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Design and Economic Evaluation of Solar Home System for a Residential

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Abstract

The growing need for sustainable energy sources worldwide, coupled with the rising price of fossil fuels, makes a deliberate move towards renewable energy sources necessary. To supplement the finite supply of conventional energy sources and address environmental issues like air pollution and climate change, solar energy is a dependable and essential option. To solve this problem, the design and financial assessment of a solar home system (SHS) for a residential flat in Parit Raja, Malaysia, are the main objectives of this research. The objectives include building a sustainable solar photovoltaic system that is both efficient and appropriate for the local environment, as well as completing comprehensive cost research. This work primarily focuses on designing a 500W SHS while considering its financial aspects, with the aim of meeting both the needs of individuals and the national energy goals effectively. The study centers on a case study in Parit Raja, Johor State, where carefully examined how power is used in single-household SHS setups. This research seeks to provide valuable insights into the practical and economic benefits of SHS for residential power generation. Therefore, the average electricity cost in Malaysia is RM0.218 per kilowatt-hour (kWh), but the COE, which represents the average cost of energy production during the system's lifespan, is RM0.1907 per kWh. This suggests that the system is a cost-effective technique of electricity production. In this work, the design and simulation tasks were used through the assistance of HOMER software.

1. Introduction

Energy is a crucial factor in the development of human civilization. Renewable energy sources are being used at a faster pace than they are being created. However, the bulk of our energy comes from nonrenewable sources, with fossil fuels being the most prominent. Currently, there are reactive energies. Constitute about 85% of the global energy production. The hypothesis posits Heavy greenhouse gas (GHG) emissions will result from a reliance on fossil fuels. Air pollution and global warming might have a significant ecological impact. Further continuation of this tendency may result in catastrophic events.

Electricity has been utilized for aesthetic purposes for several decades. Electricity is a versatile energy source that is readily manipulated and transmitted. This distinctive electrical outlet has prompted individuals to compute its application in various routine functions. Electricity consumption has exhibited an upward trend since 1949, apart from the years 1979 and 1992. The escalation of energy prices and heightened demand has been accompanied by a decline in the availability of energy sources. As a result of the increasing demand for electric power and its associated costs, a significant number of researchers have focused their efforts on exploring more efficient, cost-effective, and environmentally friendly methods of generating electricity. Renewable energy sources have garnered attention as environmentally sustainable solutions to tackle these concerns. Renewable energy, also known as essential energy, refers to the energy that is derived from sources that can replenish themselves, such as geothermal, solar, wind, biofuel, and Hydroelectric power. The advantageous attributes of renewable energy have prompted governments to explore avenues for expanding the utilization of this form of energy [1].

1.1 Problem Statement

Due to the dearth of fossil fuels and the ongoing increase in fuel costs in recent years, unconventional energy sources, like solar energy, have become necessary. Additionally, by reducing global air pollution and reversing climate change, reliance on renewable energy sources should be promoted. Solar energy is among the most significant and trustworthy ways to augment the limited supply of traditional energy sources. Electrical energy accessibility is crucial in speeding cost-effective improvement because it contextualizes ideas about human health and life cycles. A thorough plan that takes into consideration several variables, including income, geography, and consumption habits, is required to achieve the goals. For homes that are in both urban and rural areas, traditional network connections may not be sufficient. An economical and ecologically conscious option are off-grid photovoltaic (PV) systems. These systems may be implemented in two ways: as simple SHS that can power appliances, or as autonomous systems that can generate large amounts of electricity for homes and businesses. Electricity generated by SHS represents alluring energy force benefits for the world's people who lack access to electricity, especially in its remote regions. SHSs represent a neglected and untapped structure when combined with the separate range of appliances. While describing the operations and operation features of SHSs and the public grid, the various orders of electrified and non-electrified populations in the world were defined. By defining the future of serviceability through a mix of bottom-up connected individual results and top-down concentrated energy force, suggest the idea of caring for the community’s network through extensive electricity supply.

2. Literature

2.1 Overview of PV System in Malaysia

Malaysia's copious sun irradiation makes the nation's most promising renewable energy source is PV systems. The usage of photovoltaic systems has been promoted by the Malaysian government through several renewable energy initiatives. Most PV systems are single-phase, and clients request that their systems be installed. As a result, a variety of technical issues, including voltage imbalance and increase, may arise from the growth of PV systems within low voltage (LV) distribution networks. Malaysia is also a tropical nation that is geographically encircled by water [2].

2.2 The Solar Home System

An "energy graduation" paradigm has been proposed, which characterizes the evolution of energy availability as a progression via numerous categories. In rural, low- resource communities, one technology is prevalent as a "first step on the energy graduation” in the solar home system (SHS). An example of SHS is shown in Fig. 1.

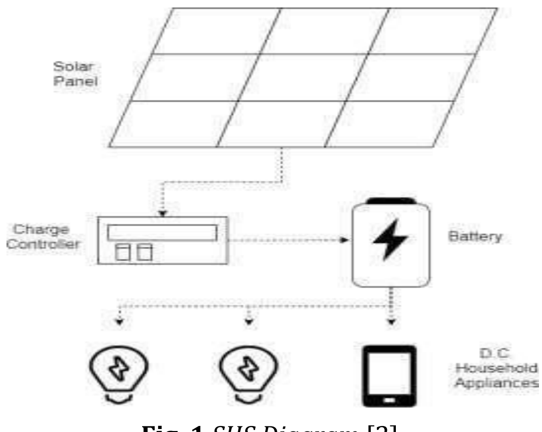

Fig. 1 *SHS Diagram* [2].

As seen in Fig. 1, SHS describes a small, modular energy unit made up of a battery, charge regulator, and solar panel. SHSs used in experimental operations can power a small array of DC appliances, often lightbulbs, for up to a few hours each day. SHSs have been widely used because they offer a relatively alluring solution for providing

Evolution in Electrical and Electronic Engineering Vol. 5 No. 1 (2024) p. 149-156

low-income pastoral communities with introduction power that is less intrusive, inexpensive, and easily transmittable. The number of SHSs in use worldwide is difficult to pinpoint, but in 2018 there were around 4.4 million of them, and in just the first half of 2020, close Sales of SHSs and other tiny solar-powered products reached one million [2].

2.3 Energy policies in Malaysia

The primary energy sources utilized in Malaysia are hydropower, coal, oil, and gas. However, other renewable energy sources are also being employed, including solar and biomass power. For the once 60 times, the Malaysian government has formulated quite several energies- related programs to insure the sustainability and security of the energy force. However, during the past thirty years, doable Energy 70 initiatives have made the path to energy development more accessible. Force, application, and terrain were the three main goals of the 1979 introduction of the National Energy Policy, which was the more important of the two policies.

With a generation capacity of 10,481 MW, Tenaga Nasional Berhad (TNB) is the largest electricity utility business in Malaysia (Haw et al., 2006). The Fifth-Fuel Policy of the Eighth Malaysia Plan set a goal of 500MW of renewable energy output to be fed into the national grid by the end of 2005. Just 12 MW were delivered out of the two projects that the Small Renewable Energy Power Programme (SREP) sponsored. It is evident from the stark difference between policy and practice that there are barriers to the successful transition from conventional to sustainable energy development (Kementerian Tenaga Air dan Komunikasi, 2005). The government has suggested that the Fifth Fuel Policy be carried over into the 9th Malaysia Plan, which runs from 2006 to 2010, due to the inability to meet the target. The administration advocated once more for encouraging and providing additional support for the growth of the nation's more sustainable energy sector. Among the suggestions is MS1525, or Energy Efficiency in Commercial Buildings [3].

2.4 Renewable Energy in Malaysia (RE)

Climate warming and the world's rapid depletion of traditional energy reserves have pushed humanity towards abundant, unexplored, and ecologically benign power sources. As previously mentioned, shaft was introduced as the fifth energy source when the Four-Energy Policy was replaced in 1999 by the Five-Energy 71 Diversification Policy, with the goal of contributing five of the total energy blends by 2010 in the Eight Malaysia Plan (2001-2005). In Malaysia, the shaft industry is still in its infancy and is developing at a very modest rate. The shaft's current state will be covered next [3].

2.4.1 Solar

Even though SREP included solar energy and it was connected to it in 2003, most solar electricity used in Malaysia is still mostly used for residential purposes; large-scale commercial use is still very minor. In Malaysia, solar power, commonly referred to as PV systems, are projected to have four times the world's reactive energy reserves (Hitam, 1999). The Malaysian Structure Five-Time Integrated Photovoltaic Technology Application Project (MBIPV) was introduced in 2005. Global Terrain Installation (GEF), the Malaysian government, and the business sector have all contributed significantly to the funding of this concept. The design features multiple PV system demonstrations in vibrant sectors, such as marketable constructions and residential homes. The Green Energy Office (GEO) building, a PTM administrative and research office, is the most noteworthy current design Another open MBIPV scheme, SURIA-1000 was launched in 2007 and targets the domestic and marketable sector in an effort to generate new BIPV requests, offer direct access to the public, and encourage diligent work in shaft enterprise [3].

2.5 Photovoltaic Cells

A solar cell, also called a photovoltaic cell, is an electrical device that converts incident photon energy into electrical energy. It is a marvel of nature and science. An extra cell unit can have a frame module also called a solar panel attached to it. A solar photovoltaic board or module consists of several solar cells arranged in a plane pattern within a single set. PV modules frequently have a glass front panel that allows light to pass through while keeping the semiconductor plate shielded by the casing. Solar cells are usually connected and arranged in modules that are either in series or parallel, based on the needs of the customer. The parallel interface unit receives a higher current, but shadow effects, for example, might have very unpleasant effects and even cause damage due to their enlightened complicity and the reversal of dark cell inclinations. They can also turn off weaker (less bright) parallel strings. Typically, a sequence of 13 stacked units is autonomous and does not link in parallel; nevertheless, as of 2014, every module regularly supplies a single power box and connects in parallel. Solar energy is transformed into electrical energy by solar panels. P-type and N-type semiconductors are used in tandem to create solar cells. By mixing boron, a trivalent impurity, with silicon, the p-type semiconductor is created. Like this, pentavalent impurity (phosphorous) is added to silicon to create n-type semiconductors. And as a result of the

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charged particle diffusion, a p-n junction is created, which creates an electric field [4]. Solar cell structure is shown in Fig. 2.

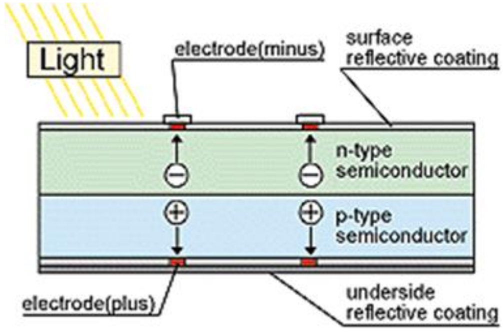


Fig. 2 *Solar cell structure* [4].

3. Methodology

3.1 Overview

As known, Malaysia is located in the equatorial zone. The hemispheres of the north-east and south-west control the climate. Throughout the whole year, sporadic monsoons were noted. The northeast monsoon and the south-west monsoon are two distinct meteorological phenomena that occur during different times of the year. The former typically transpires from October to March, while the latter takes place from May to September. The transitional phase between the two monsoons is characterized by a significant amount of precipitation. The protection offered by Sumatra results in a reduction of precipitation in the Peninsula during the south-west monsoon. In general, Sabah and Sarawak regions receive a higher amount of precipitation compared to the Peninsula. Malaysia's climate is distinguished by persistent elevated relative humidity, substantial precipitation, and elevated temperatures. Throughout the entirety of the nation, the prevailing atmospheric temperature remains consistently elevated. The temperature range of 26.0 to 32.0 °C falls within the average ambient temperature. The range of relative humidity typically falls within 80 to 88%, with the possibility of reaching nearly 90% in elevated areas, and maintains a minimum threshold of 60% [5]. A flow chart of the work with numerous significant steps is shown in Fig. 3.

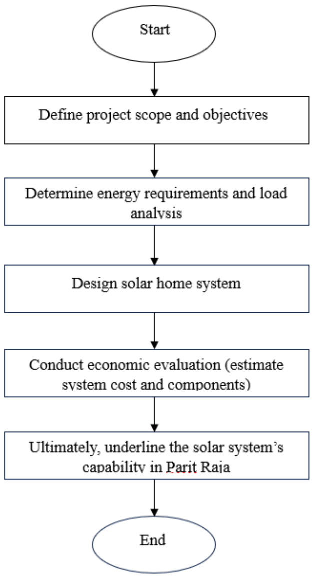


Fig. 3 *Flow chart of the work*

3.2 The process of designing a photovoltaic (PV) system

This section concerns the stage of completion of the work. The PV design is depicted in Fig. 4. Irrespective of the literature, the process of designing entails the careful consideration of site selection, as well as the collection of data for household and load analysis. Prior to the design phase, it is imperative to give due consideration to the interpretation and budgetary allocation of each component comprising a photovoltaic system. This section delineates the primary constituents. This study presents a flowchart detailing the components and operational characteristics of a propped solar photovoltaic system. The investigation also includes an analysis of the costs associated with the machinery utilized in the PV system, as well as the design considerations and sizing requirements for the battery and charge controller. This section's goal is to use the HOMER software to design a basic solar housing system. The initial step in the design process involves the estimation of primary input data, which serves to validate the technical provisions, resource data, and costs associated with the overall system design in the HOMER software tool.

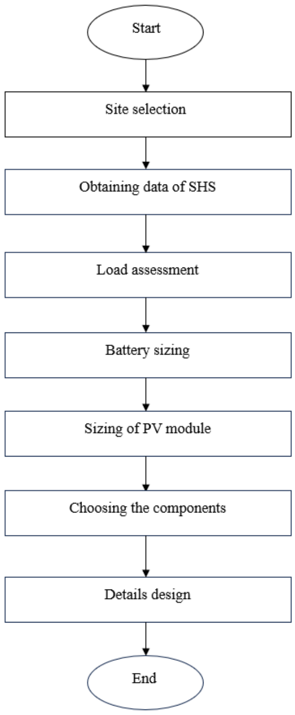


Fig. 4 *Flow chart of the SHS Design*

3.3.1 Data obtaining and identifying the location

Data gathering is a prerequisite for the layout and improvement of solar systems, and it is necessary for the task to be carried out successfully. This entails selecting the locations where the project will be carried out in the future, as well as conducting load analyses of particular villages, solar irradiance analyses of particular regions, and assessments of the renewable resources that are already accessible while taking the local geography into account. The case studies selected are located in Parit Raja, Johor, Malaysia, District of Johor. By entering the coordinates of the area into various research papers, NASA surface meteorology, and the solar energy website, secondary data was gathered. Taking into account the regional characteristics of the site, available assessments of renewable resources as well as journal articles, published reports, and published literature pertinent to the current investigation were also acquired.

3.2.2 Annual Solar Radiation in Malaysia

The most precise initial evaluation of Malaysia's solar radiation intensity for every month is derived from solar radiation mapping, this further offers the solar radiation average for the year. The average daily solar radiation for Malaysia is displayed in Fig. 5. There are no appreciable differences in solar radiation intensity between Peninsular Malaysia and East Malaysia, according to the sun radiation map for the year. Malaysia receives 4.96 kWh/m^2 of solar radiation annually. The regions that receive the greatest solar radiation include the southern portion of East Malaysia and the northern section of Peninsular Malaysia, with 5.56 kWh/m^2. Peninsular Malaysia's northeastern and southern areas, as well as the majority of Sabah, receive the least sun radiation. However, the minimum value increased slightly from 3.375 kWh/m^2 to 4.21 kWh/m^2 between 1992 and 2006 [5], [6].

4. Results and Discussion

4.1 Load analysis

The case study was conducted in a domestic apartment located at 25A, Jalan Cempaka 1 in the Parit Raja district. Table 1 displays the daily electricity loads.

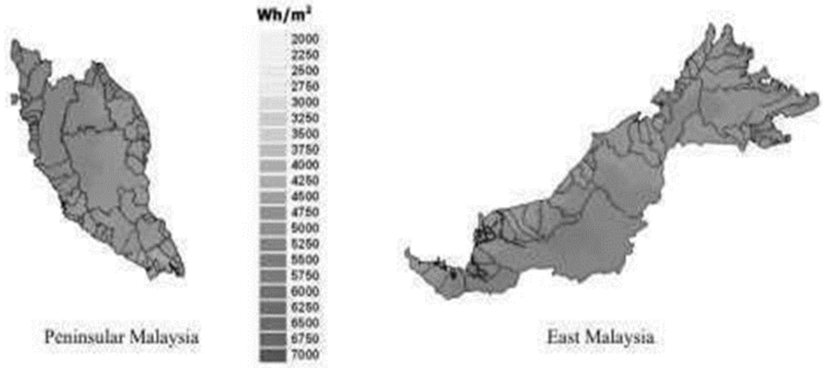


Fig. 5 *Annual average daily solar irradiation of Malaysia* [5].

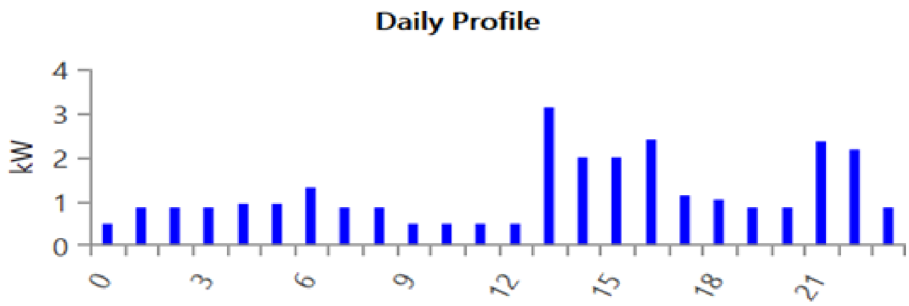
Table.1 *Electrical appliance used for the flat*

Appliance	Quantity	Power rating (W)	Total watt	Operation (hours/day)	Energy demand kWh
Fluorescent Lamp	5	40	200	6	1.2
Fan	5	75	375	11	4.125
Air Conditioning	2	750	1500	6	9
Washing Machine	1	850	850	1	0.85
Refrigerator	1	500	500	24	12
Blender	1	300	300	0.5	0.15
TV	1	150	150	5	0.75
Electric Kettle	1	850	850	1	0.85
Total Watt			4725		
Actual daily consumption of the residential (KWh)					28.925

The energy consumption of each item in use was computed using Equation 1. The outcome is used to compute the overall daily energy consumption.

$$E = Q\ x\ PR\ x\ t \quad (1)$$

The daily load curve for the flat is shown graphically and hourly in Fig. 6. Peak power demand is shown by the peak of the curve, which is around 3 kW more than baseline. This graph provides a visual depiction of the daily fluctuations in power use as well as the peak power consumption for the day. The image shows a graph with the x-axis representing time and the y-axis representing power usage in watts. The line on the graph shows that power usage is low in the morning, starts to increase around 9:00 AM, reaches a peak around 1:00 PM, and then starts to decrease again. In this flat use more appliance during the daytime such as Air-conditioning, fans, and washing machine, this can also contribute to the increase in power usage between 9:00 AM and 1:00 PM.



Evolution in Electrical and Electronic Engineering Vol. 5 No. 1 (2024) p. 149-156

Fig. 6 *Daily load profile of the flat*

4.2 Battery sizing

An independent photovoltaic system's battery is an essential part of the system. In this kind of system, the battery is necessary because the PV arrays' output is inconsistent. Because of this, during the hours of sunshine, the PV system feeds the load directly and stores any excess electrical energy in the battery. When there is minimal sun radiation or at night, the load draws energy from the battery [7]. The only time the system could run without a battery was in bright light. Every time a cloud passed, the power would cut off, which was annoying. Eighty percent of the charge is discharged by the load, yet the solar battery continues to supply electricity. Depending on the particular requirements of the system, the batteries, which are the system's base, are available in a variety of voltages and amp-hour ratings [8]. The Battery calculation results are tabulated in Table 2.

Table 2 *Battery calculation results*

Characteristics	Result
System voltage (V)	12V
Nominal voltage (V)	12V
Capacity (Ah)	100Ah
Required battery bank capacity (Ah)	2591.8Ah
Rated battery bank capacity (Ah)	4049.68Ah
No. of batteries in parallel	9
No. of batteries in series	1
Total batteries	9

Several criteria must be fulfilled to optimize the building of the chosen battery for the study. Please note that these ratings are not meant to accurately represent the operating efficiency of batteries, but rather to facilitate comparisons between different batteries. Consideration of previous charge and discharge cycles and current weather conditions goes into the engineering of the chosen batteries to ensure they supply enough power for usage throughout the night. The longevity of a battery is affected by factors such as age and temperature, which must be understood. In addition, the device can't function without a 12-volt power supply.

The capacity of storage batteries is typically determined by the manufacturer using a 20-hour rating. This situation maintains a constant capacity of 100 ampere-hours (Ah). Table 3 displays the battery specifications data. The chosen battery will store the energy generated by a 43-panel solar system and maintain the 12V, 100 Ah system level of charge. To determine the required quantity of batteries, it is customary to round any fractional results to the closest whole number. Nine batteries in all are needed for this configuration, which is the system's absolute minimum. On the other hand, since battery connections affect the system's Capacity for energy storage, understanding battery connections is essential. By connecting the batteries in series, the voltage may be increased while the amperage remains unchanged.

Table 3 *Battery specifications*

Technology	EnerSys Power Safe SBS 480
Nominal Voltage	12v
Nominal Capacity	6.64kWh
Design life	15years
Max. charging current	480A

Depth of Discharge	80%

5. Conclusion

In conclusion, the design and economic evaluation of a solar home system for a flat represents a comprehensive exploration into the feasibility and viability of implementing solar energy solutions in residential settings. Through the examination of design considerations and a thorough economic assessment, this study aims to provide insights into the practicality of adopting solar technology for homes, emphasizing both the environmental benefits and economic considerations. The outcome of this research has the potential to inform decision-makers, homeowners, and policymakers on the effectiveness of solar home systems in promoting sustainability and reducing energy costs in residential flats. According to the elements used in this analysis, Parit Raja gets 22,159 kWh on an average year, with a maximum production of 5.43 kWh per hour of electricity. This work includes a 4.7- kilowatt inverter, 12-volt 100 amp-hour batteries, and a 16.1-kilowatt photovoltaic (PV) system. This work costs a total of RM26,074.53. Per kilowatt-hour (kWh), the levelized cost of energy (COE) is RM0.191. To put this into perspective, a kilowatt- hour of grid power costs RM0.218. In 6 years, the original investment should start to pay off. This study provides detailed suggestions for PV array size, solar charge controller, backup battery, inverter, and wire connection, taking daily consumption and load needs into account. These results provide a solid platform for developing and putting into practice solar photovoltaic systems, raising awareness of the installations' positive effects on the environment and the economy.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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