TVM POWER SOLAR Training

SOLAR PV GRID CONNECTED POWER PLANTS

ABSTRACT OF THE TOPICS TO BE COVERED IN THE TRAINING

OVERVIEW OF SOLAR ENERGY

All usable energy forms, apart from nuclear energy and earth's heat, are forms of solar energy. Conventional forms of energy are stored solar energy in the form of fossil fuels or biomass. Solar energy, which radiates nearly 20,000 times the energy requirement of the world on the surface of the earth, is abundantly available all over India.

The amount of solar power available per unit area is knows as **Irradiance**. Unit is – kW/sqm or watts/sqm or mW/sqcm. Measuring device for solar irradiation is Pyranometer. Irradiation fluctuates according to the Sun's location in the sky i.e. changes in both Sun's altitude angle and its azimuth angle. The power produced by solar cells is proportional to the intensity of global radiation.

For optimal use in the northern hemisphere, a solar system is oriented southwards at an inclination from the horizontal. The appropriate inclination angle, a, is dependent upon the latitude and on the time of the year. The solar radiations incident on a horizontal surface is comprised of sky radiation and the reflected radiation.

Solar window represents the effective area through which useful levels of sunlight pass throughout the year for a specific location. Solar window is used to determine potential shading when designing a photovoltaic system.

Tilt Angle is the angle, between array and horizontal surface, which gives maximum solar irradiation. Solar panels should always face true south if you are in the northern hemisphere, or true north if you are in the southern hemisphere.

Solar insolation is radiant energy per unit area and is expressed in units of kWh/m2/day. **Peak Sun Hours** is the number of sun hours per day at a given location which is equivalent to the time at peak sun condition that yields the same total insolation.

Receiver Type-

<u>Flat-plate arrays</u> use both diffuse and direct sunlight and can operate in either a fixed orientation or in a suntracking mode. In most applications flat-plate arrays are fixed in orientation.

<u>Fixed V/s Tracking Array-</u> For flat-plate arrays Sun-tracking can increase annual energy output by 20% to 40%, depending on location and the type of tracking used. Two-axis tracking allows the array to continuously face directly at the sun and provides the maximum energy output. The tilt angle is adjusted periodically to increase the output of the array in tracking process.

Concentrator Arrays- These arrays use optical lenses and mirrors to focus sunlight onto high-efficiency cells. The major advantage of them is that they use relatively small areas of expensive plastic lenses or other materials.

Photovoltaic- The term "photovoltaic" comes from Greek phos meaning 'light', and the name of the Italian physicist Volta, after whom the volt (and consequently 'voltage') are named. It means literally, of light and electricity.

IV characteristics-

- Maximum Current (Imax) The current at which maximum power is extracted is the desired operating current (Maximum Current) for a photovoltaic cell, module or array
- Maximum Voltage (Vmax) The voltage at which maximum power is extracted is the desired operating voltage for a photovoltaic cell, module or array
- Short Circuit Current (Isc) The current at which power is not extracted and voltage becomes zero
- Open Circuit Voltage (Voc) The voltage at which power is not extracted and current becomes zero
- Maximum Power (Pmax) The maximum power point (Pmax) is the point on I-V curve for which maximum power is extracted

Effect of temperature- The higher operating temperatures result in lower power outputs and efficiencies. As temperature increases, current increases slightly but voltage decreases significantly resulting in a net reduction in power.

Solar Cell manufacturing process includes following steps-

- Wafer Surface Texturing
- p-n Junction (Semiconductor) Doping
- Junction isolation, Anti-reflection layer coating
- Back Surface Field & Contact Metallization
- Solar Cell Test

PV module assembling process includes following steps-

- Cell Interconnections & Lay-up
- Lamination & Module Framing
- PV Module Test

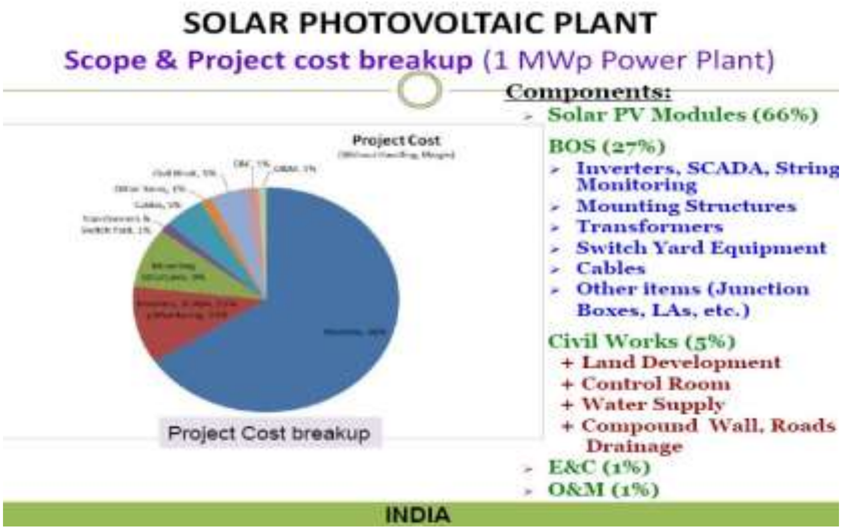
Photovoltaic Power applications- We can utilize power generated from PV module in various applications. Few of the examples are as follows:

- Home Lighting systems and Solar Lanterns
- Street Lighting systems
- Water Pumping systems
- Systems for Telecom equipment
- Systems for Railway signaling
- Hybrid systems (Wind, Diesel, BIPV)
- Stand-alone power plants for Community Lighting

- Grid-connected power plants

Features of Solar Power is as follows:

- ✓ Clean, Carbon-free (environment-friendly) & renewable energy; Only fuel required is sunlight
- ✓ Silent and minimal maintenance (requires periodic cleaning of solar glass surface)
- ✓ Distributed generation of power possible at point of use; Modular, easy to add-on
- ✓ The Sun produces enough energy in ONE HOUR to power the Earth's population for an ENTIRE YEAR!



Components of MW Scale Solar PV Systems

- Land & Infrastructure Solar Modules.
- Panel Mounting Systems.
- DC Cabling & Connectors.
- String Combiner Boxes.
- Inverters.
- Transformers.
- High Voltage AC cabling.
- Control Panels.
- Evacuation Systems.
- Monitoring Systems.

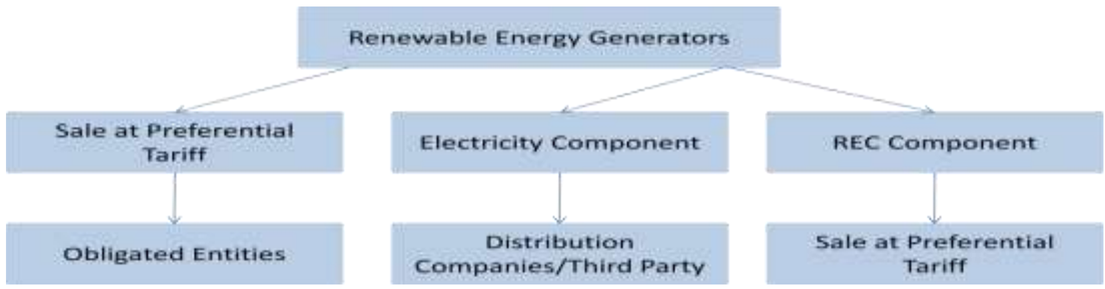
REC Mechanism

The growing consciousness towards environment, the need for sustainable development and the Kyoto protocol are gradually shifting the focus towards Renewable Energy Power. Lately, in view of growing awareness about green environment, development of renewable energy has been promoted by fiscal policies of Government of India. These include tax incentives and purchase of electricity generated through renewable energy sources. State Electricity Regulation Commissions across the country has specified a certain percentage of renewable purchase obligations for obliged entities in the state.

Since, renewable energy sources are not evenly spread across the state boundaries, Renewable Energy Certificates seek to address the mismatch between availability of renewable energy sources and requirement of obliged entities to meet their obligation, mention who all are obligated Obliged Entities may purchase the environmental attribute of renewable energy projects (not owned by them) in the form of Renewable Energy Certificates.

Thus under the present context, renewable Energy generators will have two options:

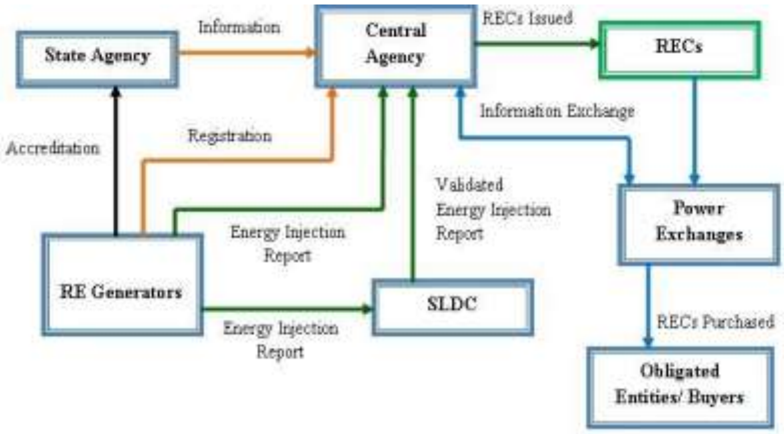
- **Either to sell the renewable energy at preferential tariff to distribution utilities, or**
- **To sell electricity generation and environmental attributes separately**



Renewable Portfolio Obligation (RPO) generally places an obligation on electricity supply companies to produce/consume a specified fraction of their electricity purchase from renewable energy sources (state specific). In India, the legislative support for Renewable Portfolio Obligation is reflected in Section 86 (1) (e) of the Electricity Act-2003. The Obligated Entities are Distribution Utilities, Open Access consumers and Captive consumers. It encourages setting up of larger generation capacities at resource rich locations and through a process of Certification, creates a market based instrument which can be traded, on Central Electricity Regulatory Commission (CERC) approved power exchanges. In January 2010, hon'able CERC announced Regulation on Terms and Conditions for recognition and issuance of Renewable Energy Certificates for Renewable Energy Generation. As per the CERC REC regulations, a project is considered a renewable energy project if it is covered under the Ministry of New and Renewable Energy's (MNRE) definition of renewable sources.

Renewable Energy Certificates

REC concept seeks to address this mismatch between availability of RE sources and the requirement of Obligated entities to meet their RPO requirement. The electricity produced from Renewable Sources will have two components. i.e. Energy attribute and Environmental attribute. The RE generators will have two options – Either to sell electricity at preferential tariffs or to sell electricity generation and environmental attributes separately. The REC mechanism is a market based instrument, to promote renewable sources of energy and development of market in electricity, leading to the sustainable development of the country. One certificate represents generation of electricity from renewable sources equivalent to 1 MW-hr. Normal validity of the REC is 365 days. However, recently it has been increased to 730 days, for REC's issued on or after 01.11.2011, looking into the fact that the market is yet to attract buyers for REC. Since the Investment cost in Solar Projects is high, the REC as well as RPO has been divided into Solar as well as Non-Solar REC's. **REC Process**



Economic Viability of Solar Projects

There are two technologies currently in operation for electricity generation through solar power:

Solar thermal: Conversion of heat to steam and then run a turbine to generate electricity.

Solar PV: Solar Photovoltaic cell technology, whereby PV cells generate electricity, which is converted in to grid parity voltage and fed to the grid.

For assessment of Solar Project Feasibility, we have to consider following parameters:

Capital Cost:

- Cost of Modules.
- Cost of BOS.
- Cost of land.
- Cost of Evacuation facility. Cost of Civil Construction.

Assessment of Revenue Streams:

- PPA at discounted tariff + CDM + VCU.
- REC revenue + CDM + VCU.
- Third Party sale + REC + CDM +VCU.
- Sale through Exchange + REC + CDM +VCU.
- Captive Consumption + REC + CDM + VCU.
- Replacement Cost of BOS.
- Tax saving due to Accelerated Depreciation.

Assessment of Expenses:

- O&M Expenses.
- Working Capital Requirements.
- Insurance cost.
- Administrative cost.
- Various fee and cost of Guarantees.
- Applicable Income Tax.
- Applicable Minimum Alternate Tax.

- Cost of Registration of CDM project.
- Revenue sharing requirement of CDM revenue.
- Revenue from CDM & VCU's.
- Availability of Tax holiday under 80 IA.
- Cost of various Approvals & Registrations.

Other Inputs Required for Assessment of Project Viability:

- Plant Load Factor.
- Auxiliary Consumption. Debt Equity Ratio.
- Cost of long term funds.
- Interest on Working Capital Loan.
- Life of the Project.
- Salvage Value.
- Period of PPA or Assumptions there off.
- Accelerated Depreciation or Normal Depreciation.
- Date of Commissioning.
- De-rating factor.
- Transmission loss.

Benchmark Calculation:

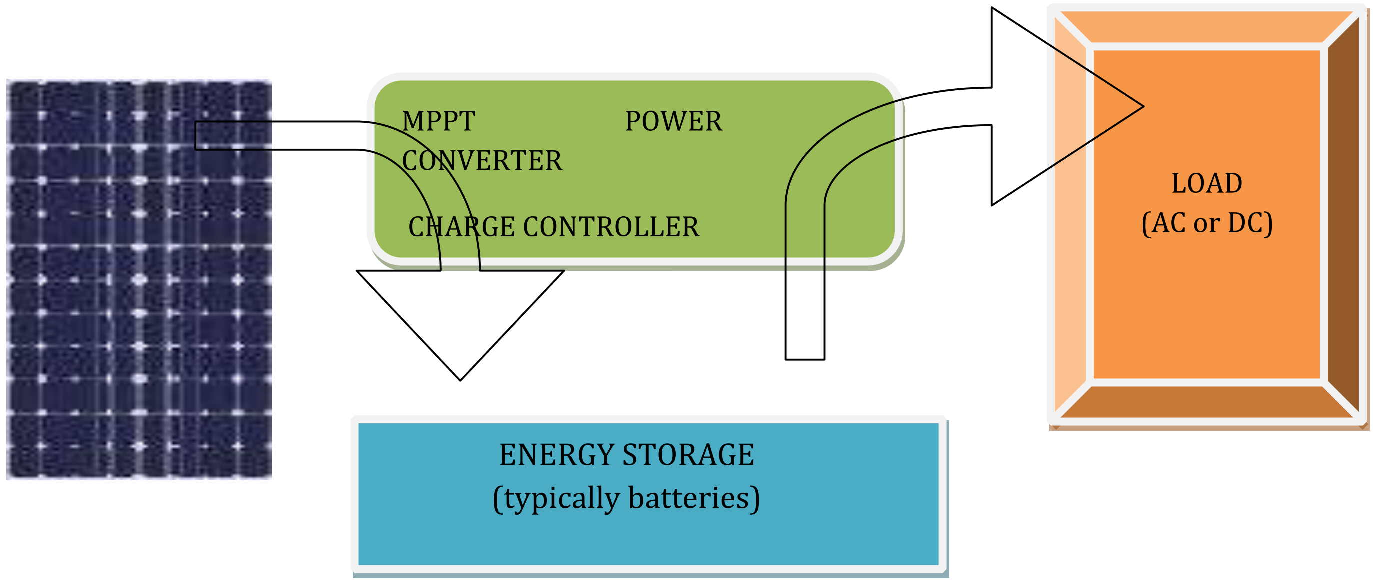
- Expected / Required returns on Equity are the appropriate Benchmark for Equity Internal Rate of Return.
- Benchmark Return = Risk free return + Risk weighted return.
- Risk Free return = Return on long term Govt bonds.
- Risk weighted return = Additional return expected due to technology specific, market specific, Govt specific etc.
- In case the project can be developed by any other Entity, then the Benchmark is calculated on the parameters that are standard in the market.

Sensitivity Analysis:

- To assess the change in IRR due to changes in major parameters, in the calculation of IRR.
- Normally this is done my changing the variation from + 10% to -10% in 2 steps of 5% each. Changing PLF
- Changing in Revenue, by changing REC price / electricity sale price.
- Change in O&M cost.
- Change in Capex.
- May also test the extent to which the PLF is reduced to get the lower band of Benchmark, beyond which a investor will not invest in the project and the possibility there off.

System Design for Off-grid PV System

Energy Flow Diagram: For a given load, the designer needs to determine the rating of the battery and the PV panels. The system design is easy to understand if the designer identifies the path of energy flow. The energy



flow path of this configuration is shown below:

It is shown that during the sunshine hours, energy flows from the PV source to the battery through electronic circuitry. When the load is operating, the energy flows from the battery to the load through the electronic circuitry. Overall the energy flows from the PV panel to the load through the power converters and the battery.

The system design proceeds in the reverse direction of the energy flow. Overall design of this configuration can be divided into three steps:

Step 1. Determine the load (in Watt-hour), power converter rating, and the system voltage

Step 2. Determine the battery size (their number, capacity, and voltage and Ah ratings) Step

3. Determine the PV panel size (their number, capacity, voltage and current ratings)

STEP 1. Load estimation (or specified load), power converter rating and system voltage:

The load refers to any appliance that needs to be powered by the PV system. While estimating the load, the following parameters are considered:

- Type of load, AC or DC;
- Number of loads;
- Power, voltage and current ratings of each load;
- Hours of load operation per day; ❖ Energy required per day by the load; and ❖ Efficiency of the power converter circuit.
- Overall losses

- Determining the inverter rating= Maximum load that can be put at any point of time. Generally 25% more than the total watt calculated
- Daily energy supplied to inverter= Total Watt-hr per day/ Inverter Efficiency
- Deciding the system voltage= this is a choice that system designer has to make. DC systems voltage, usually multiples of 12V

STEP 2. Sizing of batteries:

The parameters of concern regarding the batteries are as follows:

- ❖ *Depth of discharge (DOD) of battery;*
- ❖ *Voltage and ampere-hour (Ah) capacity of the battery: and ❖ Number of days of autonomy.*
- ❖ *Consider for battery autonomy*
- ❖ *Determine the battery capacity for a given load*

- ➢ *Watt Hr Storage= (Daily watt hr consumption X Days of Autonomy)/ (Inverter Efficiency* Depth of discharge)*
- ➢ *Battery Capacity (in Ah) = Watt Hr Storage / Battery voltage/ Battery efficiency*
- ➢ *No of Batteries= Total Amp hr / Amp hr per battery*

STEP 3. Sizing of PV modules:
The parameters of concern for the PV module sizing are:

- ❖ Voltage, current and wattage of the module
- ❖ Solar radiation at a given location and at given time
- ❖ Efficiency of the batteries
- ❖ Temperature of the module
- ❖ Efficiency of the MPPT and charge controller unit; and ❖ Dust level in working environment

- ➢ PV daily Watt-Hr= Daily watt hr consumption/ System Efficiency
- ➢ Total Ah generated by the PV panels= PV Daily Watt Hr X 1.25 / System Voltage
- ➢ Total amperes generated by PV modules= Total amperes generated/ peak sun hours
- ➢ Number of modules required= Total amperes generated/Impp of PV module

Various types of Inverters

Inverter is a switching and control circuitry device. The output of the Inverter can be a square wave or sinusoidal wave or modified sinusoidal wave. Rating of inverter ranges from several VAs to MVAs. The solar inverter works as an interface between the solar array output, batteries (if used), loads (if connected) and the grid. The solar inverter is used for conditioning of all available power sources and ensures delivery of reliable and good quality power to the loads and grid. The efficiency and reliability of the entire PV system depends to a large extent on the efficiency and reliability of the solar inverter (PCU). The solar inverter is a very important component of the PV System.

Classification of Solar Inverters can be done as per their application on following basis:

- ➢ Grid Connected Inverters ○ Central Inverters ○ String Inverters
- ➢ Stand Alone Inverters
- ➢ Hybrid Inverters

Power Conditioning Unit: Solar Inverter is also sometimes termed as "Power Conditioning Unit" as it contains-

- ✓ Inverter

- ✓ MPPT device
- ✓ Charge Controller
- ✓ Grid Synchronizer
- ✓ Reactive Power compensator
- ✓ Communication and data logging device
- ✓ Self protection device
- ✓ Automatic operation device
- ✓ Master – Slave configured device (optional)

Standards for PCU are as follows:

- ✓ IEC 61683 – Efficiency of the PCU
- ✓ IEC 62093 – MPPT feature of PCU
- ✓ IEC 60068-2 – Environmental Testing of PCU
- ✓ IEC 61727 – Grid Connected PCUs

Thermal management of PCU- A 500 kW PCU of 98% working at full load will produce the balance 2% loss as heat i.e. around 10kW. This heat needs to get removed not only from PCUs, also from control room. Cooling fans shall be provided for heat sink, L-C-L filter and also for cabinet. Ducting of PCUs shall be provided to take away the heat blown out by PCU cooling fans. ID Fan is provided (if required) at the end of the ducting to extract out the heat from the PCUs through ducting. Ducting dimensions and ID fan sizing shall be properly done so has to keep the control room temperature in PCU operating limits.

Grid synchronizing process when done among two DC sources, power can be transferred if just potential difference exists among them. When comes to AC power transfer, magnitude, frequency and phase of inverter voltage shall match with grid voltage and a little phase difference (lead) is needed for power export.

Charge Controller- Solar Inverters when needs to get coordinated with Batteries will have in-built charge controller feature. Charge controller prevents the battery from getting deeply discharged or over charged. By sensing the State of Charge (SOC) of battery, charge controller decides whether to connect/disconnect from PV array to avoid over charging or connect/disconnect from load to avoid deep discharging. Types of Charge Controllers are as follows:

- ➢ Shunt type charge controller
- ➢ Series charge controller
- ➢ DC-DC converter type charge controller

PV System-Installation, Commissioning, Operation & Maintenance Off-

grid PV System

Major Components:

- Solar Modules
- Structure
- Power Conditioning Unit
- Battery bank and Other accessories

Philosophy:

- SPV Modules mounted on structure
- SPV generates DC power from Sun light
- Fed to Power conditioning unit through AJB
- PCU monitors, battery SOC, regulate charging and supply AC Power to load Priority: Solar, battery and grid/DG

On-grid PV System

Major Components:

- Solar Modules
- Structure
- Grid connect Inverter

Metering and grid connection

Philosophy:

- SPV Modules mounted on structure
- SPV generates DC power from Sun light
- Fed to Grid connect inverter through AJB
- Inverter converts DC power to AC Power
- Synchronize and export power to Grid
- In-built Anti-islanding facility in inverter **Site Selection**

General:

- Location – Lat and Long Flat roof / Inclined / Ground
- Area available for installation.
- With Geometry of the roof
- Battery & Inverter room
- Distance from PV to Battery room
- Any shading objects, like trees, other buildings

Mechanical Installation

- Site Preparation
- MMS Installation as per design
- Module Mounting on structure

Equipment Installation

- Battery Bank (in case of off grid)
- Inverter / PCU installation
- AJB / DCDB / ACDB installation

Safety during Installation

- Read installation instruction Manual before staring.
- Careful during installation in damp area
- Using Hand tools and power tools
- Shifting material from one place to other
- Lifting heavy materials like batteries
- Installation of Structure in High Wind
- Working at heights
- Working with electrical installation
- Working with high Voltage DC
- Working with Live Electrical systems

OPERATION:

Regular monitoring

- Fault / Alarm checking
- Daily generation monitoring
- Battery state of charge
- Distilled water level in the battery
- Regular electrical connection- tightness
- Inverter display

MAINTENANCE:

- Module cleaning regularly.
- Bird droppings and shadow should be avoided.
- Inspect, maintain and record on a regular schedule.
- Keep the INVERTER clean.
- Wear safety equipment whilst working on the system
- Check bolted connections of battery
- Apply petroleum jelly to battery terminals.
- Regularly inspect cable insulation

Ensure all insulating shrouds on the cell connectors remain in position.

Earthing

'THE EARTH', is considered to be at 'zero' potential. Earthing is the process of creating an alternative path for the flow of fault/ excessive currents safely into the ground. Potential of earth will be 'zero' volts only when it is properly earthed. The primary purpose of earthing is to reduce the risk of serious electric shock from current leaking into uninsulated metal parts (PV module mounting structures, Bodies of Equipment, Fourpole and two-pole structures etc.). Although most electrical systems have fuses or circuit breakers for protection against fault current, the human body may be fatally electrocuted by a current of less than 1A which is well below the point at which fuse or breaker will operate.

Earthing protection in electrical systems is to provide a Zero potential surface in and around and under the area where the electrical equipment is installed or erected, ensure safety of equipment and personnel & ascertain correct operation of protective devices during earth faults.

To achieve this objective the Non-current carrying parts of the electrical equipment is connected to the general mass of the earth which prevents the appearance of dangerous voltage on the enclosures and helps to provide safety to working staff and public.

Types of Earthing:

- Electrical system Earthing (Neutral Earthing)
- Equipment body Earthing (Safety Earthing)
- Earthing for lightning protection ○ Solid Earthing/ Resistance Earthing /Reactance Earthing / thro' Grounding Transformer ○ Earthing electrodes- M.S/ GI / Copper / Cast Iron ○ Shape of Electrodes – Rod/ Pipe / Plate

Methods of Electrical system earthing in practice

Solid or Direct Earthing

- Resistance Earthing
- Reactance Earthing
- Resonant or Peterson Coil Earthing
- Unearthed System

Earthing in SPV plants can be classified as:

- ➢ PV Array Earthing
- ➢ Control Room Equipment Earthing
- ➢ Switchyard Earthing

Maintenance of Earthing Systems involves following steps:

- ✓ Regular watering of Earthing pits
- ✓ Adding mixture of Bentonite and soft soil
- ✓ Checking of earth resistance periodically
- ✓ Cleaning of earth spikes
- ✓ Inspection of healthiness of SPDs

Lightning

Lightning is a dangerous phenomenon where the atmospheric potential rises above 10,000 KV which can damage equipment and personnel in its vicinity.

Methods of lightning protection: Lightning Arresters – ○ Lightning Rod type ○ Early Streamer Emission Type

- ✓ Grounding wire for Substations and Transmission lines Surge Arresters for LV networks (TVSS/SPD)