial grades of silicon. These are:

- semiconductor grade silicon
- metallurgical grade silicon
- photovoltaic grade silicon

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Q.17 What is an Inverter?

An electric device which converts direct current (DC) to alternating current (AC).

Solar cells produce a direct current. Most of the electrical devices commonly in use require AC power supply. An inverter takes the DC from the solar cells and creates a useable form of AC. Besides doing this, an Inverter may also be connected to the electric grid and/or a battery backup system.

Q.18 What is a Solar Tracker?

A Solar Tracker is a device which aims a solar panel directly at the sun in order to maximize energy output. The mechanisms for achieving this can vary as per location and requirement.

Q.19 What are Concentrators?

A Concentrator is a device which increases the amount of sunlight landing on a photovoltaic module. It is in a way a logical development. Commercially available solar cells are commonly around 15% efficiency, and progress in improving this rating is relatively slow. So if you want to increase output today, why not use more sunlight?

In order to work well, the concentrator has to be aimed at the sun. Thus the design considerations for trackers come into play. One commonly used design is the reflective trough, which simplifies things by removing one dimension of adjustment.

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Q.20 What is a Charge regulator?

A charge regulator, also known as a **charge controller**, is a device in a photovoltaic system which prevents over charging ('cooking') of batteries. Depending upon the sophistication of the unit, it may also prevent over-discharge of the batteries and reverse charging of the cells.

Q.21 What is a blocking diode?

A 'diode' is a circuit element which theoretically has zero resistance to current flowing one way and infinite resistance to current flowing the other. It is like a one way valve. It is also called a 'diode rectifier'.

In the case of photovoltaics, a 'blocking diode' is a diode connected in series between solar cells and storage batteries to keep the batteries from discharging through the cells when there is low or no output. i.e. at night

Q.22 What is a hybrid system?

A hybrid system is a combination photovoltaic and solar thermal system. Typically water is circulated behind the solar cells to collect heat and to cool the cells. Often such hybrid systems use concentrators. This effectively results in a substantial increase in system efficiency.

Q.23 What is the Solar Constant?

The rate at which energy is received from the sun just outside the earth's atmosphere on a surface perpendicular to the sun's rays. Measured to be ~1365 W/m^2 by several satellites.

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Q.24 At what angle should solar panel mounted?

"The rule of thumb for fixed (never adjusted) is to set them pointing south at an **angle = latitude.** If you adjust your angle 2x a year, winter is latitude + 15 deg and summer is latitude - 15 deg.

"If you want to know the angle for "now", point them so that a stick perpendicular to the panel casts no shadow at solar noon (when the sun is at it's peak -- close to noon standard time).

Q.25 What is Net Metering?

If you take the AC output of your Inverter and run it to the mains coming from your utility power meter, any excess power you generate will feed back into the utility grid and drive your power meter backwards. This is called Net Metering.

Q.26 How has the efficiency of PV changed historically?

The efficiency of photovoltaic devices has been steadily improving since serious attention began to be paid to them in the 1950's. The first selenium cells built by Fritts were <1% efficient. In 1954, Pearson Fuller and Chapin produced silicon solar cell whose efficiency was 4% to 6%.

By the early 1970's silicon solar cells were 10% efficient. In the 1980's and 1990's exploration of multi-junction devices had raised the commonly available efficiencies to about 15%, while in the laboratory or for more exotic environments (ie. space), efficiencies were in the 20%-30% range.

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Q.27 What is the Payback Time?

The payback time of an investment is the period of time required until that investment returns an amount equal to the original investment. This is called the Financial Payback Time. Note that when dealing with money over time, one ought properly to use the standard time value of money calculations (otherwise known as interest).

Q.28 What shall be the capacity of the batteries?

The problem of sizing a battery bank arises when designing a PV system. It assumes that we know how many kilowatt-hours are required for battery bank to deliver.

The general solution is to convert energy requirement from kilowatt-hours to the amp-hour units in which the batteries are specified, while taking into account various efficiency losses and use that total to calculate the capacity of batteries.

To do - redraft this

Load requirement = 'P' watts

Time for load is working per day = 'H' hours per day.

Battery Autonomy required (non availability of sun days) = N days

Voltage of the batteries/system = V volts

Inverter efficiency (if provided) = Fi

Battery and balance of system efficiency = Fbos

All of these number you know or can measure.

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Then:

The amperage battery bank will need to deliver is $I = (P/V)$ amp.

Taking into account the efficiency of the inverter (if provided) this will be: $(P/V) \times (100/Fi)$ amp.

And taking into account all efficiencies, the battery bank will need to deliver:

$(P/V) \times (100/Fi) \times (100/Fbos)$

The total AH (amp-hours) per day which the battery bank will need to deliver:

$(P/V) \times (100/Fi) \times (100/Fbos) \times H$ (ie. Multiply by hours)

The total amp-hours which the battery bank will need to deliver:

$(P/V) \times (100/Fi) \times (100/Fbos) \times H \times N$ (ie. Multiply by no. of days backup required)

Check Manufacturer's Recommended Maximum Depth of Discharge (DOD)

Normally it is 80% for deep cycling
59% for shallow cycling

Check the temperature variations of site and determine the Maximum DOD as per data given by battery manufacturer.

Total AH required

$$\mathbf{(P/V) \times (100/Fi) \times (100/Fbos) \times H \times N \times 100/DOD}$$

No. of series Batteries = System DC Voltage / Battery Voltage

No. of Parallel Batteries = Total AH Required / AH of Individual Battery

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OBJECTIVE TYPE QUESTION

1. Sunlight, air, soil and water are the examples of
   - a. Non-renewable resources
   - b. Renewable resources
   - c. Conventional resources
   - d. Non-natural resources

2. The resources that are inexhaustible as they are replaced by nature are known as
   - a. Non-renewable resources
   - b. Renewable resources
   - c. Conventional resources
   - d. Non-natural resources

3. Solar energy can be converted directly into electric energy with the help of
   - a. Photovoltaic cells
   - b. Dry cells
   - c. Rechargeable cells
   - d. Battery

4. Solar energy can be used to cook food in a
   - a. Solar cooker
   - b. Wood stove
   - c. Gas oven
   - d. Traditional oven

5. Solar energy can be used for heating of water through
   - a. Solar water heating system
   - b. Photovoltaic cells
   - c. Solar batteries
   - d. Dry cells

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6. The transfer of solar energy from the sun to the earth is governed by which of the following processes

   a. Conduction b. Convection

   c. Radiation d. Light speed

7. Solar cell is used to convert solar energy into

   a. Electrical energy b. Chemical energy

   c. Mechanical energy d. Thermal energy

8. Renewable energy is called green power because

   a. It does not produce any harmful pollutants

   b. It is green in colour

   c. It is only produced from green plants

   d. None of the above

9. How many days in a year, on an average, is solar energy available in India?

   a. 100 days b. 150 days

   c. 225 days d. 300 days

10. What does FPC stand for in solar energy?

    a. Fluid plate circuit b. Fixed plate collectors

    c. Flat plate collectors d. None of the above

11. Solar, biomass, geothermal, wind, and hydropower are all the renewable sources of energy. They are called renewable because they

    a. Are clean and free to use

    b. Can be converted directly into heat and electricity

    c. Can be replenished by nature in a short period of time

    d. Do not produce air pollution

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12. Which is the most common material used for making solar cells?

    a. Silver b. Iron

    c. Aluminium d. Silicon

13. Electrical output of a solar cell depends on

    a. Intensity of solar radiation

    b. Heat component of solar radiation

    c. UV component of solar radiation

    d. MIR component of solar radiation

14. Solar photovoltaic cells convert energy directly into

    a. Mechanical energy b. Electricity

    c. Heat energy d. Transportation

15. ETC in solar energy means

    a. Electricity transmitting collectors

    b. Evacuated tube collectors

    c. Electricity temperature converters

    d. Electrons transport carriers

16. SPV in solar energy stands for

    a. Solar photovoltaic

    b. Solid plate voltaic

    c. Solar plate voids

    d. None of them

17. Solar energy moves through space to the earth by

    a. Conduction b. Convection

    c. Radiation d. Transportation

18. Which of the following processes occur in a solar pond?
    - a. Solar energy collection and heat storage
    - b. Only solar energy storage
    - c. Only solar energy collection
    - d. None of the above

19. Which of the following system is the application of solar thermal energy?
    - a. IC engine
    - b. Biogas generation
    - c. Solar water heating
    - d. Solar lighting

20. Which is currently the main renewable energy source used by electric utilities to generate electric power?
    - a. Solar
    - b. Hydro
    - c. Wind
    - d. Biomass

21. Which of the following is not an application of solar energy system?
    - a. Solar lantern
    - b. Biogas plant
    - c. Solar water heater
    - d. Solar air heater

22. A typical insulation material for liquid solar collector is
    - a. Fibre glass
    - b. Cotton
    - c. Glasswool
    - d. None of these

23. Which of the following appliances use solar photovoltaic technology?
    - a. Solar lantern
    - b. Biogas plant
    - c. Solar water heater
    - d. Solar air heater

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24. Which material has the highest reported solar cell efficiency?
    a. Amorphous silicon
    b. Thin-filled silicon
    c. Polycrystalline silicon
    d. Single crystal silicon

25. Solar photovoltaic panels are not utilized in general to meet the domestic needs of electricity due to their
    a. High efficiency and high cost
    b. Low efficiency and high cost
    c. Low efficiency and low cost
    d. High efficiency and low cost

26. Pyranometer is an instrument used for measuring the
    a. Temperature of a solar photovoltaic cell
    b. Solar irradiance of a solar photovoltaic cell
    c. Wind speed of a solar photovoltaic cell
    d. Efficiency of a solar photovoltaic cell

27. The angle at which an incoming solar beam strikes a surface is called
    a. Solar inclination angle
    b. Solar incident angle
    c. Solar azimuth angle
    d. None of the above

28. Stand-alone solar power plants are used for which of the following local networks?
    a. Home power supply in rural areas.
    b. Telecommunication and relay areas
    c. Community power supply applications
    d. All of the above

29. Solar radiation incident per unit time is termed as

a. Insolation b. Irradiance

c. Radiation d. Conduction

30. A stand-alone solar power plant consists of

a. Solar photovoltaic panels

b. Storage batteries

c. Charge controllers

d. All of the above

31. When sunlight falls on a photovoltaic panel, some particles gain enough energy to produce electric current. These particles are called

a. Electrons b. Protons

c. Neutrons d. None of the above

32. A group of solar collectors connected together is called a

a. Solar cell b. Solar array

c. Solar centre d. Solar concentrator

33. A stand alone solar photovoltaic power plant does not have a

a. Solar panel b. Storage battery

c. Charge controller d. Turbine

34. Sunlight reaches the earth through

a. Direct radiation b. Diffuse radiation

c. Scattered radiation d. All of the above

35. The Solar Energy Centre was set up in India with a view to develop solar energy technologies in the country. It is located at

a. Tamil Nadu b. Haryana

c. Uttar Pradesh d. None of the above

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36. Which of the following utilizes energy from the sun?

a. Passive solar heating
b. Solar electricity
c. Photovoltaic technology
d. All of the above

37. The colour generally used to coat solar energy devices is

a. Red
b. Green
c. Blue
d. Black

38. The total solar radiation received at any point on the earth's surface is termed as

a. Insulation
b. Insolation
c. Radiation
d. Insulated radiation

39. A typical single solar photovoltaic cell of $2cm^2$, when exposed to sunlight, can produce

a. 5 watt of electricity
b. 0.7 watt of electricity
c. 10 watt of electricity
d. 100 watt of electricity

40. The amount of solar radiation received on a unit area exposed perpendicularly to sunlight at an average distance between the sun and the earth is termed as

a. Solar insolation
b. Solar constant
c. Solar radiation
d. Solar insulation

TRUE/FALSE

1. Satellites use solar cells for power.
   a. True b. False

2. Solar lantern is a fixed type solar lighting system.
   a. True b. False

3. Solar energy can be used to produce thermal and electrical energy.
   a. True b. False

4. Solar energy can be stored during day and utilized during night.
   a. True b. False

5. Any device that uses solar radiation to remove moisture from a substance is known as a solar collector.
   a. True b. False

6. Solar energy is not extensively used for the generation of electricity due to the high cost of the solar cells.
   a. True b. False

7. The purpose of placing a mirror on top of a solar cooker is for absorption.
   a. True b. False

8. Silicon and zinc are used in making solar photovoltaic cells.
   a. True b. False

9. A solar lantern generates electricity through solar photovoltaic cells.
   a. True b. False

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10. Parabolic mirrors are used in the production of tidal energy.

    a. True   b. False

11. Solar photovoltaic cells are made of aluminium.

    a. True   b. False

12. Solar concentrators used to generate electricity are solar thermal devices.

    a. True   b. False

13. Flat plate collectors are used in a solar water heater.

    a. True   b. False

14. Crystalline silicon, polycrystalline silicon, amorphous silicon, and cadmium telluside are types solar photovoltaic cells.

    a. True   b. False

15. Solar energy can be converted into thermal energy and electrical energy.

    a. True   b. False

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ANSWER SHEET

Objective type Questions

1 - b	2 - b	3 - a	4 - a	5 - a
6 – c	7 - a	8 - c	9 - d	10 - c
11 - a	12 – d	13 - a	14 - b	15 - b
16 - a	17 - c	18 – a	19 - c	20 - b
21 - b	22 - c	23 - a	24 – d	25 - b
26 - b	27 - b	28 - d	29 - b	30 - d
31 - a	32 - b	33 - d	34 - d	35 - b
36 – d	37 - d	38 - b	39 - b	40 - b

True/ False

1 - a	2 - b	3 - a	4 – a	5 - b
6 – a	7 - b	8 - b	9 - a	10 - b
11 - b	12 – a	13 - a	14 - a	15 - a

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2. Book of multiple choice question on Energy issued by TERI – New Delhi.

3. Book of multiple choice question on renewal energy issued by TERI Delhi.

4. Field study and literature collected from field.

5. Suggestion comments received during seminar held on 10.08.2015.

6. Book of solar lighting systems module (Trainers Text book) issued by Ministry of New and Renewal Energy, Govt. of India.

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OUR OBJECTIVE

To upgrade maintenance technologies and methodologies and achieve improvement in productivity, performance of all Railway assets and manpower which inter-alia would cover reliability, availability, utilization and efficiency.

If you have any suggestions and any specific Comments please write to us.

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