International Conference on Renewable Energies and Power Quality (ICREPQ'17)
Malaga (Spain), 4th to 6th April, 2017
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, No.15 April 2017

Methodology to Design and Validate a Sustainable Isolated Solar Photovoltaic System

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Abstract. This paper presents a methodology for designing an affordable photovoltaic solar school system installed on an island in the Colombian Pacific Coast, without power grid connection. After meeting with the community to identify their energetic needs, design begins by evaluating social, political and economic community issues and determining a load table, to calculate the power and energy consumed by the school in a regular day. Then, the solar array, electronic devices and batteries bank is calculated taking into account the losses generated by the electronic power equipment and its autonomy. The solar array sizing considers the school maximum power consumption per hour adding the necessary power to charge the batteries charged 70%. System validation for an optimal PV design on an isolated community is performed using Homer and SaberRD computational simulations tools. Results confirm that starting on dialoguing with the community optimize the design and help to create a sustainable strategy, encouraging an efficient use of equipment and energy.

Key words

Solar PV, sizing, rural electrification, Saber-RD

1. Introduction

Global investments, new jobs and installations of renewable energy technologies are leading between others in the global energy sector with 147 gigawatts (GW) of new capacity. Meanwhile, electricity from solar PV is becoming cost-competitive compared with the grid at a global, besides in Latin America solar PV is increasing small-scale renewable systems to provide electricity for people living far from the grid [1].

Research in this topic is also growing. Some research done in developing countries such as Indonesia, Iran and Kenya, propose and report about developments on solar PV isolated systems to electrify far away communities. Low private investments and incomplete costs analysis are taken into account as some causes for a slow solar isolated PV systems development [2], [3], [4]. These renewable energy systems should be designed and then simulated with the help of computational tools to develop friendly, environmental and technical energetic solutions with an affordable cost-effective ratio

In this context, the core of this paper is to boost new considerations on the design of isolated or grid-tie PV systems, such as social, economic and productive issues, these, guaranty an sustainable system, before start technical and optimum design. the union of all parameters and considerations helps to generate a designs adjustable to community needs.

2. Methodology

A. *The entire concept*

In this research, a procedure has been developed where meeting the community has a great value. Then, local natural resources evaluation and the electric demand are assessed. After that, a regular technical design and sizing is carried out as is presented on figure 1.

As can be seen during the flow chart, community is playing an important role on the designing and certainly for a sustainable PV system. After meetings and dialogues, designers create also an educational system to allow the community support the installation process and receives the tools for a continuing internal education. It is considered the best way for the community to appropriate the renewable technology.

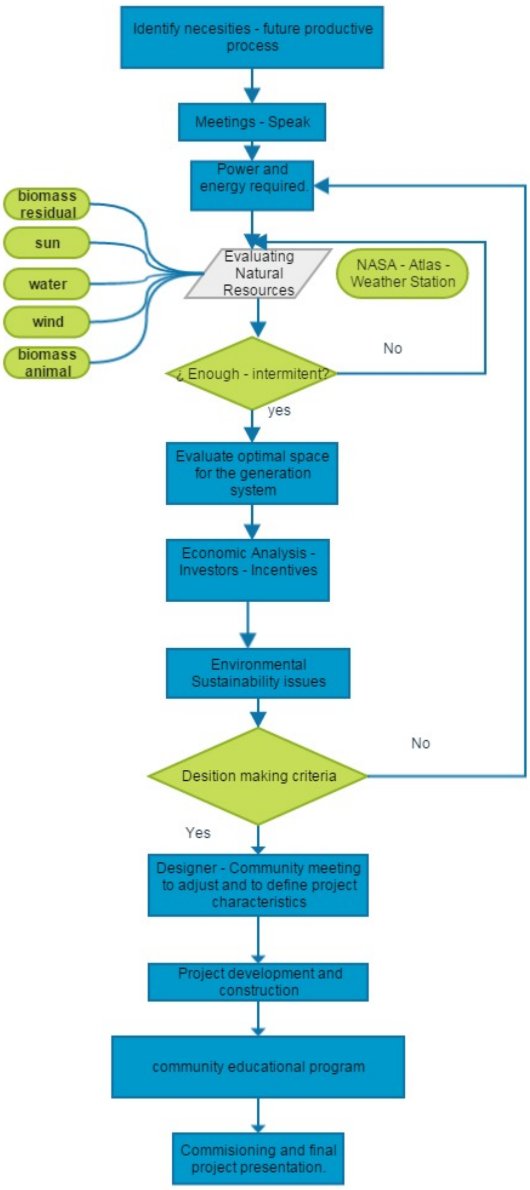

Fig 1. Flowchart of the methodology proposed.

B. *Designing the Battery Bank*

After meeting with 4 communities without power grid connection on the Colombian Pacific Coast, their needs are identified, considering future productive processes, then evaluating its energy consumption; it is possible to size a solar PV system to cover the energy demand. Technically, the first step in the development of a Photovoltaic system (PVS) is to determine energy consumption. Electric loads arranged in a table show daily consumption of each of the loads as can be seen on table 1, and the solar radiation at the zone.

Solar site radiation is compared from different sources. It is possible to download statistical data from the NASA or the Solar Radiation map [5]. There is no local data from a weather station that is the most accurate data, thus NASA and Atlas are taking into consideration. Figure 2 shows the solar radiation resource for the project.

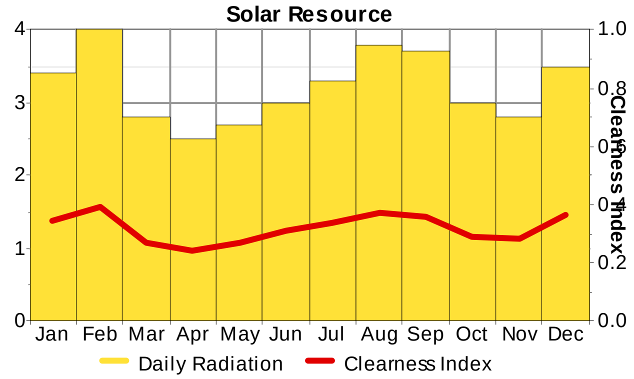

Fig 2. Solar Radiation data from the HOMER computational tool.

Table 1. Electrical Load

Item	*Power*	*Voltage*	*Current*	*Use rate*	*Energy*	*Capacity/Day*
	W	V	A	Hour per day	Wh/day	Ah/day
Fridge	400	110	3,64	8	3200	29,09
Bulb C1	20	110	0,18	8	160	1,45
Bulb C2	20	110	0,18	8	160	1,45
Bulb C3	20	110	0,18	8	160	1,45
Bulb C4	20	110	0,18	8	160	1,45
Bulb C5	20	110	0,18	8	160	1,45
Bulb C6	20	110	0,18	8	160	1,45
Stereo	50	110	0,45	3	150	1,36
PC 1	100	110	0,91	4	400	3,64
PC 2	100	110	0,91	4	400	3,64
PC 3	100	110	0,91	4	400	3,64
PC 4	100	110	0,91	4	400	3,64
Total	**970**		**8,82**		**5910**	**53,73**

The maximum power consumption is 970W with 8.82A of alternating current (AC), those values will be used to calculate the number of solar PV panels and the electronic controller. Besides, the table also shows the maximum energy consumption per day 5.9 kWh/day, with 53.7Ah/day. Those values are used to calculate the capacity of the battery bank.

Since the load AC voltage is 110V and the battery intensity is DC, is necessary to convert from AC to DC current adding the efficiency of the inverter. To do this the equation 1 is used:

$$Ah/d\ (DC) = \frac{Wh/day}{Voltage\ Battery} * (2 - \eta(inverter)) \qquad (1)$$

Where:
Wh/day: Total energy
ɲ (inverter): Is the inverter efficiency.

For this case, the result of ampere-hour per day is 258.6 Ah/d. Now, using the values of table 1, 95% of efficiency, 24V for the battery and adding a 20% of security factor, the ampere-hour obtained per day is 310.3 Ah/d. This value can be used to calculate the battery bank capacity with the equation 2 [6]

$$C = \frac{TotalAh_{day} * N}{0.9 * PDD} \quad (2)$$

Where:

C: battery bank capacity (Ah)
N: Days of autonomy of the chosen system.
0.9: Performance Factor batteries in the charge cycle - download (90%).
P.D.D: Depth of discharge for electrochemical batteries.

For stationary batteries lead acid with low antimony (Sb) in the positive plate, a depth discharge of 70% (0.7) is recommended, for batteries for plate Lead Calcium (Ca) the depth of discharge is recommended daily 50% (0.5). In our case we use lead acid battery with 70% of allowed Depth of daily discharge and two days of autonomy, applying this data in (2) and 985Ah battery bank capacity is obtained. In the process of battery selection, a standardized value or commercial value, which is 1000 Ah should be considered.

C. PV Sizing

In this system the arrangement of photovoltaic panels has two functions, power the loads and recharge the batteries, for this reason at the equation shown by Notton [6] was added half the energy needed to recharge the batteries in the calculation of the energy required as show at (3)

$$N = \frac{\text{Energy required}_{(AC)} + \text{Energy required}_{(DC)}}{\text{Energy produced}}$$

$$N = \frac{Total\ Energy\ Required}{Pnom * HEP} \quad (3)$$

Where:

N: theoretical number of PV solar panels needed
Energy required$_{(AC)}$: Total power obtained from load Table (column 2) in one hour plus losses at the inverter (5%) and a 20% of security factor.
Energy required$_{(DC)}$: Total energy required to recharge the battery when have the 65% of charge.
Pnom: Rated power for one PV panel
HEP: The theoretical number of equivalent hours of power. HEP are calculated using (4) and is expressed in hours / day.

$$HEP = \frac{Index\ of\ solar radiation (Wh/m^2)}{radiation\ constant\ (1KW/m^2)} \quad (4)$$

In this case, solar radiation on site is 3500 Wh/m^2., this value is obtained from local weather station [7]. The result of (4) is 3.5 h/d. Then, to solve equation 3, a solar pv panel with Pnom(W) = 320W (Vnom = 36.8 V, Inom = 8.69 A) are used. Hence, the number of panels obtained is 8, then this value is divided by 0.8 that represent the efficiency of the entire PV system, which gives 10 solar modules that produce 3 kW, value used in the design.

D. PV Array Configuration and Power Electronic Equipment Selection

The number of panels in series and parallel is determined by the input voltage regulator, battery bank voltage and current levels that can handle the charge controller. In this research, are using an OutBack MX60 60A controller that supports 60A and 125 VDC. The number of panels calculated at (3) was 10, if all panels are connected parallel, the maximum current that would give the system would be approximately 81A, which exceeds the maximum current limit, for that reason it was decided to use 2 panels in series in a 5 parallel arrangement, with this configuration the input current is 43.5 A and maximum input voltage is 73.6 V, giving 3.04KWh of installed power.

The selection of the inverter depends on the power required by the load and the battery voltage. Table 1 show that if all loads at the school are turned on, the total power consumption will be 970W, using a factor of 2, we decide use a 2KW inverter with 24V DC input.

E. Solar PV system connections

Fig. 3 shows the connections between different parts of the system and the highest levels of current flowing through them.

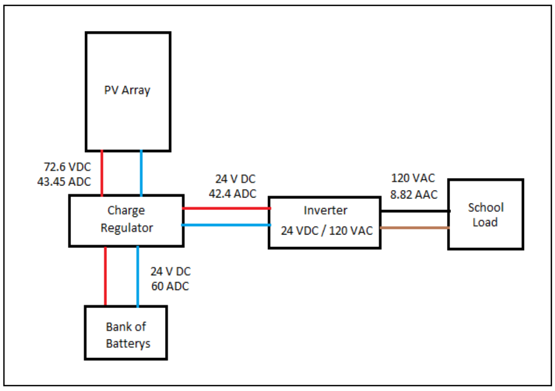

Fig 3. Maximun Voltage and current at the Solar PV system

3. PV System Simulation

To verify the battery bank capacity results calculated for two-day autonomy, the worst was simulated, when the school receives energy for two days only from the battery bank.

A. SaberRD Simulation

The PV system simulation is run on SaberRD and results can be seen in Fig 4 and Fig 5.

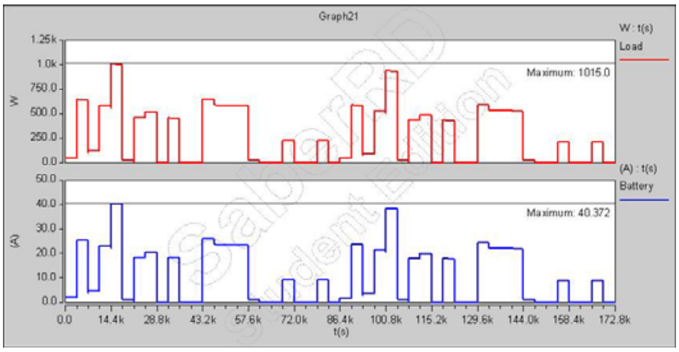

Fig 4. Simulation results for power consumption and battery current delivered

At the top of Figure 4, the power consumption of the school is observed for a period of 172800s (2 day) with peaks of 1KW, the bottom shows the waveform of the current supplied by the battery bank during simulation cycle. two days after, the battery bank has delivered approximately 550Ah, this amounts to 55% capacity, Fig 5 shows how the voltage drops 1.3V at the end of the cycle, when capacity of battery bank is 45%.

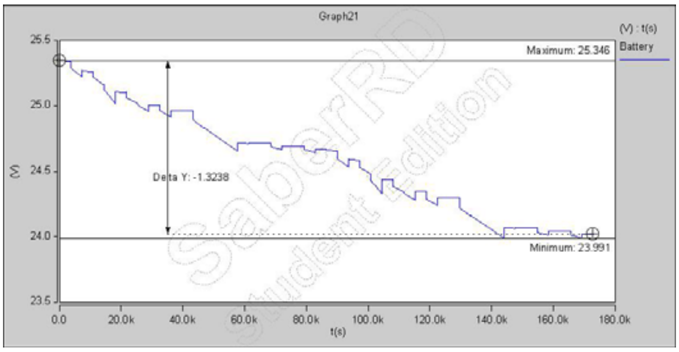

Fig 5. Battery Voltage waveform

B. Solar PV simulation using HOMER (c).

Electrical demand can be analyzed from the bar diagram showed in Figure 6.

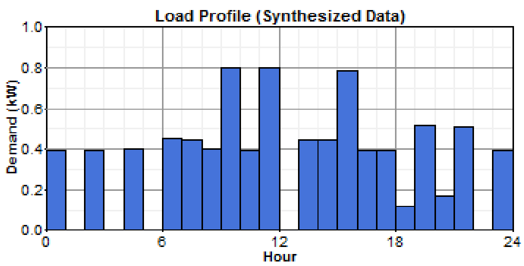

Fig 6. Demand curve

These type of energy consumption allow reducing the use of battery for night time, because there many activities during the day.

Taking into account the budget, costs are maybe in renewable technologies the main factor to be analyzed.

Figure 7, shows how cheap or expensive the components are.

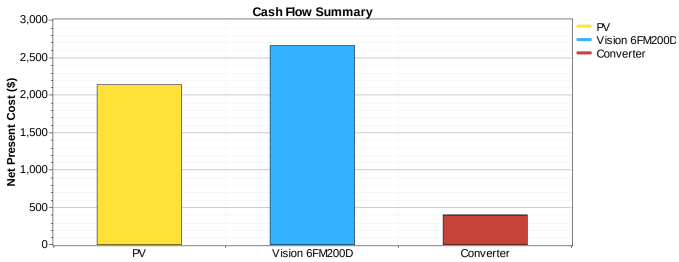

Fig 7. Project cash flow.

Similar to all the solar isolated or off-grid projects, batteries have a great value on the projects. Although, this solar PV system has a good behavior as can be seen on figure 8.

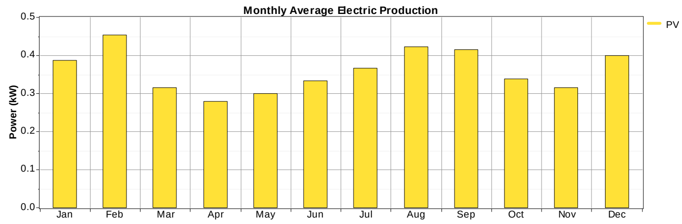

Fig 8. Monthly Solar PV production.

It shows that this system will provide 3153 kWh/y, with a consumption of 2542 kWh/y.

Figure 9 shows an example that how solar energy cover energy during two specific days in august, the curve with the higher peak its PV power and the other the AC primary Load demand.

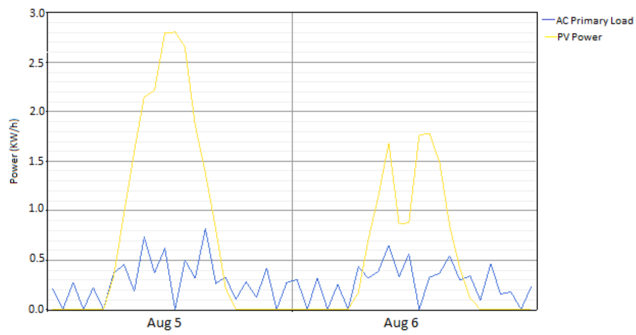

Fig 9. Comparison of solar energy production and Load demand

Certainly, in a 365 days study, some days cannot be covered by the electricity solar PV system. It is recommended to optimize this system to obtain better and maybe cost effective systems, as presented on Figure 10 from an example day of May.

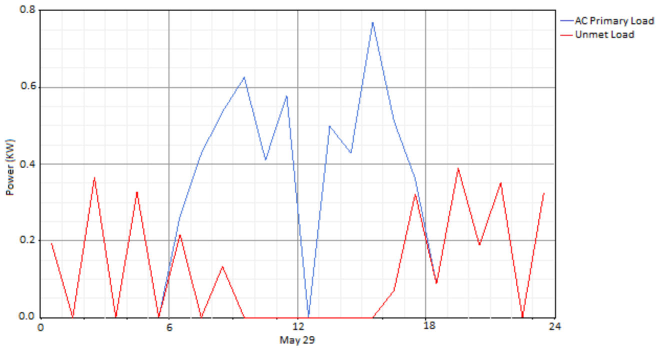

Fig 10. Unmet load on May 29.

4. Conclusions

To involve most or all the community members in the development of energy systems, is important for the right sizing and the most affordable solution for their needs, which in this case was a 3kWp PV system to provide electric power for a school, with an 3 days autonomy, a 24V / 1000Ah battery bank.

Simulation results show that the battery bank designed, can supply power for at least two days even if the PV is out of service. HOMER simulation results showed that PV can generate 2.8kWh and the maximum energy consumption is 1kWh (all the loads turned on) this is 35.7% of production, leaving 67% to charge the batteries and unexpected power demands.

The design an off grid solar PV system considering the community comments allow considering more aspects such as energy use hours per day, future productive projects that could increase its quality of life, creating a sustainable system and motivate them to learn about the technology.

Acknowledgement

This Project has been developed by the support of Direction of Research and Technological Development – DIDT, office at Universidad Autónoma de Occidente under internal calls for Project named: Sistema de Gestion Eficiente para autoconsumo con sistemas de generación hibridos renovables" under res. 6829 feb. 2014 and "Proyecto 1. Comunicación, Cambio Social y Buen Vivir para la sostenibilidad. Fase 1: Desarrollo" Res.: 7106 march 2nd 2016

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