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Design of a Stand-Alone Rooftop PV System for Electrification of an Academic Building

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Abstract: Solar energy is one of the most promising options of renewable energy in the context of energy sustainability. Nowadays, as the utilization of solar energy has been continuously expanded in wide scale, researches related to the topic have been carried out all over the world. The prime focus of this study is to provide sustainable energy generation for an academic building located in a rural place, where power outage is a frequent issue. In this study, individual power system components have been suitably designed which could electrify the building for yearlong use. A rooftop photovoltaic (PV) system with three days battery backup has been considered for the present case. Designing of the PV system is based on the selection of individual electrical appliances and its operating time in a day. For this purpose, a survey has been carried out over a year in order to identify the day in which maximum power was utilized. The study revealed that the total estimated capacity of the stand-alone PV system should be 138.6 KWp in which 446 PV modules bearing 300 Wp each are connected together in series parallel combination. Total 656 numbers of batteries (12V- 200Ah each) are required for power backup which store the excess PV generation. Suitable size also been considered for inverters and charger controller which are connected in parallel and series respectively. The area required to install PV modules on the rooftop without shadow effect has been properly assessed. Besides being PV system design, brief cost analysis has been carried out in terms of simple payback period, unit cost of power generation and cash flow in terms of present value.

Keywords : Stand-Alone, Solar PV, Battery, Inverter, Design, Cost .

I. INTRODUCTION

Installation of solar PV on building rooftop is becoming popular now-a-days, especially in tropical or subtropical zone as it receives ample sunlight during the most part of the day. Presently, in all over India, many academic and commercial buildings are fitted with rooftop PV system for power supply. In this country, there is enough vacant space on the rooftops of different academic, governmental, commercial, industrial and residential buildings for installation of PV module to meet power demand. In this system space can also be saved, because installation of PV on rooftop does not need any vacant land, it only needs vacant roof. Government has initiated various affordable policies for the installation of PV system. Several researches have been conducted by different governmental and non-governmental sectors for the implementation of rooftop PV system in mass scale. Rooftop PV installations have been promoted toward commercial and business areas offering consumers some special cost effective supports and policies. In commercial sectors cost per unit grid electricity is increasing almost every year and only PV generation could make considerable saving as its installation is easier and establishment of power grids is highly capital intensive. As the performance of the PV technology is still developing and the cost is gradually decreasing in last few years, it has become more attractive to the project developers for implementation in different residential or commercial areas. In view of its benefits and future energy prospect, the government has set an immense target of producing 40 GW power from the rooftop PV system by 2022 and more than fifty percent has already been installed all over the country. It could be possible as various Public Sector Undertaking (PSU) companies and some private manufactures have collaborated with governmental fiscal incentives and huge investments are shifting towards installing rooftop PV systems. Several banks provide loan to the individual with a low interest rate and government provides subsidy (30- 50%) for installing the PV system. Therefore, the country tends to switch power generation from conventional fossil fuel to sustainable renewable energy.

The rooftop PV system happens to be one of the astonishing and affordable electrical power generation systems in India. In this country grid tied or grid interactive PV generation is the most customary system. However in rural part of the country frequent power cut off and low voltage power transmission are the major issues. Continuous and steady power transmission can be possible only by using off-grid or stand-alone PV system. A stand alone photovoltaic (PV) system is a self power generating system that delivers energy in any hour of a day. This kind of system incorporates sufficient amounts of battery storage to provide power for a certain number of days or nights when sun is not available. In this system batteries are charged by PV panel or array during sunshine days and the array must be enough in capacity to meet the power demand of the site and recharge the batteries at the same time. Essentially, a stand-alone PV system is suitable for remote locations where grid power is unavailable or frequent voltage fluctuation or power cut off happens as mentioned earlier. Because of the aforementioned issues in remote or rural areas, researchers pay close attention to the stand-alone PV system that determines the feasibility of an individual buying or adopting it.

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All around the world, many countries have been engaged toward large scale power generation utilizing solar PV system. In last two or three decades, lots of studies have been conducted about the designs of solar PV system and economic viability of the system. Hossain et al.[1] presented optimum design for a rooftop stand-alone solar system in Bangladesh applicable for home electrification with affordable energy price. They mentioned that with this system, the unit cost of energy generation remained $0.211. Sarin et al. [2] reported that per unit power tariffs increases by 6.9 per cent every year in Delhi (India) and this could be eliminated utilizing Solar Residential Rooftop Systems (SRRS) as Delhi has approximate free rooftop space of 31 sq. km. They found that people are less conscious about SRRS and government subsidies towards its installations. They estimated an average awareness score and found to be 1.99 on a scale of 1 to 5. Al-Najideen and Alrwashdeh [3] proposed grid interacted PV system design strategy to investigate the reduction of power demand for an engineering institute building in Jordon. They designed 56.7 KWp grid-connected solar PV power plant for 25 years and which could deliver 97.02 MWh/year electricity to the power grid. They also illustrated rooftop design for PV installation suitably. Finally they did cost analysis for the proposed system and reported that the installation cost of the plant was $117,000, the electricity bill cost was $21,600, and the payback period was 5.5 years. Rahman et al. [4] conducted a techno-economic analysis for 3.40 kWp stand-alone PV system using a bottom-up data-intensive spread-sheet-based model. They found unit cost of power generation to be $0.72/kWh when a net present cost was $12,027.83. They noticed that battery cost was the major cost for the PV system. Udoh et al. [5] presented techno-economic analysis of Building Rooftop Photovoltaic (BRFPV) for a lecture hall in Nigeria. They followed a sequential approach to design existing BRFPV system using PVSyst software and found that energy generated 2804 KWh in a year keeping performance ratio of 86% and the unit production cost of 69.5 Naira per KWh. The optimum sizing strategy and its feasibility for sizing of a stand-alone PV system was presented by Khatib et al. [6]. They reviewed on different design approach and provided enough idea for sizing a stand-alone PV system. Alsheghri [7] designed a cost effective SPV powered reverse osmosis plant. The proposed system ran under less expensive batteries and less governmental subsidy for the water production. Ghosh et al. [8] studied out techno economic analysis of Roof Top PV systems (RTPV) in various regions of Karnataka (India) to observe its profitability taking existing governmental schemes, policies and incentives. It was found that semi-urban household regions in the state show better economic performance in both net metering and in Feed in Tariff (FiT) schemes. Albadi et al. [9] proposed a design strategy for a 50 KW roof top PV system at Sultanate in Oman. The study was based on sizing of PV arrays, charge regulator ratings and inverter ratings for a specific load. The expected generation cost was estimated using realistic solar radiation data. Sharma and Tiwari [10]conducted life cycle analysis to estimate cumulative performance of a stand-alone PV system. Further, they compared cost estimation between roof top mounted PV system and ground mounted PV system. Chandel et al. [11] carried out techno-economical study to understand practical feasibility of a 2.5 MW capacity PV plant for electrification of garment houses in Jaipur (India). Ganguly et al. [12] presented a design strategy for a PV powered fan-pad ventilated floricultural greenhouse. They reported that total 3825 W solar panel, each of 75 Wp with a 3.3kW electrolyzer and 960 W fuel cell stacks, each of 480 W could meet the power requirement of a 90 m^2 greenhouse. Sharma et al. [13] presented the simplest and comprehensive method of sizing a stand-alone PV system. In this paper, an attempt has been done aiming the feasibility of a stand-alone PV system of an academic building using a design strategy and cost estimation approach. Present study delineates the way to design or size the individual power system components for sustainable power generation for an academic building existing in an engineering institute. It is observed that this engineering campus requires monthly 25,000 to 30,000 unit grid power as there are seven hostels, two administrative buildings, one canteen, two academic buildings, one gymnasium, and three workshops. Here only one larger academic building has been considered for the study. This building is three storied and has total twenty class rooms, nine lavatories, two drawing halls, one computer design lab, four staff rooms, twelve laboratory rooms, and one big auditorium. The building is connected with traditional power grid to meet the power demand for the entire building load like lights, fans, air conditioners, pumps, machineries and other appliances.

II. DESIGN OF SOLAR PV SYSTEM

A. Stand-alone system

A typical stand-alone solar PV system comprises of solar modules/ panels (array), charge controller, batteries (battery bank), inverter, and connected DC or AC load. In common practice, solar modules are mounted on ground or roof with suitable tilted mounting structure to run AC load. Basic principle of a standalone solar PV system relies on receiving of solar energy by PV modules and converting it into DC electricity. The generated DC electricity transfers through inverter for converting it into single phase or three phase AC electricity to run the AC loads. The excess DC current after meeting load demand, supplies to the batteries to be utilized as backup. A charge controller manages or regulates current which is supplied to the battery and also prevents overcharging. To extract maximum power from a PV module under certain conditions MPPT charge controllers are used. Nowadays three phase hybrid solar inverter has come to the market, which can serve dual functions both for MPPT charge controller and inverter. The basic schematic of the PV system is presented in Fig.1.

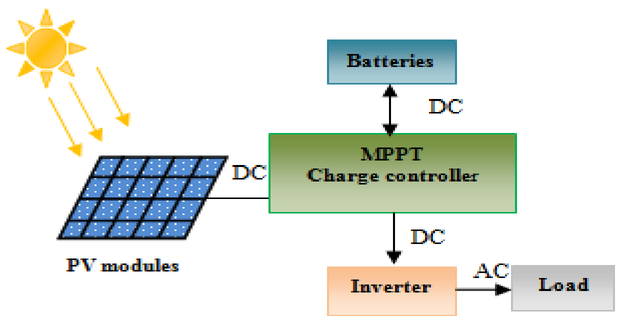

Fig. 1. A schematic diagram of a stand-alone solar PV system

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B. Steps of PV system design

The determinants of a PV system design are primarily the average solar radiation data and load demand of the site. The types of load connected, built in area available for the installation of the system are also taken under consideration. As it is an engineering institution, lots of A.C. loads like fans, lights, machinery, air conditioners, and other engineering appliances which are often require power to run. In this work, load estimation was done by observing the building over a year to examine total numbers of loads which are operated for specific purposes. It was found that maximum numbers of loads are connected with power system mainly in summer season. Consequently, a day was found when maximum numbers of loads were connected to grid power supply. In the following table shows different loads which were connected to the power system on that day. Thus, this consideration could help the system year long performance. The maximum power demands for the building are tabulated in Table-1. The table displays the rated power of the individual appliances, its quantity, and hours for operation in a day. The miscellaneous load is considered for unknown loads. To design the standalone PV system the following steps have been considered.

Step 1: Identify the average solar radiation for different months in the site.

Step 2: Survey and estimate of the building loads and their operation hours.

Step 3: Establish the suitable voltage to run the power system components.

Step 4: Evaluate the solar PV size to meet the maximum load demands.

Step 5: Estimate Battery capacity.

Step 6: Determine the capacity of inverter and charge controller.

Step 7: Determine reliable size for DC Cables.

Step 8: Identify the required rooftop space for PV installation without any shading effect.

Step 9: Economic Analysis.

C. Study location and solar radiation analysis

The site selected for the case study is based on academic institution campus located at Guptipara (Longitude- 23.25ºN, Latitude- 88.45º E) in Hooghly district, 70 KM away from Kolkata (India). In this academic building about 350 students are studying and thus a constant power source is a requirement. This academic building has an ample free space on rooftop as only a water storage tank is situated there.

As mentioned earlier, solar radiation data of a site is the primary criteria for designing of PV system. It has been identified that study location is subjected to plenty of solar radiation throughout the year. Fig. 3 presents the average global solar radiation per day for different months on horizontal surface and tilted surface (tilt-angle equal to latitude angle of the site i.e. 23.25º) [14]. It is clearly understood that solar radiation is higher on a surface during winter when it is placed at latitude angle than the horizontal placement. Meanwhile during the summer the opposite thing is happen. As a result, PV panel could generate required power during winter to run the winter load. Yearly average value of the solar radiation found to be 5.13 KW/m^2 for the horizontal and 5.3 KW/m^2 for the tilted surface equal to latitude angle. Thus, the PV plane when placed at latitude angle could produce more power and consequently reduces the investment cost.

Fig. 2. Satellite image of the academic building

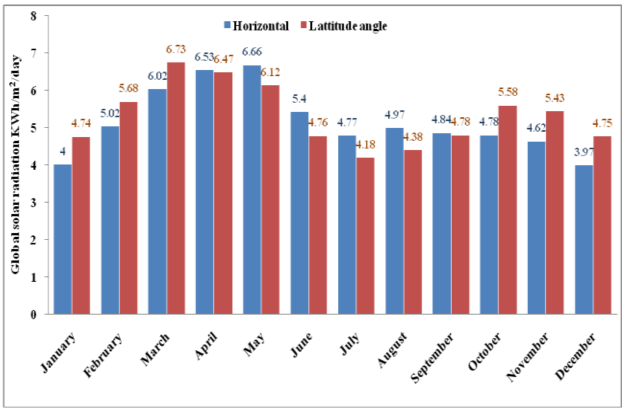

Fig. 3. Monthly average daily global solar radiation on a horizontal and tilted surface (latitude angle) [14]

D. Designing of solar PV

It was discussed earlier that the rating and duty hours of individual loads were identified for a day based on survey. Thus, total energy required in Ah for the electrical loads like fans, pump, machineries etc. can be calculated as:

$$I_L = \frac{\sum_{i=1}^{n} W_i \times N_i \times h_i}{V_S \times P.F} \quad (1)$$

where, I_L is the total connected load in Ah, W_i is the ith load in Watt, N_i is the number of ith loads, h is the duty hour of ith load, V_s is the system voltage, P.F is the power factor.

The current (I_{inv}) which is flowing through inverter

$$I_{inv} = \frac{I_L}{\eta_{inv} \times \eta_{wire}} \quad (2)$$

The required current for PV module (I_{pv}) is thus given as:

$$I_{pv} = \frac{I_p}{PSH \times D.F \times \eta_{charge}} \quad (3)$$

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Table-II: Design loads and their duty hours

Sl no.	Appliances	Rating (W)	Numbers	Running time (hrs)
1.	Light in class rooms (day)	45	200	4
2.	Light in laboratory (day)	45	40	2.3
3.	Light (night)	45	21	11
4.	Fans in class rooms (day)	75	144	4
5.	Fans in laboratory (day)	75	30	2.3
6.	Fans in staff rooms (day)	75	16	6
7.	Fans (night)	75	5	12
8.	Air conditioner	2700	5	3
9.	Water purifier cum cooler	575	1	5
10.	Machine (Lab-I)	100	1	1
11.	Machine (Lab-II)	380	1	0.35
12.	Machine (Lab-III)	200	1	0.5
13.	Machine (Lab-IV)	350	1	0.3
14.	Machine (Lab-V)	7500	1	0.25
15.	Machine (Lab-VI)	500	1	1
16.	Machine (Lab-VI)	3000	1	0.3
17.	Pump	1118	1	1
18.	Miscellaneous	100	1	1
	Auditorium			
19.	Air conditioner	2700	14	4
20.	Projector	300	1	4
21.	Amplifier	240	1	4
22.	Sound box (large)	200	2	4
23.	Sound box (Medium)	90	4	4
24.	Sound box (small)	30	4	4
25.	Lights on wall	20	50	3
26.	Lights on stair	5	40	3

where, DF is the de-rating factor of the module and η_{charge} is the efficiency of the charge controller. PSH is the duration of peak sunshine hours, which varies from place to place. For the present location the standard value is 6 peak sun hour per day [12].

Considering the standard current from a single PV module under reference condition to be I_{std} the number of modules to be connected in parallel will be given as:

$$N_p = \frac{I_{pv}}{I_{mp}} \qquad (4)$$

where, I_{mp} is the current available from a module under maximum power condition.

The number of modules to be connected in series of the photovoltaic array will be

$$N_S = \frac{V_S}{V_{mp}} \qquad (5)$$

where, V_{mp} is the voltage of the module at maximum power condition and V_s is system voltage.

Total number of module is given by

$$N_{m_{total}} = N_S \times N_P \qquad (5)$$

The sizing of the SPV modules is carried out on the basis of the peak load for the building. We observe over a year and found that the electric load demand is maximum in the month of summer when both irradiance and ambient temperature is maximum. Mainly, load is maximum in the month May and which is considered as design month. Energy consumption takes place inside the building due to the operation of fans, lighting, water pump, machineries and air conditioner. The estimation of PV modules depends daily duty hours of those parameters, which has been shown in earlier table. Following table shows sizing parameters and their values to size PV modules.

Table-II: Input parameters for designing PV module and specification of the module

Item	Parameter	Value
SPV module (CEL –PM 300) [15]	Rated current (I_{mp})	8.05 A
	Rated voltage (V_{mp})	37.3 V
	Short circuit current (I_{sc})	8.65 A
	Open circuit voltage (V_{oc})	45 V
	Number of cells in a module	72
	Area of module	1965×990 mm²
	Module efficiency	17.4%
Other sizing parameters	System voltage (Vs)	48 V
	Power factor (P.F)	0.85
	Charge controller efficiency	0.94
	Inverter efficiency	0.88
	De-rating factor (D.F)	0.9

E. Designing of battery bank

Battery bank means numbers of batteries which are connected in series parallel combination to store electrical energy at a specific system voltage. The battery capacity is designed such a way that it could meet maximum load demand when there is no SPV generation. The days without sunshine or numbers of consecutive cloudy days, which named as the days of autonomy (DoA) are considered for designing battery capacity. Again, the battery can be discharged up to a certain level, named as depth of discharge (DoD) which is also to be considered. The total battery capacity in Ah is then evaluated as:

$$I_{bt} = \frac{I_L \times DoA}{DoD \times \eta_b} \qquad (6)$$

where, I_{bt} is the total battery capacity in Ah, η_b is the battery efficiency. In raining season, foggy day or cloudy days some places in India DoD lies within 2-3 days. In the present location it can be considered as 3.

To estimate number of batteries required for battery bank means number of batteries in series and in parallel following equation can be used.

The number of batteries in parallel (N_{Bp}) can be given as:

$$N_{Bp} = \frac{I_{bt}}{I_{bh}} \quad (7)$$

where, I_{ah} is the given battery capacity in Ah
Batteries in series is given by

$$N_{Bs} = \frac{V_s}{V_b} \quad (8)$$

where, V_b is the battery voltage of a given battery.
Total numbers of batteries in a battery bank is

$$N_{B_{total}} = N_{Bs} \times N_{Bp} \quad (9)$$

F. Sizing of inverter

In this building some heavy duty machines are present and some periods of time air conditioners are also operated. Thus, three phase AC line has to be considered. During inverter selection, three phase bridge type inverter is chosen. Inverter capacity often is given as KVA. Its size depends upon total connected load. Total inverter load (KVA_{in}) is expresses as:

$$KVA_{in} = P_A \times 1.3 \quad (10)$$

where, P_A is total peak power of PV array in KW, 1.3 is the safety factor [16].
Inverters are connected in parallel and total number of inverter needed for the system is given as:

$$N_{inv} = \frac{KVA_{in}}{KVA_{single}} \quad (11)$$

where, KVA_{single} is the capacity of a single inverter.

Table-III: Summary of the designed capacity of the power system components

SPV	Battery	Inverter	Charge Controller
N_p = 223 N_p = 2 N_{mp} = 446 Total rated power = 133.8 KWp	N_{bp} = 164 N_{bs} = 4 N_{btotal} = 656	24 numbers Total capacity 180 KVA	62 numbers Total capacity =2464.15A

G. Sizing of charge controller

Rating of a charge controller (I_{cc}) depends on short circuit current of array and given by following equation

$$I_{cc} = 1.3 \times I_{sc} \times N_p \quad (12)$$

Total numbers of charge controller requires is thus

$$N_{cc} = \frac{I_{cc}}{I_{cc_{single}}} \quad (13)$$

where, I_{sc} is the short circuit of PV module and 1.3 is the safe factor [16]. Following table is used to find the rating of different PV power system components.

Table-IV: Specification of battery, inverter and charge controller

Battery [17]	Inverter [18]	Charge Controller [18]
Voltage =12 V Current = 200 Ah DoD =0.8 Efficiency = 90%	3 phase sine wave 15 KVA Capacity= 15kVA Efficiency = 88-90%	MPPT type Current = 40 A Voltahge = 48V

H. Sizing of DC cable

In common practice, nominal system voltage of PV system especially dc components (PV module, and battery) remain to 24 volt or 48 volt which leads to higher current flow through the cables. DC cables are sized according to the current supplied to it. Therefore, more insulation has to put on dc cable than ac cable. Presently Cross-linked polyethylene is used for dc cable insulation. The DC cables are used to transmit power from (i) inverter to Battery via charge controller, and (ii) PV to inverter.

(i) Sizing of cable used between Inverter and battery

The maximum current of constant magnitude that should supply to the battery through cable (I_{bi}) is expresses as [19]:

$$I_{bi} = \frac{W_t}{\eta_{inv} \times V_{lb}} \quad (14)$$

where, W_t is total load demand for the appliances, and V_{lb} is the lowest battery system voltage at which further discharging may not be happened. The lowest battery system voltage is clearly mentioned in inverter specification.

(ii) Sizing of cable used between PV and inverter

As mentioned earlier, inverter is provided 25-30% safe factor whenever it is designed. Thus, the maximum current which may pass through the inverter cable is given as:

$$I_{in_{max}} = 1.3 \times I_{pv} \quad (15)$$

Voltage drop in the inverter DC cable can be expressed as [19]:

$$V_{inv_{Drop}} = \frac{2 \times L_{DC_{cable}} \times I_{inv} \times \rho}{A_{DC_{cable}}} \quad (16)$$

where, ρ is the resistivity of DC cable. 'L' and 'A' represent length and area respectively. Generally 3% voltage drop is considered for DC cables. Thus,

$$V_{inv_{Drop}} = 00.3 \times V_{pv} \quad (17)$$

Table-V: Summary of cable sizing

Cable link between	Current rating of the cable	Cable size
(i) Inverter to battery via charge controller	320 A	10mm
(ii) PV to inverter	210A	8 mm

I. Inter-row spacing and required rooftop area for PV installation

It is common practice that PV modules are positioned facing the South in northern hemisphere in order to receive maximum radiation during mid part of a day. Generally modules are fitted at certain angle equal to latitude of that location and some cases this tilt is kept such a way where optimum solar radiation can be received. Again, solar PV modules are spaced such a way that no shade falls to the other module.

Whenever PV modules are fitted, shadow appears up to a certain distance and therefore sufficient distance need to be given to avoid the shading.

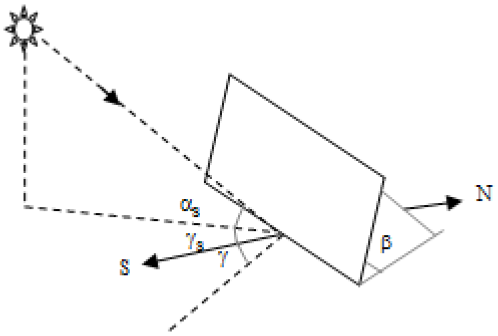

Fig. 4. Solar radiation on tilted solar module [20]

In this study, modules are considered to be mounted on roof with a tilt angle, which is equal to the latitude of the location. It is found that shadow may appear closer to a certain height of top edge of the adjacent module whenever modules are tilted width wise. Shadow length or inter-row distance (D_m) between the modules can be evaluated as [3]:

$$D_m = h \times \frac{\mathrm{Cos}(\gamma)}{\tan(\alpha_s)} \tag{18}$$

where, α_s is the altitude angle and γ is the surface azimuth angle which is deviation of the projection on a horizontal plane of the normal to the surface from the local meridian. It varies from -180° to 180°, with zero due South, east negative and West positive. Inter-row distance will be considered for a day when shadow lengths of an object occupy maximum distance in comparison with other days. In India it is considered to be 22 December.

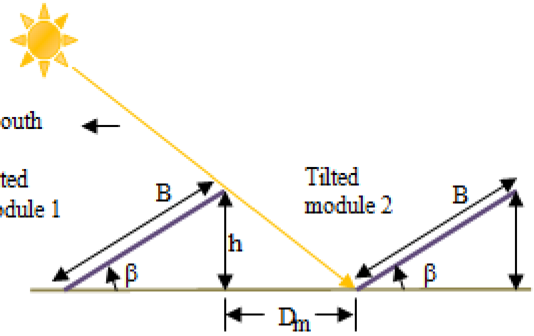

Fig. 5. Inter-row spacing of modules

The altitude angle can be expressed as [20]:

$$\alpha_s = 90^o - \phi_L + \delta \tag{19}$$

where, ϕ_L and δ are the latitude and declination angle of the side respectively.

$$\delta = 23.45 \mathrm{Sin}\left(\frac{360}{365}(284 + n)\right) \tag{20}$$

where, n represent numbers of day taking from first January. Base length (L_m) covered by a module

$$L_m = B\mathrm{Cos}\beta \tag{21}$$

Simultaneously some clearance should also be provided along the length of the module for inspection, cleaning and servicing purposes.

Thus, actual base area (A_m) is needed for a single module can be estimated simply by

$$A_m = (L_m + D_m) \times (L + L_c) \tag{22}$$

where, L is the length of the module and L_c is the clearance provided beside the module. Present case it is considered by 0.25 mm.

Total free area (A_R) on roof for PV installation can be estimated as:

$$A_R = A_m \times N_{m_{total}} \tag{23}$$

In this academic building there is 1650 m^2 free space on rooftop and it is enough to install these 446 numbers of modules successfully as estimated area of rooftop for PV installation is found to be 1397 m^2. Layout diagram of PV modules on rooftop are shown in Fig. 5. According to building design firstly ten modules can be fitted in a string and there may be sixteen numbers of strings; secondly nine modules can be fitted in the another string and there may be sixteen numbers of strings; and lastly there may be ten numbers of string and each string can consist maximum fifteen numbers of modules.

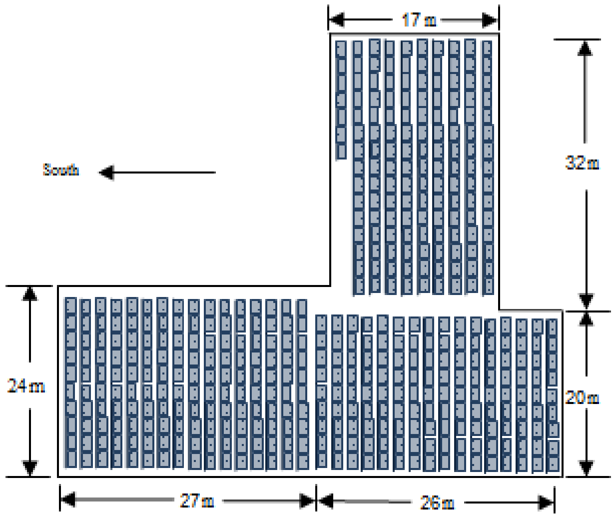

Fig. 6. Proposed layout diagram of PV modules on rooftop

III. COST ANALYSIS

A. Energy generation and payback period

A typical stand-alone solar PV system comprises of solar modules/ panels (array), charge controller, batteries (battery bank), inverter, and connected DC or AC load. In common The economic analysis is based on sizing of power system components and their market prices. For cost analysis following considerations have been taken under consideration. Actually these considerations are taken from literatures. A simplified form of cost/benefit analysis is presented here considering actual grid power cost for running the building. Following equation is the cost that would be required for the grid power consumption in a year.

$$C_g = 365 \times E_L \times C_u \tag{20}$$

where, E_L is the daily average load demand and C_u is the unit cost of electricity

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The NABARD (National Bank for Agriculture and Rural Development) provides 40% subsidy for the capital cost of PV installation with 60% soft loan mainly [21]. The scheme is given to school, educational institute by IREDA (Indian Renewable Energy Development Agency Ltd.).

Thus, considering a subsidy total capital cost is given as:

$$C_{capital} = (1 - C_{sub})C_{inv} \quad (21)$$

where, C_{inv} is the initial investment of the PV system and C_{sub} is the subsidy in fraction of total investment.

Solar module has been provided 25 year warranty. In present case mono-crystalline solar module has been taken under consideration and this module can generate power more than 30 year. Main reason is as this kinds Solar modules have high efficiency and durability. However after certain time period any module can start to degrade due to high temperature and other environmental affects and thus efficiency decreases. As the present system is a stand-alone power generation unit proper considerations must have to taken. It is considered up to five year modules are 95 percent efficient and then efficiency decreases 0.4% per year. Energy generation in every year is considered on that basis. It had been found that there was 285 clear sunny days remained on the present site taking a survey. Thus, it is considered 280 clear sunny day in a year as a standard value for the energy estimation.

Table-VI: Number of clear sunny days and power consumption (data sheet based on survey in 2018)

Months	Number of clear sunny days	Power consumption (KWh) per day
January	21	112.4
February	23	142.6
March	28	246.4
April	25	275.1
May	27	302.3
June	23	282.5
July	18	176.8
August	17	277.6
September	22	289.6
October	28	215.7
November	27	165.4
December	26	137.2

Table-VII: Summary of PV system initial investment cost

Sl no.	Item	Quantity	Cost/unit (Rs)	Total cost (Rs)
1.	Solar panel [23]	133,800 W	45/W	6,021,000
2.	Mounting structure [23]	133,800 W	3.5/W	4,68,300
3.	Balance of System (BOS) [24]	133,800 W	3/W	4,01,400
4.	Cables [24]	133,800 W	2/W	2,67,600
5.	Battery [23]	656 Nos.	16000	1,04,96,000
6.	Inverter [23]	24 Nos.	61000	14,64,000
7.	Charge controller [23]	62 Nos.	7000	434,000
8.	Design and project management [22]	5 man in 20h	200/ man-h	20,000
9.	Labour cost [22]	40 man in 20h	50/man-hour	40,000
10.	Miscellaneous	-	-	20,000
11.	Travelling expenses	-	-	15,000

Payback period:

The payback period is the time to recover the actual amount or the capital amount invested in an asset from its net cash flow. Implementing off-grid PV rooftop system, the benefit is obtained by avoiding the purchase of electricity from the grid. It can be given as:

$$Y_{payback} = \frac{C_{capital}}{365 \times E_L \times C_u} \quad (22)$$

The energy generated by PV array depends on the daily average global solar radiation (KWh/m^{2}day) receiving by the array. From this daily energy generation and yearly generation can be estimated. Energy generation from a PV array per day can be expressed as:

$$E_{pv} = PR \times A_m \times n_{m_{total}} \times \eta_{inv} \times \eta_{wire} \times \eta_m \times I_{tp} \quad (23)$$

where, PR is the performance ratio, A_m is the area of a module, η_m is the module efficiency, I_{tp} is the solar radiation falling on tilted PV modules (KWh/m^{2}day). The performance ratio of a PV array depends on various factors like irradiance loss, electrical efficiency loss due to increase in temperature, module quality Loss, module mismatch loss, Ohmic loss due to electrical wiring and others. Present case its value has been considered to be 0.78.

B. Life cycle cost analysis

A typical stand-alone solar PV system comprises of solar modules/ panels (array), charge controller, batteries (battery bank), inverter, and connected DC or AC load. In common practice, for life cycle cost analysis (LCCA) all costs including capital cost, yearly maintenance cost, replacement cost, residual/salvage value are added in terms of present value over the whole life span of the PV system. The LCCA converts all cash flows into present equivalent values considering a suitable discount rate. Here, a 10% interest rate is considered as a base case study over 30 years.

Maintenance cost (C_m):

The maintenance cost in terms of present value is expressed as:

$$C_M = C_m \times \left[\frac{(1+i)^n - 1}{i(1+i)^n} \right] \quad (24)$$

C_m is the yearly maintenance cost of the PV system.

Replacement cost (C_R):

It is the total cost due to the replacement of PV auxiliary components like batteries, inverters, and charge controllers. The replacements cost depends on the components numbers and life time. It is considered that C_{R5}, C_{R10}, C_{R15},....,C_{Rn} are the replacement costs in every five year for batteries and other components. Thus net present value, in associated with replacement cost can be expressed as [10]:

$$C_R = C_{R5}\left[\frac{1}{(1+i)^5}\right] + C_{R10}\left[\frac{1}{(1+i)^{10}}\right] + C_{R15}\left[\frac{1}{(1+i)^{15}}\right] + \ldots + C_{Rn}\left[\frac{1}{(1+i)^n}\right] \quad (25)$$

Residual/Salvage value:
It is the resale value of components when its life is over. Residual or salvage cost in associated with net present value can be expressed as:

$$C_S = SV \times \left[\frac{1}{(1+i)^n}\right] \quad (26)$$

where, SV is the salvage value of the components.
Thus, the net Life cycle cost of the PV system in terms of present value can be given as:

$$C_{Net} = C_{capital} + C_M + C_R - C_S \quad (27)$$

Cost of electricity:
Electric cost on basis of per unit generation (Cu) in Rs/kWh, by the PV system is estimated as the ratio of annualized uniform cost and the annual cost of energy generation [10].

$$C_u = \frac{C_{annual}}{C_{generation}} \quad (28)$$

When

$$C_{annual} = C_{Net} \times CRF \quad (29)$$

Capital recovery factor (CRF) over lifespan of the PV system is expressed as:

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \quad (30)$$

C. Carbon emission

Power generation using the PV system is beneficial compare to the thermal power plant as it is environment friendly. According to the Central Electricity Authority (India) CO_2 emission is 0.82 t/MWh of energy generated [25]. Thus, shifting from thermal power plant to rooftop PV plant following expression can be used to estimate the reduction of CO_2 emissions.

$$CO_2(\text{Emission}) = \frac{E_L \times 365 \times 0.82 \times 30}{1000} \quad (31)$$

IV. DISCUSSION

The present work has been accomplished using the RETScreen software, Microsoft Excel and Matlab software. Cost of conventional (grid) power including fix tariff for educational building is starting from Rs. 7.5 per unit. This institution requires around 20,000 to 23,000 unit in a month and also cost per month lies within 1.5- 2 lakh. Thus, when one of the buildings will be shifted from the traditional power grid to PV power plant it could reduce grid dependency. Design approach suggests that the stand-alone PV array capacity should be 133.8 kWp for steady supply of power to the academic building. Simple payback period of the present power system is found to be 18.8 yrs. Without any subsidy this payback periods is much more. Thus, dependency and applicability of a stand-alone PV system is established on economic support. The monthly variation of energy demand and energy output of PV array have been shown in Fig. 7. It is clearly understood that power generation always excess than the building load. Thus, the PV system could meet required load and store excess energy with battery backup for worse conditions.

Estimated annualized energy generation by PV array is 14245 kWh/yr. It is considered that annual power generation affected after 20 year of the PV generation due to loss of PV efficiency in lieu of high temperature and other environmental factors.

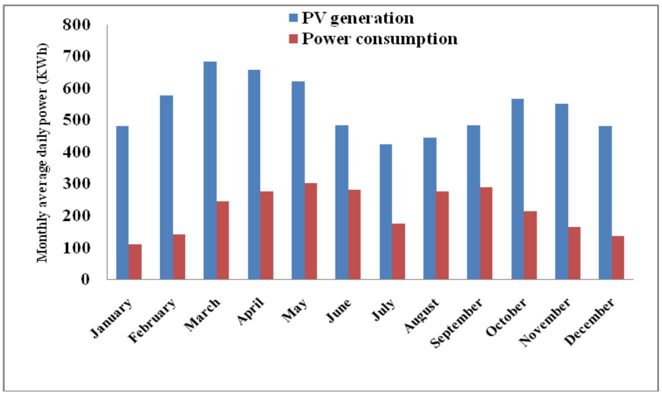

Fig. 7. Monthly daily power consumption and PV output for different months

Cash flow analysis of the proposed system is shown in Fig.8. It is found that batteries are required huge cost during the life span of a Stand-alone PV system. Whereas PV panel provides feasibility as its has long life and just only requires maintenance cost.

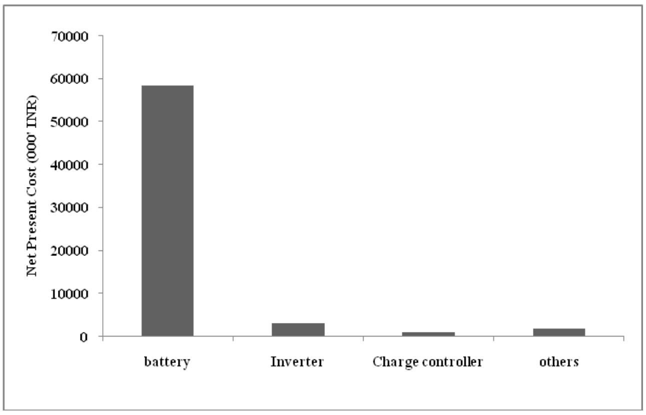

Fig. 8. Cash flow of different components of PV system over a life span of 30 years

Fig. 9 shows the annual cash flow of individual component of the stand-alone PV system for the total lifespan. The diagram gives a clear illustration of the expenses of individual components. Though initial investment is high for the system, there will be huge investment after certain time periods. Batteries will be replaced by every five years and it's have a 15 % salvage value in terms of its cost in India.

Life span of inverter and charge controller are considered 10 year and at the end of the life they will be replaced completely. These systems provide a salvage value of 8% of its initial cost. The minimal cost also is necessary in every year for periodic cleaning the array and for servicing of the inverters.

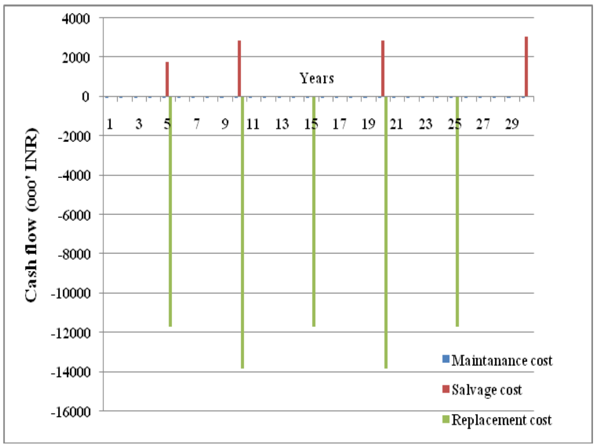

Fig. 9. Cash flow over a periodic time of lifespan of PV (except capital cost)

It is found that using the proposed rooftop PV system 15,406 tones CO_2 emissions can be reduced over the entire life span of the system.

V. CONCLUSION

The present work explains the design strategy of a standalone solar PV system to ensure uninterrupted power supply for an academic building located in a rural area. Daily average meteorological data have been considered for different months to evaluate PV generation for the location. It is found that with the present design strategy power generation is always more than the demand load. Different cost like individual component cost, total capital, and maintenance cost are suitably considered to observe payback period, Life cycle cost analysis and unit cost of power generation. Simple payback period of the PV system found to be 18.8 years. However, considering full life cycle, unit cost of power generation is found to be Rs 24.7/KWh. It has been found that for long term operation PV system requires lots of expenses mainly for batteries, inverters and charge controllers. However, the more utilization of such system can help in solving sustainable energy generation.

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