



ORIGINAL RESEARCH ARTICLE

MODELING AND SIMULATION OF A SOLAR FARM USING HOMER PRO SOFTWARE FOR UNIVERSITY OF MAIDUGURI SENATE COMPLEX

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ABSTRACT

The current state of energy insecurity in Maiduguri calls for immediate action to explore and implement alternative energy sources, especially off-grid sources such as solar power, wind power etc. which could provide reliable, cost-effective, and sustainable energy solutions to the town and neighbourhoods. The University of Maiduguri is not an exception, equally faced with electricity disruptions that almost ground down the academic and administrative activities. This study aims at modeling and simulation of a solar farm using HOMER PRO software for University of Maiduguri senate complex to enhance power supply. It involves conducting an energy audit to determine the complex's electrical energy consumption, Prediction of future energy demand using HOMER PRO software, designing a solar farm model based on the energy audit and the predicted energy demand of the Senate Complex using same software. Data collected were analysed and optimised for system sizing. Based on the optimization results, model 1682 Canadian Solar Max Power CS6U-340M, 340 W per panels, 144 lead acid generic batteries rated at 1KW each (totalling 4603Ah) and 2 inverters with a combined capacity of 318kW were designed, which met the annual load demand of the complex (1.03 GWh). This study, if implemented will address the power challenges faced by the Senate complex building, thereby reducing the administrative and academic bottle neck faced by the University.

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1.0 Introduction

Electricity supply in Maiduguri, the capital of Borno State, Nigeria, has been severely hindered due vandalization because of security challenges, inadequate infrastructure and with recent high cost of electricity bills, many areas were in darkness (Edomah et al., 2021). These disruptions have caused significant interruptions in socio-economic activities, administrative and academic in higher institutions of learning across the state. Thus, the need to look for more alternative energy, most especially upgrade for better, sustainable and uninterrupted supply. Solar power in particular, presents a promising solution for regions like Maiduguri, which experience high levels of solar radiation. Solar energy technologies, such as Photovoltaic (PV) systems that directly convert sunlight into electricity, and Concentrated Solar Power (CSP) systems, offers significant potential to meet the region's energy needs (Lewis et al., 2010). Despite their advantages, solar power systems face challenges, such as intermittency, energy storage, and system integration, which must be addressed to ensure reliability (Nguyen et al., 2022). Optimization tools, such as the Hybrid Optimization Model have been instrumental in overcoming these challenges by simulating various renewable energy configurations and enabling effective system design (NREL, 2008). In Nigeria, the privatization of the power sector in 2013 left many areas, particularly Maiduguri, with an unreliable electricity supply, as the privatized grid infrastructure remains inadequate and vulnerable (NERC, 2015). This instability directly impacts critical institutions, such as the University of Maiduguri, where facilities like the Senate Complex regularly experience power shortages that disrupt academic and administrative functions. This calls for immediate action to explore and implement alternative energy sources, such as solar power which could provide reliable, cost-effective, and sustainable energy solutions for these institutions. This study aims to design and model a solar farm to meet the energy of the Senate Complex at the University of Maiduguri using HOMER Pro software with the objective of optimizing the system for energy reliability, sustainability, and cost-effectiveness. The research will begin with

an energy audit of the Senate Complex to assess its current and future energy requirements, and then design and optimized the solar farm that can meet these energy demands of the senate complex efficiently using HOMER Pro software. The significance of this study lies in its potential to address the pressing energy challenges at the University of Maiduguri Senate Complex, ensuring the continuity of academic and administrative functions, and reducing dependence on an unreliable grid system. By utilizing HOMER Pro software or system optimization, this research will demonstrate the potential of solar energy to offer a sustainable, cost-effective, and reliable solution to the power supply challenges faced by institutions in Borno state. Furthermore, the findings from this study could serve as a model for other institutions and regions in northeastern Nigeria that face similar electricity access challenges.

Recent studies have emphasized the increasing importance of solar energy and the need for efficient system design in off-grid and rural areas. Akinwale *et al.* (2022) explored the economic viability of solar energy systems in Nigerian universities, demonstrating that solar power could offer long-term cost savings while reducing dependence on the grid. Oladele *et al.* (2023) focus on optimizing hybrid renewable energy systems for off-grid rural communities in Nigeria, underscoring the importance of system integration and energy management. Olatunji & Akpa, (2023) highlighted the vast solar energy potential in northern Nigeria and the importance of harnessing this resource using appropriate technological solutions. Similarly, Olayanju *et al.*, (2022) explored the feasibility of solar power for universities in Nigeria, revealing that integrating renewable energy could improve energy security while minimizing operational costs. Other studies, including that by Ibitoye & Olanrewaju (2024) emphasize the role of simulation and optimization tools like HOMER Pro in designing efficient and reliable renewable energy systems. Udeh *et al.* (2022) also explores the potential of solar energy in addressing Nigeria's power crisis, with a focus on the integration of renewable energy technologies in educational institutions. Their findings underscore the importance of system design and energy optimization for the successful adoption of solar power in universities. Additionally, the work of Ibrahim & Shehu (2023) in evaluating the impact of solar PV systems on energy consumption and sustainability in Nigerian universities provides a key insight into how these technologies can be adopted to reduce grid dependency. In a similar vein, Adeyemi (2023) provide a thorough analysis of the policy landscape for renewable energy in Nigeria, suggesting that solar power adoption can be supported by aligning with national and regional energy policies aimed at promoting sustainability. These works collectively reinforce the relevance and timeliness of this research, as they demonstrate how solar energy, when properly optimized, can provide reliable power solutions for institutions and regions with unreliable electricity access.

2. Method

2.1 Description of the Case Study

Maiduguri lies at 11°50'N latitude and 13°09'E longitude and experiences average daily solar radiation of 5.5 kWh/m². The Senate Complex includes a two-story Senate Building and a large Senate Chamber. The building accommodates 56 administrative offices, air conditioning units, lighting fixtures, and computer systems. The Senate Chamber seats 350 and uses audio systems, fans, and display equipment.

2.2 Energy audit

Energy audit of Senate Complex University of Maiduguri is conducted according to the procedure in Figure 1. The data obtained from energy audit is used to project the future energy demand of the University of Maiduguri Senate Complex.

2.3 Data Collection and Analysis

2.3.1 Design Analysis

Hybrid Optimization Model for Electric Renewable (HOMER) tool developed by National Renewable Energy Laboratory (NREL) in USA is used to carry out this analysis. This software application is used to design and evaluate technically and financially the options for off-grid and on-grid power systems for remote, stand-alone and distributed generation applications. The software is a complete weather data base mainly used in modeling various energy systems and processes. The information to be inputted into the HOMER software is the electric load data, solar radiation, and temperature.

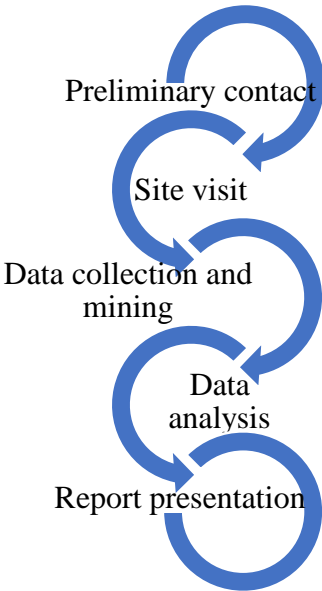


Figure 1: Energy audit procedure

2.3.2 Load Assessment

The load assessment was determined based on the energy audit conducted. The average yearly, daily and hourly energy consumption was determined from the audit conducted and used for the design accordingly.

Table 1: A load in the Senate Complex

Items	Power Ratings	Quantity	Total
Air Conditioners	2.5HP	9	79
	2HP	49	
	1.5HP	15	
	1HP	6	
Refrigerators	2HP	10	31
	1HP	21	
TV sets	56 Watts	19	23
	60 Watts	4	
Standing Fans	56 Watts	13	13
Elevators	6491.9 Watts	2	2
Computers	LCD Monitor 29.8 W	53	106
	CPU 56 W	53	
Printers	Laser Jet 805 W	13	18
	Desk Jet 575 W	5	
Photocopiers	1400 W	7	7
Pumping Machines	2HP	1	4
	1HP	3	
Lighting	Incandescent 100 W	16	317
	CFL 18 W	301	

2.3.3 Solar radiation Data of the Study Area

The solar radiation data for the study area, Maiduguri, is sourced from the Nigerian Meteorological Agency (NiMet). Maiduguri, at latitude 11°N, experiences high solar radiation, with an average global horizontal irradiance (GHI) of 5.5 kWh/m²/day.

Solar Radiation Calculations

Solar radiation values were determined using standard solar geometry relations. The declination angle (δ) is obtained from:

$$\delta = 23.45^{\circ} \times \sin\left(\frac{360}{365} (284 + n)\right)$$

I

Where n is the day of the year.

The hour angle (ω) is given by:

$$\omega = 15^\circ (t_{\text{solar}} - 12)$$

2

Where t_{solar} is the solar time in hours. At solar noon, $\omega = 0^\circ$

The solar zenith angle (θ_z) is calculated as:

$$\cos \theta_z = \sin \phi \sin \delta + \cos \phi \cos \omega$$

3

Where ϕ is the site latitude

For example, on July 15, 2025 ($n = 196$), the declination angle was 21.74° . At solar noon ($\omega = 0^\circ$) and latitude 11.85° N (Maiduguri), the zenith angle was computed as 10.23° . These calculations informed optimal PV panel positioning for the simulation

Tilt Angle (θ) Determination

Based on geographic latitude and seasonal variation, a tilt angle of 12° was selected for optimal solar energy capture. This was applied in the HOMER Pro model to simulate real-world orientation of the solar panels at the installation site.

Solar Radiation Potential

The solar energy potential for Maiduguri, as shown in Figure 2, reflects the typical radiation levels throughout the year, with a strong peak during the dry season months. This analysis of solar radiation data provides a foundation for understanding the available solar energy at the site, which is crucial for the design and optimization of solar energy systems.

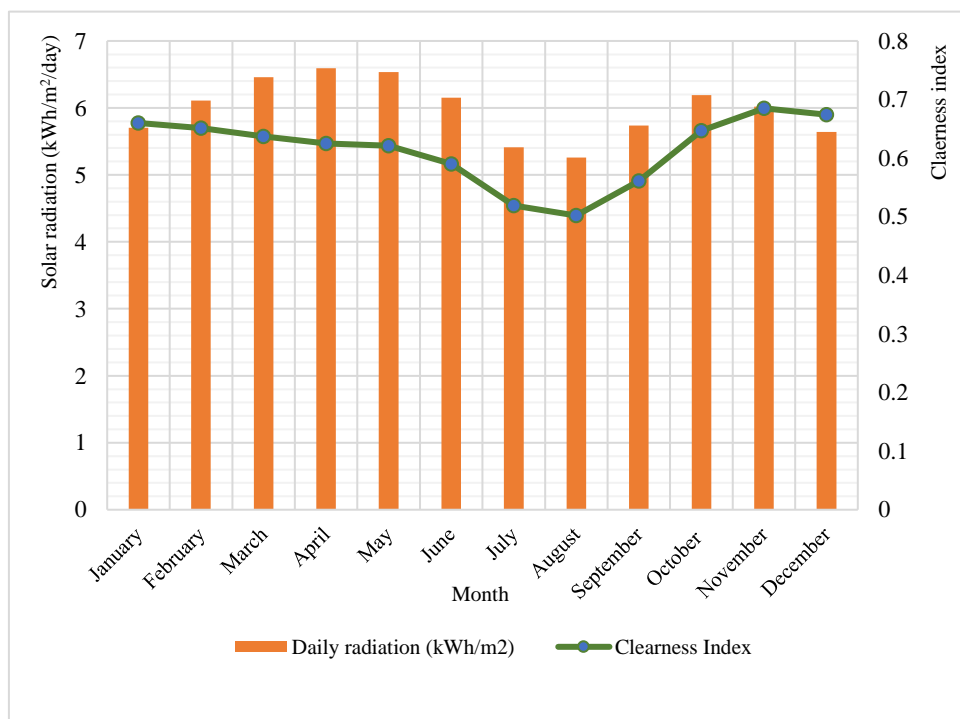


Figure 2: Monthly solar radiation profile for Maiduguri, Nigeria

2.4 Physical Modeling Using HOMER PRO Software

2.4.1 Solar PV System

The model selected from HOMER PRO library was Canadian Solar max power CS6U-340M 340W monocrystalline PV module manufactured by Canadian Solar max power CS6U-340M 340W with 17.49% efficiency and 0.34kw rated capacity. The power output of the PV System is given in Equation (4) (Lambert, 2006).

$$V_{PV} = F_{PV} \times Y_{PV} \times \frac{I_T}{I_s}$$

Where, F_{PV} – Derating factor, Y_{PV} the rated capacity of the PV array (kW), I_T the global solar radiation (beam plus diffuse) incident on the surface of the PV array (kW/m²), and I_s is 1 kW/m², which is the standard amount of radiation used to rate the capacity of the PV array. The efficiency of solar PV system considers all losses in a solar PV panel due to temperature variation, shadow on panel, dirt, and inverter losses. The photovoltaic derating factor F_{PV} is a factor that HOMER tool applies to the PV array power output to account for reduced output in real-world operating conditions.

2.4.2 Battery Storage Sizing and Modeling

The battery bank consists of individual batteries, each capable of storing a specific amount of DC electricity with fixed round-trip energy efficiency, as depicted in HOMER. These batteries have constraints on charging/discharging rates, depth of discharge, and total energy throughput before replacement. HOMER assumes constant battery characteristics over its lifespan, unaffected by factors like temperature. Key attributes include nominal voltage, capacity curve, lifetime curve, minimum state of charge, and round-trip efficiency. Given solar power's intermittent nature, energy storage is vital to meet demand, particularly during nights and cloudy days. Battery selection considers factors like cost, availability, size, mobility, and system compatibility. HOMER calculates battery bank lifespan using Equation 5 (Lambert, 2006) after assessing suitable battery options.

$$R_{batt} = \min\left(\frac{N_{batt} \times Q_{lifetime}}{Q_{thrpt}}, R_{batt, f}\right) \quad 5$$

Where N_{batt} is the number of batteries in the battery bank, $Q_{lifetime}$ the lifetime throughput of a single battery, Q_{thrpt} the annual throughput (the total amount of energy that cycles through the battery bank in one year), and $R_{batt, f}$ the float life of the battery (the maximum life regardless of throughput). The model of the battery selected from HOMER library was idealized battery model (Lead-Acid generic batteries). It has a nominal voltage (V) of 380, nominal capacity (kWh) of 210, nominal capacity (Ah) of 553, efficiency (%) of 88%, maximum charge current (A) of 131 and maximum discharge current of 131.

2.4.3 Converter

The Converter chosen from the HOMER library, was a system converter with a capacity of 0.34 kW and an efficiency of 90%. It's intended to supply the maximum AC load in the Complex. The power rating for the inverter, denoted as P_{inv} , was determined using Equation (6), where P_{ACload} represents the total power from AC load demand, and an oversized factor of 1.25 was applied (Nordin & Rahman, 2016).

$$P_{inv} = P_{ACload} \times 1.25 \quad 6$$

3. Results and Discussion

3.1 Energy Audit Analysis

The energy audit reveals that cooling systems (73 air conditioners) account for 57% of the total daily demand, equating to approximately 901 kWh. Refrigerators contribute 16%, while elevators account for 7%. Printers consume 7%, photocopiers 5%, lighting 3%, computers and pumping machines 2% each, TV sets 1%, and standing fans less than 1% of the total energy supplied. This data guided system sizing to prioritize uninterrupted cooling and essential operations.

The audit results shed light on the vulnerability of University of Maiduguri Senate Complex to intermittent power supply issues. High energy consumption coupled with substantial losses exacerbates the impact of power outages on the institution's operations. The intermittency of power supply can disrupt academic activities, compromise research projects, and hinder administrative functions, underscoring the urgent need for robust energy management strategies. In light of the audit results, the imperative for sustainable energy solutions becomes evident.

Table 2: Load requirement of the complex

Items	Power Ratings (W)	Quantity	Power (kW)	Daily Usage (Hours)	Daily Load (kWh/day)
Air Conditioners	1890	9	112.64	8	901.12
	1512	49			
	1134	15			
	756	6			
Refrigerators	1512	10	32.06	7	224.42
	756	21			
TV sets	56	19	1.30	10	13.00
	60	4			
Standing Fans	56	13	0.73	10	7.30
Elevators	64919	2	12.98	12	51.92
Computers	29.8	53	4.55	9	9.10
(Monitor)					
Computers (CPU)	56	53			
Printers (LaserJet)	805	12	13.34	7	93.38
Printers (DeskJet)	575	5			
Photocopiers	1400	9	9.80	5	49.00
Pumping Machines	1512	1	3.78	4	15.12
	756	3			
Lighting	100	16	7.20	12	84.24
(Incandescent)					
Lighting (CFL)	18	301			
TOTAL	—	—	198.20	—	1448.60

3.2 System Sizing and Optimization

3.2.1 Physical Modeling and Optimization Using HOMER PRO

The process of determining the optimal system size was conducted using HOMER Pro. Figure 2 illustrates the solar irradiance data utilized in this study. The analysis involved an extensive examination of various configurations, considering diverse combinations of PV panels and battery banks. The final system selection took into account factors such as excess electricity generation and overall system efficiency. Consequently, multiple combinations with varying numbers of PV panels and battery banks were simulated in HOMER. Ultimately, the selected system was identified based on its surplus electricity generation and system efficiency.

Based on the optimized results, a configuration comprising 1682 Canadian Solar Maxpower CS6U-340M 340W PV panels, 144 Lead-Acid generic batteries rated as 1kW (arranged in 36 strings of 48V with 4 strings in parallel), and a 318kW converter was projected to meet the annual load demand of 1.03 GWh. Figure 3 illustrates the storage state of charge and discharge percentage, ensuring that the depth of discharge never falls below 25%.

**Figure 3:** Battery Bank State of Charge (SoC)

Figure 3 shows the battery performance. The peaks at around 40% and 87% state of charge (SOC) mean the batteries usually operate either at partial charge or near full charge. Between days 180 and 270, the SOC drops more often, which aligns with the rainy season when solar input is lower, and the batteries work harder to meet demand.

Figure 4 presents the inverter and rectifier outputs. The inverter, with a 318-kW capacity, operates year-round but mostly below full load, giving a 19% capacity factor. This confirms it is sized for reliability but often runs at lower outputs. The rectifier output is almost negligible, showing that little energy flows back into the DC bus.

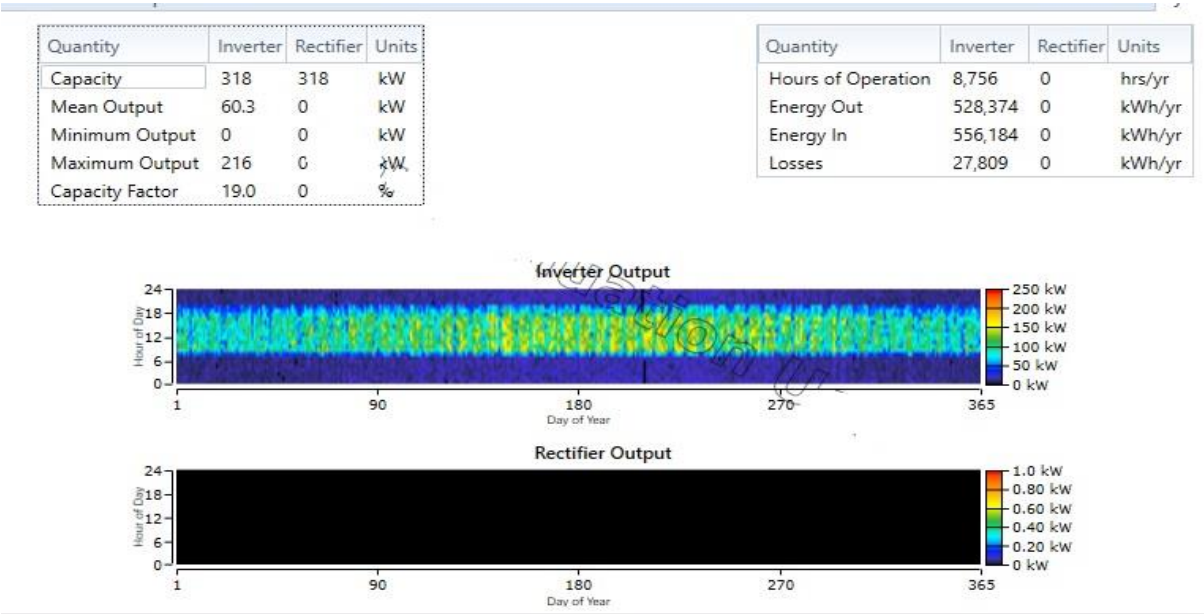


Figure 4: Inverter Output Profile

Figure 5 illustrates PV array performance. The system delivers about 1.03 GWh annually with a 20.5% capacity factor, which is typical for the region. Output declines between day 180 and 270, again reflecting reduced solar radiation in the wet season. The PV system reaches up to 517 kW, close to its rated value, while excess energy at peak times contributes to the high PV penetration.

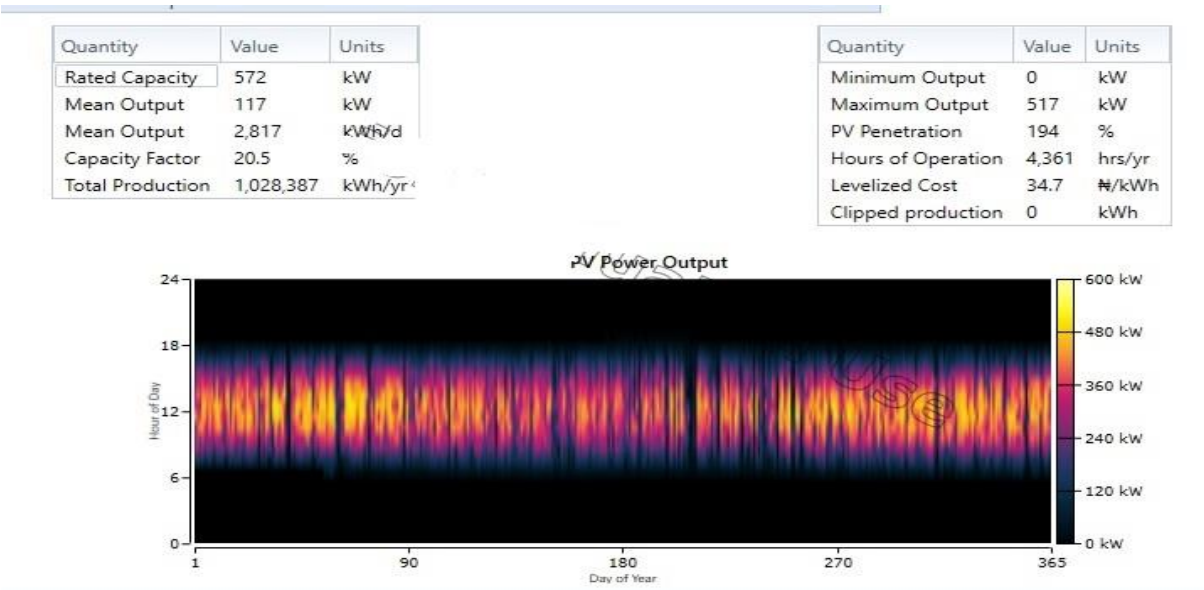


Figure 5: PV Array Output

The choice of Canadian Solar Max power monocrystalline panels for the photovoltaic (PV) system was motivated by their efficiency of 17.49% and monocrystalline nature. The power inverter, sized at 318 kW, was determined based on the peak demand of the AC load, limited to 1.03 GWh/year. Sizing the PV panels considered factors such as load demand, necessary power backup, and available irradiance.

The battery bank operates in a floating state when PV output matches demand, discharging only during periods of insufficient PV output or at night. This strategy optimizes battery usage and ensures continuous power supply when solar generation is inadequate.

The system block diagram is depicted in Figure 6 illustrating the solar panel connected to the DC bus, equipped with a maximum power point tracker (MPPT). The battery bank block, inclusive of a charge controller and under/overvoltage protection, is also connected to the same DC bus. The third block in this figure is the converter, responsible for converting DC to AC, ensuring power quality (harmonics reduction), and linking the DC and AC buses

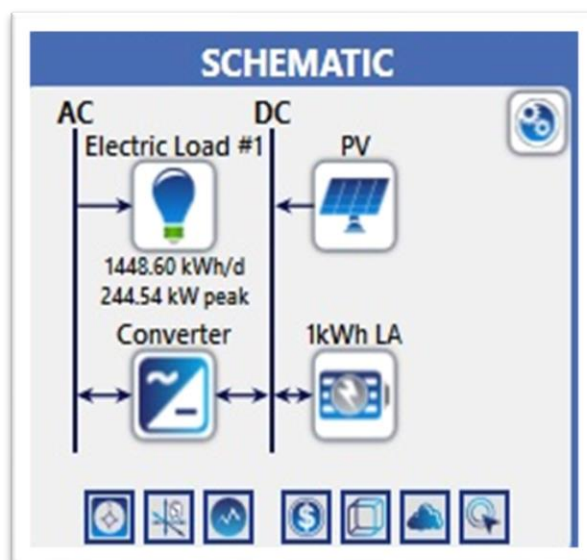


Figure 6: System structure with integrated sub block

4. Conclusion

The study was able to conduct the energy audit of the University of Maiduguri Senate Complex and found out that the building consumed 1448.6kWh and the yearly projected energy consumption of 1.03GWh. The study also employed HOMER PRO software for system sizing and optimization, considering various PV configuration and battery banks. From the results of system sizing and optimization, the chosen system comprises of 1682 Canadian Solar Max Power CS6U-340M-340 W PV panels, 144 lead-acid generic batteries rated at 1 kW each (totaling 4603 Ah), and 2 inverters with a combined capacity of 318 kW, successfully meeting an annual load demand of 1.03 GWh.

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