Dimensioning, Design and Simulation of a Self-sustaining Photovoltaic Energy System to Power the Water Quality Monitoring Equipment of the Burgay River - Ecuador

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Abstract— **This project shows the methodology for the design and implementation of an isolated photovoltaic energy system to power low consumption equipment, a specific case of monitoring physical variables. The methodology consists of the characterization of the site, the calculation of the energy demand, the design of the photovoltaic system and its implementation. The PVsyst software is used as the main tool to generate the simulations and obtain the results. The final objective of the project is to obtain the adequate parameters for the choice of the components of the photovoltaic system (photovoltaic panel, controller, battery). In addition, this article will serve as a tutorial for researchers who wish to generate similar projects.**

Keywords — photovoltaic, system, monitoring, river, environmental, pollutants, PVsyst

I. INTRODUCTION

Taking measurements of physical phenomena is currently a necessity to determine characteristics, understand the behavior of said variables and show results; For this, electronic measuring equipment is required. Some of these systems demand to be located in areas where conventional electricity is lacking. For the specific case when taking measurements of a river at different points, it is necessary to have a team that is on the banks to obtain exact results of what you want to measure.

Having a self-sustaining energy measurement system that only requires scheduled preventive maintenance is a significant contribution for those applications that seek to measure physical phenomena through electronic devices that require energy supply, indicates [1].

Several solutions can be implemented for the energy self-sustainability of an isolated system, among some of them [2] is cited, who within his research work proposes energy storage using ultracapacitors in autonomous photovoltaic systems, [3] conducts a study of hybrid renewable energy system (solar - biomass gasification) to meet energy needs. Indicates in his study carried out by [4] describes an experimental methodology for the development of a prototype of an electric hydrogenerator as a generation alternative in rural areas showing an efficiency of 95%. The work developed by [5] shows the results of a hybrid system of photovoltaic and wind energy in small isolated energy systems.

The investigative work of [6] shows that energy generation through photovoltaic systems is currently one of the most common alternatives to provide a solution to the energization of electrical and electronic equipment in which there is no network of electricity. conventional electrical distribution. In this same sense, [7] concludes, additionally providing the advantage of applicability to any type of geographical location.

Currently several works have been developed on the subject under discussion and it is thus that at a global level one of the main isolated systems for obtaining and transmitting information that requires energy self-sustainability are artificial satellites. According to [8], it shows the use of two main photovoltaic generators as a power source for an artificial satellite by exposing it to the sun. A contribution of a doctoral work carried out by [9] exposes the results of the implementation of solar cells for space use as the main power source of the artificial satellite of scientific applications SAC-A of the CONAE in Argentina.

Several authors [10], [11], [12] expose the design, simulations and implementation of a measurement station powered by an isolated photovoltaic system and management of the transmission of information measured by different sensors (solar radiation, velocity of the wind, temperature, etc.) quantify the resources used by solar radiation and temporarily analyze the results obtained.

Adopting for the implementation of a renewable solar energy system is convenient given its low cost and its reliability in the electrical service for isolated systems [13] concludes in its design of an autonomous photovoltaic system for the supply of electrical energy. In the development of the investigation of [14] he contributes with a complete analysis on the reliability of photovoltaic technology, doing laboratory work on the technical quality of the components (batteries and regulators). Other very relevant works that contribute substantially to the implementation of these projects are discussed by [15], [16] and [17].

The problem is the lack of a conventional energy self-sustaining system based on photovoltaic energy for measurement systems of variables that pollute a river, a specific case for the research project "Monitoring of pollutants in the Burgay River"

For the reasons mentioned, it is necessary to implement an isolated energy system for the generation of electrical energy through the use of renewable energies such as photovoltaics, to contribute to the aforementioned research project. Figure 1 reveals the need to be implemented during the development of the investigation.

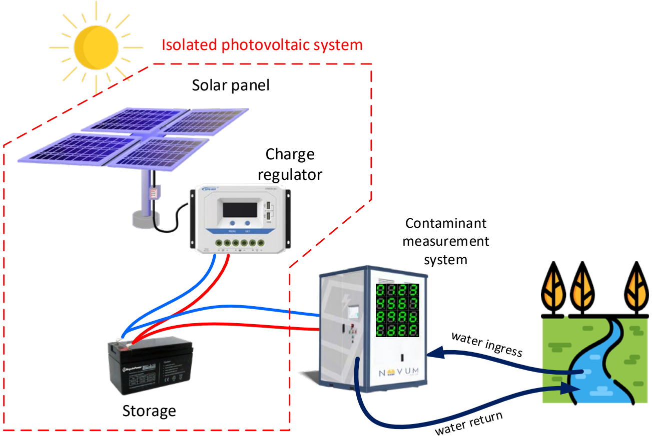

Figure 1. Functional design of the energy isolated measurement system

II. LOCATION OF THE RESEARCH

The Project is located at the Universidad Católica de Cuenca Sede Azogues, Canton Azogues-Ecuador, where there is a physical space next to the laboratory of the Civil Engineering career with the characteristics required for the assembly of the equipment. It can be seen with its coordinates in Figure 2.

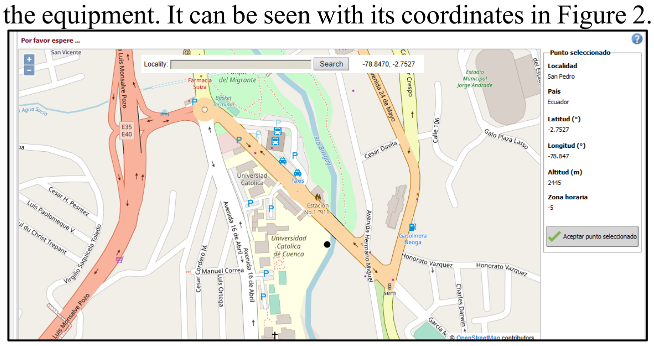

Figure 2. Location of the project

III. METHODOLOGY

Type of research: For the development of the project, the research methodology is followed based on a non-experimental design of an analytical observational type, following the phases shown in the flow chart (Figure 3) below:

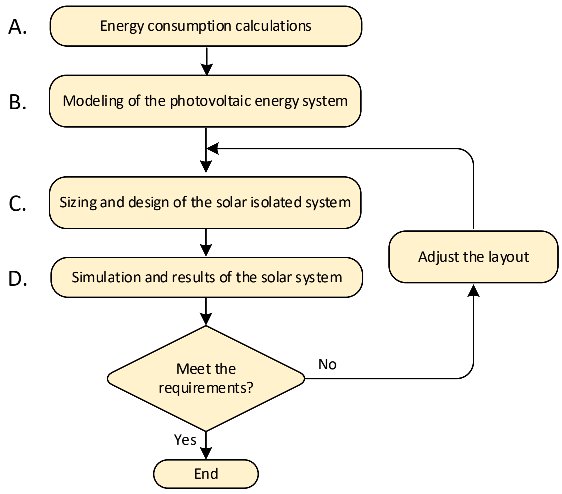

Figure 3. Flowchart

A. *Energy consumption calculation:*

In this stage, the survey of the energy consumption of the sensors and actuators that the measurement system has is carried out through the documentary study of the technical sheets of the equipment to determine the general consumption demand of the system. Table 1 shows the partial and total results.

Table 1. Energy consumption calculation

ENERGY CONSUMPTION CALCULATIONS								
ID	Equipment Description	Quantity	Power (W)	Total power (W)	Daily use (h/day)	Weekly use (d/week)	Weekly weighting factor	Daily consumption (Wh/day)
1001	Transformer	1	0,6	0,6	24	7	1,00	14,40
1002	PH-sensor	1	0,05	0,05	24	7	1,00	1,20
1003	TDS Meter	1	0,03	0,03	24	7	1,00	0,72
1004	Temperature sensor	1	0,03	0,03	24	7	1,00	0,72
1005	Ultrasonic sensor	1	0,075	0,075	24	7	1,00	1,80
1006	Turbidity sensor	1	0,2	0,2	24	7	1,00	4,80
1007	Conductivity sensor	1	0,2	0,2	24	7	1,00	4,80
1008	LORA device	1	0,025	0,025	24	7	1,00	0,60
1009	Arduino	1	0,25	0,25	24	7	1,00	6,00

Total daily consumption (J) (Wh/day)	35,0
Simultaneity factor (K) (%)	100
Safety factor (L) (%)	15
Daily Simultaneous Consumption (M=JxK+(1+L/100)) (Wh/day)	40,3
Monthly Simultaneous Consumption (N=M*365/12) (kWh/mes)	1225,7
Annual Simultaneous Consumption (O=N*12) (kWh/año)	14708,0
Power Installed (W)	**1,46**

B. *Modeling of the photovoltaic system:*

Within this phase, the modeling of the photovoltaic system was carried out based on the energy requirements analyzed in the previous point, to obtain results through simulations giving different scenarios.

Considering the variables according to the table:

- Transformer power $\rightarrow P_T$
- PH Sensor power $\rightarrow P_{PH}$
- TDS Sensor power $\rightarrow P_{TDS}$
- Temperature sensor power $\rightarrow P_{Tem}$

- Ultrasonic Sensor power → P_U
- Turbidity Sensor power → P_{Tur}
- LORA device power → P_L
- Arduino module power → P_A

Then the installed power (P_i) can be calculated using the Equation (1)

$$P_i = P_T + P_{PH} + P_{TDS} + P_{Tem} + P_U + P_{Tur} + P_L + P_A \qquad (1)$$

Substituting the data obtained from Table 1, we obtain,

$$P_i = 1{,}46 \text{ W}$$

If the irradiance and temperature in the area of installation are considered constant, and also that the load connected to the panel varies, starting from the circuit shown in Figure 4, the characteristic curves of current versus voltage (I-V) can be modeled [18].

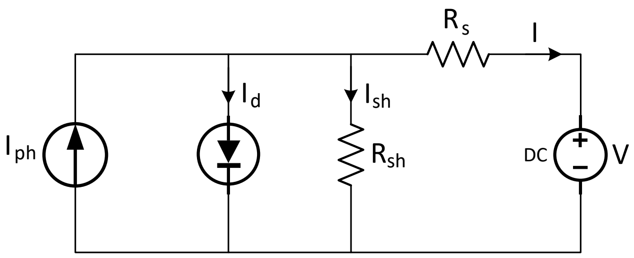

Figure 4. Electrical model of the photovoltaic module.

The equations that govern the modeling of the electrical circuit of the photovoltaic module are shown below:

$$I = I_{ph} - I_0\left(e^{\frac{q(V+R_S I)}{aKTN_S}} - 1\right) - \frac{(V+R_S I)}{R_{sh}} \qquad (2)$$

Where I_{ph} is the photogenerated current, I_0 is the reverse saturation current of the diode, q is the charge of the electron ($1{,}6\,x\,10^{-19}\,C$), V is the voltaje of the solar cell, K is the constant of Boltzmann ($1{,}38\,x\,10^{-23}\,J/K$), T_c is the operating temperature of the cell, and A the ideality factor.

In addition, the photogenerated current is a function of solar radiation and the temperature measured in the cell, the equation can be generated:

$$I_{ph} = \left(I_{sc} + K_i(T - 298.15)\right)\frac{G}{1000} \qquad (3)$$

The diode reverse saturation current is also a function of temperature variation, as described by the following equation:

$$I_0 = \frac{I_{sc} + K_i(T - 298.15)}{e^{\frac{q(V+R_S I)}{aKTN_S}} - 1} \qquad (4)$$

I_{ph}, I_0, N_s, V_m, I_m, T, a, K, q, G, R_s y R_{sh} designate, respectively, the photocurrent, the reverse saturation current of the diode, the number of cells in series, the voltage at the terminals of the module, the ambient temperature in K, the ideality factor, the charge of the electron, the Boltzmann constant, the solar irradiation in W/m^2, the resistance in series and in derivation of the module.

Equation (2) is very important to know the power of the photovoltaic panels emitted by the different voltage and current values that make up the I-V curve. Equation (2) is solved by iterative algorithms and using it to find the power of the panels is a very complicated task. Reason why for our case we will use the King model [19]for the development of the model, which shows five essential points that must be considered, which are found depending on the irradiance and temperature of the cell, as shown in Figure 5.

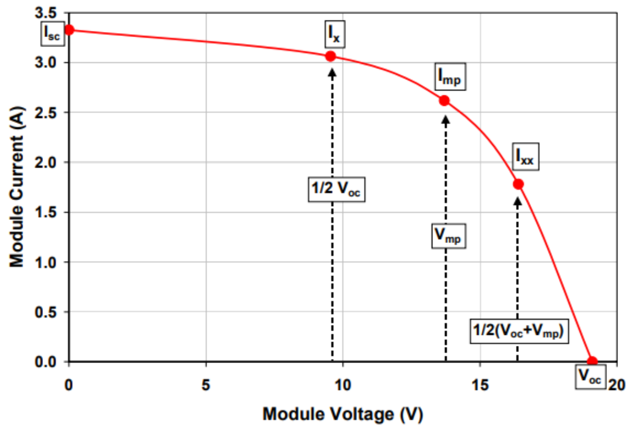

Figure 5. Curve I-V of a solar panel – model of King [19]

For our case that we are going to choose a Trimex Tesla M-S36-53 panel, the data from its technical sheet is shown in Figure 6.

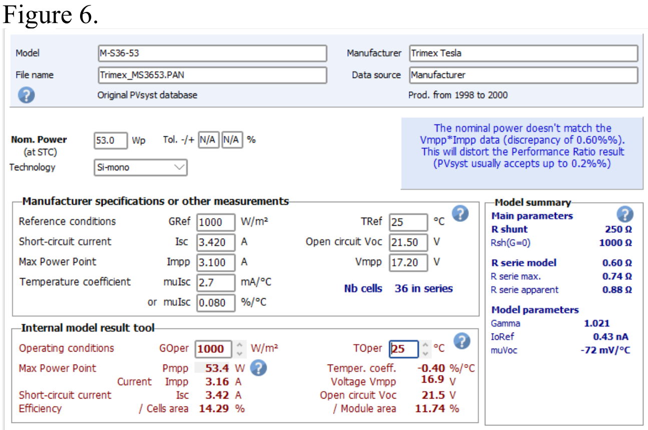

Figure 6. Panel data Trimex Tesla M-S36-53.

And we simulate for different values of incidence irradiation as shown in Figure 7. Considering a referential irradiance of 1000 W/m^2,, we have that V_{mp} = 15.427 V e I_{mp} = 3.1854 A , giving a power of 49.139 W. From the same way you can get the power values for different irradiation values.

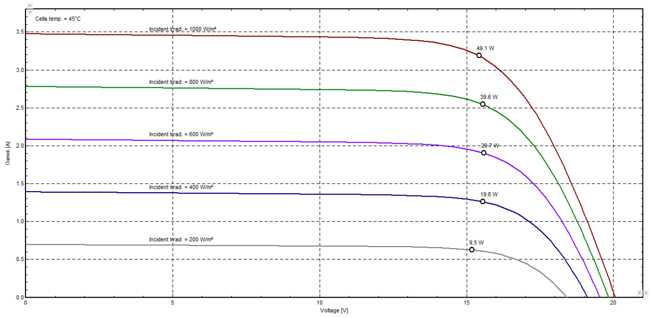

Figure 7. Curve I-V of the panel Trimex Tesla M-S36-53.

Figure 8 simulates the power vs. voltage curve for the chosen panel.

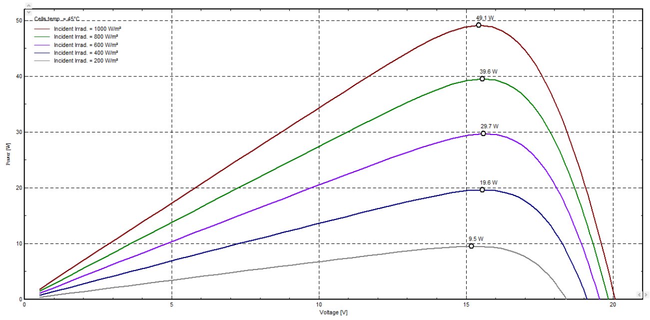

Figure 8. Curve P-V of the panel Trimex Tesla M-S36-53

C. *Solar System sizing and design*

The sizing and design of the system is carried out using the specialized PVsyst software, based on the previous parameters that adjust to the project requirements, such as: energy demand, autonomy time, if it is isolated or connected to the network, etc. For our specific case and according to the needs of the project, the system that is adjusted is a "Typical design of an independent system", which is shown in Figure 9.

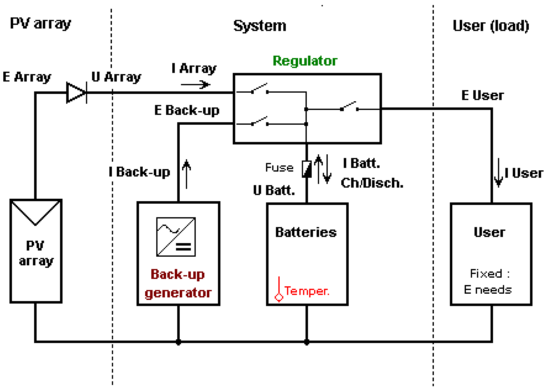

Figure 9. Typical design of a stand-alone system.

The following are the points to follow to obtain the components of the independent system using PVsyst:

1. The coordinates of the location where the project is going to be implemented are taken, being these:

Site	UCACUE-Azogues
Country	Ecuador
Region	South_America
Source	Meteonorm 8.0 (2010-2014), Sat=100%
Latitude	-27.527 °
Longitude	-788.470 °
Altitude	2445 m
Time Zone	-5 GMT
Albedo	0.20

With the location data, the monthly meteo data is obtained, shown in Table 2.

Table 2. Monthly weather data.

Values Month	GlobH kWh/m²	DiffH kWh/m²	Temp °C	Wind Vel m/s
January	146.7	75.1	14.5	3.61
February	130.9	70.2	14.4	3.39
March	158.8	78.3	14.3	3.10
April	153.3	57.8	14.0	2.90
May	160.9	64.4	14.1	3.50
June	140.8	58.4	13.3	4.40
July	136.1	61.5	13.3	4.79
August	119.3	67.1	13.4	4.80
September	130.2	61.9	13.5	4.30
October	118.2	67.8	14.4	3.40
November	132.8	72.4	14.2	3.00
December	149.1	73.4	14.4	3.29
Year	1677.1	808.3	14.0	3.71

2. The project must be a system isolated from the grid due to its location in the Burgay river basin since there is no conventional electrical grid, and it also leaves the possibility of changing its location if necessary.

3. We define the orientation of the panels according to the best annual performance to capture solar radiation, resulting in a plane tilt of 10° and an azimuth of 0°, these results can be seen in Figure 10.

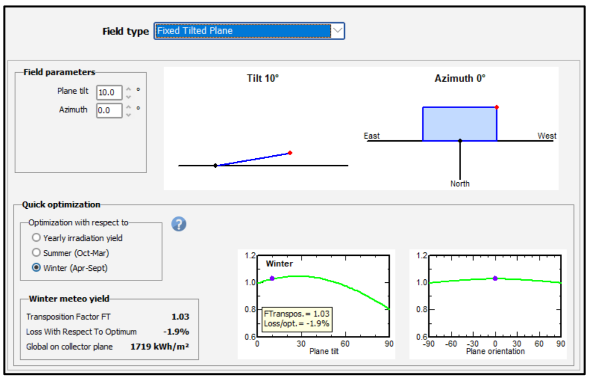

Figure 10. Orientation

4. The parameter found in the consumption calculations section refers to the installed power and leaves an additional percentage for some energy requirement in the future, which allows us to define in the PVsyst the daily consumption for the year, considering that

the team will work 24 hours a day and 7 days a week. This information can be reviewed in Figure 11.

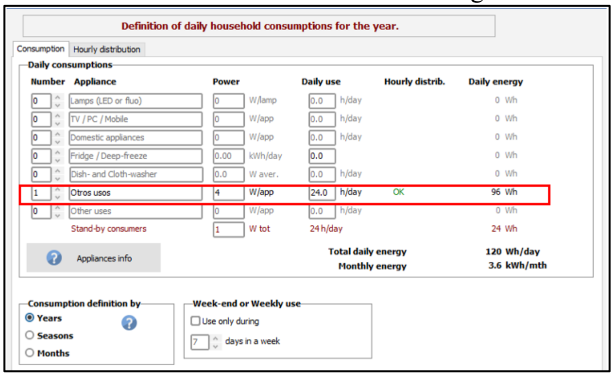

Figure 11. Definition of daily consumption for the year

5. As already indicated, the system must be continuously powered by its constant monitoring conditions and it is thus necessary to have a storage that allows me to have an autonomy of at least 1 day. In addition, at this point it is necessary to indicate the voltage of the battery to be used. This data is considered and dependent on the power supply of the electronic equipment of the monitoring system, being 12 V. In the same way, the storage shows (Figure 12) the details of the information load in the PVsyst.

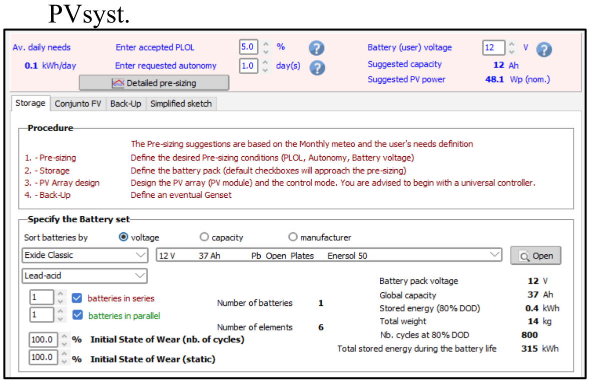

Figure 12. Definition of daily consumption for the year

6. We select the photovoltaic module and the controller, the ones that best fit our requirements are shown in Figure 13.

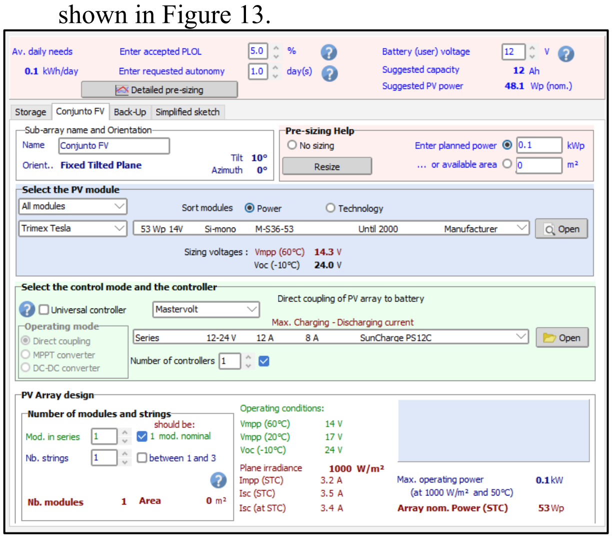

Figure 13. Selection of PV panel and controller

D. *Simulation and results of the solar system:*

The simulation is carried out based on the information entered in the PVsyst according to the needs described above. Figure 14 shows the normalized production to have during the year. Having an available energy production of 62.06 kWh/year, of which 43.80 kWh/year will be used, leaving an excess of 16.54 kWh/year.

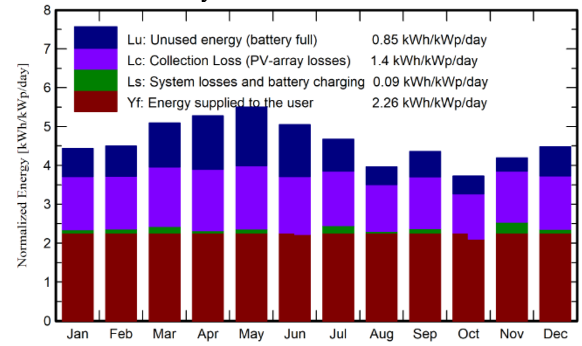

Figure 14. Normalized production (per installed kWp)

Figure 15 shows the performance ratio (PR) for the year month by month. Understanding that the months of August and October reach their highest peaks in PR. In general, a performance ratio of 49.18% is considered.

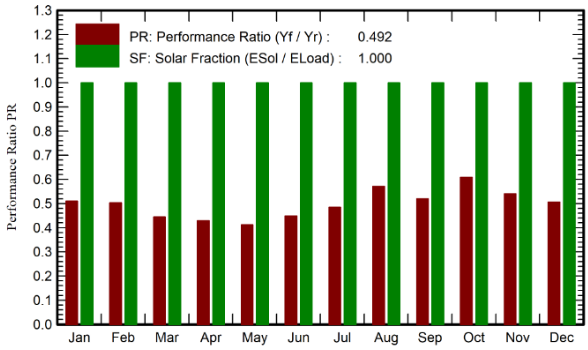

Figure 15. Performance ratio (PR)

The balances and main results are indicated in Table 3, both on a monthly basis and the consolidated values for the year.

Table 3. Balance sheets and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E_Avail kWh	EUnused kWh	E_User kWh	E_Load kWh
January	146,7	132,60	5,04	1,18	3,72	3,72
February	130,9	121,70	4,66	1,14	3,36	3,36
March	158,8	153,20	5,86	1,85	3,72	3,72
April	153,3	154,10	5,87	2,18	3,60	3,60
May	160,9	166,00	6,36	2,46	3,72	3,72
June	140,8	147,30	5,67	2,12	3,60	3,60
July	136,1	140,70	5,38	1,34	3,72	3,72
August	119,3	119,20	4,53	0,75	3,72	3,72
September	130,2	126,90	4,81	1,02	3,60	3,60
October	118,2	111,50	4,20	0,74	3,72	3,72
November	132,8	120,90	4,57	0,53	3,60	3,60
December	149,1	133,70	5,12	1,23	3,72	3,72
Year	**1.677,10**	**1.627,80**	**62,06**	**16,54**	**43,80**	**43,80**

Where,

GlobHor	Glabal horizontal irradiation
GlobEff	Global Cash
E_Avail	Solar energy available
EUnused	Energy not used (battery full)
E_User	Delivered to the user
E_Load	Energy need of the user (Load)

Finally, the data obtained in the simulation of the solar system for the losses due to the different factors indicated in Figure 16 are shown.

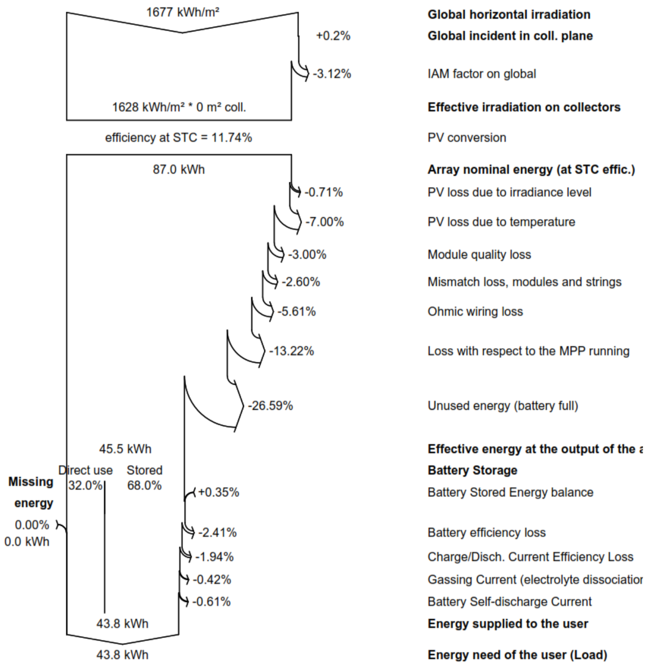

Figure 16. Loss diagram

IV. Conclusions

The results of the simulation with the data required to meet the energy needs of the system under different changes in solar radiation and panel temperature were presented as expected by choosing the Trimex Tesla M-S36-53 photovoltaic panel. In the system simulation, the power measurement was determined by taking 60 samples.

Analyzing the solar panel through its mathematical model and understanding its electrical diagram leads us to understand that through its current-voltage and power-voltage graphs, it facilitates the choice of parameters and it was also possible to verify the technical data provided by the manufacturer. at their points of operation. In Figure 6 it was possible to obtain the maximum tension ranges in order to obtain the best performance.

The objective of the research work was to compare the results obtained to analyze the best option according to the needs raised to supply energy to the pollutant measurement system.

Using specialized software such as PVsyst facilitates the calculations for a complete system connected to the grid or autonomous as in our case, and above all it generates simulation alternatives for different solar panels, controllers, batteries.

With the results obtained in the simulations, it can be indicated that it is feasible to implement the isolated photovoltaic system, in addition to the geographical location that presents good solar radiation conditions, the components have a duration between 8 and 10 years (considering the batteries as the most vulnerable). to a change in the period described), granting energy independence to the school during that time.

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