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Load Survey based Solarification Project for a Remote Village

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***Abstract*:- As compared to Renewable Energy Sources (RES) like biomass and wind, the concept of generating and utilizing power in a more distributed way and at flexible scales suites best with Photovoltaic (PV) technology. The PV panel concept is truly distributed with common (public) as well as private ownership and environmentally it is best suited with lower scale of investment and just as per decided size of PV system. For wind, observations like huge Wind Turbine (WT) investment, land availability at appropriate location, a wiring network to consumer houses and future maintenance seems to be major issues. Wind farm is more feasible for an agency who can invest and take its benefit but still there is uncertainty of customer users on a long way. Solar energy integration at village level requires proper planning that spans across social, government policy, technical and economic dimensions. Initiating such a planning process in a participatory way and designing integrated PV solutions for different categories of consumers in a 'large but distributed' scale is quite a challenging task. In this paper, a case of village Solarification considering load study and PV system adoption matching tech-economic needs of various categories of community, is submitted.**

INTRODUCTION

Solarification is a concept in which a village supported by committee of villagers; moves towards energy security by meeting most of its daily energy needs in terms of electricity by distributed solar PV solutions[2]. The concept does not mean 100% of the electricity demand is met by solar PV. There should be an optimum level of offsetting grid load [1] with solar by integrating 'custom made' solutions to different category of consumers. These 'custom solutions' can be in terms of selected technology, based on demands, load patterns, time spread and classification of loads, reliability with back up of supply and appropriate financing models. Finally, the operation and maintenance of the distributed power generation systems will also be undertaken by a 'local co-operative body' itself, which can then generate a pool of local jobs. The institutional or social enterprise (business) model has to be carefully designed. Individual houses may be equipped with PV panels and inverters [3] with net metering concept especially where roof top PV installation is feasible. Following standards [11] for safety of equipments and personnel is a basic step in project implementation

The aim of this study is to create a proper design methodology and implementation strategy to add a village Solarification through innovations in technology design, planning, implementation, and post implementation management. This needs technical know-how, micro level strategic planning and capacity building for implementation, operation and maintenance. Following objectives may be submitted:

1. Current load data collection and analyzing them to decide planning strategy of solar equipments.
2. To identify the existing solar PV technologies with or without wind power matching [4] and solutions which can be implemented to meet the regular load patterns of existing customers in a village
3. To identify, analyze and develop appropriate PV solutions [9-10] for rural areas for easy integration to the existing grid or an off grid.
4. To study the designs and implementation challenges of a de-centralized solar PV power project [5] at a village level and to come up with an appropriate planning and execution strategy at comparatively lower cost [12].
5. To document the learning's from this project in terms of conducting a load survey, technology solutions, and implementation strategy for larger understanding and replication of such projects in other places of the state and the country.

REFERENCES

The paper includes organization covering section II for action plan, RES survey at site, data cleaning and data analysis. Considering load demand analysis, the section III covers proposed inverter sizes as per load category. The section IV proposes the design packages of PV modules along with inverters for five categories of consumers from lowest slab to most upper slab consumer. The section V covers an energy case study example of grid connected roof top PV system [6,7 and 8] without feed in tariff in a school located in the village. At last conclusion is presented with foreseen limitations.

SECTION II
PROPOSED ACTION PLAN FOR VILLAGE SOLARIFICATION

Figure 1 shows the action plan for total project activities starting from goal planning to execution including technology decision and villager's category wise techno-economic solution.

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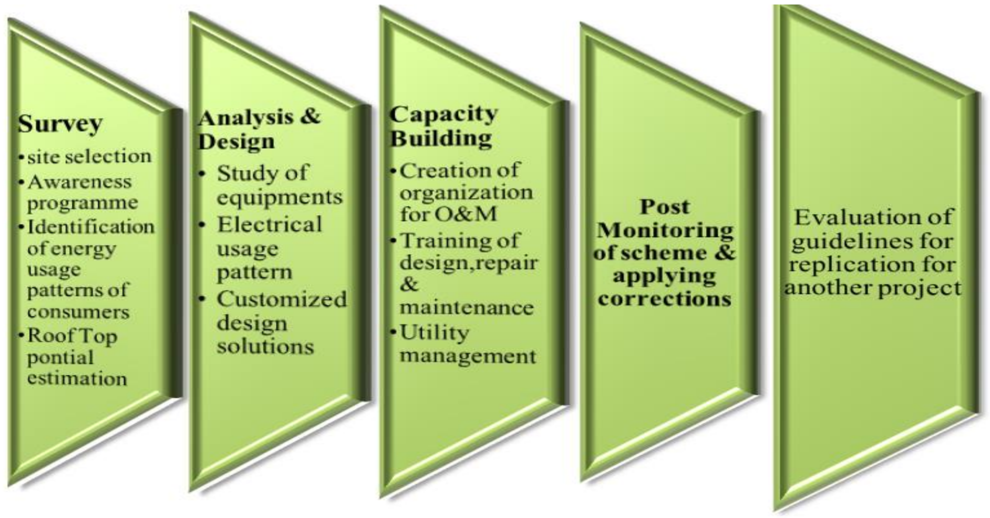

Figure 1 Action Plan of the proposed project at a village near Kukas Jaipur

Energy Survey at Site

Although the detailed information about power consumption was available from secondary data (RSEB Energy bills), a 100% survey of households for each category of consumers is conducted. Planning for roof-top PV installations at village level is also included. A questionnaire survey was planned with following key objectives of the Survey:

- To collect the power consumption and load data of all the houses, schools and offices in the village.
- To identify the approximate shade-free roof-top area in different buildings in the village.
- General details of the building's ownership, use, type of construction etc.
- Data from utility bills such as kWh consumed, connected load, bill amount (for past 3 bills).
- Load consumption pattern of households and commercial establishments (approximate load and duration of usage of different appliances).

A used questionnaire for household's survey is added in figure 2. For surveying the public buildings, the above mentioned questionnaire is modified with questions pertaining to average working days and a detailed table for used equipments.

Model Questionnaire for solar PV Requirement of the village and School		**Date---------**	
Ward no.		House No.	
Owner's name			
Consumer Bill no.			
Address			
		Mobile	
Is electricity available		Yes ☐	No ☐
Tariff		Single Phase ☐	Three Phase ☐
Connection Load			
Average Monthly Consumption		Units	
		Amount	
Alternate source of Electricity		Yes ☐	No ☐
DG set Monthly Expenses			
LPG Lamp Monthly Expenses			
Owner's signature			

Figure 2 showing load survey questioner

Data Entry and Cleaning

Several errors were found in the data so collected. To improve the accuracy of data, cleaning was done by data correction, deletion, and matching the figures with cross checking before analysis. Following steps were helpful in data cleaning:.

1) Manual correction of forms, from the secondary data available online by entering consumer's bill number.

2) 35 cases on sampling basis were cross-checked with online bill data by entering the consumer number which was in the questionnaire form.

3) Limits for each field were also used at the next stage for data correction. For domestic users, the counts of certain equipment were rounded off to an upper limit in some cases. *e.g.* if the response in a questionnaire states that there are more than 2 television sets in a house or there

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are more than 10 incandescent lamps/ fans etc., the counts were limited to a maximum number (2 for T.V, 10 for incandescent lamps, fans and other lighting sources). Similarly the lower limit for connected load was set as 20 W. After all these filtering and validation procedures, 100% entries were available for detailed analysis on which the data analysis was carried out. In the following discussions all percentages are with reference to these 143 entries unless otherwise stated.

Data Analysis of Survey data

Nearly 100% consumer base has been covered in the survey. A good percentage of the survey data (Average: 67%) has been taken for analysis after data cleaning from all wards. Table 1 shows the category and number of houses/office buildings that were covered during the survey.

Table 1 Building classification of Consumers

Category	Number
House	143
Shops	5
School	2
Hospital	0
Official Building	0
Bank	0
Community Hall	1
Temple/Dharmashala	1

Data Analysis and Discussions

Analysis of data should be done separately for households and public buildings but in our case there is no public building. Demand of the consumer and their roof-top potential are the key parameters used for this analysis.

Demand Analysis

Demand analysis looks basically into the load and energy demand of the consumers including primary and secondary data sources. The classification of households under various ranges of connected loads is done to understand the distribution of household loads under various connected load categories as shown in figure 3.

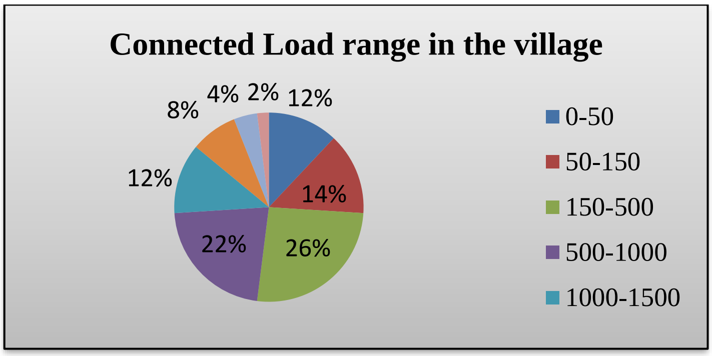

Figure 3 showing Load distribution of the surveyed Village

Figure 3, shows that majority of the domestic consumers (74%) have their connected load less than 1000 W (between 50 - 1000 W) and 86% under 1500 W connected load. This indicates that majority of the households are using electrical appliances of comparatively low power ratings. This also gives an indication that most of the households in the village are using only those appliances to meet their basic needs (like lights, fan and TV). Following observations are recorded:

- 94% of the consumers are covered in tariff range between 0 to 400 kWh (bimonthly)
- 12% of households consume between 0 - 80 kWh and 52% between 0 – 150 kWh
- And 14% houses in the village are consuming more than 300 kWh per month.
- The energy usage pattern of the village is majorly governed by a large number of consumers (66%) who are using 80 to 300 kWh monthly.

Further, figure 4 shows that there is a steady increase in the ownership of water pumps and washing machines if we move from the lower slabs to the higher slabs. They become very common equipment used in the households at the higher consumption slabs.

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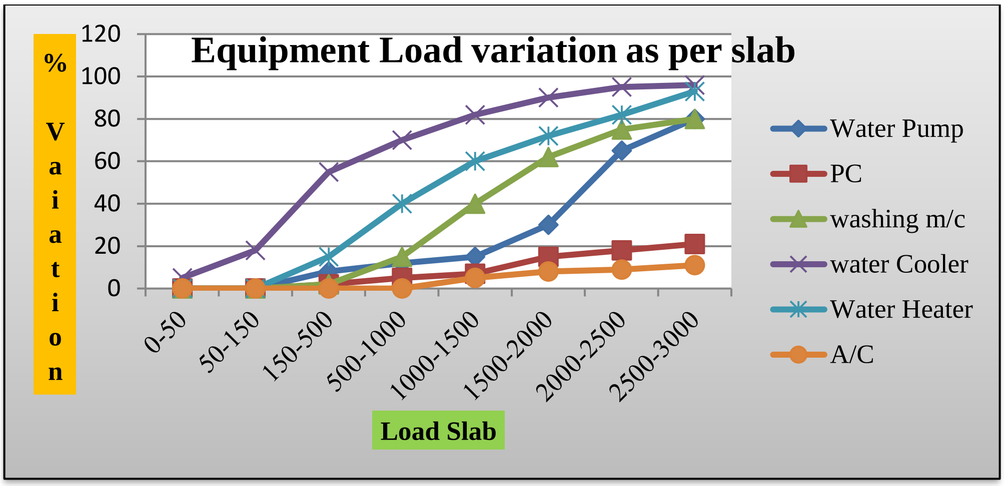
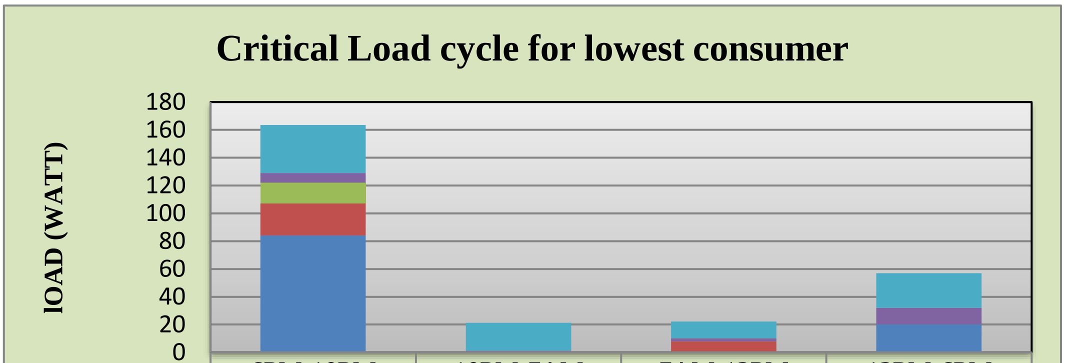


Figure 4 showing slab wise additional connected load equipments

For study of equipment usage Pattern of Domestic Consumers considering time based electricity usage pattern of both critical and normal load, the entire day is split into 4 time slots of variable duration for analysis Slot1(6 PM to 10 PM having 4 hours – peak hours), Slot 2 (10 PM to 7AM with 9 hours – off peak hours), Slot 3(7 AM to 12 noon with 5 hours as normal period), and Slot 4(12 noon to 6 PM with 6 hours as normal period).The connected load consumption for lower, middle and upper middle class of consumers are shown in respective following figures 5-6.



	6PM-10PM	10PM-7AM	7AM-12PM	12PM-6PM
FAN	34.5	20	12	25
CFL	6.9	1.2	2.2	12
INC LAMP	15	0	0	0
FT	23	0	8	0
TV	84	0	0	20

Figure 5 showing critical load share for lower load category

The figures 5-6, show that even if the equipments used are same, the number of equipments in use and duration of use varies. Additional equipments like refrigerator and washing machine also account for significant power consumption in the load curves of 150 - 500 kWh. TV consumes more or less constant amount of power in all categories. The power consumed by lighting sources varies from category to category.

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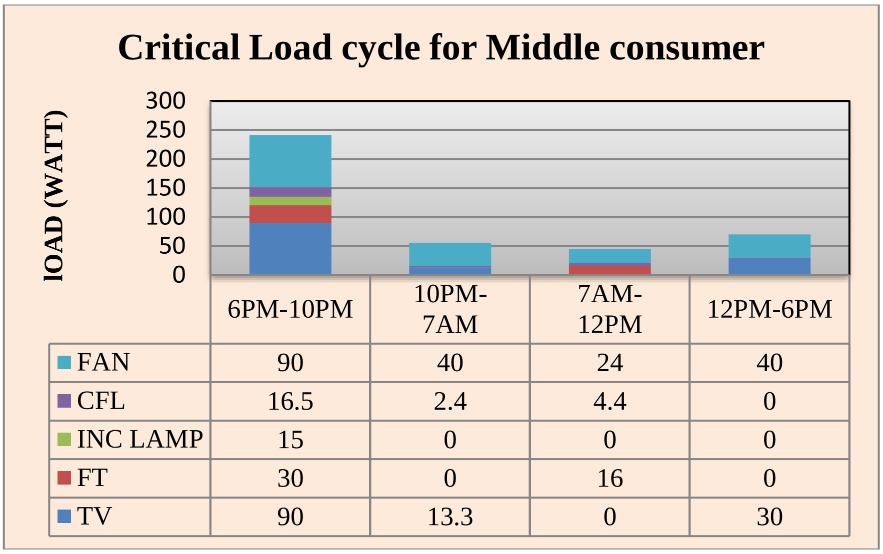

	6PM-10PM	10PM-7AM	7AM-12PM	12PM-6PM
FAN	90	40	24	40
CFL	16.5	2.4	4.4	0
INC LAMP	15	0	0	0
FT	30	0	16	0
TV	90	13.3	0	30

During slot 3 and slot 4, i.e. from 7 AM to 6 PM, the electricity demand from different categories of consumers can be analyzed from the above load curves. One of the options for meeting this energy requirement can be through implementation of grid interactive rooftop PV systems, without any battery backup. Considering higher value of the load under these two slots, as shown in table 3, one can determine the minimum size of the PV modules supporting these loads.

Table 3 Proposed optimum roof top PV size for partial meeting the day time loads

Load Slab (watt)	Minimum PV capacity with back up from grid
0-50	50
50-150	70
150-300	140
300-500	250

SECTION III USAGE OF INVERTERS IN THE VILLAGE

The use of inverters in the village as per different load slabs, is analyzed in this section and proposed inverter sizes are proposed in table 4.

Table 4 Proposed Inverter sizes as per consumer Load requirement

Consumer Load Slab watt	Consumer Population %	Number of Houses	Inverter Rating (VA)		Capacity (VA)	
			Minimum	Maximum	Minimum	Maximum
0-50	12	17	250	-	3000	-
50-150	14	20	250	500	3500	10000
150-500	26	36	500	800	13000	28800
500-1000	22	32	800	1500	17600	48000
1000-1500	12	17	1500	2000	25500	34000
1500-2000	8	12	3000	4000	36000	48000
2000-2500	4	6	3000	4000	18000	24000
2500-3000	2	3	4000	5000	12000	15000
Total	100%	143	_	_	128600	207800

Table 4 shows that inverter size and range varies as we go from lower to higher slab because when load variety and ratings are larger their operation time and consumption too varies widely. Roof top investment into such systems varies from Rs 2000 to Rs 24000. It is interesting to note that among the people who use consuming above 300 kWh of electricity bimonthly, around 33 % own power backup systems.

Based on PVSyst simulation software package (for study, sizing and designing PV systems) and NASA satellite based Surface Solar Energy (NASA SSE) meteorological data; shows that using minimum 13% efficient panels in proposed village application, the area required per kW is 118 sq. ft. If 15% efficient panels are used then area required is 78 sq. ft. per kW. Efficiencies of commercial crystalline silicon modules, which are a leading technology for rooftop installations, vary from 13-20%. Assuming an inter-panel spacing of 25% of the active area, the typical area required for installation of solar panels in the efficiency range from 13-16% will be maximum 150 sq. ft. per kW. Based on these, guidelines, the roof-top potential of domestic consumers is classified from 1kW to 5kW PV capacity to meet their load demands.

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PVSyst data shows that a solar PV installation of 1 kW in the village would give about 4.5 kWh yield per day. By adding up, all the average installations, the harvested power works out 121.5 kWh at 0.6 power factor and requiring 15,150 sq. ft. area for installing PV modules. The area may be an open non fertile area identified by Panchayat or roof top area in part.

SECTION IV DESIGN PACKAGES FOR DOMESTIC CONSUMERS OF THE VILLAGE

Based on primary survey information, a design approach for different slabs of domestic consumers, based on the critical load curves (Figure 4) and on possible use of the equipment in their custody are .proposed with following assumptions as ready to use condition.

- The number and types of loads required for a class of consumer is decided as per the.
- The sizing of PV modules is based on their average daily consumption from grid, i.e. based on the tariff slab they belong to.
- Further, the major assumption is *that 50% of the daily energy consumption is offset by PV packages*, i.e. a consumer who uses to 30 kWh per month must offset at least 0.5 kWh daily using PV.
- Battery bank designed is slightly undersized in some packages based on the assumption that some part of the PV energy produced (in the 50% grid offset energy) is directly utilized during day time (using grid tied inverters). Hence decreasing the need for storage and avoids some efficiency losses.
- The prices are indicative and based on the primary data collected from open market.
- It is mandatory for all manufacturers offer a guarantee of performance over a period of 25 years with 90% output for first 12 years and up to 80% after 25 years of operation. It has to be kept in mind that there is a degradation of about 0.9% per year in PV module output while designing the packages.

The packages are designed by using different standard module sizes and batteries. This set of packages is one set of example for each category of consumers. Further these may be optimized based on the actual expected daily energy need, monthly energy consumption, number of kWh to be saved to jump down to the next lower consumption slab to avail additional benefit of lower tariff. There are three slabs of consumers and accordingly three set of solar packs are designed and shown in table 5 for lowest slab, as per table 6 for middle slab consumers and as per table 7 for upper middle consumers while table 8 for upper most slab of consumers.

Table 5 Lowest slab consumer solar pack

Slab	Equipment in use			Proposed Solar Pack			Other Spec.	Cost(INR)
	Equipment	Qty	Power	Equipment	Qty	Spec.		
0-80 w	Fan	1	40-60 w	PV module	100 w	Mono/Multi crystalline	10 years product warranty and 25 years performance warranty	6000
	TV	1	80-120W	Inverter/ Power Conditioning Unit	300 VA	Minimum Efficiency of 90%, Pure Sine wave	Automatic load management system	5000
	Fluorescent light (4 ft)	1	40w	Battery Bank	100Ah, 12V (1200 wh)	Tubular GEL VRLA		12000
	CFL	2	12w	Other BOS and installation Charges				3000
Total								26000

Table 6 Mid-slab consumer solar pack

Slab	Equipment in use			Proposed Solar Pack			Other Spec.	Cost(INR)
	Equipment	Qty	Power	Equipment	Qty	Spec.		
50-150 w	Fan	1	40-60 w	PV module	200 w	Mono/Multi crystalline	10 years product warranty and 25 years performance warranty	12000
	TV	1	80-120W	Inverter/ Power Conditioning Unit	500 VA	Minimum Efficiency of 90%, Pure Sinewave	Automatic load management system	5000
	Fluorescent light (4 ft)	1	40w	Battery Bank	100Ah, 12V (1200 Wh)	Tubular GEL VRLA		12000
	CFL	3	12w	Other BOS and installation Charges				8000
Total								37000

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Table 7 Upper Middle- slab consumer solar pack

Slab	Equipment in use			Proposed Solar Pack			Other Spec.	Cost(INR)
	Equipment	Qty	Power	Equipment	Qty	Spec.		
160-240 w	Fan	3	40-60 w	PV module	500 w	Mono/Multi crystalline	10 years product warranty and 25 years performance warrranty	30,000
	TV	1	80-120W	Inverter/ Power Conditioning Unit	1200 VA	Minimum Efficiency of 90%, Pure Sinewave	Automatic load management system	10,000
	Fluorescent light (4 ft)	1	40w	Battery Bank	150Ah, 12V,2no's (3600 Wh)	Tubular GEL VRLA		32000
	CFL	3	12w	Other BOS and installation Charges				22,000
	Fridge, washing m/c Water pump		200-300W					
Total								94,000

Table 8 Upper Most - slab consumer solar pack

Slab	Equipment in use			Proposed Solar Pack			Other Spec.	Cost(INR)
	Equipment	Qty	Power	Equipment	Qty	Spec.		
250-500w	Fan	3	40-60 w	PV module	1000 w	Mono/Multi crystalline	10 years product warranty and 25 years performance warrranty	60,000
	TV	1	80-120W	Inverter/ Power Conditioning Unit	1500 VA	Minimum Efficiency of 90%, Pure Sinewave	Automatic load management system	15,000
	Fluorescent light (4 ft)	1	40w	Battery Bank	150Ah, 12V,4no's (7200 Wh)	Tubular GEL VRLA		64000
	CFL	3	12w	Other BOS and installation Charges				40,000
	Fridge, washing m/c Water pump		200-300W					
	Refrigerator* Washing Machine* Mixer* Water Pump (0.5 HP)*	1 1 1	200-300W 500-700W 200-300W 373W					
Total								1,79,000

SECTION V
CASE STUDY: INSTALLATION OF GRID CONNECTED ROOFTOP POWER PLANTS IN SCHOOLS

In this case following assumptions are made (1) RSEB has approved 17 kW PV roof top installation for grid connectivity. (2) RSEB will not exempt the PV system owners from their *fixed charges* since they provide them a reliable back up option, but there will be incentive for feeding excess energy into the grid. (3) We shall take Rs 5/kWh as feed in tariff (nearly same as current cost for RSEB). (4) This will ensure that the system owners can utilize the entire rooftop potential and sell power to the grid. (5) Some part of their bi-monthly consumption may be still drawn from the grid, during non sunshine hours (rainy days, shading by clouds etc.). But since *net metering* is used, these kWh will be deducted from the total generated energy. In other words it may be said:

- Net energy fed into the grid = (Net energy produced by PV – self consumption)
- Total income to the rooftop system owner = 100% energy charges +energy duty + feed in tariff for remaining energy produced.

The cost data and savings based on following steps are summarized in table 10.

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Energy generated (bimonthly) = 17 kWp *3.75 kWh/kWp/day*60 day = 3825 kWh
Energy consumed (self use) 366 kWh
Energy fed into the grid = (3825-366) = 3459 kWh

Income on feed in tariff = 3459 * 5 = Rs 17,295
Total benefit to the rooftop owner in 2 months = 17295 + 2053 (energy charge) = Rs 19,348
Simple payback period = (8, 50,000)/ (19348*6) = 7.3 years

Table 10 when a Roof top system is grid connected at a school

Item Head	Data/Calculated values
Size of PV system (Utilising full rooftop potential) (Wp)	17KW
Investment on PV (Rs 50/Wp - MNRE bench mark price) (Rs)	8,50,000
Net energy fed to the grid (bimonthly) (kWh)	3459
Bimonthly saving (from bills) (Rs)	2,053
Total Income (bimonthly) (Rs)	19,348
Simple payback period (years)	7.3

An important learning from the above calculation is that, the return of investment is more determined by the feed in tariffs, rather than by the savings from energy bills. The school may not be ready to invest such a huge capital on rooftop PV systems. This throws an opportunity for third party investors to step in and install rooftop PV system on school rooftops. The schools can demand for free power or a fixed lease amount per kWh produced.

CONCLUSION:

In the exercise of Solarification the load survey and site study including roof part and small buildings like school, shop, hospital or small scale industries etc. along with involvement of villagers at various capacities is the foundation of Solarification. The design and sizing of PV modules with corresponding inverters and back up batteries based on surveyed load data is second important aspect. The various five packages have been suggested covering minimum to upper slab of consumers. Additionally a case study of school building with roof top grid tied PV system exercise has been added to cover up total Solarification range from a small home needs to fully fledged grid connected PV system.

REFERENCES:

[1] K. Strunz, E. Abbasi and D.N. Huu, “DC microgrid for wind and solar power integration,” *IEEE Trans. Power Electron.*, vol. 2, no. 1,pp. 115-126, 2014.
[2] SubhenduGuha, “Can your roof provide your electrical needs? – The growth prospect of building-integrated photovoltaic”, in *Conf. Rec. Thirty-first IEEE Photovoltaic Specialists Conference, 3-7* Jan. 2005. pp: 12 – 16.
[3] S. D. Reddy, M. P. Selvan, and S. Moorthi, “Design, operation, and control of S3 inverter for single-phase microgrid applications,” *IEEE Trans. Ind. Electron.*, vol. 62, no. 9, pp. 5569–5577, Sep. 2015
[4] A. Chermini; M. Bencherif; Z. Nakoul; N. Bibitriki; B. Benyoucef, " Assesment parameters and matching between the sites and wind turbines", Eight International Conference on Material Science(CSM8), 2014.
[5] Y. Wang, X. Lin, and M. Pedram, “Adaptive Control for Energy Storage Systems in Households with Photovoltaic Modules,” IEEE Transactions on Smart Grid, Vol. 5, No. 2, pp. 992-1001, 2014
[6] “Roof top Solar PV Systems”, Ramesh Kumar, Director, Solar Energy Corporation of India. Available from: mnre.gov.in/file-manager/UserFiles/presentations
[7] Bureau of Indian Standards, “Code of Practice for Design Loads for Building and structures”.
[8] M. Sechilariu,B.Wang, and F. Locment, “Building integrated photovoltaic system with energy storage and smart grid communication,” *IEEE Trans.Ind. Electron.*, vol. 60, no. 4, pp. 1607–1618, Apr. 2013.
[9] “Overview of control and grid synchronization for distributed power generation systems”, IEEE Transaction on Industrial Electronics, vol. 53, Issue 5, Oct. 2006, pp.1398-1409
[10] A. Elrayyah, Y. Sozer, and M. Elbuluk, “Microgrid-connected PV-based sources: a novel autonomous control method for maintaining maximum power,” *IEEE Ind. Application Mag.*, vol. 21, no. 2, pp. 19–29, Mar./Apr.2015.
[11] IEC, “International Standard IEC 61400-1 Third edition 2005-08,” 2005. http://webstore.iec.ch/preview/info_iec61400-1%7Bed3.0%7Den.pdf.
[12] Shrimali, D. Nelson and Gireesh, “Finance Mechanisms for Lowering the Cost of Renewable Energy in Rapidly Developing Countries,” April 2014.:http://climatepolicyinitiative.org/wp-content/uploads/2014/01

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