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Solar Photovoltaic Systems: A Technical and Economic Feasibility Design Approach with Homer Pro

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ABSTRACT

With the declining cost of solar photovoltaic (PV) modules and batteries used for energy storage, many users are now shifting towards solar energy because of its renewable nature and availability. Though this is a great step to combat climate change, most of the solar systems installed always fail due to poor system sizing. For this reason, optimal systems are required to be deployed. This paper presents a technical and economic feasibility design approach for a solar PV system using Hybrid Optimization of Multiple Energy Resources (HOMER) Pro software. The design is based on site-specific data collected from Moi University in Kenya. The temperature and solar radiation data were collected from the weather station of the university, while the power demand data was collected from the Margaret Thatcher Library of the university using the PCE-360 power analyzer. The simulation results show that a 100kW solar PV system is required to power the Margaret Thatcher library with a financial investment of KES 32,000,000. This system is strongly recommended to be used by the university as it will ensure reliability of power supply for students to study and also save on costs incurred on utility bills.

Key Words: Battery, Hybrid Optimization of Multiple Energy Resources, Renewable energy, Solar PV, Solar photovoltaic.

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1. INTRODUCTION

As the quest for clean and decentralized energy alternatives grows, solar/battery systems have been a leader in recent years. A wide range of customers, from individual households to large-scale commercial companies, are finding these systems increasingly affordable and appealing because of the declining cost of solar panels and developments in battery technology [1]. Batteries store excess energy for use during times of poor or no solar radiation [2], while solar panels harvest solar energy and transform it into electricity. This integration improves energy independence, self-sufficiency, and cost savings in addition to making the switch to cleaner energy sources easier [3, 4].

Solar/battery systems are promising, but deploying and using them effectively requires a multifaceted strategy. In order to make sure the system runs as efficiently as possible, technical concerns include load matching, energy management, performance analysis, and system sizing [5]. In terms of the economy, risk assessment, incentive maximization, and financial projections are crucial for making well-informed decisions about solar and battery system investments. But because these assessments are intricate and multidimensional, they frequently call for sophisticated modelling methods in order to produce precise forecasts and enhance system design [6]. This is the setting in which software modeling shows up as a crucial tool for well-informed decision-making. Sophisticated modeling methods make it easier to size components precisely, anticipate energy generation under a range of situations, and project long-term financial benefits. Software modeling plays two key roles in the analysis and optimization of solar/battery systems: it directs the technical design phase, guaranteeing that system components are well-matched and work together harmoniously, and it offers insights into the financial feasibility and return on investment.

This paper is divided into six sections. The current section 1 is the introductory section which highlight the generalities and importance of using solar energy and good design tools. Section 2 is the literature review which looks into some related works in this area. Section 3 gives the goal and objectives while section 4 details the methodology adopted for this research. Section 5 is the result section while section six concludes the paper.

2. LITERATURE REVIEW

Different approaches have been used for PV system design. This ranges from solar home systems [7] to hybrid systems [8–20]. These designs are done using different software modelling tools [21]. Aziz et al. [22,23] in order to power a remote rural town in Iraq, they investigated the technological, financial, and environmental viability of using a PV-diesel-battery hybrid energy system. Using a multi-input module, they evaluated the optimization and the sensitivity analysis using HOMER software. Khavari et al. assessed the viability of a hybrid renewable energy systems for the electrification of remote area in Binalood, Iran. They used HOMER to assess the techno-economic benefits of using the system and their results show that the wind-diesel-battery storage hybrid system was the most efficient [24]. Rice et al. [1] used HOMER to evaluate the viability of a hybrid PV/diesel energy system in DR Congo and suggested that the system is advantageous for the community due to its reduced cost of operation.

3. AIM AND OBJECTIVES

The aim of this paper is to design a solar PV/Battery system with objective to determine its technical and economic viability using sight specific data for the Margaret Thatcher Library in Moi University.

4. MATERIALS AND METHODS

4.1 Study Site

Moi University is an institution of higher learning in Kenya. Its main campus is located between Latitude 0.286694^{o}N and Longitude 35.294028^{o}E in Eldoret. Figure 1 below is a google earth view of the campus. The main source of power supply for the University comes from the grid. Because of this, the University spends huge sums of money for utility bills monthly. In this study, the Margaret Thatcher Library is used for the power consumption data collection which is used for the design of an optimal PV system to supply the building.

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Figure 1: View of Moi University Main Campus (Source: Google Earth)

4.2 Data collection

Figure 2 below shows the proposed block diagram used for the data collection and analysis.

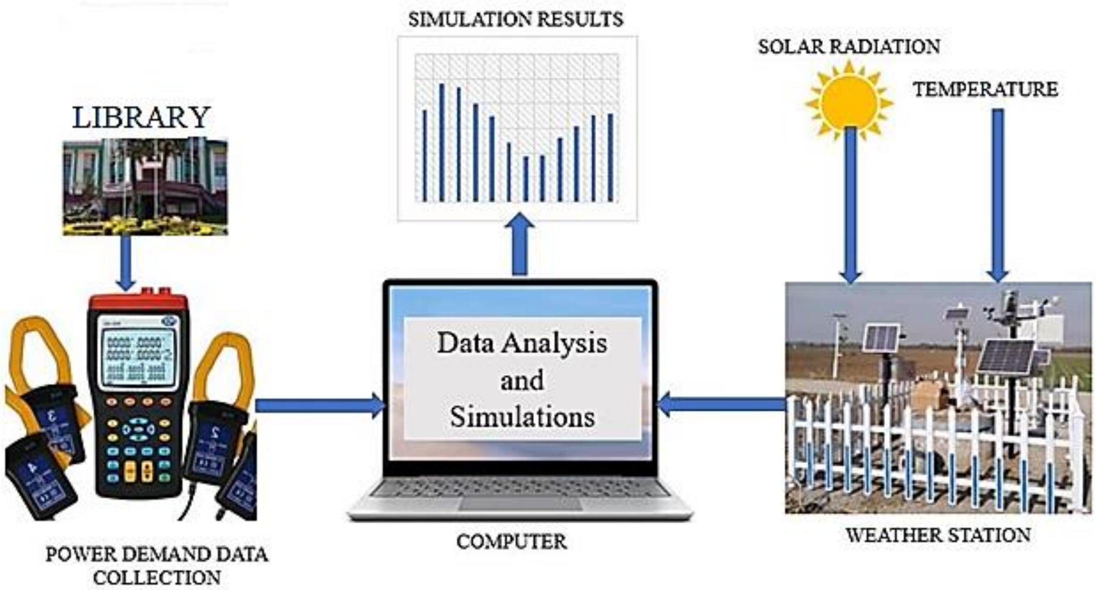

Figure 2: Block diagram

The power consumption data for the Margaret Thatcher Library for a period of one month was logged using the PCE-360 Power Analyser. Also, to accompany this, data from an inventory on power consumption for the library was used. The logging was done for an interval of 5 seconds to ensure that detailed information about the power usage was obtained. The temperature and solar radiation data for a period of 4 years was collected from the meteorological weather station of the University.

With the load demand, temperature, solar radiation, and component specification data, the solar PV/battery system was then designed and simulated using the HOMER Pro software as shown in Figure 3. The SunPower E20-327

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monocrystalline solar module with a peak power of 327W, the lead acid trojan SAGM 12 205 battery with capacity 219 Ah, and the 120kW MTP-4110F 3 phase hybrid inverter were chosen for the simulation.

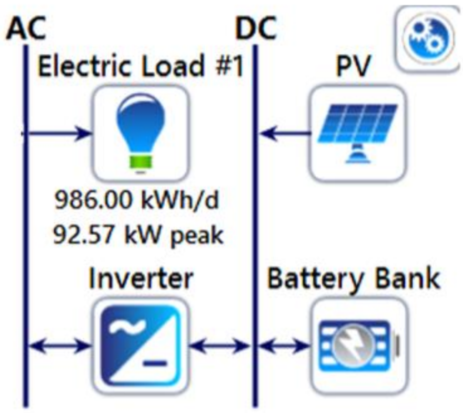

Figure 3: System Design with HOMER Pro

5 RESULTS AND DISCUSSION

5.1 *Measured Solar Radiation and Clearness Index*

Figure 4 displays the average monthly solar radiation measured on the horizontal surface at Moi University's main campus in Eldoret. At this site, the average yearly solar radiation is 4.93 kWh/m^2/day, approximately 5 hours of sunshine per day. The maximum solar radiation of 5.7 kWh/m^2/day occurred in the month of February, while the lowest solar radiation of 4.03 kWh/m^2/day occurred in the month of July. This is a useful capacity for the production of solar PV energy. On the other hand, the clearness index quantifies the degree of brightness or cloudiness in the sky. It ranges from zero to one, where zero denotes an entirely cloudy sky and one denotes a day that is absolutely sunny. It should be mentioned that using site-specific data is usually beneficial when discussing solar PV projects.

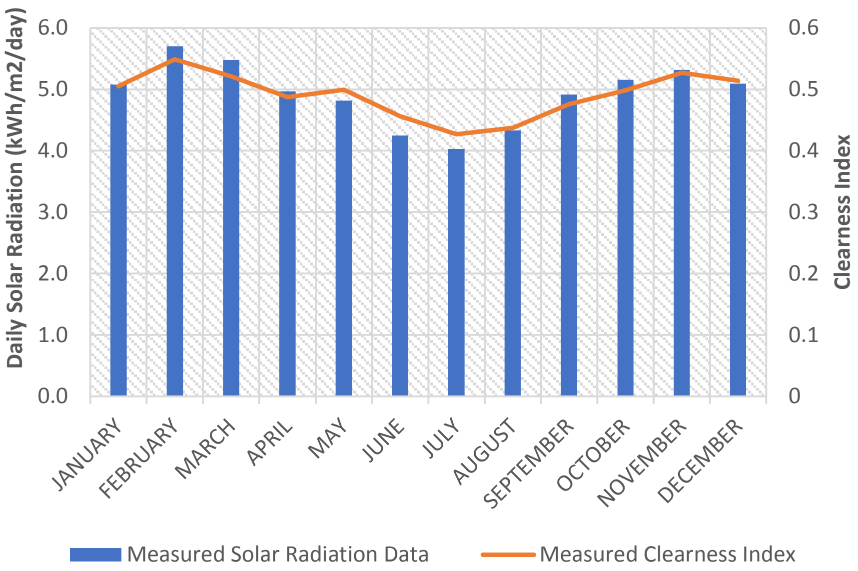

Figure 4: Measured Solar Radiation and Clearness Index

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5.2 Measured Temperature

The average monthly temperatures from the site collected data were analysed and the results showed that the hottest month is February with an average monthly temperature of 18^{o}C while the coldest month is July with an average monthly temperature of 15^{o}C as shown in Figure 5. This means that solar panels installed within this site will perform much better as external cooling systems will not be needed for cooling of the solar panels. Cooling of solar panels is often needed because temperature has an effect on the output power of solar modules. For the solar panel that was selected for the simulations, the operating temperature is 45^{o}C and the power temperature coefficient is -0.38 %/^{o}C. This power temperature coefficient is calculated based on the industry standard test conditions used to characterize solar panels which is 25^{o}C. For every degree rise in temperature above 25^{o}C, the solar panels output will drop by that specified power temperature value. In this work, because the temperature collected on site showed that the temperatures will barely go above 25^{o}C, the simulations were done using the industry standard value.

Furthermore, the temperature collected on site was compared with the National Aeronautics and Space Administration (NASA) data. The results showed a slight variation of about 3^{o}C. This is because the temperature found on the NASA database for a particular location covers a broader area. This is why it is always important to collect site specific data when designing solar PV systems.

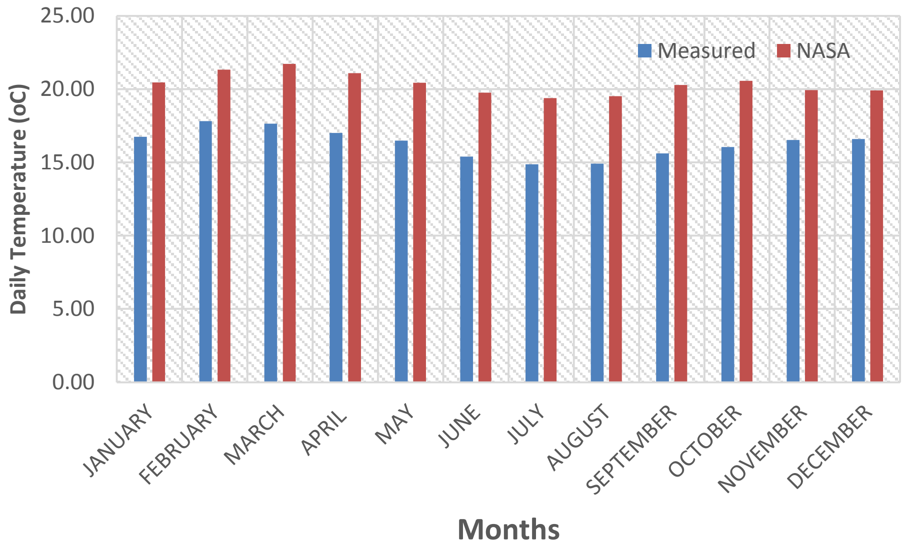

Figure 5: Temperature profile for the study site

5.3 Load Profile for the building

The results depicted on Figure 6 shows that the power consumption in the library is higher than that of the Administration block on weekdays and on weekends.

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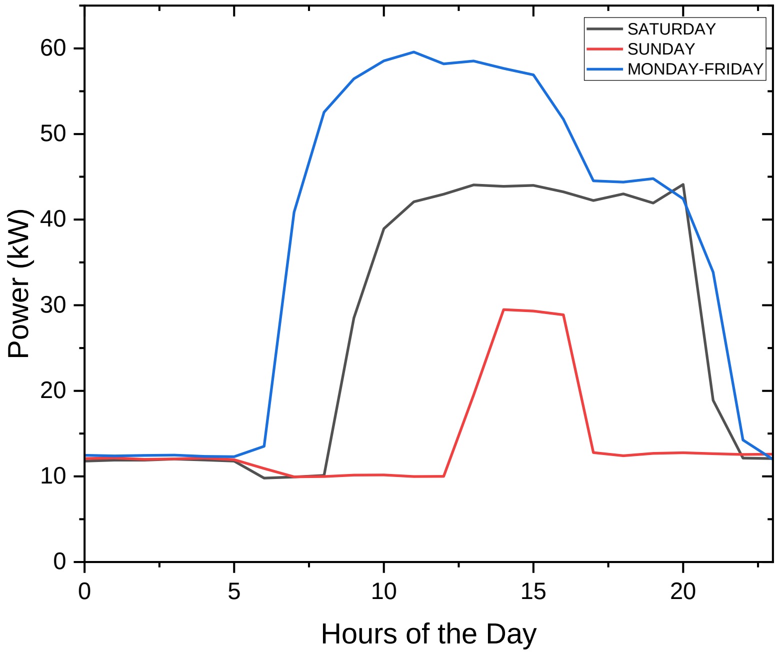

Figure 6: Load Demand Profile for Library

A combination of factors relating to working hours and user activity can be blamed for the excessive power consumption that was found in the library on weekdays from 7 am to 9 pm. This is the time when the library usually welcomes visitors. As a result, the library is open from 7 am to 9 pm, during which time lighting, computers, and other electrical devices are used to serve users and support their activities. Users, such as students, researchers, and staff members, are most active during this time period. They use lighting, plug-in electronic gadgets, and use computers as they read, study, research, and engage in other academic tasks. The combined effect of these activities results in higher power demand.

Furthermore, the annual load variation from the HOMER Pro simulation is shown in Figure 7. From the results, it shows that throughout the year, high power demand occurs during the day.

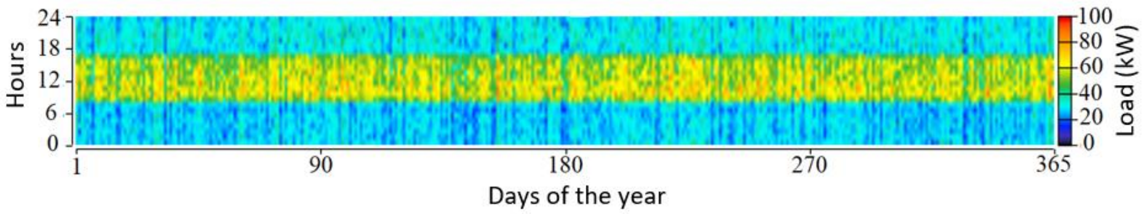

Figure 7: Yearly load profile for the Margaret Thatcher Library

Figure 8 shows the charging spectrum for the batteries. From the figure, it shows that the batteries will always be charged throughout the year which means energy will always be available for use during hours of no sunlight.

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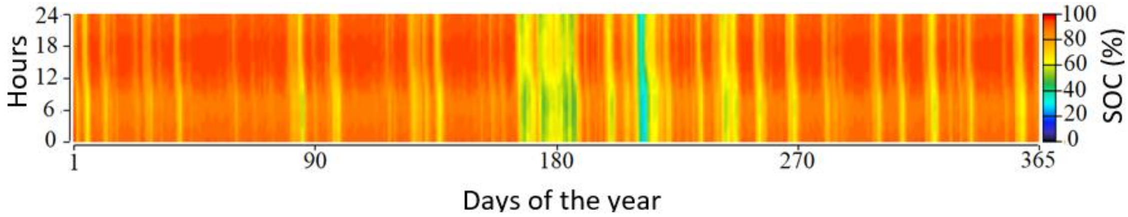

Figure 8: Battery State of Charge for the Margaret Thatcher Library

Table 1 below gives a technical summary for the simulated solar PV/battery system.

Table 1: Technical summary of the solar PV/Battery system

SN	Parameter	Margaret Thatcher Library PV System
1	Annual energy consumption	395,263 kWh
2	Average monthly energy consumption	32,938 kWh
3	Average daily energy consumption	1,098 kWh
4	Scaled Average daily peak demand	93 kW
5	System size	100 kW
6	Power per PV module	450 W
7	Number of PV modules	222
8	Battery capacity	4,575 Ah

From the HOMER Pro simulations, the annual energy consumption for the Margaret Thatcher Library was 395,263 kW. The average monthly energy consumption was 32,938 kWh while the average daily energy consumption was 1,098 kWh.

In Table 2, the cost for installing and running the Solar PV/battery system is presented. This gives a total net present cost of 32,000,000 Ksh and a total replacement cost of 20,000,000 Ksh. The replacement cost is less than the net present cost because the life time of the system was 25 years which coincides with the life time of the solar PV modules. This means much replacement will be done for the batteries as they have a relatively short life span. This means that the amount spent on installing the PV system can be recovered in 6 years using the simple Pay Back Period (PBP). Therefore, the system is economically beneficial for the University and it is strongly recommended to be implemented to save on annual utility bills.

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Table 2: Economic summary of the solar PV/Battery systems

SN	Parameter	Margaret Thatcher Library PV System
1	Net Present Cost	32,000,000 Ksh
3	Replacement cost	20,000,000 Ksh
3	Annual cost of energy from Utility bills	8,815,980 Ksh
4	Pay Back Period	6 years

6 CONCLUSION

In light of the growing urgency to combat climate change and reduce our dependence on non-renewable energy sources, the move towards solar energy is a commendable step. However, the paper has highlighted a critical issue, which is the failure of many solar systems due to inadequate system sizing. It is a challenge that demands attention and innovative solutions. To address this challenge, a technical and economic feasibility design approach for a solar PV system is introduced which makes use of the HOMER Pro software. This approach represents a significant advancement in the field, enabling accurate and customized system design based on site-specific data. The research focuses on Moi University in Kenya and leverages temperature and solar radiation data collected from the university's weather station, as well as power demand data obtained from the Margaret Thatcher library using the PCE-360 power analyzer. The simulation results provide a clear and compelling insight into the requirements for the solar PV system. The recommendation for a 100kW solar PV system to power the Margaret Thatcher library at a financial investment of KES 32,000,000 is not merely a numerical output; it signifies a comprehensive solution to the university's energy needs for the library. This optimal system size is not only technically sound but economically justified, promising substantial cost savings over time. The significance of this work extends beyond Moi University or the context of Kenya. It underscores the importance of data-driven, site-specific system design in ensuring the success of solar installations worldwide. In a time when sustainability and energy efficiency are paramount, the approach presented in this paper serves as a model for addressing the issue of poor system sizing and, by extension, the challenges of climate change and rising energy costs. The recommended solar PV system represents more than just a technological solution; it embodies a commitment to reliability, sustainability, and cost-effectiveness. By ensuring a steady power supply to the Margaret Thatcher library, it contributes to the educational and research pursuits of the university. Simultaneously, it reduces the financial burden of utility bills, thus freeing up resources for other critical academic and institutional needs. Finally, the paper offers a compelling case for the adoption of optimal solar PV systems, backed by robust data and advanced software modelling tools. It is a testament to the transformative power of solar energy when harnessed efficiently and thoughtfully. It is a beacon of hope in the broader global effort to create a sustainable and environmentally responsible future.

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