International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 19 (2018) pp. 14461-14468
 http://www.ripublication.com

Design, Analysis and Economic Investigation of Standalone Roof Top Solar PV System for Rural India

Adithya Ballaji[1], Ananda M H[2], K Narayan Swamy[3], Venkatesh Murthy B S[4]

[1]Teaching Associate, [2]Assistant Professor, [3]Associate Professor, [4]Director
School of Electrical and Electronics Engineering, REVA University,
Bengaluru- 560064, Karnataka, India.

Abstract

Increase in electricity consumption in India is increasing the use energy through renewable energy and conventional type such as coal or oil. Use of renewable energy is on rise in India. Setting up of a photovoltaic power requires planning and commissioning considering factors like land area, climate condition, irradiance, load utilization etc. In this paper a point by point plan of an independent housetop or rooftop solar powered PV framework was designed to supply continuous and uninterrupted power to a typical house in rural India. In this, a delineation of step by step method for designing and implementation of the rooftop solar based PV framework was done. Also the designed rooftop PV system's economic investigation was done utilizing System Advisory Module. The cost of PV power generation and environmental advantage are likewise accentuated.

INTRODUCTION

Consumption of electricity in India is being increased day by day. Most of the generation is done using the fossil fuels which includes coal or oil. According to the studies 33.9% of the power generation is using the renewable energies whereas the rest is by fossil fuels. Figure 1 represents the total electricity generation in India consisting of both renewable and non-renewable energy sources.

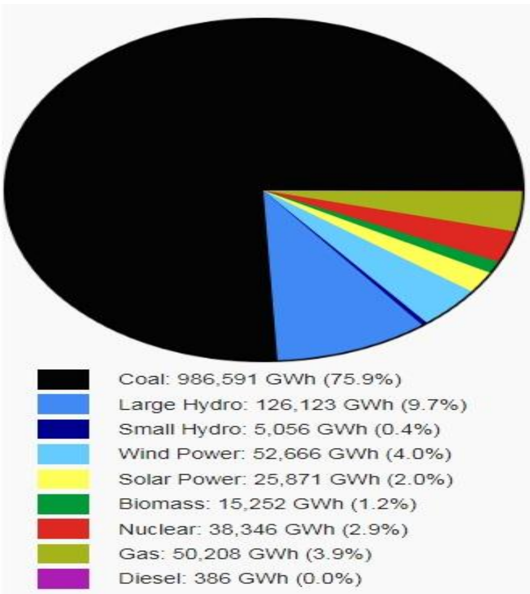


Figure 1. Total Electricity Generation in India

India has surplus amount of electricity which is generated but lacks proper infrastructure for supply of power to the rural India. Installing and maintaining a power supply line from a grid to rural India may cost more. Renewable energies can be of best plan when it comes to rural India. Renewable energies such as solar energy or wind energy or hybrid systems can be used for power consumption in villages where it will discard the use of supply line from the Electricity Supply boards. Figure 2 presents the villages electrified till now in India.

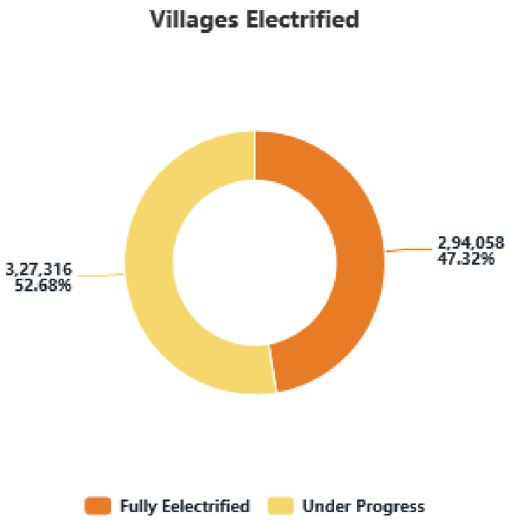


Figure 2. Villages electrified in India

In this paper, a cost effective design of the rooftop PV system is done where it can light up an average household in rural India. Also an economic study was performed on for the PV system for cost effective purpose.

The Objectives of this study are:-

- To study the site and the access for the solar system to be installed
- To design and implement the rooftop solar system using simulation and prototype at the selected site for the rural India
- To evaluate the economic behavior of the proposed and implemented rooftop

Factors effecting solar PV system production

Taking into account any system will have efficiency problems related to various factors. When setting up a solar

PV system different factors affect the efficiency of the system. Some factors may be intensity of sun, covering of clouds, humidity and building up of heat. On the good sunny days and in the peak hours of the sun i.e. at mid-day the power output of the PV system will be more. On the days when there are clouds the power output decreases as the consumption by the PV cells will not be more.During summer when the heat is more compared to normal days the power output of the PV system decreases because of the factor that the absorption of that much heat decreases conductivity of the semiconductor and results in production of less electric field. Consumption or entering of humidity in the solar panels may result in total loss of panels or reduce the productivity.

- The efficiency of the PV system depends on the module temperature and irradiance
- Productivity depends on the meteorological factors
- Correct alignment and bending of the solar PV system for efficient output
- Over shadowing of the PV system which will produce less amount of energy
- Efficiency of inverters or converters
- Cables connecting between the system and module

Simulation of solar PV array system

For modeling of a PV system using simulation many factors and many inputs have to be taken into account like irradiance. Whether condition where the system has to be installed and other technical parameters for the simulation of the PV system have been shown in table 1. For building up the system these factors have to be considered and the model has to be estimated on the values decided.

PV Design with Design Simulation Software	Purpose	Developer
PV F-Chart	Simulates and determines analysis and sizing PV system	Sandia National Labs, Albuquerque, NM
PV Sol	Includes economic analysis of PV system with simulation	Valentin Software Company, Berlin
PV Planner	Provides simulation for sizing of grid connected PV system	Center for Energy and Environmental Policy, University of Deleware
SAM	Provides estimation for th e cost and energy	National Renewable Energy Laboratory (NREL)
Blue Sol	Simulation system which calculates irradiation and the productivity of the PV system	Regen Power Pvt. Ltd., Western Australia
PVSyst	PV system can be designed, managed and sizing can be done using this. An overall economic analysis of the PV system can be done using this software.	

METHODOLOGY

Site Information

The site selected for the analysis, design and implementation of PV system is Vinayaka Nagar which is one of the rural village of India. The site location and the coordinates are shown below in figure 3

Figure 3. Map of Vinayaka Nagar where experiment was carried

System Description

A rooftop PV system will have only few components which consists of, a battery, a PV cell, a charge controller, set of cables and a load. In rural India few lights and socket for mobile charging has been designed as shown in figure 4.

From the PV system the power is passed through a charge controller. The purpose of the charge controller is to charge or discharge the battery and provide the power to the load through the charge controller. This is connected to a inverter which converts DC power to the 230V Ac power used for household purposes. A typical layout has been shown in figure 5 which represents the rooftop standalone system for rural India.

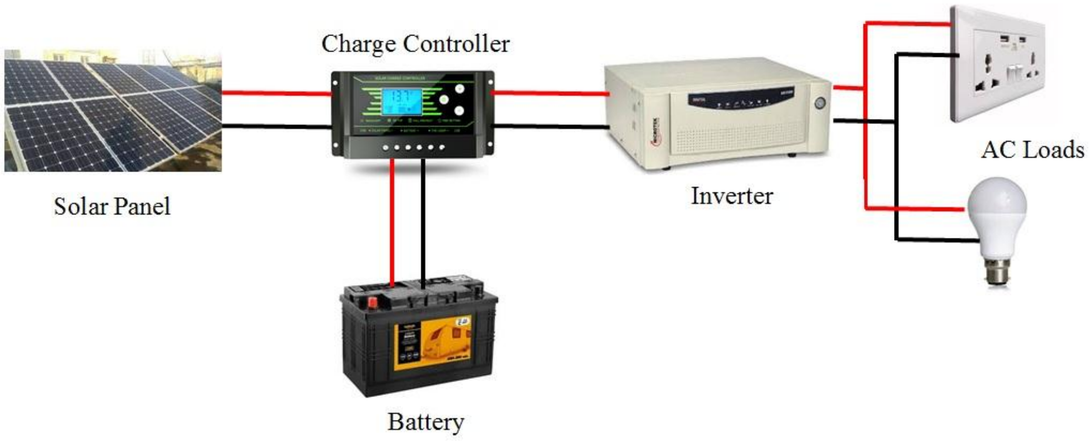


Figure 4. Schematic representation of rooftop solar PV system

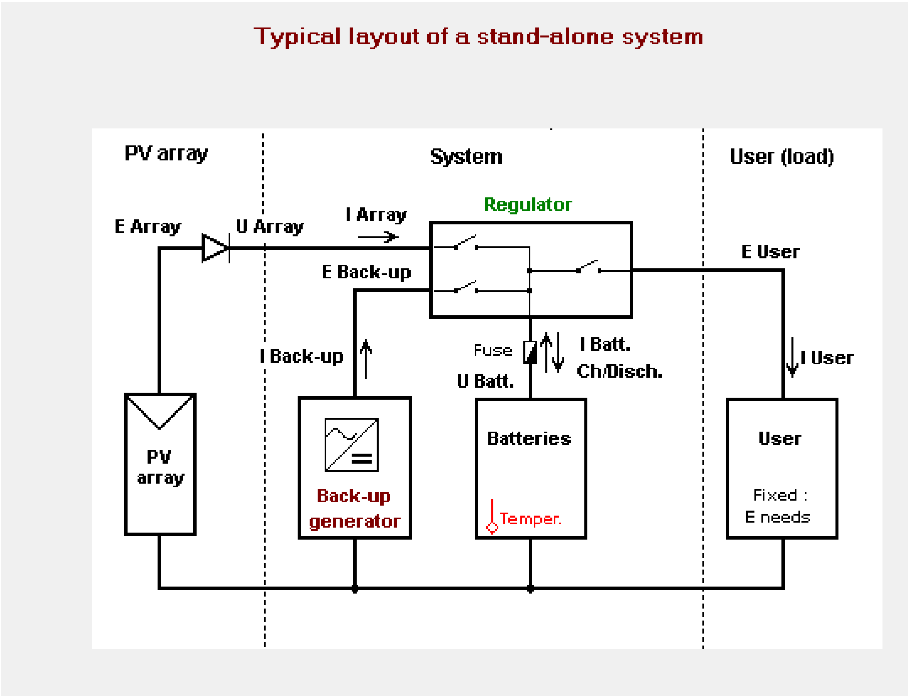


Figure 5. Layout of standalone system in PVSyst software

Simulation of the proposed PV system using SAM and PVSyst

SAM is electric energy generation software which predicts estimation of energy using the parameters given to the input of the PV system. Using Sam we can predict either Standalone system or Grid connected system. It calculates energy generation depending on the PV system performance.

PVSyst does managing, design and economic analysis of the PV system. In this input values along with the other parameters have to be fed which will calculate and lets the user know the performance analysis of the PV system.

SOLAR PV SYSTEM SIZING

1. Determination of power demand

The first and fore step in designing a PV system is calculation of load consumption which are given below:

1.1 Calculate total Watt-hour/day for each load
Add the Watt-hour needed for all loads to get the total Watt-hours per day which is consumed by the loads.

1.2 Calculate total Watt-hour/day required from the PV system
Multiply the total load Watt-hour/day times 1.3 (the energy lost in the system) to achieve the total Watt-hour/day from the PV system.

2. Sizing of PV module system

Power produced by the PV system depends on the different size of PV modules. The peak watt (Wp) produced depends on size of the PV module and climate of site location which is required to produce the power needed for loads. "Panel generation factor" has to be considered which varies for different site locations. Calculations are as follows to determine the sizing of PV module:

2.1 Calculate the required Watt-peak rating for PV modules
Divide the total Watt-hour/day needed from the PV modules to get the total Watt-peak rating needed to run the loads.

2.2 Calculation for the number of PV panels
Divide the answer obtained in 2.1 by the rated output Watt-peak of the PV module. Increase any fractional part of result to the next higher full number which will be the number of PV modules required. Calculated results will depend on the number of PV panels being used. If the modules are installed more, than more efficiency if less then, less efficiency.

3. Sizing of Inverter

An inverter is used in the system to supply AC power to the AC loads. The input rating of the inverter should never be lower than the load. The inverter voltage must be same as battery voltage.

For stand-alone systems, the size of the inverter must be large. The inverter size should be 25-30% bigger than total Watts of load. In case of load type is motor then the size of inverter must be minimum 3 times the capacity of the load. For grid tie systems or grid connected systems, the input rating of the inverter must be same as PV system rating to allow safe and efficient operation.

4. Sizing of Battery

The battery type usually recommended is deep cycle battery. Deep cycle battery is specifically designed to be discharged to low energy and rapidly recharged or cycle charged and discharged day after day for years. The battery should be large enough to store sufficient energy required for day as well as for the night. Calculations for sizing of battery are given:

1. Calculate total Watt-hours/day used by loads.
2. Divide the total Watt-hours/day used by 0.85 for battery loss.
3. Divide the answer obtained in item 4.2 by 0.6 for depth of discharge.
4. Divide the answer obtained in item 4.3 by the nominal battery voltage.
5. Multiply the answer obtained in item 4.4 with days of autonomy i.e. the number of days that you need system to operate when there is no power produced by PV panels.

To get the required Ampere-hour capacity of deep-cycle battery

Battery Capacity (Ah) =

$$\frac{\text{Total Watt-hours per day used by appliances x Days of autonomy}}{(0.85 \text{ x } 0.6 \text{ x nominal battery voltage})}$$

5. Sizing of Solar charge controller

The solar charge controller is typically rated against Amperage and Voltage capacities. Solar charge controller must match the voltage of PV array and batteries. Make sure that solar charge controller has enough capacity to handle the current from PV array.

For the series charge controller type, the sizing of controller depends on the total PV input current which is delivered to the controller. According to standard practice, the sizing of solar charge controller is to take the short circuit current (Isc) of the PV array, and multiply it by 1.3 times

Solar charge controller rating = Total short circuit current of PV array x 1.3

The figure 6 represents the irradiance for a week in that area where the installation has to be done.

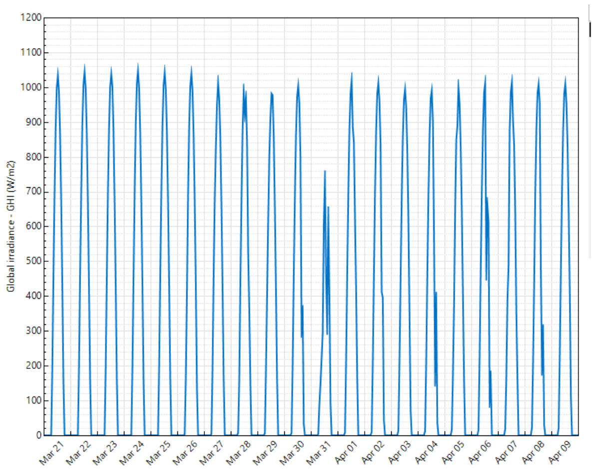


Figure 6. Irradiance for a week

Figure 7 represents the irradiance for a year from January to December where the most of the heat is generated at 10 to 15 hours of the day.

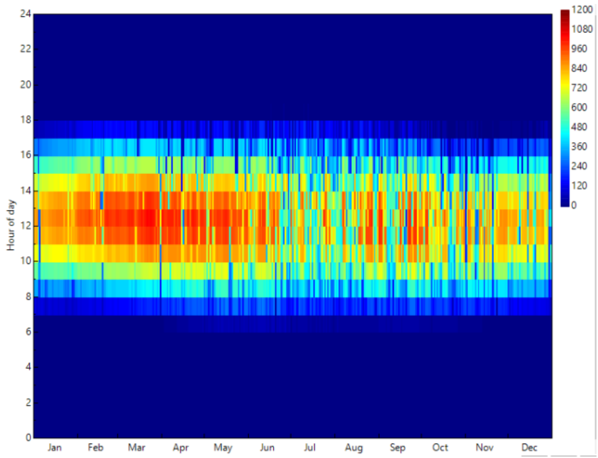


Figure 7

A house has the following electrical appliance usage:

- Two LED Light of 5W used 5 hours per day.
- One 60 Watt fan used for 5 hours per day.
- One 100 Watt Television for 4 hours.
- Mobile charging 5W for 2 hours.

1. Determine power consumption demands

Total appliance use

= ((5 W x 5 hours) x 2)+ (60 W x 5 hours) + (100 W x 4 hours) + (5 W x 2 hours))

= 760 Wh/day

Total PV panels energy needed = 760 x 1.3

= **988 Wh/day**

2. Size the PV panel

1. Total Wp of PV panel capacity needed = 988 / 3.4

= 290 Wp

2. Number of PV panels needed = 290 / 110

Number of PV Panels = **2.6 modules**

Actual requirement = **3 modules**

So this system should be powered by at least 3 modules of 110 Wp PV module.

3. Sizing of Inverter

Total Watt of all appliances = 5 + 5 + 60 + 100 + 5 = 175 W

For safety, the inverter should be considered 25-30% bigger size.

The inverter size should be about **227 W or more.**

4. Sizing of Battery

Total appliances use = ((5 W x 5 hrs) x 2) + (60 W x 5 hrs) + (100 W x 4 hrs) + (5 W x 2 hrs)

Nominal battery voltage = 12 V

Days of autonomy = 3 days

Battery capacity = [((5 W x 5 hrs) x 2) + (60 W x 5 hrs) + (100 W x 4 hrs) + (5 W x 2 hrs)] x 3 / (0.85 x 0.6 x 12)

Total Ampere-hours required **372.5 Ah**

so the battery should be rated **12 V 400 Ah** for 3 day autonomy.

5. Sizing of Solar charge controller

PV module specification

Pm = 110 Wp

Vm = 16.7 Vdc

Im = 6.6 A

Voc = 20.7 A

Isc = 7.5 A

Solar charge controller rating = (3 strings x 7.5 A) x 1.3 = 30 A

So the solar charge controller should be rated **30 A at 12 V** or more.

RESULTS AND DISCUSSIONS

The calculations for the rooftop standalone PV system were done in this paper. This was performed through the MNRE website where all the analysis including economic investigation and costing with loan and EMI are presented for the installation of rooftop solar panel of 1kWh economic wise. These calculations represent the economic analysis of a solar panel.

- Average Solar irradiance in Karnataka state is 1266W/Sq.m
- 1kWp solar rooftop plant will generate on an average over the year 5.0 kWh of electricity per day (considering 5.5 sunshine hours)

1. Size of Power Plant

- Plant size as per your Capacity : 1kW

2. Cost of the Plant:

- MNRE current Benchmark Cost :

  Rs. 60000 Rs. / kW
- Without subsidy (Based on current MNRE benchmark) : Rs. 60000
- With subsidy 30% (Based on current MNRE benchmark): Rs. 42000

3. Total Electricity Generation from Solar Plant

- Annual : 1500kWh
- Life-Time (25 years): 37500kWh

4. Financial Savings:

- Tariff @ Rs.6.90/ kWh (for top slab of traffic) - No increase assumed over 25 years :
- Monthly : Rs. 863
- Annually : Rs. 10350
- Life-Time (25 years) : Rs. 258750

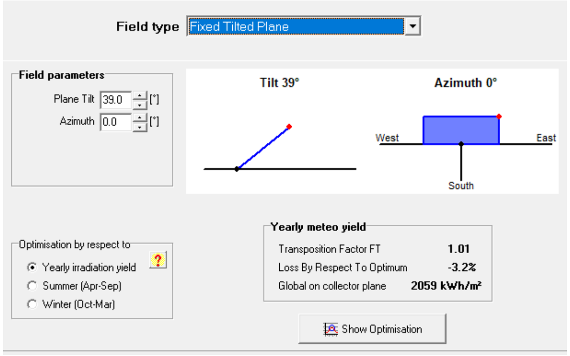
Carbon dioxide emissions mitigated is 31 tones. This installation will be equivalent to planting 49 Teak trees over the life time. (Data from IISc) Disclaimer: The calculation is indicative in nature. Generation may vary from location to location.

5. EMI Calculation

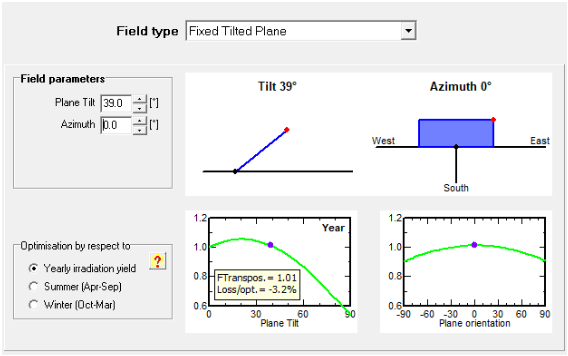
- Cost of the solar plant : 60000

  Subsidy: 30 % (Based on current MNRE scheme)
- Debt-Equity Ratio: 70 : 30 (Based on current subsidy)
- Down-payment : 18000 Rs. / kW
- Loan amount : 42000 Rs. / kW
- Loan Interest Rate :8.45 %
- Loan Period :10 years
- EMI for Loan amount of Rs. 42000 for loan period of 10 years @ 8.45 % is Rs.520 / month

Figure 8(a) & (b) represents the tilt angle including plane tilt which is 39^0 and orientation of the PV panel along with optimization details. The optimization was done with respect to yearly irradiation.



(a)



(b)

Figure 8 (a) & (b) Field parameters of the PV panel along with Optimization

Figure 9 represents the simulation parameters the standalone PV system which was calculated. The values were fed to the software to determine the analysis of the system.

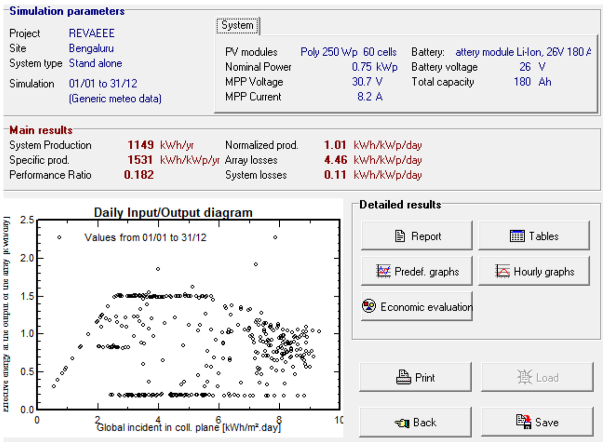


Figure 9. Simulation Parameters

Figure 10 and 11 represents the power consumption by loads which are household appliances for a monthly. The parameters can be seen for daily or monthly or yearly basis. As calculated the simulation parameters achieve total monthly energy of 27.1KWh/month.

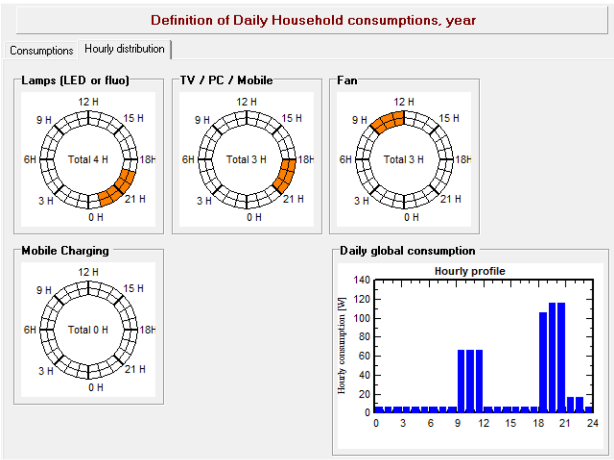


Figure 10. Energy consumption on Hourly basis

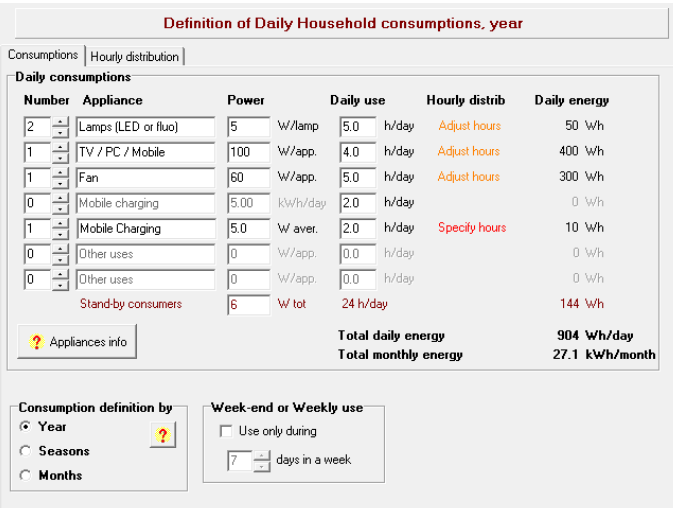


Figure 11. Energy consumption representations on monthly basis for the appliance used

CONCLUSION

In this paper a point by point plan of an independent housetop or rooftop solar powered PV framework was designed to supply continuous and uninterrupted power to a typical house in rural India. Load/ Appliances used were described in this paper.. Also the designed rooftop PV system's economic investigation was done utilizing System Advisory Module. The calculated values and the simulation results match with each other stating the system was efficiently designed and can be implemented. The standalone rooftop PV system was designed, compared and was analyzed through theoretical calculations and software based calculations.

ACKNOWLEDGMENT

We are very thankful to the Management of REVA University and School of EEE for providing us all support to complete this research work.

REFERENCES

[1] Alamsyah, T.M.I., Sopian, K., Shahrir, A., 2003. In techno-economics analysis of a photovoltaic system to provide electricity for a household in Malaysia. In: Proceedings of the International Symposium on Renewable Energy:Environment Protection & Energy Solution for Sustainable Development, Kuala Lumpur, pp. 387–396.

[2] Batainesh, K., Dalalah, D., 2012. Optimal configuration for design of standalone PV system. Scient. Res., Smart Grid Renew. Energy 3, 139–147.

[3] Building Integrated Photovoltaic Power Systems: Guidelines for Economic Evaluation. Report IEA PVPS T7-05, 2002. Cebecauer, T., Huld, T., Šúri, M., 2007. Using high-resolution digital elevation model or improved PV yield estimates. In: Proceedings of the 22nd European Photovoltaic Solar Energy Conference, Milano, pp. 3553–3557.

[4] Dunlop, E.D., Halton, D., 2005. The performance of crystalline silicon photovoltaic solar modules after 22 years of continuous outdoor exposure. Prog. Photovolt. Res. Appl. 14 (1), 53–64.

[5] Causes of Global Warming. (September 2012). [Online]. Available: http://www.ecobridge.org /causes_of_global _warming.html

[6] Schlissel D. Coal-Fired Power Plant Construction Costs. Synapse, July 2008.

[7] The Hidden Cost of Fossil Fuels. (October 2012). [Online]. Available: http://www.ucsusa.org/clean_energy/our-energy-choices/coal-and-other-fossil-fuels/the-hidden-cost-of-fossil.html

[8] Emeregece of Photovoltaic. (September 2012). [Online]. Available: http://ezinearticles.com /?Emergence-of-Photovoltaics&id=601630

[9] Antony. *Photovoltaic For Professionals*. Earathscan, 2nd ed., 2007

[10] Energy(DOE), U.D.o., *Guidebook for Solar Photovoltaic Projects in Philadelphia*. 2nd ed. June 2010.

[11] Residential Photovoltaic (Solar Electric) Stand Alone Systems. (February 2012). [Online] Available: http://www.azsolarcenter.org/images/docs/presentations/Brochure-PVStandAlone.pdf

[12] Markvart T., *Solar Electricity*. 2nd , UK: University of Southampton, 2008

[13] Photovoltaic Power Systems. (October 2012). [Online]. Available: http://www.polarpower.org/static/docs/ PVWhitePaper1_31.pdf

[14] Types Of PV Modules. (November 2012). [Online]. Available: http://www.leonics.com/product/renewable/pv_module/ pv_module_en.php

[15] How Solar Charge Controller Work. (October 2012). [Online]. Avialable: http://www.sunup-solar-power.com/solar-charge-controller.html

[16] Solar PV - Solar PV Inverters. (September 2012). [Online]. Available: http://www.solarpv.co.uk/solar-pv-inverters.html

[17] Definition of RETScrean. (December 2012). [Online]. Available: http://www.retscreen.net

[18] Modules Parameters. (November 2012). [Online]. Available: http://www.bydenergy.com/bydenergy/userfiles/file/ PV%20Module%202.pdf

[19] Price of PV Inverters. (September 2012). [Online]. Available: http://www.power-one.com/renewable-energy/ products/solar/string-inverters/aurora-trio/trio-200-tl-trio-276-tl/series

[20] Central electrical authority report T&D losses. (2004). [Online]. Available: http://www.cea.nic.in/ reports/monthly/executive_rep/mar13/mar13.pdf

[21] PV Module Cost. (December 2012). [Online]. Available: http://www.freecleansolar.com/BYD-Solar-Panel-250-watt-pallet-price-p/byd-250p6-30-3bb.htm

[22] Joachim Seel G.B., R. Wiser, *Why Are Residential PV Prices in Germany So Much Lower Than in the United States?* Environmental Energy, 2010.

[23] Electercity P.A.F. *Annual Report*. Sultanat of Oman, Muscat, 2010-2011

[24] Al-Badi A.H., Al-Lawati A. M., Malik A.S. Economic perspective of PV electricity in oman. *Elsevier*, 2010.

[25] Morgan Bazilian, I.O., Maichael Libreich. Ian MacGill, jennifer chase, jigar shah, dolf gielen, douh arent, doug landfean, and Shi Zhengrong. *Re-considering the Economics of Photovoltaic Power*, 2012.

[26] MNRE - https://mnre.gov.in/solar-systems

[27] SPIN - An online application for solar Solar photovoltaic installation - https://solarrooftop.gov.in /rooftop_calculator