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SOLAR POWER PLANT DESIGN TO SUPPORT ECOMIL LH300 AT THE COFFEE PROCESSING CENTER "LA ESPERANZA" IN THE MUNICIPALITY OF LA PLATA

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ABSTRACT

This research aims to design a photovoltaic solar power plant for the coffee processing center "La Esperanza", in the municipality of La Plata, Huila. The coffee process is carried out by coffee growers, mostly in facilities they own called coffee processing centers, and where they basically harvest, extract, and remove mucilage, wash, classify and dry the pulp. The Ecomil LH300 allows to wash coffee with less than 0.7 liters of water per kg of dry parchment coffee. The Ecomill® LH-300 maintains the characteristics of the Ecomill® technology, developed by Cenicafé to reduce the use of water in the process of benefit. This research presents a solar power plant design that allows Ecomil to work independently from the public power grid, thereby, contribute to the use of alternative energy. These agribusiness initiatives are well regarded by the European Community (EC). If a product is manufactured to have extraordinary environmental characteristics, it may be eligible to use the C.E eco-label. At present, more than 37,000 products marketed in Europe have the C.E ecolabel, which means that they meet rigorous ecological criteria. To obtain the eco-label, a series of criteria have been defined that cover diverse groups of products. Having the eco-label on its products demonstrates to its customers and consumers that its product meets strict ecological criteria. This brand is verified by third parties and is recognized in all the European community. Finally, the calculations of the systems that make up the photovoltaic power plant, simulations in Matlab / Simulink are presented and the results obtained are discussed.

Keywords: sustainability, renewable, farming, matlab.

INTRODUCTION

Advances in technology and engineering allow the improvement of agricultural production processes. It is very important to make efforts to contribute to cleaner production in the agricultural sector. In recent decades notable contributions in the field of renewable energy generation can be observed.

The Ecomill technology allows to treat coffee bean with natural fermentation and its subsequent cleaning process with up to 0.7 liters of water per kilogram of dry parchment coffee (cps) produced. This new equipment joins the Ecomill® family, which in essence allows the reduction of water use in the coffee process compared to other systems. Ecomill® produces soft coffee and water pollution can be reduced by treating and reusing wastewater recycling it back to the same coffee treatment process [4].

Designed for washing coffee batches (up to 1,000 kg/day), the Ecomill® LH-300 can be used on small farms and in micro-batches for larger farms. In its design, the number of components was reduced and elements manufactured by the national industry were used to contribute cost reduction of the new technology, without affecting equipment quality [5].

From above, it can be inferred that if we implement a renewable energy system to be used in the pulping of coffee with the Ecomill LH300, the coffee processing center "La Esperanza" will be able to obtain the ecological label that allows the shipment to be sent to the European Community at a better price [6].

Coffee crops at La Plata, Huila are favored by local climate conditions. Local climatological data (Ideam climatological station code 21115170&21055020) plays a major role to design and build a renewable energy system. For La Plata, Huila it was found that annual mean precipitation reaches 1573 mm. Precipitation peaks in March (197 mm/month) and reaches its lowest point in August (58 mm/month). The mean temperature year-round is 22°C with a peak at 29°C near noontime and lowest at 16°C. The relative humidity is 80%; the solar bright average is 125 hr/month with a maximum of 145 hr in December and 112 hr in April. Solar radiation averages 3.9 Kwh/m^2 with a maximum of 4.4 Kwh/m^2 in January and a minimum of 3.6 Kwh/m^2 in March.

This research developed a design of a wind-powered solar power plant that allows giving autonomy to the Ecomil LH300 device in the process of pulping the coffee bean and improving the process of extracting the bean by reducing the consumption of energy consumed from the public network [1], [2]. Demonstrating that the bean is obtained in a more environmentally friendly way may open the request of a special watermark offered by the European community for coffee producers and, thus, increase revenue per load [3], [4].

a) State of the Art and Problem Statement

A systematic search was carried out to find the main contributions to the design of renewable energy plants that have been carried out around the world during 2015-2019 to contextualize this case study. Besides, a search for scientific articles was carried out in the main bibliographic databases available on the Internet, specifically in Scopus, Scimago, ISI Web of Knowledge, Google Scholar, Springer, Science Direct, among others.

The resulting references (about 26, 422 articles) were limited to articles containing methods of evaluating solar-powered agricultural processes, emphasizing those that analyzed the information obtained. According to (Rodríguez *et al.*, 2016) review articles, editorials, and articles from congress were excluded. Likewise, if a duplicate article were found, the one that would be published would be found in a more recent magazine with the greatest impact. In Figure-1, the graph shows the items by year.

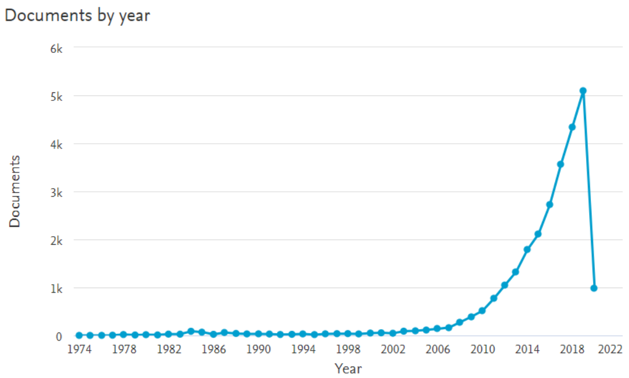

Figure-1. The number of articles per year. 46,422 articles written on the subject of the design of photovoltaic plants in the coffee sector. Scopus

From the previous graph, it can be inferred that the design of photovoltaic plants in the coffee sector is a current topic as shown in the ascending graph. It can be seen that in recent years the publication of articles on this topic has increased. Many investigations around the world are being carried out on this topic, such as: [4-9].

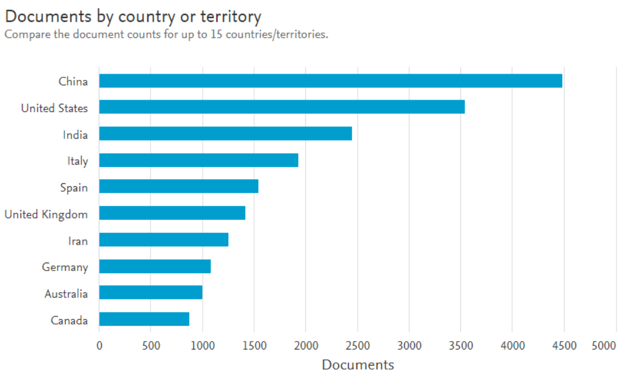

Figure-2. Articles per year. Scopus.

Likewise, Figure-2 shows the countries where more articles are published on photovoltaic plant design in the coffee sector. China is the country that publishes the most on the subject with 17% of documents, followed by the United States with 13.2%, India with 9%, and Italy with 6, 8%. Figure-3 shows that 58.6 %% of the publications on this topic are scientific articles in indexed journals, approximately 25.9% are articles from international conferences and congresses, 1.6% are books, 10.2 % are review articles, and 2.9% are book chapters.

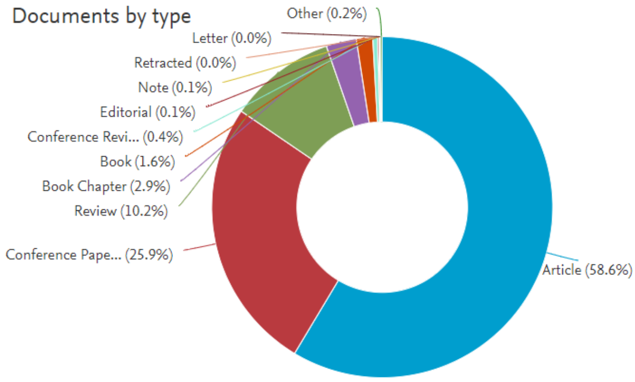

Figure-3. Type of article on the topic of customer service quality in banks. Scopus.

The stages of post-harvest coffee processing in Colombia are described below:

Cherry coffee harvesting. On farms with less than 300 arrobas of dry parchment coffee per year, cherry coffee is received in the hopper of the pulping machine. On dry farms, dry feed hoppers can be used, where coffee is received and transported by gravity to the pulper. Water should not be used at this stage [10].

Pulping. This consists of removing the pulp of the cherry through pressure exerted by the grater sleeve and must be started immediately after the fruits are harvested. The delay for more than 6 hours affects the quality of the drink and can cause the defect called "ferment". Ripe coffee contains mucilage, which allows pulping just by pressing the cherry. Therefore, water is not used to pulp coffee [11].

Mucilage removal. The mucilage is the slime that covers the pulped grain. The mucilage must be removed by the process of natural or mechanical fermentation [12].

The fermentation process. It is carried out in the tanks where the pulped grain is received. In natural fermentation, time is controlled to ensure the final quality of the grain, because if the coffee grain is overheated, defects of vinegar-like taste and aroma, ferment, pineapple, wine, onion, and stinker can occur. If pulped coffee from different days is mixed, there may be over-fermentation [13].

Every coffee processing center must have at least two fermentation tanks, each with the capacity to store peak day coffee. To carry out fermentation, the following must be taken into account:

Time: Between 12 and 18 hours, depending on the temperature. To estimate the washing point it is recommended to use the Fermaestro, developed by Cenicafé. Once the fermentation is complete, the coffee is washed [14].

Washing. Washing allows the fermented mucilage to be completely removed from the grain. Use

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clean water to avoid defects such as stained, dirty grains, fermented flavor, or contamination [15].

Other technological options for the post-harvest process and for saving water are:

a) Ecological post-harvest processing of coffee (BECOLSUB). The ecological post-harvest processing for obtaining dry parchment coffee developed by Cenicafé, which reduces water consumption. Becolsub technology consists of a process where coffee is pulped without water, the mucilage is mechanically removed from the coffee in a slim mucilage processor and the pulp and the mucilage are transported and mixed in a screw conveyor. The high concentration of mucilage and the viscosity of the mucilage-water mixture, allow greater control of the contamination generated in the Becolsub process during its transportation in the screw. The value reached, of around 20%, added to the balance obtained from pulping without water (72%), allows controlling more than 90% of the potential contamination obtained from the washed process [16].

b) ECOMILL®: To meet the needs of coffee growers who use the natural fermentation process in Colombia, as well as the requirements of buyers of coffee abroad that require processed coffee with natural fermentation, and the changes in environmental legislation in Colombia (Decree 3930 2010), which drastically limit the permissible discharge points at the coffee facilities' effluents, Cenicafé developed the ECOMILL® technology, where coffee with degraded mucilage is mechanically washed in the process with natural fermentation or with enzyme application, which shows a noticeable reduction in the specific volume of water, with values between 0.3 and 0.5 L.kg-1 dpc. Due to the low specific volume of water, highly concentrated wastewater can be mixed with the coffee pulp, retaining more than 95% of the added volume and controlling up to 100% of the pollution generated in the process. Currently, there are three models with a capacity for 500, 1, 500, and 3,000 kg.h-1 of washed coffee [17].

Figure-4. Structure of the ECOMILL LH300.

The following engines need to be powered for the ECOMILL operation and ensured to work in the best way.

Table-1. Motors inside the ECOMILL.

Motor Type	Power	Voltage
Washing motor	3 hp	230v
Endless screw conveyor washing motor	1 hp	220v
Coffee bean sorting machine motor	1 hp	115 - 220 v
Floating hopper Screw conveyor motor	0.5 hp	115 - 220 v
Pulping Motor	2 hp	115 - 220 v
Screw conveyor motor for coffee bean elevation	2 hp	115 - 220 v
Floating hopper Screw conveyor motor	0.5 hp	115 - 220 v
Brush chipper motor	3 hp	115 - 220 v
Milling motor	0.5 hp	115 - 220 v

A photovoltaic module is a set of interconnected photovoltaic cells protected from the outside by a structure composed basically of a glass and a rigid frame. Photovoltaic cells are elements that, thanks to the properties of silicon, allow solar radiation to be transformed into electrical energy at very low voltage using the photovoltaic effect [5], [6].

Photovoltaic Panels

The photovoltaic panel has the function of grouping all these small voltages generated to provide a higher nominal voltage to the system. The photovoltaic modules provide a direct current voltage. The rest of the elements of the photovoltaic system will be responsible for managing and transforming this voltage into alternating current, if necessary. Solar collectors are solar panels that, through the laws of thermodynamics, utilizes the heat of the sun to heat a liquid [7], [8].

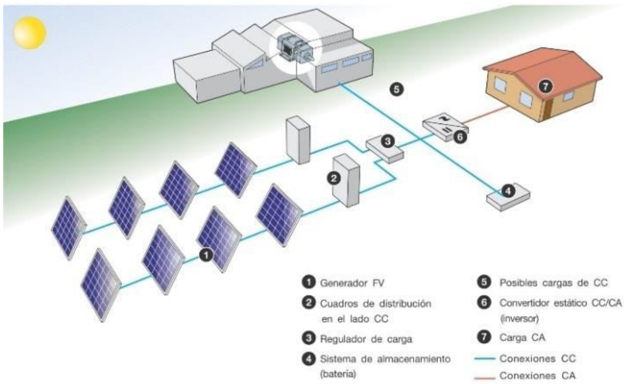

Figure-5. Scheme of the proposed plant.

Regulator

A solar charge regulator is placed between the photovoltaic field and the battery field and is responsible for controlling the flow of energy that circulates between both teams. The control of the energy flow is carried out by controlling the Intensity (I) and Voltage (V) parameters to which it is injected into the battery. This energy flow depends on the state of charge of the batteries and the energy generated by the photovoltaic field. The solar charge controller constantly monitors the state of charge of the batteries to make the optimum filling and thus extend its useful life [9], [10].

Charge States

There are three possible charge states:

a) **BULK phase:** the battery is discharged and all the electricity produced in the photovoltaic field is injected into the batteries, increasing the voltage in the battery as it is filled.

b) **Absorption phase:** when the battery voltage reaches the absorption voltage (in open 14.4V lead-acid batteries and AGM batteries and 14V GEL batteries), the solar charge controller maintains the voltage slightly below this value and reduces the electricity until the battery is practically full.

c) **FLOAT phase:** in this phase, the voltage is reduced to the flotation voltage (usually 13.5 V) and the injected electricity is reduced until the battery is filled.

Inverter

An inverter is a device that changes or transforms a direct electricity input voltage to a symmetrical output voltage (sinusoidal, square, or triangular) of alternating electricity, with the magnitude and frequency desired by the user or the designer. The inverters are used in a wide variety of applications, from small power supplies for computers, to industrial applications to control high power. The inverters are also used to convert the direct electricity generated by the photovoltaic solar panels, accumulators or batteries, etc., into alternating electricity and thus be able to be injected into the electricity grid or used in isolated electrical installations [11], [12].

METHODOLOGY

Once the review of the literature on the different characteristics to be taken into account for the design of the renewable energy plant has been done, we developed our fitted design, specifically adapted to the coffee process sector and services provided by the coffee processing center.

The plant will be located in the coffee processing center "La Esperanza", in the municipality of La Plata, department of Huila. It is located at latitude: 2 ° 23.2 '2.58' 'and longitude: -75 ° 54' 29', values taken from Garmin GPS 64s.

The coffee processing center inclines 56° and south disorientation of 30°; values were taken with the SEIKA 200U inclinometer. The type of electrical power that is required is alternating 110v / 220v to power the Ecomil's motors. The energy consumption per requested day given the characteristics established for the motors in Table-1 are 3.8 Kw / day, working a maximum of 16 hours per day.

All annual power consumption has been assumed upon the worst scenario. That is, mechanical equipment consumes 100% of the energy requested by the machine. The assumption has been developed upon the knowledge that in many Colombian regions blooms are generated almost all year-round and consequently ripe fruits, during 50 weeks of the 52 weeks per year.

Modeling the solar power plant in Matlab was carried out to perform the necessary calculations such as power demand, project location, photovoltaic generator dimensioning, accumulation system dimensioning, charge controller dimensioning, and, finally, the inverter size.

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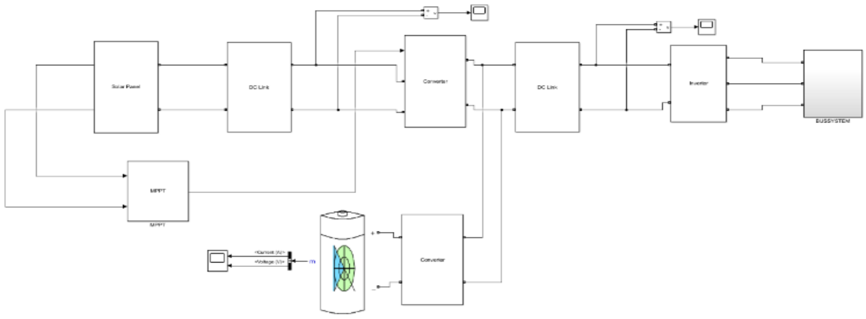

Figure-6. Block diagram of the simulated photovoltaic plant in Matlab 2018b. Authors.

RESULTS

Design

The following technical data were taken into account for the design of the photovoltaic power plant: the system voltage 24v, the theoretical daily energy 6.18 kW / day, with a quality ratio of 82% and real energy of 6.2 kWh / day.

The average daily consumption was obtained from equation (1), according to [5], like this:

$$L_{md} = \frac{L_{md,DC} + \frac{L_{md,AC}}{\eta_{inv}}}{\eta_{bat} * \eta_{con}} \quad (1)$$

Being L_{md} the average daily energy consumption, $L_{md,DC}$ the average daily energy consumption of the continuous loads and $L_{md,AC}$ the alternating loads. The battery performance $\eta_{bat})$ was assumed of 95%, of the inverter (η_{inv})of 90% and of the conductors (η_{con}) of 100%.

$$L_{md} = \frac{3{,}000 + \frac{2.588}{0{,}9}}{0{,}95 * 1{,}0} = 6.185$$

Then, the total number of solar modules required in equation (2) is calculated, according to [6], obtaining:

$$N_T = \frac{L_{mdcrit}}{P_{MPP} * HPS_{crit} * PR} \quad (2)$$

Where:

L_{mdcrit} is the average monthly daily consumption for the critical month, (in this case, it is always the same [5-6] 6,185 wh/day, since the daily consumption is constant throughout the year).

P_{MPP} the peak power of the module under Standard Test Conditions (STC)measurement conditions, in this case, we are using the SW180 model of the SolarWorld manufacturer, with 180 watts of peak power in STC.

HPS_{crit} are the peak hours of the critical month calculated from the "Radiation Table", i.e.: Irradiation of the critical month/ 1000 W / m2 = 3.32 HPS.

PR is the overall operating factor that varies between 0.65 and 0.90. We will use 0.90 by default, obtaining:

$$N_T = \frac{6.185}{180 * 3{,}32 * 0{,}90} = 11{,}5 = 12$$

It is concluded that 9 solar panels would be needed.

The photovoltaic field was calculated with an optimum annual inclination for consumption of: 15 °, a necessary photovoltaic power of: 2068 Wp. Regarding the connection of modules calculated in series or parallel, taking into account that the Solar World SW180 has a Vmax = 36.55 Volt, we have:

$$N_{SERIE} = \frac{V_{BAT}}{V_{MOD,MPP}} \quad (3)$$

$$N_{SERIE} = \frac{24}{36{,}55} = 1$$

$$N_{PARALELO} = \frac{N_T}{N_{SERIE}} \quad (4)$$

$$N_{PARALELO} = 12$$

12 branches must be connected in parallel with one panel per branch. If a regulator with maximum MPPT power point monitoring is not going to be installed, another criterion, the Ampere-Hour Criteria, should be used, since it will then be the battery that marks the system voltage (12, 24, 48 Volt.) and the maximum power point of the modules used will rarely be reached.

We initially have the average energy consumption in Ah/day calculated above:

$$Q_{Ah} = \frac{L_{md}}{V_{BAT}} \quad (5)$$

$$Q_{Ah} = \frac{4.500\text{Wh/dia}}{24\text{V}} = 187.5\ \text{Ah/dia}$$

With the above, we can calculate the electricity that the photovoltaic collection plant must generate under conditions of a critical month can be calculated.

$$I_{GFV,MPP} = \frac{Q_{Ah}}{HPS_{crit}} \quad (6)$$

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Where:

$I_{GFV,MPP}$ is the electricity generated by the photovoltaic collection field (all solar panels installed).

$$\mathrm{I_{GFV,MPP}} = \frac{187.5\ \mathrm{Ah/dia}}{3{,}32} = 56{,}47\ \mathrm{Amp}$$

If we divide it by the unit electricity of each photovoltaic panel$I_{MOD,MPP}$ which in the case of SW180 is $I_{máx} = 4{,}90\ Amp.$ the total number of necessary modules connected in parallel will be obtained:

$$\mathrm{N_{PARALELO}} = \frac{\mathrm{I_{GFV,MPP}}}{\mathrm{I_{MOD,MPP}}} \quad (7)$$

$$\mathrm{N_{PARALELO}} = \frac{56{,}47}{4{,}90} = 11{,}52$$

For the calculation of the necessary solar batteries for our design of the photovoltaic plant, the following characteristics were taken into account, according to [7]:

a) Maximum Stational Discharge Depth ($PD_{máx,e}$), we take a value of 75%, that is, 0.75.

b) Maximum Daily Discharge Depth ($PD_{máx,d}$), we take a value of 14%, that is, 0.14.

c) The number of days of Autonomy (N), we take 6 days.

The nominal capacity of the battery based on the maximum daily discharge, $C_{nd}(Wh)$:

$$C_{nd}(Wh) = \frac{L_{md}}{P_{Dmáx,d} * F_{CT}} \quad (8)$$

$$\mathrm{C_{nd}(Wh)} = \frac{4.500\mathrm{Wh/dia}}{0{,}14 * 1} = 32.142\ \mathrm{Wh}$$

$$C_{nd}(Ah) = \frac{C_{nd}(Wh)}{V_{BAT}} \quad (9)$$

$$\mathrm{C_{nd}(Ah)} = \frac{32.142\ \mathrm{Wh}}{24\ \mathrm{V}} = 1.339\ \mathrm{Ah}$$

The battery’s nominal capacity based on the maximum stational discharge is:

$$C_{ne}(Wh) = \frac{L_{md} * N}{P_{Dmáx,e} * F_{CT}} \quad (10)$$

$$\mathrm{C_{ne}(Wh)} = \frac{\frac{4.500\mathrm{Wh}}{\mathrm{dia}} * 6}{0{,}75 * 1} = 36000\mathrm{Wh}$$

$$\mathrm{C_{ne}(Ah)} = \frac{\mathrm{C_{ne}(Wh)}}{\mathrm{V_{BAT}}} \quad (11)$$

$$\mathrm{C_{ne}(Ah)} = \frac{36.000\ \mathrm{Wh}}{24\ \mathrm{V}} = 1.500\ \mathrm{Ah}$$

The highest was selected, i.e. the nominal capacity of the batteries was at least, C100 = 984Ah.

The calculation of the regulator was made bearing in mind the calculations of the input and output currents of the selected modules, SW180 from SolarWorld is $Isc\ =\ 5{,}30\ Amp.$

$$\mathrm{I_{entry}} = 1{,}25 * \mathrm{I_{MOD,SC}} * \mathrm{N_P} \quad (12)$$

Where:

$I_{MOD,SC}$is the unit current of the photovoltaic module in short-circuit conditions. The short-circuit current is used to calculate the input current to the regulator because it will be the maximum current that could be generated by the photovoltaic module and it must be that which we take into account to avoid yield losses.

N_PIs the number of branches in parallel, in this case, 12. 1, 25 is a safety factor to avoid occasional damage to the regulator.

$$\mathrm{I_{entry}} = 1{,}25 * 5{,}30\ \mathrm{Amp} * 12 = 79{,}5\ \mathrm{A}$$

For the calculation of the output current, the powers of the DC loads and the AC loads are evaluated:

$$\mathrm{I_{output}} = \frac{1{,}25 * (\mathrm{P_{DC}} + \frac{\mathrm{P_{AC}}}{\eta_{\mathrm{inv}}})}{\mathrm{V_{BAT}}} \quad (13)$$

Where:

P_{DC}, is the power of the loads in continuous. P_{AC}, is the power of alternating loads. η_{inv}, return on the inverter, around 90-95%.

$$\mathrm{I_{output}} = \frac{1{,}25 * (15 + \frac{350+110}{0{,}95})}{24\ \mathrm{V}} = 26\ \mathrm{A}$$

The charge controller should withstand a current of at least 80 Amp. at its entry and 26 Amp. on its output.

The power of the inverter was selected taking into account that the Ecomil 300H has several engines, these engines used have certain "starting peaks", which means that for their start-up they will demand more power than the nominal, sometimes up to 4 or 5 times more than the expected nominal power.

$$\mathrm{P_{inv}} = 1.2 * 5 * \mathrm{P_{AC}} \quad (14)$$

$$\mathrm{P_{inv}} = 1.2 * 5 * 460 = 2.760\ \mathrm{W}$$

Finally, the photovoltaic generation plant was simulated with Matlab / Simulink with the parameters obtained in the design, obtaining the following results.

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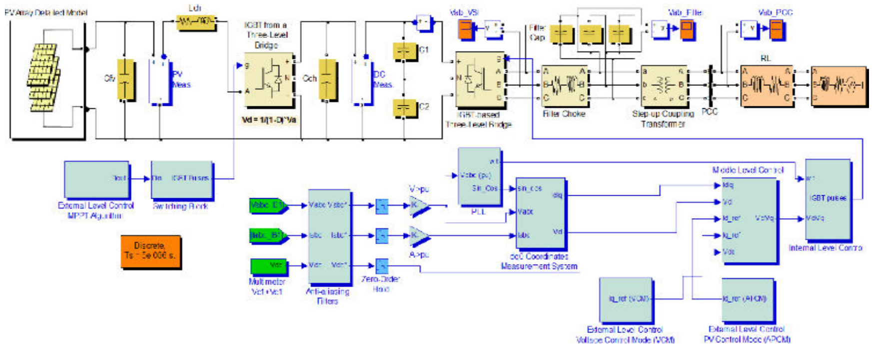

Figure-7. Matlab / Simulink of the photovoltaic plant. Authors.

Today, solar modules are so optimized that the manufacturer risks giving between 10-15 years of warranty with a production of 90% and about 25 years of warranty with a production of 85%, in addition to about 10 years in materials. That is why calculating the panel temperature takes a great deal of importance

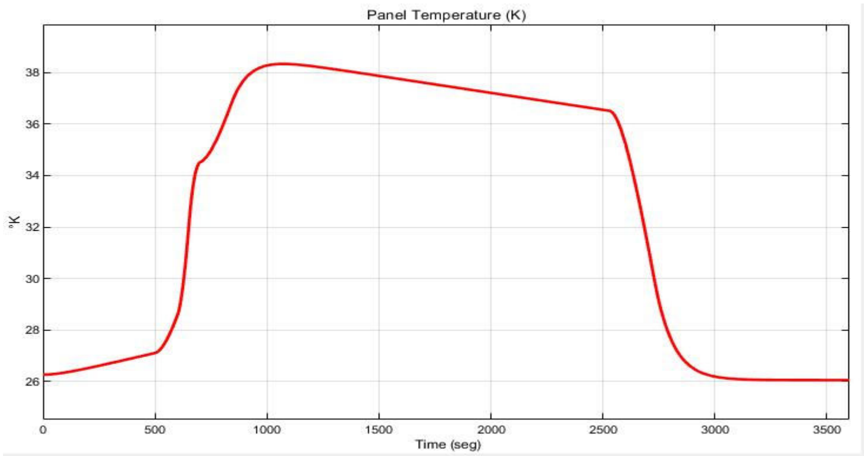

Figure-8. Solar panel temperature. Authors.

Figure-8 shows that the temperature of the solar panels reaches 38 ° K, in the range of 500 to 2600 seconds. The point of the maximum performance of a solar panel is when the environment is warmer, like all conductive devices or producers of electricity; heat negatively affects the solar panels decreasing their performance. However, this negative effect of heat on solar panels is more than compensated by the increase in solar exposure hours during summer. That is, in the summertime, the solar panel has less instantaneous efficiency, but throughout the day solar production is higher than in winter days.

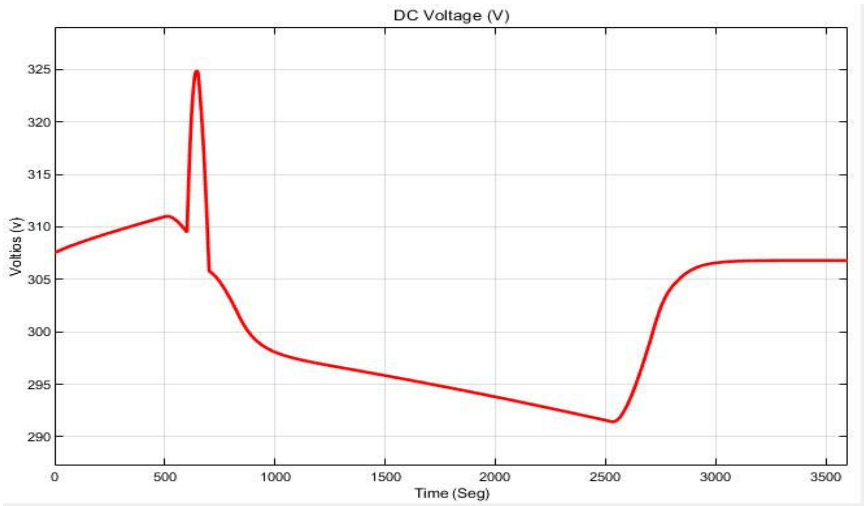

Figure-9. DC voltage of the photovoltaic power plant. Authors.

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Figure-9 shows a peak voltage of 325 volts close to 620 seconds. This is due to the simulation of inductive loads present in the Ecomil 300H motors. There is respectively a negative slope of voltage reaching the point of 292 volts DC at 2580 seconds. After 3000 seconds the DC voltage of the solar panels stabilize at 307 volts.

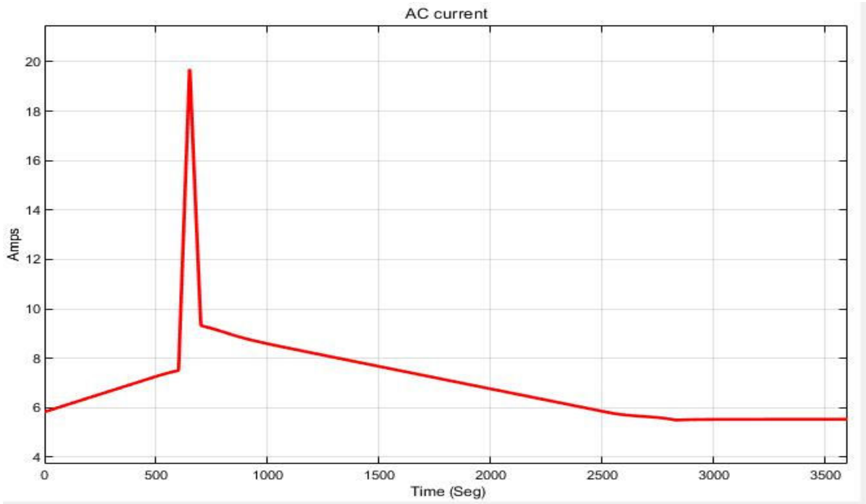

Figure-10. AC current of the photovoltaic power plant. Authors.

A peak of alternating current of 19.5 amps close to the values obtained in the simulation at 620 seconds can be observed in Figure-10. It has a negative slope from 9.6 amps, then the current decreases until it reaches stabilize at its value of 5.8 Amps after 3000 seconds.

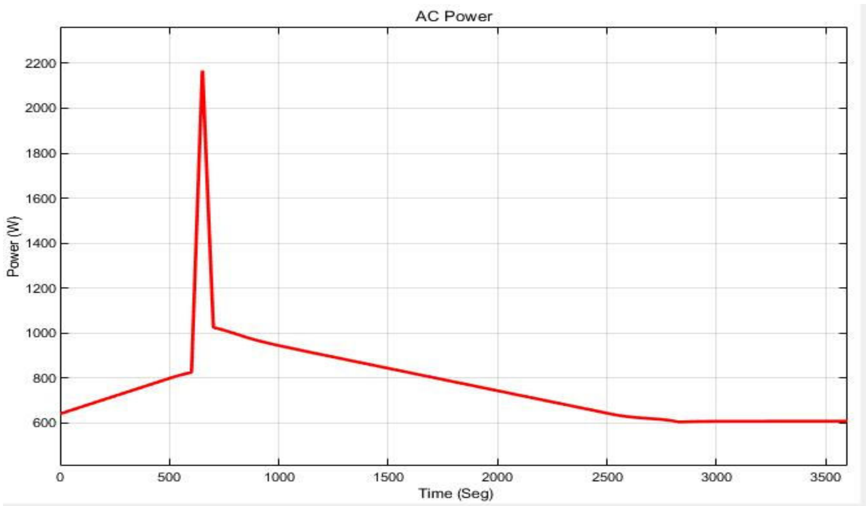

Figure-11. AC power of the photovoltaic power plant. Authors.

Figure-11 shows the behavior of the photovoltaic power plant electric power in AC, presenting a peak of power close to 2,000W, at 620 seconds, achieving its stability from 3000 seconds at a value 605W.

CONCLUSIONS

As the proposed model used as input climate data the registered irradiation and temperature values, considerations are taken into account in regards to the measurement of these values thus periodic calibration of the equipment is recommended to meet the energy requirements of the Ecomil 300H.

On the other hand, other not considered parameters that could affect the performance of the generators such as power factor ($\eta_{inv} = 0{,}95$) and voltage levels (325 V_{DC}) are highlighted. The theoretical model developed was calibrated, obtaining those deviations reached by the empirical model proposed for the power required by the engines associated with the Ecomil in the pulping stage. Due to the practicality of the empirical model and the results achieved, its use is suggested.

A methodology for the design of photovoltaic power plants is presented, calculating each of the components: batteries, regulator, inverter, solar panels, etc. Using the model implemented in Matlab / Simulink, it was possible to check the operation of each of the system components. Temperature values were obtained in the panels of 38 ° k (48 ° C), peak voltages of 325 V_{DC}, and

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obtaining stability at 307 volts. Similarly, it was possible to verify that the current in AC had a peak of 19.5 Amps, stabilizing at 5.8 Amps.

Finally, when modeling plants with solar tracking, a revision of the proposed model is recommended.

Conflict of interests

The authors declare that no conflicts of interest exist regarding the publication of this document.

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