

Feasibility for Small Scale Rooftop Solar Photovoltaic System in Heritage Buildings of Jaipur

Dr. (Ar.) Vibha Upadhyaya¹

Professor, Amity School of Architecture & Planning, Amity University Rajasthan, Jaipur, India¹

ABSTRACT: Interest among people is increasing for adopting Renewable energy technologies for energy generation, owing to various reasons including saving in energy bills, investment subsidies, net metering and other government policies supporting renewable energy sources. There is a great need to generate environment friendly energy which not only increases energy efficiency but help in sustainable development also. This paper discusses the small-scale building level application of solar Photovoltaic and thermal system in general with detail study of Solar Photovoltaic. Energy consumption in residential buildings is increasing day by day due to extensive use of HVAC and other electrical equipment for more comfort with changing lifestyle. In this study, a sample survey of about 100 Household conducted in the old city of Jaipur and after analyzing their energy consumption, suitable solar system capacity is calculated with their costing and payback period. The main objective of this article is to present the financial feasibility of grid connected rooftop solar PV systems. The study concluded that thought initial cost of the solar system is very high but if we consider its long-term feasibility & the payback period with net metering and Govt. incentives, it is a viable option.

KEYWORDS: Renewable energy, solar photovoltaic, Roof top installation, solar irradiation, Grid Interactive, stand-alone, Net metering, Heritage

I. INTRODUCTION

As per a report by Global Buildings Performance Network, the energy consumption from residential buildings is predicted to rise by more than eight times by 2050 for India [17]. Therefore, it is very importance to develop energy-efficiency strategies focused on the residential sector to limit the current trend of unsustainable escalating energy demand.

We need to adopt the alternative or renewable energy sources for production of power and sustainable development. The main renewable energy sources are Solar energy, Wind energy, Hydro energy, Geothermal energy and Biomass energy. Out of all these, solar energy is the most suitable option, owing to lot of available research activities and successful projects in India. Among rest four of the sources, the wind energy is subject to wind speed which is varying all over India, hydro power is related with availability of water sources, bio mass is related to proper waste collection and management and geothermal power need more research.

Solar energy is the most readily available and free source of energy since prehistoric times. It is estimated that solar energy equivalent to over 15,000 times the world's annual commercial energy consumption reaches the earth every year [2]. All forms of energy generates from solar energy. In addition, Climatic conditions in India are very suitable for solar energy for a solar plant to be successful.

Being located in the equatorial sun belt of the earth, India receives abundant radiant energy from the sun. As per Indian meteorological department, in most parts of India, clear sunny weather is experienced 250 to 300 days a year with average solar radiation of 5-7 KWh/Sqm which is quite sufficient to install a solar powerfully system [17]. The annual global radiation varies from 1600 to 2200 KWh/Sqm [17]. The highest annual global radiation is received in Rajasthan and northern Gujarat. In Jaipur, average radiation received is 5.6 KWh/Sqm for 325 days [7, 17].

II. SOLAR ENERGY TECHNOLOGIES

Solar energy can be used through various ways viz; in the form of Solar cookers, Solar Lamps, Solar Battery charging, heating water, etc, but for power generation the technologies can be broadly classified into two broad categories: first is Solar photovoltaic's for Electricity and other is Solar Collectors for heating via thermal route.

Solar panels or photovoltaic's (PV) - for electricity: Photovoltaic technique in which electricity generates by converting solar energy to be used for a numerous purposes such as lighting, pumping and generation of electricity.

Solar Collectors (thermal Route): - for heating: in this the solar collectors use sunlight to heat water, the heat of the water is transferred through the pipe walls. This heat is used for generation of electricity other than heating and cooking etc. It produces electricity by converting the solar radiation into high temperature heat using mirrors and reflectors.

The collectors are referred to as the solar-field. This energy is used to heat a working fluid and produce steam, which is then pumped through an insulated pipe to a thermal store. Steam is then used to rotate a turbine or power an engine to drive a generator and produce electricity. All thermal plants are based on four basic essential systems, which are collector, receiver (absorber), and transport/storage and power conversion.

Table 1 Advantages and disadvantages of solar renewable technology

Technology	Advantages		Disadvantages
	Environmental	Energy-related	
Solar photovoltaic or Thermal	Good substitute for fossil fuel based water heating. No operational pollution, gaseous emissions, waste, or risk of physical accidents	Can apply to any place with good sunlight. Very little maintenance Available in various sizes	Orientation of system towards sun is major concern. The system need to be complemented by other water heating technology in case of insufficient sunshine

Above Table explains the Advantages and disadvantages of Solar photovoltaic or thermal system. Although the basic advantages and disadvantages is common for both but there is lot of difference in their working technologies. Also As per RERC, Per Megawatt cost of Solar thermal (11.95 Crores) is very high as compared to Solar Photovoltaic (6.65 Crores) [12]. In this article, a detail technical and economic feasibility study is done for Solar photovoltaic's system only.

III. TECHNOLOGY AND COMPONENTS IN SOLAR PHOTOVOLTAIC SYSTEM

Photovoltaic converters are semiconductor devices that convert part of the incident solar radiation directly into electrical energy. The main Components of of Solar photovoltaic system is given in the figure below:



Figure 1 Components of Solar Photovoltaic system

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

- **Photovoltaic Panels:** It is the most critical and expensive parts of Solar PV system which supplies the electricity to charge the batteries. Their placement and mounting is very important as it may affect the system performance.
- **Charge Controller or regulator:** It is needed to prevent overcharging of the batteries. It adds efficiency to the system by regulating the amount of energy supplied.
- **Mounting equipment:** To mount the PV panels for its complete lifecycle. Tracking mounts can move as per sun direction.
- **DC-to-AC inverters:** The electricity generated in a Photovoltaic array is direct current (DC). Inverter converts this to alternating current (AC) to use for electrical appliances or fed back into the grid.
- **Storage Batteries:** Batteries are used to store solar-produced electricity for use later when it is needed, if there is no generator or other electricity supply for emergency backup.
- **Disconnect switches:** It helps to turn the PV system on or off to provide safety reasons during maintenance or emergencies.
- **Wiring, cables and fuse box connections:** Used to connect the components of a Solar Energy System. Fuse boxes need to be included in the system to prevent short circuits.
- **Utility power meters:** Utility meters are special digital meter. System meters measure and display several different aspects of a PV system's performance and status of battery bank production of electricity from solar-electric array and electricity consumption.

The system has no moving parts and, therefore reliable and require little maintenance. The expected life cycle of PV modules is 25 years or more and is suitable for use in urban areas as they take up little space, are not heavy and make no noise.

PV devices use the chemical-electrical interaction between light radiation and a semiconductor to obtain DC electricity. Approx 87% of the base material is made of Silicon in solar cell. There are mainly three types of technologies in use Polycrystalline, Monocrystalline and Thin Film solar cell. The table below explains the comparison of different types of PV modules. The table shows that efficiency of Mono-crystalline silicon cell is highest and area requirements are less though it is more expensive.

Table 2 Comparison of Different Types of PV Modules

Types of Panel	Efficiency	Area per kW _p	Application	Voltage Rating	Component	Remarks
Mono-crystalline silicon cell	15-18 %	7-9 m ²	Residential/ Commercial	80%-85% (Higher is better)	Made of silicon wavers cut from one homogenous crystal in which all silicon atoms are arranged in the same direction.	affected by small Shadows, More expensive but Most efficient
Polycrystalline silicon cell	13-16 %	8-9 m ²	Residential/ Commercial	80%-85% (Higher is better)	Slice cut from a block of silicon, consisting of a large number of crystals	less energy and time needed for production Lower cost, affected by small Shadows
Thin film solar cell: • Copper indium diselenide • Cadmium telluride • Amorphous silicon (a-Si)	6-12 %	9-11 m ²	Commercial/ Utility	72%-78%	extremely thin layer of amorphous (non crystalline) silicon onto a wide choice of surfaces	Less expensive, low-cost Large and heavy equipments, less affected by small Shadows

Source: https://energypedia.info/wiki/Solar_Cells_and_Modules & <http://www.civicsolar.com/resource/thin-film-vs-crystalline-silicon-pv-modules>

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

IV. TYPE OF SYSTEM

There are mainly four type of system for connecting the electrical energy received from renewable energy source to the electrical system; Direct Connection, Off-grid Connection and Grid Connection.

Direct connection: In this, the Generated energy is connected directly to the load it is supplying. An example of this is modern street lighting, in which, the panels are fixed to the street lighting column and supply the individual street light only.

Stand alone (Off-grid) System: in this no mains electricity is available; a renewable energy source can be used to replace or supplement the existing local electricity supply similar to a diesel generator. In this, the system is connected to the fuse board or dedicated load via the controller and inverter. Batteries can be used to store the generated energy, for use later in absence of generator or other electricity supply.

Grid Interactive system: In this, the generated energy can be used to complement main electricity, providing the security of an uninterrupted power supply. In this case, there are two inputs to the fuse board, one from the energy source and one from the mains. Whenever, due to some reasons, there is less energy generation, mains electricity can be used. If more than needed electricity is generated than the excess can be connected to the national grid. This Building-sited renewable energy systems generating electricity and connected to the electrical utility grid system is known as distributed generation (DG) systems

In this two meters are required, one to measure the amount of imported electricity and the other to measure the generated electricity by the system to be exported. Net metering allows for the flow of electricity between a grid-connected DG system and the customer with the help of a single and bi-directional meter. This optimize the electricity consumed by the customer at a different time during the same billing cycle or is carried over as a credit on future billing cycles.

Hybrid System: Although grid interactive systems do not require battery backup as the grid acts as the backup for feeding excess solar power and vice-versa. However, to enhance the performance reliability of the overall systems, a minimum battery-back of one – two hour of load capacity can be suggested. In this Battery backup can be combined with Utility grid connection, so that energy can be stored for use during an outage, which is not possible in the system without battery backup to provide additional reliability and scheduling flexibility. However, this will increase the system cost as battery cost is additional to grid connected system and also as life of battery is 3-8 years [25], it need to replace after lifecycle, it require more maintenance and can make the system more complex along with decrease in savings credits of net metering.

Table 3 Comparison of Standalone and grid connected system

	Grid connected solar PV systems	Stand alone solar PV systems	Remarks
Batteries	Can work without Batteries	Stand alone solar PV systems work with batteries.	batteries require replacement once in every 3-8 years [25]
Location	Suitable for Urban areas having grid connectivity	More suitable for remote areas without grid supply or with unreliable grid supply	More suitable for urban areas
Installation	comparatively easier to install as they do not require a battery system	Battery installation in needed also a back-up generator is usually required for power back up	Battery makes the system more complex with Diesel generator noisy and produce a lot of fumes
Costing	reduce the power bill as it is possible to sell surplus electricity produced to the local electricity supplier under net metering	life cycle costing of the PV system installation cost, battery replacement cost and Maintenance & operation cost will be added to initial cost with price inflation	High cost of standalone system
Reliability	In case of no sunshine electricity can be imported from grid	Emergency back is completely dependent on battery performance or diesel generator	Good quality battery may be costly, Diesel generator noisy and produce a lot of fumes

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

Efficiency	advantage of effective utilization of generated power because there are no storage losses involved	Loss of energy during storage and transfer resulting less efficiency	Grid interactive is more efficient
Operation & Maintenance	Low maintenance required	More maintenance required due to battery system	Simple system with less maintenance is preferable

Compiled by Author

The table 3 gives the Comparison of Standalone and grid connected system. The comparative analysis of these system results that for urban areas having grid connectivity the more preferable option is solar photovoltaic system with grid connection. Therefore, costing and payback of the grid interactive system is calculated for feasibility of Solar PV installation with and without battery backup, in old buildings of Jaipur.

SMALL SCALE/BUILDING LEVEL APPLICATIONS IN HERITAGE BUILDINGS

Before Application of renewable energy techniques at small scale in residential building, it is important to know the potential of system installation in these Havelis. The table 4 explains the requirements for installation of solar PV system in Heritage Buildings, which includes required sun light, Orientation of system, Location and potential to generate energy.

Table 4 Requirements for system installation in heritage buildings

Available sun power	It is important to calculate, how much unobstructed sunlight is received at the location where system needs to be installed. It means there are no shadows. If a tree, neighboring building etc cast a shadow in that particular spot, that time will not be counted. Hence, only hours that get full-unobstructed sunlight shall be counted for PV calculation, also since days are shorter in winter, for full efficiency winter hours should be counted.
Orientation	The most suitable direction for Installation of solar system is southeast- to southwest-facing roof as these sides have the maximum exposure to sun. Alternatively East and west direction can be used. However, North faces shall always be avoided for installation, as this will badly affect the energy generation.
Shading/ Location	Trees or any parts of building such as Chajjas, canopies or chimney etc should cast shadows on the PV array, as this may reduce its energy output. Precaution should be made while installing equipments to safeguard the Bats, birds and other wildlife.
System Installation	Solar panels or solar collectors can be installed on a building's roof or in a separate location on the ground as per space availability. A collector on a roof may be fixed on top of the roof covering. The optimum angle for mounting a collector is 30° off the horizontal [16].
Visual Aspect	Where a tilted collector/Panel might have an undesirable visual impact, it may be mounted horizontally. A horizontal installation can also be done to hide it from ground-level view behind a parapet wall.
Potential	As Havelis in the walled city of Jaipur have flat roofs, this is a favorable condition to install the solar system. Here the frame can be constructed on flat roof to hold the collector at the optimum angle. The frame can be held in place with ballast or fixed more permanently with screws through the roof structure.

Compiled by Author

HOW MUCH POWER NEEDED?

For calculation of power requirement for residential units in walled city Jaipur from renewable energy sources, the data was collected from primary and secondary sources. A household survey of around 100 Household has been conducted and based on the survey the average consumption of electricity is analyzed. The findings of survey show that there originally there were mainly three types of Havelis/ residences but now there is a lot of change in use of many building.

- House for High income groups - Large, spacious, multistoried Havelis with more than one courtyard covering 50% of Haveli area
- House for Middle class - small houses G+2 structures, small inner courtyards covering 25% of plinth area

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

- House for low income groups - Occupied by artisans & laborers, usually single or two room tenements, mostly semi- pucca, over crowded with no open spaces

Among all these types major transformation in structure and use is happened in large & middle class Havelis. Similar kind of houses have different use pattern of traditional Havelis as follows:

- Haveli residential use continued as original with no change in structure but partly/fully dilapidated
- Haveli residential use continued but with major changes in building structure renovation/ addition/ alternation as per modern life style
- A large Haveli size plot subdivided into various residential units without planning
- Havelis subdivided or rented out with partly modification or use changed as commercial
- Haveli Partly converted to commercial (small Manufacture/retail/wholesale /storage) use
- Havelis completely converted to commercial (small Manufacture /retail/wholesale /storage) use

With all these categories, the electricity consumption in different buildings varies from 150 KWH to 6000KWH per Month. To calculate the desired capacity of renewable energy source, energy consumption per day is calculated in further sections. However, before selecting system component and sizing a PV system for existing building evaluation of energy consumption pattern in essential. In addition, it is important to reduce buildings energy consumption.

POLICIES AND GOVERNMENT INTERVENTIONS FOR SOLAR PHOTOVOLTAIC IN RAJASTHAN

Central & state Governments have launched many policies and incentives scheme in the field of energy for development of renewable energy sources in Rajasthan. The Ministry of New and Renewable Energy (MNRE) provides Central Financial Assistance (CFA) in the form of capital subsidy and financial incentives to the renewable energy projects in India. CFA is allotted to the projects based on its installed capacity, energy generation and its application etc. Financial support will be made available selectively through a transparent and competitive procedure.

Table 5 Policies and Government interventions for solar energy system installation

Policy intervention	Incentives/ Financial Support for small scale solar PV				
Policy for promoting generation of electricity through non-conventional energy sources 2004 (promotes generation of power from non-conventional energy sources)	<ul style="list-style-type: none"> • Exemption from Electricity Duty On electricity generated for captive use • Exemption for entry tax on equipments required for solar project Incentives available Same as for industrial unit viz; <ul style="list-style-type: none"> • Reduction in VAT on Solar Products from 14% to 4% • Exemption on Stamp duty and land tax @ 50% for a period of 7 years • Investment subsidy up to 30% of the tax deposited • Employment subsidy 20% of the tax deposited 				
Rajasthan Solar Energy Policy, 2014 (Promotes development of solar parks in the state with private participation.)	<ul style="list-style-type: none"> • Single Window Clearance, Availability of Water for Power Generation, Availability of Land on Concessional Rate, and Clearance from Pollution control board It is notified under green categories.				
Development of Solar Cities Programme (To minimize the projected demand of conventional energy)	Financial Assistance of up to 50 Lakh is to be provided to municipalities depending upon population and initiatives taken.				
Jawaharlal Nehru National Solar Mission (JNNSM) (To achieve grid tariff parity)	The Mission would consider up to 30 % capital subsidy for promoting renewable energy application				
Rajasthan Electricity Regulation Committee Net Metering Regulations, 2015 (Credits for excess energy generation for Renewable	The maximum capacity of Rooftop PV Solar Power Plant installed shall not be more than 80% of the sanctioned connected load but shall be in the range of 1 KWp to 100 KWp. <table border="1" data-bbox="502 2004 1436 2060"> <thead> <tr> <th>Connected load of Eligible Consumer</th> <th>Connectivity level</th> </tr> </thead> <tbody> <tr> <td> </td> <td> </td> </tr> </tbody> </table>	Connected load of Eligible Consumer	Connectivity level		
Connected load of Eligible Consumer	Connectivity level				

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

energy for more than 50 units)	Up to 5 kW	240 V- single phase
	Above 5 kW and up to 18.65 kW	415 V-Three phase
	Above 18.65 kW and up to 50 kW/kVA	415 V-Three phase
	Above 50 kW/kVA	HT/EHT level
Exemption from banking and wheeling charges and cross subsidy surcharge. The CDM benefits arising from solar energy generation from the roof top PV facility will pass to consumers through distribution licensee		
Renewable Energy Certificate and Renewable Purchase Obligation Compliance Framework) Regulations, 2010	Provision of Renewable Energy Certificates to fulfill renewable purchase obligation to demonstrate compliance with regulatory requirements (RECs) for excess energy. REC represents 1MWh of renewable energy generated.	
Rajasthan Electricity Regulation Committee Renewable energy Tariff Regulations, 2014	<p>The operators of such systems will also be eligible to receive the feed-in tariff fixed by the Electricity regulatory commission both on the solar power consumed by the operator and the solar power fed into the grid.</p> <ul style="list-style-type: none"> • Accelerated Depreciation (AD) benefit (Rs/kWh) 0.87% • Levelised Tariff (Rs/kWh) without AD 7.50 • Levelised Tariff (Rs/kWh) with AD 6.63 	

Source: Compiled by author based on various Govt policies and schemes

Table 5 demonstrates various Policies and schemes, which provides financial support for solar power plant installation; this also includes Renewable energy certificates to fulfill renewable purchase and electricity tariffs. Utilities will debit/credit the operator for the net saving on conventional power consumed and the solar power fed into the grid, as applicable. A Generation Based Incentive will be payable to the utility to cover the difference between the solar tariff determined by CERC, less the base price of Rs. 5.50/kWh with 3% p.a. escalation. The metering and billing arrangements between the utility and the rooftop PV operator will be as per guidelines/regulations of the Appropriate Commission. Thus, it is necessary that uniform principles for applicable tariff, standard guidelines for metering/billing/energy accounting are adopted; to the extent feasible, across States to facilitate smoother implementation of the Programme.

LOAD REQUIREMENT AND SYSTEM SIZE FOR SOLAR POWER

In Further section, Load requirement is calculated for energy consumption in different buildings. As per primary survey consumption of energy ranges from 150 KWH/Month to 6000KWH/Month. In further table 6 per day energy requirement and system size is calculated for 150KWh/Month.

Table 6 Calculation of Load requirement for energy consumption per household

Electricity Consumption		The per day load will be $(5 + 5*30\%) = 6.5$ KWH	Since solar panels only generate their rated output when pointed directly at the sun, and if your solar panels are fixed, they will not be facing directly at the sun most of the time. Hence, for safety @ 30 % power losses is assumed [8].
per month 150 units	Per Day 150/30 =5		
System size = Energy Requirement /Insolation level		6.5/5.6 = 1.16 ≈ 1KWp	To calculate system size for solar power system, solar insolation/irradiation of the place is essential. In Jaipur, average solar irradiance is 5.6 kWh/m ² /day [7].
Energy demand For 6.5 KWh/day			

Author (The load requirement in houses is purely based on electricity billing information collected during primary survey.)

Further To calculate the renewable energy demand for different consumption the data is divided in some ranges, as given in table and average Capacity of Solar system is calculated based on the above calculation.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

Table 7 Load requirement for energy consumption of different building

SI	KWH per Month	KWH Per Day	Adding 30 % as safety margin (~)	Approx Capacity of Solar PV system (KW)
1	<150	5.00	6.50	1
2	250	8.33	10.83	2
3	500	16.67	21.67	4
4	1000	33.33	43.33	8
5	1500	50.00	65.00	12
6	2000	66.67	86.67	15
7	4000	133.33	173.33	30
8	5000 (Partially Commercial use)	166.67	216.67	40
9	> 6000 (Partially Commercial use)	200.00	260.00	>50

Author

Power generation performance of Solar Plant

Solar power plant performance is often denominated as Capacity Utilization Factor or CUF. CUF is the ratio (expressed as a percentage) of the actual output from a plant to the maximum possible output under ideal conditions if the sun shine throughout the day and throughout the year. For Rajasthan the CUF is 20% and for Jaipur it is 15%. The CUF and the approximate output per day for solar plant are calculated as follows:

$$\text{Capacity Utilization Factor (CUF)} = \frac{\text{Actual Energy Generation from the Plant (KWh/day)}}{\text{Plant Capacity (KWh/day)}}$$

As per Rajasthan electricity regulatory commission, Jaipur the CUF is 20% for Rajasthan.

Hence for 1KW capacity Solar PV system the Output will be 20% = Actual Energy/ 1KW

That means Actual Energy is $1 \times 20 / 100 = 5$ KWh/day

Based on above calculation the Actual energy generation from the solar plant for various loads in residential building is given in table. However, the Generation on different days at different location may vary based on meteorological conditions. The table below shows the Solar PV System capacity and output energy.

Table 8 Solar PV System capacity and output energy calculated

Plant Capacity (KW)	1	2	4	8	12	15	30	40	50
Output KWh/Day	5	10	20	40	60	75	150	200	250

The calculation of CUF supports the previous calculation done for system capacity

However, outside India Performance ratio (PR) is used in place of CUF. It gives percentage and describes the relationship between the real and the theoretical possible energy output of a solar PV plant. It shows the proportion of the energy that is actually available for export to the grid after deduction of energy losses and energy consumption for operation.

Performance Ratio (PR) of a plant for a period of time = $\frac{\text{Energy measured (kWh)}}{(\text{Irradiance(kWh/m}^2\text{)} \times \text{panel x Active area of PV module(m}^2\text{)} \times \text{PV module efficiency})}$ [28]

The difference between PR and CUF is that PR is a measure for the performance of a PV system taking into account environmental factors (temperature, irradiation, etc.) while CUF ignores all these factors and degradation of the panels. PR can work as a tool to compare different solar PV systems with each other even at different locations since all environmental factors are taken into account.

AREA REQUIREMENT FOR SOLAR SYSTEM INSTALLATION

Due to less rain fall and hot dry climate of Rajasthan majority of buildings have flat roofs. During the survey also it is found that all the buildings in walled city have flat roofs in which majority of the building have shade free flat roof area ranging from 10 Sqm to 1000 Sqm or more. The possible spaces for installation of PV modules include mainly Rooftops of buildings. Most of the buildings in walled city are of same height and flat terraces offer excellent Siting and locations for SPV installations. Since most of the building has connected roofs, the potential for roof top

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

installation also increases if habitants are interested for installation in partnership or a third party installation due to unaffordable costing for low-income people.

For installation of a rooftop solar PV system, about 10- 12 Sqm area is required for per kW (kilowatt) [26]. This area also includes clearances between solar PV array rows and other areas for maintenance at later stage. These solar panels should face south or west with tilt angle to get maximum sunshine. The roof area required for Different PV system capacities is as follows:

Table 9 Shade free Roof areas required for solar PV system

Capacity of Solar PV system (KW)	1.5	2	4	8	12	15	30	40	50
Shade free Roof area required (Sqm)*	20	26	52	108	156	195	390	520	650

* The area requirement varies depending on PV module efficiency.

The area of PV installation can reduce by using high efficiency panels for same capacity. For example installing 1 kW system with high efficiency panels will require 13 Sqm area while for same low efficiency it may require 15 Sqm or more.

COST CALCULATION FOR SOLAR PV SYSTEM

The life cycle of a PV system is 25 Years and economics of a solar photovoltaic or electric system depends on its life cycle cost which includes capital cost and operating cost over its life span. The figure below demonstrates the Cost component of Grid interactive Solar PV system which includes Module and Non module component with Operation cost.

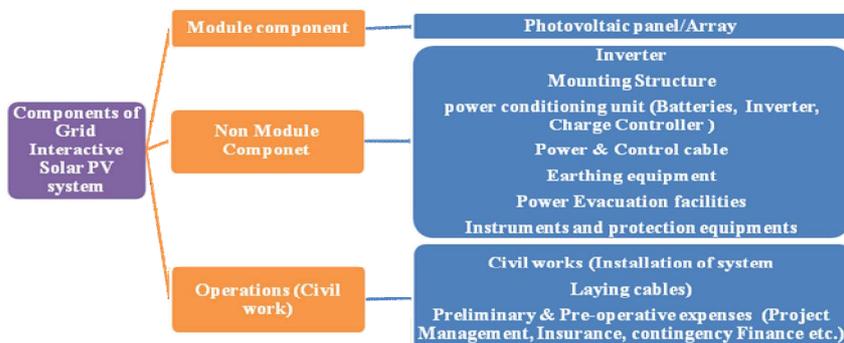


Figure 2 Cost Components of Grid interactive solar PV system

Capital cost includes the initial cost of designing and installing a PV system. Operating cost include the cost associated with maintaining and operating the PV system over its useful life. Initial Capital cost to install a system capacity of 1 KW (Grid Interactive PV system) may be calculated as follows:

Table 10 Calculation of Capital cost for one KWp solar PV system

Component	Approx Costing For 1 KW (1000 WP) system	
PV Module cost	40000	@ INR 40000/ KW
Additional Module Cost as against Degradation	1000	@ INR 1000/KW
Civil and General Works	6000	@ 6000/KW
Mounting Structure (fixed axis /without tracking systems)	8000	@ 8000/KW
Power Conditioning unit (Inverter, Grid Charger/ cost)	20500	@ 20500/KW
Evacuation cost & Grid Connectivity Charges (Cables & Transformers	9000	@5000/KW
Preliminary and Pre-operative expenses including IDC and Contingency	4500	@ 2000 KW
Sub Total (Initial capital cost)	89000	

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

Source: Compile by author Based on data of RERC [13] & CERC [3]

If somebody wants to add the battery to make it a hybrid system additional cost of battery need to be considered in capital cost. To calculate the costing of the PV system with battery bank of 24 Volt, 100 AH, battery cost will be added for 1-2 hour back up during outage for more reliability. This Battery cost will Include Rs.15000 for Battery (To replace after five years) and 5000 as one time charge for battery box, cable, Additional accessories and installation. Hence capital cost of PV system with batteries will be (89000+ 20000) = 109000/-

NET COST AFTER INCENTIVES AND SUBSIDY

Table 11 Calculation of Net PV system cost after subsidy and Accelerated depreciation

Component	Cost Rs (INR)	
	Without Battery (Rs)	With Battery (Rs)
Cost of 1 KW Solar PV Plant	89000	109000
Subsidy @ Rs 24/watt(Without battery bank), @Rs 30% on capital cast (With Battery bank) cost*	24000	32700
Net cost after subsidy	65000	76300
Further Accelerated Depreciation @87%	56550	66381
Tax rate @32.45%	18350	21541
Net cost after accelerated depreciation	46650	54759

* Rajasthan Renewable Energy Corporation

For example in the above case the Life of battery is 5 years, we need to replace the battery with every 5 years. Therefore, till 25 years the lifecycle cost will include four more groups of batteries with costing (15000X5 = 75000). Now since the life of system is considered as 25 years or more the lifecycle costing need to be calculated to know the payback period. The life cycle cost will include O & M cost. Hence, the life cycle cost for 1KW Grid interactive PV system is = (Initial cost of the PV system + operation and Maintenance costs) and with battery bank, the cost of replacement of battery bank will be added.

Table 12 Calculation of Life cycle cost of PV system

Life cycle cost @ 25 Year	Without Battery (Rs)	With Battery (Rs)
Initial Capital cost after subsidy	46650	54759
operation and Maintenance costs @ 1.5% for 25 years of operation	17494	20535
Battery replacement cost approx. after every 5 years	0	75000
Life cycle cost	64143	150294

Source: RREC

Calculation of Payback Period

Calculation of Payback period is derived from Total Lifecycle costing, Life cycle output energy and electricity billing. Existing and Approved Tariff for FY 2014-15 for Residential users for electricity consumption above 250 units is as follows:

Table 13 Electricity tariffs (2014-15) for Rajasthan

Energy Consumption Per Month	Energy charges (Rs/Unit)	
	Existing	Proposed (2015-16)
For Consumption Up to First 50 Units	3.00	3.5
For Consumption above 50 Units and up to 150 units	4.65	5.45
For Consumption above 150 units Up to 300 Units	4.85	5.7
For Consumption above 300 units Up to 500 Units	5.15	6.00
For Consumption above 500 Units	5.45	6.40

Source: Rajasthan Electricity Regulatory Commission, Jaipur, Tariff Regulations 2014

Generation of bill to pay for monthly electricity consumption for 250 KWh (Units) based on rates prescribed by RERC.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

Table 14 Calculation of Payback period for 2KWp System

2KWp PV system is calculated for electricity consumption of		250 units
Units /Month generation by 2KWp plant		2X5X30 =300
Electricity billing	0 - 50 units = Rs. 3.5 / kWh 50 - 150 units = Rs. 5.45 / kWh 150 - 300 units = Rs. 5.7 / kWh	So, total electricity bill = Rs. 1290
Net Saving	Meter billing + Excess PV generation (Monthly)	1290 + (300-250)X6.63* = 1622
Annual Saving	1622X 12	19458
Payback period for the investment **	Lifecycle cost/ Saving per year	
	Without Battery	64143 / 19458 = 3.5 Years
	With Battery	150294 / 19458 = 8 Years

* As per RERC, the Levelised Tariff (Rs/kWh) with Accelerated Depreciation (87%) is 6.63

** Per KW Cost for one KW PV system 64140 (Without battery), 735580 (With Battery for 25 years life), as calculated above.

Table 15 Lifecycle costing and payback period calculation for grid interactive PV System

S	KWH / Month	of Solar PV system (KW)		Lifecycle costing (Lakh)		Savings per Month (Rs)		Total Saving Per Year	Payback Period (Years)	
		System Capacity	Energy generation / Month	without Batteries	With Batteries	Generated units @6.63/unit	Electricity bill		without Batteries	With Batteries
1	150	1	150	32072	75147	0	720	8640	4	9
2	250	2	300	64143	150294	332	1290	19458	3.5	8
3	500	4	600	128286	300588	663	2775	41256	3	7
4	1000	8	1200	256572	601177	1326	5975	87612	3	7
5	1500	12	1800	384859	901765	1989	9175	133968	3	7
6	2000	15	2250	481073	1127206	1658	12375	168390	3	7
7	4000	30	4500	962146	2254412	3315	25175	341880	3	7
8	5000	40	6000	1282862	3005883	6630	31575	458460	3	7
9	6000	50	7500	1603577	3757353	9945	37975	575040	3	7

Author

This table gives the simple payback period i.e., the number of years needed for a system to pay itself off. Considering the modern, high quality solar panels having an expected life of approximately 25 years or more. In this case, the simple payback calculation may not be enough because it does not take in to account the time value of money and does not measure profitability, price inflation or escalation in electricity billing; hence, the actual calculation may vary from this. In addition, many incentives like Exemption from banking and wheeling charges and cross subsidy surcharge, CDM benefits and renewable energy certificates adds to its advantages.

FINDINGS

Solar energy is a very attractive energy resource because it is virtually inexhaustible supply, distributed over complete and pollution free nature. Both solar Thermal and solar photovoltaic are usually mounted on roofs to catch the most direct sunlight an unshaded sloping south-facing roof is best.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

Solar technologies can be described two types firstly passive solar or active solar based on how they capture, convert, and distribute the solar energy generation. In active solar technique, photovoltaic panels and solar thermal collectors are used to harness the energy while passive solar technique includes building orientation as per sun path, building material with positive thermal mass or light dispersing properties, and designing buildings that naturally circulate air, for example the case in this article includes courtyard havelis, which have a system of natural light and ventilation with its passive techniques.

Havelis of Jaipur are more than 250 years old having a great heritage importance, and with maintenance they can still continue their good condition for another 500 years or more. A PV array or collector system has a useful life of around 20-25 years. Equipment should be located to permit easy access for maintenance and repair for their life span. In addition, it is important to ensure that wherever the roof covering is penetrated, adequate measures have taken to seal it against the weather.

V. CONCLUSION

Solar Photovoltaic is a mature technology with high reliability and long lifetimes. It consists of automatic operation with low maintenance requirements. No additional cost required for fuel and it is very Environment friendly as compared to conventional sources. However, its Performance is dependent on sunshine level and local weather conditions. In addition, It has a high investment cost but for long-term use it is a viable option. The calculation of Lifecycle cost and payback clearly shows that PV systems with batteries have higher payback period than system without batteries due to high costing. In addition, payback period reduces as PV system capacity increases. Cost of PV system is reduced much with available subsidies and tax benefits, further easy loans can be availed for 70% of the system cost. Load on energy and infrastructure can be reduced only by using alternate renewable energy resource. However, along with this it is very important to reduce energy consumption in the building. The sun is the most abundant and unlimited source of energy. The sun functions as a global source of energy and has tremendous potential. As a result, solar energy is one of the most important non-conventional sources of energy that are utilized in India. Rajasthan receives the highest solar radiation in the country, it has a huge potential to tap solar energy thru various techniques. Grid interaction solar PV technology is one of very good option for this. Although PV technology is one of the most expensive technology but with available grants and incentives like tax deductions, renewable energy credits, CDM benefits, net metering programmes and Accelerated depreciation and other grant, it can be widespread. In addition, many nationalized bank provides loan for the costing with easy payment methods. This can even create lot of employment opportunities promoting economic development. Rooftop Solar PV with or without battery has a huge potential and a large-scale deployment of solar energy can be promoted with the help of policies and Government interventions.

ACKNOWLEDGEMENT

The research performed in this article forms a part of Ph. D. of author Vibha Upadhyaya.

REFERENCES

- [1] Bureau of Energy Efficiency, Application of non-conventional & renewable energy sources, Page 147
- [2] Central Electricity Regulatory Commission, Performance of solar power plants in India, 2011
- [3] Central Electricity Regulatory Commission, Renewable energy tariff regulation, 2012
- [4] Central Electricity Regulatory Commission New Delhi, Draft Explanatory Memo for Tariff Guidelines for Rooftop PV & Small Solar, 2010
- [5] Global Buildings Performance Network, Residential buildings in India: energy use projections & savings potentials-Technical Report Page 6, Sept 2014
- [6] Govt. of India A mission document on Jawaharlal Nehru National Solar Mission Towards Building Solar India, 2008
- [7] Kamdar Saurav, Risks & Opportunities in securing Financing Phase I and Phase II National Solar Energy Summit 2012 'Solar Thermal Power', 2002
- [8] Makhija B.K, Challenges and Issues in Solar RPO Compliance /RECs, Solar Power in Rajasthan, Rajasthan Renewable Energy Co. Ltd. Jaipur, 2012
- [9] Pandey S. et al., Renewable and Sustainable Energy Reviews, Page 3594, 2012,
- [10] Panjwani K. M., Narejo Dr. G.B., Effect of Humidity on the Efficiency of Solar Cell (photovoltaic), International Journal of Engineering Research and General Science Volume 2, Issue 4, June-July, Page 499, 2014

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

- [11] Policy for promoting generation of electricity through non-conventional energy sources 2004
- [12] Rajasthan Solar Energy Policy, 2014
- [13] Rajasthan Electricity Regulation Committee Renewable energy Tariff Regulations, 2014, Page 12
- [14] Rajasthan Electricity Regulation Committee Net Metering Regulations, 2015
- [15] Renewable Energy Certificate and Renewable Purchase Obligation Compliance Framework Regulations, 2010
- [16] Small-scale solar thermal energy and traditional buildings, English Heritage, Page 4-5, 2008
- [17] The Solar Quarterly, The Complete Solar Magazine - TERI, Page 15, January 2012

Web References

- [18] Development of Solar Cities Programme, Govt of India <http://www.mnre.gov.in/related-links/decentralized-systems/solar-cities> accessed 15/04/2015
- [19] <http://www.civicsolar.com/resource/thin-film-vs-crystalline-silicon-pv-modules> accessed on 24/05/2015
- [20] <http://www.cleaneenergyflorida.org/photovoltaics-for-homeowners/> accessed on 14/05/2015
- [21] <http://www.dummies.com/how-to/content/the-basic-components-of-a-home-solar-power-system.html> accessed on 15/05/2015
- [22] <http://www.eai.in/> accessed 10/04/2015
- [23] https://energypedia.info/wiki/Solar_Cells_and_Modules accessed on 14/05/2015
- [24] <http://www.freesunpower.com/overview.php> accessed on 14/05/2015
- [25] <http://www.lifelinebatteries.com/marine.php> accessed on 15/06/2015
- [26] <https://livingonsolarpower.wordpress.com/2013/03/23/basic-solar-energy-math/> accessed on 14/05/2015
- [27] <http://www.ireed.gov.in/> accessed on 10/04/2015
- [28] <http://www.mnre.gov.in/solar-mission/jnnsn/introduction-2/> accessed on 13/05/2015
- [29] <http://www.re-solve.in/perspectives-and-insights/solar-pv-plant-performance-capacity-utilisation-factor-cuf-vs-performance-ratio-pr/> accessed 13/06/2015
- [30] <http://www.rrecl.com/Index.aspx> accessed on 23/04/2015