AKENTEN APPIAH-MENKA UNIVERSITY OF SKILL TRAINING AND ENTREPRENEURIAL DEVELOPMENT

FEASIBILITY STUDY AND ECONOMIC ANALYSIS OF PHOTOVOLTAIC SYSTEMS FOR TECHNICAL AND VOCATIONAL EDUCATION AND TRAINING(TVET) INSTITUTIONS IN THE UPPER EAST REGION OF GHANA. (A CASE STUDY OF BAWKU TECHNICAL INSTITUTE)

BY

AWUNI DAVID

(7201200004)

A thesis submitted to the School of Graduate Studies, Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development in partial fulfillment of the requirements for the award of a Master of Technology degree in Electrical and Electronic Engineering.

JULY 2024

DECLARATION

CANDIDATES DECLARATION

I hereby declare that this project work is the result of my original research and that no part of this has been presented for another degree in the university and elsewhere.

NAME:

Candidates signature…………………………… Date………………………

SUPERVISOR'S DECLARATION

I hereby declare that the presentation of this long essay was supervised in accordance with the guidelines on the supervision of long essays laid down by the Akenten Appiah-Menka University of Skill Training and Entrepreneurial Development

SUPERVISOR:

Signature………………………… Date……………………………

DEDICATION

This research project is truly dedicated to my understanding and helpful wife, who motivated and inspired me to carry out this investigation. She has supported me the entire way and has given me hope and strength when I felt like giving up. She gave me a lot of motivation and persistence to keep on with this. It would not have been able to conduct this research without her support and affection.

In addition, I dedicate this research paper to my classmates, who I frequently turned to for support when things were hard. I sincerely appreciate my family's words of wisdom and their unwavering moral, emotional, and material support for lifting my spirits.

Finally, I dedicate this to the All-Powerful God who has given me the ability to think clearly, strength, wisdom, competence, security, and good health throughout this process. I give all of these to you.

ACKNOWLEDGEMENT

Taking advantage of this chance, I would want to thank God Almighty, my maker, for being my strength, my ultimate guide, and the reason I was able to finish my research thesis.

Dr. Patrick Nyaaba Ayambire has helped me immensely, and I would like to thank him sincerely for all his support and guidance throughout my research project. For my MTech research, I couldn't have asked for a greater advisor and mentor. I would want to thank the other committee members in addition to my supervisor for their encouraging words and perceptive remarks.

I am grateful to my spouse for her unwavering support of my studies, particularly at periods when I most needed her inspiration and encouragement. I truly cannot put into words how appreciative I am of her.

ABSTRACT

This study delves into the feasibility of implementing a grid-tied solar photovoltaic (PV) system with battery energy storage for educational institutions, utilizing data collected through surveys for load estimation. Simulation and optimization of four distinct power generation scenarios, from grid-only to PV with battery storage were carried out using HOMER software. The findings revealed a compelling trend in favor of renewable energy integration resulting in cost-efficiency and environmental responsibility. Particularly, Scenario D (SD) emerged as the most promising option offering an optimal balance between economic viability and sustainable energy integration. This scenario significantly reduced grid dependence achieved a substantial renewable fraction and exhibited substantial cost-saving potential. Sensitivity analysis on specific economic inputs underscored the system's resilience to changing interest rates and inflation rates. The results of the sensitivity analysis show that the cost of electricity in a solar grid-connected system is expected to increase whenever the nominal discount rate rises (24.0%, 26.92%, 29.24%). Yet, because of the larger effect of discounting on future operating and maintenance costs, the total present cost might go down, illustrating the complex interplay between financial factors and the overall economics of renewable energy projects. The sensitivity analysis also made it abundantly evident that raising the projected inflation rate from 10.2% to 38.34% will probably lower energy costs while raising the overall present value of a solar grid-connected system. There could be a small drop in energy costs or stability in the next phase, which runs from 38.34% to 40.30%, along with a slight rise in the overall present cost. Overall, this research provides a robust blueprint for achieving reliable, cost-effective, and environmentally conscious energy solutions for educational institutions in Ghana, emphasizing the trans-formative potential of renewable energy integration for energy security and sustainability.

Table of Contents

Content **PAGE**

List of figures

List of tables

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Energy is a necessary commodity like food and water. Everything around us needs energy. Day- in-day-out the world population keeps on increasing and this has a direct effect on energy utilization as well. Most of the gadgets and equipment in our homes, offices, industries, etc. need some form of energy to function. However, the cost of fossil fuel energy is too exorbitant apart from its devastating effects on the environment (Kassem et al., 2018).

The greenhouse effect, global warming, and air pollution result from an excessive reliance on fossil fuels for energy. Utilizing more renewable energy sources can significantly reduce carbon dioxide and greenhouse gas emissions (Qolipour et al., 2016). Transitioning to renewable energy, such as wind and solar power, can have a remarkable positive impact on the environment by reducing air pollution (Mehrpooya et al., 2018). Countries worldwide are grappling with energy challenges and exploring various resources, including solar energy, to meet their energy needs (Razmjoo and Davarpanah, 2019). Renewable energies also play a crucial role in sustainable urban development, starting from rural areas and extending to entire communities (Cebotari et al., 2017). However, a challenge with standalone renewable systems is their dependence on environmental conditions, which affect energy production. Integrating Renewable Energy Sources (RESs) with conventional energy systems (CESs), like diesel generators, to create hybrid renewable energy systems (HRES) can enhance reliability and minimize supply interruptions. Energy storage systems (ESSs) can further optimize renewable energy use by storing excess energy for later use (Shafiullah et al., 2018).

While the high initial capital requirement for renewable energy sources may be a concern, policies promoting renewable energy growth have led to significant cost reductions, making solar power more affordable (Chatain, 2018). For instance, utility-scale solar power generation costs have decreased by 85% in the past decade (Calma, 2020). Additionally, using solar power, particularly in regions with abundant sunlight like sub-Saharan Africa, can help mitigate global warming and reduce carbon emissions (Asumadu-Sarkodie & Owusu, 2016). Photovoltaic (PV) systems can be either off-grid or grid-connected. Off-grid systems are suitable for remote and rural areas, where extending the electrical grid is not cost-effective, while grid-connected systems feed excess energy back into the grid. Batteries play a crucial role in ensuring reliability in standalone PV systems, and grid-connected systems can also benefit from energy storage (Abdin and Noussan, 2018; Jasuan, Nawawi, and Samaulah, 2018).

Battery energy storage systems (BESS) integrated with grid-tied PV systems enhance self-sufficiency and reduce grid dependency. These systems allow for efficient use of grid energy only when PV and stored energy are insufficient to meet the load demand (Dorahaki et al., 2022). They offer various energy services, such as PV energy time-shifting and distribution transformer modifications, which can contribute to cost savings (Tercan et al., 2022).

The use of conventional biomass and associated technology can lead to health issues, climate change, and hinder sustainable development. Off-grid solar PV systems have emerged as a viable alternative, particularly in regions where access to electricity is limited (Energy Africa-Uganda, 2018; Grimm et al., 2019). The PV system is considered an attractive option in the global energy market due to its relatively low initial cost compared to other renewable resources (Nurunnabi and Roy, 2015). The integration of hybrid energy sources has gained attention in recent years, aiming to overcome technical and economic barriers associated with renewable and distributed systems (Allison, 2017; Cano et al., 2017; Goel and Sharma, 2017; Kabalci, 2013; Perez-Navarro et al., 2016; Reddy et al., 2018, 2017; Yin et al., 2017). Studies have shown the effectiveness of hybrid PV-wind-diesel battery systems in reducing fossil fuel consumption (Baghdadi et al., 2015) and the feasibility of hybrid hydrogen fuel cell and PV systems to meet energy demands (Singh et al., 2017). Furthermore, economic analyses have demonstrated the cost-effectiveness of PV systems in various applications, including residential, commercial, and distributed grids (Nhau et al., 2021; Rout and Kulkarni, 2020). This research aims to assess the feasibility and economics of implementing PV systems in technical and vocational education and training (TVET) institutions in Ghana, addressing not only technical and economic aspects but also considering the optimization of the PV system's tilt angle, which is often overlooked in such studies. Sensitivity analysis is conducted to determine the system's response to input variations.

1.2 Statement of the problem

The Upper East Region of Ghana is known for its shorter rainy season and long dry season characterize with longer periods of sunlight and heat throughout the year which is an excellent requirement for Photovoltaic (PV) power system development. Technical and Vocational Education and Training Institutions (TVET) in the Upper East region and for that matter Ghana have common characteristics and energy needs and therefore stand to benefit immensely from PV power system to meet their energy demands especially for lighting loads. The frequent power outages in this part of the country often have significant negative consequences on the operations of these institutions. Principals of these institutions often squeeze money out of their already limited budgets just to buy diesel for generators to power certain essential appliances such as computers, printers, projectors etc. Teaching and Learning programs, especially those scheduled for the evening and night preps are normally disrupted also.

This study proposes the use of grid-connected solar PV power system with storage system in TVET institutions to ensure electricity reliability and availability. When the energy from the PV system and Battery Energy Storage System (BESS) is insufficient to power the load, grid support can be provided by the design. When the solar PV system generates more energy than the load demand and the BESS is fully charged, the energy received from the grid is returned.

1.3 Aim and Objectives

The utmost aim of this dissertation is to investigate the feasibility of using and developing PV systems capable of powering the lighting loads in the TVET institutions in the upper east region of Ghana. To perform this, the net benefit, net present value, internal rate of return and payback period are determined.

The specific objectives of this project are to conduct a:

1. Conduct a feasibility study on the possibility of implementing a grid-connected power system with a storage system in TVET institutions in the Upper East Region.
2. Perform a comparative analysis between a Stand-alone system and the Grid-connected system based on the given case study.
3. Conduct technical, economic, and environmental performance analysis of both standalone and grid-connected systems proposed in this thesis.

1.4 Significance of the study

A typical TVET institution has large number of buildings which makes it favorable for installing solar panels. Another good reason is that all the buildings are managed by a single entity. Hence the installation paves the way for smooth operation and maintenance of the solar panels (Sai Pujitha Karanam,2020). Some institutions have already installed solar PV on rooftops and parking lots. Solar installation costs have been subsidized by more than two-thirds over the last eight years (Environment America Research Centre and Policy, 2017).

Ghana witnessed major power outages in the years 2013 to 2015 which had an adverse effect on businesses and educational institutions, due to her over-reliance on hydroelectric power which is, often, dependent on the country's rainfall pattern (Ghana Energy Commission,2015). TVET institutions spend large sums of money on diesel fuel to power generators due to these shortages. These monies could have been used for other developmental projects in the schools should the institutions have a reliable alternative source of power at an affordable cost. Apart from the cost, academic activities were affected negatively in these institutions and resulted in the breakdown of electronic gadgets such as computers, printers, photocopy machines, air-conditioners, TVs, fridges, projectors etc.

Therefore, this dissertation presents a cost-effective energy system for TVET institutions. Bawku technical institute is used as a case study because of its strategic location in the region. The proposed design focused on energy efficiency and making the institution practically self-sufficient in energy generation.

1.5 Structure of the Study

The study's context, problem description, aim, and objective are all covered in Chapter 1. A summary of the research tool and technique is also provided, along with the study's boundaries and scope. In Chapter 2, the literature review of PV systems is introduced, covering topics such as PV systems in general, different types of PV systems, how solar energy works in them, the electrical properties of PV cells, PV modules. The methodology section of Chapter 3 identifies the suggested design model, applies the design model, and outlines the design phases. It also covers the research methodologies and approach utilized to construct a performance-based PV system design model. The methodology portion, found in Chapter 4, details the research techniques and model creation. The key results and recommendations are presented in Chapter

5, which also summaries the thesis. The study's schematic diagram of its organizational structure is shown in Figure 1.1.

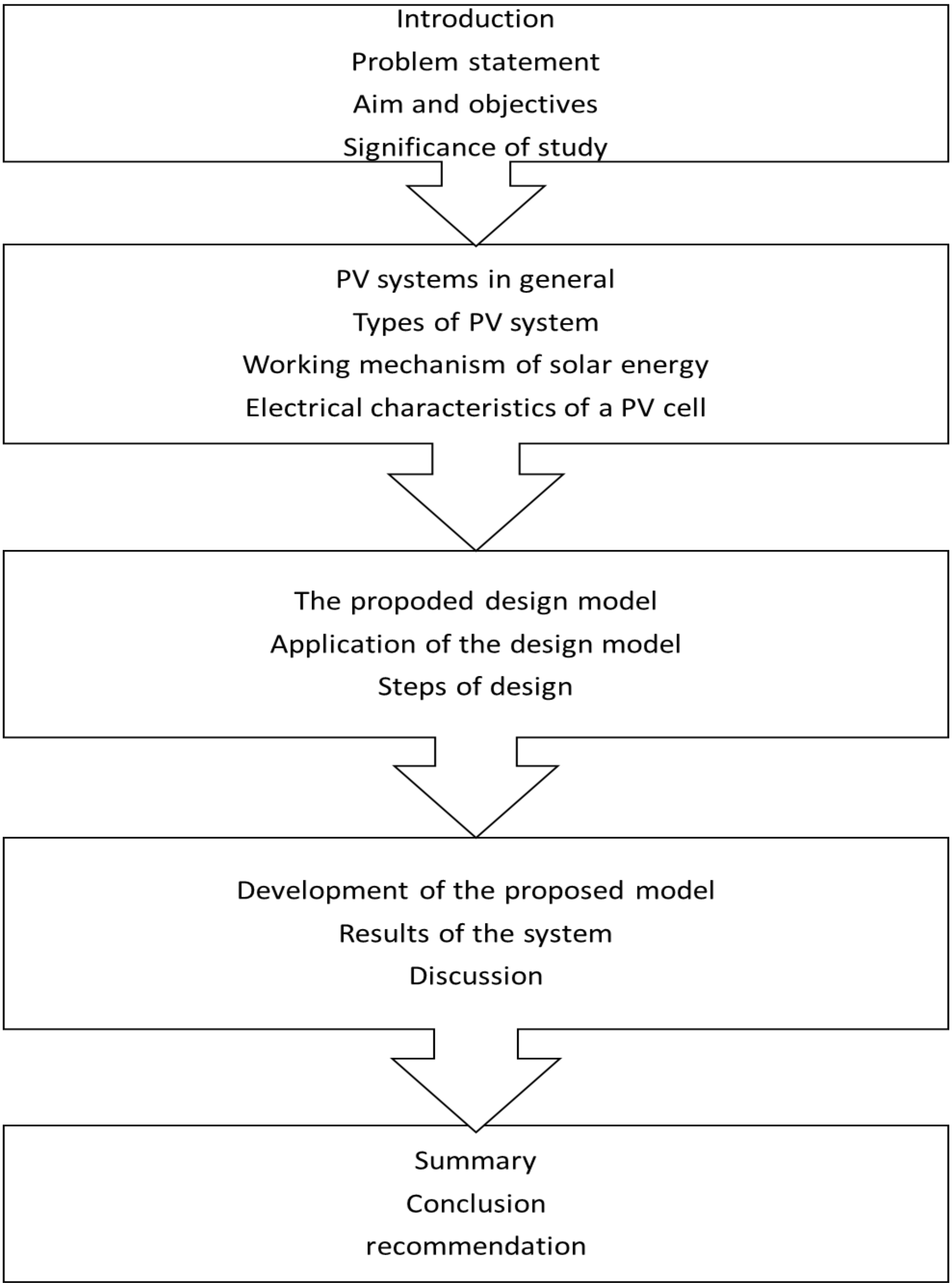

Figure 1.0: Organizational structure schematic diagram

CHAPTER TWO

LITRATURE REVIEW

2.1 Overview of related work

This chapter outlines the theoretical aspects related to Grid-connected Solar Photovoltaic Systems. It covers various subjects such as Solar photovoltaic (PV) System, feasibility studies in renewable energy, Electricity Power Plants in Ghana, Solar photovoltaic power plants, Solar Resource and Photovoltaic System development in Ghana, as well as the design and types of Solar Photovoltaic Systems.

2.2 Solar Photovoltaic (PV) Systems

Solar photovoltaic (PV) systems have gained substantial attention in recent decades as a sustainable and clean energy source. A solar PV system is a technology that converts sunlight into electricity through the photovoltaic effect, in which photons of light are absorbed by semiconductor materials, creating an electrical current (Singh et al., 2021). These systems play a significant role in the global transition to renewable energy sources.

2.2.1 Historical Development and Growth of the PV Industry

The historical development of solar PV technology can be traced back to the mid-20th century, with the creation of the first practical PV cell by Bell Labs in 1954 (Singh et al., 2021). Over the years, advancements in materials and manufacturing processes led to increased efficiency and reduced costs. The PV industry has seen remarkable growth, and solar PV technology has become a mainstream energy source in many regions, contributing to the reduction of greenhouse gas emissions and the promotion of sustainable energy solutions (Luque & Hegedus, 2019).

2.2.2 Overview of Different Types PV Technology

Solar PV technology encompasses a variety of materials and designs, with the most common types being crystalline silicon (c-Si) and thin-film PV cells (Green, 2019). Crystalline silicon is the dominant technology, with both mono-crystalline and multi-crystalline variants. Thin-film PV technologies include amorphous silicon, cadmium telluride, and copper indium gallium selenide (CIGS). Each type has its unique characteristics, efficiency levels, and applications, allowing for flexibility in design and deployment based on specific requirements (Green, 2019).

2.2.3 Components of a PV System

A typical PV system comprises several key components that work in tandem to convert sunlight into electricity. These components include solar panels, inverters, batteries, and mounting systems. Solar panels, often made of PV cells, capture, and convert sunlight into direct current (DC) electricity (Luque & Hegedus, 2011). Inverters are essential for converting DC electricity into alternating current (AC), which is compatible with the electrical grid and household appliances (Chen et al., 2016). Batteries, such as lithium-ion batteries, are used for energy storage, allowing excess energy to be stored and used during periods of low sunlight (Green, 2019). Mounting systems are crucial for securely positioning the solar panels to optimize exposure to sunlight and ensure stability (Luque & Hegedus, 2019).

2.3 Feasibility Studies in Renewable Energy

Feasibility studies are a critical component of decision-making in the renewable energy sector, guiding investments in projects that harness sustainable energy sources. Renewable energy sources, including solar, wind, hydro, biomass, and geothermal, are becoming increasingly essential in the global shift toward clean and sustainable energy production. The feasibility studies in this context aim to assess the technical, economic, environmental, and social aspects of renewable energy projects to determine their viability and potential benefits (Tawfik et al., 2018).

2.3.1 Technical Feasibility

The technical feasibility of a renewable energy project focuses on evaluating the project's viability from an engineering and technology perspective. It involves examining the availability of the resource (e.g., solar irradiance, wind speed, water flow) and the suitability of the chosen technology to capture and convert that resource into energy (Katarzyna Piwowar-Sulej et al., 2023). Technical assessments consider factors such as the efficiency of energy conversion, reliability, and compatibility with the existing infrastructure.

2.3.2 Economic Feasibility

The economic feasibility of a renewable energy project centers on financial viability and return on investment. This aspect involves estimating the costs associated with project development, including equipment, installation, maintenance, and operation, and comparing them to the expected financial benefits, such as revenue from energy generation and potential incentives (Delapedra-Silva et al., 2022). Key economic indicators, such as the Net Present Value (NPV), Internal Rate of Return (IRR), and Levelized Cost of Electricity (LCOE), are commonly used to assess the economic viability of renewable energy projects.

2.3.3 Environmental Feasibility

Assessing the environmental feasibility of renewable energy projects is crucial, as it involves the impact on the environment and the surrounding ecosystem. This includes evaluating potential consequences on air and water quality, wildlife, and the landscape (Hertwich et al., 2015). The aim is to ensure that renewable energy projects contribute to environmental sustainability and reduce greenhouse gas emissions, aligning with the broader goals of mitigating climate change.

2.3.4 Social Feasibility

Social feasibility examines the acceptance and integration of renewable energy projects within the local community and society. It considers factors such as community engagement, public perception, and the potential socioeconomic benefits of the project (Walker et al., 2016). Addressing social concerns is crucial to ensure the successful implementation and long-term operation of renewable energy projects.

2.4 Electricity Power Plants in Ghana

Hydroelectricity has traditionally been the primary source of energy in Ghana. However, in response to the increasing energy demands, fossil fuel-powered electricity plants have been introduced alongside hydroelectric facilities. As of 2016, the current electricity generation mix stands at approximately 42.3% hydroelectric, 57.1% thermal (utilizing sources like Natural Gas, Light Crude Oil, and Diesel), and a minor 0.6% contribution from renewable energy sources like Solar, as reported by the Energy Commission. The specific breakdown of this electricity generation mix in Ghana is detailed in Table 1, with the fossil fuels used being Natural Gas (NG), Light Crude Oil (LCO), and Diesel, according to data from the Energy Commission in 2016.

Table 2.0. Generation mix in Ghana

Installed Generation Capacities in Ghana as of 2021 (MW)

Plant	Installed Capacity	Dependable Capacity
Hydro Power Plants		
Akosombo	1,020	900
Kpong	160	140
Bui	404	360
Sub-total	**1,584**	**1400**
Thermal Power Plants		
Takoradi Power Company (TAPCO)	330	300
Takoradi International Company (TICO)	340	320
Tema Thermal 1 Power Plant (TT1PP)	110	100
Tema Thermal 2 Power Plant (TT2PP)	87	70
Cenit Energy Ltd	110	100
Kpone Thermal Power Plant	220	200
Ameri Plant	250	230
Sunon Asogli Power (Ghana) Ltd	560	520
Karpowership	470	450
Trojan	44	39.6
Amandi	203	190
AKSA	370	350
Cenpower	360	340
Early Power / Bridge	144	140

Genser[2]	155	131
Sub-total	**3,753**	**3,480.60**
Other Renewables		
On-grid		
VRA Solar (Navrongo)[2]	2.5	2
VRA Solar (Lawra)[2]	6.5	4.5
VRA Solar (Kaleo)[2]	13	10
BXC Solar[2]	20	16
Meinergy[2]	20	16
Bui Solar[2]	51	46
Safisana Biogas[2]	0.1	0.1
Tsatsadu Hydro	0.05	0.05
Distributed Solar PV	30.9	-
Sub-total	**144.05**	**94.65**
Off-grid		
Solar	7.42	-
Wind	0.02	-
Sub-total	**7.44**	-
Mini grid		
Solar	0.314	-
Wind	0.011	-
Sub-total	0.325	-
Total Renewable	119.865	94.6
Total	**5,488.82**	**4,975.25**

Source: Energy Commission, 2022

2.5 Solar PV Power Plants

Continuously occurring natural processes provide the source of renewable energy. In addition to being easily used, affordable, and naturally abundant, it also emits less pollution. For this reason, the importance of renewable energy surpasses that of nonrenewable energy. As it doesn't contribute to global warming, using renewable energy preserves the environment (Khan and Arsalan,2016, Shukla et al, 2018). In Ghana, this is quite concerning because most households rely on wood and fossil fuels for household use. The community's health and the nation's progress will both be impacted by this. The efficient use of renewable energy resources is crucial for the prosperity of the nation.

Solar power, for example, is generated by converting solar radiation into electricity using either the photovoltaic (PV) effect or concentrated solar power (CSP). Concentrated solar systems employ lenses, mirrors, and tracking mechanisms to concentrate a substantial amount of sunlight into a concentrated beam. On the other hand, photovoltaic systems directly convert sunlight into electrical currents through the photovoltaic effect.

Sunlight contains photons that can liberate electrons from their bonds, enabling them to conduct electricity (Home Power Magazine, 2012). Once a solar photovoltaic system is in operation for electricity generation, the energy source is inexhaustible and remains impervious to economic fluctuations in the energy market. This has led to a growing transition to solar energy in numerous developed and developing countries due to its minimal environmental impact during electricity generation. As of the conclusion of 2015, the countries listed in table 2 had the highest installed capacity for solar photovoltaic energy.

Table 1.1. Top fourteen solar PV energy installers in 2022.

Country	**Installed Capacity (GW)**
China	392.4
United States	111.4
Japan	78.8
Germany	66.5
India	62.8
Australia	26.8
Italy	25.1
Brazil;	24.1
Netherlands	22.6
South Korea	20.9
Viet Nam	18.5
Spain	18.2
France	17.4
United Kingdom	14.4

solar photovoltaic (PV) technology finds diverse applications, ranging from powering consumer gadgets like calculators and solar lamps to supplying electricity for residential properties in both urban and rural settings, as well as for commercial and industrial structures. Additionally, it serves as an energy source for remote highway signs. Notably, solar PV also plays a crucial role in delivering power to satellites orbiting in space.

2.6 Solar Resource and Photovoltaic Systems Development in Ghana

2.6.1 Solar Energy Resource in Ghana

Ghana lies close to the equator and therefore has solar energy in abundance but is yet to be tapped. Table 2.2 shows the solar resources at the various locations.

Table 2.2. Solar resource of Ghana

LOCATION	**SOLAR RESOURCE**	**REMARKS**
Around Kumasi	4.4 – 5.6kWh/day with sunshine hours of 5.3hours	The area lies in semi – cloudy forest region
Upper East, Upper West, Northern, Northern part of Brong Ahafo and Volta regions	4 – 6.5kWh/day with sunshine ours of 7hours	The area has one major rainy season between July and September follow by harmattan between November and February.
Ashanti, part of Brong Ahafo, Eastern, Western, part of Central and Volta regions	3.1 – 5.6kWh/day	The area is a forest area
Greater Accra, coastal part of Volta and Central regions	4.0 -6.5kWh/day	This is the coastal areas

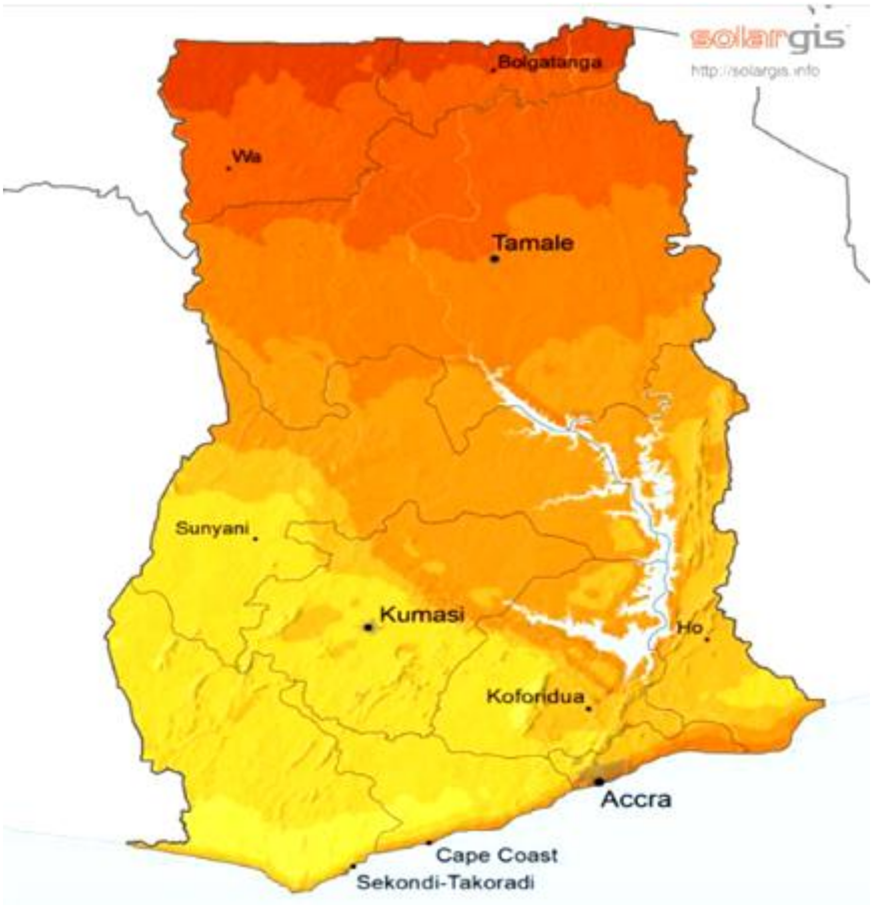

Figure 2.0. GHI solar map of Ghana (Mensah, Yamoah, and Adaramola, 2019)

2.7 Photovoltaic Systems Development in Ghana.

Ghana has an abundance of solar-powered energy resources, but not much of this potential is used. Following Ghana's electrical crisis in 1997, several businesses joined the photovoltaic (PV) industry in the first half of 1999 to capitalize on the situation and promote the usage of renewable energy. But in less than a year, most of them had reportedly collapsed owing to a lack of incentives and a legal framework to support that industry (Anaadumba et al., 2021).

The Grid-connected solar photovoltaic system had a 160kWp overall capacity about 2010. This consisted of 50kWp at the Ministry of Energy, 101.75kWp in houses sponsored by the Ghana Energy Commission, 4kWp in the Engineering College of Kwame Nkrumah University of Science and Technology, and 4.25kWp at the Ghana Energy Commission's headquarters.

A Renewable Energy Law (Act 832) was passed in 2011 with the goal of encouraging private sector participation by offering a regulatory framework and certain incentives. This law's provisions cover the following: research and development; feed-in tariff (FiT); renewable energy purchase obligation; net metering (distributed generation); off-grid electrification of remote communities; creation of a Renewable Energy Authority; and research and development (Nyasapoh et al., 2022). There is now increased investment in Ghana's photovoltaic industry because to this legal framework. Table 5 below lists a few of the PV projects that the VRA has worked on in Ghana.

The first solar manufacturing facility in Ghana, located at Kpone in the Greater Accra Region, began for business in April 2016 with a 30MW yearly production capacity. A 20 MW solar PV facility at Onyandze in Greater Accra was put into service that same month by Beijing Xiaocheng, a Chinese company (PV magazine, 2016). 40,480 polycrystalline silicon panel pieces, 20 step-up transformers, 20 inverter rooms connected to the transformer, and a 33kV overhead transmission line spanning 9 km to the ECG sub-station close to Winneba are all part of the solar PV project.

2.8 Design and Type of Solar PV system

2.8.1 Design Type and Component

A solar cell is a device that uses the photovoltaic effect to convert solar energy into direct current electricity. It is composed of two layers of a semi-conductive substance. Al-Ezzi and Ansari (2022) state that the device has one positively doped layer and one negatively doped layer. Every time light reaches the cell, some of the photons are absorbed by the semiconductor atoms in the light, which causes electrons to escape the cell's negative layer and return to the positive layer via an external circuit. This kind of electron movement is known as an electric current. The amount of solar power that strikes a surface determines how much current a solar cell internally generates (Al-Ezzi & Ansari, 2022).

2.8.2 Type of Solar cells

Solar cells come in three primary varieties: amorphous, poly-crystalline, and mono-crystalline**.**

Mono-crystalline cells

Cells taken from a single silicon crystal are used to create these kinds of cells. They provide the best performance in terms of efficiency (around 18% conversion of incident sunlight) and have a higher degree of material purity. Due to the intricate production procedures required to achieve the required level of material purity, it is marginally more expensive (Singh, 2010).

Poly-crystalline Silicon cells

The massive, liquid silicon blocks known as cast square ingots are subjected to a rigorous cooling and hardening process to create poly-crystalline crystalline silicon cells. (Andreani et al., 2018; Green et al., 2020) estimate their efficiency to be between 14% and 18%. According to Olivia (2023), these solar panels are also constructed from silicon. Wafers are created through the melting of many silicon fragments together, which makes the production process distinct. After that, solar panels are made from these wafers. The term "poly-crystalline" or "multi-crystalline" solar panels originated from the manufacturing process. Comparing this type of cell to mono-crystalline solar panels, it produces less power and has a lower efficiency because it provides less room for electrons to pass.

Amorphous Silicon

The cheapest and least effective kind of photovoltaic cell is amorphous/microcrystalline, which is created by depositing a thin layer of silicon onto a substance like glass. There is a range of 8–11% efficiency (Nandal, Singh, and Kumar, 2019). Silicon, the second most common natural element on Earth, can take the form of amorphous silicon. Its non-crystallized and disordered nature, like that of regular glass, means that certain atoms in its chemical structure resist bonding, which sets it apart from silicon. The so-called "dangling" linkages influence the material's intrinsic qualities, increasing its defect density—the quantity of flaws that exist naturally. This material, sometimes shortened to a-Si, is still preferred to crystalline silicon for making thin films that cover a range of electronic components, especially photovoltaic (PV) systems, because it has a few benefits over the latter. For example, it adheres to glass, plastic, and metals and may be applied more homogeneously to huge areas at extremely low temperatures than silicon can.

2.9 Types of Photovoltaic System

Photovoltaic systems come in three forms: Grid connected, Stand alone and Hybrid system.

2.9.1 Grid Connected System

An on-grid or grid-tied photovoltaic (PV) system is a renewable energy system that uses solar panels to produce power. Households and commercial buildings are powered by the electricity produced, with any extra energy being able to be re-injected into the power system. Grid-connected photovoltaic systems so contribute significantly to the reduction of carbon emissions, the advancement of energy independence, and the expansion of access to clean energy (Waaree Energies ,2023). Inverters, charge controllers, distribution panels, monitoring systems, and solar panels are the standard components of a grid-connected photovoltaic system. Sunlight exposure causes solar panels to generate direct current (DC) electricity. This DC electricity is subsequently transformed by the inverter into AC electricity, which is used in most homes and businesses. Between the solar panels, the inverter, and the electrical distribution panel, the charge controller controls the flow of electricity. The system's performance is monitored by the monitoring system, and it is connected to the electrical grid through the electrical distribution panel (Waaree Energies ,2023). In this system, the PV modules are installed to produce power on the rooftops of residential structures or on a piece of bought land. When compared to ground-mounted PV systems, rooftop PV systems may have a smaller capacity. They range from 5-20kW whereas those atop commercial buildings might reach 100kW or more.

Many developed and developing nations have plans in place to use rooftop photovoltaic systems to boost their electricity production. A few of the projects are as follows: the 2012-commissioned Gunma project in Japan, which comprises 550 homes with rooftop PV systems connected to the grid. In a 1 km radius, the estimated total capacity is 2.2MW, or 85% of the PV electricity penetration level. Germany has 40GW of installed PV capacity at the end of 2015, with rooftop solar PV systems accounting for 74% of the capacity. 70% of the rooftop systems on one- or two-family homes had capacities under 10 kW. About 2GW of distributed solar photovoltaic, or rooftop solar, was added to the installed capacity of the United States of America. In the first three months of 2016, China increased the capacity of its rooftop photovoltaic system by 970MW. Since the generation is done at the customer's location, this technology eliminates losses that would have happened in the transmission lines. The PV modules for the central grid-connected system are installed on land that has been purchased to produce electricity that is fed into the national grid. Higher capacity ratings in the kilowatt and megawatt range are present in this system. The following are the principal elements:

Solar PV modules: these directly generate power from sunshine. An inverter is a device that changes the direct current produced by solar PV modules into alternating current. Transformer for increasing the power produced for transmission. The transmission line serves as a link between the plant and the mounting system.

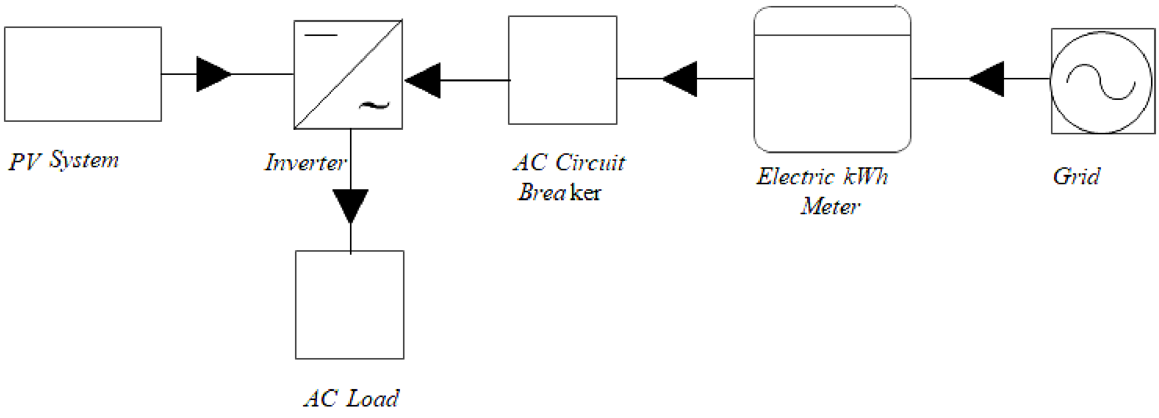

Figure 1.1. Photovoltaic system for solar power connected to the grid.

International data on renewable energy indicates that as of the end of 2016, there was 178GW installed worldwide capacity for the generation of electricity powered by solar energy, the majority of which was grid-connected. This accounted for almost 1% of the global electricity demand (IRENA, 2015). Leaders of the 2014 PV system revolution included China, Germany, Japan, the USA, Italy, and many more. PV system installations have increased dramatically in several nations, including Slovakia, Ukraine, Chile, South Africa, India, and Bulgaria.

2.9.2 Stand-alone PV System

A standalone PV system, which operates independently from the public utility network, generates electricity from sunlight. It then either uses this electricity directly or stores it in batteries for nighttime use and periods with limited daylight. Such systems serve isolated areas by supplying DC and/or AC loads.

As the standalone system is not connected to the grid, it's crucial to appropriately select the energy storage capacity to avoid situations where the load surpasses the storage capacity and cannot be met (Lugue and Hegedus, 2019). Systems with power ratings ranging from a few Watts to megawatts currently use DC to AC power converter technology, also known as inverter typologies. Energy sources like wind and solar power in a renewable energy system can be sporadic. On the other hand, a home's electrical demands need steady, uninterrupted electricity (Ansari et al., 2018). Because of this, it is a standard procedure to incorporate a battery into distant photovoltaic systems in areas without grid connectivity. It is believed that a battery or PV panel provides the inverter input power for the inverter typologies and operating modes.

Bonkoungou et al (2022), Power transistors, a conversion device installed in the inverter, are designed to convert the direct current (DC) into an alternating output voltage (AC) that approximates a sinusoidal waveform. This inverter's primary job is to convert a direct voltage to an alternating voltage. The two power stages that are connected are utilized by the suggested inverter. Each stage delivers a rectangular signal. An output that resembles a sine wave is then produced by combining these two signals. The output voltage can be converted into a sinusoidal voltage with minimal distortion rates by placing an inductance-capacitance (LC) filter at the output. The output voltage is controlled by adjusting the duty cycle of the rectangular waves.

Off-grid photovoltaic systems are the best choice for remote rural sites and applications when traditional power sources are either unfeasible or unable to supply electricity for lights, appliances, and other uses. Under these conditions, installing a single standalone PV system makes more sense than paying the local utility company to run cables and power lines straight to the house as part of a grid-connected PV system (Altenenergytutorials, 2023).

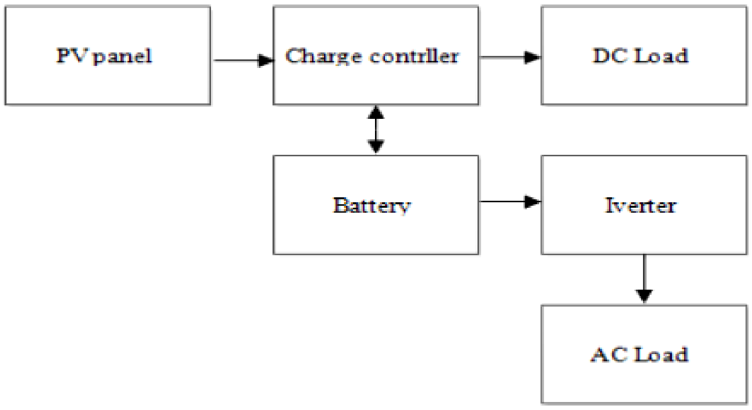

Figure 2.2. Standalone system with charge controller

Subsidies are offered for PV system electricity storage technologies in a few developed nations, such as Germany and Japan. Currently, ten thousand rooftop solar PV systems connected to battery storage systems exist in Germany (IRENA, 2015). Leasing solar photovoltaic systems in conjunction with battery storage technology is becoming a popular business model in several nations. While China boasts 40GW of off-grid power installed in 2014, Australia only installed 16MW of such systems.

Sweden installed 1.1 MW in 2014, while most European nations built around a MW each. Japan's installed capacity now stands at 125MW after the installation of roughly 1MW (IRENA, 2015). More than 150MW of PV was used on the French island of La Reunion to power 840,000 people. In Bangladesh, six million photovoltaic systems are currently being installed to supply thirty million people with basic electricity. It is anticipated that by the end of 2017. By the end of 2017, 2GW of off-grid PV installation is anticipated in India.

2.9.3 Hybrid System

One of the least expensive and less sophisticated types of PV systems is a grid-connected system. The technique is more effective because there is no need for a storage battery, which also removes maintenance concerns. It should be mentioned, though, that unlike stand-alone systems, grid-connected systems do not have their own power supply, thus whenever there is a grid outage, the system likewise shuts off. By adding a storage battery, the grid-connected system's vulnerability was addressed, and a hybrid system was created. (2014, AET). A grid-connected photovoltaic system with battery storage is seen in Figure 2.3 below.

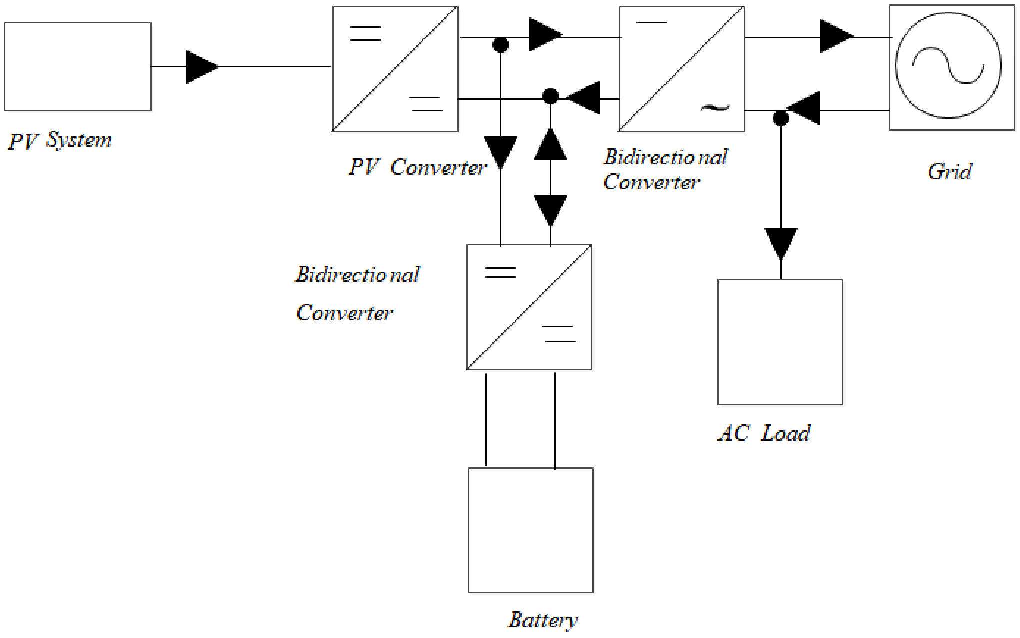

Figure 2.3. Grid connected PV system with battery storage.

The hybrid system is configured similarly to a grid-connected photovoltaic system, but it also includes a charge controller and battery storage. Any solar power system must include solar charge controllers because they govern how much energy is transferred from solar panels to battery banks and make sure the system runs smoothly. They optimize energy output, safeguard the battery bank from harm, and contribute to the system's longer lifespan. You may optimize your solar power system's efficiency and lessen your carbon footprint by selecting the kind and capacity of solar charge controller that best suits your demands (NAZ Solar Electric,2023). Hybrid systems have advantages and disadvantages of their own that every buyer should be aware of when weighing the many solar energy system options available.

Using a hybrid system has several advantages over other solutions, the primary one being the ability to store solar energy for use when needed most. A hybrid system also allows you to use the public grid if your energy reserves run low in addition to earning money from the excess energy your system generates because it is still connected to the public utility grid. It is crucial to remember that hybrid systems, with their additional battery storage and power backup technology, will cost a little bit more than standard on-grid solar systems. On the other hand, the price of a solar PV system with batteries drops when the retail energy price rises. The economies of power providers are at risk due to this occurrence, particularly in regions with year-round sunshine. Rocky Mountain Institute (RMI) reports that among other things, it was discovered that if consumers choose this hybrid system, utility firms' profits will be negatively impacted.

The national grid's supply to non-residential consumers in Westchester County, New York, is predicted to decrease from 100% today to 25% by around 2030 and less than 5% by 2050, according to analysis. However, to make up for the shortfall, solar PV contribution can increase dramatically. According to the analysis, utilities in the US Northeast would experience a decline in energy sales by 2030 (RMI, 2015).

2.10 Economic Analysis

It is imperative to underline the need to conduct an economic analysis of the project. They draw attention to whether the initiative is financially viable. The economic effectiveness of the installation was evaluated using a straightforward payback period and levelized cost of energy (LCOE) economic indicators. The following queries were also answered in addition to the financial statistics listed above: (i)In the first ten years following FiT, will this installation be able to recoup its investment costs? (ii) Should this FiT be installed or not? (iii) Over the installation's anticipated 25-year economic project life, what is the labor cost over equity (LCOE) using reasonable assumptions.

2.11 Factors Affecting PV System Feasibility and Economics

The feasibility and economic viability of photovoltaic (PV) systems are influenced by a myriad of factors that extend beyond the technical and financial aspects. Understanding these factors is essential for making informed decisions about the implementation of PV systems and ensuring the long-term success of such projects.

2.11.1 Solar Resource Availability

One of the most critical factors affecting the feasibility of PV systems is the availability of solar resources. The amount of sunlight a location receives directly impacts the energy production of PV systems. Solar irradiance, seasonal variations, and weather patterns in a specific region play a significant role in determining the potential for energy generation (Duffie & Beckman, 2013). Therefore, choosing the right location for a PV installation is a key consideration.

2.11.2 System Design and Configuration

The design and configuration of a PV system can significantly influence its feasibility and economics. Factors such as the orientation and tilt angle of solar panels, the choice of PV technology (e.g., mono-crystalline, poly-crystalline, thin-film), and the type of tracking system (e.g., fixed or tracking) can affect the system's efficiency and overall performance (Huld et al., 2010). The right design decisions can maximize energy output and financial returns.

2.11.3 Financing Options and Incentives

The availability of financing options and incentives can greatly impact the feasibility and economics of PV systems. Government subsidies, tax credits, feed-in tariffs, and net metering programs can reduce the upfront costs and improve the financial attractiveness of PV installations (Sigrin & Kittrick, 2016). Understanding and accessing these financial incentives is essential for a comprehensive economic analysis.

2.11.4 Policy and Regulatory Considerations

The regulatory environment, including policies related to renewable energy targets, grid connection requirements, and permitting processes, can significantly affect the feasibility and economics of PV systems. Clear and supportive policies can streamline project development and reduce regulatory barriers (Bovin et al., 2016). Conversely, unfavorable regulations can hinder project implementation and impact financial returns.

2.11.5 Market Dynamics and Electricity Prices

The market dynamics and prevailing electricity prices in a specific region also play a crucial role. The economic viability of PV systems is influenced by the cost of electricity from other sources, such as fossil fuels or nuclear power (IEA, 2018). As electricity prices fluctuate over time, the financial feasibility of PV installations can change as well. The ability to sell excess energy to the grid and the price at which it can be sold are important considerations.

2.11.6 Environmental and Social Impact

The environmental and social impact of PV systems is a growing consideration in feasibility assessments. Projects that minimize negative environmental impacts and provide social benefits, such as local job creation and reduced greenhouse gas emissions, are often more favorable (Sovacool, 2009). Sustainability and corporate responsibility are becoming integral to project feasibility and stakeholder support.

CHATER THREE

METHODOLOGY

3.0 Introduction

This section outlines the research technique used in the design and development of control methods for the micro-grid system's dependable operation in islanded mode, which is facilitated by BESSs with inverter interfaces. In this study, a dynamic control system approach for BESS in islanded mode is created to achieve the rapid temporal shifting between generation and consumption of energy. Several techniques that can be used to identify frequency variations caused by load variations are created in this research. Having a storage battery that can be charged and discharged, the control mechanism described in this work can handle both forms of frequency variation induced by load and power reduction. Additionally, it keeps the battery's state of charge (SOC) in a safe charging and discharging condition. Subsequently, by combining the intended techniques and creating control tools in a bidirectional islanded micro-grid with a battery, the frequency fluctuation was reduced, which raised the system's overall efficiency. On the other hand, this part also covers how to build a PV grid-tied system and evaluate its performance. First, to get the most precise data for the precise position on the planet, meteorological data sets were collected and processed. A computation tool was created to manage many data, such as weather, PV plant, load, and storage variable data, that are required for modelling and simulation. Later, a model was created to inject the PV plant into the grid and enable it to meet the management requirements set forth by the system operator. To acquire the necessary capacity and cycles of the storage system for the many conceivable scenarios and ratios of storage capacity/production, the electrical storage system (ESS) was simulated and optimized using the injection model. Additionally, the production of plants was computed under various injection parameters and storage conditions.

After compiling and analyzing all the final data, the design was simulated, and its performance was examined using HOMER software. When combined with battery backup, the grid-tied system improves time functionality. Before the system is put into action, it gauges the sun's radiation levels to determine whether the solar modules can provide enough energy to both charge the batteries and power the AC loads via the inverter. The system leverages the grid to charge the batteries and provide the extra electricity produced by the solar panels on days with low radiation. The system will check the battery status to make sure there is power coming from the backup if the grid goes down for whatever reason. In island mode, the batteries and solar panels will function similarly to an off-grid setup. If the batteries run low on power, the solar panels will alternate between charging the batteries first to a certain point and then discharging them until the grid is back up.

3.1 Background of the Study Area

The institute was founded in 1967 with the intention of developing the nation's middle-class human resources through the dissemination of engineering and entrepreneurship expertise. The Institute currently comprises 10 departments, including Electrical Engineering, Business, Electronics Engineering, Plumbing and Gas fitting Technology, Mechanical Engineering, Welding and Fabrication Engineering, Wood Construction Technology, Brick Laying Technology, and Hospitality and Catering Technology. The school has approximately 2000 pupils and roughly 300 members of the teaching and non-teaching staff. Electrical energy is typically provided to specific components in TVET Institutions, such as lights, computers, projectors, and HVAC (heating, ventilation, machines, and air conditioning) systems (Mehreen, and Sandhya. 2015). Bawku Technical Institute uses electricity for lighting, air conditioning, and electrical equipment like machines, projectors, printers, and computers. The main aim of this work is to examine and create a PV system with Battery Energy Storage System (BESS) as a backup that can supply lighting loads, computers, refrigerators, Televisions, and other electronic devices except the electrical machines in Ghana's TVET institutions during grid outages. The load profile, which displays the Institute's energy usage, is based on projected electricity costs for 2022.

Figure 3.0: Satellite View of Bawku Technical Institute

Simulation

The four different configurations of power generation systems (scenarios) were simulated for comparison as possible options for energy generation in the community. These four scenarios include.

Scenario A (SA) - A power generation system that uses Grid only.

Scenario B (SB) - A system that uses an SPV system and a Grid as generation sources.

Scenario C (SC) – A system that uses an SPV system as a generation source and a Battery bank as an energy storage device.

Scenario D (SD) - A system that uses SPV system, Grid as sources of generation, and a battery bank as an energy storage device.

All four configurations of power generation systems were simulated using Hybrid Optimization for Multiple Electric Renewable (HOMER) professionals' software, version 3.14.5. A side-by-side comparative analysis of the technical, economic, and environmental output parameters was presented for the four different models to determine the most feasible option of electrification for the community. The most feasible system in this study is the system that offers the least NPC over the lifetime of the project as well as maximizes the use of renewable energy generation and produces the least amount of GHG emissions during its operational lifetime, as simulated by the HOMER software. Sensitivity analysis is carried out on the most feasible system to determine the effect of a change in the project's economic input on its cost. The economic input variables considered were (1) inflation and (2) discount rate interest rate. The project costing variables considered were (1) NPC, (2) CC and, (3) LCOE. A breakdown of the study methodology is given in the figure below.

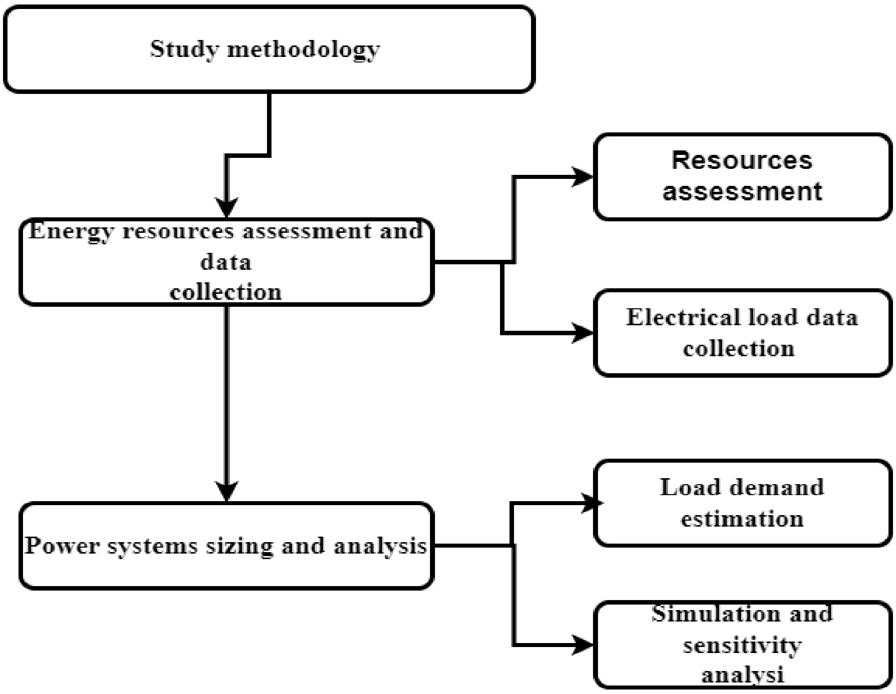

Figure 3.1: Flow chart of the research methodology

3.1 Description of HOMER software

"Homer software, developed in 1993 by the National Renewable Energy Laboratory (NREL), serves as a widely utilized optimization tool for designing small-scale renewable and conventional energy systems. It finds applications in both off-grid and grid-connected scenarios and boasts a global user base spanning 193 countries (Kassam, 2010).

Homer's primary functions encompass simulation, optimization, and sensitivity analysis (Okinawa Entech Co., 2016). To initiate the simulation, the software relies on input parameters like Energy resources, obtainable from sources like NASA or NREL online databases, including data on climate resources such as solar radiation, air temperature, relative humidity, wind speed, hydropower, biomass, and more were utilized for the simulation.

A time series with 24 hours was used to organize the electrical load data. Analysis was done on the cost and performance requirements of the controllers, converters, storage devices, and power generators that make up hybrid systems. The economic features of the project, such as economics, restrictions, and sensitivity parameters were also considered. Homer provides a comprehensive component catalog from global manufacturers, covering generators, energy storage devices, power converters (inverters), and power controllers. For economic analysis, Homer considers inputs like the nominal discount rate, inflation rate, and the price of diesel fuel (if applicable). It calculates the real discount rate and leverages it to assess the economic performance of a project over its designated lifetime. The software conducts multiple simulations based on these inputs, evaluating both technical and economic aspects over a year (8,760 hours) with user-defined time intervals (typically ranging from 15 to 60 minutes). This process, termed optimization, aims to identify the most balanced system in terms of technical and economic criteria. The system with the lowest Net Present Cost (NPC) over the project's lifetime is typically considered the optimal choice.

Additionally, Homer conducts sensitivity analyses to gauge the impact of input variables on the calculated output results. For instance, it assesses how variations in the inflation rate affect the NPC of a project. Over the years, HOMER software has been widely utilized in various academic studies, covering topics such as techno-economic analysis, specific optimization, and management strategies for hybrid energy systems.

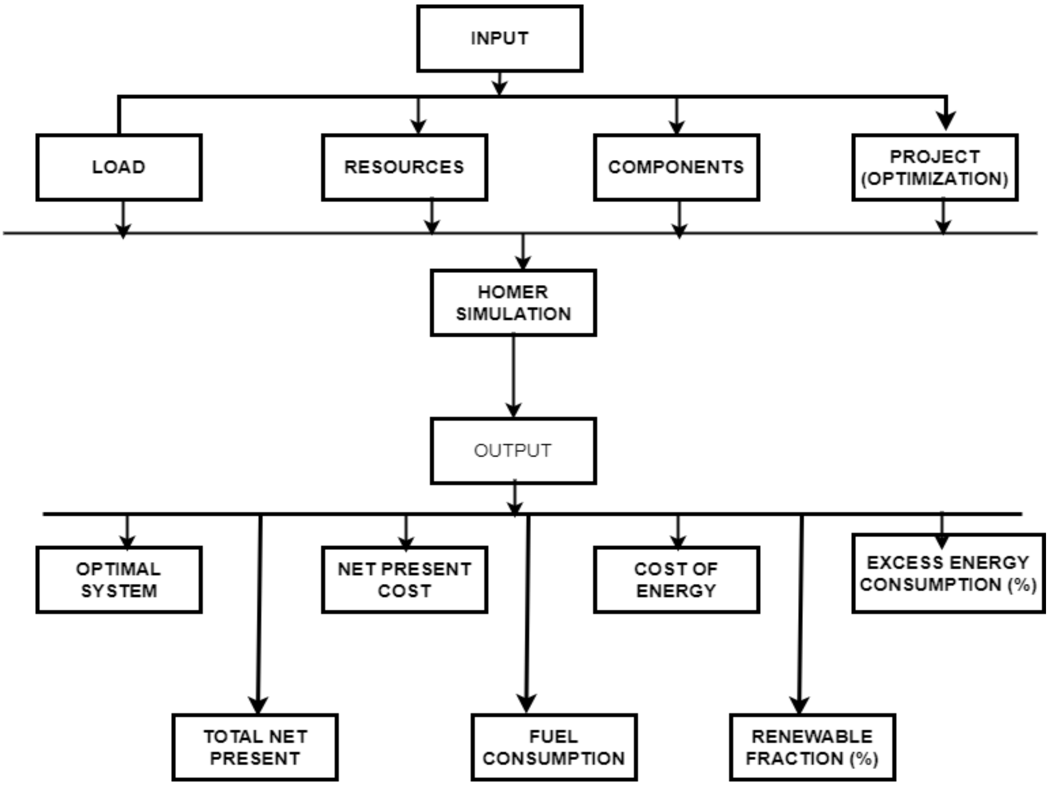

Figure 3.2 Outline of how HOMER works

3.2 Solar Radiation of the Study Area

The HOMER results showed an average annual solar irradiance of 5.69kWh/m^2/day with detailed monthly averages shown in figure 3.3. In this study, the one year of solar global horizontal irradiance (GHI) data obtained from National Renewable energy Laboratory.

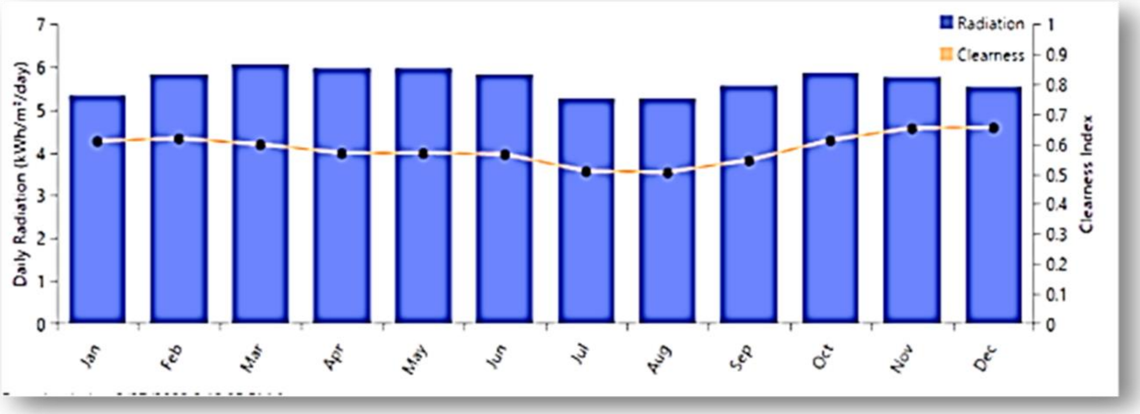

Figure 3.3. Monthly solar GHI data and clearness index for Bawku, Ghana

Table 3.0. Monthly Average Solar Global Horizontal Irradiance (GHI) Data

Month	Clearness Index	Daily Radiation (Kwh/m^2 /Day)
January	0.607	5.313
February	0.616	5.828
March	0.596	6.072
April	0.567	5.972
May	0.567	5.947
June	0.563	5.836
July	0.507	5.264
August	0.503	5.255
September	0.543	5.565
October	0.610	5.876
November	0.650	5.771
December	0.652	5.537

August, the heaviest month of the region's rainy season, saw the lowest solar radiation readings. The solar panels can be powered by the estimated solar insolation for the study area, which is 2,023.2 kWh/m^2 /year. Temperature varies between 14ºC at night and 40ºC during the daytime in the area (Cudjoe et al, 2017) because of the harmattan winds that blow from the Sahel in December and February. The measured temperatures fall within the operating range of flat plate solar panels, which is 47ºC. With an average module efficiency of 16.4% under standard test conditions (STC), mono-crystalline solar panels were used in our study.

3.3 Electrical demand Load estimation

3.3.1 Load category

The electrical load demand for the Bawku Technical Institute were divided into three categories, namely, administration block loads, Classroom block loads, and Electrical lab loads. The projected energy consumption for the location was estimated based on assessment from a survey and typical assumptions about the type of load consumed, the load's electrical power requirements, and the load's time of use. In this regard, it was assumed the following.

3.3.2 Electrical loads requirement

The projected energy consumption for the location was estimated based on assessment from a survey and typical assumptions about the type of load consumed, the load's electrical power requirements, and the load's time of use. In this regard, it was assumed the following.

3.5.3 Assumptions for load estimation

Power ratings of equipment are assumed to be of standard average sizes, to cater for the probability using non-energy saving appliances. All electrical loads considered are Alternating Current (AC) loads.

Table 3.1. Estimation of Electric Power Demand for Critical Appliances in Bawku Technical Institute

Appliance	Quantity	Power Ratings (W)	Total Power (Kw)	Usage Time (Hr)	Daily Consumption (Kwh)
Led bulbs	60	20	1.2	4	4.8
Led bulbs	20	15	0.3	4	1.2

Led bulbs	50	40	2	4	8
Ceiling fan	60	70	4.2	6	25.2
Refrigerator	3	200	0.6	8	4.8
Deep freezer	2	300	0.6	24	14.4
Water pump	1	750	0.75	2	1.5
Air-conditioner	4	1500	6	1	6
Desktop computer	5	200	1	2	2
Laser printer	4	600	2.4	1	2.4
Scanner	2	18	0.036	1	0.036
Projector	3	270	0.81	2	1.62
42 inches led TV	2	60	0.12	12	1.44
TOTAL			20.016		73.396

3.6 Simulation input parameters

3.6.1 Electrical load profile

The load profile for Bawku Technical Institute during a 24-hour period is shown in the figure below, with each row indicating the time of day and the associated number of kilowatt-hours (kWh) of power used. The load profile reveals that during the early morning hours from 0 to 5, the electricity consumption stays reasonably steady at 1.6 kWh per hour.

The load profile starts at hour 0, which corresponds to midnight. Electricity usage starts to noticeably rise around hour 5 and reaches 2.4 kWh, which may signal the start of morning activities or an increase when people awaken and begin their days. The load profile then keeps increasing, reaching a high between hours 18 and 21 of 9.6 kWh. This likely correlates to the institute's busiest times, which may include times when classes, workshops, or other activities that use a lot of electricity are taking place. After hour 21, the electricity consumption starts to decrease, with a notable drop to 7.2 kWh at hour 22, and further to 4 kWh at hour 23. These decreasing values suggest a reduction in energy-intensive activities as the day progresses and people begin to wind down for the evening.

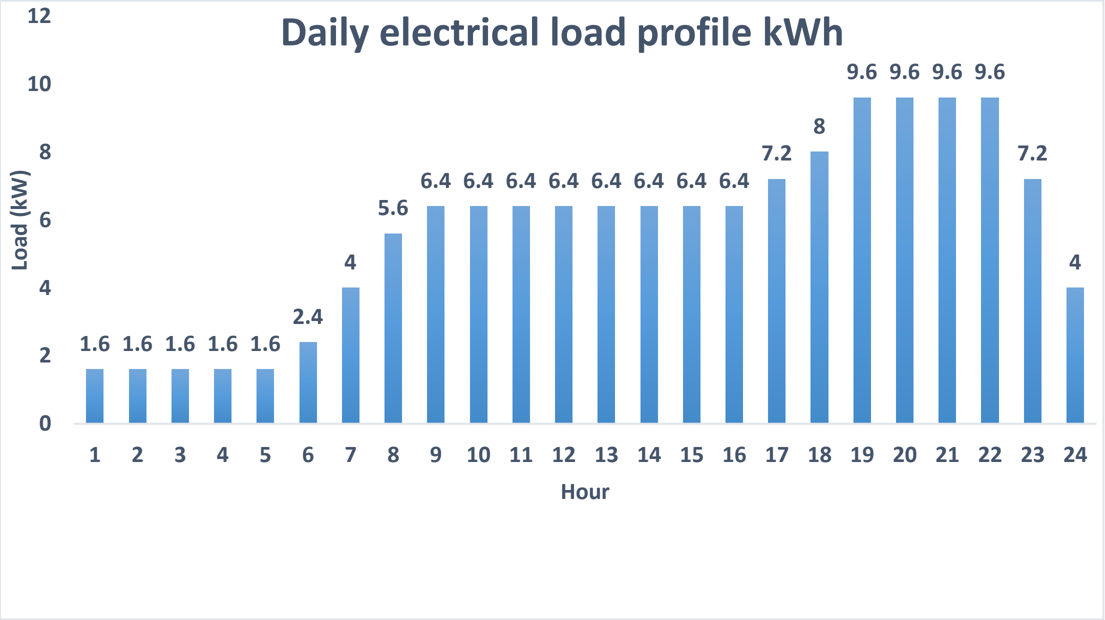

Figure 3.4. Daily electrical load profile of the Institute

3.7 Technical input

3.7.1 Solar photovoltaic panel

A SPV module produces electricity to power daytime electrical demands and as needed, recharges a battery bank. PV panels are typically sized to correspond to the whole daily load need while considering compensation factors for both technical and non-technical losses. In this study, HOMER will replicate the PV panel's capacity, which is necessary to give the Institute a steady supply of electricity. For this, HOMER requires the chosen panel to provide some technical and economic inputs. The panel chosen for this investigation was a 250W mono-crystalline silicon solar module, and the table 3.2 below lists its specifications. The typical lifespan of a PV module is 20 to 25 years, after which the estimated power output is drastically reduced. In this case, a solar module lifetime of 25 years was assumed, necessitating no replacement expenditure over the course of the 25-year project. The cost of the solar panel is $200 per unit. It is expected that each kilowatt will cost $10 to operate and maintain. To gather more energy, numerous PV panels are linked together in series and parallel within a PV array (Hossain et al, 2020).

Photovoltaic modules transform solar radiation into DC electrical power. Equation 1 is utilized to calculate the variance in the power output generated by PV modules.

3.8 System component modelling.

Numerous factors, including solar radiation, cell temperature, temperature coefficient, derating factor, type of cell structure, weather at the panel location, and environmental factors, affect a PV module's output power (Garni et al. 2018, Jatoi et al. 2018). Mathematical models of the PV array, batteries, charge regulator, and inverters are used in its execution. The following equations provide a concise summary of the mathematical models.

$$R_{PV} = R_{PV,\,STC}\, U_{PV}\, (Q_{Sr} / Q_{Sr,\,STC})[\,1 + T_o\, (T_1 - T_{2,\,STC})] \qquad (3.0)$$

Where

$R_{PV,STC}U_{PV}$ = the rated power (kW) of a PV array for standard test conditions;

U_{PV}= derating percentage.

Q_{Sr} = the quantity of solar radiation (kW/m2) hitting the PV array.

Standard radiation (1 kW/m2) is denoted by $Q_{Sr,\,STC.}$

T_o = Temperature Coefficient of Power (%/C);

T_1 = PV cell temperature (◦C)

$T_{2,\,STC}$ = PV cell temperature at 46.1°C for standard test conditions.

$T_1 = T_{amt} + (0.0256 \times Q_{Sr})$

Where T_{amt} is the ambient temperature.

Table 3.2. Technical characteristics and economic cost of the solar PV panel

	PV panel specifications
Manufacturer	Jinko Solar, China
Name plate	Slar250JKM250P60B
Type(kW)	Mono-crystalline silicon
Rated power	250
Rated Voltage(V)	37.7
Rated current(A)	8.9
Temperature of the solar cell(ºC)	46.1
Temperature coefficient(ºC)	0.432
Derating factor (%)	85
Efficiency	13
Lifetime(years)	25
Capital cost ($) per kW	800
O&M cost-($/year)-per kW	10

3.8.1 Sizing of PV generators.

To get the daily energy demand from the solar array, we first divide the total average daily energy demand (E_T) by the component system efficiencies to avoid under-sizing:

$$E_{drPV} = E_T / \delta prod \qquad (3.1)$$

Where E_{drPV} = daily PV energy requirement, E_T = total average energy demand per day, δprod = product of component′s efficiencies

Peak power is obtained by dividing the daily PV array energy requirement by the average sun hours per day for the geographical location S_{ahpd}.

$$P_p = E_{drPV} / S_{ahpd}. \tag{3.2}$$

Where P_p = Peak power, and S_{ahpd}. = average sun hours per day

Divide the peak power by the system's DC-voltage to get the total current required.

$$I_{DC} = P_p / V_{DC} \tag{3.3}$$

To get the desired voltage and current, modules must be linked in series and parallel in line with: First, the quantity of parallel modules that equals the total current of each module divided by the rated current (I_R) of each module .

$$I_{DC} / I_R = N_p \tag{3.4}$$

For number of modules in series, divide the system’s DC voltage by the rated voltage of one module.

$$V_{DC} / V_R = N_S \tag{3.5}$$

The total number of modules (M_{TN}) is equal to the product of the parallel and series modules:

$$M_{TN} = N_p \text{ x } N_s \tag{3.6}$$

3.8.2 Converter

A bidirectional power converter facilitates the transfer of energy between the micro-grid's DC bus and AC bus. The converter functions as both an inverter and a rectifier, depending on the micro-grid's energy generation, consumption, and storage conditions (Miao et al 2020). For the hybrid micro-grid, a generic system converter has been adopted. A 1kW output power is also used to calculate the converter cost. This converter has \$350 in capital and replacement costs, \$10 in O&M expenditures, and a 15-year life expectancy. It is assumed that the converter with two bus bars attached has an efficiency of 97.5%.

Normally a safety factor of 30% is considering to cater for a future increase in the size of a system. For this study, HOMER will simulate the exact size of the inverter required to efficiently handle the voltage conversion process in the system during the assumed project lifetime of 25 years, as well as estimates economic cost associated with its operation. A summary of the converter's specifications is given in Table 3.3 below.

Table 3.3. Technical characteristics and economic cost of the converter

	Converter Specifications
Item	Description
Name	System Converter
Type	Bi-directional
Rated Voltage	480
Efficiency	97.5
Lifetime	15
Capital cost($/kW)	350

Sawle et al (2021), provides the converter efficiency as:

$$E_{ff\ conv} = P_{conv(out)} / P_{conv(in)} \qquad (3.7)$$

Where $P_{conv(out)}$ is the converter output power (KW), and $P_{conv(in)}$ is the input power of the converter (KW).

3.8.3 Charge controller

A controller in HOMER serves the purpose of charging the batteries and determining power generation sequence and strategies. In homer, a controller can use different types of dispatch strategies to regulate/ rotate power production among the selected power sources. A dispatch strategy is a set of guidelines for managing dispatchable sources, such as batteries, generators, and the national grid, when the load is too big for the RESs to handle alone (Shezan et al,2021). In the HOMER software, the two main default dispatch techniques are load following (LF) and cycle charging (CC). Without forecasting the load profile or source conditions for the future, these techniques select the most economically viable configuration to meet the electrical demand at each time step.

This study used two different dispatch strategies: Homer Cycle Charging (HCC) and Load Following (LF) strategy, based on the generation sources selected. The generator doesn't charge the battery while using the LF method; it just provides enough power to meet the electrical load. RESs oversee battery charging under this technique. Conversely, under the CC method, the generator runs at full capacity to fulfil the demand for electricity and supply excess power to charge the energy storage (Aziz et al, 2019).

The array's short circuit current (I_{sc}) and the maximum battery to load current ($I_{L,max}$) should both be supported by a charge controller (Kathmandu, 2011). To figure out the load current, apply the following equation.

$$I_{L,max} = T_p / V_{syst} \qquad (3.8)$$

where $I_{L,max}$ (in Amperes) is the maximum battery to load current, V_{syst} (in Volts) is the system voltage, and T_p (in Watts) is the total power.

The charge controller should typically be chosen so that its current-carrying capacity is two times more than that of $I_{L,max}$ and I_{sc}. Since there are no inductive loads with high spike currents connected to the PV system, the scaling factor can be disregarded. However, this issue becomes crucial when there are loads in the system that have high surge currents. The charge controller's voltage rating needs to match the PV system's operational voltage.

Controller inputs are summarized in the table below. The input specifications for the controller have summarized in the table below.

Table 3.4. Technical Characteristics and Economic Cost of the Controller

	Controller specifications
Item	Item
Type	Homer cycle charging/Load following
Lifetime(yr.)	25
Capital cost ($)	3000
Set point state of charge (%)	80

3.8.4 Battery storage

Battery storage stores electrical energy and can serve as a secondary or a backup power supply, where needed. For this study, the selected battery was a generic lead-acid battery type with a charge capacity of 134Ah, a nominal voltage of 12V. Battery lifetime normally depends on the charge and discharge capacity (Shah, 2015). A minimum state of charge must be kept for batteries in a PV system to ensure better battery performance and prolong the lifetime of use of the battery. A single unit's worth of battery is calculated. Batteries have $250 initial cost,

$250 replacement cost, and $10 annual operating and maintenance expense. A six-year battery life is calculated. At least 30% discharge is possible from the battery, which is originally charged to 100%. The battery is connected to the DC bus of the hybrid micro-grid in tandem with the PV power system.

Battery replacement is required thrice during the project's lifetime. Homer simulates and determines the number of units of this kind of battery that matches the system requirement and calculates the related technical and economic output variables over the battery's lifetime. Energy storage is a significant component of the hybrid setup. The improvement of system reliability is considerably aided by it. The additional electricity produced by other power sources is stored in the battery and released when there is a lack of power (Xia et al, 2021). Round-trip efficiency is the term used to describe how effectively a battery uses its input and output energy. It may be utilized as a battery performance indicator. High system efficiency can be attributed to high round-trip efficiency, which entails minimal energy losses. The specifications of the battery used in the simulation are summarized in table 3.5 below.

Table 3.5. Technical Characteristics and Economic Cost of the BS.

	Battery Characteristics
Item	Description
Manufacturer	EnerSys PowerSafeSBS XC 190F
Type	Lead-Acid
Battery capacity (Ah)	2.51
Rated Voltage(V)	12
Throughput	2589
State of charge(initial)	100
State of charge (Minimum)	30
Efficiency	97
String	4

Lifetime	6
Unit cost	250

The following formula describes the relationship between the total system efficiency and the battery round-trip efficiency, where AC power is converted to DC power, stored in the battery, and then converted again to AC power, which is used to meet the demand for electricity (Aziz et al, 2019):

$$E_{ff(overall)} = E_{ff(inv)} \text{ x } E_{ff(rect)} \text{ x } E_{ff(brt)} \tag{3.9}$$

Where

$E_{ff(inv)}$ = inverter efficiency (%);

$E_{ff(rect)}$ = rectifier efficiency (%);

$E_{ff(brt)}$ = battery round-trip efficiency (%).

The battery discharge ($Batt_{disch}$) cost in the LF technique can be calculated using the calculation below (Aziz et al, 2019) :

$$Batt_{disch,cost} = Batt_{w,cost} \tag{3.10}$$

where $Batt_{w,cost}$ is cost of battery wear ($/kWh), and it is calculated using(Aziz et al, 2019):

$$Batt_{w,cost} = Batt_{cost,ref} / \sqrt{\eta}_{brt} \times Z_{life} \times B_t \tag{3.11}$$

where

Z_{life}: throughput of a single battery (kWh);

B_t: total number of batteries in the storage bank.

3.9 Load Following (LF) Strategy

The following examples give an overview of how the system functions under this technique.

Case 1: The following potential sub-cases could occur if the national grid is available:

- If PV production surpasses the load, the surplus power is stored in the batteries for future use.

- If PV production is less than electricity use, the cost of discharging the batteries is compared to the cost of purchasing grid power to satisfy the net load. There are two possible outcomes:

1. In cases where the cost of purchasing electricity from the grid to fulfil the net load exceeds the cost of discharging the batteries, the batteries satisfy the net load. Keep in mind that the net load is the total amount of electricity produced by photovoltaic cells less the whole amount of electricity consumed.
2. If it is less expensive than the cost of the batteries' discharge, the national grid supplies the net load.

Case 2: If the national grid is unavailable, there are two potential outcomes:

- If the electrical load is less demanding than the PV panels' output, the PV power meets the load, and the extra electricity is used to charge the batteries.

- The batteries are discharged to meet the net load if the electricity consumption exceeds the PV production.

The flowchart presented in Figure 3.5 illustrates the internal interactions of the system.

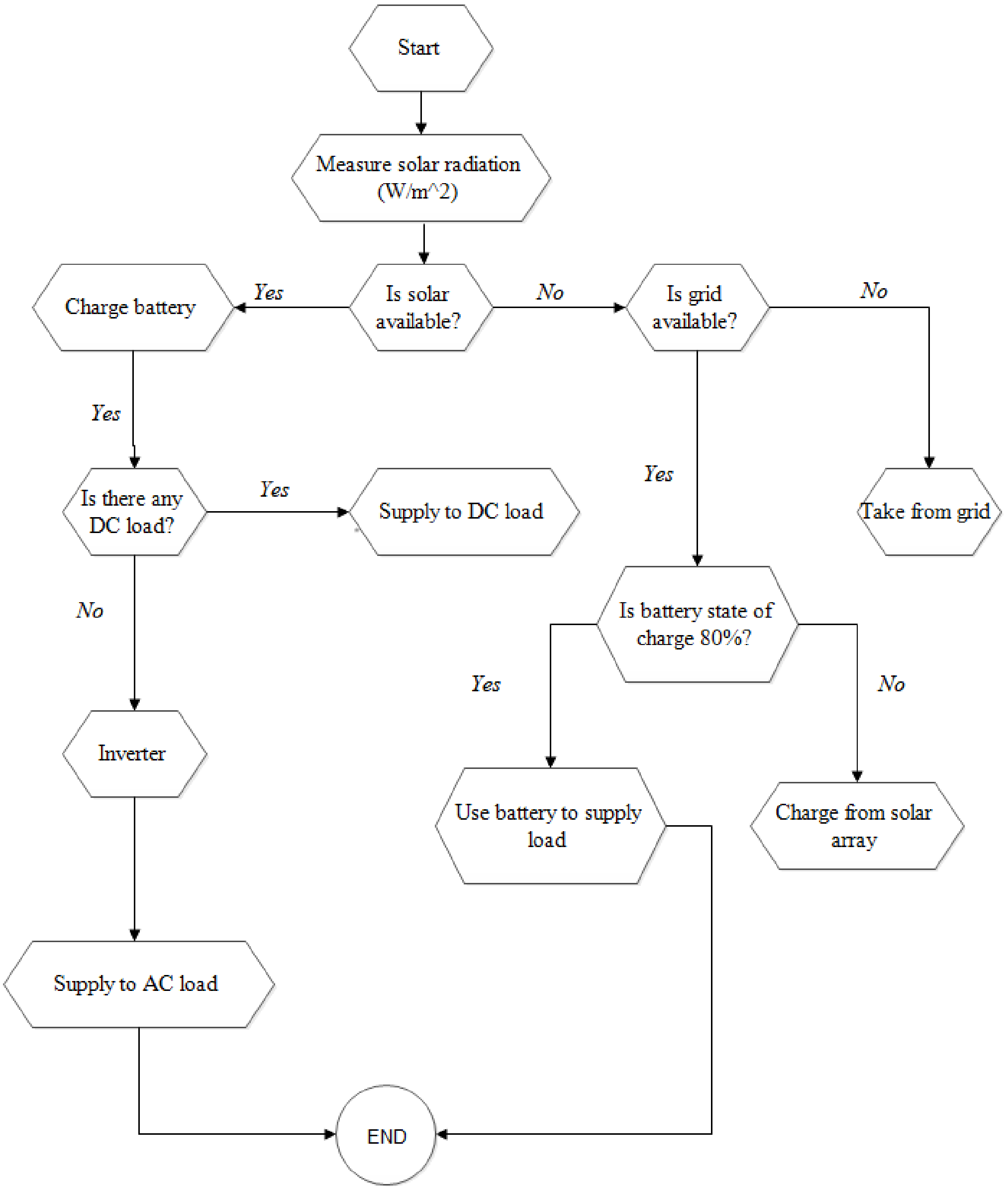

Figure 3.5. Grid-tied battery system algorithm flowchart

3.10 Overview of the Proposed PV System

Grid-connected as well as stand-alone operation are both possible with the suggested PV system. It primarily consists of the control system, block batteries, power conditioning devices, and PV generator. A grid-connected PV system without batteries will shut down during a utility power loss. Battery backup maintains some or all the electrical equipment, such as lighting, refrigeration, or fans, when a utility power failure occurs. A grid-connected system might additionally have a generator backup if the building can't withstand power outages. Design and Sizing of Systems for Solar Photovoltaic With battery backup, power interruptions could not even be noticed. Although there are several drawbacks to adding batteries to a system, they must be considered against the benefit of having a backup power source.

Homer software has been used to simulate the suggested PV system. The obtained simulation results, which are presented in this paper, confirm the suitability of the developed system design, and demonstrate that the produced and stored electrical energy is more than enough to meet the total load demands throughout the year, indicating a workable solution to the grid blackout issue affecting a sizable portion of TVET institutions in Ghana. Unfortunately, because there aren't many publications on such a unique PV system that is made for a specific use, the testing findings received could not be compared to other results of same quality.

3.11 Sensitivity

3.11.1 Specific economic Inputs

The specific economic inputs considered for HOMER include (i) the discount rate and (ii) the inflation rate. As of March 2023, in Ghana, the national inflation rate was reported to be 40.10%, and the nominal discount rate for financial lending provided by the Bank of Ghana was *26.97* (Ghana Statistical Services, 2023).

The link between the real discount rate and the nominal discount rate is illustrated by the equation below (HOMER Help Files):

$$R_{dr} = N_{dr} - E_{ir} / 1 + E_{ir} \qquad (3.12)$$

where N_{dr} is the nominal discount rate, E_{ir} is the expected inflation rate and R_{dr} is the real discount rate.The project lifetime in a HOMER Grid simulation is the time frame during which system costs are incurred. In HOMER, annualized costs are calculated from net present costs using the project lifetime. The annualized amount represents the total annualized cost of all power system components, including capital, operating, and maintenance expenses. Costs for replacement and gasoline are also included (Rezzouk and Mellit, 2015). The project lifetime for this study is 25 years.

3.11.2 Sensitivity variables

In this study, we have selected specific input variables, namely the inflation rate, discount rate, and diesel fuel prices, to conduct sensitivity analysis. Sensitivity analysis, often referred to as 'what if analysis, serves as a method to assess the impact of changes in input variables on various output variables.

In this research, the output variables under scrutiny encompass NPV (Net Present Value), capital cost, LCOE (Levelized Cost of Electricity), O&M (Operations and Maintenance) expenses, IRR (Internal Rate of Return), ROI (Return on Investment), and the payback period.

The subheadings below provide a full description of each requirement.

The HOMER program defines the cost word "NPC" as follows. "The present value of all installation and running costs for a component during the course of the project, less the present value of any revenues earned during that period, is the component's net present cost, also known as life-cycle cost. Each system component's net present cost as well as the system's overall cost are determined using HOMER. The NPC is a representation of the system's life-cycle cost and is calculated using (Beitelmal et al, 2021):

$$NPC = T_{ann,cost} / C_{rf} (R_{dr}, L_{proj}) \tag{3.13}$$

$$C_{rf} (R_{dr}, N) = R_{dr}(1 + R_{dr})^N / R_{dr} (1 + R_{dr})^N - 1 \tag{3.14}$$

Where $T_{ann,cost}$ is total annualized cost ($/year), C_{rf} is capital recovery factor, R_{dr} is real discount rate and L_{proj} is project lifetime (years),N is number of years.

Table 3.6. Input variables for sensitivity analysis

Sensitivity input variables		
variable	values	sensitivity input values
Interest rate/ discount rate (%)	26.97	29.24
Inflation rate (%)	40.3	38.34

The results of the sensitivity analysis show that the cost of electricity in a solar grid-connected system is expected to increase whenever the nominal discount rate rises (24.0%, 26.92%, 29.24%). Yet, because of the larger effect of discounting on future operating and maintenance costs, the total present cost might go down, illustrating the complex interplay between financial factors and the overall economics of renewable energy projects. The sensitivity analysis also made it abundantly evident that raising the projected inflation rate from 10.2% to 38.34% will probably lower energy costs while raising the overall present value of a solar grid-connected system. There could be a small drop in energy costs or stability in the next phase, which runs from 38.34% to 40.30%, along with a slight rise in the overall present cost.

3.11.3 Levelized Cost of Energy

Cost of energy (COE) (HOMER Help Files) is the average price per kWh of electrical energy produced by the system. Using the equation below, COE is determined in HOMER:

$$COE = T_{ann,cost} / P_{LAC} + P_{LDC} + T_{Lgridsales} \quad (3.15)$$

where P_{LAC} is the primary load served by AC in kWh/year, P_{LDC} is the primary load provided by DC in kWh/year, and $T_{Lgridsales}$ is the total load served by the grid in kWh/year. The annualized costs of each system component are added together to form the overall annualized cost, or $T_{ann,cost}$. COE and NPC are computed in HOMER using these parameters.

3.11.4 Simple Payback

According to HOMER, the simple payback period is the number of years after which the cumulative cash flow of the difference between the current system and the base case system turns positive (Moien and Marwan,2019). The simple payback illustrates how long it will take for the system to recoup its entire investment expenditures.

Payback period = Capital cost /Average yearly electricity bill. Equation. 15 below can be used to calculate capital cost.

Capital cost = Initial cost of PV system + Operation and Maintenance cost (3.16)

3.11.5. Initial Rate of Return

Internal rate of return (IRR) in HOMER is the discount rate where the base case and current system have the same net present cost (IRR). The discount rate that makes the difference between the two cash flow sequences' present values equal to zero is used by HOMER to calculate the IRR (HOMER Help Files).

3.11.6. Return on Investment

The return on investment (ROI) calculates how much money was made in comparison to the initial investment. The following equation is used in HOMER to compute ROI:

$$\mathrm{ROI} = \sum_{Rdr=0}^{Lproj} C_{NAF,ref} - C_{NAF} / L_{proj} \left(C_{syst} - C_{syst,ref}\right) \qquad (3.17)$$

Where C_{syst} the capital cost of the current system is,$C_{NAF,ref}$ is the nominal annual cash flow for the base (reference) system,C_{NAF} is the nominal annual cash flow for the current system, and

$C_{syst,ref}$ is the capital cost of the base (reference) system. A percentage or a ratio is used to express the ROI.

3..12. Summary

In this study, the methodology is meticulously outlined in a multi-section approach. The research begins by categorizing electrical load demands into administration, classroom, and electrical lab blocks, estimating energy consumption based on surveys and standard load assumptions. Technical parameters for the PV system are carefully detailed, including the specifications of mono-crystalline solar panels, converters, charge controllers, and lead-acid batteries. The load profile of Bawku Technical Institute is also presented, showcasing daily electricity consumption variations. Furthermore, the study describes the proposed PV system, capable of both grid-connected and standalone operation, with the suitability of the design confirmed through Homer software simulation. Specific economic inputs and sensitivity variables for analysis are defined, such as discount rates and inflation rates, allowing for comprehensive evaluation of the system's feasibility and economic performance.

Overall, the methodology provides a robust framework for modeling and optimizing a grid-tied PV system, considering technical and economic factors, load estimation, and sensitivity analysis. It offers a detailed roadmap for researchers and practitioners interested in implementing similar renewable energy solutions.

CHAPTER FOUR

RESULTS ANALYSIS AND DISCUSSION

4.0 Background

This chapter delves into the crucial discoveries unearthed from the study, expounding upon the load profile of the case study area, and delving into the salient simulation results derived from the configurations of systems employed. Furthermore, the chapter broaches the subject of the proposed system, deemed the most feasible, and elucidates upon the outcomes of the sensitivity analysis.

4.1 Simulation scenarios

The four different scenarios for which simulations were done are the following.

Table 4.0. Simulation for all the scenarios

Scenario	Configuration
Scenario A(SA)	Grid only
Scenario B(SB)	PV + Grid
Scenario C(SC)	PV + BS
Scenario D(SD)	PV + Grid +Battery

4.1.1 Scenario A (SA) – Grid only

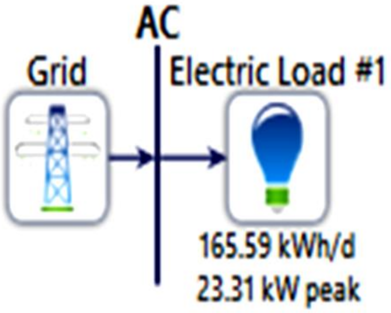

Figure 4.0: Scenario A (SA) for Grid only

Table 4.1. Scenario A (SA) for Grid only

SCENARIO A	
NPC ($)	108,899.36
Levelized cost of energy (LCOE) ($)	0.427kWh
Annual operation ($)	27,209
Renewable fraction (%)	0
Initial cost ($)	3,000
AC and DC primary load (kWh)	60,442kWh

In this configuration a Grid was selected to be the only source of power generation. The key economic outputs are discussed in the following paragraphs. From the simulation and the table 4.1 above, the size of the grid proposed to meet the expected electricity demand for Bawku technical institution Net Present Cost (NPC) for Scenario A amounts to $108,899.36. This value represents the total discounted cost of energy consumption and relevant expenses over the operational lifetime of the project. The Levelized Cost of Energy (LCOE) for Scenario A is calculated to be $0.427 per kilowatt-hour (kWh). This metric provides an average cost for producing each unit of energy, encompassing both the initial investment and ongoing operational costs. With an annual operating cost of $27,209, Scenario A incurs continuous expenses associated with the maintenance and operation of the energy infrastructure. Notably, Scenario A exhibits a renewable fraction of 0%, indicating an exclusive dependence on grid-provided energy. The absence of renewable energy integration underscores a missed opportunity to introduce sustainable and environmentally friendly energy sources.

The initial cost linked to Scenario A is $3,000. This relatively modest amount likely pertains to initial setup expenses, although it is noteworthy that this cost is considerably smaller compared to the cumulative costs over the system's operational lifespan. Furthermore, Bawku Technical Institute's yearly AC and DC primary load consumption is measured at 60,442 kWh.

This amount reflects the total energy consumption by the institution's primary loads, encompassing both alternating current (AC) and direct current (DC) systems.

4.1.2 Scenario B (SB) PV + Grid

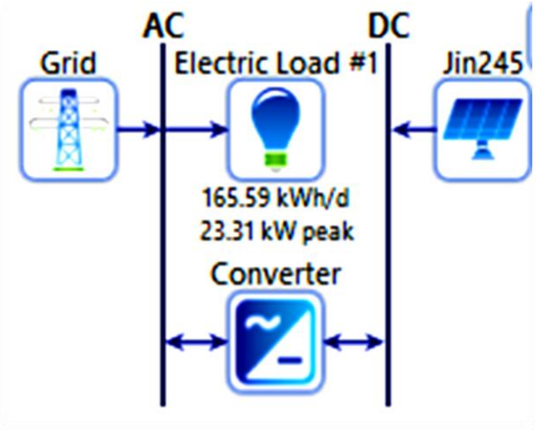

Figure 4.1. Scenario B (SB) for Grid and PV

Table 4.2. Scenario B (SB) for Grid and PV

SCENARIO B	
NPC ($)	201,995.23
Levelized cost of energy (LCOE) ($)	0.454kWh
Operating cost ($)	27,035
System converter electrical loses	9.96kWh/yr
Renewable fraction (%)	0.643
Initial investment ($)	3,064
System converter operating hours	4,380hrs
Excess electricity	1.14kWh

Scenario B introduces a hybrid energy solution that intelligently combines solar photovoltaic (PV) energy with grid-supplied power. The Net Present Cost (NPC) for Scenario B is calculated at $201,995.23. This figure encapsulates the comprehensive discounted costs associated with energy consumption and other relevant expenses throughout the operational lifespan of the hybrid system.

The Levelized Cost of Energy (LCOE) for Scenario B stands at $0.454 per kilowatt-hour (kWh). This metric represents the average cost of generating each unit of energy, considering both the initial investment and the ongoing operational costs. Operating costs for Scenario B amount to $27,035 annually. This encompasses expenditures linked to the maintenance and operation of the hybrid energy infrastructure, striking a balance between sustainable practices and economic feasibility.

The initial investment cost for implementing Scenario B is $3,064. This investment encompasses the necessary expenditures to establish the hybrid system that seamlessly integrates solar PV and grid connections. The renewable fraction achieved within Scenario B is calculated at 0.643%. This value signifies that approximately 0.643% of the overall energy consumption is sourced from the renewable solar PV system, marking a positive step toward sustainability.

Furthermore, the usable renewable capacity's complete utilization, reaching 100%, underscores the efficient harnessing of the available renewable energy potential. The solar PV system contributes an annual energy production of 400 kWh. This productive capacity symbolizes the yearly energy output from the solar PV system, highlighting its potential to contribute to the institution's energy needs. An excess of 1.14 kWh of electricity is generated annually by the hybrid system. This surplus energy could be employed for grid feedback or other purposeful applications, potentially yielding additional cost savings. The system converter, operational for 4,380 hours per year, indicates a substantial utilization rate. This statistic portrays the converter's active engagement in the energy conversion process.

However, the system converter also incurs electrical losses amounting to 9.96 kWh per year. These losses serve as a reminder of the inherent inefficiencies in energy conversion processes, warranting ongoing optimization efforts.

4.1.3 Scenario C (SC) PV + BS

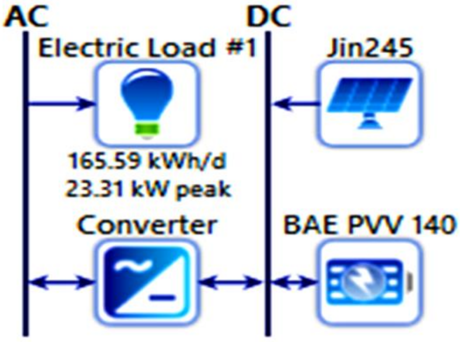

Figure 4.2. Scenario C (SC) for PV and Batteries

Table 4.3. Scenario C (SC) for PV and Batteries

SCENARIO C	
NPC ($)	203,995.23
Levelized cost of energy (LCOE) ($)	0.451kWh
Operating cost ($)	19.035
System converter electrical loses	9.96kWh/yr
Renewable fraction (%)	0.643
Initial investment ($)	3,064
System converter operating hours	8,760hrsb
Excess electricity	1.14kWh

Scenario C introduces a solar photovoltaic (PV) system in tandem with battery storage. The Net Present Cost (NPC) for Scenario C is calculated at $203,995.23. This numerical representation encapsulates the discounted aggregate cost of energy consumption and pertinent expenses across the operational lifespan of the hybrid system.

The Levelized Cost of Energy (LCOE) for Scenario C stands at $0.451 per kilowatt-hour (kWh). This metric delineates the average cost of generating each unit of energy, encompassing the initial investment, and sustained operational costs. Operational costs for Scenario C amount to $19.035 on an annual basis. This comprises the financial commitments linked to preserving and operating the hybrid energy infrastructure, demonstrating an equilibrium between sustainability and financial prudence.

The initial cost associated with implementing Scenario C is $3,064. This initial investment encompasses the necessary disbursements for establishing the hybrid system, harmonizing solar PV generation with battery storage capabilities. A renewable fraction of 0.643% is achieved within Scenario C. This percentage highlights that approximately 0.643% of the total energy consumption is sourced from the renewable solar PV system, attesting to a deliberate step toward sustainable energy practices. Moreover, the hybrid system's energy production capacity reaches 400 kWh annually. This productive capability represents the annual energy output from the solar PV system, underlining its potential to significantly contribute to the energy requirements of the institution.

The system converter, operating for a substantial 8,760 hours annually, emphasizes a robust utilization rate. This statistic underscores the system converter's active involvement in the energy conversion process, contributing to sustained energy flow. Scenario C holds the promise of enhanced energy autonomy and stability, facilitated by its integration of battery storage. The modest Net Present Cost underscores the potential long-term economic benefits, making it a viable option for consideration. Incorporating battery storage could enable the institute to harness solar energy during peak generation periods and deploy it during high-consumption periods or when solar production is low. This strategy can lead to reduced reliance on the grid and lower energy costs over time.

4.1.4 Scenario D (SD) PV + Grid + Battery

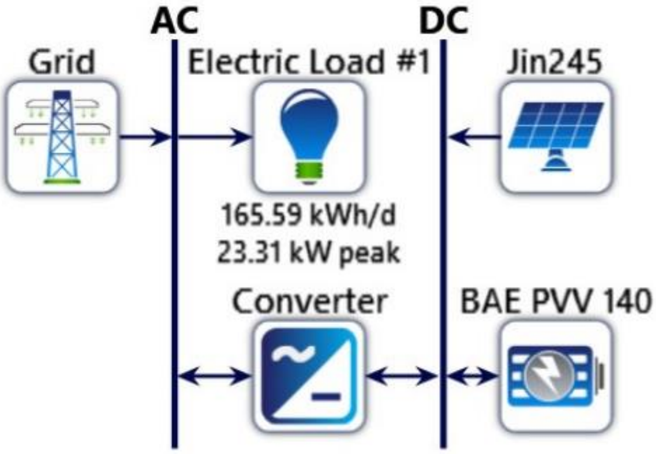

Figure 4.3. Scenario D (SD) for PV, Battery, and Grid

Table 4.4. Scenario D (SD) for PV, Battery, and Grid

SCENARIO D	
NPC ($)	204,221.00
Levelized cost of energy (LCOE) ($)	0.446kWh
Operating cost ($)	26,410.00
Renewable fraction (%)	3.69
Initial investment ($)	4,363.00
Total energy production	58,611kWh

Scenario D introduces a comprehensive energy strategy involving solar photovoltaic (PV) generation, grid connection, and battery storage. The Net Present Cost (NPC) for Scenario D amounts to $204,221. This numerical representation captures the discounted aggregate cost of energy consumption and other relevant expenses spanning the operational lifetime of the integrated energy system.

The Levelized Cost of Energy (LCOE) for Scenario D stands at $0.446 per kilowatt-hour (kWh). This metric signifies the average cost of generating each unit of energy, encompassing both the initial investment and ongoing operational costs. The annual operating cost for Scenario D is $26,410. This encompasses the financial outlays associated with maintaining and operating the comprehensive energy infrastructure, combining solar PV, grid connection, and battery storage.

The initial investment cost for implementing Scenario D is $4,363. This initial outlay encompasses the requisite expenditures for setting up the multifaceted energy system, seamlessly blending solar PV and battery storage with grid integration. A renewable fraction of 3.69% is achieved within Scenario D. This percentage indicates that approximately 3.69% of the total energy consumption is sourced from the renewable solar PV system, signifying a marked advancement toward sustainable energy adoption. Furthermore, the hybrid system's energy production capacity reaches 400 kWh annually. This productive capability underscores the yearly energy output from the solar PV system, highlighting its contribution to the institute's energy needs. Intriguingly, the scenario reports zero fuel consumption, demonstrating the system's complete independence from conventional fuel sources. The total energy production for the institution tallies to 58,611 kWh annually. This holistic energy generation capacity showcases the integrated system's ability to meet the energy requirements of Bawku Technical Institute effectively.

The calculated renewable production divided by total energy generation results in a value of 0.682%. This percentage underlines the proportion of energy generated from renewable sources within the overall energy mix. Scenario D presents an all-encompassing energy approach, uniting solar PV generation, battery storage, and grid connectivity. This solution showcases the potential for cost savings, reduced environmental impact, and enhanced energy security.

In conclusion, the battery storage allows for energy capture during optimal solar production periods, subsequently enabling its deployment when energy demand peaks or solar generation is limited. This strategy can contribute to lowered energy costs and greater energy self-sufficiency.

4.2 Comparative analysis of the four scenarios

The table 4.5 below gives a summary of some of the important outputs based on optimization results for the various scenarios.

Table 4.5. Economic output parameters of the four scenarios

SCENARIO TYPE				
Architecture	Scenario A (SA) Grid only	Scenario B (SB) PV+ Grid	Scenario C(SC) PV+Battery	Scenario D (SD) PV+Grid+Battery
NPC ($)	108,899.36	201,995.23	207,618.00	204,221.24
CC ($)	3,000.00	3,020.00	4,478.57	4,362.90
LCOE ($)	0.427	0.451	0.454	0.446
O&M	7,899.36	15,014.15	204,581.20	198,708.59
Total electricity production(kWh/y)	60,442.00	48,271.00	60,453.00	58,611.00
Excess electricity produced(kWh/yr)	0	1.09	1.14	1.02
Renewable fraction	0.00	0.64	0.64	3.69
Fuel consumption	0.00	0.00	0.00	0.00
Greenhouse Emission	0.00	0.00	0.00	0.00

When comparing the economic viability of the scenarios, Scenario A solely relies on the grid, resulting in a high Net Present Cost (NPC) of $108,899.36 due to substantial operating and maintenance expenses. The Levelized Cost of Energy (LCOE) is relatively high at $0.427 per kWh, reflecting the costly nature of grid-based electricity. However, this scenario lacks renewable energy integration, resulting in no reduction in operating expenses or greenhouse gas emissions.

Scenario B, incorporating solar PV with the grid, offers a more cost-efficient alternative. The NPC drops significantly to $201,995.23 showcasing the advantage of renewable energy. The LCOE decreases to $0.451 per kWh, indicating cost savings in energy production. Operating and maintenance costs (O&M) are reduced to $15,014.15. With a renewable fraction of 0.643%, this scenario contributes to lowering grid reliance and environmental impact, while excess electricity production demonstrates the potential for energy surplus.

Scenario C introduces battery storage to the solar PV system. The NPC increases to $207,618.00 due to battery costs, but the LCOE remains competitive at $0.454 per kWh. Operating and maintenance costs (O&M) rise to $204,581.20 due to battery maintenance. The slightly improved renewable fraction of 0.644% and optimized energy management potential are notable. Initial battery investment increases costs, but reduced grid reliance and optimized energy consumption may yield long-term benefits. In terms of viability, Scenario D integrates solar PV, grid connectivity, and battery storage.Even though the Net present cost and the Levelized cost of energy increased to $204,221.24 and $0.446/kWh respectively as compared to the grid only (Scenario A),it is still seen as cost-effective because of its dependability and reliability aspect. Operation and maintenance costs (O&M) is still high as compared to grid only but with the improvement of renewable fraction to 3.69% coupled with the battery integration the reliability on grid has significantly dropped. Battery integration enables excess energy management and potential cost savings, making it a favorable option. In summary, when considering the economic and environmental aspects, transitioning from conventional grid reliance to comprehensive renewable energy solutions consistently leads to improved cost efficiency, reduced operating expenses, and potential long-term benefits. The incorporation of renewable energy sources and storage technologies enhances the potential for sustainable and viable energy systems.

4.3 Net present cost for all scenario

The data presents Net Present Cost (NPC) values in dollars for various energy scenarios, offering insights into the financial implications of each scenario over the project's lifespan. In the "Grid Only" scenario, where electricity is solely sourced from the grid, the associated NPC value is $108,899.36. This indicates the estimated cost of relying entirely on grid-supplied electricity. Transitioning to the "PV + Grid" scenario, which combines solar photovoltaic (PV) panels with grid electricity, the NPC value increases to $201,995.23. This reduction implies that integrating solar panels leads to potential cost savings compared to relying solely on the grid. The "PV + Battery" scenario, involving solar panels and battery storage, results in an NPC value of $207,618.01. Despite the additional costs of battery integration, this scenario remains financially viable, suggesting benefits in terms of energy independence and possible cost savings during varying demand periods. In the scenario of "PV + Grid + Battery," where solar panels, grid electricity, and battery storage are combined, the NPC value is $204,221.24. This configuration demonstrates a lower cost compared to relying solely on the grid, indicating the economic advantages of incorporating both solar generation and battery storage.

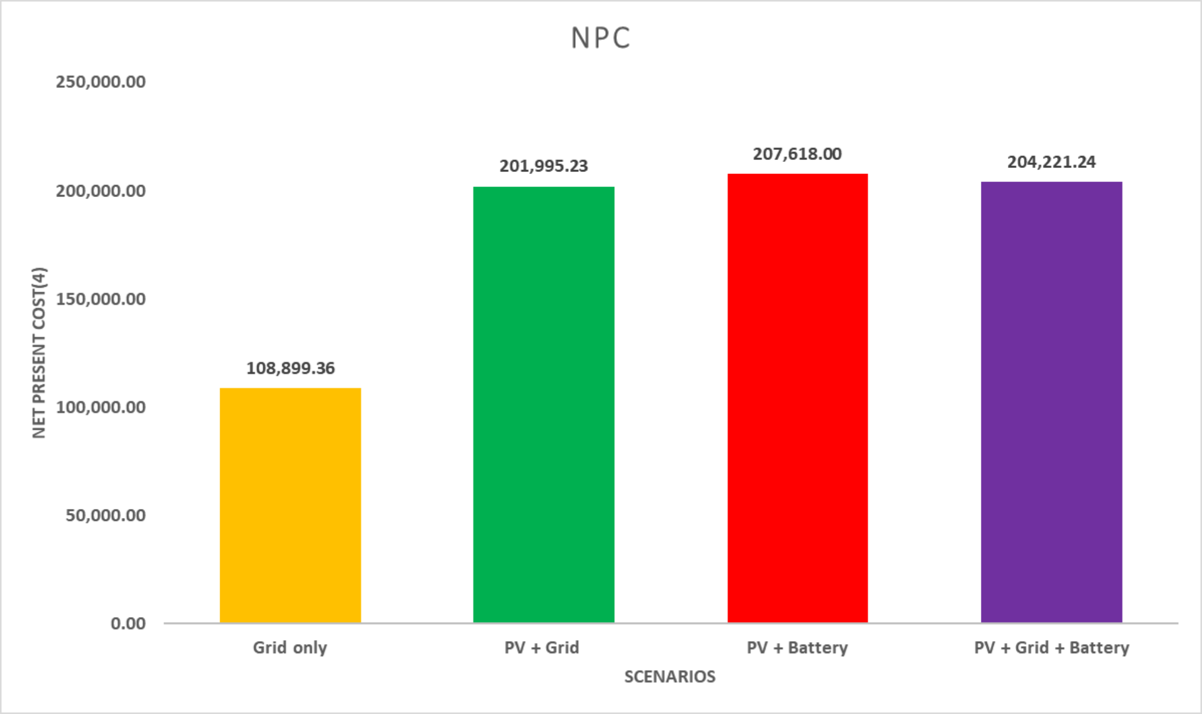

Figure 4.4. Net present cost for all scenario

4.4 The Levelized cost of electricity.

The levelized cost of electricity (LCOE) of the four scenarios, SA, SB, SC, and SD, as obtained from the optimization findings, are \$0.427/kWh, \$0.451/kWh, \$0.454/kWh, and \$0.446/kWh, suggesting SD as the system with the lowest LCOE.

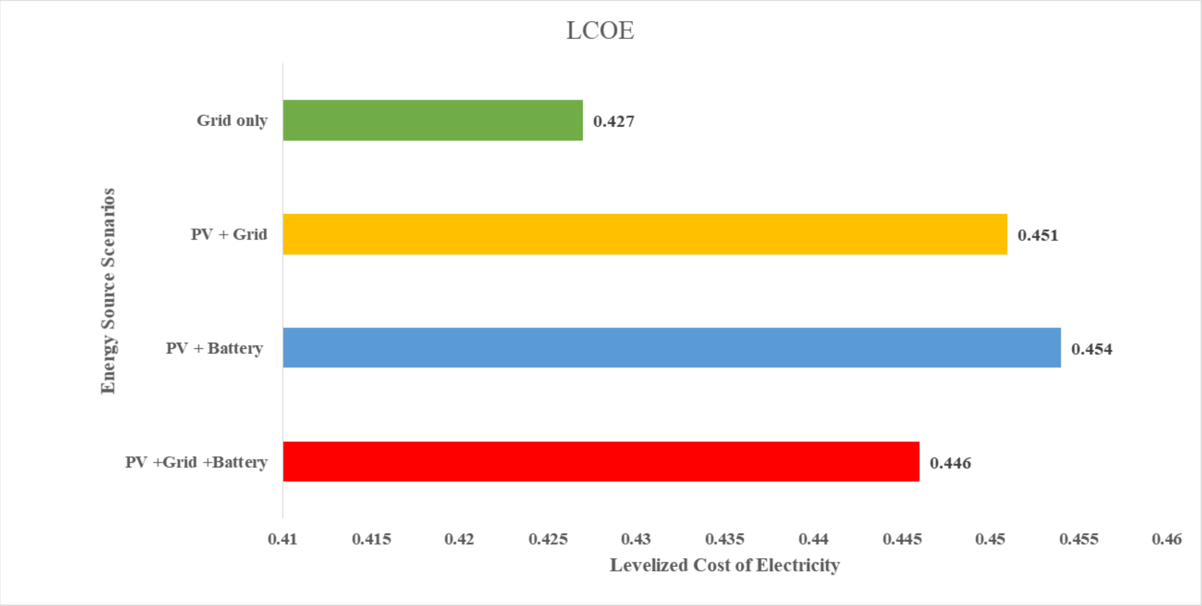

Figure 4.5. The Levelized cost of electricity for all scenarios.

4.5 Total electricity production (kWh/yr)

In the "Grid Only" scenario, the total electricity production stands at 60442 kWh/yr. This scenario reflects a traditional setup where electricity needs are exclusively met through the conventional grid infrastructure. Transitioning to the "PV + Grid" scenario, which integrates solar PV panels with grid electricity, the total electricity production decreases to 48271 kWh/yr. This reduction indicates that the joint contribution of solar panels and grid supply is insufficient to fully satisfy the electricity demand observed in the "Grid Only" setup.

Conversely, the "PV + Battery" scenario demonstrates a notable increase in total electricity production, reaching 60453 kWh/yr. Here, surplus energy generated by the solar panels is harnessed through battery storage, augmenting electricity availability during periods of limited solar output. A closer examination of the "PV + Grid + Battery" scenario, involving a combination of solar panels, grid electricity, and battery storage, reveals a total electricity production of 58611 kWh/yr. Although slightly lower than the "PV + Battery" scenario, this outcome suggests potential optimization opportunities for the coordination of these energy sources.

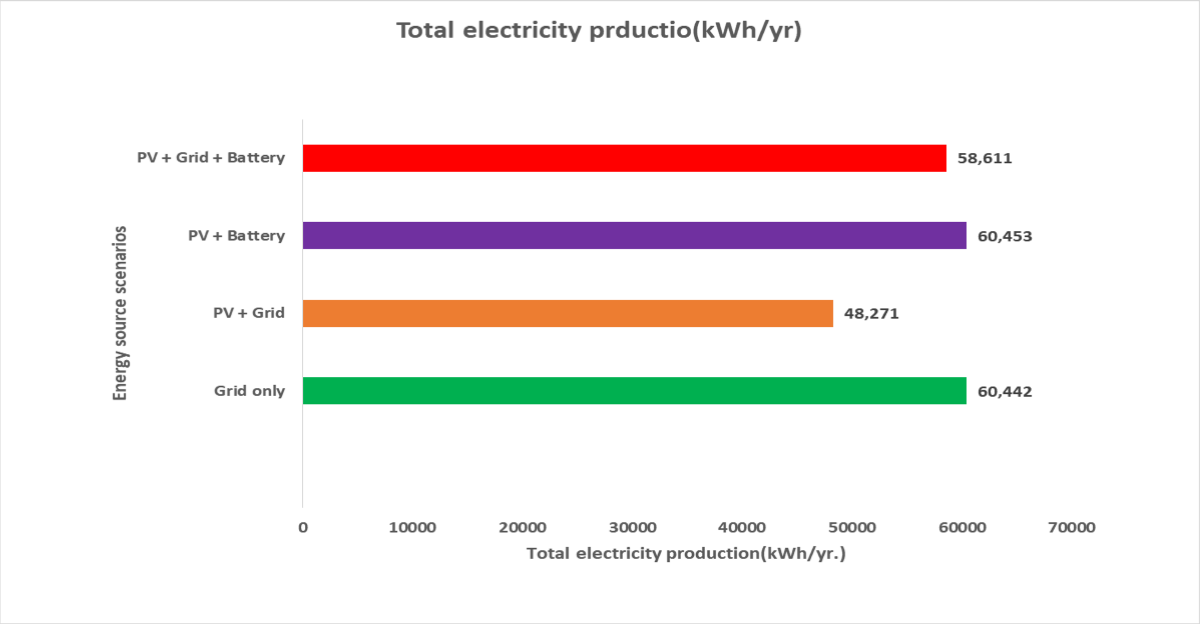

Figure 4.6 Total electricity production (kWh/yr) for the four scenarios

4.6 The proposed system

The HOMER software was used to optimize the economic feasibility of a hybrid power generation system to offer reliable electrical supply for the Bawku technical institute. The best-case scenario for energy supply for the Bawku technical institute was determined using the methodology of a comparative analysis among four possible scenarios evaluated in this study, taking into consideration economic and technical output characteristics. Among the most reliable hybrid energy systems that boost the dependability of educational institution energy consumption are those that integrate renewable energy sources with the main grid. The on-grid scenario, depicted in Figure 4.7, considered four devices: PV panels, the grid, converters, and batteries, together with primary load 1, which has a peak power of 23.31 kW and a daily consumption of 165.59 kWh. According to the optimization results, 246 simulated solutions and 246 workable ones were found. 39 cases were excluded altogether (0 because it was not feasible, 22 because there was no converter, and 13 because there was an extra converter). Table 4.5 illustrates how four optimized solutions for the on-grid hybrid system are ordered according to NPC.

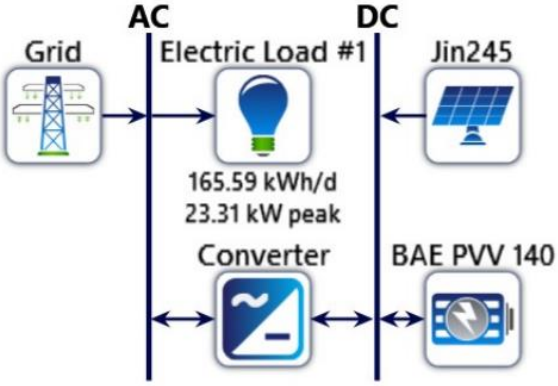

Figure 4.7. Schematic layout of the proposed system

4.6.1 PV panel

The SPV array has a rated capacity of 0.245kW, which is projected to provide a source of steady power supply to fulfill the expected electrical demand, with a selected PV nodule of 250 watts rating. The PV array has a daily average output capacity of 1.10 kWh. The SPV penetration is 0.661% and is scheduled to operate for 4,380 hours per year, producing 400kWh of energy per year, accounting for 18.6% of the total electricity generated by the system. The PV array's LCOE is $0.0177/kWh. Figure 4.8 shows that because of the availability of sunshine, energy production is significant during the day (from 6:00 a.m. to 5:00p.m.). Additionally, from October through April, the amount of power generated reached its highest level.If one closely examines Figure 4.8, one will notice that the darker areas correspond to the times of day when the PV production is zero, which are, respectively, from 0 to 6 am and 6 pm to 6 am. When that moment comes, the institute will have to match the load demand by either discharging battery energy or utilizing energy from the national grid. Figure 4.8's centre section depicts the daytime peak PV output, which occurs between 6 a.m. and 6 p.m. Figure 4.8 indicates the PV output power for the grid-connected PV system with storage. The output ranged between 0.0 kW and 0.25 kW (peak). The 0.25kW output peak occurred about mid-day throughout the day although much of the year produced between 0.10kW and 0.15kW,respectively

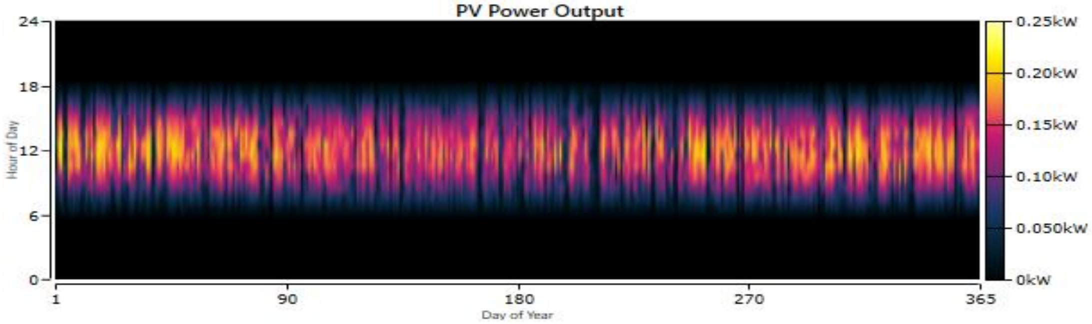

Figure 4.8. Power output from PV array for scenario D(SD)

4.6.2 Battery

Homer approximated the hybrid system's battery bank demand as 68 batteries with a nominal capacity of 6.45kWh and a string size of 4 batteries, meaning the number of batteries in a serial connection is 4, resulting in a system voltage of 48V. Battery autonomy is the number of hours that the demand load can be met entirely by energy stored in the battery bank. Homer calculated the battery autonomy for the hybrid system to be 0.654 hours, with a projected lifetime of years and an annual throughput of 10.7kWh/yr in accordance with the SOC attributes displayed in Figure 4.9. In addition, the battery must have a minimum SOC of 30% to power the load. Given that the most practical working condition is independent of the storage system utilization, the energy delivered to the battery from the utility through the converter is rectified to zero watts.

The sum of energy inputs and outputs from the batteries is 6.56kWh/yr and 10.2kWh/yr, respectively, and the battery storage accounts for a 0.888kWh/yr loss in total energy stored. The capital cost of the 67 batteries is $3,049, while the average energy cost is $0.0214/kWh.The blue section in Figure 4.9 shows that the battery is fully charged throughout the day and may be used to power the essential loads of the institute when the grid is unavailable at night.The battery's status of charge during the year is shown in Figures 4.9. It is evident that the battery is at minimum charged, readings falling between 30% and 40%. During the raining season, we can also observe lower numbers, ranging from 0% to 20%.

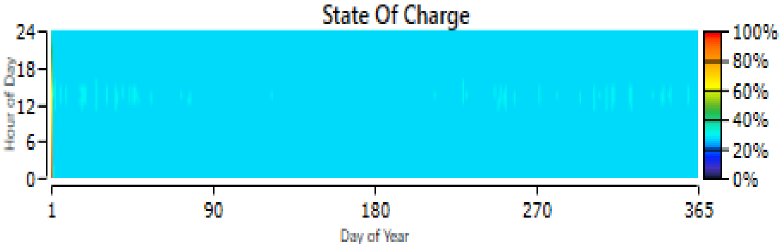

Figure 4.9 Average battery SOC per year for various loading scenarios during the day.

4.6.3 Converter

With a capacity factor of 27.4%, the inverter in Fig.4. 10 (top) illustrates that the largest power transfer happened during the day, from 6:00 a.m. to 6:00 p.m. Alternatively, when the PV generators are not in use at night, the battery system is often charged from the grid..The simulation results again revealed that the converter's capacity, or maximum output, was 0.164kW. The inverter unit is projected to run for 7,050 hours per year, with a 403kWh intake and a 393kWh output. The rectifier operates for 6,234 hours per year, with annual energy input and output of 425kWh and 375kWh, respectively.From 6 a.m. until 6 p.m. every day, the inverter output reaches its maximum. The darker regions in Figure 4.10 represent the inverter's lowest output during the early morning, which is between 0 and 6 am, and late evening, say after 6 pm.

However, based on the simulation results displayed it is evident from Fig 4.. 10 (bottom) that the rectifier was turned off to recharge storage devices from the grid. This can prolong the life of the converter, lower O&M expenses, lessen the effects of harmonics, and lower emission levels. Figure 4.10's dark-appearing rectifier indicates that it is turned off to give the inverter time to recharge at night from the national grid.Fig. 4.10 indicates the the inverter output power for the grid-connected PV system. The output ranged between 0.0 kW and 0.20 kW (peak). The 0.20kW output peak occurred about mid-day throughout the day although much of the year produced between 0.08kW and 0.16kW,respectively.

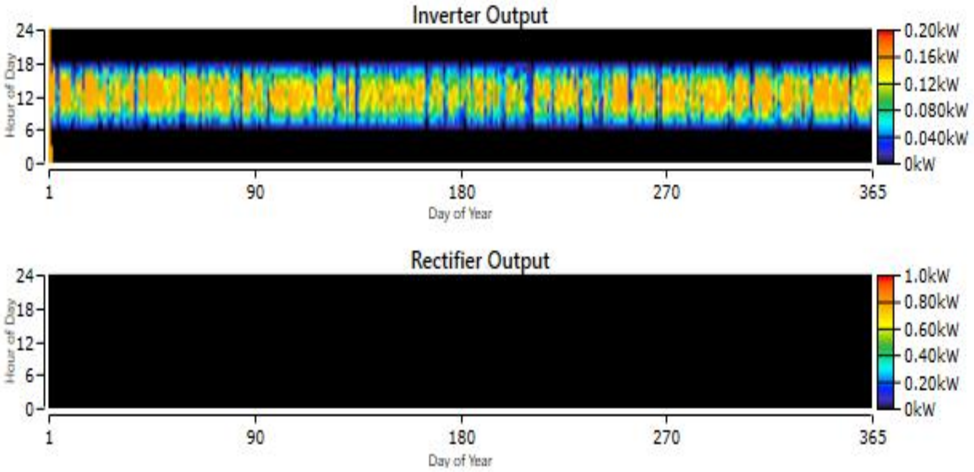

Figure 4.10. Daily performance of the output of the rectifier and inverter.

4.6.4 Grid only.

This paper's major goal was to use hybrid solutions to lessen reliance on the grid. The grid was intended to be inactive and occasionally partially functional. Since solar PV generation peaks during the day, the grid is typically turned off at that time. Since the school is already linked to the grid, there is no need for construction expenditures. The total amount of electricity purchased from the grid for the duration of the project is $27,022. The monthly energy purchased from the grid, peak demand, and associated energy charge are displayed in Table 4.6

Table 4.6. Grid power consumption per month

Month	Energy Purchased(kWh/yr.)	Energy Charge
January	$4,030	$1,813
February	$3,709	$1,669
March	$4,691	$2,111
April	$4,954	$2,229
May	$5,529	$2,488
June	$5,828	$2,623
July	$6,058	$2,726
August	$6,182	$2,782
September	$5,467	$2,460
October	$5,015	$2,257
November	$4,388	$1,975
December	$4,196	$1,888
Annual	$60,048	$27,022

The provided datasets in table 4.6 include monthly energy usage in kilowatt-hours (kWh) and the related energy charges for each month of the year, as well as the annual total. The energy consumption in January was 4,030 kWh, resulting in a $1,813 energy charge. The measured energy consumption for February was 3,709 kWh, resulting in a $1,669 energy charge. Moving on to March, total energy consumption for the month was 4,691 kWh, resulting in a $2,111 energy bill. In April, the total energy consumption was 4,954 kWh, resulting in a $2,229 energy charge.

The energy consumption for the month of May was 5,529 kWh, resulting in a $2,488 energy charge. As we enter June, our energy consumption increased to 5,828 kWh, with a $2,623 energy bill. July's energy consumption was considerably greater, at 6,058 kWh, resulting in a $2,726 energy a charge. In August, energy consumption was 6,182 kWh, with an accompanying energy charge of $2,782. In September, energy use was lowered to 5,467 kWh, resulting in a $2,460 energy penalty. Energy consumption in October was 5,015 kWh, resulting in a $2,257 energy charge. In November, the energy consumption fell to 4,388 kWh, with a $1,975 energy bill. Finally, in December, the energy use was measured at 4,196 kWh, resulting in a $1,888 energy charge. The overall yearly energy bill was $27,022, based on a total annual energy consumption of 60,048 kWh. Figure 4.11 below depicts the quantum of energy that the institute purchased from the national grid.

4.7 Summary of the chapter

In summary, a comprehensive analysis of the various energy scenarios evaluated for the Bawku Technical Institute, shedding light on their economic and technical implications. The Net Present Cost (NPC) values reveal that transitioning from a grid-only scenario to those incorporating solar PV panels and battery storage can lead to significant cost savings, with Scenario D (PV + Grid + Battery) emerging as the most economically favorable choice. The Levelized Cost of Electricity (LCOE) further underscores the financial benefits of renewable energy integration, with Scenario D having the lowest LCOE. Total electricity production demonstrates the potential for surplus energy generation when battery storage is introduced, with Scenario C (PV + Battery) and Scenario D offering the most promising outcomes. The proposed system combines grid supply with a solar PV array and battery storage, boasting the lowest NPC and LCOE, making it the most cost-efficient solution. Grid energy consumption data provides insights into monthly energy usage and charges, while a breakdown of energy purchased from the grid highlights seasonal variations. In summary, this chapter underscores the economic and technical advantages of renewable energy integration, battery storage, and a well-balanced hybrid energy system, offering valuable guidance for selecting the optimal energy scenario for the Bawku Technical Institute.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Summary of the finding

This thesis work has led to several critical findings, unveiling the path toward a sustainable and economically viable energy solution specifically designed for Bawku Technical Institute.

First, a comprehensive analysis of four primary energy scenarios was conducted: Grid Only (SA), PV + Grid (SB), PV + Battery (SC), and PV + Grid + Battery (SD). Among these, Scenario D (SD) emerged as the most promising option due to its optimal balance between economic viability and sustainable energy integration. Throughout the research, a notable trend was the consistent increase in cost-efficiency as renewable energy sources were progressively integrated into the energy systems. The Levelized Cost of Energy (LCOE) demonstrated a continuous reduction, underlining significant cost savings.

Renewable fraction, which indicates the proportion of energy from sustainable sources, notably increased with the incorporation of solar PV and battery storage. Scenario D (SD) achieved the highest renewable fraction, indicating reduced grid dependence and a stronger commitment to sustainability.

Battery storage played a pivotal role in efficiently managing surplus energy. It promised energy self-sufficiency, decreased reliance on the grid, and potential cost savings, positioning it as a catalyst for sustainability. Environmental considerations revealed a consistent reduction in greenhouse gas emissions in scenarios with renewable energy sources, ultimately reaching zero emissions.

The study also highlighted a meticulously designed hybrid system exemplified in Scenario D. This comprehensive system includes a solar PV array, battery storage, and an inverter, which efficiently integrates solar PV, grid connectivity, and battery storage. Scenario D achieved a substantial renewable fraction of 3.69%. A compelling finding was the significant reduction in energy purchased from the grid, indicative of substantial cost savings and fortified energy self-sufficiency. Scenario D demonstrated potential financial stability through a substantial decrease in grid reliance.

Lastly, the proposed hybrid system, as portrayed in Scenario D (SD), succeeded in satisfactorily catering to the institute's annual energy consumption, standing at 60,048 kWh. These findings emphasize the viability of the hybrid system to meet the institute's energy needs while presenting opportunities for further optimization and efficiency enhancements.

In summary, the findings collectively underscore the transformative potential of transitioning toward sustainable energy solutions. By reducing grid dependency, integrating renewable energy sources, and optimizing energy systems, Bawku Technical Institute can effectively meet its energy needs while upholding financial prudence and environmental responsibility. The proposed hybrid system, exemplified in Scenario D, serves as a robust model for achieving these objectives, contributing significantly to the overarching goal of energy security and sustainability. This research offers a solid basis for making well-informed choices as the institution looks for an effective, dependable, and environmentally responsible energy solution.

5.2 Conclusion

In conclusion, this thesis research has thoroughly examined various energy scenarios for Bawku Technical Institute. The study emphasized the critical need to transition towards sustainable energy sources. As the level of renewable energy integration increased, there was a consistent improvement in cost-efficiency and environmental responsibility.

One significant finding was the value of battery storage, which plays a vital role in enhancing energy management. Batteries allow the capture of surplus energy during peak solar production periods and its deployment during high-consumption phases, leading to cost savings and reduced grid reliance. Across all scenarios, there was a significant reduction in energy purchased from the grid, indicating the potential for significant cost savings and increased energy self-sufficiency. Scenario D (SD) stands out as a model for achieving energy self-sufficiency, significantly reducing grid dependence. The research culminated in the proposal of an optimal hybrid system represented by Scenario D. This hybrid system features a solar PV array, battery storage, and an inverter. It efficiently blends solar PV generation with grid connectivity and battery storage, serving as a strong foundation for achieving reliable, cost-effective, and environmentally conscious energy solutions. The study also highlighted the potential for further optimization and efficiency enhancements. The proposed hybrid system in Scenario D provides a valuable blueprint for making informed decisions to ensure a reliable, cost-effective, and environmentally sustainable energy future for Bawku Technical Institute. In summary, the research underlines the transformative potential of embracing sustainable energy practices to align with the institution's energy security and sustainability goals. By adopting renewable energy sources, battery storage, and efficient energy management, Bawku Technical Institute can move towards a resilient and sustainable energy future. This work contributes to the knowledge base for implementing energy solutions that ensure reliable power supply while respecting economic and environmental considerations.

5.3 Recommendation

Scenario D (SD) is opted for Bawku Technical Institute as it presents the most balanced approach between economic viability and sustainability. This involves the implementation of a comprehensive hybrid energy system, which combines solar photovoltaic (PV) systems, battery storage, and grid connectivity. This option significantly reduces reliance on the conventional grid and offers the potential for long-term energy cost savings. To move towards sustainable energy solutions, the institute should prioritize the installation of appropriately sized solar PV systems as the primary source of electricity generation. Regular maintenance of these systems is essential to ensure their optimal performance and longevity. Battery storage systems should be emphasized to capture surplus energy during periods of high solar production. This stored energy can be utilized during peak demand times, reducing costs, and increasing energy self-sufficiency. Efficient energy management practices are crucial to maximize the benefits of the hybrid system. Proper maintenance and optimization of the inverter and rectifier systems for energy conversion are essential.

Establishing a regular monitoring and maintenance schedule for the hybrid energy system will ensure reliable performance and early detection of any issues that may arise. In addition to implementing technical solutions, promoting energy conservation practices within the institution is important to reduce overall energy consumption. Staff and students should be educated on energy-efficient behaviors, and incentives for conservation efforts could be introduced.

Collaboration with relevant government agencies, local authorities, and potential donors is necessary to secure funding and support for the implementation of sustainable energy solutions. Exploring available grants, subsidies, and incentives for renewable energy projects is recommended. Community engagement is vital. Engaging with the local community will foster support and cooperation for sustainable energy initiatives. Opportunities for sharing excess energy with the community and promoting sustainability at the regional level should be explored.

The institutional management should provide strong support and commitment to the transition to sustainable energy solutions. Academic staff can play a pivotal role in the design and delivery of educational programs related to renewable energy and sustainability.

Students should be actively engaged in promoting energy conservation practices and raising awareness about sustainable energy. Technical and maintenance teams should receive comprehensive training in the operation and maintenance of the hybrid energy system to ensure its efficient performance.

Engaging with the local community is crucial to build support and explore collaborative opportunities for energy sharing and community development.

By implementing these recommendations and involving these key stakeholders, Bawku Technical Institute can make significant progress toward achieving reliable, cost-effective, and environmentally responsible energy solutions. This transition to sustainable energy will contribute to the institution's long-term energy security and environmental sustainability goals.

REFERENCES

Aarakit, S. M., Ntayi, J. M., Wasswa, F., Adaramola, M. S., & Ssennono, V. F. (2021). Adoption of solar photovoltaic systems in households: Evidence from Uganda. *Journal of Cleaner Production*, 129619. https://doi.org/10.1016/j.jclepro.2021.129619

Al-Ezzi, A. S., & Ansari, M. N. M. (2022). Photovoltaic Solar Cells: A Review. *Applied System Innovation*, *5*(4), 67. https://doi.org/10.3390/asi5040067

Al Garni, H., Kassem, A., Awasthi, A., Komljenovic, D., and Al-Haddad, K. (2016). A multicriteria decision making approach for evaluating renewable power generation. Sources in Saudi Arabia. Sustain. Energy Technol. Assessments 16, 137–150. doi:10.1016/J.SETA.2016.05.006

Andreani, L.C.; Bozzola, A.; Kowalczewski, P.; Liscidini, M.; Redorici, L. Silicon solar cells: Toward the efficiency limits. Adv. Phys. X 2018, 4, 1–25.

Ang, T.-Z., Salem, M., Kamarol, M., Das, H. S., Nazari, M. A., & Prabaharan, N. (2022). A comprehensive study of renewable energy sources: Classifications, challenges and suggestions. *Energy Strategy Reviews, 43,* 100939. https://doi.org/10.1016/j.esr.2022.100939

A. K. Shukla, K. Sudhakar, P. Baredar, and R. Mamat, “Solar PV and BIPV system: barrier, challenges and policy recommendation in India,” Renewable and Sustainable Energy Reviews, vol. 82, pp. 3314–3322, 2018.

Armin Razmjoo, A., Sumper, A., & Davarpanah, A. (2019). Development of sustainable energy indexes by the utilization of new indicators: A comparative study. Energy Reports, 5, 375–383. https://doi.org/10.1016/j.egyr.2019.03.006

Aziz, A.S.; Tajuddin, M.F.N.; Adzman, M.R.; Azmi, A.; Ramli, M.A. Optimization and sensitivity analysis of standalone hybrid energy systems for rural electrification: A case study of Iraq. Renew. Energy 2019, 138, 775–792.

Aziz, A.S.; Tajuddin, M.F.N.; Adzman, M.R.; Ramli, M.A.; Mekhilef, S. Energy management and optimization of a PV/diesel/battery hybrid energy system using a combined dispatch strategy. Sustainability 2019, 11, 683

Beitelmal, W.H.; Okonkwo, P.C.; Al Housni, F.; Alruqi, W.; Alruwaythi, O. Accessibility and sustainability of hybrid energy systems for a cement factory in Oman. Sustainability 2021, 13, 93.

Cebotari, S., Cristea, M., Moldovan, C., & Zubascu, F. (2017). Renewable energy's impact on rural development in northwestern Romania. *Energy for Sustainable Development*, *37*, 110–123. https://doi.org/10.1016/j.esd.2017.02.002

Cheng, X., Chen, J., Jiang, S., Dai, Y., Zeng, J., Shuai, C., Liu, J., Li, W., Liu, Y., Kang, X., Wang, C., Zhou, M., Zhang, P., Song, Y., Zou, L., Zhou, H., Wang, C., Chu, Q., & Liu, G. (2021). Pursuing sustainable development goals: A review of renewable energy and poverty alleviation nexus. *Environmental Development*, *40*, 100679. https://doi.org/10.1016/j.envdev.2021.100679

Delapedra-Silva, V., Ferreira, P., Cunha, J., & Kimura, H. (2022). Methods for Financial Assessment of Renewable Energy Projects: A Review. *Processes*, *10*(2), 184. https://doi.org/10.3390/pr10020184

Dondariya, C., Porwal, D., Awasthi, A., Shukla, A. K., Sudhakar, K., S.R., M. M., & Bhimte, A. (2018). Performance simulation of grid-connected rooftop solar PV system for small households: A case study of Ujjain, India. *Energy Reports*, *4*, 546–553. https://doi.org/10.1016/j.egyr.2018.08.002

Gielen, D., Boshell, F., Saygin, D., Bazilian, M. D., Wagner, N., & Gorini, R. (2019). The Role of Renewable Energy in the Global Energy Transformation. *Energy Strategy Reviews*, *24*(24), 38–50. ScienceDirect. https://doi.org/10.1016/j.esr.2019.01.006

Green, M.A.; Dunlop, E.D.; Hohl-Ebinger, J.; Yoshita, M.; Kopidakis, N.; Ho-Baillie, A.W.

Solar cell efficiency tables (Version 55). Prog. Photovolt. Res. Appl. 2020, 28, 3–15.

Jasuan, A., Nawawi, Z., & Samaulah, H. (2018, October 1). *Comparative Analysis of Applications Off-Grid PV System and On-Grid PV System for Households in Indonesia*. IEEE Xplore. https://doi.org/10.1109/ICECOS.2018.8605263

J. Khan and M. H. Arsalan, "Solar power technologies for sustainable electricity generation

A review," Renewable and Sustainable Energy Reviews, vol. 55, pp. 414–425, 2016.

Kamalesh Chandra Rout, & Kulkarni, P. S. (2020). *Design and Performance evaluation of Proposed 2 kW Solar PV Rooftop on Grid System in Odisha using PVsyst*. https://doi.org/10.1109/sceecs48394.2020.124

Kammen, D. M., Alstone, P., & Gershenson, D. (2015). *Energy access and sustainable development*. https://doi.org/10.1063/1.4916165

Kassem, Y., Gökçekuş, H., Iravanian, A., & Gökçekuş, R. (2021). Predictive suitability of renewable energy for desalination plants: the case of güzelyurt region in Northern Cyprus. *Modeling Earth Systems and Environment*, *8*(3), 3657–3677. https://doi.org/10.1007/s40808-021-01315-0

Katarzyna Piwowar-Sulej, Mariusz Sołtysik, Jarosz, S., & Ryszard Pukała. (2023). The Linkage between Renewable Energy and Project Management: What Do We Already Know, and What Are the Future Directions of Research? *Energies*, *16*(12), 4609–4609. https://doi.org/10.3390/en16124609

Kipkoech, R., Takase, M., & Amankwa Afrifa, E. K. (2022). Renewable Energies in Ghana in Relation to Market Condition, the Environment, and Food Security. *Journal of Renewable Energy*, *2022*, e8243904. https://doi.org/10.1155/2022/8243904

J.O. Yamoah, L.D. Mensah, M.S. Adaramola, Performance evaluation of a utility-scale grid-tied solar photovoltaic (PV) installation in Ghana, Energy Sustain. Dev. 48 (2019) 82–87.

Mehrpooya, M., Ghorbani, B., & Hosseini, S. S. (2018). Thermodynamic and economic evaluation of a novel concentrated solar power system integrated with absorption refrigeration and desalination cycles. *Energy Conversion and Management*, *175*, 337–356. https://doi.org/10.1016/j.enconman.2018.08.109

Milman, O. (2023, January 30). *US renewable energy farms outstrip 99% of coal plants economically – study*. The Guardian. https://www.theguardian.com/us-news/2023/jan/30/us-coal-more-expensive-than-renewable-energy-study

Mojtaba Qolipour, Mostafaeipour, A., Shahaboddin Shamshirband, Alavi, O., Goudarzi, H., & Dalibor Petković. (2016). *Evaluation of wind power generation potential using a three-hybrid approach for households in Ardebil Province, Iran*. *118*, 295–305. https://doi.org/10.1016/j.enconman.2016.04.007

Nandal, V.; Kumar, R.; Singh, S.K. Barriers identification and analysis of solar power implementation in Indian thermal power plants: An Interpretative Structural Modeling approach. Renew. Sustain. Energy Rev. 2019, 114, 109330.

Nkuriyingoma, O., Özdemir, E., & Sezen, S. (2022). Techno-economic analysis of a PV system with a battery energy storage system for small households: A case study in Rwanda. *Frontiers in Energy Research*, *10*. https://doi.org/10.3389/fenrg.2022.957564

Nyasapoh, M. A., Elorm, M. D., & Derkyi, N. S. A. (2022). The Role of Renewable Energies in Sustainable Development of Ghana. *Scientific African*, e01199. https://doi.org/10.1016/j.sciaf.2022.e01199

Organization, W. H. (2016). World Health Statistics 2016 [OP]: Monitoring Health for the Sustainable Development Goals (SDGs). In *Google Books*. World Health Organization.

https://books.google.com/books?hl=en&lr=&id=4LDgAAQBAJ&oi=fnd&pg=PP1&dq=(World+Health+Organization

Segundo Sevilla, F. R., Parra, D., Wyrsch, N., Patel, M. K., Kienzle, F., & Korba, P. (2018). Techno-economic analysis of battery storage and curtailment in a distribution grid with high PV penetration. *Journal of Energy Storage*, *17*, 73–83. https://doi.org/10.1016/j.est.2018.02.001

Shezan, S.A.; Hasan, K.N.; Rahman, A.; Datta, M.; Datta, U. Selection of Appropriate Dispatch Strategies for Effective Planning and Operation of a Microgrid. Energies 2021, 14, 7217.

Singh, B. P., Goyal, S. K., & Kumar, P. (2021). Solar PV cell materials and technologies: Analyzing the recent developments. *Materials Today: Proceedings*, *43*, 2843–2849. https://doi.org/10.1016/j.matpr.2021.01.003

Strielkowski, W., Civín, L., Tarkhanova, E., Tvaronavičienė, M., & Petrenko, Y. (2021). Renewable Energy in the Sustainable Development of Electrical Power Sector: a Review. *Energies*, *14*(24), 8240. https://doi.org/10.3390/en14248240

Solar-dc Microgrid for Indian Homes: A Transforming Power Scenario. (n.d.). Ieeexplore.ieee.org. Retrieved November 6, 2023, from https://ieeexplore.ieee.org/abstract/document/7480918/

Wu, Y., Liu, Z., Li, B., Liu, J., & Zhang, L. (2022). Energy management strategy and optimal battery capacity for flexible PV-battery system under time-of-use tariff. *Renewable Energy*. https://doi.org/10.1016/j.renene.2022.09.118