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Modelling and Balance Energy Analysis of Photovoltaic for 1.300 VA Household Electric in Jember Indonesia

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ABSTRACT: In Indonesia, 1,300 VA of electricity customers are very growing, therefore in order to an effective acceleration for the use of renewable energy, energy transfer from fossil energy to renewable energy planning needs to be directed at 1,300 VA load customer. The problem is how to design an effective system, especially in terms of determining the installed capacity in accordance with the renewable energy potential in a particular location. In this research, photovoltaic models, load models, irradiant models, and temperature models in Jember were developed as research locations. With the model and simulation made using PSIM, it can be concluded that with the model made using 60 photovoltaic modules, with 5 parallel formations from a series of 12 modules composed of 36 PV cells, or there are 2,160 PV cells, the system can balance between source and used electric energy.

KEYWORDS: Renewable Energy, Photovoltaic, Balance Energy, 1,300 VA, Jember Indonesia

I.INTRODUCTION

Depleting fossil fuel reserves and increasing environmental pollution caused by the conversion of fossil fuels for electricity for household use, transportation and other sectors, are serious global problems. A large amount of toxic and non-toxic waste is generated during the extraction, refining and transportation stages of coal, oil and gas. Some of its by-products, such as volatile organic compounds, nitrogen and sulphur compounds, and spilled oil that can contaminate air, water, and soil, are already at levels that are harmful to life. Climate warming, ocean acidification, and sea level rise are global changes that continue to increase due to greenhouse gas emissions in the form of carbon dioxide (CO2), methane, and aerosols of micro-particles such as black carbon [1].

One of the effective technologies to overcome this problem is the use of electrical energy derived from renewable energy, especially electricity based on sunlight. However, there is a problem in generating electricity with sunlight, namely that the intensity of sunlight always fluctuates, so that to meet this energy, careful planning is needed, namely planning that is tailored to energy needs, the system used and the weather in certain locations [2-9].

The need for electrical energy is very dependent on the load used. To classify the need for electrical energy and regulate the tariff, the Minister of Energy and Mineral Resources of the Republic of Indonesia has set 13 load classifications, namely (a) Households, covering 5 groups namely R-1/TR 900 VA – RTM, R-1/ TR 1,300 VA, R-1/TR 2,200 VA, R-2/TR 3,500 VA to 5,500 VA, and R-3/TR 6,600 VA and above (household electricity tariffs), (b) Big Business, covering 2 groups namely B-2/TR 6,600 VA up to 200 kVA and B-3/TM above 200 kVA (big business electricity tariff), (c) Large Industry, covering 2 groups namely 2 I-3/TM above 200 kVA and I- 4/ TT 30,000 kVA and above (large industrial electricity tariffs), (d) Government, includes 3 groups namely P-1/TR 6,600 VA to 200 kVA, P-2/TM above 200 kVA, and P-3/TR (government agency electricity rates), (e) Special Services, there is only 1 group, namely 1 L/TR, TM, TT (special electricity rates) [10].

Among these classifications, household customers R1 with a power of 900, 1,300 and 2200 VA are currently the customers who use the most electrical energy [11]. 1,300 VA customers are highly developed customers, both in terms of power use and energy independence (not subsidized), therefore in order for the use of renewable energy to have a good market, renewable energy planning needs to be directed at this 1,300 VA load customer.
The system that is widely used to generate electrical energy from sunlight is a system that uses solar panels. Generally, the system consists of the main elements, namely solar panels, charge controllers, batteries, inverters and control

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systems. The main problem in this system is how to determine the capacity of the solar panels so that the required energy is fulfilled independently from solar panels and dependence on fossil energy can be eliminated [4-9]. Determining the capacity of solar panels is certainly closely related to spending on the purchase of solar panels. The determination of the capacity of solar panels is also very important to be calculated carefully, considering that recently the weather has changed very fluctuate, plus in recent years the long dry season has no longer occurred.

This research develops a model and analysis of the electrical energy balance of a household with a power of 1,300 VA based on a Solar Photovoltaic Array or Photovoltaic (PV) or Photovoltaic. For this purpose, the data needed are irradiance and temperature, PV characteristics, load, and battery, while data related to inverter and solar charger can be ignored. Load data, load patterns, PV and batteries will be obtained from observations and measurements, while irradiance and temperature data will be searched from the internet. The data are then modelled and simulators are made, in the hope that they are easy to use in the system analysis process.

II.LITERATURE REVIEW

2.1 Classification of Electricity Tariffs in Indonesia

Based on the Regulation of the Minister of Energy and Mineral Resources of the Republic of Indonesia No. 26 of 2016 concerning Tariffs for Electricity Provided by PT Perusahaan Listrik Negara (Persero), the classification of tariff groups in Indonesia is divided into 13 groups [10]. Meanwhile, from the tariff groups, groups 1 to 3 are the customers with the largest number and users of electrical energy, as presented in Table 1.

Table 1 Electricity Tariff Class

NO.	GOL. TARIF	BATAS DAYA
1.	R-1/TR	900 VA-RTM
2.	R-1/TR	1.300 VA
3.	R-1/TR	2.200 VA
4.	R-2/TR	3.500 VA s.d. 5.500 VA
5.	R-3/TR	6.600 VA ke atas
6.	B-2/TR	6.600 VA s.d. 200 kVA
7.	B-3/TM	di atas 200 kVA
8.	I-3/TM	di atas 200 kVA
9.	I-4/TT	30.000 kVA ke atas
10.	P-1/TR	6.600 VA s.d. 200 kVA
11.	P-2/TM	di atas 200 kVA
12.	P-3/TR	-
13.	L/TR, TM, TT	-

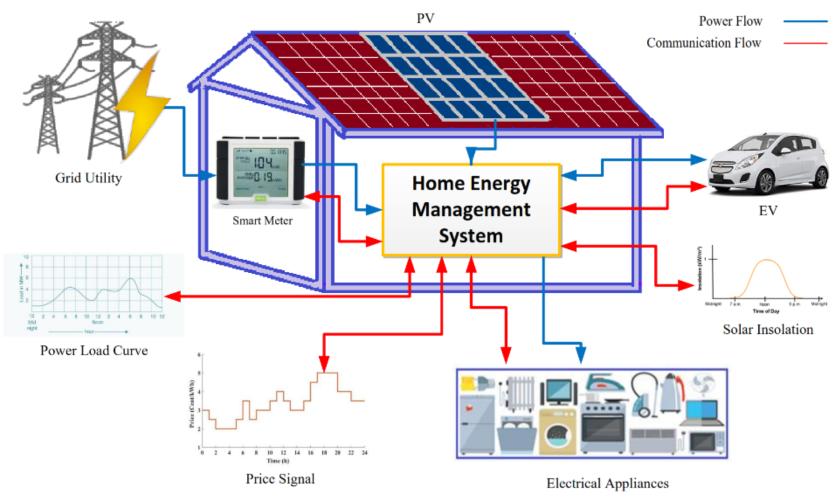

Figure 1 Household electrical system [9]

2.2 Photovoltaic-Based Household Electrical System

The photovoltaic-based household electrical system in this study shows that homes can provide electricity with the main energy coming from solar panels. The power flow is controlled in such a way that optimal power can be supplied from the solar panels.

A schematic representation of a photovoltaic-based household electrical system is shown in Figure 1, which consists of household appliances, electric vehicles or Electric Vehicles (EV), photovoltaic or Photovoltaic (PV) systems, daily load curves, daily sunlight intensity curves, price signals daily, utility grids, smart meters, and control systems to manage and control the flow of power between utility grids [9].

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An energy management strategy for smart homes that integrates EV and PV is created to minimize household electricity costs and flatten the household electricity load curve. Eight energy management strategies were developed, divided into two stages [9].

Stage A, which operates in three modes depending on the unavailability of PV generation (i.e., PV power is equal to zero), and Stage B, which operates in five modes depending on the availability of PV power (i.e., PV power is greater than zero). EV parameters, usage time prices, household power demand that varies with time, and PV generation profiles are used as inputs for determining strategies to ensure that electricity costs and power curves can be minimized, while in terms of power requirements can still be met.

The research has provided analysis results that the daily electricity costs for PV integrated smart home systems can bring significant economic benefits to homeowners, wherein the daily electricity costs are reduced from $32.7 to $28.1, or $4.6.

2.3 PV Hierarchy

Solar energy is the energy source of almost all energy on earth. Humans, all other animals, and plants depend on the sun for heating and food. However, humans also take advantage of solar energy in various forms. Fossil fuels, which are coal and petroleum, are plant material from past geological times that is currently used for transportation and electricity generation. Similarly, biomass converts solar energy into fuel, which can then be used for heat, transportation, or electricity.

Photovoltaic (PV) is a simple method for harnessing solar energy. PV devices are unique, in that they directly convert the incident solar radiation into electricity, without noise, pollution, or moving parts, making them strong, reliable, and durable. A photovoltaic panel or solar panel (PV Panel) consists of photovoltaic cells or solar cells (PV Cell) connected together, while a Solar Photovoltaic Array or Photovoltaic (PV Array) is a system consisting of a group of solar panels connected together [10]. Figure 2 shows this hierarchy.

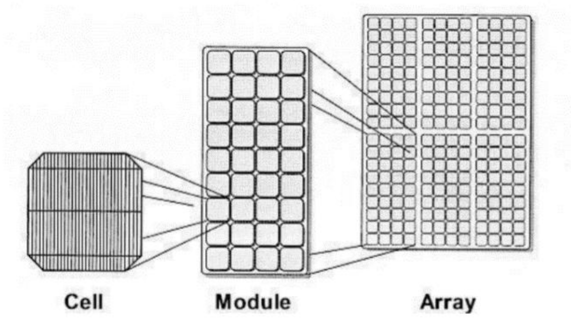

Figure 2 PV Hierarchy [12]

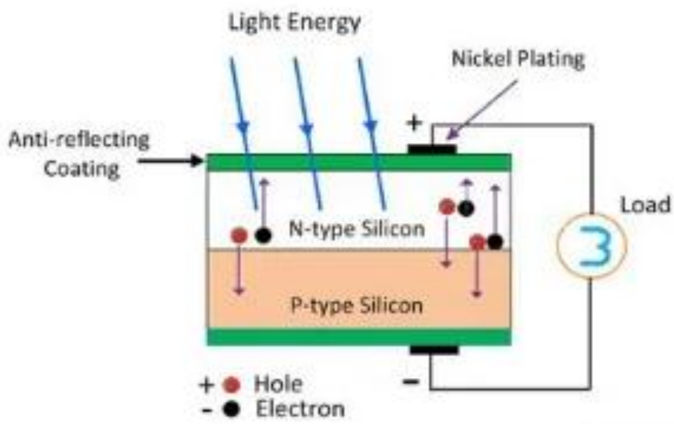

Figure 3 The working principle of PV cells [12]

2.4 Principle of PV Cell

PV cells have the function of converting the intensity of sunlight into electrical energy. PV cells produce electrical power with a certain voltage and current. PV cells that convert light intensity into electricity. When the light intensity is reduced (cloudy, rainy, cloudy) the electric current generated will also decrease. The working principle of PV cells can be explained in Figure 3.

The semiconductor material in the PV cell is doped to form a PN structure as an internal electric field. P-type (positive) silicon has a tendency to lose electrons and gain holes whereas N-type (negative) silicon accepts electrons. When sunlight hits the cell, the photons in the light excite some of the electrons in the semiconductor into electron-hole pairs (negative-positive). Since there is an internal electric field, this pair is induced to scatter. As a result, the electrons move to the negative electrode while the holes move to the positive electrode. If in the system there is a conducting wire connecting the negative electrode, load, and positive electrode in series, then an electric current will be generated to supply the load.

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2.5 Photon Energy

Sunlight is a form of electromagnetic radiation and the visible light we see is a small part of the electromagnetic spectrum. Light can be thought of as consisting of packets or particles of energy, called photons. Photons, like all other quantum mechanical particles such as electrons, protons, etc., are most accurately described as packets of waves. A wave packet is defined as a collection of waves that can interact in such a way that the wave packet may appear spatially localized (in the same way as a square wave that results from the addition of an infinite number of sine waves), or may alternately appear as just waves.

In cases where the wave packet is spatially localized, it acts as a particle. Therefore, depending on the situation, photons can appear as waves or particles and this concept is called wave-particle duality. There is an inverse relationship between photon energy (E) and light wavelength (λ) which is given by equation [12]:

$$E = h\,c\,/ \quad \text{………………………………………………………(1)}$$

where h is Planck's constant, h = 6.626 × 10 -34 joules s and c is the speed of light, c = 2.998 × 108 m/s or hc = 1.99×1025 joules-m

When discussing particles such as photons or electrons, the most commonly used unit of energy is the electron-volt (eV). An electron volt is the energy required to raise an electron at a voltage of 1 volt, so that a photon with an energy of 1 eV = 1.602 × 10 -19 J. Therefore, we can rewrite the constant hc above in the form of eV:

hc = (1.99×10 -25 joules-m) × (1ev/1.602 × 10 -19 joules) = 1.24 × 10 -6 eV-m
hc = (1.24 × 10 -6 eV-m) × (10 6 m/m) = 1.24 eV-µm

Thus, the energy of the resulting photon can be rewritten as:

$$E(eV) = 1.24 / (\mu m) \quad \text{…………………………………………(2)}$$

2.6 PV Cell Equivalent Model

The model is conventionally equivalent to a PV cell, and consists of an anti-parallel diode, a single current source, a resistance. The PV cell model is shown in Figure 4.

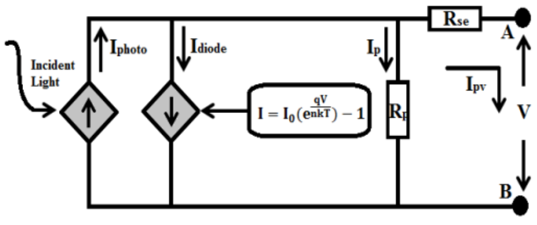

Figure 4 PV Cell Equivalent Model [7]

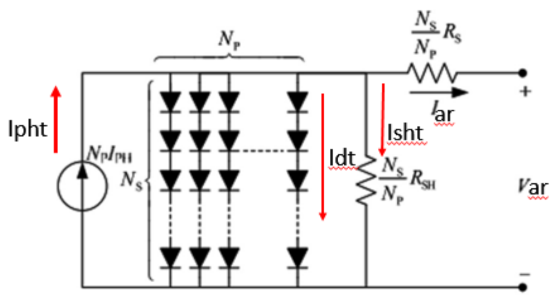

Figure 5 PV Array Equivalent Model

By applying Kirchhoff's current law to the model shown in Figure 4 the total PV current is [7]:

$$I_{pv} = I_{photo} - I_{diode} - I_p \quad \text{…………………………………………(3)}$$

where Iphoto is a photocurrent of radiation or photocurrent when the PV cell is exposed to sunlight. This photocurrent varies linearly with solar radiation at a given temperature. Idiode is an antiparallel diode current, and produces a non-linear current in the PV cell. The current flowing through the shunt resistor is represented by Ip. By substituting the equations for Ip and Idiode in Eq, and PV, the equation becomes [7]:

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$$I_{pv} = I_{photo} - I_0(e^{\frac{q(V+I_{pv}R_{se})}{nkT}} - 1) - (\frac{V+I_{pv}R_{se}}{R_p}) \quad \text{..........(4)}$$

where q = 1.602×10−19 C, the idealistic factor of the diode is denoted by n, the Boltzmann constant is represented as k = 1.3806503×10−23 J/K, Io is the saturation current of the diode, the temperature of the PV cell is represented by T, Rp & Rse represent the resistance shunt and series in PV cells.

2.7 PV Array Models

In a PV array, the PV modules are connected in series and in parallel. The configuration of the PV array is shown in Figure 5. The number of series connected is denoted by Ns (in the PV Module), while the parallel connected PV is denoted by Np. The relationship between the current and voltage of this PV array is [7] :

$$I_{ar} = N_p I_{photo} - N_p I_0(e^{\frac{q\left(V_{ar}+I_{ar}\frac{N_s}{N_p}R_{se}\right)}{N_s nkT}} - 1) - \left(\frac{V_{ar}+I_{ar}R_{se}\frac{N_s}{N_p}}{\frac{N_s}{N_p}R_p}\right) \quad \text{....... (5)}$$

2.8 One Year PV Array Energy

To calculate the electric power in a PV array in one year, the following general formula can be used [12]:

E = A * r * H * PR …………………… (6)

Where:
E = Energy (kWh)
A = total photovoltaic area (m2)
r = Photovoltaic efficiency (%)
H = Annual mean solar radiation on inclined panel
PR = Performance ratio, coefficient of losses (between 0.5-0.9, general value = 0.75)

r is the photovoltaic yield given by the ratio: electric power (in kWp) of one photovoltaic divided by the area of one panel. The photovoltaic efficiency of a 250 Wp PV module with an area of 1.6 m2 is 15.6%. Note that this nominal ratio is given for standard test conditions (STC): radiation=1000 W/m2, cell temperature=25 degrees centigrade, Wind speed=1 m/s, AM=1.5.
H is the annual mean solar radiation on the inclined panel. Between 200 kWh/m2.y (Norway) and 2600 kWh/m2.y (Saudi Arabia) Indonesia 1000kWh/m2.y
PR (Performance Ratio) is a very important value for evaluating the quality of photovoltaic installations because it provides installation performance independently of orientation, panel tilt. This covers all losses.

- Inverter loss (4% to 10%)
- Temperature loss (5% to 20%)
- DC cable loss (1 to 3%)
- AC cord missing (1 to 3%)
- Weather 0% to 80%
- Losses on weak radiation 3-7%
- Losses due to dust/snow (2%)

III.METHOD

The first step in this research method is modelling the customer's 1,300 VA energy requirement based on observation. From the load data and ignition timing, the required energy can be determined. Data loading and active time are made in tabular form. After getting daily energy data, the monthly and annual energy needs will then be calculated.

The second step is search and access sources of irradiance data and temperature data from the internet. To get irradiation and temperature data used as input for PV, search the internet for websites related to the keyword irradiation data. From this search, we will try to access it and choose sources that are easily accessible and have high data compatibility.

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The third step is modelling and simulation. Modelling begin for Photovoltaic cell that converts sunlight (photons) into electrical energy through the photovoltaic effect. Photovoltaic cell then connected in series-parallel (array) to obtain the required current and voltage values. By referring to the literature review and observing the model, the PV array modelled by the equation 5. Model built using PSIM and simulate to find balance energy and number of PV in the system 1,300 VA household electric.

IV.RESULT AND DISCUSION

4.1 Energy Pattern of 1,300 VA Customer

To find out the energy pattern of a 1,300 VA customer, it is necessary to first know the load data installed on the customer, which in this case is household electrical equipment. There are Refrigerator, Front downstairs lamp, lower water pumps, Lower Chamber Lights Middle, water pumps up, Living Room Lights Down, TV bottom, Bottom Porch Light, Dining Room TV, Top Porch Lights, Water Boiler, Upper Room Lights, Rice cooker, Bottom Bathroom Lights, Lap top 1, Bathroom Lamp Top, Lap top 2, Top Section Lights, HP Charger, Room Lamp Upper Right, Rear bedroom light, Upper chamber light Left, Kitchen Lights, Top Garden Lights, Dining room lights, Garage lights, Living Room Lights, Air Conditioner, and Center Basement Lights.

Based on the observations made, the daily load pattern is as shown in Figure 6. Based on the observation results, the energy used in one day (Wth) is 11,174 KVAH. Based on daily energy needs, monthly energy needs can be estimated, namely by multiplying daily energy needs multiplied by 30 days. Based on these assumptions, the monthly energy requirement is 335,205 KVAH. Using the same assumptions as the monthly energy needs, the energy requirement for one year can be calculated by multiplying the daily energy multiplied by 365 days, and the energy requirement is 4,078,328 KVAH.

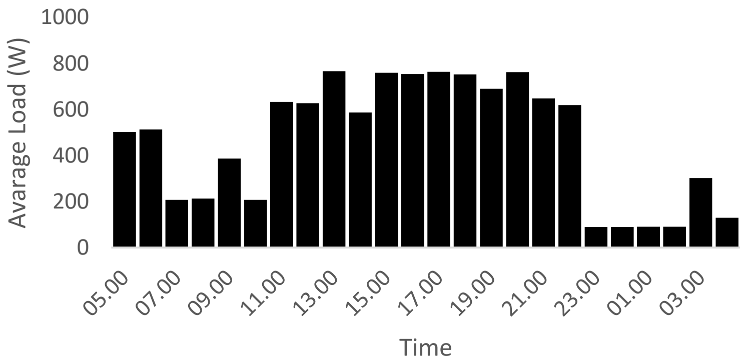

Figure 6 Daily avarage load

4.2 Irradiance and Temperature Data from Internet

As a result, a number of websites will be found including https://solcast.com/, http://www.soda-pro.com/, https://solargis.com/, https://www.ncei.noaa.gov/, https://power.larc.nasa.gov/data-access-viewer/, and https://ec.europa.eu/jrc/en/pvgis. Among these websites, the last website, namely https://ec.europa.eu/jrc/en/pvgis is a website that is easily accessible and can provide more appropriate data.

On the website, apart from the location, the desired data period can also be determined, although the data displayed is data up to 2016. Examples of daily, monthly and yearly irradiant and temperature data obtained in graphical form are presented in Figure 7.

4.3 Irradiance, Temperature and Load Modeling using PSIM

The data obtained must then be readable by the simulator. With the PSIM simulator, the data is modeled using the look up table in the Element –Other-Functional Block-Look up Table (External File) menu as shown in Figure 8. While the irradiant model is shown in Figure 9. The model for temperature and load is similar to the irradiance model, only the data differ; as well as for the daily, monthly and yearly period.

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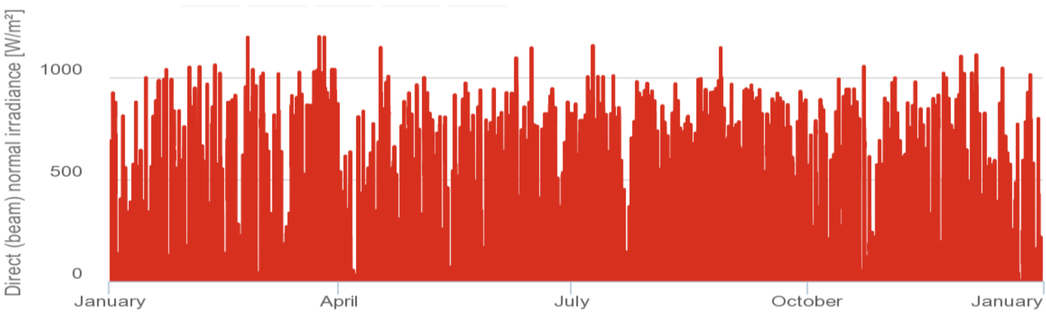
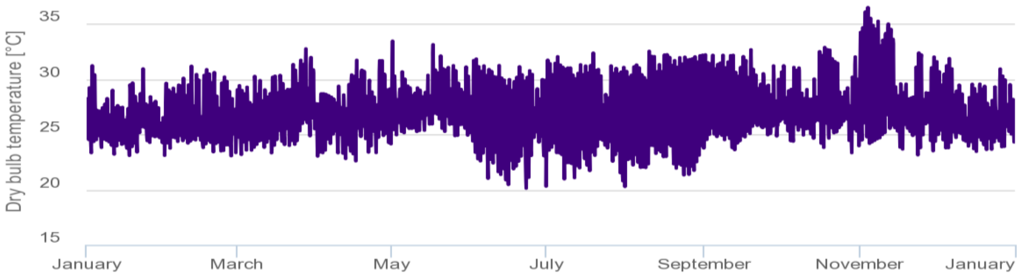


(a) One year irradiance data



(b) One year temperature data

Figure 7 One year irradiance and temperature data

In the look up table, the main thing that must be considered is the use of indexes and data files that must be in the form of tables or with the extension .tbl. Index will represent time, so the number of indexes must be equal to the amount of time. While the formation of files in .tbl extension is done by changing the .csv file to .tbl in the note.

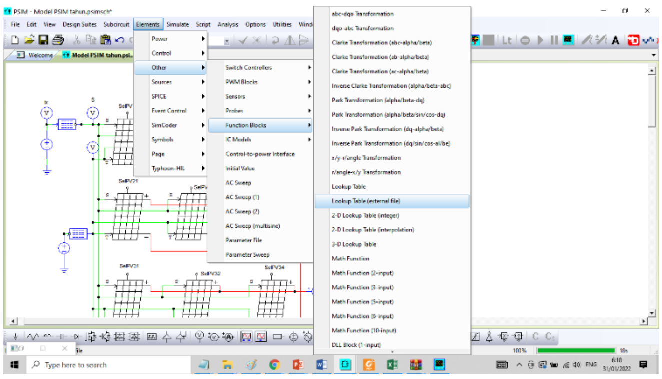


Figure 8 *Look up Table* menu on PSIM

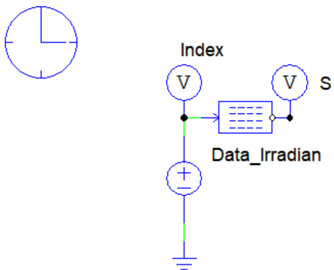


Figure 9 Irradiance model using PSIM

4.4 PV Modeling

The modeling is based on a single PV cell model as shown in Figure 10(a). Then a number of Ns of PV cells are arranged in series, and a number of Np of series arrangement is then paralleled, so that the modeling becomes PV array as shown in Figure 10(b).

Using the parameters and referring to the schematic drawing of the model and based on the results of the literature search, the modeling will use equations (3), (4) and (5), the modeling results are shown in Figure 11. This model is generated after conducting several evaluations of the simulations made. From the evaluation carried out, there are several notes related to modeling, including:

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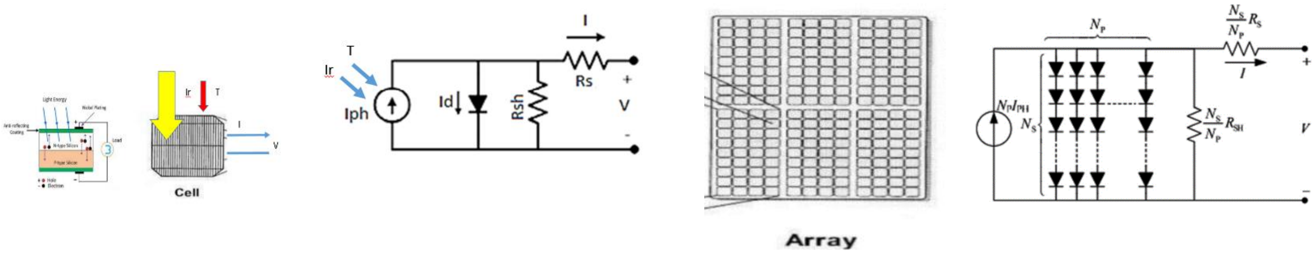
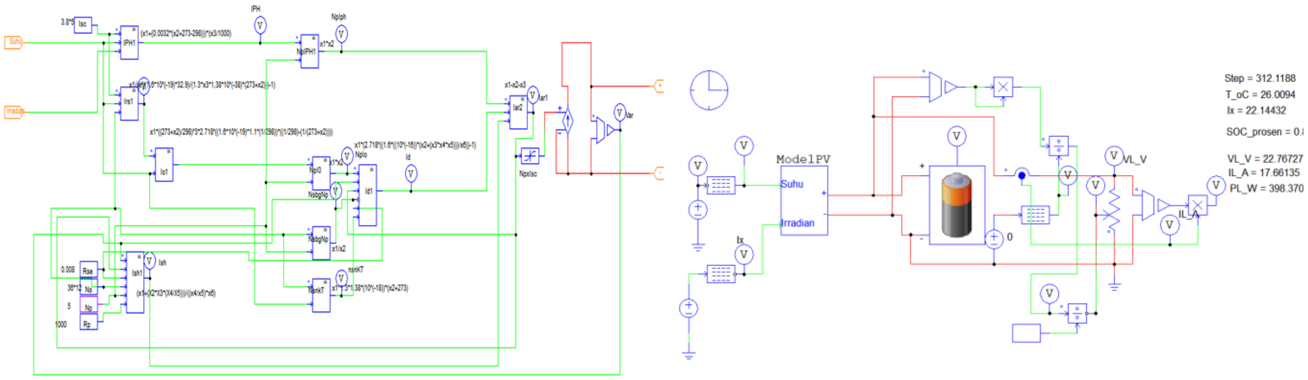


(a) PV Cell Model (b) PC Array Model

Figure 10 PV Model

1) The model is built using mathematical blocks that are in the other menu element in the Function Bloks sub menu.
2) To convert the mathematical equations model into electrical power, a Voltage-controlled current source block is used.
3) Irradiance and temperature inputs are made out of model variables by connecting them via the Input Signal Port.
4) The model outputs which are + and – ports are connected to the Bi-Directional Port



(a) PV model (b) Simulation circuit

Figure 11 PV Array model and simulation using PSIM

4.5 Annual PV Module Model Analysis

The annual PV module model analysis was carried out using model at Figure 11. PV module consist of 36 cells in series. The difference is that the irradiance and temperature data used are data for one year. The amount of data used is 24 (hours) X 365 (days) or 8,760 data for irradiance and temperature respectively.

From the trial error results of the load resistor value so that the SOC returns to its initial value or energy balance occurs as shown at Figure 12. It is found that the load is 57 Ohms, or for an average power for 24 hours (P) of 7.66 W. If it is associated with electricity customers 1,300 VA which consumes 11,174 W.hours of energy per day, it can be determined the need for PV modules (N) is as much as:

N = [W / (P x 24)] = 11,174 W.hours/(7.66 W x 24 hours) = 60 modules.

4.6 Analysis of 1,300 VA PV Array System

The analysis were carried out using the model Figure 11 using data annual of radiation, temperature, and load data. In this examination, there are several things that need to be considered, including:

1) The test circuit is made using a PV module model in which there are 36 serial cells, 12 circuits, then there are 5 parallels of the 12 circuits, so the total is 60 PV modules or 2160 solar cells.

2) In the model, the load is created by adjusting the size R according to the load. Nominal load is calculated based on the formula:

P(power) = V2(voltage)/R(Resistance), then R=V2/P.

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If P= 1,300 VA (maximum load) and V=220 V, then R=37.2 Ohm, if P=89 VA (minimum load), then R=543.8 Ohm.
Thus the value of R is 37.2 – 543.8 Ohms. In the simulation, such a load is created with a Rheostat block and with a regulating input on the Tap Position leg using the equation R= V2 / P.

3) The required amount of data is displayed and measured using the features in the PSIM simulator. As shown in Figure 11 there are several written displays as a way to monitor important electrical quantities, and there are a number of probes that serve to measure electrical quantities.

The balanced energy analysis for one year and the 1,300 VA household electricity system was carried out using the simulation results as shown in Figure 13. The picture shows the graph of irradiant (S), temperature (T), battery SOC (SOC) and electric power (PL).

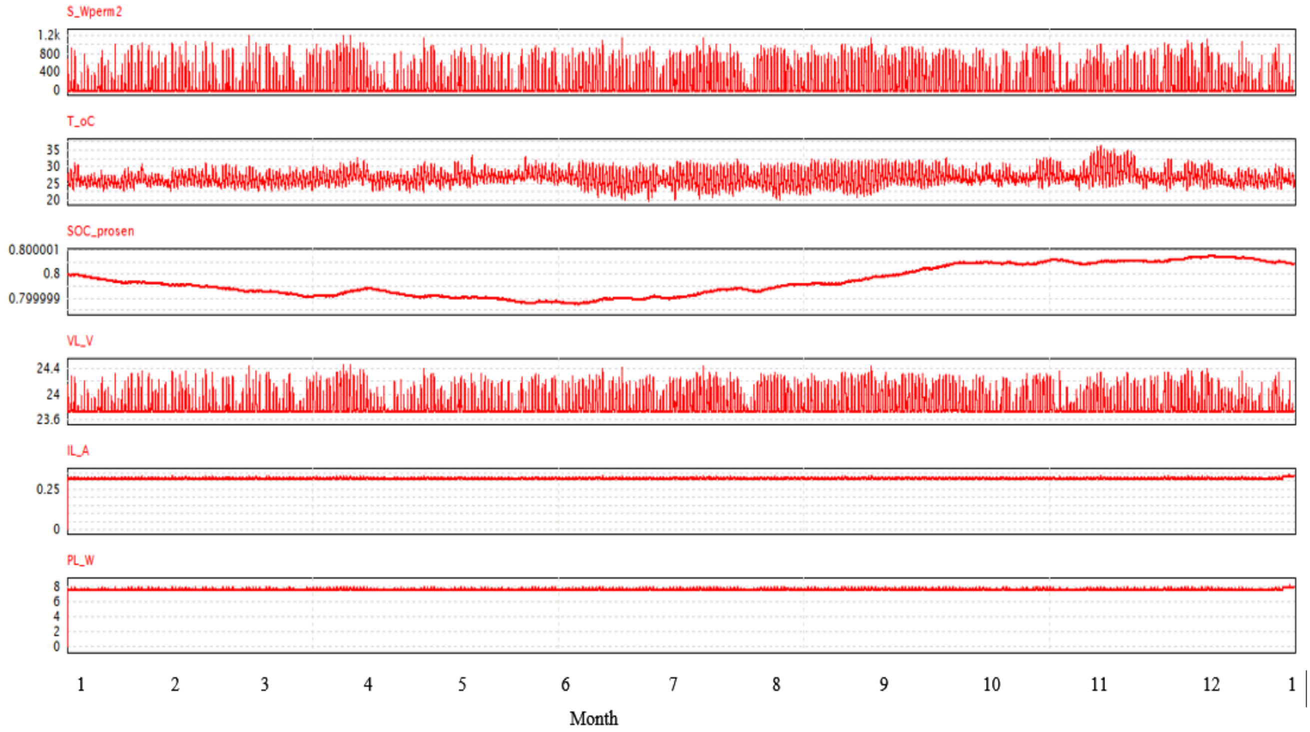

Figure 12 Simulation result annual data of one module

The most prominent of these charts is the third figure, namely SOC. The figure shows that the SOC value set at 80% has decreased from January to June. This is in line with the irradiation value which also experienced a decrease in average, due to the rainy season in these months a lot of rain and clouds. SOC then experienced an increase in value from July considering that from that month onwards the dry season and the radiation were also higher, because there was no rain and the clouds no longer blocked the sunlight. SOC returned to initial value (80%), more or less in mid-December.

The total energy used by the load for one year is calculated from the average power of 523,451 V.A. Or in 24 hours or a day the amount of energy used is 12,562,824 V.A. hours or 12,563 W.hours. This value when compared with the modeling in section 4.1, which is 11,174 W.hours, it means that there is a higher difference of 12,563-11,174=1.389 W.hours. There is a difference of 12.4%. This difference is due to the difference between the real load and the absorbed power.

These results indicate that the model made has been able to provide quite appropriate results, because it has produced energy balance data for one year and for household electrical energy needs of 1,300 VA.

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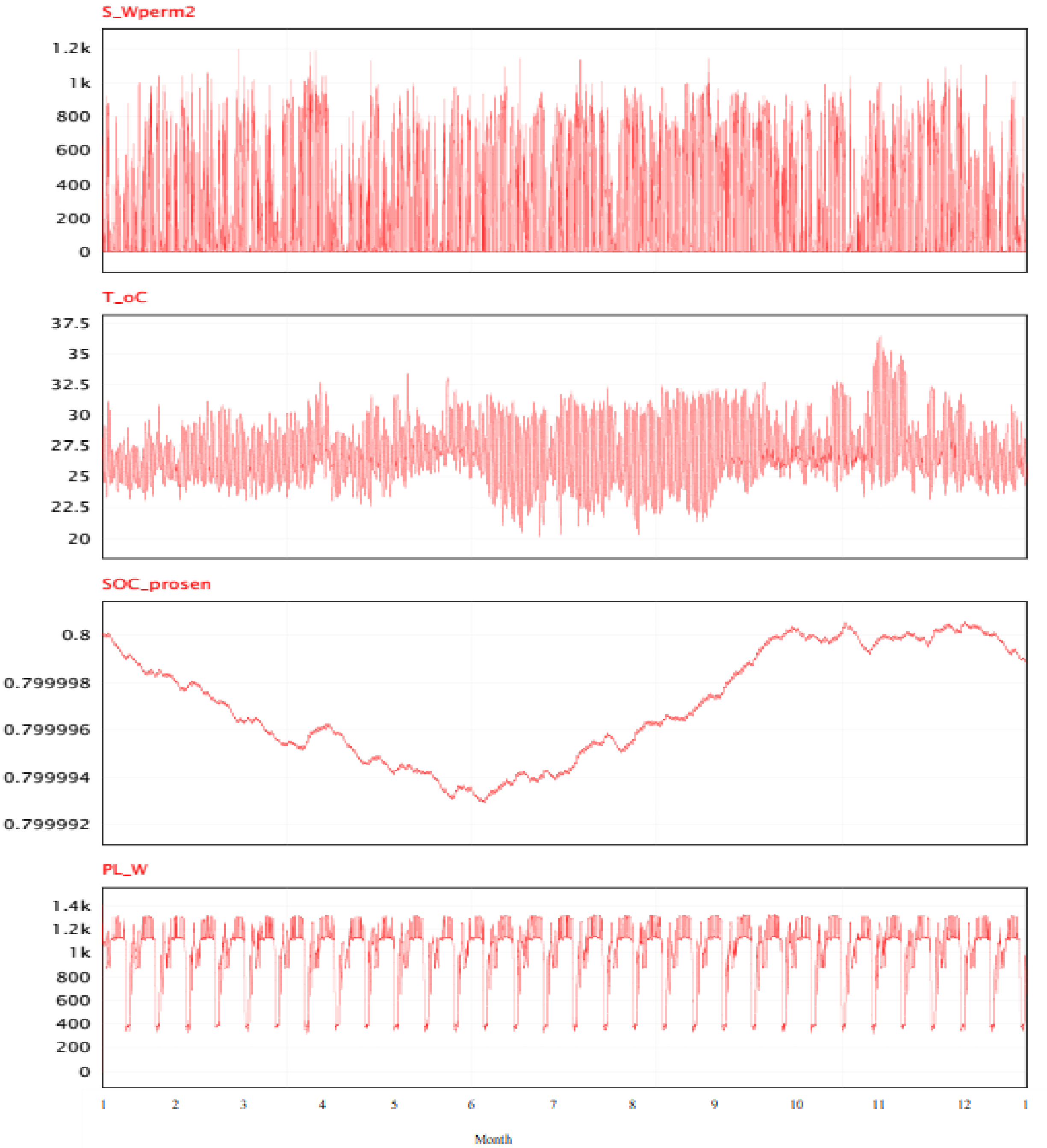

V. CONCLUSION

Photovoltaic modeling is done by using the equation that occurs at the PN junction which creates a current model when exposed to radiation and temperature and has series and parallel resistance. For irradiance and temperature, modeling is done by taking data from the Photovoltaic Geographic Information System page (https://re.jrc.ec.europa.eu/pvg _tools/en/tools.html#), then modeling it using the Look table toolbox. The load is modeled using the same toolbox, but with data obtained from observations. While the battery model, using the existing battery model in PSIM.

Based on a balanced energy analysis with a 1,300 VA household electrical system model made, the system can achieve energy balance by using 60 PV modules, with 5 parallel formations from a series of 12 PV modules consisting of 36 PV cells, or there are 2,160 PV cells.

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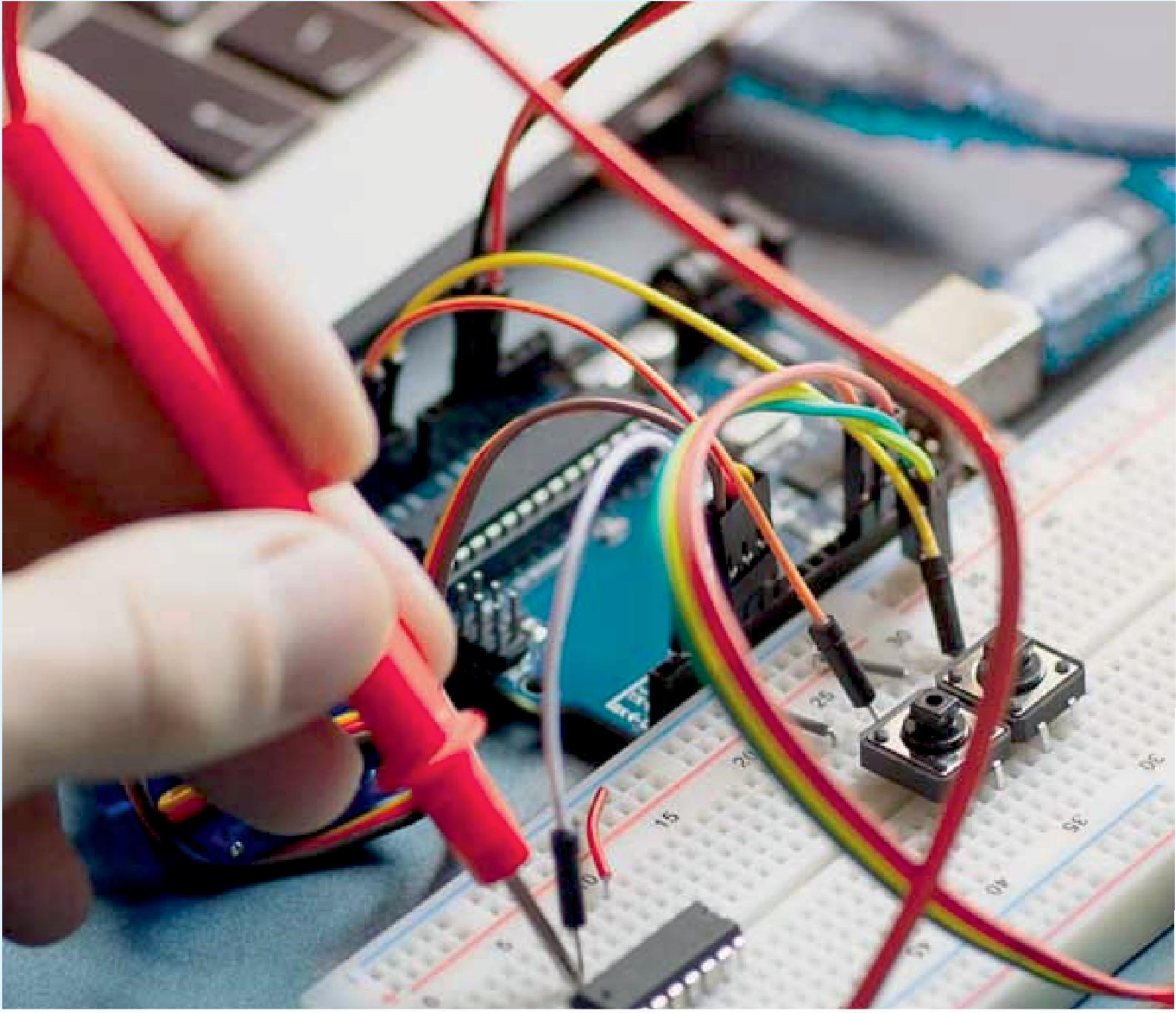

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