Rooftop Solar Photovoltaic System Design and Assessment for the Academic Campus Using PVsyst Software

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***Abstract*—This study aims to design and evaluate the grid-connected solar photovoltaic roof-top system for academic campus. A design and feasibility study of rooftop solar photovoltaic system project is conducted using tools- PVsyst and design software by inspecting project area by utilizing the NASA surface meteorology data through geographical coordinator of project place. The performance of the system was simulated using PVsyst software and the results were analysed. The analyses of the simulation results show that the project yields energy about 590MWh annually which is about 11% of total annual energy consumption in Pondicherry University. The process of electricity generation from solar photovoltaic system could saves ~42 tonnes of carbon dioxide. The proposed roof top grid connected system is analyzed for the academic campus.**

***Index Terms*—grid-connected, solar photovoltaic, PV system, PVsyst, roof-top solar PV, carbon dioxide**

I. Introduction

India has taken initiatives for promotion and use of green energy technologies both in academic practice and implementation under the development of Solar Institutional campus Programme by India ministry [1]. Grid-connected solar photovoltaic (PV) systems employ the direct conversion of sunlight into electricity which is fed directly into the electricity grid without the storage in batteries. Building integrated PV system does not require any excessive space. This option, like many other renewable energy options, is generally carbon free or carbon neutral and as such does not emit greenhouse gases during its operation, since global warming and climate change are mostly caused by the release of carbon dioxide and other greenhouse gases into the atmosphere.

In most parts of India, clear sunny weather is experienced 250 to 300 days a year. The annual global radiation varies from 1600 to 2200kWh/square meter, which is comparable with radiation received in the tropical and sub-tropical regions. The equivalent energy potential is about 6,000 million GWh of energy per year [3]. India declared in its solar mission a goal of producing 22GW of electricity from solar energy by 2022 [4]. Energy production capacity of solar is very little compared to other countries. Grid Connected photovoltaic system has been generated 30,000MW in India and ~973MW stand alone systems in January 2014 [5]. Estimated PV growth is to around 100 MW in 2022, till now about 592,000 solar street and home lighting systems and 7300 agricultural pumps have been running in the rural area [6]. India's solar mission is structured in three phase in 2010: the purpose is to achieve the target 1 GW of grid-connected solar by 2013, the second 4GW by 2017 and the final to reach 22GW of PV capacity for power generation by the year of 2022. India stands now over 1GW PV capacity all over country [7].

Pondicherry University is one of the pioneering universities in India which is located on the side of east-coast road of Puducherry in Tamil Nadu. Pondicherry is situated at 11.94 (11°56'24"N) latitude and 79.83 (79°49'48"E) longitudes receives good amount of solar radiation. The geographical co-ordinates of the campus are 12.01° North and 79.9° East. The solar radiation data is based on National Aeronautics and Space Administration renewable energy resource website [2].

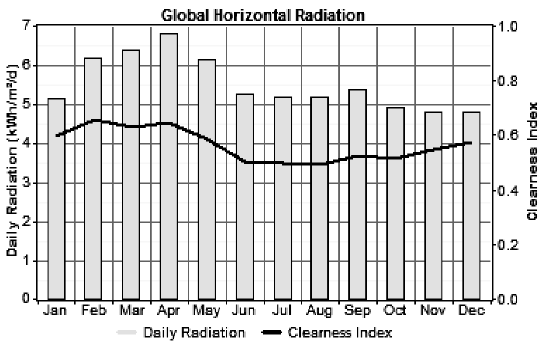

Figure 1. Relation between radiation and sky clearness [2]

The mean annual average of global horizontal solar insolation for the project site is 5.36kWh/m^2/day. The monthly average wind speed is 4.08ms^{-1} at 50m and 3.22ms^{-1} at 10m. Monthly 22-years averaged air

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temperature is 27℃ at 10 m above the surface of the earth. Clearness index and global horizontal radiation are shown in Fig. 1, where clearness index (0 to 1.0) is the fraction of radiation at the top of the atmosphere which reaches the surface of the earth. Global, direct and diffuse solar isolation is shown in Fig. 2. This article describes the design and numerical simulation of a PV system for producing electricity and energy solution for the campus of Pondicherry University. Through numerical simulation, the optimum size of the grid-connected PV system and the feasible sites are analyzed for PV-grid connected power plant aspect of academic Campus.

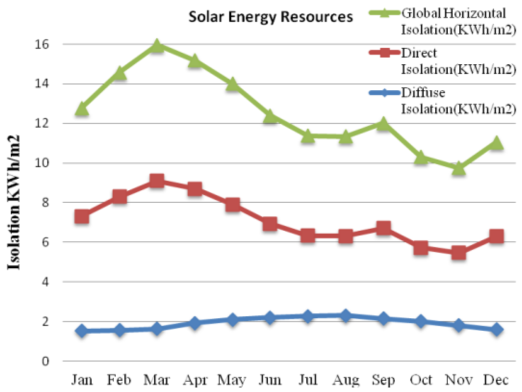

Figure 2. Global, direct and diffuse solar isolation [2]

II. Feasibility Study of Project Site

In department buildings of campus, there is always enough roof space to install PV system for supplying electricity to the building. The places can be used for mounting PV modules with a flat consumption of 1.5W/ft^2 [8]. Normally the roof tops of academic campus are not used for useful purposes and available for use. Installation PV modules at the rooftop will have additional advantage of reducing the heat gain of the building from the top. A grid connected system does not have any battery backup usually. In the case of rooftop connected PV systems, the electricity demand of the building are met by the PV system and only the excess is fed into the grid [9]. But during the unsuitable atmospheric conditions, when the load demand is not met by the PV generation, at that instant the required energy can be taken out from the utility grid. Also when the PV generation is more than the load requirement then the excess energy can feed to the utility grid.

The building's roof or orientation depends on solar radiation directly. The design of the solar PV array layout is planned diligently to avoid presently possible shadow from the water tanks, sidewalls, columns and nearby buildings. The department's architecture view and roof are shown in Fig. 3 and Fig. 4. Rows of the arrays are laid in such a way that there is no shadow from one row to another. A simple rule for minimum spacing between rows is to allow a space equal to three times the height of the top of the row or obstruction in front of an array [10]. The physical orientation of the PV system and the tilt angle of the array should be considered relative to the geographical location of the installation to maximize solar access and power output.

In the northern hemisphere, solar panels should be tilted to face south. An easy way to determine the tilt angle is the latitude of the location. Pondicherry is located at 12° latitude, the energy yield is calculated based on a tilted array surface at 12° considering 0^o azimuth angle.

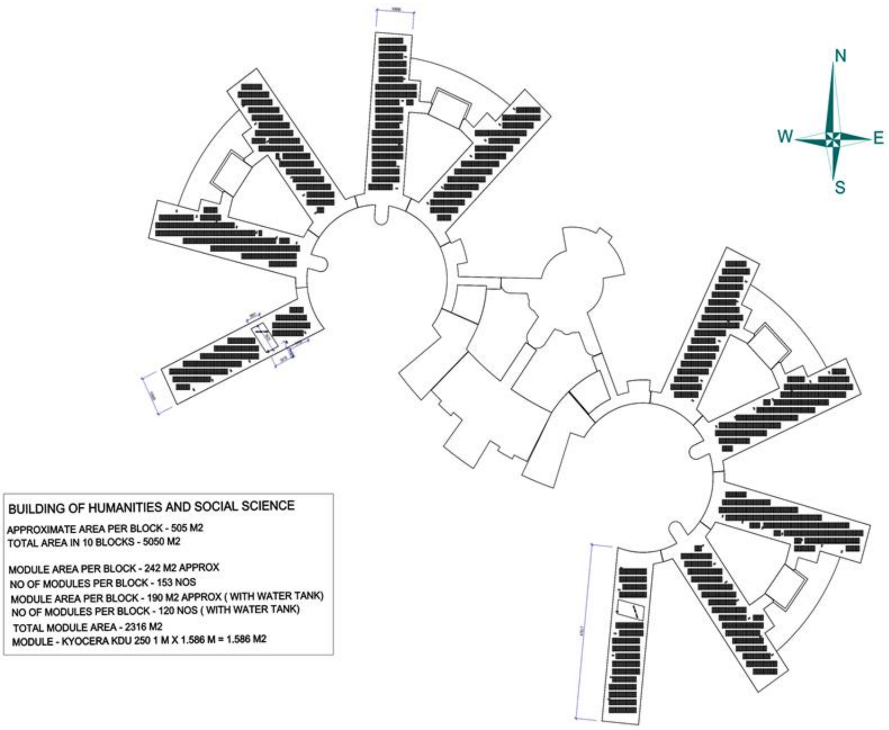

Figure 3. Architectural views of department roof of the project place

Figure 4. Roof of department building

One of the important goals of project is to estimate the solar PV potential of the rooftops of building. In the first stage, architectural drawing of building with roof area is used to implement solar PV system. The project is planned and designed in campus for installation solar PV electricity energy with total roof area of about 5000m^2. The inspection has been done based on parameters such as roof area, roof type, roof pitch and orientation. Key item to evaluate during a site survey for roof-mounted PV arrays include [10] building type and roof design, roof dimensions, slope and orientation, roof surface type, condition and structural support, fall protection methods required, access for installation and maintenance.

The roof area is separated 10 blocks, there are 2 types roof where one type is having water tank, thus two types design is mentioned in this project, detail design requirements are shown in Table I and Table II. In accordance with shadow analysis, space has been left between two rows and sidewalls for allowing free movement of people for inspection, maintenance and cleaning.

TABLE I. PROJECT REQUIREMENTS AFTER SIMULATED BY PVSYST SOFTWARE

System Capacity (Kw_p)	Nos. of Module ($250W_p$)	Nos. of module per string	Nos. of String per system	Inverter Capacity (KVA)	Nos. of Inverter
30	120	20	6	15	2
38	152	19	8	20	2

TABLE II. AREA DESCRIPTIONS AFTER INSPECTED PROJECT SITE

Nos. of System (Roof Blocks)	Each Roof Area (m^2)	Module Area (m^2) (250 W_p)	Total Module Area(m^2)	Total Capacity (kW_p)
30kWp X 2	440	1.642	197	60
38kWp X 8	505	1.642	250	304

III. TECHNICAL CONSIDERATION

The solar cell is a semiconductor device, more precisely, a special type of diode. Incident light generated free electrons which are separated by internal electromagnetic field as a consequence of the potential difference. Crystalline silicon cells are usually manufactured from silicon wafers. The wafers are sawn out of single or multi crystalline silicon ingot. Multi-crystalline silicon is composed of large crystal gains. Multi-crystalline silicon cells are slightly cheaper, but have a somewhat lower efficiency compare to single crystalline. The mono-crystalline silicon PV Module has been selected for this project. High-performance photovoltaic modules made of mono-crystalline silicon solar cells with power 250W module. The electrical properties of PV device are given: at Standard Test Condition (STC); these are cell temperature 25 ℃, solar irradiance 1000Wm^{-2} and solar spectrum air mass 1.5. A rule of thumb is that a square foot of single PV module area produces 10 watts of power in bright sunlight [11]. Anti-reflex coating to increase light absorption. Only modules will be delivered that have the specified power or more for high energy yield. It is improved temperature coefficient to reduce power losses at higher temperatures and high power performance even at lower irradiations.

The major component of grid-tied PV system is the grid-tie inverter which along with regulating the voltage and current received from solar panels ensures that the power supplies in phase with the grid power. Solar grid-tie inverters should be designed to operate within allowable power quality limits set [12]. On AC side, it keeps the sinusoidal output synchronized to the grid frequency (nominally 50Hz). The voltage of the inverter output needs variable and a touch higher than the grid voltage to enable current to supply the loads in the campus or even supplies excess power to the utility. The inverter is downsized with the typical rule-of-thumb to take 70% of the nominal power of the PV panels [13]. There are multiple factors that influence the inverter sizing strategy. Three types of factors are: meteorological, economic, and inverter characteristics [14].

Software controlled Maximum Power Point Tracking (MPPT) techniques will be utilized in the control system to optimize the solar energy fed into the grid. The control system detects if the insolation level is above a predetermined value and the grid supply is within the pre-set limits in voltage and frequency, the inverter modules synchronise and connect to the grid supply and proceed to export the available solar energy. The control unit will automatically disconnect from the grid if the grid voltage or frequency moves out of its operating range.

Modules are mounted on a non-corrosive support structure suitable for site condition with facility to adjust tilt to maximize annual energy output. The array structure is designed to withstand storm condition with wind speed up to maximum 180Kmph. The structure designs for simple mechanical and electrical installation to absorb and transfer the mechanical loads to the roof structure and ground subsequently.

The size of the cables module/array interconnections, array to junction boxes and junction boxes to PCU etc.

shall be selected to keep the voltage drop and losses to the minimum. All cables shall be PVC insulated with appropriate grade conforming to IS 694:1990 equivalent. The junction boxes are dust, vermin, and waterproof and made of metal or thermoplastic.

The monitoring system have features for simultaneous monitoring and recording of various parameters of different sub-systems, power supply of the Power Plant at the DC side and AC side. This will enable monitoring the status of inverters to gather information on energy generation. These are: ambient air, temperature near array field, control room temperature, module back surface temperature, wind speed at the level of array plant, solar radiation incidental to array plant, inverter output, system frequency, DC bus output, energy delivered to the GRID in kWh.

30kW PV System Design for 2 blocks (Table I & Fig. 5):

Each PV Module Capacity 250W
In series, 20 PV modules Connected
In Parallel, 6 Strings
Total Modules 120 and 15KVA, 2 inverters

38kW PV System Design for 8 blocks (Table I & Fig. 5):

Each PV Module Capacity 250W
In series, 19 PV modules Connected
In Parallel, 8 Strings
Total Modules 152 and 20KVA, 2 inverters

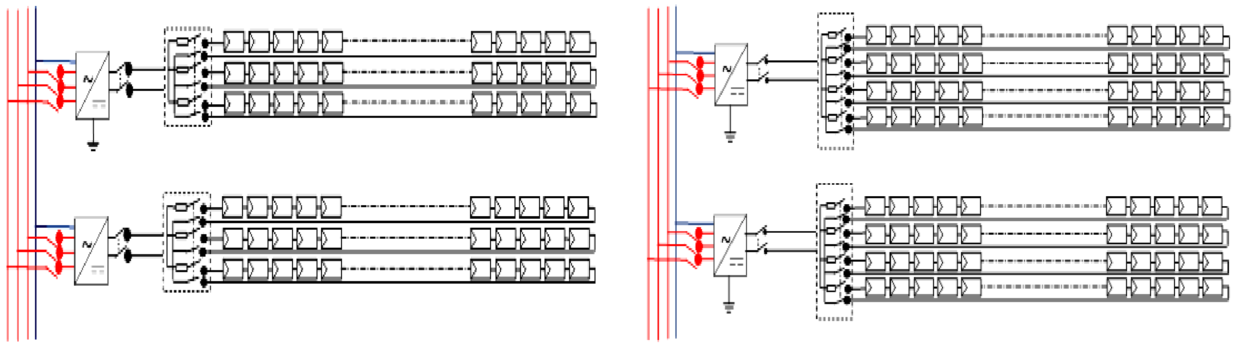

Figure 5. Electrical system layout of 30kW$_p$ and 38kWp system

The Symbol Fig. 6 is used to design entire project. And total designed of system is shown in Fig. 7 which is placed on building roof of 10 blocks (Fig. 3).

The condition of a Distributed Generation (DG) generator continuing to power a location even though power from the Electric utility is no longer present is termed a "islanding". The situation may cause an electrical shock and dangerous to Utility workers. To prevent islanding, the Power Conditioning Unit has to disconnect quickly (within a few second) in response to failures on the immediate distribution line. Grid-connected PV systems are required to have an over voltage relay (OVR), an under voltage relay (UVR), an over frequency relay (OFR), and an under frequency relay (UFR) which disconnect the PV system from the utility in the event that the magnitude or frequency of the PCU's terminal voltage goes beyond certain limits [15]. The SPV Power plant is provided with Lightning and over voltage protection connected to proper earth mats. The main aim of over voltage protection is to reduce the over voltage to a tolerable level before it reaches the PV or other sub-system components. The Lightning Conductors and all protection is made as per applicable Indian or International Standards for smooth and continue runs the grid connected PV system.

All equipments of the PV power plant have been conformed to international standards including IEEE for design and installation of grid connected PV system. The standards cover various aspects such as PV modules, cable types and selection, temperature considerations, voltage ratings, BOS wiring, inverter wiring, blocking diodes, Bypass diodes, disconnect devices, grounding requirements, surge and transient suppression, load centre, power qualities, protection features and safety regulations. The following codes and standards will be followed while constructing the power plant: IE Rules for design of the electrical installation, National Electrical NFPA 70-1990 (USA) or equivalent national standard, National Electrical Safety Code ANSI C2 -1990 (USA) or equivalent national standard, IEEE 928 - 1986: Recommended criteria for terrestrial PV Power Systems,

IEEE 929 – 1988: Recommended practice for utility interface or residential and intermediate PV systems, IEC 61215: Standard for crystalline silicon PV Modules, IEC 61646: Standard for thin film PV Modules, IEC 61730: PV modules must qualify for safety qualification testing, IEC 61701: For modules used in highly corrosive atmosphere.

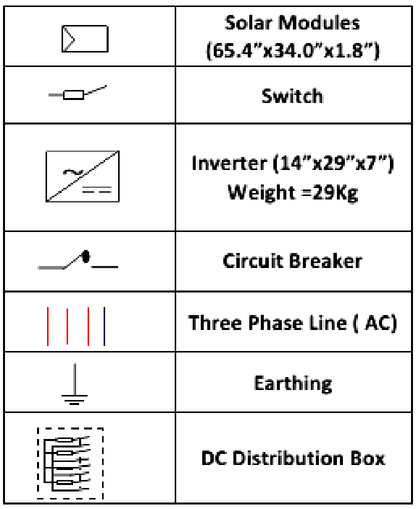

Figure 6. Symbols used in electrical system layout

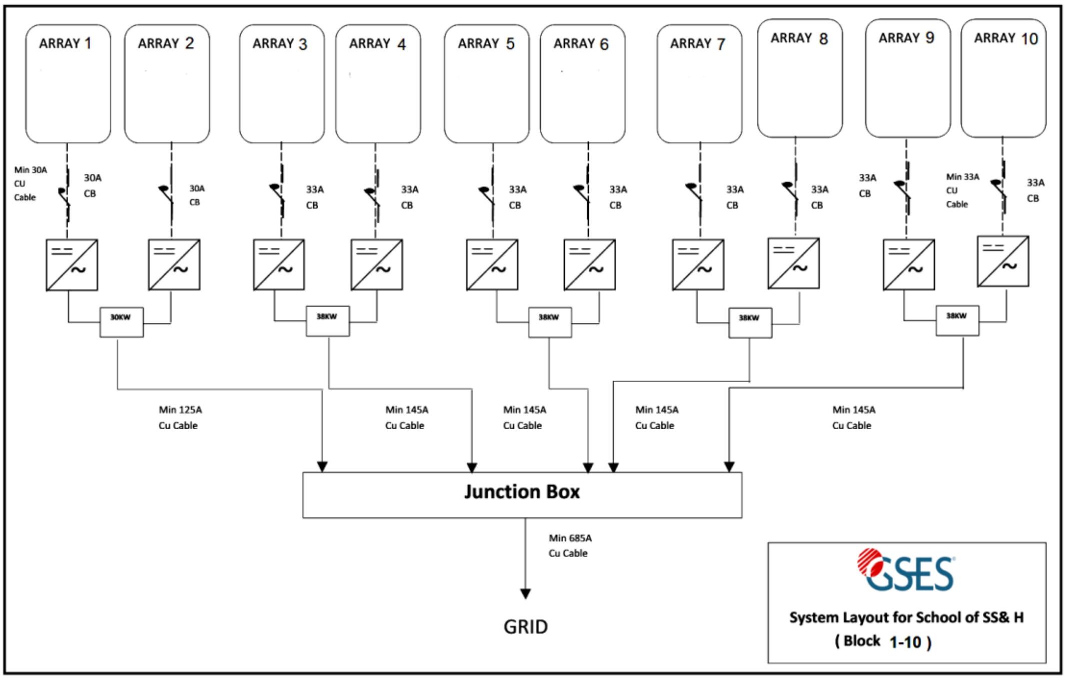

Figure 7. Electrical layout of total PV system

IV. Result and Discussion

Annual energy yield for this PV power plants is defined as the amount of energy fed into the building grid after due consideration of all kinds of generation and distribution losses. The simulation tool (PVSYST v6.04) has been used to estimate 364Kwp power plant to yield energy from PV power plants. PVSYST simulation result is in Fig. 8.

Nominal Power 30KW_p each block
Produced Energy is 49.80 MWh/year
Performance ratio (PR) is 76.1%.
Collection/distribution loss 1.33kWh/kW_p/day
System loss 0.11kWh/kW_p/day
Produced useful energy is 4.55kWh/kW_p/day.

Nominal Power 38KW_p each block
Produced Energy is 62.8 MWh/year
Performance Ratio (PR) is 75.7%.
Collection/distribution loss 1.35kWh/kW_p/day
System loss 0.1kWh/kW_p/day
Produced useful energy is 4.53kWh/kW_p/day.

Simulated energy production of total system 364kW_p is $(2x49.8)+(8x62.8)=602 MWh/year$ with highest generation 61MW in March and lowest 39.3MW in July after collection and system loss (shown in Fig. 9).

The loss in the PV system depends on the PV module and inverter technology; efficiency and quality of PV modules, inverter, junction box and wires; workmanship of installation and scheduled maintenance and cleaning. In the simulation process, Losses have been considered best quality modules and inverters of international standard. How PVSYST is produced losses, it is shown thoroughly in Fig. 10.

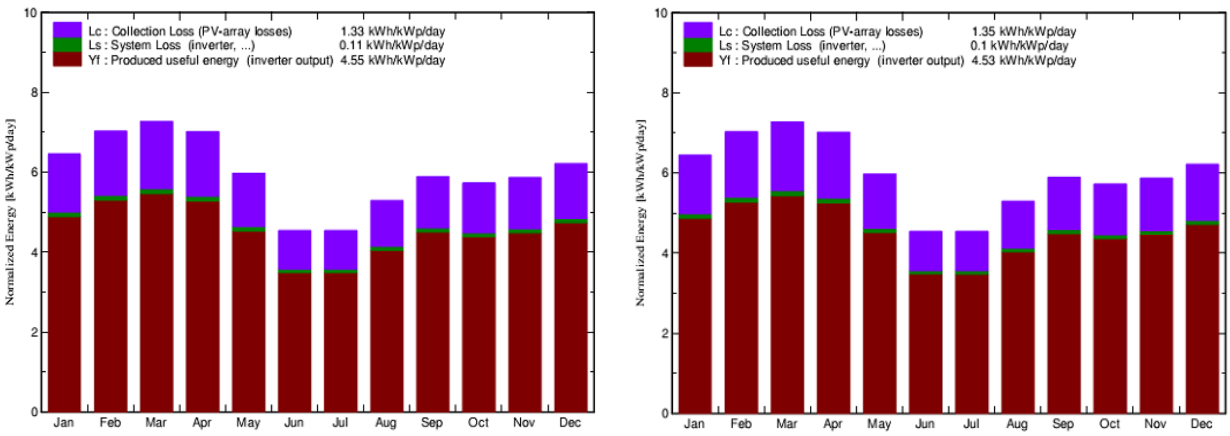

Figure 8. Monthly normalized production from 30KWp and 38KWp system

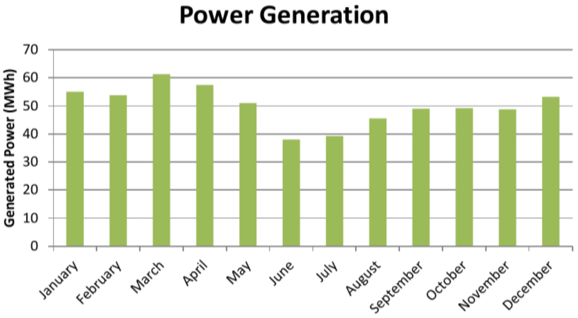

Figure 9. Monthly generation of total 364Kw$_p$ system

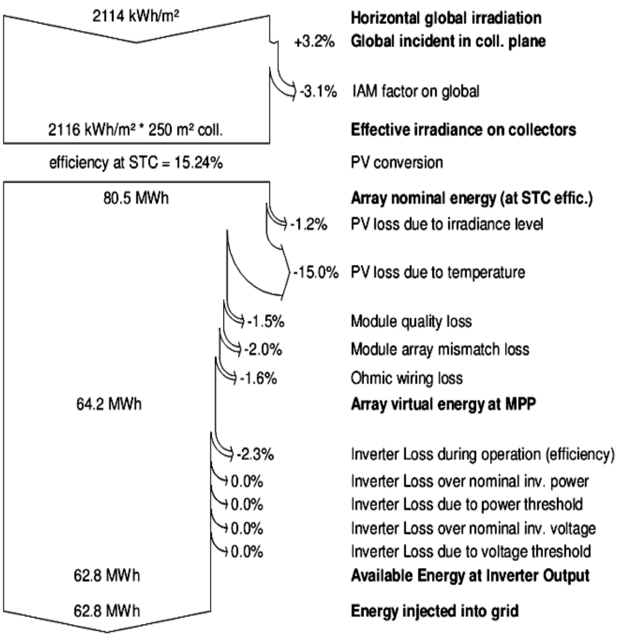

Figure 10. Diagram of losses how to reduce energy production in PVSYST

TABLE III. LOSS DURING POWER GENERATION

Loss	30KW$_p$ System	38KW$_p$ System
Loss due to Irradiance level	1.2%	1.2%
PV loss due to temperature	15%	15%
Ohmic wiring loss	1.2%	1.6%
Inverter loss	2.3%	2.3%
Total loss	19.7%	20.1%

The transformer and distribution losses beyond the inverter output will depend on the quality of power equipments and conditions specific to the location and connected grid infrastructure (Table III). Loss in the electrical systems will occur due to self-consumption, control, protection, and no load losses of step up transformers. The total losses from the Inverter output till the Bus bar output is considered as 2%, considering best quality equipment and best installation practice.

Power plant 364KWp
Annual Generated power 590MWh (after loss)
Annual Plant Load Factor (PLF) or CUF 18.5%
Annual Save 42 ton CO_2 (grid factor 0.84tCO_2/MWh [16])

V. Prospect Analysis for Academic Campus

The opportunity and implementation outcomes of the proposed system in perspective of academic campus as a model of Pondicherry University has been analysed. Generally in academic campus the rooftops of multi-storied buildings are available. The installation of highly visible solar PV building on university campuses would be a promising action with regard to the further dissemination of renewable energy technology among the future decision makers while research related to renewable energy sources has already become a current topic in many universities. The state-of art of renewable energy technologies is not well known to most students. Awareness of the rapid development of renewable energy technology can very efficiently be raised by practical application in student's daily environment in the university campus [17]. So it is easier to do energy solution with PV systems, and use of solar PV system in campus will create scope for young mind on importance of renewable energy technologies who would become future researcher, academicians or policy maker.

Even Academic campuses are ideal places for use of solar PV module. Most of the operations of academic campuses take place in the day time, which is in synchronous with the availability of sunlight, academic campuses do not have significant heavy loads meaning that the required power density is low [18]. The load of Pondicherry University is similar with the solar radiation in day time, shown in Fig. 11. So, it is very effective to supply electricity from grid connected solar PV plant in day time in academic campus.

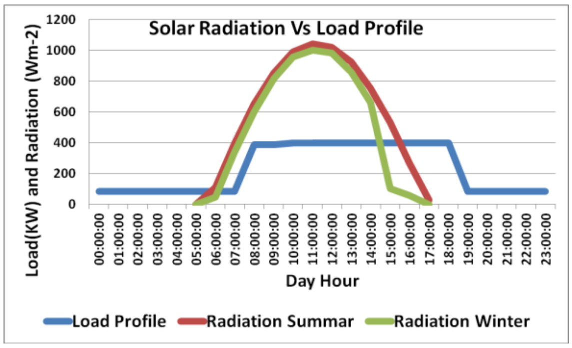

Figure 11. Graph of synchronous time university schedule and daylight

The Ministry of New and Renewable Energy (MNRE), Govt. of India has launched a Scheme on "Development of Solar Cities" under which a total of 60 cities/towns and 50 townships/campuses are proposed supported for development as "Solar Campus" during the 11thPlan period [19]. This project would facilitate country to reduce 10% of use of conventional energy. The favourable government policies exist in the country for promotion of solar PV technologies for power generation and public awareness which can be useful in setting appropriate policies for long term sustainable development. Solar PV Plant for power generation would results in creation of employment across the country.

The project for academic campus is worthwhile strategy. Academic building would be advantageous itself to cut down on electricity costs, research opportunity, less instalment cost and improve the energy mix of the campus. The green Energy in the university campus would support discovering low carbon technology by reducing the carbon dioxide in the campus atmosphere as well as follow the country policies.

VI. Scope and Limitation of the Project

Renewable energy (wind, solar) generated electricity can be intermittent. For the continuous power supply from solar energy is needed storage device. But the solar energy grid tie system does not always necessary to use storage device. The grid-tie system is mandatory to synchronous with power grid frequencies, voltages and component performance, causing instability in the power generation system and interrupted service to customers. The proposed grid-tied system without storage can't supply electricity if utility grid is disconnected during night or on rainy day when sunlight is not sufficient. Installation of a small battery could solve the problem but the installation cost would be higher and efficiency has compromised.

To implement and rectify of this project work is to lead on experimental setup by Life Cycle Analysis (LCA) and establish the solar grid-tie system. The system will be analyzed and tune it to provide grid quality AC supply restraining harmonics, DC injection etc. Moreover, the utilities should step forward to upgrade the existing girds in academic campus of Pondicherry University in order to get full benefit of grid-tied systems. Net metering and incentive tariff could promote and encourage PV grid-tied electricity generation.

VII. Conclusion

India facing fuel shortage for electricity generation and in near future the whole world is going to face the same scarcity because of world's limited fuel stock. So worldwide renewable energy demand and research are rising and our government is also taking steps for green energy. Hence, Pondicherry University is selected solar energy as a secondary energy source. The various advantages of the proposed system are: (1) less dependence on grid supply (2) system become more reliability (3) reduction in pollution (4) improvement of supply reliability. (5) Build green power infrastructure (6) establish energy security.

This project illustrated a solar PV system for the Silver Jubilee campus of University. Detailed design including system specification has been worked out. Our study revealed that the Silver Jubilee campus has solar energy potential as rooftop, ground in addition to solar thermal. Renewable resource assessment has been assessed from NASA data website according to Pondicherry geographical coordinator. Campus drawing and electric system design has been done by specialist AutoCAD and Engineer. PVSYST simulation software is used to simulate power generation and design PV system. In this paper, an optimized project scheme is proposed which is suitable for academic campus to demonstrate how the grid-tied PV systems can be deployed with the idiosyncrasies of University campus through analyzed the future prospects of Pondicherry University in India.

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