ON-GRID PHOTOVOTAIC SYSTEM SIZING FOR SENAI CIMATEC USING HOMER GRID SOFTWARE

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Abstract: This paper determines the optimum Photovoltaic (PV) system sizing to install at SENAI CIMATEC. The objective is to evidence the economics and environmental advantages of PV production to supply the CIMATEC loads. The Hybrid Optimization Model for Electric Renewable (HOMER) Grid software is used, and the local solar radiation, the CIMATEC load profile, and the costs of the components are considered as the input data in the sizing process. The results show that the 2,100 kW is the optimum PV system size to CIMATEC, and the benefits of PV generation are not just economic but also environmental. Approximately R$ 1.2 million are saved annually using the energy generated by the PV system instead of the electric grid, and more than 1,800 tons per year of CO_2 are not emitted.

Keywords: Energy Transition; Decabornization; PV system; Homer Grid.

DIMENSIONAMENTO DE SISTEMA FOTOVOLTAICO PARA O SENAI CIMATEC UTILIZANDO O SOFTWARE HOMER GRID

Resumo: O presente artigo tem como objetivo determinar o dimensionamento ótimo de um sistema Fotovoltaico (FV) para ser instalado no SENAI CIMATEC, evidenciando as vantagens econômicas e ambientais da geração FV. O software HOMER é utilizado e a radiação solar do local, o perfil de carga do CIMATEC e os custos dos componentes são alguns dos dados considerados para modelagem e simulação do sistema. Dessa forma, os resultados mostram que um sistema FV de 2.100 kWp resulta em uma economia de cerca de R$ 1,2 milhões anuais ao CIMATEC com contas de energia, ao passo que mais de 1.800 toneladas de gases poluentes não são emitidos para a atmosfera.

Palavras-chave: Transição Energética, Descarbonização; Sistema FV; Homer Grid.

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1. INTRODUCTION

Electric power systems have changed significantly in the last years due to the new technologies and paradigms created [1]. Photovoltaics (PV) systems, for example, convert solar energy into electrical energy and have been one of the most used [2]. Economic incentives, reduction costs, fast technological developments, and installation simplicity are some of the aspects that allow PV systems such attention [3].

The growth of PV systems is evidenced by its installed capacity in the world's electric matrix [4]. The 2020 global PV cumulative capacity achieved at least 760.40 GW [5], against 303 GW in 2016 [6]. In Brazil, PV systems gained popularity after the Normative Resolutions nº 482/2012 and 687/2015, which regulated the Distributed Generation (DG) grid connection [7]. The 2020 Brazil total PV cumulative capacity reached about 8 MWp and 61% was from distributed systems [8].

According to the Brazilian Electricity Regulatory Agency (ANEEL, Agência Nacional de Energia Elétrica), DG is defined as small generators connected in electrical grids close to the end-users [9]. Due to the elevated solar radiation levels, the progressive reduction costs of PV devices, and the favorable net metering system, the PV installed power capacity increases year by year [7].

From the grid perspective, DG defers investments in distribution and transmission systems expansion, has a low environmental impact and diversifies the energetic matrix. From the consumer's point of view, DG fetches savings with energy bills and offers energy security, reliability, and efficiency [9]. However, despite the benefits, DG from renewable resources is unpredictable and depends on weather and climate changes [10].

In PV systems, the generated energy depends on the solar energy availability at the site. Furthermore, geographical location, ambient temperature, clearness index, tilt, and PV modules orientation also affect the collected solar energy. To ensure the optimum operation of the PV system, it is recommended to evaluate the technical-economic feasibility to ensure that the system is not over or undersized [10].

In that sense, to help SENAI CIMATEC be a more sustainable and energy-efficient Institute and to ensure the optimum PV system, this work will present a PV system sizing for CIMATEC’s load supply. The goal is to evidence the technical-economic feasibility and the environmental aspects of providing PV generation for SENAI and estimate its benefits. It's used The Homer Grid software to model, simulate, and design the PV system.

2. METHODOLOGY

This section describes the methodology used in this paper. Therefore, the software used, the local description and the characteristics used to model the system components will be detailed.

2.1. HOMER Grid Software

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Originally developed at the National Renewable Energy Laboratory (NREL), Homer Grid simulates renewable distributed systems, offers optimized power configurations considering their associated costs, and enables sensitivity analyses. The HOMER Grid's key features are simulation, optimization, and sensitivity analysis. HOMER uses input data as renewable resources, component costs, demand load, resources environment, and electricity tariff to model the system components for simulation. Through optimization, the viability and profitability of different systems are shown. The sensitivity analysis permit evaluates the impact of parameters changes (solar radiation and electric tariff, for example) [11].

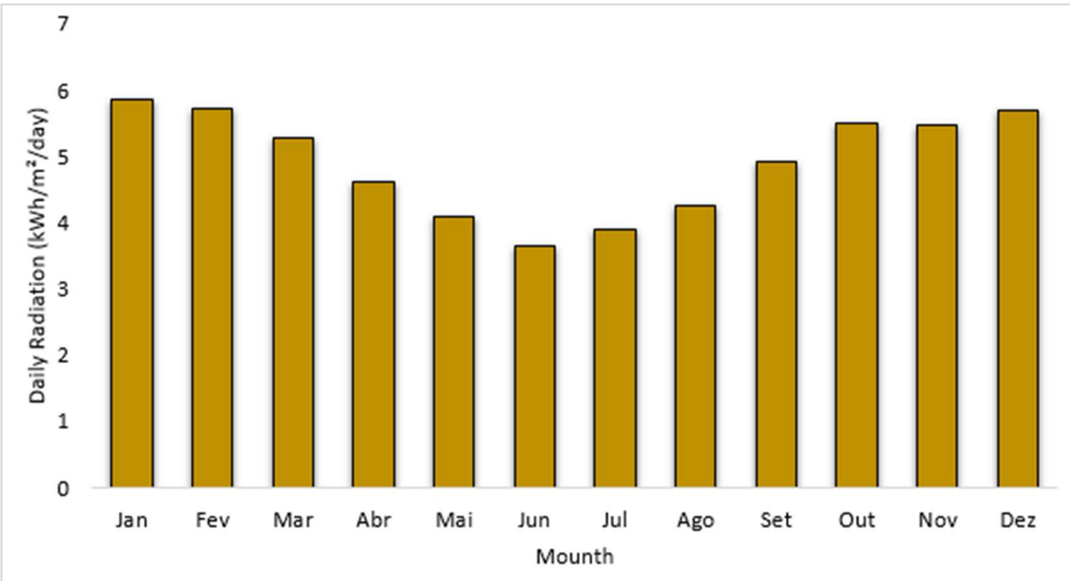
2.2. Modelling

HOMER Grid software is performed based on data inputs, including components (e.g., generator, storage, and solar), component costs, and resource availability, for system modeling.

2.2.1 Location and Load Profile

The PV system is designed to be installed at SENAI CIMATEC, located in Salvador, Bahia, Brazil (latitude = 12.938779° S, longitude: 38.490146° O). Through the data provided by NASA at Homer Grid, Figure 1 shows the daily radiation in Salvador. The average annual solar irradiation is 4.91 kWh/m²/day, and the minimum and maximum values are 3.66 kWh/m²/day and 5.86 kWh/m²/day, respectively. The minimum occurs in June and the maximum in January.

Figure 1. Daily radiation in Salvador, Bahia



CIMATEC is one of the country's most advanced centers for education, technology, and innovation, having a four-building structure of more than 35,000 m².

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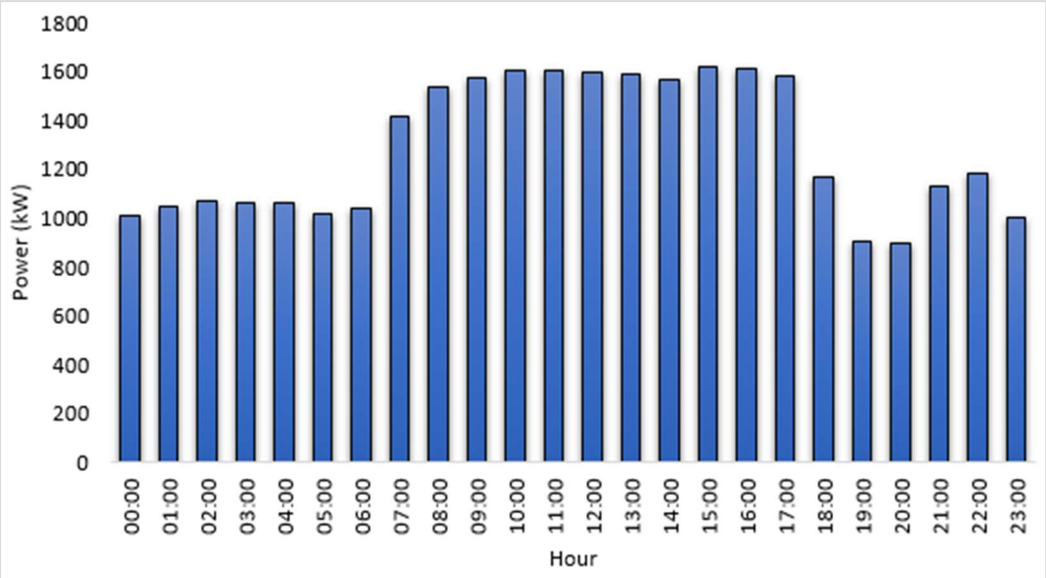
Essentially, the electrical loads are classrooms, meeting rooms, professor's offices, study rooms, and laboratories. The electrical load profile of a typical day at SENAI CIMATEC is shown in Figure 2, and the calculated scaled annual electricity consumption average is 26,425 kWh/day. In reason of the atypical year of 2020, caused by de COVID-19 pandemic, the calculated electricity consumption considers the electric bills of 2019.

Figure 2. Electrical load profile of a typical day at SENAI CIMATEC



2.2.2 Utility

The electricity grid is modeled through the tariff mode (rates to the energy consumption from the grid) applied by the local energy distribution company, the Bahia State Electricity Company (COELBA, Companhia de Eletricidade do Estado da Bahia). SENAI CIMATEC is a medium voltage consumer and belongs to the A4 subgroup (green rate) on the tariff mode. Thus, there are different tariffs on the energy consumption according to the day hours, and just one to the contracted power demand.

The energy consumption from the grid is R$ 2.43/kWh in peak hours and R$ 0.28/kWh in off-peak hours. The peak hour is the period between 6 p.m. and 9 p.m. during weekdays, excluding holidays. The off-peak is the remaining hours. Moreover, the tariff value of power demand contracted is R$ 32.70/kW; if exceeded, the value is R$ 65.40/kW. The power contracted by CIMATEC is 2,100 kW. The values used to model the grid agree with the tariff prices established by COELBA in 2021 and do not include taxes [12].

2.2.3 PV System

To modeling the PV system is required the module model and acquisition, replacement, and O&M costs. Hence, the PV module model used is the CS6U-340M

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from Canadian Solar, with monocrystalline cells type, 340 Wp of output power, 25 years of lifetime, and 16.97% of efficiency. The system costs are R$ 3,500/kWp to the acquisition, R$ 3,500/kWp to replacement, and 1% of cost acquisition to O&M. The adopted values are according to the average prices practiced in the Brazilian market.

Furthermore, simulations are divided into two parts to determine the optimum PV system. In the first part, there is no limitation to the installed PV power, then the "Homer Optimizer" mechanism is selected. In the second part, the PV power is equal to the contracted power demand, i.e., 2,100 kW, and the "Size Your Own" mechanism is selected. Conforming to the Normative Resolutions nº 482/2012 and 687/2015 of ANEEL, the PV power is limited by the power demand value.

2.3. HOMER's Calculations

The PV system generation is calculated by HOMER Grid through equation (1).

$$P_{PV} = Y_{PV} f_{PV} \frac{G_T}{G_{T,STC}} [1 + \alpha_p (T_c - T_{c,STC})]$$

where, Y_{PV} is the nominal capacity of the PV module under Standard Test Conditions (STC) (kW), f_{PV} is the PV energy reduction factor (%),G_T is the solar radiation incident on the PV panel in real conditions (kW/m²), $G_{T,STC}$ is the incident irradiance under STC (1 kW/m²), α_p is the temperature coefficient of power (%/°C), T_c is the PV cell temperature in real conditions (°C), $T_{c,STC}$ is the PV cell temperature under STC (25 °C).

Besides that, table 1 describes the economics parameters used at this paper to identify the optimum PV system to SENAI CIMATEC.

Parameter	Description
Net Present Cost (NPC)	Value of all the installing and operating costs over the project lifetime, minus the present value of all the revenues that it earns over the project lifetime.
Levelized Cost of Energy (LCOE)	Average cost per kWh of electrical energy produced by the system
Payback	Is the number of years at which the cumulative cash flow of the difference between the current system and base case system switches from negative to positive.

3. RESULTS AND DISCUSSION

The specified sizing by HOMER Grid results is based on the system with the lowest NPC. Over the "HOMER Optimizer" mechanism, the results show that a 6,194 kWp PV power has the lowest NPC and is the most viable system to supply the SENAI

CIMATEC. The acquisition and operational costs obtained are R$ 24.8 million and R$ 2.55 million/year, respectively.

Moreover, the LCOE for this system is R$ 0.2450/kWh, and the payback is 9 years. Table 2 presents the energy balance of the system. Despite the high level of PV production, the grid sales occur due to the energy consumption by the load in different moments of the day, even when there is not PV production. The grid sales express the excess PV production injected into the grid.

Table 2. Energy balance to the system with the 6,194 PV plant

PV system generation (kWh/year)	Grid sales (kWh/year)	Grid purchases (kWh/year)	Load consumption (kWh/year)
9,142,278	4,559,388	5,062,235	9,645,125

The obtained PV system size, 6,194 kWp, stimulated the second part of the simulations due to restrictions of Normative Resolutions nº 482/2012 and 687/2015. Besides the value overpasses the contracted power demand by SENAI CIMATEC, the limited power to mini-generation is exceeded. Therefore, the PV power is limited to 2,100 kWp in the "Size Your Own" mechanism. After simulations, the results showed that the PV system of 2,100 kWp provides the lowest NPC to the system architecture.

The payback is 6.7 years, and the LCOE is R$ 0.4463/kWh for this system. Further, the acquisition and operational costs are R$ 8.4 million and R$ 4.06 million/year, respectively. Table 3 shows the energy balance of the system, considering the 2,100 kWp PV System. The PV production is smaller than the first part of simulations due to the PV system size, as well the excess PV production injected into the grid. In consequence, the grid purchases are larger.

Table 3. Energy balance to the system with the 2,100 PV plant

PV system generation (kWh/year)	Grid sales (kWh/year)	Grid purchases (kWh/year)	Load consumption (kWh/year)
3,099,781	165,600	6,710,944	9,645,125

Moreover, it is estimated a saving of R$ 1,258,363.67 annually with electric bills due to the use of the generated energy by the PV system to supply the SENAI CIMATEC loads. Additionally, 1,854,402 kg per year of CO_2 emissions would be removed from the atmosphere through PV system. Then, beyond the economic advantages to SENAI CIMATEC, the PV system benefits the environment with cleaner generated energy.

Figure 3 presents the system performance simulated by HOMER Grid. The generated energy by the PV system is used to supply the load whenever there is PV

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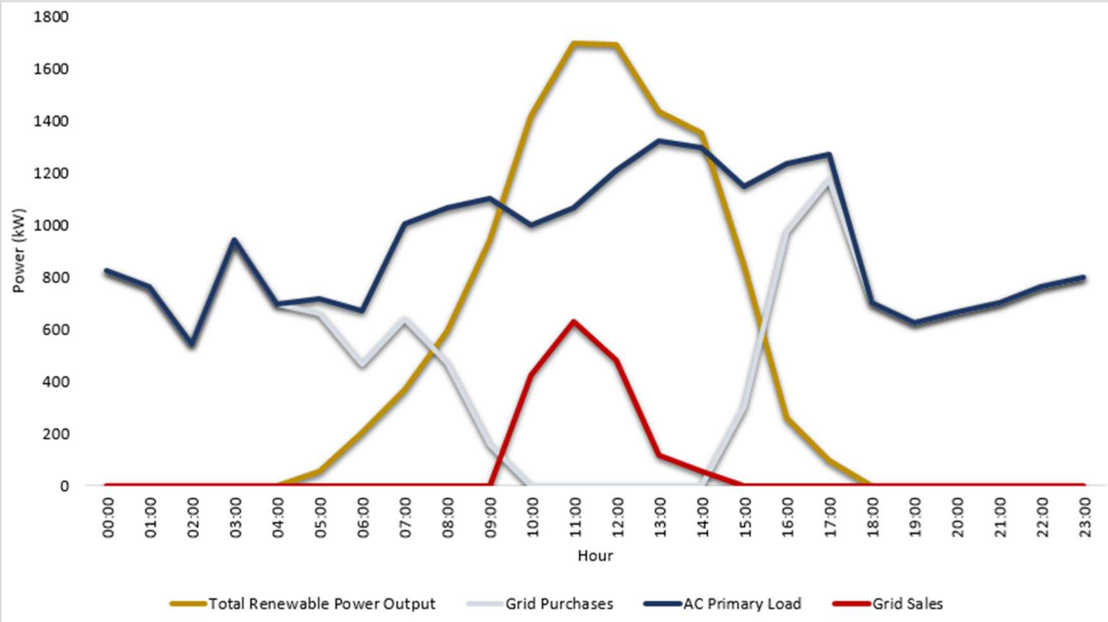
production, whereas the energy from the grid is consumed when the PV production is not sufficient or available. The grid sales occur when the PV production is bigger than load consumption, and the energy excessed is injected into the electricity grid.

Figure 3. System performance



4. CONCLUSION

Encouraged by the energy transition, PV systems have been one of the most used technology to clean energy generation. For an effective PV system performance, it is essential to predict the sizing and PV production. In that sense, this paper aimed to estimate the feasibility and the environmental aspects of providing PV generation for SENAI CIMATEC. Results showed that an installed 2,100 kW PV system at CIMATEC produces over 3 GWh/year, representing 32.14% from load consumption. Through this system, above R$ 1.20 million are saving annually using the generated energy by the PV system instead of the electric grid, and more than 1,800 tons per year of CO_2 are not emitted.

Acknowledgments

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