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Simulation and Economic Savings Study of Solar Renewable Systems for a House.

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RESUMEN

El paso a la energía sostenible es un reto mundial que exige el avance de las fuentes renovables. Los sistemas fotovoltaicos y solares térmicos son tecnologías prometedoras de energía limpia. Los modelos matemáticos mejoran crucialmente nuestra comprensión del rendimiento de estos sistemas. Este estudio se centra en el desarrollo de modelos aproximados para estimar el rendimiento de los sistemas fotovoltaicos y solares térmicos en diferentes entornos, mejorando su eficiencia y fiabilidad. Los modelos pretenden aproximar la reducción de costes mediante el fomento de las energías renovables y la mitigación del cambio climático. Utilizando Simulink®, estos modelos matemáticos se validan mediante comparaciones con equipos reales, mostrando un error máximo del 6,57%.

***Palabras clave*:** Energías renovables, sistemas fotovoltaicos, sistemas solares térmicos, eficiencia, fiabilidad, costes de la electricidad, mitigación del cambio climático, validación.

ABSTRACT

The move to sustainable energy is a global challenge that requires the advancement of renewable sources. Photovoltaic and solar thermal systems are promising clean energy technologies. Mathematical models crucially improve our understanding of the performance of these systems. This study focuses on the development of approximate models to estimate the performance of photovoltaic and solar thermal systems in different environments, improving their efficiency and reliability. The models are intended to approximate cost reduction through the promotion of renewable energy and the mitigation of climate change. Using Simulink®, these mathematical models are validated through comparisons with real equipment, showing a maximum error of 6.57%.

***Keywords*:** Renewable energy, photovoltaic systems, solar thermal systems, efficiency, reliability, electricity costs, mitigation of climate change, validation.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

DEDICATORIA

Quiero dedicar este logro con profundo cariño y gratitud a las personas que han sido fundamentales en este camino académico. A mi adorada madre, cuya constante inspiración y apoyo incondicional han sido mi faro en las adversidades. A mis queridas hermanas, cuyo amor y ánimo han iluminado cada paso que he dado. A mi padre, quien generosamente compartió su vasto conocimiento y me proporcionó las herramientas necesarias para hacer realidad este trabajo.

Además, deseo extender esta dedicatoria a un protagonista silencioso pero vital: nuestro amado planeta Tierra. Como esta tesis se adentra en el mundo de las energías renovables, reconozco la responsabilidad que tenemos hacia nuestro hogar común. A través del estudio y la promoción de estas fuentes sostenibles de energía, espero contribuir en la preservación y cuidado de nuestro entorno para las generaciones venideras. Esta dedicación no solo es para las personas que han estado a mi lado, sino también para honrar y proteger el maravilloso mundo que nos rodea.

AGRADECIMIENTO

Quiero expresar mi sincero agradecimiento a todos aquellos que han contribuido de manera invaluable a la realización de esta tesis. A mi familia, en especial a mi padre, quien no solo compartió su vasto conocimiento, sino que también me proporcionó las herramientas y el apoyo necesario para llevar a cabo este trabajo con éxito. Su guía y consejos han sido fundamentales en cada etapa de este proyecto.

También quiero extender mi gratitud al profesor y tutor de esta tesis, Oscar Camacho. Su compromiso inquebrantable con la educación y su dedicación constante hacia sus estudiantes han sido un faro de inspiración a lo largo de mi carrera.

CHAPTER 1

INTRODUCTION

Global concerns about climate change and the pressing need to reduce carbon emissions have elevated discussions about sustainable energy solutions to a mainstream level in contemporary society. A key component of this dialogue is the concept of carbon footprint (United Nations, 2022), which measures the environmental impact of human activities, mainly in terms of greenhouse gas emissions. This emphasis on reducing carbon footprint has sparked considerable interest in renewable energy sources, such as solar, and their potential to transform energy production (Martínez, 2019) radically.

In the academic realm, articles have been written on the same topic: the use of solar renewables. These articles emphasize various aspects, such as economic studies, cost reduction, carbon footprint, pollution mitigation, efficiency, and application, on-grid or off-grid (Lin and Wu, 2023, Díaz et al., 2021). In this thesis, we will create a simulated design from the equations of the mathematical model used by the authors (Buzás, 2009, Matics Ingeniería Eléctrica, 2021), where (Buzás, 2009) describes the equations of the mathematical modeling of a solar thermopanel, and on the other hand, (Matics Ingeniería Eléctrica, 2021) describes the equations of the mathematical model that defines a photovoltaic panel system. Both authors were chosen because the equations they propose contain several parameters that, when implemented in a simulation, provide an accurate approximation and a resemblance to a real-life system.

This paper will present a composite of all these equations from the mathematical models, highlighting and emphasizing each of them instead of focusing only on a few or on a few parameters or on very general concepts, as is often the case in other research. The importance of this thesis is reflected in its "switching" system, which is presented in the solar thermopanel.

When there are no optimal environmental conditions to heat the water inside, an electric thermostat (electric resistance) comes into operation, in charge of heating the water in the home. The energy consumption generated by this resistance will be compensated by a system of photovoltaic panels connected to the electrical grid (On-Grid), which will constantly compensate for the consumption generated by the thermostat throughout the day.

Another main objective presented in the theis is the demonstration of the economic viability of these renewable systems compared to non-renewable systems. This is achieved by means of a financial analysis that approximates the reality using the Present Value of an annuity equation (Roldán, 2020, Aponte, 2017). In summary, the objectives of the present work are to implement in simulation the equations of the mathematical models proposed by (Buzás, 2009, Matics Ingeniería Eléctrica, 2021), with which the "switching" system will be developed. Subsequently, these models will be validated with real-world systems, and, finally, an approximate economic study will be carried out to demonstrate the feasibility of the installation of these systems.

The theis is structured as follows. Its first Section 2 shows a solid foundation of the important concepts and topics to be discussed in the thesis. The Section 3 presents the equations of the mathematical models of photovoltaic panels and solar thermal panels (Roldán, 2019, Buzás, 2009, Matics Ingeniería Eléctrica, 2021). The Section 4, shows the analysis of these two models designed in simulation. In Section 5, the results of the simulations and their validation by comparison with real systems are presented, together with an analysis of the economic viability of the system. Finally, Section 6 details the conclusions of the thesis.

CHAPTER 2

FUNDAMENTALS

This section briefly introduces some of the concepts that will be utilized in the development of this work.

2.1 Renewable energy

Renewable energy refers to forms of energy that come from natural sources that are replenished more rapidly than they are consumed. Examples of these sources include sunlight and wind, which are constantly regenerated. Renewable energy sources are abundant and can be found in any environment. The transition from fossil fuels to renewable energy is essential to address the climate change crisis, as renewable energy generation produces fewer emissions compared to the burning of fossil fuels, which is currently responsible for the majority of emissions (Martínez, 2019).

2.2 Solar thermal panel

A solar thermal panel is a system that uses solar energy to heat water and can be used in homes or businesses. The system consists of a tank that stores the hot water and distributes it at the desired temperature. Solar water heaters are autonomous and do not require other supplies for operation. They are highly efficient and environmentally friendly, making them a great advantage for energy saving in homes and businesses (Soto, 2022).

2.3 Photovoltaic panel

The device that converts this form of energy into electrical energy is known as a photovoltaic panel. It is a slim rectangular sheet that usually measures about 4-5 centimeters in thickness. The panel is composed of numerous photovoltaic cells that are specifically designed to capture and convert solar energy into electrical energy (Martínez, 2019).

2.4 Present Value

The principal idea of the present value relies on a fundamental equation that allows us to determine the current value of a monetary sum designated for receipt at a future date. In simpler terms, the present value enables us to assess the present value of a financial quantity set to be acquired not immediately but rather later (Roldán, 2020).

CHAPTER 3

MODEL CHARACTERIZATION

This section gives an overview of mathematical models of two categories of solar panels: photovoltaic panels (Fig. 5.1) and solar thermal panels (Fig. 5.4). These models are harnessed to replicate and gain insight into the operation of these systems, taking into account variables such as solar radiation and ambient temperature.

3.1 Mathematical Modeling for the photovoltaic panel (PV).

A mathematical model for a photovoltaic panel system captures its behavior and variables such as solar radiation, temperature, efficiency, current, and voltage (Roldán, 2019). This model estimates the performance of the system in different environments and helps optimize the design. From this we derive equations that define the mathematical model of the photovoltaic panel system (Matics Ingeniería Eléctrica, 2021).

Photo-current: In this equation, it is possible to visualize the presence of the photocurrent (I_{ph}), measured in amperes, as well as the short circuit current (I_{sc}), also measured in amperes. Furthermore, the short-circuit current of a cell (k_i) can be appreciated in ideal environmental situations, such as an ambient temperature of 25 [$°C$] and solar irradiation of 1000 [W/m^2]. Finally, the variation of solar irradiation as a function of ambient conditions (G [W/m^2]) can be observed.

$$I_{ph} = \frac{[I_{sc} + k_i \ (T - 298)]G}{1000} \tag{3.1}$$

Saturation Current: The equation representing the saturation current (I_0 $[A]$) includes certain elements that define it, such as the inverse saturation current (I_{rs} $[A]$), the operating temperature (T_n $[K]$) and the nominal (T $[K]$), the electron charge (q $[C]$), the semiconductor energy band gap graph (E_{g0} $[eV]$), the solar irradiance variation (G $[W/m^2]$), the value of the diode factor (n), and, finally, the Boltzmann constant (K $[J/K]$).

$$I_0 = I_{rs} \left(\frac{T}{T_n}\right)^3 exp \frac{\left[qE_{g0} + \left(\frac{1}{T_n} + \frac{1}{T}\right)\right] G}{nK} \tag{3.2}$$

Reverse saturation current: The equation defining the value of the reverse saturation current (I_{rs} $[A]$) includes the following parameters: the short circuit current (I_{sc} $[A]$), the electron charge (q $[C]$), the open circuit voltage (Voc $[V]$), the diode factor (n), the number of cells connected in series (N_s), the Boltzmann constant (K $[J/K]$), and the nominal temperature (T $[K]$).

$$I_{rs} = \frac{I_{sc}}{e^{\left(\frac{qVoc}{nN_sKT}\right)} - 1} \tag{3.3}$$

Shunt current: The shunt current is defined by the following values: the voltage generated by the photovoltaic panel (V_{pv} $[V]$), the current of the photovoltaic panel (I_{pv} $[A]$), the series resistance (R_s $[ohm]$), and finally, the shunt resistance (R_{sh} $[ohm]$).

$$I_{sh} = \left(\frac{V_{pv} + I_{pv}R_s}{R_{sh}}\right) \tag{3.4}$$

Current generated by the photovoltaic panel: Finally, the equation we use to define our system is the PV panel current (I_{pv} $[A]$), which combines the parameters previously defined in the equations of the mathematical model.

$$I_{pv} = I_{ph} - I_0 \left[\exp\left(\frac{q\,(V_{pv} + I_{pv}R_s)}{n\,K N_s T} \right) - 1 \right] - I_{sh} \tag{3.5}$$

3.2 Mathematical Modeling for the solar thermal panel.

It is known that a solar thermal panel is divided into two systems: the collector and the tank. The collector is the component where the tubes that heat the water are located by solar irradiation and ambient temperature. On the other hand, the tank system stores the hot water produced by the collector and is the one that supplies the water to the domestic piping network, finally reaching the shower (Buzás, 2009). The equations of both systems are shown below. Note that in some equations it is detailed that they are in function of time, implying that all the others will also be in function of time.

Mathematical model of the collector: The parameters defining the solar collector subsystem include the water temperature at the outlet (Tco [°C]), the collector area (Ac [m^2]), the optical coefficient (no), the heat capacity of the water (Cc), the solar radiation (Is), the collector loss coefficient (UL), the average temperature (Tmc [°C]), the collector ambient temperature (Tca [°C]), the volumetric flow rate (vc [m^3/s]), the volume of fluid inside the collector (Vc [m^3]), and, finally, the inlet (Tci [°C]) and outlet (Tco [°C]) temperature of the water.

$$\frac{dTco}{dt} = Ac\,\frac{no}{Cc} Is - UL\,\frac{Ac}{Cc}\,(Tmc - Tca) + \frac{vc}{Vc}\,(Tci - Tco) \tag{3.6}$$

Average temperature: To define the average temperature of the fluid in the solar collector, only the value of the inlet temperature and the outlet temperature of the water, which have been previously mentioned as parameters of the solar collector subsystem, are required.

$$Tmc = \frac{Tci + Tco}{2} \tag{3.7}$$

Heat capacity: The equation that defines the heat capacity (Cc) of the fluid in the solar collector includes the following parameters: the density of the water (ρ [Kg/m^3]), the specific heat of the water (cc [J/kg °C]), and the volume of the fluid (Vc) within the previously mentioned collector.

$$Cc = \rho \cdot cc \cdot Vc \tag{3.8}$$

On the other hand, the mathematical model that defines the tank system is defined by the following equation.

Mathematical model of the tank The parameters that define the solar tank subsystem are as follows: the value of the first term (vl/vs) is equal to 1 because both have the same value and both represents the volumetric flow rate (vc [m^3/s]). Other parameters include the temperature of the water at the entrance of the tank (T_{ti} [°C]), the ambient temperature of the water in the tank (T_{ta} [°C]), the water outlet temperature of the tank (T_t [°C]), the volume of the tank (Vs [m^3]), the exterior surface of the tank (As [m^2]) and finally the loss coefficient of the tank (Ks [W/ m^2 °C]).

$$\begin{aligned} \frac{dTt}{dt} = \left(\frac{vl}{vs}\right)(Tti - Tt) + \left(\frac{vs}{Vs}\right)(Tco - Tt) - ... \\ ... \left(\frac{As\,Ks}{\rho \cdot cc \cdot Vc}\right)(Tt - Tta) \end{aligned} \tag{3.9}$$

Once the equations that detail each mathematical model of each system are defined, both for the solar thermal panel system and for the photovoltaic panel, they are implemented in simulation using the Simulink®software. To obtain an accurate mathematical model, the complexity of the system was taken into account, and factors that can vary according to the time of day, such as solar radiation, ambient temperature, water flow, etc., or values that allow for more precise measurement such as the collector area and collector loss coefficient, among others, were considered.

CHAPTER 4

MODELING SIMULATION ANALYSIS

The joint simulation of the mathematical models of the solar thermal and photovoltaic panel systems will be performed in Simulink®software. This simulation will be used to generate an on-grid energy compensation system, which will automatically operate from the PV system (The Home Depot, 2017) when the electric thermostat, which is located inside the tank of the solar thermal panel system, is not in use.

To represent the equations of the mathematical model of the photovoltaic panel, a diagram (Fig. 5.1) was designed in Simulink®. Similarly, for the solar thermal panel, the corresponding diagram (Fig. 5.4) was also created using the same software.

As mentioned, the proposed system consists of a solar thermal panel for heating water and an electric thermostat inside the water tank. The thermostat has a power of approximately 1500 $[W]$ and will be activated when the water temperature at the outlet of the thermo panel tank drops below the set value of 31 $[°C]$.

In addition, as mentioned above, the intention is to provide the necessary power for the thermostat through solar panels, thereby aiming for an approximate electricity cost of \$0. To achieve this, the goal is to ensure that the power generated by a solar panel matches, particularly during the peak hours of solar radiation around midday, the power required for the thermostat's operation. This approach will significantly reduce electricity consumption and consequently lower the associated cost.

The employment of the power consumption compensation system in Simulink®enables the optimization of model parameters, ensuring the attainment of zero power consumption objectives.

To realize power consumption compensation, the PV system will not directly supply the power required by the thermostat at the time of its use, given that hot water usage can occur at any time during the day. The energy generated by the panels during these peak hours will be redirected to the grid (On-grid system) rather than immediately powering the thermostat in real time. This signifies that the consumption resulting from the thermostat's operation will be offset by channeling the energy back into the grid through the PV system.

This energy compensation system that uses photovoltaic panels has advantages for both the user and the utility. It offers greater flexibility in the use of hot water, as it is not restricted by the immediate availability of solar energy (Renovaenergia S.A., 2022). In addition, it contributes to the reduction of electricity consumption and the reduction of the carbon footprint. On the other hand, the utility benefits from receiving surplus energy generated by photovoltaic panels, which helps balance demand at times of greater need and favors the integration of renewable energy into the electrical grid. For a clearer understanding of the operation of the simulated system, a flow diagram has been designed and can be seen in Fig.4.1. This diagram shows the switching system and the method of energy compensation to the grid by means of the photovoltaic panel (PV).

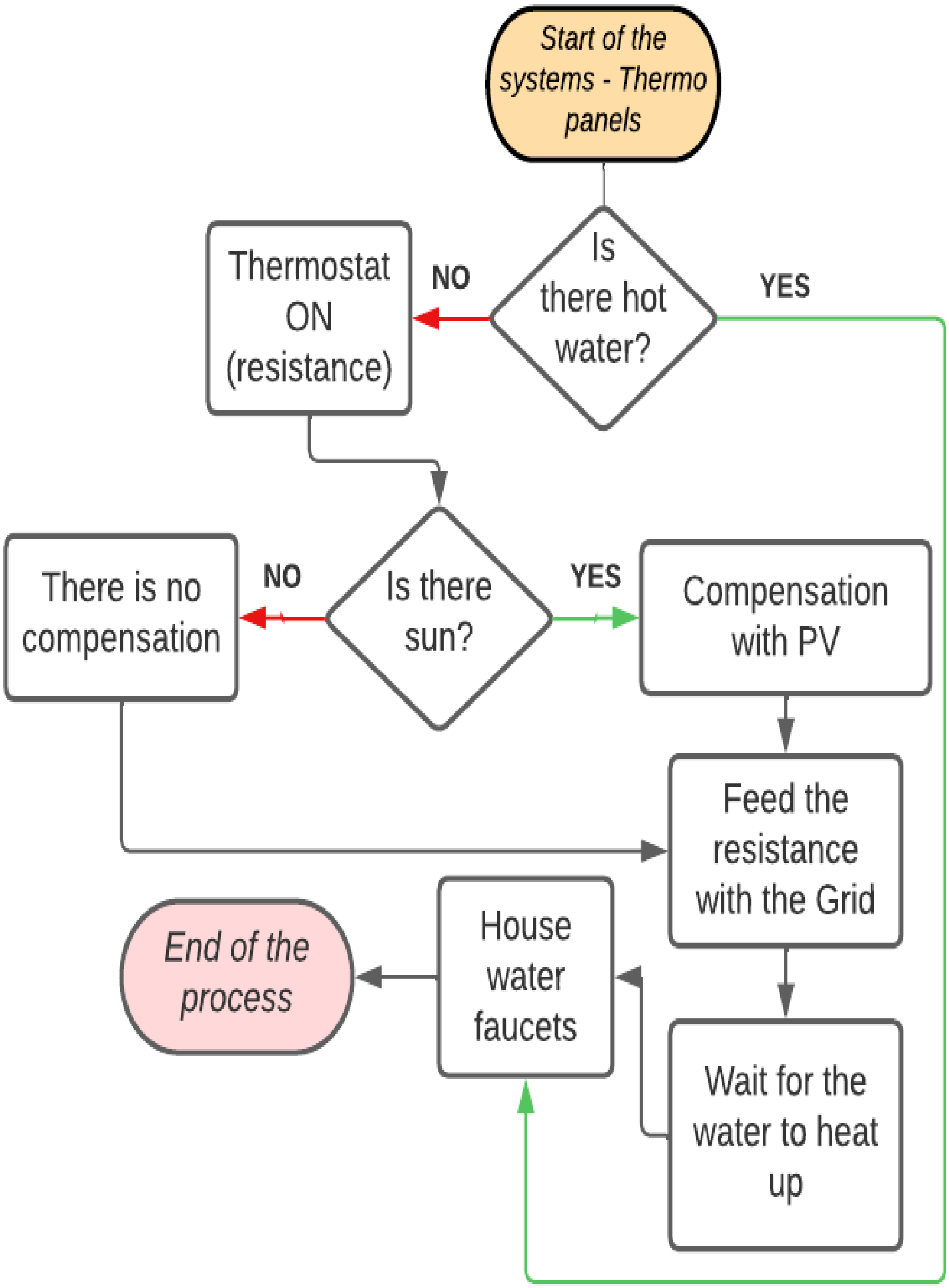

Figure 4.1: Flowchart of the simulation operation.

CHAPTER 5

RESULTS

The proper operation of the system is depicted in Fig. 5.1 and Fig. 5.4. Let's commence by analyzing Fig.5.1 and its outcomes. In this diagram, the photovoltaic (PV) panel is centrally depicted, with all equations defining the mathematical model of the panel being simulated and designed within blocks in the central portion of the figure. Particularly highlighted are the input variables of the system denoted as "Irra" and "tamb". The former variable represents the variability of solar irradiance measured in [*W/m²*], while the latter signifies the ambient temperature to which the PV panel is exposed, measured in [°*C*]. These two variables are pivotal in determining the power generated at the panel's output.

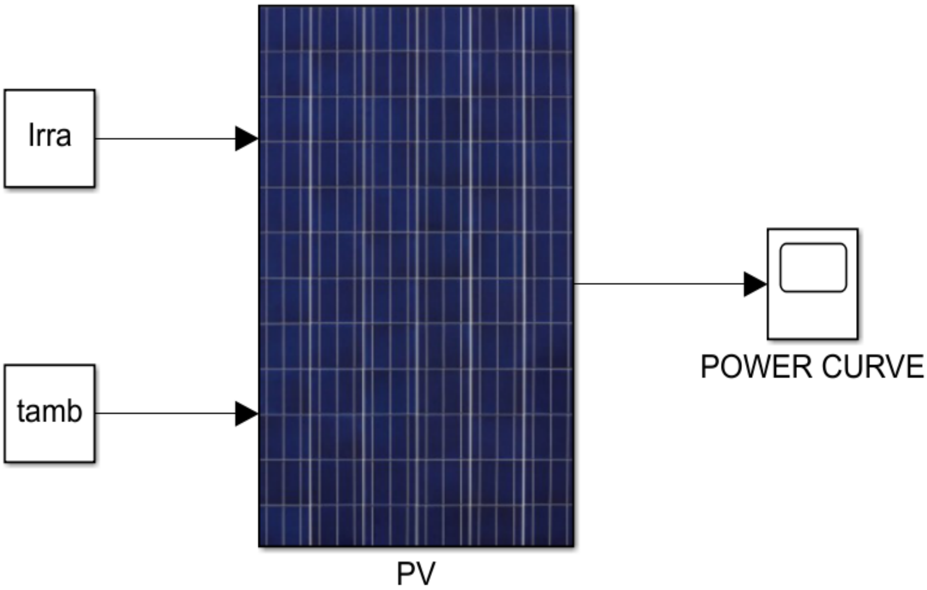

Figure 5.1: Representative diagram of the Photovoltaic Panel (ProViento, ND).

Under ideal ambient conditions, with a solar irradiation of 1000 [*W/m²*] and an ambient temperature of 25 [°*C*], a peak power of 432.90 [*W*] can be achieved, as illustrated in Fig. 5.1. The power generated curve is presented in Fig. 5.2.

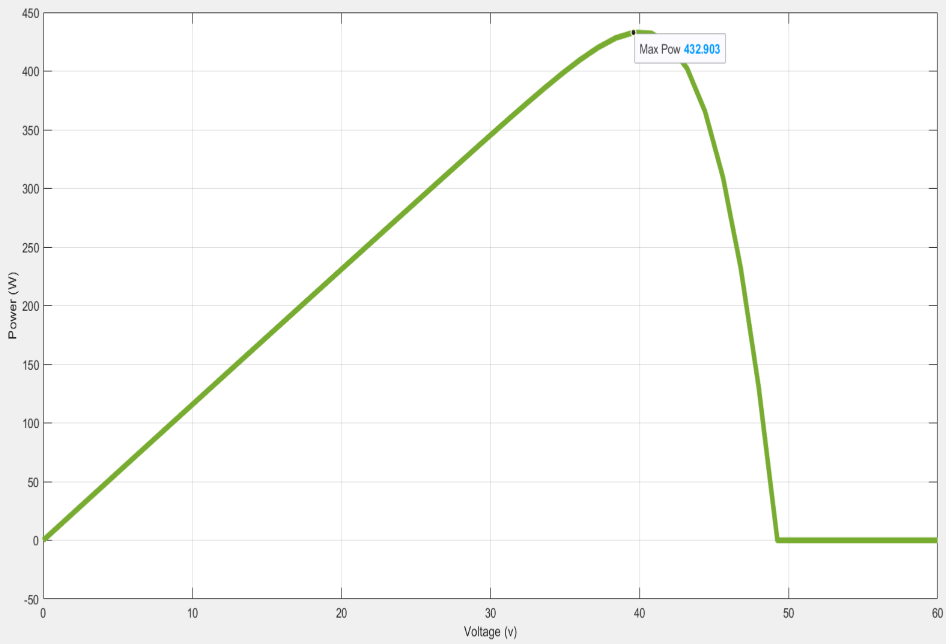

Figure 5.2: Power-Voltage Curve of one (Simulated) PV

To validate the PV array system, a comparison will be made between the real-world performance of the system and the simulation conducted in Simulink®, based on the mathematical model equations. This approach ensures the alignment of actual performance with predicted results, confirms the accuracy of the model, and establishes a foundation for future improvements. According to the supplier (ProViento, ND), the maximum power output of the *RS7I-M* brand photovoltaic panel *ERA* is approximately 450 $[W]$ under the same environmental conditions utilized in the simulation. This validation method reveals a 3.79% error between the actual and simulated values, signifying the closeness to reality and confirming the proper operation of the system.

In the case of the second system, depicted in Fig. 5.4, the large central block represents the thermal panel system. Within this block, there are subsystems that represent the collector and the water tank. At the system's input, once again, we have the same variables detailed earlier: "Irra" and "tamb". Additionally, the inlet temperature of the water is taken into consideration, which may vary and will be measured using a thermometer in $[°C]$.

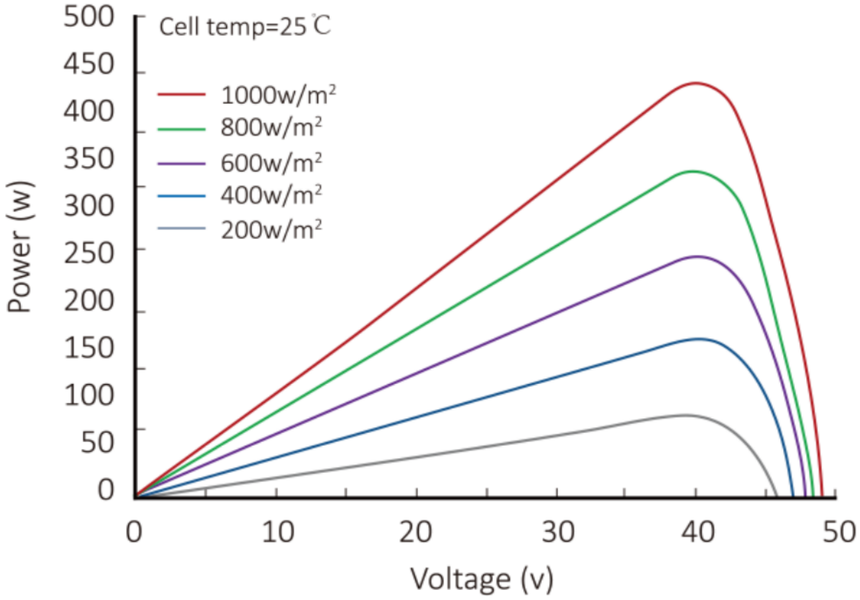

Figure 5.3: Power-Voltage Curve (RT71-M)

As for the outputs, there are four displays indicating the measurements of each of the components present within the system. Under ideal environmental conditions, with a solar irradiation of 1000 [W/m^2], an ambient temperature of 25 [$°C$], and a water inlet temperature of 25 [$°C$], the following values are obtained: the collector's temperature is 72.87 [$°C$], and the water tank's temperature is 41.76 [$°C$].

For the thermal panel system, a similar validation approach will be employed. The efficiency of real-life equipment (The Home Depot, 2017) under ideal environmental conditions will be compared with the projections generated in Simulink®. In this process, the data on the maximum operating temperature value of the collector, which the manufacturer specifies as 78 [$°C$] under the conditions mentioned above, will be juxtaposed. These data will be compared with projections from the design phase of the simulation for the collector, resulting in a maximum operating temperature of 72.87 [$°C$]. Once both values have been presented, the simulated system will be validated by calculating the percentage error between the simulated model and the actual value. This error is found to be 6. 57%, indicating that the values of both the photovoltaic panel and the thermal panel closely match the reality, thus affirming their proper operation within the system.

Figure 5.4: Representative diagram of the Solar Thermo Panel System (The Home Depot, 2017).

In addition to these displays, there are two indicators that provide important information. The "TEMP OR POW" block and the "1=TP , 0=termostat" block show practically the same but with different representations. The "TEMP OR POW" block shows the current operating system by the actual value of the operating element. For example, if the water temperature at the outlet is above 31 $[°C]$, indicating that the ambient conditions are optimal for a hot shower, the value displayed by this block will be the actual water temperature at the outlet of the tank. In case the ambient conditions are not favorable for the water heating of the thermo panel and the thermostat is activated, which is a resistive load that requires a starting power of 1500 $[W]$, the value displayed by that block will be 1500.

The same concept applies to the block called "1=TP , 0=thermostat". This block in abbreviated form indicates us by means of a "1" if the system that is currently operating is the thermo panel, otherwise, it will show us a "0" if the thermostat is in operation.

5.1 Study of economic feasibility and energy savings

First, we will seek to improve the knowledge about the economic feasibility and energy savings by comparing a previously designed system using renewable energy and a system of equipment using conventional energy. It is important to note that this analysis projects a period of 10 years, coinciding with the estimated useful life of the components of both systems, for a household where 4 people live together, since it is known that on average households in Ecuador are made up of 3.8 people (Erazo, 2011).

We will begin by analyzing the investment required to implement the renewable energy system. Table 5.1 presents the costs that make up this investment, including equipment, additional wiring/accessories and labor. The sum of these elements amounts to approximately 2065.9 USD. It is important to note that this investment will be made in cash, i.e., the entire amount will be paid at the time of initial contracting and installation of the system.

Table 5.1: Investment in Renewable Energy (The Home Depot, 2017, AliExpress, ND, ProViento, ND)

ELEMENT	**AMOUNT**	**VALUE (USD)**
PV Panel	1	220
Inverter	1	83.9
Thermo-panel	1	752
Labor cost	-	500
Accessories/Cable/Pipe	-	510
TOTAL	2065.9 USD	

Although initially mentioned that the study projection would be extended to 10 years due to the useful life of the equipment in both systems, it has been determined that the renewable energy system can have a durability of approximately 20 years with proper maintenance.

On the other hand, as a comparison and in order to obtain a close estimate of the cost-benefit difference between the two systems, let us consider the system that operates with conventional energy, specifically an electric sanitary water heater. The analysis of the costs associated with this system is somewhat more complex. First, we will consider the costs related to the electrical equipment involved. Then, we will evaluate the installation, labor, wiring, and piping values, which together represent a one-time initial investment of $643.1 USD this can be observed in table 5.2.

Table 5.2: Investment in Conventional Energy Equipment (Pintulac, 2021).

ELEMENT	**AMOUNT**	**VALUE ($USD)**
Electric water heater (14.4 kW)	1	448.1
Elec. connection [2x6 + 8 THHN AWG]	10 [m]	65
Labor cost (per meter of cable)	x meter	30
Electric heating installation	-	100
TOTAL	643.1 USD	

It is relevant to note that some readers might initially infer that the renewable energy based system is more expensive than the electric heater when comparing the values provided for both systems. However, it is of utmost importance to consider an essential fact: the annual consumption and cost of electricity generated by the use of the water heater. This data will be analyzed by projecting a useful life of the equipment of 10 years.

To determine the 10-year future value expressed in present terms, we will use the theory of financial mathematics, specifically the "Present Value" equation (Roldán, 2020). This formula allows us to calculate, as its name indicates, the present value of a future amount of money, taking into account factors such as time and interest rates. Thanks to this tool, we will be able to properly evaluate the profitability of investments, in this case, of the electric water heater over 10 years.

To carry out this financial exercise, we will proceed to calculate the interest rate for this type of investment, taking as a reference the interest rate of a 10-year consumer credit provided by a bank, specifically the rate of the Central Bank of Ecuador, which is 16.18% per year (Banco Central del Ecuador, 2023).

Next, we will proceed to calculate the electricity consumption and the expenses generated by the electric heater caused by 4 people at the time of showering. According to Table 5.2, the power of the equipment is 14.4 [*kW*], which is equivalent to a consumption of 14.4 [*kWh*] per hour. Given that the average duration of a daily shower is 15 minutes (Restrepo, 2015), the resulting consumption will be a quarter of the above mentioned, i.e., 3.6 [*kWh*], which multiplied by the number of times the heater is used (4 times) gives a consumption of 14.4 [*kWh x day*]. Multiplying this value by 30 days, we obtain an approximate monthly consumption of 432 [*kWh x month*]. According to the information provided by EEQ (Ochoa, 2019), the electricity rate averages 0.10 ctvs per kilowatt hour. Considering that this value will increase in approximately 10 years to an average of 0.15 ctvs per kilowatt hour, the projected monthly electricity consumption for the heater is 64.8 USD, which represents 777.6 USD per year.

Once this annual value is obtained, we will use the "Present value" equation to estimate the present cost of paying the electric bill for the electric water heater over 10 years (Aponte, 2017). The equation of present value is defined as follows in equation 5.1:

Present value equation: In the given context, we have three key variables: "A", which represents the value of the annuity and has a known value of 777.6 USD; "i", which denotes the interest rate and is set at 16.2%; and finally, "n", which represents the number of periods or terms, which in this situation corresponds to a period of 10 years.

$$VP = A\,\frac{1-(1+i)^{-n}}{i} \tag{5.1}$$

Replacing the values in the equation we have the following result:

$$VP = 777.6\,\frac{1-(1+0.162)^{-10}}{0.162} = 3733.3 \text{ USD} \tag{5.2}$$

Based on the findings, we can determine that the electricity consumption generated by 4 members of a family using an electric water heater for 10 years is approximately 3733.3 USD. This amount, when added to the initial investment cost of the equipment, including installation and labor (643.1 USD), results in a total value of 4376.4 USD. It is important to note that this cost is a little more than double compared to the renewable energy-based system.

CHAPTER 6

CONCLUSIONS

The stated objectives were successfully achieved, resulting in the creation of a simulation based on accurate mathematical modeling that represents solar renewable energy systems. An approximate study was carried out to reduce energy costs, demonstrating that the use of these systems effectively reduces the carbon footprint.

Analyzing the findings presented in Section 5, we can summarize the advantages and disadvantages of each system. The most expensive option, conventional electric heating, offers ease of installation, market availability, and lower initial costs, but it also comes with drawbacks, such as increased electricity consumption and a significant environmental impact.

In terms of ecological systems (photovoltaic and thermo-panel), their advantages include the use of renewable solar energy, leading to a reduced carbon footprint, long-term economic savings, and uninterrupted hot water availability. These systems require a higher initial cost than traditional energy sources and are dependent on the electrical grid. If electricity is not available, the thermopanels will not heat, affecting the nighttime hot water supply. It should be emphasized that in Section 5 both thermopanel and photovoltaic systems are validated by comparison with the real-life operation of the systems. This yields results with a maximum error percentage of 6.57%, which leads us to conclude that the simulated system is very close to reality and it is feasible to use it to estimate the values of its operation.

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CHAPTER 7

APPENDIX

Table 7.1: Values of each element present in the photovoltaic system.

Units	**ELEMENT**	**VALUE**
1	PV	432.90 [W]
1	THERMOSTAT	1500 [W]

Table 7.2: Technical Parameters of the Photovoltaic Panel System (ProViento, ND)

Var	**Val.**	**Descrip.**
Ego	1.1	Semiconductor energy band graph (eV)
Isc	11.60	Short-circuit current (A)
k	1.38E-23	Boltzmann constant (J/K)
Ki	0.0032	Short-circuit current of one cell (250C, 1000 W/m2)
Tn	298	Nominal temperature (K)
q	1.60E-19	Electron charge (C)
Voc	49.30	Open circuit voltage (V)
n	1.3	Diode factor
Ns	72	Number of cells connected in series
Rs	0.221	Serial resistance (ohms)
Rsh	415.405	Shunt resistance (ohms)

Table 7.3: Technical Parameters of the Solar Thermo Panel System (The Home Depot, 2017)

Var.	**Val.**	**Descrip.**
As	1.6745	External tank sup in (m2)
cc = cs	4186	Specific heat of water (J/kgoC)
d	0.0125	"Tube diameter (1/2"")"
dta	0.41	Tank diameter
Ks	2	Coef tank losses (w/m20K)
L	2	Longuitud of a tube tube
Lt	16	Length tube (m)
Lta	1.3	Long tank
N	12	Number of tubes
no	0.72	tao*alpha
p	7.18E+05	ro*cs*Vs
ro	1000	Water density
tao	0.8	Transparency of the cover
Tci	25	Temp entrance to the water collector
Vc	0.0019	Vol fluid
vl = vs	1.00E+05	Flow rate in (m3/s)
Vs	0.1716	Tank volume (m3)