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TECHNICAL DUE DILIGENCE ANALYSIS OF SOLAR PHOTOVOLTAIC POWER PLANT

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ABSTRACT:
The growing demand for energy by human society, climate change, and depletion of conventional energy sources require a low-cost and safe, energy source. This demand can be satiated by utilizing renewable energy resources as they become very popular, while solar energy that comes from sun is one of the environmentally friendly sources of renewable energy solution to fulfill the power demand by utilizing the potency of the sun in an eco-friendly way. The Indian government has set a goal of installing over 100 Gigawatts SPV plants by 2022, to meet its energy demand. Consequently, the generic PV power plant installation and commissioning checklist for the validation of installation quality of photovoltaic system components and complete grid-connected PV system has been described for the assistance of project developers and clients. In Addition, a set of recommended strategies and assessments has been described and possibly that can be provide a measure of hardware and installation integrity, verify the safety, compliance with the applicable standards/codes and overall system performance. For the above study, a particular case of 50kW Solar PV plant was taken and the complete design and performance evaluation method was discussed in detail.
Keywords: Photovoltaic, inverter, field tests, PV array tests, anti-islanding, earthing, earth fault protection, open - circuit test, short circuit test.

1.0 Introduction:

India is on a growing trajectory in terms of population as well as development and energy is the engine & prime mover of the economic and social growth. But in fact, today more than 60% of electrical power is produced from coal-fired thermal plants rather than renewable sources. The country is rich in coal, but it is also rich in renewable energy resources such as solar, wind, hydro and bioenergy. Future economic growth highly depends on the long-term availability of the energy resources from affordable, accessible, and environmentally friendly energy sources [1]-[2]. To maintain the pace of development without losing sight of its environmental sustainability goals, the country has explored & implement various new capabilities such as smart grid, renewable energy technologies, etc., with its “Go Green” policy and undertake various initiatives by government of India (GOI) and repeated by their respective authorities. This double requirement focused on renewable energy sources such as wind and solar [3]-[4]. India’s plans for generation of electricity through renewable resources are ambitious and aggressive. The target of the 12th Five Year Plan is 36 Gigawatts energy and increasing the amount of energy production from renewable energy resources and increasing the share of renewable energy resources from the current 12% to 20% i.e., it increases 8% to 10 % every year to ensure its reliability and stability [5]-[6]. In response, Jawaharlal Nehru National Solar Mission (JNNSM, also known as the Government of India's "National Solar Mission") has suddenly increase the installed capacity of utility grid-connected solar power plants in India by a factor of five (from 20 Gigawatts to 100 Gigawatts) [7], As a result, India is swiftly running in constructing solar parks and many business groups are investing to harness the sun. But it led to unhealthy competition between the equipment suppliers, project developers, construction companies and service provider. Often this leads to compromises quality standards in project design, equipment selection & system balancing, installation, and even operation & maintenance practices. A huge number of grid connected SPV power plants are underperformance due to some known or many of unknown reasons. To improve or increase the performance of the existing and upcoming power plants, many developers and investors are desperate, but do not understand why they are underperforming. A survey conducted jointly by IIT Bombay and NISE Gurugram [8], considering different climatic zones in India reported that mostly the young PV modules (life less than 5 years) suffered from hot spots, discoloration of internal circuit, problems in back sheet and corrosion in grounding wire and hence over all degradation is higher. The study also reveals Roof-(rack)-mounted modules had a higher rate of degradation as compared to ground-mounted modules and recommended due diligence while selecting and procuring the material [9]. Another report [10] shows that the reasons for modules' failures are highly dependent on the environment in which the modules are installed and off course their design methodology. Many researchers reported that regular system monitoring can provide the system status indicative of potential degradation and any impending system failure [11-13]. It also helps in maintaining quality of the system and ensure the optimal performance from the system for its life span [11].

The Pareto Principle [13], sometimes known as the 80-20 rule, holds that, in most circumstances, 20% of the causes account for 80% of the results. Like this, an SPV project's installation phase accounts for 20% of the factors that influence 80% of the power generation during the project. The orientation and inclination of the installed module, in addition to the design and quality of the material chosen, are all elements in the installation phase accounts for the 20% of the factors. A well designed and installed grid-tied SPV system should ensure a fault-free operation for many years because once designed and then chosen material is installed, it cannot be changed in the later stages of the project.

Poorly designed SPV systems can result in the inverter being disconnected from the grid for a prolonged period because of SPV array is operating at voltages outside the inverter's operating range. Additionally, inaccurate PV module orientation and miscalculation of the effects of shading on the PV module surfaces result in a surface area catches less solar radiation and hence produces less energy. Due to these factors, the installers often give the plant owners unreasonably high energy yields from their SPV system. This is usually the result of the SPV system designer or consultant's ignorance or inaccurate calculation of SPV system losses. However, even though some of these losses are relatively simple to fix, others require for a careful analysis of the malfunction and testing of the system and its components.

The objective of this paper is to serve as a guide for conducting technical due diligence on the installation quality of an SPV power plant and confirming that the system has been installed in accordance with contract documents, complies with safety standards, is compliant with applicable laws, and meets the minimal standards required by the industry. It also discusses the performance evaluation measures used to assess the plant's productivity during its lifecycle.

2.0 Study Base:

The data accumulated to frame this study report is from a 50 kW (AC) SPV plant situated in university premises. It is equipped with 180 Nos. of polycrystalline modules each of 280 Watts capacity.

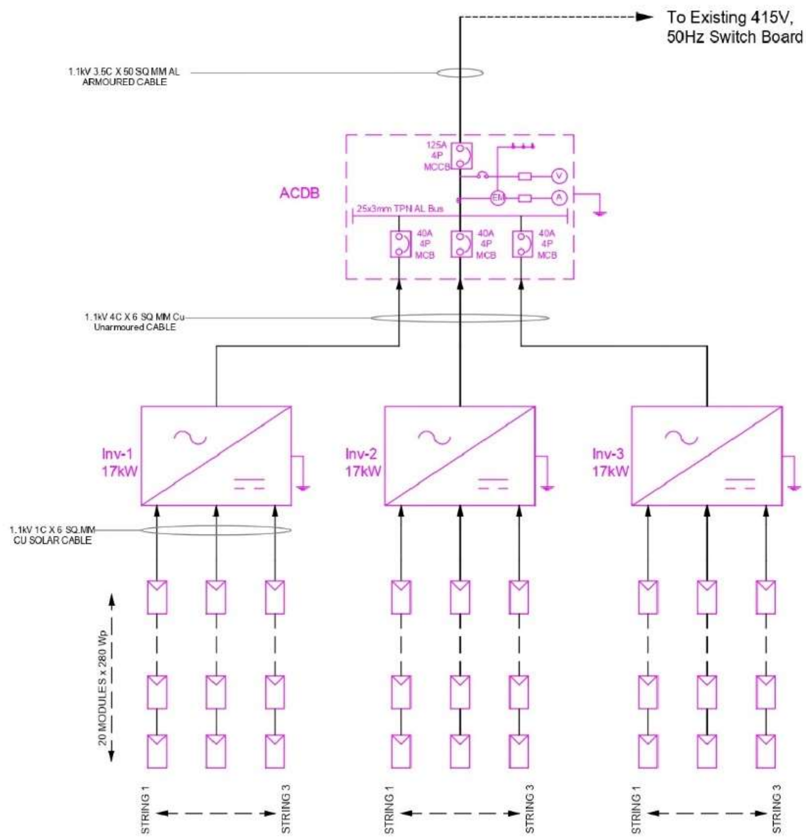


Fig 1: 50kW Solar PV Power Plant's Schematic layout

Data is recorded by SRRA installed instruments, and received at central data receiving & processing station (C-WET Chennai) via using GPRS mode of communication. The central station was equipped with hot-standby dual-redundant servers & each server have effective storage capacity of 2TB, while both servers was loaded with software to receive and store the data [38]. Weather monitoring equipment is essential for both solar DAS and SCADA. Environmental conditions such as solar irradiance, ambient temperature, wind speed and wind direction, can be measured by these monitoring equipment's, which are installed in the plant premises. According to a study by MNRE, the Murthal region has an average daily DNI of 4-7 kWh/m2/day, with an average ambient temperature of 30°C-40°C and almost 300 sunny days on the site [7]. Fig 1 shows the schematic layout of selected SPV system, while the electrical output calculation of solar module is given below:

Each module have 72 cells, which are organized in groups of four in series, with 18 cells running parallel in each group. There are also nine strings, each string contains 20 modules connected in series to produce a maximum output (Vmax & Imax) of 700 V and 8.00 A. Three strings join with an array junction box of 700V, 72A output and are connected to an appropriate capacity inverter.

V_{OC} = 43 V
I_{SC} = 8.68 A
V_{PM} = 35 V
I_{PM} = 8.00 A

20 modules in series (One String):
V_{OC} = 43 x 20 = 860V
I_{SC} = 8.68A
V_{PM} = 35 x 20 = 700V
I_{PM} = 8.00 A

3 Strings in parallel at DCDB:
V_{OC} = 860 V
I_{SC} = 8.68 x 3 = 26.04A
V_{PM} = 700 V
I_{PM} = 8.00 x 3 = 24A

3 DCDB (with all 3 strings and each string have 20 modules in series) in parallel at 3 string inverters and connected at ACDB

V_{OC} = 860 V
I_{SC} = 26.04 x 3 = 78.12A
V_{PM} = 700 V
I_{PM} = 24.00 x 3 = 72A

Power at STC: 700*72=50,400W

3.0 Objective of the study:

This study's principal objective is to meet all necessary requirements for achieving due diligence procedures while installing SPV power plants by various stakeholders. Process in this paper refers to a 50kW power plant project to simplify the explanation.

4.0 Procedure Followed:

A detailed checklist has been developed comprising the parameters, which need to be inspected for the installation quality of the SPV power plant. The checklists prepared are predicated on the general requirement. The installation checklist may vary depending on the type and characteristics of the installation: for stands alone, grid-connected, ground-mounted, or roof-mounted SPV systems.

5.0 Impediments to SPV Power Plant Performance:

The amount of the energy generated by an SPV system most commonly due to the Size of an SPV array, amount of irradiation (sunlight) falls on the system and overall system's efficiency. But SPV systems are subject to a variety of losses, including environmental factors, equipment's limitations, and manufacturing defects. These losses will include pollution (dust), partial & complete shading, manufacturer tolerance, ambient & SPV module temperature, voltage drop, inverter efficiency & inverter type used, SPV module orientation and tilt angle, SPV module degradation and type of solar cells utilized in SPV module, while other site-specific factors that affect array performance. Degradation of SPV modules in a system is also known by the gradual deterioration of the initial characteristics. This is caused by the systems operating and surrounded environmental conditions. A degraded module can still produce electricity from sunlight, even if it drops significantly from the value originally labeled [14], so production can't be completely stopped. However, this can become a serious problem or issue when the deterioration rate exceeds a predefined threshold level [15]. A median deterioration of 0.5% per year was found, when a study of about 2000 deterioration rates, derived from the measurements of individual modules or whole system [16]. A module is said to be degraded when its output drops below 80% of the initial power during its operating time, but a degraded module doesn't last the entire useful life [10]. The IEA-PVPS report on task 13 provides [9] an overview of the most important degradation observed in crystalline silicon modules, as shown in Figure 2.

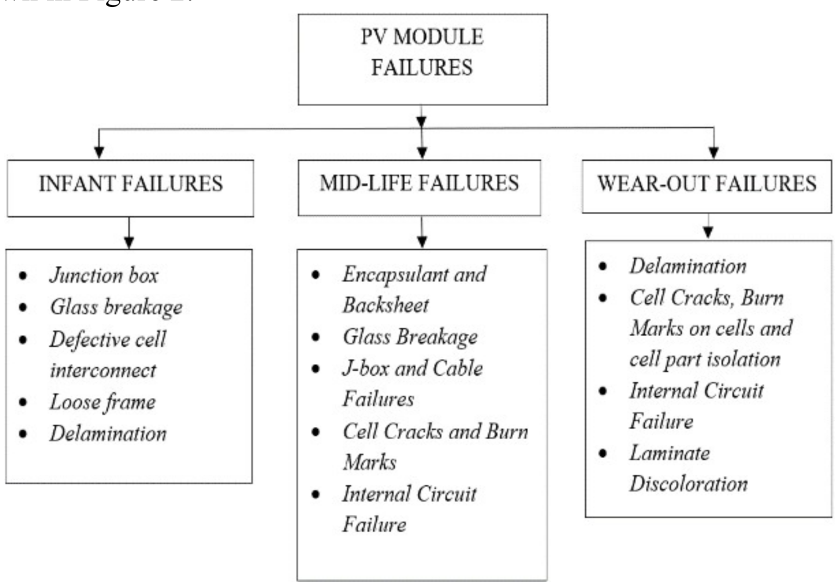


Fig 2: Significant causes of deterioration of SPV module [9].

But these aren't only the factors who determine the performance of a SPV system. Favorable sunlight that comes from sun and the best of equipment alone will not work well if the whole SPV system is not technically competently designed or installed. Some of the factors that contribute or responsible for the underperformance of a SPV power plants are: -

• Poor System Design.
• Poor Quality of Equipment and Materials used in SPV system.
• Under sizing of Equipment.
• Improper Installation and Integration of Equipment.

• Discrepancies in Various Parameters.
• Unstable Grid.
• Frequent Equipment Failure and Shutdown.
• Potential Induced Degradation (PID).
• Poor Operation & Maintenance orchestrating etc.

6.0 Technical Due Diligence:

Due diligence is an investigation into the viability of a potential project which occurs in some form before every investment or major decision [17-21] in case of SPV power plants, the system owners have a specific goal in mind to get maximum power output from available space and avoid extra investment and manufacturers want to offer power purchase agreement (PPA) as the market grows. We felt that encouraging sustainable industry expansion was something that regulators and financial managers ought to do. System integrators are responsible for helping to assure the security, quality, and productivity of installed systems. Then the SPV system designers develops a strategy to fulfill the above requirements and prepares a document that describes the desired system components and the calculated expected power output. This technical part is called technical due diligence (TDD) [18]. The TDD process begins with the project's inception (at the preliminary design stage) and continues throughout the facility's full lifespan. The classified tasks should be carried out at each step of the project to ensure that the design, construction, and training are appropriates for the project's needs and that the project execution is up to the owner's satisfaction.

Summary of Basic Technical due diligence tasks:

- Ensure that all necessary equipment and systems are installed in accordance with contractual agreements, manufacturer guidelines, and minimal requirements that are generally acknowledged.
- Verify that the installed system complies with safety requirements and statutory provisions.
- Analyzing the installation to make sure that it appears Alright.
- Make sure that the installation contractors do the satisfactory operational audits.
- Confirm and record that systems and equipment are functioning properly.
- Verify the completeness of the documents for on-site O&M.
- Verify that the operating personnel of the owner has received the necessary training.

7.0 Methodology of TDD preparation:

Due diligence is applicable in almost all cases where a detailed pre-contact analysis is required by law or by the business partners. Usually, the due diligence prepared for any purpose includes his three detailed analyses focusing on the legal, financial, and technical aspects of the asset [20]. In this way, due diligence not only for financial & legal consideration but additionally includes operational & strategic aspects also [21-22]. In the case of a building, the Roman rule “Caveat emptor” (let the buyer beware) is widespread nowadays, as per the accordance of this law “seller is not bound to disclose the defects of its property, but potential buyer should have full access to check its technical condition”. But in the case of the SPV power plant, the above law does not hold because it is a new technology, and the client has little or sometimes no knowledge about the technical know-how of the system's equipment. Therefore, onus lies on the project designer to incorporate the technical due diligence during the design phase while preparing the technical specification and including required documentation, checklists, test procedures, expected performance, basis of design, describing project timeline while preparing bid documents in case of large-scale projects.

For a small SPV system, Technical due diligence means having the installer step back and check the installation, tests the voltages at some points, make sure that everything starts up properly and check the system performance and validate the performance of the system. Conversely, for a large SPV system, there might be a dedicated TDD team with a multi-day and multi-layered TDD agenda, including follow–up activities and written reports. Whatever the scale, and whoever does the Technical due diligence, the basic task and the aim of the process remains same. To analyze TDD for the SPV plant the whole process is divided into three stages: Pre-installation, Installation, and post-installation.

7.1 Pre-Installation Stage:

Designing is the first and most important step of a SPV power plant. A major goal in designing a SPV system is to combine SPV modules in series and parallel combination, to form a SPV array, due to which increasing the current and voltage to achieve the higher power. In a PV module array, modules are connected in series (forming a module string) to get higher voltage, however strings are connected in parallel to get higher currents. The power output of an SPV system is increases in both series and parallel combination. As soon as the PV power requirements are higher than the individual power output, the formation of PV generators becomes necessary. Individual PV modules are available in power ranges from few watts to few hundred watts. Nowadays, PV arrays are currently being installed for residential application wherein the power requirements ranging from few hundreds of watts to several kilowatts (kW). Solar photovoltaic power plants are installed within power range from a few hundred kilowatts to several megawatt (MW).

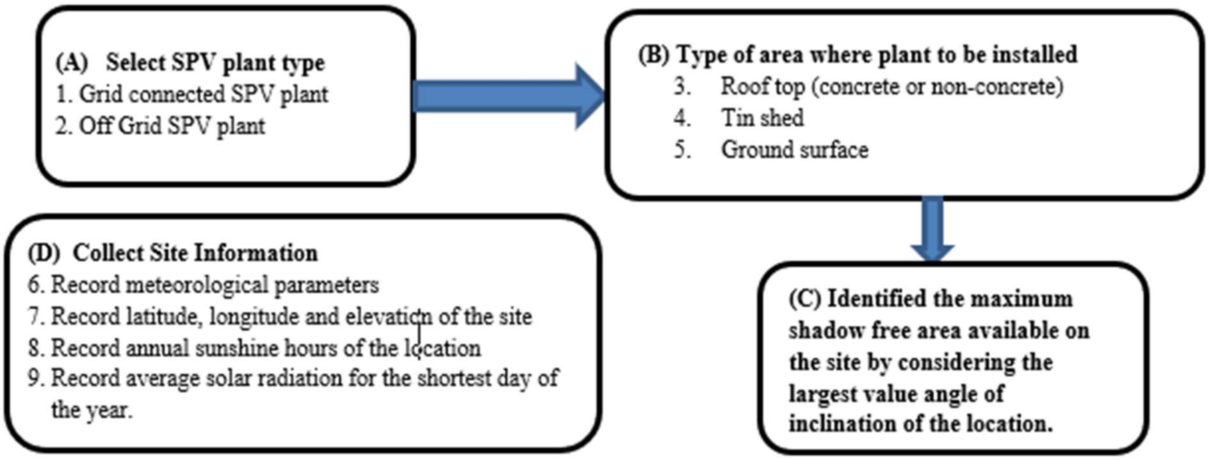
The number of PV modules connected in series and parallel can be estimated by the following procedure:

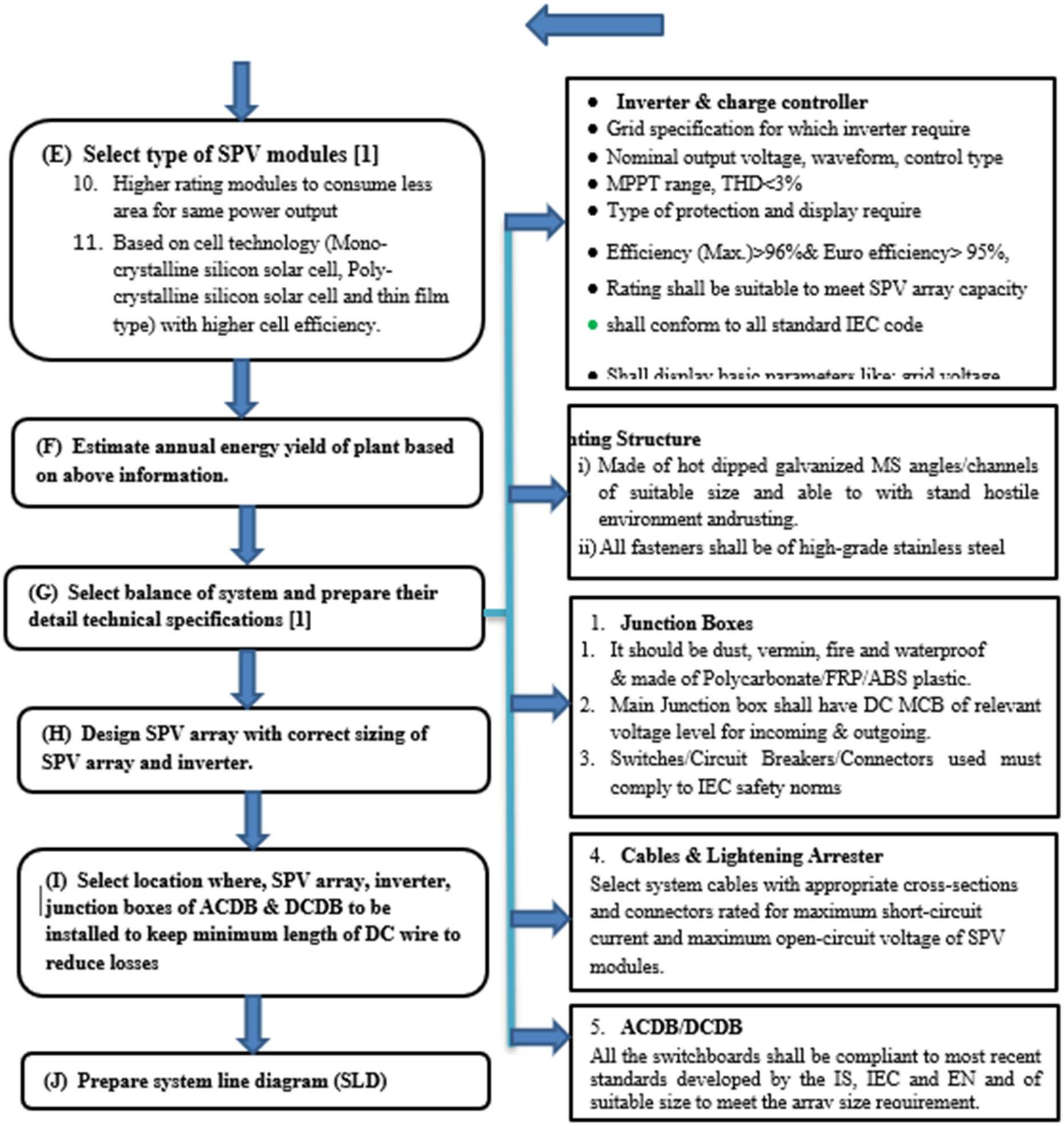
Step 1 - Power Requirement of SPV Panel Array: In SPV module array, the modules can be connected either in series or in parallel to achieve the maximum current (Imax), maximum voltage (Vmax) and consequently maximum power (Pmax) can be obtained by the following relation

$$(P_{max} = I_{max} \times V_{max})$$

Step 2 – Parameter for SPV Module that Connects to the Array: SPV modules are expected to operate under condition of maximum power point, so the current & voltage should be measured at maximum power point. While other PV modules parameters such as Voc, Isc and Pm can also be recorded to get the maximum output power of any SPV system.

Flow Chart 1 - Flow Chart for Pre-Installation Stage.





Step 3 - Estimation of The Number of SPV Modules Connected in Series/Parallel: To determine the maximum number of SPV modules connected in series, the total number of array voltage is divided by the voltage of the individual PV module. However, to determine the maximum number of PV modules connected in parallel, total PV array current is divided by the current of the individual PV module. All these parameters should be recorded under the condition of maximum power point. The values of Ns (Number of PV modules in series) and Np (Number of PV modules in parallel) must be integers. If the calculated ratio is not an integer, the next highest integer value should be chosen.

Step 4 - Estimating the total Power of the Series SPV Module Array: The total power of an SPV array is the summation of power of all SPV modules connected to the array. Series connection sums SPV modules voltage and power, while parallel connection sums SPV modules current and power. Therefore, before designing the number of SPV modules connected in series or parallel, ensure the maximum power of an SPV array we need to design.

7.2 Installation Stage:

After finalizing the design, need to devise the strategy to install the SPV system. Project developers are advised to employ skilled or semi-skilled persons for this purpose, specifically, an electrician should be an experienced one. Detailed discussions of the installation of various components of the SPV plant are discussed in sections to be followed.

7.2.1 Structures:

For installation of SPV modules the module mounting structure should be composed of galvanized iron, aluminium, or both. The iron structures should have galvanization thickness of the order of 100-120 microns to protect the structure from corrosion and the support structure design and foundation of module mounting structure should be designed to have enough mechanical strength to sustain in high wind speed. The rooftop or façade where SPV systems are being installed should have enough strength to bear the dead weight of the structure and module. The structure should be grouted at locations as per drawing of SPV array layout and devise a strategy to avoid seepage through the roof if structures require penetrating the roof by utilizing the concrete mix of M-20/M-25 grade (1:1.5:3) for filling pedestal and earth pit chambers and apply waterproofing compound in the base and side of the pit. Since plant life is 25 years so all fasteners shall be of stainless steel of grade SS 304 or higher grade. In the case of a non-penetrating type, use ballasted footing mounts with concrete or steel bases that can stand as individual structures.

7.2.2 Modules Placing:

Solar modules are very sensitive to the reduction of solar radiation due to shade. Shadowing can be caused by hard obstacles (walls, trees, simple pillars, etc.) or conditions (overcast skies, heavy smoke or dust), So estimation of sun radiation inclined on tilted surface & shading on panel, i.e., placement or installation of the SPV modules is a very important factor to achieving the maximum performance of the selected SPV system, because it is mandatory to identify the effect of energy production, when you design a solar plant. Inclined surfaces receive more sun radiation in comparison of horizontal surface, because horizontal surface receive a direct and a diffuse component of radiation, while the inclined plane receive direct, diffuse and ground reflection. The radiation reflected from ground is the product of horizontal solar radiation, the ground reflectance, and the visibility factor. Therefore, G_T is the radiation on the inclined plane can be expressed formally as,

$$G_T = G_b R_b + F_S G_d + F_g \rho_g G \quad \text{(Eqn-7.1)}$$

Where - ρ_g is the ground reflectance (typically 0.2/0.7 for snow-covered ground, 0.9 for concrete, 0.35 for new typical gray concrete and 0.7 for new typical white concrete), R_b is the instantaneous tilt factor for direct radiation. It is defined as the ratio of the direct radiation to the surface under consideration and the direct radiation to the horizontal surface. [32].

Where, $R_b = G_{bT}/G_b = \cos\theta / \cos\theta_Z$ (Eqn-7.2)

Fs and Fg are the appropriate factors for sky diffuse and ground reflected components of radiation.

Where, $Fs = (1+\cos\beta)/2$ (Eqn-7.3)

$Fg = (1-\cos\beta)/2$ (Eqn-7.4)

While Shading is most important factor to achieve the pre-defined or assumed power from a plant, so when you design a solar system then need to understand a shadow how long will be, so that you can properly manage or plan for row spacing between solar modules. Shadow analysis is one of the most important steps to consider during the design and analysis phase of SPV system design. The sun position is obtained from a time function, latitude and longitude and then used to calculate the size and position of the shaded area. The altitude "α" of the Sun as a function of latitude "Ø", solar declination "δ" and angle "ω" subtended by the sun at a particular hour is given by-

$\sin\alpha = \sin\text{Ø} \sin\delta + \cos\text{Ø} \cos\delta \cos\omega$ (Eqn-7.5)

The angle "θ" from the direction of the sun's rays on the inclined surface of solar cell is expressed by the following equation-

$\cos\theta = \cos\delta \cos\omega (\cos\gamma \sin\beta \sin\text{Ø} + \cos\text{Ø} \cos\beta) + \sin\delta (\sin\text{Ø} \cos\beta - \cos\gamma \cos\text{Ø} \cos\beta) + \sin\gamma \sin\beta \cos\delta \sin\omega$ (Eqn-7.6)

For south-facing surface, "$\gamma = 0$" and equation (12), Where "γ = azimuth angle" and "β = tilt of the surface azimuth".

$\cos\theta = \sin(\text{Ø} - \beta) \sin\delta + \cos(\text{Ø} - \beta) \cos\delta \cos\omega$ (Eqn-7.7)

Some of the important factors to consider when placing the SPV module are:

- Installation of solar SPV panels should only be done by a licensed professional, contractors or electrician. The installer is always at-risk during installation due to electric shock because modules connected in series have a high DC voltage which can be resulted in a lethal shock if he had contact with electrically active terminals of modules. Therefore, the installer should avoid wearing metallic jewelry during installation and keep the front surface of the SPV module, covered with a dense and opaque material such as cardboard box and work under dry conditions and insulated tools. Severe cell-level micro-cracks can occur when a heavy object such as a work tool is dropped on the module, or additional localized pressure is applied to the module by a thumb or foot.
- Identify areas not shaded by obstacles like buildings and trees categorically, from 9:00 am to 3:00 pm.
- Use modules of the same specifications and cell size in the same array structure of modules having series and parallel combinations.
- Modules must be securely attached to the structure to withstand all expected loads, including wind and snow loads.
- Do not drill additional holes in the SPV module structure as the frames have built-in mounting holes for easy & proper installation.

- Keep proper orientation and tilt angle of the modules to get the required performance round the year.
- Install modules facing due south and north in the northern and southern hemispheres, respectively. If a particular site has constraints of due south and due north facing of modules, then consider the south-east or southwest direction that module faces in the northern hemisphere and vice versa.
- SPV modules should be installed with junction box at top, to minimize the water ingress.
- Nuts, bolts, and other fastening materials should be made of suitable materials to protect the module frame from corrosion.
- Maintain sufficient spacing between the SPV module frame & the mounting surface to allow ambient air to circulate behind the module and disperse any condensation or moisture.
- Do not seal the mounting surface of an SPV module with sealant, because it prevents air from circulating under the module consequently rise in module surface temperature.
- Keep adequate clearance (atleast10 mm) between the adjacent modules to accommodate the thermal expansion of the frames.

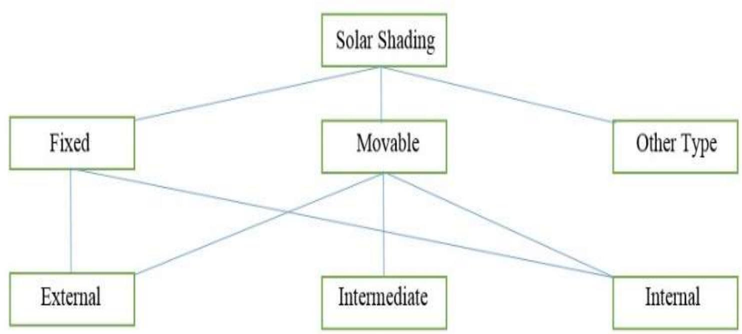


Fig 3: Solar shading systems for buildings: a possible classification.

Temporary shadow include shadow caused by clouds, bird droppings, dirt & leaves, while shadows from buildings are critical because the building shadows are direct. The best example for this type of shading includes chimneys, lighting conductors, dish antennas, roof and façade overhangs and offset building structures etc. Because this type of direct shade caused significant energy as PV solar panels cannot capture the light when they are in close proximity to the shading object. Therefore, shadow analysis is most important parameter, which perform during the site survey to evaluate eventual and potential obstacles such as trees and buildings that may block the sunlight and provide customers a realistic expectation of the energy that can be generated by the PV system [33].

7.2.3 Inverter:

The project developer has already selected the inverter as per the project requirement during the pre-installation stage, section7.1. The inverter is an important component of the SPV plant as energy produced by the plant depends on its efficiency based on Maximum PowerPoint Tracking (MPPT) control with IGBT-based design. It should have a display unit to show its parameters along with the parameters of the SPV array to monitor the plant's performance and to diagnose the problem, if any. The inverter shall be compatible with On-Grid Connected Mode (Synchronization with grid) and must comply with the latest IEEE 1547 standard for interfacing with the grid as well as the degree of protection against environmental conditions should be high as per IEC 529. Selected inverter must have test certificates/reports from either NABL/ IEC Accredited Testing Laboratories or any nationally recognized test centers. To obtain optimum power from the selected inverter of the desired specification the following steps should be taken while installing the inverter:

- Installed under a shed on a solid wall in the vertical direction and hazard-free area.
- Mounting structure should be strong enough to bear the dead weight of inverter and for the discharge of electric potential whole assembly must be connected to ground stud.
- Install the selected inverter with a minimal clearance from the wall and ceilings, or other devices in the vicinity for necessary heat dissipation of the device and to provide safe excess to the equipment for installation and service activities.
- Before connecting the SPV string, connect the selected inverter to the power grid and with ground stud and ensure that the device is safely connected to the protective earth conductor.
- Connect the SPV strings to the selected inverter only when the inverter is in the de-energized state. Live SPV strings can be under lethal voltages.

7.2.4 Wiring:

- All wiring must be done by qualified & licensed professional engineer/electrician in accordance with applicable electrical codes and must be protected to ensure personal safety and prevent damage.
- Connect a wire from the positive terminal of one module to the negative terminal of the next module. All modules connected in series must be the same model number and/or type to ensure they are identical in capacity.
- To increase current or voltage, connect modules in parallel or series, respectively utilizing a connection box.
- An appropriately rated and certified overcurrent device (fuse or circuit breaker) must be connected in series with each module or string of modules when reverse current scan exceeds the maximum protective fuse rating that is written on the back side of the module.
- The maximum protective fuse rating, which is displayed on the back side of the panel, shall not be exceeded by the connected overcurrent device rating. Match the polarity of the connected cable and terminals, otherwise the module may be damaged.
- Do not connect the modules with high current source of reverse polarity, such as a battery, which will destroy the bypass diodes and render the module operative, because the bypass diodes are not user replaceable.
- The system installer must choose according to the appliance (installation and wiring method) and by national regulations, the cable material.

7.2.5 Grounding of SPV systems:

Accumulation of static charge due to lightning may cause a sudden failure in SPV systems and a well-designed grounding system avail to drain off accumulated charge and reduces shock hazard from higher AC/DC voltage. In the case of the ground the type of earth (dry or moist) and ambient temperature too high or too low play a vital role in designing a safe and effective grounding system. For a safe and cost-effective grounding system, consider a foundation supporting metal structures of the SPV array as auxiliary ground electrodes. Prepare the foundations with a huge cross-sectional area consisting of metal components like, concrete foundation with concrete coated piles and steel reinforcing bars. These foundations help drain the ground fault current to earth and, consequently, reduces the ground potential rise and the arising touch and step voltages within the installation in case of a ground fault. To install a proper grounding system following steps should be followed:

- Estimate the soil resistivity, maximum allowable touch, grid current and step voltages, before designing the ground system.
- For a roof-mounted SPV system with concrete-encased foundation, ground resistivity is not a critical parameter.
- Grounding depth and numbers of conductor required are decided based on the environment is dry or humid and the ground is rocky or sandy.
- All module frames and mounting structures must be suitably grounded, in accordance with the respective applicable national electrical codes.
- Pre-drilled earthing holes in the module frames should be used only for grounding purposes, not for mounting purposes.
- To assure good electrical contact, the ground wire must be properly connected to the SPV module frame utilizing connectors recommended by an authorized national agency.
- Anodization layer on module frames should be pierced by grounding hardware for efficacious grounding connection.

7.3 Post Installation:

Once the installation process is over the SPV professionals and system owners need to understand the basics of the commissioning, operation & maintenance, and monitoring of SPV systems to prolong the operation of SPV systems and assure expected energy production for entire life span of the project. Before, the commissioning installer should ensure that installations of all equipment are as per design documentation and compliance with all local and national code met. For safety, purpose cleans the job site and post all necessary warning signs and labels.

7.3.1 Commissioning:

The process of plugging the SPV system into the grid after completion of the installation as discussed in section 7.2.1 to 7.2.5 and inspection thereof, to transfer energy is referred to as commissioning of the system. This process to ensure that the SPV system is safe, reliable, meets design goals, functions, and produces the energy that estimated during the pre-installation stage.

Certain general guidelines should be followed for commissioning an SPV systems, depending on the size of the selected SPV system and complexity of the design as shown in fig.4.

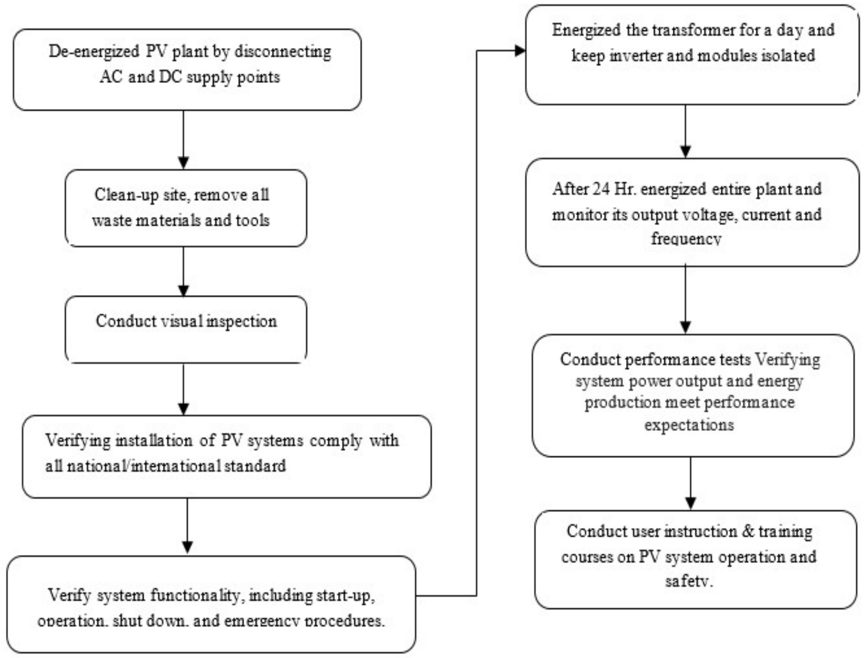


Fig 4:- The crucial steps of a SPV system commissioning procedure

First, connect the selected inverter to the main power grid via ACDB, then connect the SPV strings to the selected inverter via DCDB. While connecting the selected inverter and SPV strings, first disconnect the power connection and be sure that the SPV system is powered off and forfend the respective circuit breaker to prevent it from switch on again. Before connecting the SPV strings to the selected inverter, an insulation measurement is carried out, automatically checks the isolation of the system every time when system is turning on. If the insulation is defective, the connected inverter will automatically turn off.

7.3.2 Operation and Maintenance

On the application of the Pareto 80-20 rule [13], it is evident that the work carried out during the pre-installation stage, installation stage, and commissioning stage, as discussed in section 7.1, 7.2, and 7.3.1 contribute 20% of the total efforts applied on the plant and remaining 80% of work will be done in the form of maintenance and operation for 25 years life cycle of the plant. Further, initially performed 20% of the work has a deep impact on the performance of the SPV plant, and maintenance & operation is performed during plant life cycle has mere aim to keep the performance of the plant as it was obtained at the time of commissioning. Consequently, the project developer after commissioning the plant must handover the plant site to the client along with all drawings (System single line diagram, SPV array layout, Routing diagram of cables and wire, Datasheets, and user manuals of the SPV Panels and solar grid inverter, Module certification with BOM list utilized in a certified SPV module, Data Sheets and compliance information of – inverter, cables and all other components utilized in SPV Plant, Sizing design calculations of cables, fuses, MCCB's, disconnector unit (AC&DC) size, Earthing line diagram with specifications and compliance information of all components and material used), and a system operation and maintenance manual to the client also, explain the system description with working principles to the client.

- Check the tightness of all the fastener, alignment of modules mounted on the structure, and galvanized layer structure
- Do not raise any temporary structure near SPV module installation during daytime because shadow cast by the structure result into a hot spot & burn on the cell or module
- Do not step or walk on the modules, it may develop the crack in encapsulation, consequently, decreases power generation capacity
- Periodic cleaning of SPV modules as per vendor's instruction manual, either during early morning or late evening hours to remove dust and bird poo from module surface
- Don’t expose the SPV modules to concentrated solar radiations focused by devices like, mirrors, lenses, or any other means.
- Periodically check connections of all cable terminals.
- Ensure the ventilation and cleanliness surroundings the inverter and cool inverter through the natural convection, only.
- Periodically check working condition of Inverter’s exhaust fan and clean its front air filters and fins by utilizing blowers
- Earthing check carried out once a year for any loose connection or damage of earthing strip also periodically pour water at earthing area to make it effective.

7.3.3 Monitoring Standards and Policies

With the advancement of the solar photovoltaic (SPV) system, the level of energy production from the associated SPV systems need to be properly measured and validated on regular interval.
International standard parameter for measurements and monitoring of SPV system, IEC 61724 (International Electrotechnical Commission) provide guidelines for analyzing and monitoring the performance of SPV system. However, IEC 61724 series [23] is now used instead of the IEC 61724 standards. The IEC 61724 consists of three separate parts, while each part with a specific purpose as opposed to the former one. First part of IEC61724-1 is pronounced as monitoring, the second part IEC61724-2 is called as capacity evaluation method and the third one IEC 61724-3 pronounced as energy evaluation method. The new standard provides guidance on what measurements can be done for each category of the system. A monitoring class is divided into three parts. Class ‘A’ is the highest accuracy, class ‘C’ is the most basic one and class ‘B’ is a medium accuracy level of class. Table 1 provides a list of parameters that should be monitored in the SPV system.

Table 1: Basic parameters required for monitoring.

Ann. For. Res. 65(1): 7263-7293, 2022
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SPV System Type	**Parameters**		
	Metrological	**Electrical**	
Grid Connected	i) Total Irradiance-Plane Array ii) Ambient Temperature iii) Module Temperature iv) Wind Speed v) Wind Direction vi) Humidity	SPV Array: i) Output Voltage ii) Output current iii) Output Power iv) Output energy	Utility Grid : 1.Grid Voltage 2.Current to utility grid 3.Current from utility grid 4.Power to utility grid 5.Power from utility grid 6.Utility grid impedance
Stand Alone	i) Total Irradiance-Plane Array ii) Ambient Temperature iii) Module Temperature iv) Wind Speed v) Wind Direction vi) Humidity	SPV Array: i) Output Voltage ii) Output current iii) Output Power iv) Output energy	Load: 1.Output Voltage 2.Output current 3.Output power

Table 2: Check List for General and Visual Inspection of whole plant.

A	**General**
1	Report of hazard analysis and risk assessment done at the site during the conception stage and related actions need to be taken up.
2	Array frame correctly fixed on MMS and stable.
3	All cable entries are weatherproof and taken care for seepage of water, moisture and insects.
4	SPV module location, perimeter, gate, control room & switch yard, plant internal road location as per approved layout drawing.
5	Components comply with standards and are selected as per design & not damaged.
6	Equipment’s, cables & other accessories are connected as per approved drawing.
7	Equipment & protective measures are appropriate to external influence.
8	All cables are selected for approved designs for ampacity & voltage drop.
9	Laid Conductors are in safe location or protected from mechanical damage.
10	Danger boards displaying dos and don’ts instruction chart for recovering a person from Electric Shock, fire extinguishers details and operations and value of voltage etc.
11	A board with a list of O&M personnel with names, qualification and job responsibility.
12	Inverters, charge controllers or other equipment are properly calibrated and programmed.
B	**DC Side**
1	Adequate physical separation of AC, DC & communication cables and using UV proof conduit. Yes, but conducting used not UV proof- mentioned separately in other findings
2	All DC components are sized for rated operation at maximum DC system voltage
3	All DC cables are meant for SPV applications and as per design documents
4	SPV string fuse are available in the combiner boxes
C	**Protection against Electric Shock**
1	SPV frame grounding correctly integrated with existing installation
2	All Live parts are isolated and protected by the barriers or enclosure, placed out of reach.
3	Lightening arrester is available and properly grounded to drain the sudden voltage surge
4	Structural and electrical components are properly installed and secured
D	**AC Side**
1	Inverter protection setting as per local regulation (labelling & identification mark)
2	Grid tested for anti-islanding and SPV plant is in sync with the grid
E	**Module Mounting Structure & Civil Work**

1	Mounting structure and jointing materials as per approved drawing Structures are correctly fixed at specific tilt and orientation as per design document
2	Foundation dimensions as per approved drawing Switch yard civil foundation as per approved drawing
3	The material for structure has corrosion proof coating (check for availability of factory test certificate)
4	Structures are designed based on the maximum wind load of the location (check for availability of structure engineer certificate)
5	No rust (for steel) or discoloration (for aluminium) found in the structure materials (e.g. frame, clamp, bolt and nuts, etc.)
6	Water drainage is available.

8.0 Performance Evaluation of Plant:

The SPV systems performance depends on several factors, including the design of the solar SPV power plant and other environmental parameters, thus not all the insolation collected is converted to energy. The performance assessments represent a yardstick for an effective delivery of SPV-systems, according to the field's experts. Plant load factor (PLF) also known as capacity utilizing factor (CUF), and Performance Ratio (PR) are the two main measures used to evaluate the performance of SPV plants worldwide.

However, the location, weather, ambient temperature, and solar irradiations received annually at location, determine how effectively the SPV plant performs. India is a subtropical country with a wide range of temperatures, from extremely hot desert parts to high altitude regions with extremely cold weather, like northern Europe. This is due to India's unique geographic location. Out of India's six climate zones the first five are segmented into, Hot and dry, Warm and wet, temperate, Cold and Sunny, and Cold and Cloudy. Each of the five zones is assigned to a specific area of the country where the specified circumstances have persisted for more than 6 months. The sixth one, however, is referred to be a composite zone because none of the conditions of five climatic zones were met. The composite zone, in contrast to the other five zones, experiences an extremely hot and dry summer, followed by a humid season with monsoon rains. It progressively gets more pleasant in the autumn after the monsoon leaves, and then there is a brief winter with both cloudy and sunny days. There is a pleasant but brief spring season before the summer arrives. In the composite zone, all mentioned seasons last for two to four months.

8.1 Average Ambient Temperature

Since the SPV plant under investigation is situated in a composite zone, where variations in seasons have a great effect on both the ambient temperature and the magnitude of solar radiations received by the earth's surface. Therefore, since seasonal fluctuations are rapid and unexpected in this zone, so collecting the ambient temperature and sun irradiation data for one meteorological cycle to predict their impact on the performance of the SPV plant is insufficient.

The average temperature for the full five-year meteorological cycle from 2017 to 2021, as shown in Fig 6. In this region, January and December are regarded as being extremely cold months, yet in the year 2020, January had the lowest average temperature and December had the highest, compared to earlier years. The average ambient temperature in the year continued to decline from January to April before reaching its peak in May. In contrast, after the month of April in the year 2021, the average temperature recorded for the following months is at its lowest level when compared to other years during the same months.

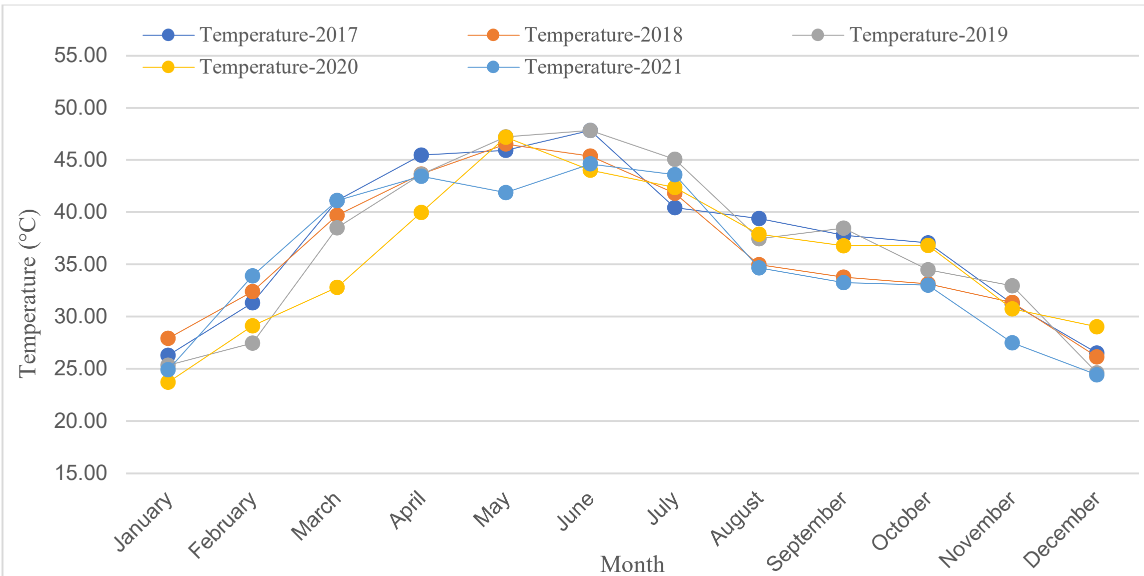

Fig 6. Ambient temperature for complete five meteorological Cycles.

Further data comparison, reveals that average ambient temperatures changed by 8.7% in June and 30.4% in March, as shown in Fig 7. The average yearly percentage variation in ambient temperature is 16%, which is a sizable amount.

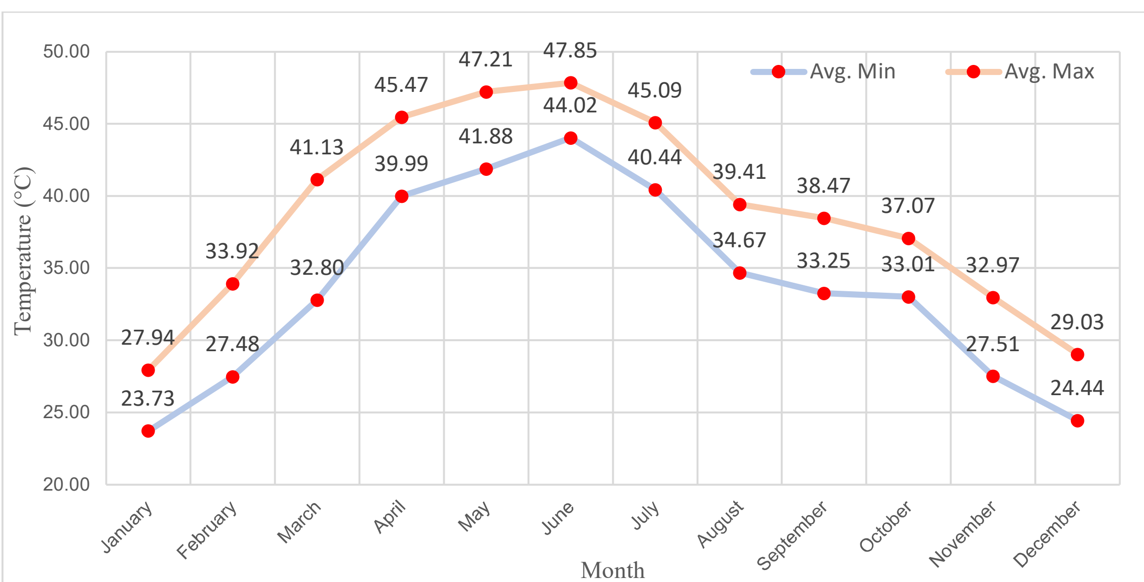

Fig 7. Average Minimum & Maximum Ambient temperature for complete five meteorological Cycles.

8.2 Solar Radiations

Sun light is essential for solar power generation and can only be available during daytime. Sun light is one of the most essential parameters for power generation from SPV systems. Sudden drops or rise in the power generation can affect the health of transmission and power infrastructure. As the solar radiation varies or solar isolation changes, there are fluctuations in the generated power by the photovoltaic system.

Energy production of PV system is directly depending on solar radiation; however, sun radiation varies with latitude & longitude of location and climatic conditions prevail. In India, the annual global radiation fluctuates between about 1600 and 2200 kWh/m2, comparable to the radiation received in the tropical & sub-tropical regions. India has six climatic zones, while Northern part of the comprising the regions like, Rajasthan, New Delhi, and Haryana, the parts of Andhra Pradesh, Northern Gujarat, Maharashtra, parts of the Ladakh region and Madhya Pradesh receive significant amounts of radiation as comparison to the remaining part of the country [37].

Fig. 8 shows the solar radiations for five meteorological cycles from 2017 to 2021. The magnitude of the radiations received by the earth's surface in the composite zone varies between 2 and 4 kWh/m2/day in the months of January, February, November, and December, and it reaches 6 kWh/m2/day in the months of April, May, and June, according to the graph. The remaining months, on the other hand, have radiation levels between 4 and 6 kWh/m2/day.

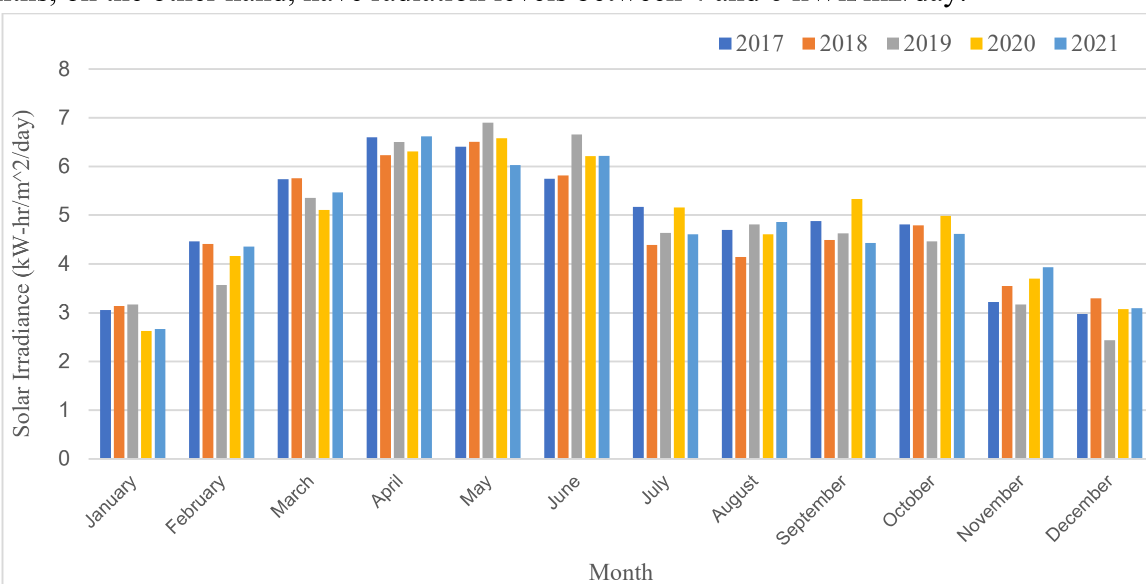

Fig 8. Average Solar Radiation per day for complete five meteorological Cycles.

For further insight, the average minimum and maximum solar radiation values for each month were computed using the five-year radiation value and depicted in Fig 9. According to the figure, the region receives as little as 2.43 kWh/m2/day in December and as much as 6.90 kWh/m2/day in May. Further data comparison reveals that the variation in solar radiation received on the earth's surface in the study area varies the least in the month of April, at 6.26%, and most in the month of

December, when this region experiences extremely cold weather and the sun is at a declination angle of -23.4^0. The yearly average variation in solar radiation is 16.75%, which is a substantial amount.

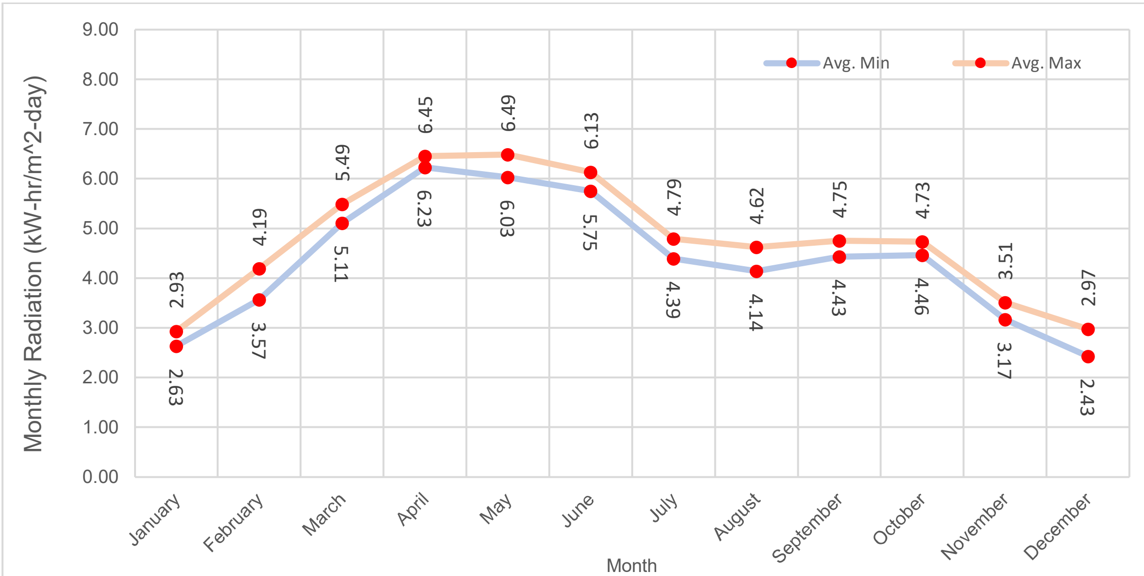

Fig 9. Average Minimum & Maximum Monthly Solar radiation for complete five meteorological Cycles.

The average minimum value of ambient temperature and solar radiation values plotted in Fig 7 & 9, respectively are replotted together in Fig 10 for further understanding. The threads on the graph represent for the ambient temperature, while the bars show solar radiation versus the months of the year. As can be seen from Fig. 10 the ambient temperature and solar radiation vary according to the region's climatic conditions. While ambient temperature and solar radiation are at their lowest during the coldest months of December and January when the sun is at its farthest from location, respectively, these values are higher in May and June, when the sun is at its closest to the region. It can be concluded from above discussion that the composite region has highly variable and unpredictable and hence energy production computed for the solar plant located in the composite zone is found to be variable monthly as well as yearly.

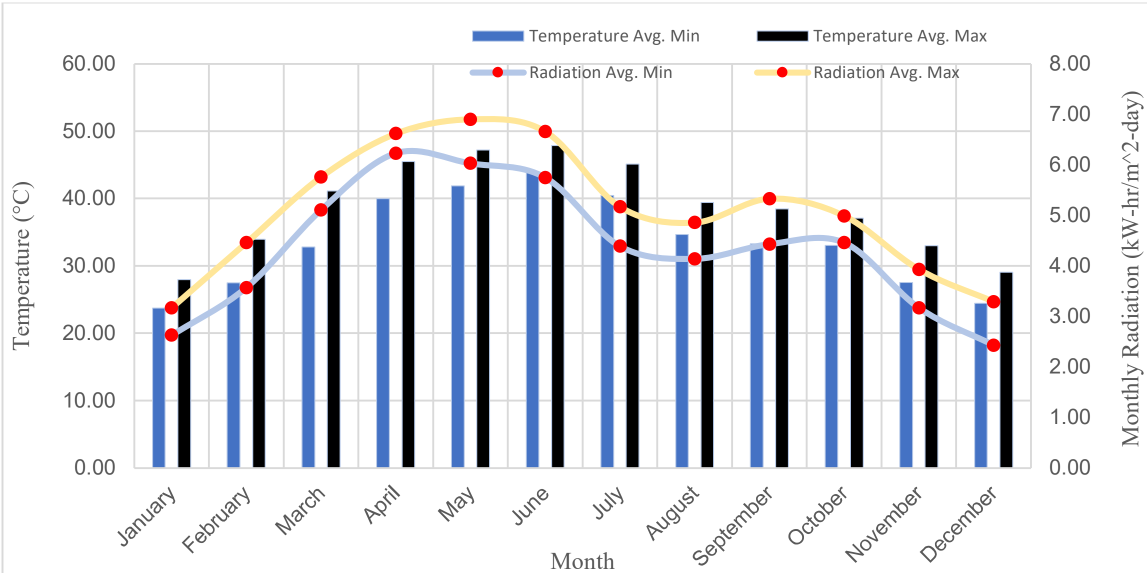

Fig 10. Average Minimum & Maximum Monthly Solar radiation & Ambient Temperature for complete five meteorological Cycles.

Therefore, the seasonal fluctuations are unexpected, while potential is very high due to its geographical location & climatic zone. This potential can be utilized in PV cells, solar cooker system, solar water heater, solar lighting system, desalination systems, solar heat collectors, building heating system etc.

8.3 Performance Ratio:

Production and performance of the grid connected SPV system are frequently assessed using the Performance Ratio (PR), and occasionally using the annual energy yield [28] which further considers the rate of degradation of the plant during the guaranteed term. The decline in the plant's performance ratio over time reflects the degeneration of the PV modules, which are losing their ability to produce usable power from falling solar radiation.

Performance ratio (PR) is defined as the ratio of final yield to base or assumed reference yield [24]. The reference yield is the expected yield from the system considering the incident light energy and the rated efficiency of the module, whereas the final yield is the total yield after various losses have occurred i.e. generated DC power finally converted in to AC power. Therefore, PR represents the relationship between the actual energy output of an SPV system and its theoretical energy outputs, which is available to supply the grid after deducting the energy loss (e.g., due to thermal losses and conduction losses), that indicates the percentage of energy consumption for operation. The PR value is closer to 100%, it means the systems works more efficiently [20]. However, in real practice, 100% PR value can't be achieved, as always, some unavoidable losses occur during the operation of the SPV system (for e.g., Heat loss due to overheating of the SPV modules). However, according the SMA solar technologies, a German leading solar inverter manufacture in the solar Industry, high capacity SPV modules can achieve up to 80% PR [21-28].

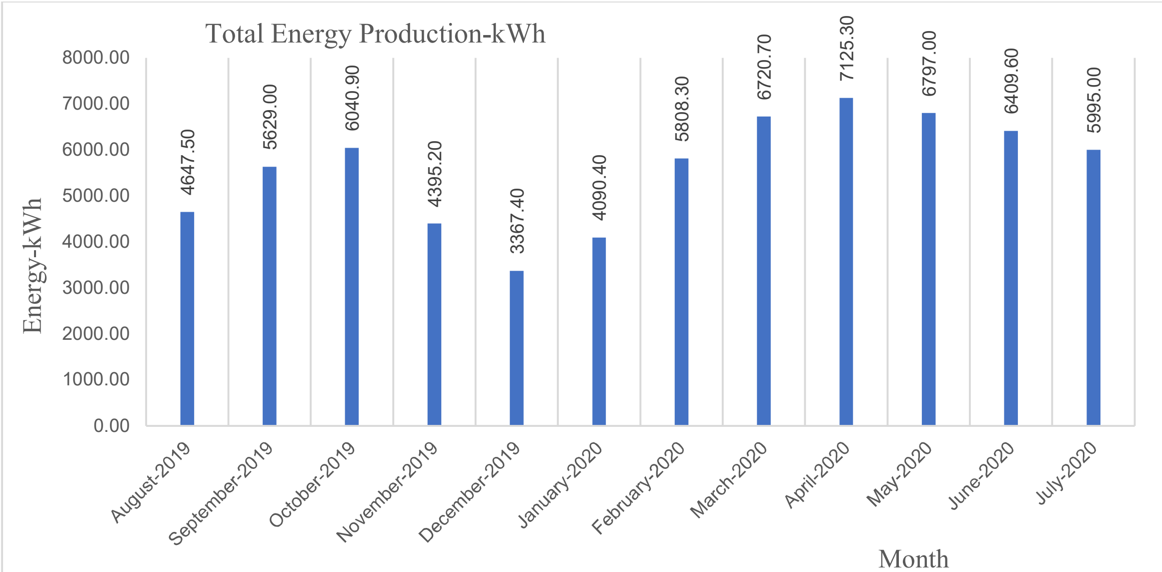

Fig 11. Total Energy Production for 50kW SPV system.

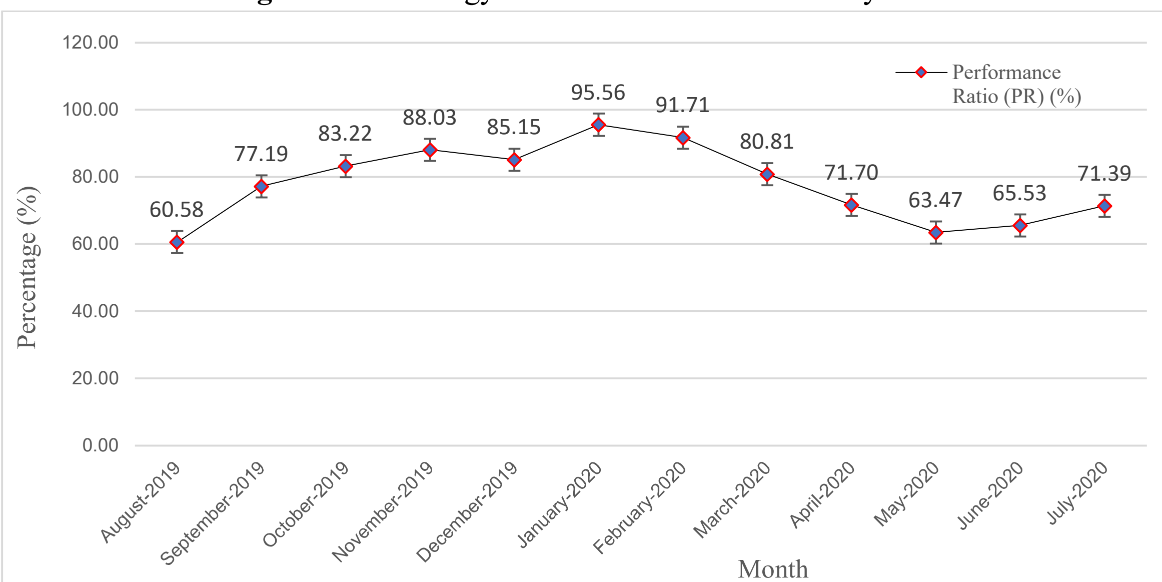

Fig 12. Performance ratio for 50kW SPV system.

For a single meteorological cycle, the 50kW solar photovoltaic power plant's total monthly energy output in kilowatt-hours is recorded and depicted in Fig. 11. A total of 7125.30 kWh and 3367.40 kWh of energy were produced at their highest and lowest points, respectively, in the months of April and December. The plant's energy production is linked with the ambient temperature and solar radiation. A likely explanation for why energy production is higher in April than in May and June is that the month has a relatively low ambient temperature. In contrast, the solar radiation measured in December is at its lowest and results in low energy production.

$$PR = \frac{Energy\ Measured\ (kWh)}{(Irradiance\ on\ panel\ \left(\frac{kWh}{m2}\right)\ x\ Active\ area\ of panel\ (m2)\ x\ Panel\ efficiency)}$$

The plant's performance ratio was computed and shown in Fig. 12. According to the calculated PR values, the plant's performance between 60% and 80% from April through September and significantly above 80% for the remaining months is an indicator of the plant's overall health. PR is dependent on irradiance, the ideal inclination angle, air temperature, design parameters, module quality and type, chosen inverter efficiency, etc. is grouped under environmental and technical factors and depicted in Fig. 13,

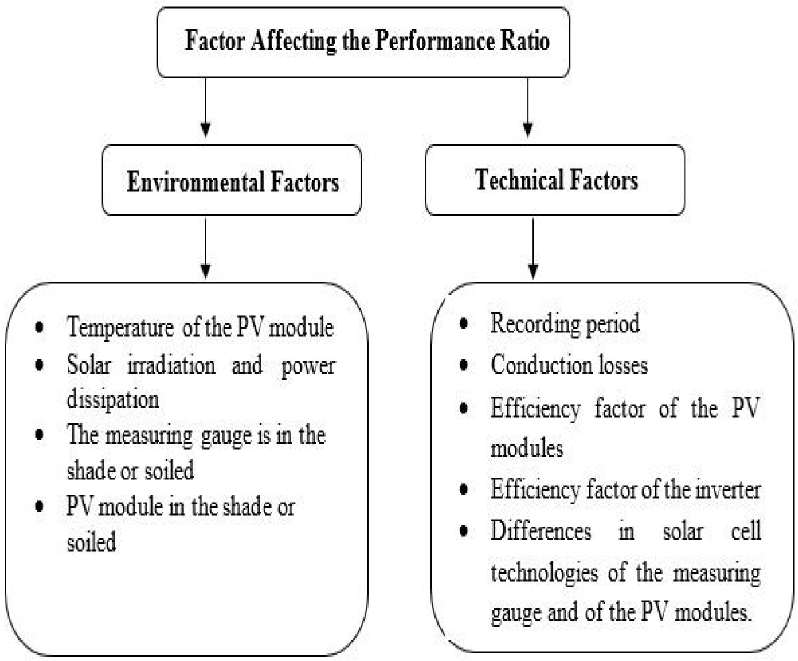

Fig 13: Factor affecting the Performance Ratio

The Performance Ratio (PR), also known as the quality factor, analyses the solar photovoltaic plant's quality in terms of its capacity to generate power despite of its location. Performance of SPV power plants is affected by several factors, including site location, meteorological conditions, and several additional loss mechanisms [24–27]. Under the headings of capture losses and system losses, Fig. 14 lists the overall anticipated losses from solar power plants.

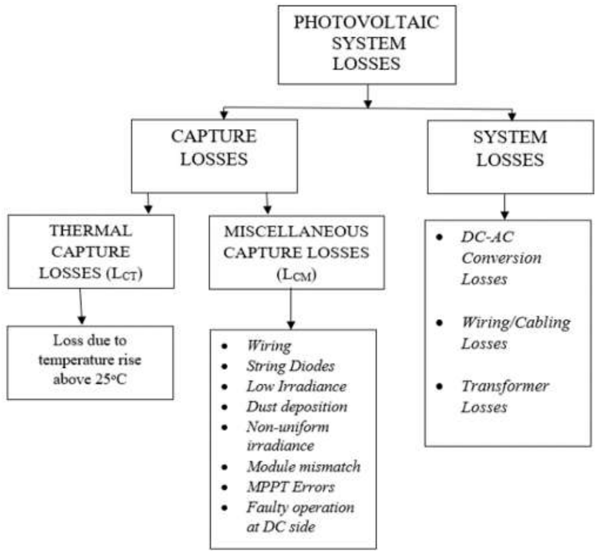

Fig 14: Categorization of losses in SPV systems

8.4 Capacity Utilization Factor:

The performance of a solar SPV power plant is best defined by its capacity utilization factor (CUF) which defines the ratio of plant's actual power generation or production to its maximum possible power generation for one complete meteorological cycle. The estimated power output of a solar power plant depends on the design parameters and for computing the performance of the plant standard software are available. The CUF a plant varies over a wide range because it depend on several variables like, poor quality module selection, higher ambient or module temperature, low solar radiations at the location and other design parameters such as resistive losses, atmospheric factors such as prolonged cloudiness and huge amount of fog. In India, the capacity utilization factor of a fixed inclined SPV system is typically in the range of 16%-17% [39]. This means that a 50kW installed SPV system will generate the same energy as 9kW SPV system generate in continuous operation. The power plants in India operating on a highly reliable grid network are expected to have a similar capacity factor. CUF does not consider any environmental factors such as irradiance variation from one year to another, nor does it consider module aging & degradation [23].

$$CUF = \frac{Energy\ Measured\ (kWh)}{Installed\ Capacity\ (kW)\ x\ 8760\ hours}$$

The capacity utilization factor (CUF) so computed is plotted in Fig 15. The plots of CUF shows that the value of 0.028 of CUF is lowest in the month of December depicting the same tendency as energy generation in the same month shown in Fig 11. Further the highest CUF of the order of 0.059 was computed for the month when plant generate the maximum energy. while on the other side for the month of December and April the performance ratio is shows entirely different picture because CUF is completely opposite to the PR of the system, that completely ignoring all these factors and the deration or degradation of the panels [30-31].

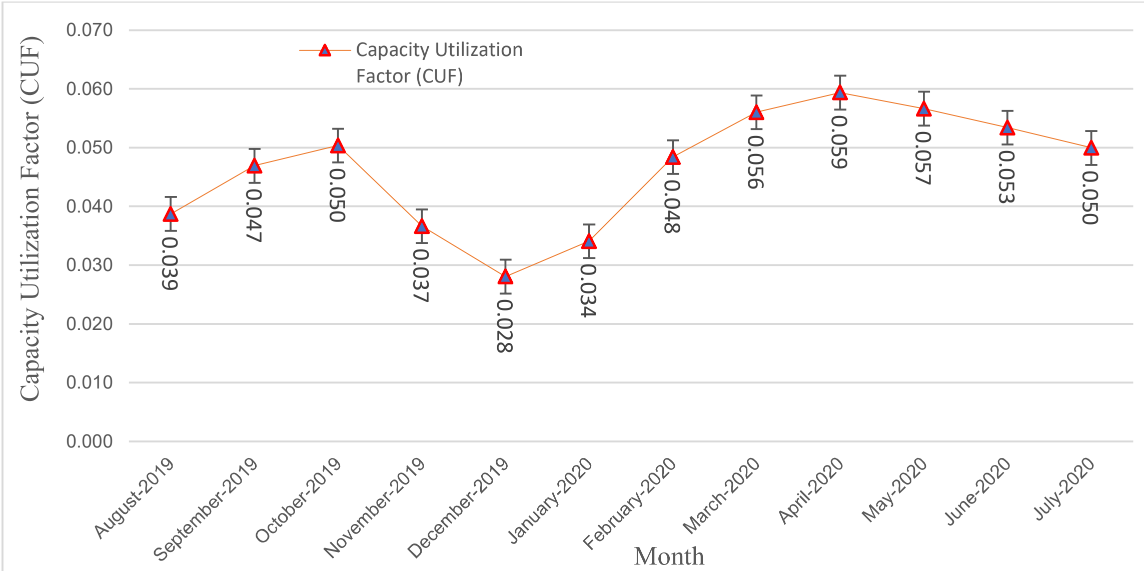

Fig 15. Capacity Utilization Factor for 50kW SPV system.

9.0 Limitations:

This study is not intended to be an exhaustive or definitive list as it is limited to the climatic zone (composite zone) and hence doesn't guarantee that cover all possible situations in detail prevail in the other climatic zone. Therefore, engineers should use their expertise & professional judgments and consult all current building standards & codes, health, and safety regulations, standards, codes, and other applicable guidelines issued from time to time by the relevant governments and the technical manuals for the equipment to be used or recommended.

10.0 Concluding Remarks:

According to the study carried out on 50kW Grid Connected Solar Power Plant in Sonipat region, Haryana and result can be summarized as below:

1. Module efficiency is directly depending on Plant designing, so before installing any power plant it's mandatory to record the meteorological parameters, latitude, longitude and elevation of the site, annual sunshine hours of the location.
2. Energy generation of any SPV system is depends on Module size, Module efficiency & type of module used, because based on cell technologies like monocrystalline, polycrystalline, and thin film type, selection of correct type & size with efficiency is necessary, because higher rating modules to consume less area for same power output.
3. Energy production of solar power plant also correlate & positively depends on the Module placing, installation structure, selection of inverter etc. Because tilted surface of module receives more energy than the horizontal module and if module placing is not correct then module is shaded by obstacles like buildings, trees and also shadowed by adjacent rows if not properly spaced, then energy production is affected up to 70%.

4. 20% Performance and Energy generation of any system is depending on the efforts applied during designing & installation stage, however remaining 80% of work will be done in the form of operation & maintenance. Periodic cleaning of SPV modules and removal of dust & bird poo from module surface to decrease the shading effect & periodically check the working condition of Inverter's exhaust fan and clean its front air filters and fins by utilizing blowers, is mandatory for better performance of the system.
5. The best performance ratio was found in January-2020 (95.56%) where energy production was 4090.40 kWh AT-23.73 °C & SR-81.53 kW-hr/m^2, while on the other side is CUF in April-2020 (0.59) where energy production was 7125.30 kWh, AT-39.99 °C & SR-189.3 kW-hr/m^2. During the observation April-2020 receives maximum generation. Solar radiation, ambient temperature are most important parameters for the Performance ratio of any system, but on another side CUF totally ignores all these factors.

The present study on technical due diligence ensures secure, safe, and highly reliable & high performing systems and set a precise framework for technical and economical evaluation. It encourages the integrators to take responsibilities for their installations and leads to satisfied installers, employers, and system owners. Therefore, satisfied customers become regular customers and lead to new customers. Technical due diligence should be considered throughout the SPV installation project. It should be planned for during the design phase, integrated into the system costs, actively implemented during and at the end of construction phase and repeated as often as necessary after project completion. Understanding and paying attention to technical due diligence is critical for the SPV industry to continue to expand and become a significant part of country's energy portfolio. Short-term and long-term system performance is critical to maintaining public trust and goodwill.

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