AKENTEN APPIAH-MENKA UNIVERSITY OF SKILL TRAINING AND
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FACULTY OF TECHNOLOGY

FEASIBILITY ANALYSIS OF HYBRID MICROGRID SYSTEM FOR THE ELECTRIFICATION OF EDUCATIONAL INSTITUTIONS

(A CASE STUDY OF THE WESTERN REGION OF GHANA)

(MTECH ELECTRICAL AND ELECTRONICS ENGINEERING)

PAUL KUSI

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PAUL KUSI
(7201200003)

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NOVEMBER, 2023

DECLARATION

CANDIDATE'S DECLARATION

I hereby declare that this dissertation, except for the quotations and references found in published works which I have duly cited, is the result of my own original research work and that no part of it has been presented for another certificate or degree in this institution or elsewhere.

CANDIDATE'S NAME: PAUL KUSI
CANDIDATE'S INDEX NUMBER: 7201200003
SIGNATURE: …………………………….
DATE: …………………………….

SUPERVISORS' DECLARATION

I hereby declare that the preparation and presentation of the dissertation work was supervised in accordance with the guidelines on supervision of dissertation work laid down by the Institute of Education, Akenten Appiah-Menka University of Skills And Entrepreneurial Development.

SUPERVISOR'S NAME: ENGR. PATRICK NYAABA AYAMBIRE
SIGNATURE: …………………………
DATE: …………………………

DEDICATION

This project work is dedicated to all my siblings.

ACKNOWLEDGEMENT

My first appreciation goes to the almighty God. I thank Him for the wisdom and strength He has bestowed upon my life.

I wish also to express my heartfelt gratitude to my supervisor, Engr. Patrick Nyaaba Ayambire, whose advice, helpful suggestions, and guidance enabled me to complete this work; may he prosper throughout his life.

To all my friends, I say God bless you.

ABSTRACT

This study presents a feasibility study of hybrid microgrid system for the electrification of educational institution in the Western Region of Ghana. The technical, economic and enviromental analysis of the hybrid microgrid system was analysed based on the use of HOMER software. Several options of hybrid microgrid power supply systems were evaluated based on the one which had the lowest net present cost (NPC), cost of energy (COE) and emissions. The hybrid microgrid system (PV/Grid) emerged as the most viable option, displaying a significantly low levelized cost of electricity (COE) at $0.0320 and the lowest net present cost (NPC) of $18,332. This system also incurred the second-lowest operating cost ($9,300) among the hybrid microgrid options. Furthermore, the PV/Grid system exhibited a substantial renewable fraction of 55.2%, outperforming other hybrid options. In comparison to the national grid, where the commercial electricity cost is approximately $0.057/kWh, the PV/Grid hybrid microgrid system proves to be a more economical alternative. The hybrid microgrid (PV/Grid) system successfully purchases 57,102 kWh of electrical energy from the grid, generates 78,100 kWh from renewable sources, and sells surplus energy amounting to 23,002 kWh back to the grid. Notably, the CO_2 emissions associated with the educational institution's assigned load are 36,088 g/kWh, demonstrating its environmental friendliness when compared to the national grid.

Furthermore, the study conducts sensitivity analysis, indicating a clear relationship between an increase in grid power pricing and a rise in both NPC and COE. This finding underscores the importance of strategic planning and policy interventions in minimizing the financial challenges posed by rising energy costs, ensuring the long-term sustainability of hybrid microgrid systems in educational institution.

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CHAPTER ONE

INTRODUCTION

1.1 Background of study

Like food and water, energy is a requirement. Everything in our environment uses energy. Population growth on earth has occurred over time, and this growth is strongly correlated with energy consumption. All devices and machinery of every kind require some form of energy to operate. Fossil fuels including coal, oil, and natural gas provide the majority of the energy utilized for commercial purposes globally. These high-carbon sources have a detrimental impact on our environment, including the health, land, air, and precipitation. As a result, low-carbon energy is now receiving more attention from most nations worldwide (Shahsavari & Akbari, 2018).

Natural resources that are abundant in renewable energy can be used now without jeopardizing our ability to meet future energy needs. That depletes over time, unlike fossil fuels. Renewable energy resources, such as biomass, solar, wind, and potential hydropower, are abundant in Ghana. Taxes on energy usage are being utilized to fund the development of the power industry, including renewable energy investments. The market development of renewable energy has been limited, nonetheless, by institutional and policy concerns. As interest in and investment in renewable energy grow globally, so does the use of this energy. In response to these developments, Ghana's government sees renewable energy as crucial to the nation's total energy balance and as a way to reduce the negative environmental effects of energy production (Akrofi & Antwi, 2020).

Despite the fact that there isn't a well-defined, comprehensive strategy for the long-term development and promotion of renewable energy resources in the nation, the Renewable Energy Master Plan was created to address the consequences of short-term planning on the sector's overall development. The Plan's objectives are to offer a framework for investment-focused promotion and development of Ghana's renewable energy resources in order to promote sustainable economic growth and combat climate change. (Adjei, Amoabeng, Ayetor, Obeng, Quansah, & Adusei, 2022).

A hybrid microgrid system is becoming more practicable due to rising environmental concerns, consumer demands for dependability and higher quality power supply, and increasing economics of distributed energy resources based on renewable sources. For the successful integration of a hybrid microgrid system, the current electrical distribution system presents numerous technical and operational issues.

As the electrical grid of the future, hybrid microgrids are blossoming in the scientific community. There is general consensus that the grid is a small-scale energy network made up of loads and distributed energy resources, despite the fact that neither its definition nor its extent is fully standardized (Guerrero, Gebbran, Mhanna, Chapman, & Verbič, 2020). In order to meet the energy needs of the 21st century, hybrid microgrid systems are self-sufficient energy ecosystems. A programmable local energy system known as a microgrid provides power to a specific area, such as a neighborhood, business district, hospital complex, or college campus (Isa, Tan & Yatim, 2018).

The microgrid concept involves a collection of loads and a variety of distributed energy resource units, including solar panels, wind turbines, combined heat and power, energy storage devices like batteries, and electric car charging stations. With the potential to participate in demand response, cost optimization, and grid-balancing programs, hybrid microgrids help to improve flexibility, reliability, and resilience as well as accessibility to green and safe energy (Hajizadeh & Hakimi, 2020).

The key concern for many scholars, however, has been the feasibility analysis of electrification using hybrid energy systems. Below is a discussion of the relevant literature.

Awopone (2021), examined the viability of using an off-grid hybrid energy system in Northern Ghana to energize rural area. He anticipated that in a few years, PV systems will be able to compete with utility grid electricity for widespread distributed applications. Emad, El-Hameed, Yousef and El-Fergany (2020), reviewed the computational approaches used in the design of hybrid renewable microgrids. The article addressed the unpredictability of solar and wind energy sources and provides helpful tips for upcoming scholars in this area.

Also, Suman, Guerrero and Roym (2021), used hybrid particle swarm optimization and a grey wolf optimizer to examine how to best optimize an off-grid hybrid system combined with diesel and a storage system. Oladigbolu, Ramli and Al-Turki (2020), carried done a comparison study of hybrid renewable power systems in Nigeria for off-grid rural electrification. For that specific location, our analysis suggested a hybrid hydro/PV/wind/diesel/battery system with a 77.4% renewable fraction.

In line with global trends, Ghana must increase its use of renewable energy in order to not only meet its citizens' electrical demands but also to take the lead in lowering carbon gas emissions and battling climate change. With these energy problems in relation to economic development, Ghana must expand, diversify, and investigate more energy sources in order to increase its generation capacity and address the recent supply shortages (Kuamoah, 2020**).**

The ultimate energy consumption in Ghana increased by 4.3% in 2019, according to the Energy Commission. Peak power consumption in 2019 was only 2804 MW, far less than

Ghana's 5,172 MW installed capacity overall. Thermal energy makes up the majority of installed capacity (68%), followed by hydropower (31%), and sporadic renewable energy (0.82%) (Aglina, 2017).

The energy sector in Ghana envisions a robust "energy economy" with dependable, high quality energy services. The national energy strategy goals adopted by the power ministry will help the nation realize this ambition. As a result, renewable energy has a huge potential to help Ghana's energy industry sustainably achieve its ambitious national policy goals (Kuamoah, 2020**).**

1.2 Statement of the problem

Excellence in education today depends on a variety of things. One of those important aspects is the availability of a reliable electrical supply, which enables many other factors to come into play. However, Ghana's electrification rate is at 84%, and the average yearly increase in power usage is 5% (Diawuo, Scott, Baptista, & Silva, 2020). Despite this, Ghana's limited ability to produce electricity had created a persistent power crisis marked by load shedding and blackouts (Gyabaah, Twumasi & Gyamfi, 2021).

One of the sectors of life most affected by this subpar electricity supply is the education sector. The majority of the time, classes are taught at Ghana's educational facilities without power. Several classes that need the use of electrical devices like computers, projectors and machines in workshops, etc., an unstable power supply from the central grid frequently presents issues. The outcomes of this include substandard cutting-edge research outputs, poor administrative operations, and ineffective teaching and learning. It strains other services, like water supply. On certain campuses, water is distributed using electric-powered pumps. If there is a power outage that lasts up to 24 hours, the delayed water availability is enough to mess with students' schedules.

Also, the majority of these institutions' reliance on fossil-based generators as a support or alternative power source is not a sustainable one because grid outages frequently continue for hours or even days. Moreso, these generators pollute the environment and are expensive to operate and maintain.

Ghana still lacks access to the significant blessing that science has brought, despite the country's abundance of renewable energy resources. The goal of this study is to evaluate if a hybrid microgrid power system can be implemented at second-cycle educational facilities in Ghana's Western Region.

1.3 Research Aim and Objectives

The aim of this research is to analyze the feasibility study of hybrid microgrid power system for the electrification of second-cycle educational institutions in Western Region of Ghana.

The objectives of this research are to;

1. Assess the technical feasibility of implementing a hybrid microgrid power for electrification of an education system.
2. Conduct an economics feasibility analysis of the proposed hybrid microgrid energy power system.
3. Perform environmental impact assessment of the proposed hybrid microgrid system.

1.4 Significance of the study

The power industry in Ghana offers enormous growth potential that might assist the people of that nation overcome their energy challenges and adopt a more contemporary and determined approach to manufacturing and wealth creation. The findings of the study will inform policymakers and stakeholders about the feasibility and benefits of implementing hybrid microgrid systems in educational institutions. Evidence-based decision-making is crucial for designing effective policies and initiatives to promote sustainable energy solutions in the education sector.

Also, electrifying second-cycle educational institutions ensures a conducive learning environment. Access to electricity enables the use of modern teaching aids, computers, and internet connectivity, enhancing the overall quality of education. Introducing hybrid microgrid power systems in educational institutions exposes students to renewable energy technologies and fosters technological literacy.

Furthermore, hybrid microgrid systems often incorporate renewable energy sources like solar or wind power, reducing reliance on fossil fuels. By promoting clean energy usage, the study contributes to the reduction of greenhouse gas emissions, mitigating climate change effects.

1.5 Scope and Delimitation of the Study

This research aims to analyze a feasibility assessment for a hybrid microgrid system electrification in a learning environment. A hybrid microgrid system combines solar PV, wind power, an inverter, and batteries. Due to the difficulties in using those two renewable energy sources, other components like utility grid and diesel generator are also utilized. This study focuses mostly on hybrid microgrid systems incorporating solar and wind energy. The chosen educational institution's electricity load demand was computed and compared to the necessary load.

Different strategies were implemented to achieve the study's goals. The difficulties encountered while conducting the research are regarded as study constraints. Due to time and budget limitations, just one school, Ghana Senior High Technical School, was employed while all the educational institutions in Western Ghana should have been included in the research.

1.6 Organization of the Study

The study is organized in five chapters. Chapter one looks at the introduction of the study which includes the background to the study, the statement of problem, the aim and objectives of the study, the significance of the study, Scope and delimitations of the study. Chapter two reviews related literature. The methodology that is used to carry out the study is presented in chapter three while chapter four presents and discusses the results of the study. The summary, conclusions and recommendations are presented in chapter five.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This particular chapter aim at reviewing related literature which are available in book, articles unpublished work and handout by lectures, magazines, long essays and other research works that are related in a broad way or focused on the problem under research. The review has been classified under the following subtopics;

2.1 Literature Review

Kharrich, Kamel, Alghamdi, Mosaad, Akherraz, and Abdel-Akher, (2021), an economic microgrid system for the Yanbu region of Saudi Arabia. They sought to choose the ideal microgrid design while decreasing NPC and LCOE while taking into account a number of technical factors, such as the likelihood of a power supply failure and the availability index. Construction of the Giza Pyramids is the optimization methodology employed (GPC). Also, AlKassem, Draou, Alamri, and Alharbi (2022) conducted research on a microgrid design for the Institute of Environmental Engineering and Management (IEEM) in Pakistan, comparing the performance of on-grid and off-grid systems in terms of economic criteria.

Moreover, Khan, Pasupuleti, Al-Fattah, and Tahmasebi (2019) proposed a microgrid model with a Model Predictive Control Energy Management System (MPC). The model was created by simulating actual load profiles and renewable resources like solar radiation. Several disturbances, including as load change, generation, and PV shading, were simulated to assess the EMS's performance. Aziz, Tajuddin, Adzman, Mohammed and Ramli (2020), presented a feasibility study for the operation of a solar PV microgrid system both linked to the grid and on an island. The total study was performed using

HOMER software and five distinct control techniques. This research demonstrated how executing such a project may offer clean, affordable, and consistent power generation in nations that experience regular blackouts.

Ayodele, Ogunjuyigbe, and Ekohm (2019), proposed a model for optimizing a hybrid energy microgrid for a microbank in a far-off rural neighborhood. They came to the conclusion that the technique may be utilized in other rural areas of developing nations with comparable environmental circumstances. Salehi, Martinez-Garcia Velasco-Quesada and Guerrero (2022), gave an in-depth analysis of optimization techniques and control strategies for both private and public microgrids. In order to research the advanced optimization techniques, the Pareto-optimal solution was applied.

Also, Idoniboyeobu, Wokoma and Salihu (2018), implemented micro-grid model for power generation in rural communities They established the strategy of using renewable sources to deliver power to rural communities since the financial cost is justified and it would help decrease carbon emissions to the atmosphere as part of the country's international commitment. Oguntola (2021), developed a model of energy sources that can be integrated into a microgrid system. An algorithm for microcontroller with energy meter to measure and display energy generated, was implemented for coordinating and monitoring of the microgrid energy system on MATLAB/SIMULINK (version 2018b).

Abedini, Vahabzadeh, Ahmadi, Karimi, Manoochehri, Nazeri, and Sanaye-Pasand, (2020), focused on smart microgrid educational laboratory with integrated electric and communications infrastructure platform. Muqeet, Munir, Javed, Shahzad, Jamil and Guerrero (2021), suggested campus microgrid energy management system with modern and upcoming issues. They anticipated that their findings will pave the way for fresh minds to enter the field of campus microgrid research in the future.

Bihari, Sadhu, Sarita, Khan, Arya, Saket and Kothari (2021 undertook a thorough analysis of microgrid control mechanisms and an effect evaluation for the integration of hybrid renewable energy. They discussed the economic overview of the microgrids framework, including cost analysis, financial and technology analysis, risk assessment, and microgrid initiative.

2.2 Future of renewable energy in Ghana

In many nations, support and financing for renewable energy technology have increased significantly over the past ten years, which has led to considerable cost reductions for the majority of renewable energy sources (Asante, Ampah, Darko, Fosu & Amoh 2022). The Ghanaian government has acknowledged renewable energy as a practical choice for the growth of the nation's economy, society, and environment. Renewable energy technologies offer a huge potential to assist Ghana's total electricity supply mix and enable social and economic development, as recently successful renewable energy programs and initiatives have shown. In order to encourage investment in renewable energy over the next ten years, the government has released the Renewable Energy Master Plan (REMP) (Gyamfi et al., 2022).

2.3 Renewable energy master plan (REMP)

The Government of Ghana is working hard to meet the target of 10% renewable energy contribution to the country's electricity supply mix by enacting the Renewable Energy Law (Act 882) in 2011 (Aboagye, Gyamfi, Ofosu, & Djordjevic, 2021). However, the Renewable Energy Law lacked a clear integrated roadmap and financial commitment for long-term development and advancement of the country's renewable energy resources. As a result, a number of renewable energy projects and interventions were being trialed or implemented on a short-term basis. To address this shortcoming, the government created the Renewable Energy Master Plan (REMP) in 2019 with targets and a clear roadmap to provide an investment-focused framework for developing and promoting renewable energy technology in Ghana for socioeconomic growth and reducing the negative effects of climate change by the end of 2030. (GREMP, 2019. Gyamfi et al., 2021).

The Government of Ghana requires approximately US$ 460 million per year, which equates to approximately US$ 5.6 billion from 2019 to 2030 for the successful implementation of the REMP (GREMP, 2019). With the current trend of renewable energy generation, Ghana will require approximately US$ 732 million to achieve the 10% additional electricity supply from renewable energy sources by the end of 2020. (GREMP, 2019. Gyamfi et al., 2021).

2.4 Renewable Energy Potentials in Ghana

2.4.1 Wind energy

There are several wind resources in Ghana that might be utilised to produce a significant quantity of power. Specific locations along Ghana's coastline that could support wind power generation were identified in 2004 by the Solar and Wind Energy Resource Assessment (SWERA) project, which was carried out in collaboration with the US National Renewable Energy Laboratory (NREL), UNEP, and the Global Environment Facility (Agyekum, 2020). A few number of locations in Greater Accra, Central, Eastern, Western, Volta, Brong Ahafo, Ashanti, and the Northern region contain the majority of Ghana's moderate wind resources (Gyamafi et al., 2021).

The majority of Ghana's good to exceptional wind resources are located along its eastern coast, in the highlands surrounding Lake Volta, and along its border with Togo. The yearly average wind speed is between 8.4 and 9.9 m/s and there are a few great websites that give information about it. Winds in Ghana's coastal region may produce roughly 2000 MW of power at rates of 9 to 9.9 m/s (Baloch et al., 2017). Theoretically, current technology can use the available wind energy to generate up to 500–600 GWh of electricity per year (Lei et al., 2020). Additionally, near the country's coasts, excellent possibilities for the generation of wind energy have been discovered (Gyamfi et al., 2021).

2.4.2 Wave/Tidal power potentials

Ghana's wave energy potential for power production has not yet been fully exploited, despite plans to develop a 500kW wave energy plant in Ada in the Greater Accra Region, near to the Volta River estuary (Nyasapoh et al,, 2022, Debrah et al., 2022). Tidal power is anticipated to be readily available in the future for the generation of energy in Ghana due to the vastness of the country's seas. The waves to the east of the meridian are powerful, suggesting a significant potential for tidal wave growth, reaching at least 200 MW by 2047, according to a preliminary analysis (Asante et al 2022). Despite its importance in lowering emissions, tidal energy still confronts technological challenges on a worldwide scale.

2.4.3 Biomass and waste-to-energy

The development of biofuels in Ghana utilizing energy crops like oil palm fruit and jatropha has a huge potential (Ewunie, Morken, Lekang, & Yigezu, 2021). Combined Heat and Power (CHP) systems in the wood and oil palm sectors, which burn solid wastes to create electricity, are just a few waste energy technologies that have been employed in Ghana. Utilizing oil palm and sawmill waste, the country has biomass co-generation plants with a total capacity of over 6 MW. In 2018, Ghana began using 0.1 MW of the biowaste-powered Safisana power plant's energy (Ghana's Energy Commission, 2021).

2.4.4 Hydropower

Since 1963, Ghana has been working on a project to accelerate growth in the power sector in line with the objectives of a long-term development plan, with a carefully planned "take-off" of the industrial, agricultural, and service sectors (Mante & Balana, 2017). With the intention of quickening growth, the Akosombo Hydro Electric Power project was funded in 1963; it was completed in 1965. (Mante & Balana, 2017, Debrah, Nyasapoh, Ameyaw, Yamoah, Allotey &Agyeman, 2022). Currently, it is thought that the country has a hydropower potential of about 2420 MW (Debra et al., 2020).

Additionally, among the huge hydropower potentials that have been utilised to produce energy are the 1020 MW Akosombo Hydropower Plant with a reliable capacity of 900 MW and the 160 MW Kpong Hydropower Plant with a reliable capacity of 148 MW (Mante & Balana, 2017). The third is the 400 MW Bui Hydropower Plant on the Black Volta River, which regularly generates 342 MW (Mante & Balana, 2017).

The remaining capacity, projected to be 840 MW Mini-Hydroelectric Power Plants, is required to generate a dependable capacity of 500 MW. Ghana's undeveloped hydro resources are thus classified as mini-hydropower potentials because they are less than 100 MW in size. There are other instances, including Hemang on the Pra River (90 MW), Juale on the Oti River (90 MW), Pwalugu on the White Volta River (60 MW), Lanka on the Black Volta River (95 MW), and Abemia on the Tano River (50 MW) (Ghana Energy Commission, 2020).

2.4.5 Mini-Hydroelectric

Hydropower sources were redefined, and all forms of renewable energy were taken into account, in Ghana's revised renewable energy bill (Nyasapoh et al., 2022). Despite this, all of the major hydro potentials have been utilized with the exception of the 840 MW mini-hydro prospects. Ghana is anticipating that the sources would be developed to produce at least 500 MW (Ghana Energy Commission, 2020, Debra et al., 2020). Additionally, work on the first 0.045 MW micro-hydro demonstration power plant at the Tsatsadu Waterfalls in the Volta region started in 2018 and was finished in 2019 (Nyasapoh, Elorm, & Derkyi, 2022).

2.4.6 Solar energy

Due to Ghana's good geographic exposure to solar radiation, it is perfect for thermal and electrical energy uses (Agyekum, 2020). Ghana experiences solar radiation that ranges from 4.5 to 6.0 kWh/m2/day, with the majority of the greatest levels concentrated in the country's north. Every year, the nation experiences between 1800 and 3000 hours of sunlight. The average sun irradiation over the country varies from 4.4 to 5.6 kWh/m^2/day, with a relatively low dispersed radiation of approximately 32%. The average length of the day's sunshine ranges, according to the Energy Commission, from 5.3 hours in gloomy and semi-deciduous forest zones like Kumasi in the middle belt to 7.7 hours in dry and savannah zones like Wa (Asante et al 2022).

The capacity of solar PV electricity installation as of 2020 was estimated at 59 MW, with over 85% in areas connected to the grid. The installed capacity at Navrongo and Lawra, respectively, is 3 MW and 7 MW VRA Solar, respectively (Nyasapoh et al., 2022). Additionally, there are the 10MW Bui Solar, 20MW Meinergy, and 20MW BXC solar.

More than 1.8 GW of generating capacity have also been granted provisional licenses by Ghana's Energy Commission (Aboagye et al., 2021).

Additionally, the Ghanaian government launched a rooftop solar PV program in 2016 to relieve the national grid of 200 MW of peak load by providing solar PV panels with a maximum peak power of 500 watts (Wp) to prospective residential applicants with a balance of systems (Nyasapoh et al., 2022). According to Asante, Ampah, Afrane, Adjei-Darko, Asante, Fosu, and Amoh (2022), the "Ghana Energy Development and Access Project (GEDAP)" has installed nearly 8500 solar home systems.

2.5 Barriers to renewable energy implementation in Ghana

Although renewable energy sources have made significant progress over the past ten years in some developed continents like Europe, Asia, and America, they still face significant challenges (Chen et al, 2021). Despite this, these challenges aren't unique to RE sources; some arise from a market and regulatory environment that are more stringent, while others are inherent to all new technologies (Union of Concerned Scientists, 2017). Market entry has thus consistently been a significant obstacle for emerging industries.

Therefore, well-established markets for current technologies like fossil fuels present difficult obstacles for renewable energy sources. Since wealthier industries that profit from existing infrastructure, knowledge, and policy must compete with solar, wind, and other renewable energy resources, it is difficult to enter the market (Union of Concerned Scientists, 2017).

The capital cost, which includes the up-front cost of construction and installation, is another significant known barrier to the penetration of renewable energy sources. A new natural gas plant, on the other hand, might have cost around $1000/kW, whereas wind energy costs between $1200 and $1700/kW. (Union of Concerned Scientists, 2017).

Secondly, decentralized renewable energy sources like solar and wind are available. As a result, these renewable energy sources are less dependent on a small number of high output power plants than more centralized energy sources like coal, natural gas, and nuclear power plants (Singer & Yener, 2017).

2.6 Concept of Microgrid

A microgrid is a self-sufficient energy system that provides power to a specific geographic area, such as a neighborhood, commercial district, hospital complex, or college campus. Additionally, many more recent microgrids have energy storage, which is often provided by batteries. Several now also feature charging facilities for electric vehicles. The microgrid, which is connected to surrounding buildings, delivers power to its clients as well as perhaps providing heat and cooling using complex software and management systems (Wood, 2020).

A microgrid combined with power electronic interface is a complete self- sufficient network, with preferably autonomous control, communication and protection. It is capable of providing capacity support to the transmission grid while in grid connected mode, and with capacity in excess coincident in peak demand (Wood, 2020).

2.7 Benefit of Microgrid

A rapidly expanding sector of the energy sector is microgrids, which reflect a paradigm change away from distant central station power plants and toward more localized, distributed generation, particularly in communities, colleges, and cities (Elmasri, 2020).

Microgrids are robust due to their ability to isolate from the main grid, and their capacity for flexible, parallel operations enables the supply of services that boost the grid's competitiveness. Microgrids are robust because of their ability to operate independently of the main grid, and their capacity for flexible, parallel operations allows them to offer services that boost the grid's ability to compete (Souza et al., 2022).

In times of crisis, a microgrid can "island" from the grid to continue serving its included load even if the grid is down while also serving the community it is located in by offering a platform to support vital services, such as housing first responders and government operations and offering emergency shelter and key services (Elmasri, 2020)

Microgrids offer reliable, affordable, clean energy, boost local resilience, and increase the functionality and stability of the broader electric grid. Unprecedented for an energy resource, they offer dynamic response (Venkatanagaraju & Biswal, 2020).

Microgrids work in parallel to the utility Grid; by dealing with specific burdens, they bolster the utility network. The additional limit given by Microgrids can help avoiding over-burden circumstances and power outages of the national grid (Chakraborty, Arvind & Kumar, 2021).

Economically, there is diminishment in long transmission line establishment and the comparing transmission. The minimal effort establishment of the Microgrid networks locally impressively spares foundation expenses and transmission misfortunes. Microgrids additionally help in decreasing the utilization of fossil energy (Kumar et. al., 2021).

The Microgrid exploits heat energy sparing when utilizing combined heat and power. This is a simple procedure to accomplish with the micro source in a Microgrid. The microsource can be sent nearer to heat and electrical loads for amplifying energy proficiency (Zhang, Xiong, & Sun, 2017).

2.8 Hybrid AC/DC microgrid configuration and power management strategies

Hybrid AC/DC hybrid microgrid configuration systems are composed of AC/DC power sources and AC/DC loads. Based on the connections between the power sources and loads, hybrid AC/DC hybrid microgrid configuration systems may be categorized into three groups: AC-coupled hybrid microgrid configuration system, DC coupled hybrid microgrid configuration systems, and AC/DC-coupled hybrid microgrid configuration systems. The descriptions of each group are provided below. The output active and reactive powers of these distributed generation and storage devices, as well as the control of their voltages and frequencies, are determined by these hybrid microgrid's power management strategies. (Sedaghati & Shakarami, 2019, Gupta, Doolla & Chatterjee, 2017).

2.9.1 AC-coupled hybrid microgrid configuration system

The setup of the AC-coupled hybrid microgrid configuration system is shown in Figure 1, where different distributed generating and storage components are interconnected to the common AC bus by their respective interface converters. To guarantee that electricity may flow in both directions, storage devices employ bidirectional converters. When renewable energy sources supply grid-level AC voltages directly or indirectly through integrating power converters, this configuration is frequently employed (Datta, Kalam, & Shi, 2021).

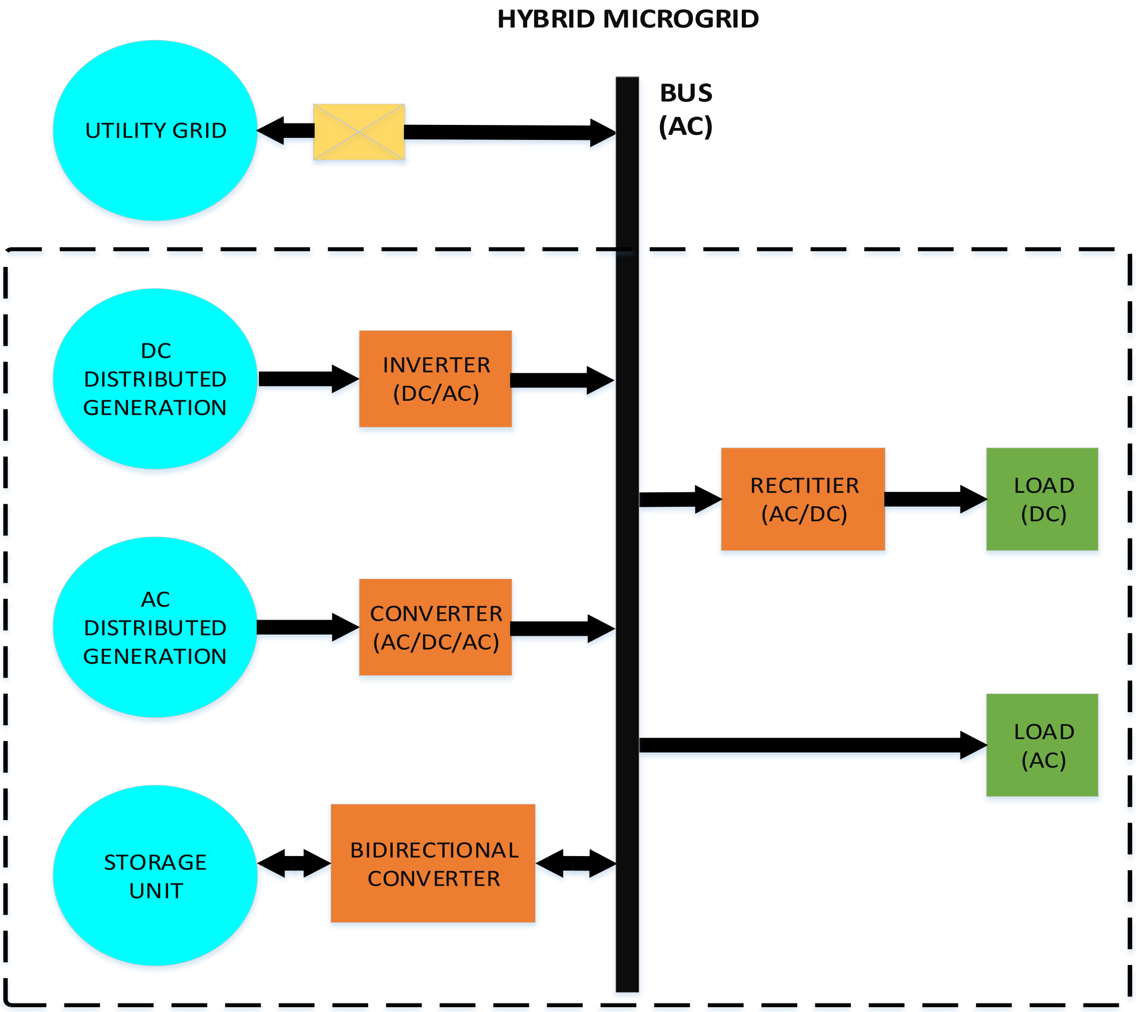


Figure 2.1; AC-coupled hybrid microgrid configuration (Saravanan, Venkatachalam, Arumugam, Borelessa,& Hemapala, 2021)

The primary goals of control strategies and power management plans for an AC-coupled hybrid microgrid configuration system are power balancing inside the system, AC bus voltage control, and frequency control in stand-alone operating mode (Nempu & Jayalakshmi, 2022). The power management strategies for the AC-coupled hybrid microgrid configuration system, which may operate in grid-connected or stand-alone modes, are shown in an overview in Figure 2.

The power trade between the microgrid and the main grid is transmitted from a higher-level control plan in the untransmitted power mode of power management for grid-connected mode. In the untransmitted output power mode, the microgrid output power is not transmitted (Saravanan et al., 2021). The power exchange between the microgrid and the main grid is transmitted from a higher-level control plan in the transmitted power mode of power management (PM) for grid-connected mode. In the untransmitted output power mode, the microgrid output power is not transmitted Pippia & Schutter 2019. Saravanan et al., 2021)

Power management strategies are concentrated on AC hybrid microgrid bus voltage and frequency control as well as demand power sharing among distributed generation and storage components when operating in standalone mode (Baghaee, Mirsalim, Gharehpetian, & Talebi, 2017).

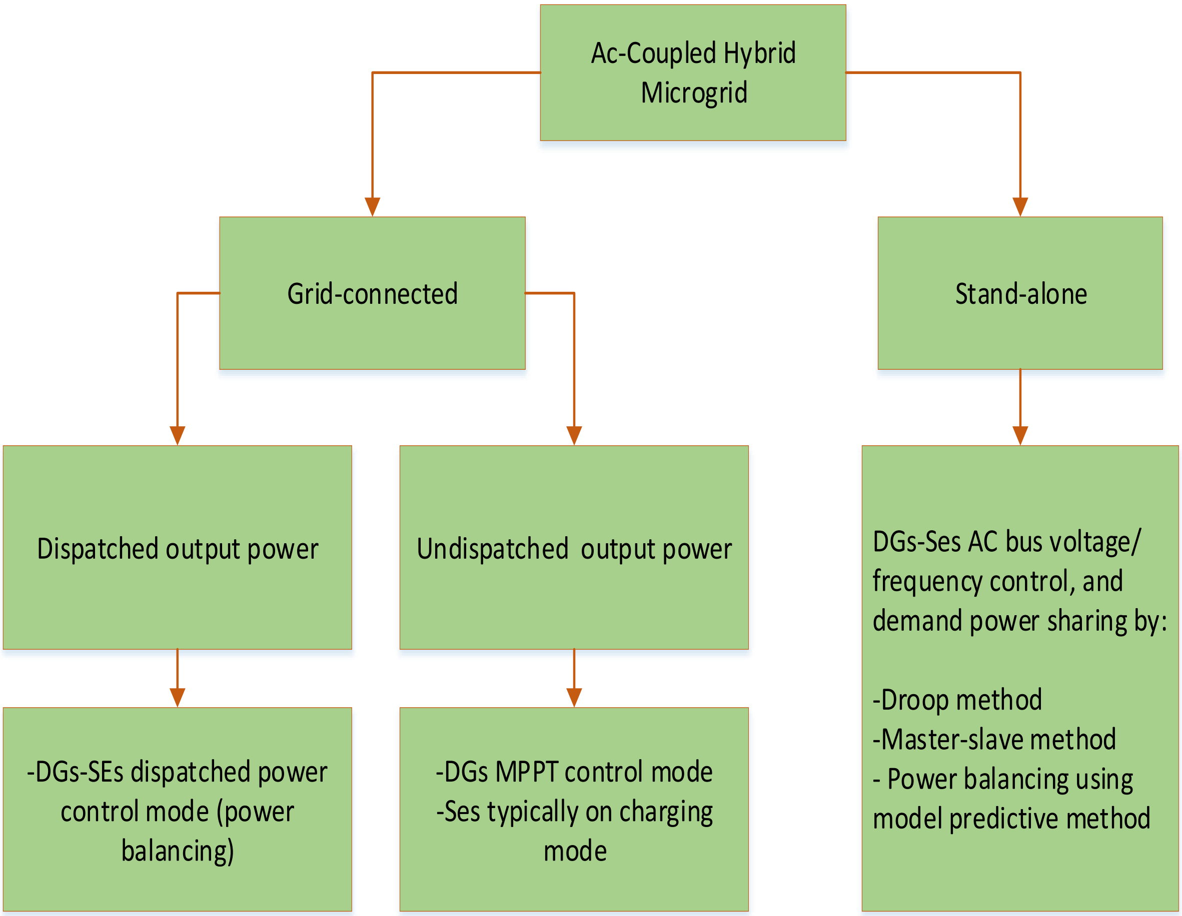


Figure 2.2; AC-coupled hybrid microgrid power management strategies (Saravanan et al., 2021)

2.9.2 DC-coupled configuration system

Interfacing converters are used to connect the DC/AC buses in a DC-coupled hybrid microgrid configuration system, as shown in Figure 2.3, where distributed generation \ and storage elements are connected to a common DC bus. When DC power sources are the principal power production devices in the hybrid microgrid, this structure works well. Interfacing converters in this system provide bidirectional power flow between AC and DC buses, and a DC-coupled hybrid microgrid configuration system integrates different distributed generation sources without the need for synchronization (Nejabatkhah, & Tian, 2019).

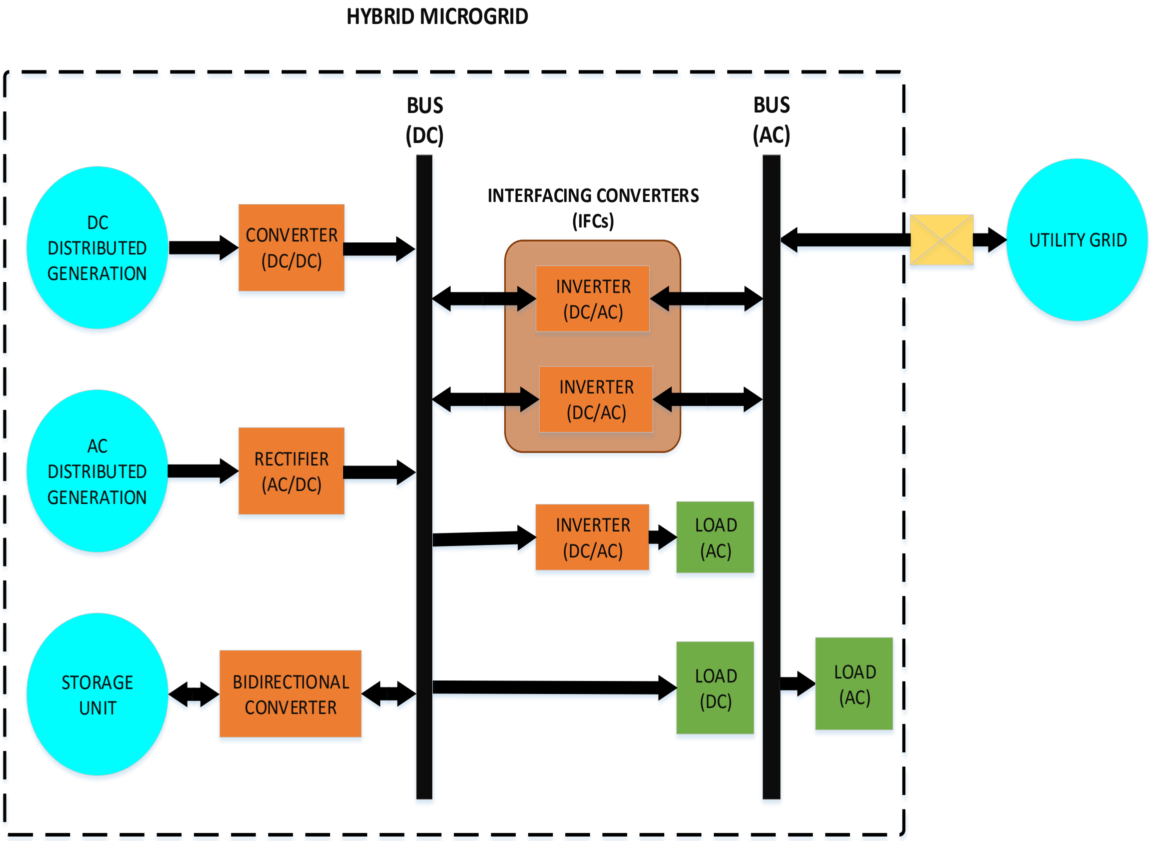


Figure 2.3; DC-coupled configuration system (Saravanan et al., 2021).

DC link voltage control, power balancing between generation and demand, and AC link voltage and frequency control are the primary objectives of power management strategies in DC-coupled configuration systems. Figure 2.3 depicts an overview of the power management and control techniques used by DC coupled hybrid microgrid systems.

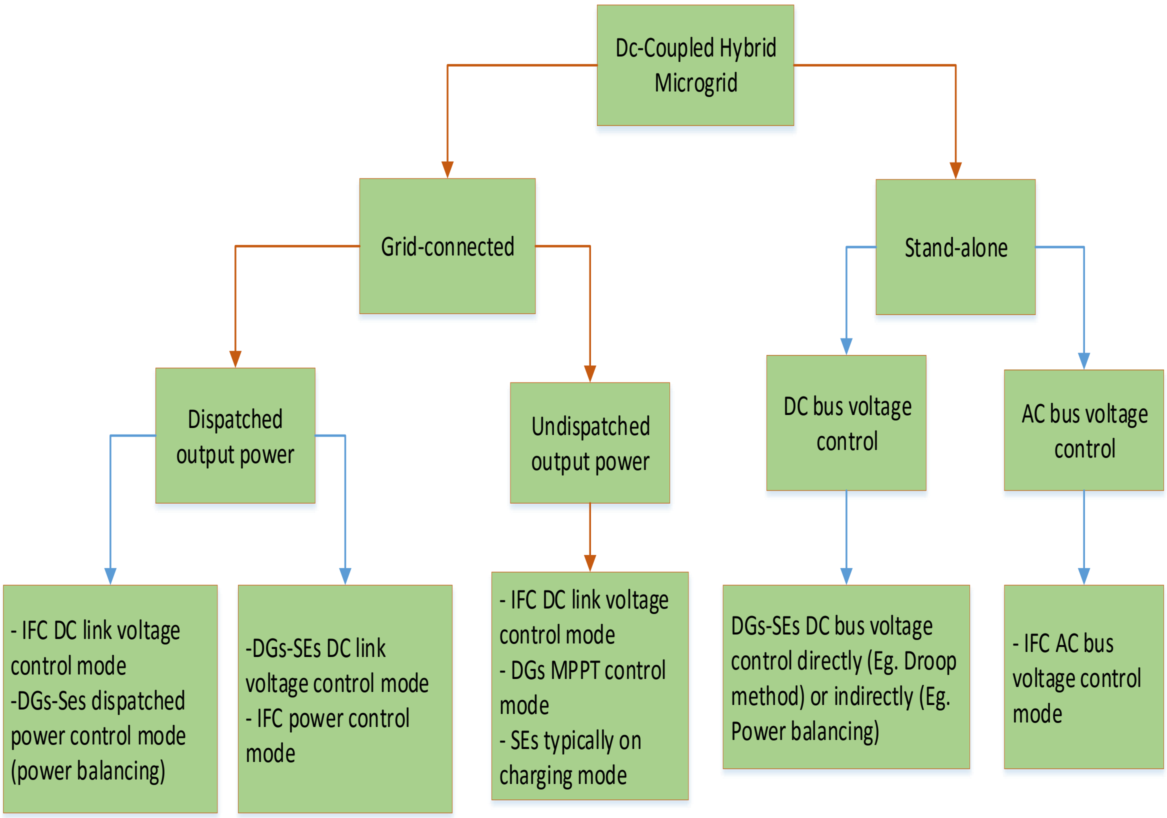


Figure 2.4; DC-coupled hybrid microgrid power management strategies (Saravanan et al., 2021).

Power control mode regulates Interfacing converters output power on its reference value by adjusting converter output voltage or current. Interfacing converters control DC link voltage in this mode, balancing power production and consumption on the DC bus. Interfacing converters operate primarily in the AC link voltage control mode for standalone microgrids, controlling the voltage and frequency of the AC subsystem. If a grid-connected DC-coupled configuration system is used and it is in dispatched power mode, there are two ways to control the DC link voltage (Kumar et al., 2022., (Saravanan et al., 2021)

The first method uses interfacing converters to regulate the DC link voltage while operating in the DC link voltage control mode. By using the second approach, distributed generation can participate in droop control or operate at maximum power point while storage element on DC bus control and DC link voltage are controlled collectively. Interfacing converters are used in this situation to operate in power control mode and supply grid power. Interfacing converters operate in DC link voltage control mode when operating with untransmitted output power (Saravanan et al., 2021).

A DC-coupled hybrid microgrid's stand-alone operation calls for simultaneous control of the DC and AC bus voltages and frequencies. Interfacing converters control the AC bus voltage and frequency in the AC link voltage control mode, whereas DC bus voltage can be controlled either directly or indirectly (Saravanan et al., 2021).

2.9.3 AC/DC-coupled configuration system (Nagaraj, 2022).

Multiple distributed generation and storage element components are linked by an interlinking converter in an AC/DC-coupled configuration system, as depicted in Figure 4, with the least amount of power conversion needed.

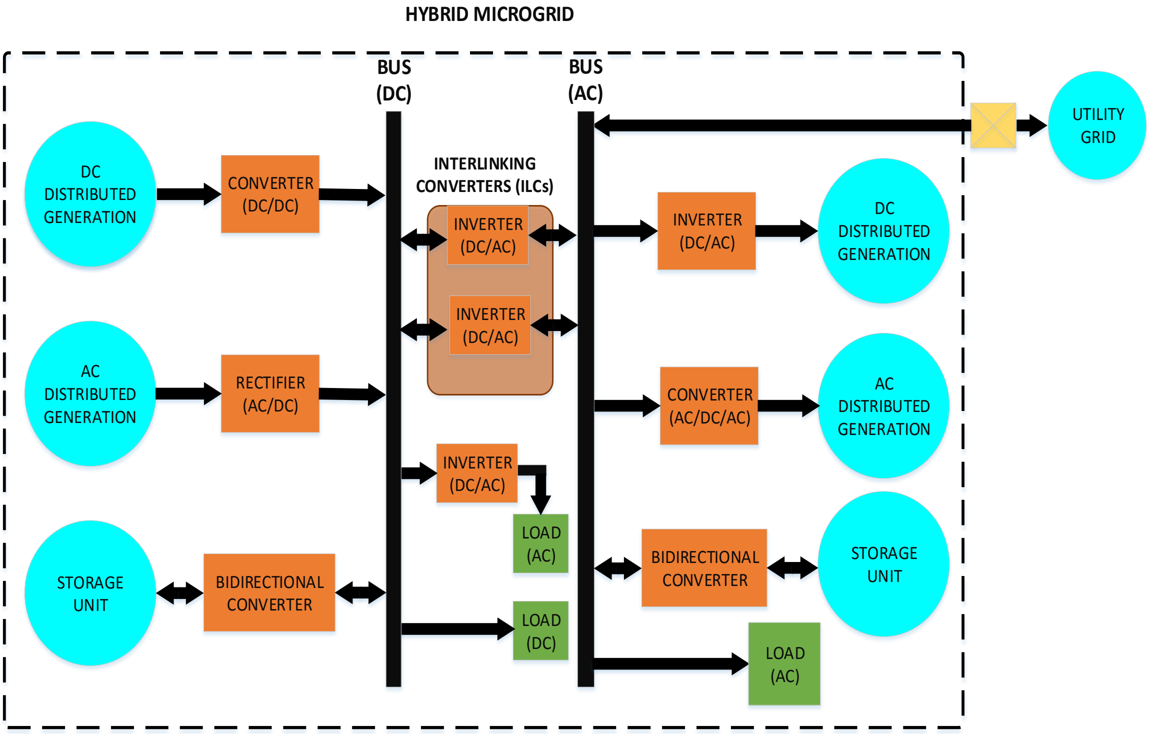


Figure 2.5; AC/DC-coupled configuration system (Saravanan et al., 2021).

Figure 5 depicts an overview of the power management plans for an AC/DC-coupled hybrid microgrid configuration system. An AC/DC-coupled hybrid microgrid configuration system interfacing converters can operate in bidirectional power control, DC voltage control, or AC voltage control modes. There are two ways to control the DC-link voltage and generate dispatched power in grid-connected operation mode with hybrid microgrid system output power.

In the first method, interfacing converters works on DC link voltage regulation mode to set the DC bus voltage on its desired value. In this mode, coordination between distributed generations-storage elements on the DC bus and distributed generations-storage elements on the AC bus is necessary to produce the transmitted output powers. To set the DC bus voltage to the desired value in the first method, interfacing converters operate in the DC link voltage regulation mode (Perez, 2020). To produce the transmitted output powers in this mode, coordination between distributed generations storage elements on the DC bus and distributed generations-storage elements on the AC bus is required.

Distribution generations storage elements on the DC bus control output powers dispatched by DC link voltage in the second operating mode. Interfacing converters operate in power control mode in the second operating mode, which is where distribution generations storage elements on the DC bus control the DC link voltage (Saravanan et al., 2021).

To control DC bus voltage, AC bus voltage and frequency, and balance the microgrid's total generation and demand powers simultaneously in stand-alone operation mode, coordination between interfacing converters, distribution generation-storage elements on the AC bus, and distribution generation storage elements on the DC bus is crucial (Saravanan et al., 2021).

The AC-coupled hybrid microgrid's stand-alone operation mode's Power Management strategies, such as droop, master-slave, etc., can be applied in this mode to regulate the voltage and frequency of the AC subsystem and to share demand power. Similar to a DC coupled hybrid microgrid operating independently, DC bus voltage can be directly controlled by distribution generations storage elements on DC bus (Saravanan et al., 2021).

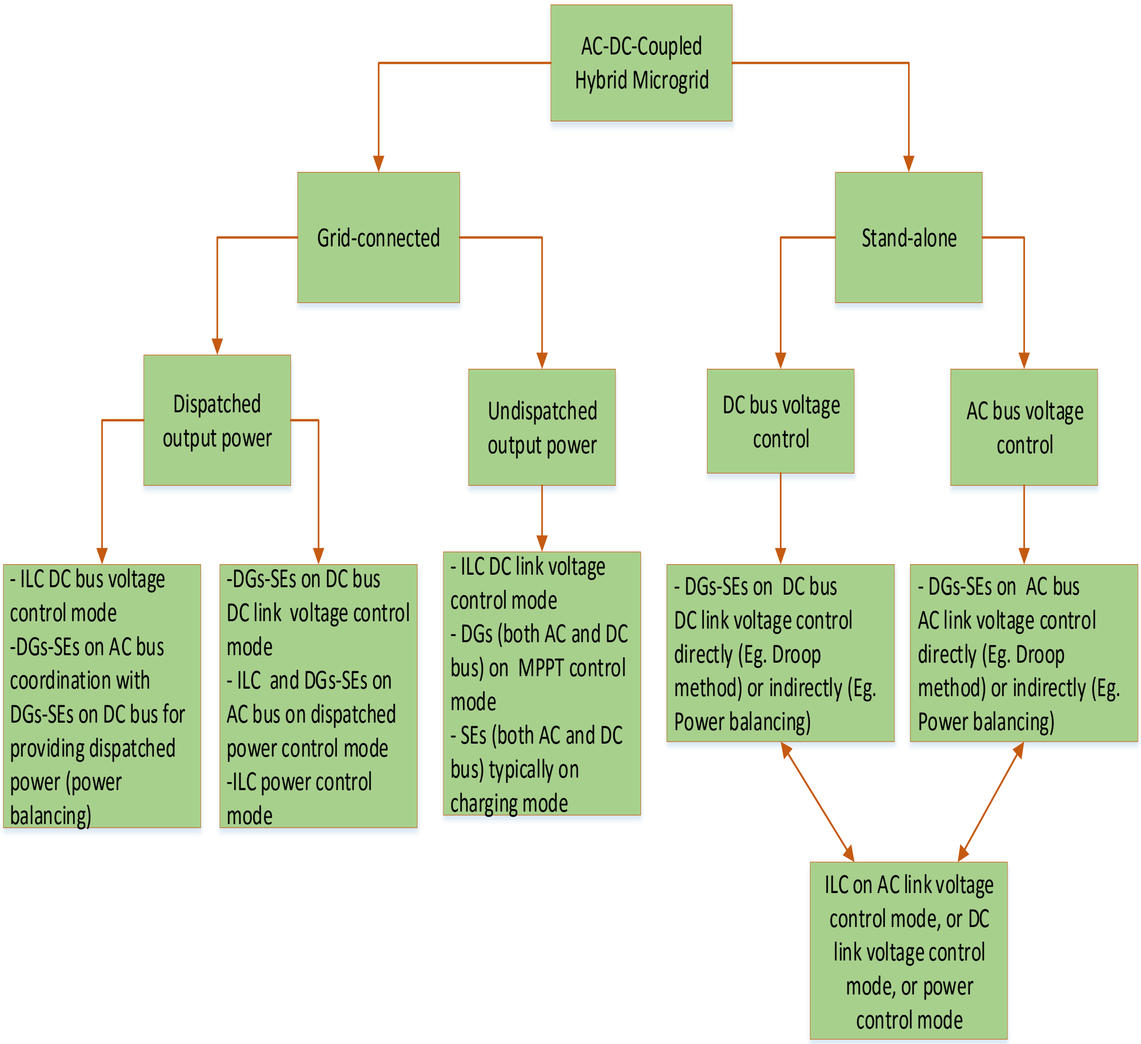


Figure 2.6; AC/DC-coupled hybrid microgrid power management strategies (Saravanan et al., 2021)

Depending on the AC and DC buses' control techniques, this converter can be utilized in output power control mode, AC-bus control mode, or DC-bus control mode. The interface converters are in charge of controlling the power flow between the two in order to maintain a balance between the power produced and consumed on the AC and DC sides. Distribution generations storage elements attached to the DC bus control the voltage of the bus, while distribution generations storage elements connected to the AC bus control the voltage of the bus (Saravanan et al., 2021).

2.10 Control methods used for hybrid microgrid operation

Typically, the microgrid uses a centralized, distributed, or decentralized model to operate (Shafiee, 2017). The control strategies used for its operation were covered in this section:

Centralized Model: The Microgrid in this instance needs a central controller that interacts with all of the Distributed Energy Resources in the Microgrid. The central controller must be able to process all the data that is transmitted from the microgrid's other components. The reliability of centralized controllers is regarded as low (Han, 2018).

Distributed Model: In this case, the microgrid's distributed control system eliminates the need for a centralized controller by having autonomous "agents" collaborate to achieve system-wide objectives (Cintuglu et al., 2018). Distributed control systems improve the MG's scalability and system resistance to single-point malfunctions (Han et al., 2018).

Decentralized Model: In this case, each Distributed Energy Resources unit's (agent's) control system is implemented using just local measurements. Droop controllers are employed through a physical link to distribute the Microgrid load among the Distributed Generation (DG) units in line with their power capacity (Salehi, Martinez-Garcia,Velasco-Quesada, & Guerrero, 2022). It's crucial to remember that this technique lacks communication routes, which makes it challenging to create secondary and tertiary control systems. Although certain techniques, such the use of high-pass "wash-out" filters, have been proposed in the literature (Saleh et al., 2019).

2.11 Hybrid Energy in the system

Hybrid solar and wind power systems combine photovoltaic panels and wind turbines to maximize total energy output and system efficiency ((Nasser et al., 202, Ramadan et al., 2020). The following provides an overview of solar PV and wind power systems, as well as a discussion of the main benefits and challenges of their combination.

2.11.1 Solar Power in hybrid microgrid system

The global market for photovoltaic (PV) generating systems is predicted to increase dramatically. Due to their modest size and silent operation, PVs are a desirable renewable energy source for dispersed urban power generation. The benefit of using PV producing technologies is that more units may be added to meet rising load demand (Gulagi, 2017).

2.12.2 Solar Photovoltaic Terminology

PV unit: Using the photovoltaic effect, a PV unit is made up of a number of PV cells that convert light energy directly into direct current (DC) power (Zou, Wang, Zhang, Ding, & Wang, 2020).

Inverter: To convert the DC output of a PV unit into AC power, an inverter is utilized.

MPPT: In order to use the full amount of power produced by the PV modules, the power conversion equipment has to be equipped with a maximum power point tracker (MPPT). (Myla, 2017). It is an apparatus that constantly keeps track of the voltage at which the greatest electricity is consumed. Proficiency is assessed in the lab under controlled settings using I-V curves. I-V curves are created by varying the external resistance from zero (short circuit) to infinite (open circuit). Voltage (V) and current (I) work together to generate electricity from a PV cell (I). When the circuit is either open or closed, the power is zero.

At the same midway, the power is greatest (around the knee point). The solar cell's temperature and the amount of light energy (irradiance) it receives affect its current. The peak point moves to the left and power diminishes as irradiance drops. Additionally, during operation, the extreme power point shifts to the left once again as the cell temperature rises, resulting in a loss in power yield. (Myla, 2017).

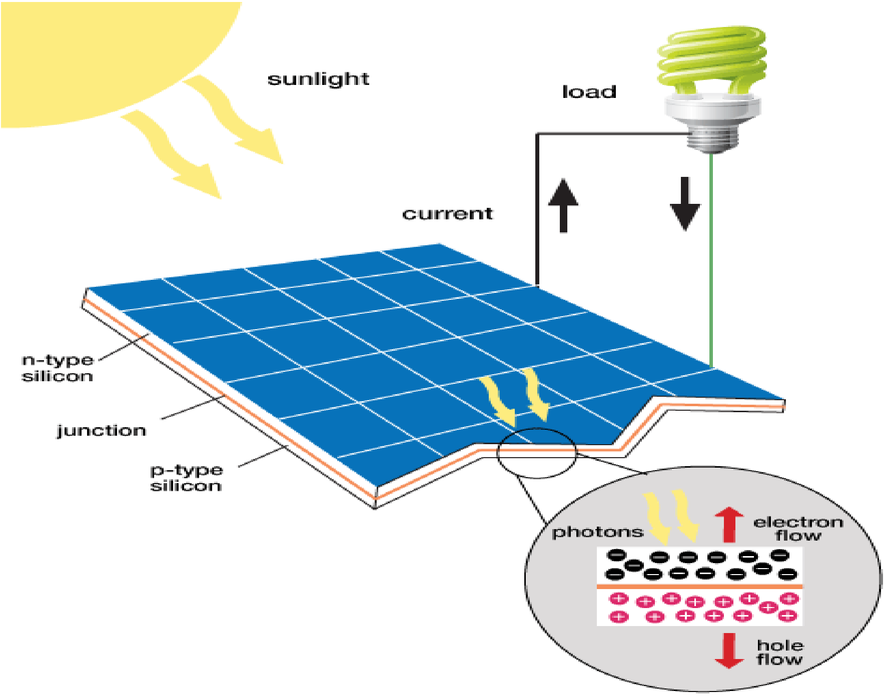


Figure 2.7; Photovoltaic operation (Hernández-Callejo, Gallardo-Saavedra,& Alonso-Gómez, 2019)

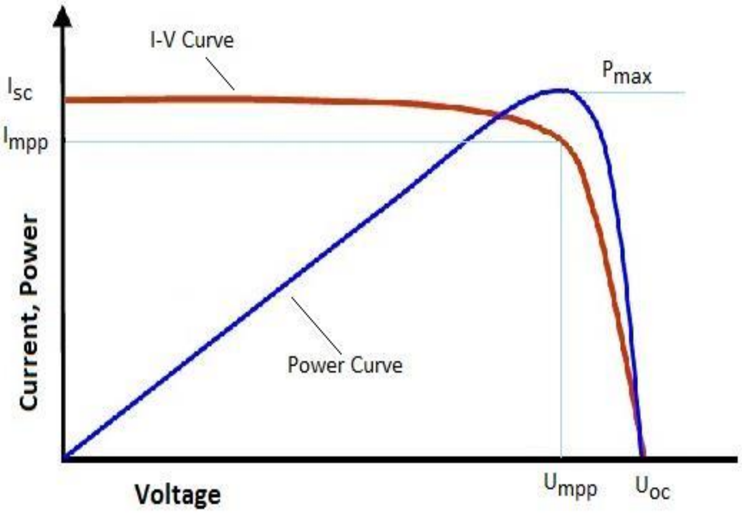


Figure 2.8; Typical P-V & I-V curve of a photovoltaic cell. (Kongphet, Migan-Dubois, Delpha, Lechenadec, & Diallo, 2022).

2.12.1.2 PV cell equivalent circuit

A current source and a diode could be used to create an ideal solar cell, but since such a solar cell does not exist in the real world, the model also includes shunt resistance and series resistance (Khatibi, Razi & Ahmadi et al., 2019). The following solar cell circuit is shown in the fig. below.

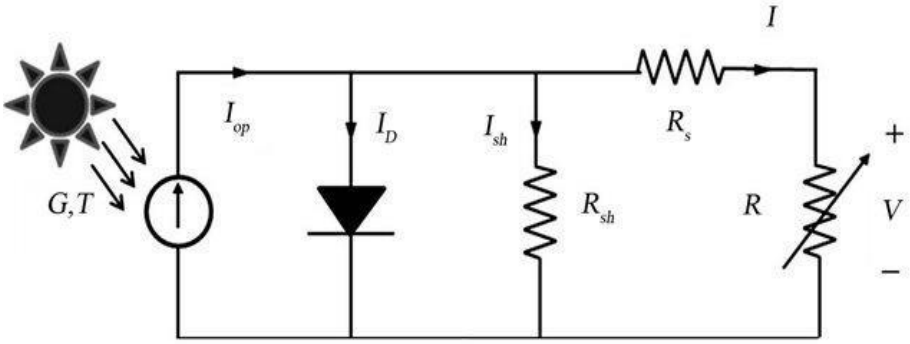


Figure 2.8; Equivalent circuit of solar cell (Ahmadi et al., 2019).

2.12.3 Wind Power in hybrid microgrid system

Electricity is produced by the air moving naturally through the atmosphere of the Earth. Its impact on the environment and the global warming catastrophe is substantially less than that of burning fossil fuels because it is a renewable resource that won't be exhausted via use. (Gooyert & Gürsan, 2021). Utilizing the kinetic energy of flowing air, or the energy in the wind, wind power systems transform it into another kind of useable energy, often mechanical or electrical. Wind turbines are the machines through which this change occurs (Joshuva, A., Aslesh, A. K., & Sugumaran, 2019).

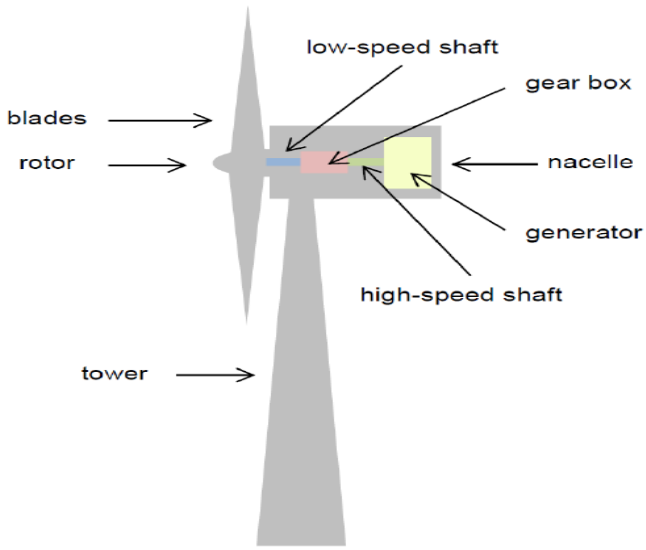


Figure 2.9; Components of a wind turbine (Hopgood, 2019).

2.12.4 Combination of PV and wind power in hybrid microgrid

Wind and solar energy are referred to as variable renewable energies because of their great spatial and temporal variability (Yamamoto, Fujioka, & Okano, 2021). Variable renewable energy cannot be transferred, in contrast to fossil or nuclear fuels. Since they must be delivered to the end consumers via the grid in the form of electrical energy, distribution and transmission losses will arise.

Second, because of the large seasonal fluctuation in wind speed and solar irradiance, variable renewable energy systems' production of electricity changes (Yamamoto et al., 2021) Because of this, standalone solar and wind power systems usually require excessive levels of storage and have trouble supplying the necessary demand.

Additionally, these resources' prediction uncertainty presents a considerable barrier to the predictability of their power output, making it difficult to dispatch electricity from these resources since it precludes the perfect synchronization of power supply and demand (Khan, Hussain & Baik, 2022).

However, due to the complementarity of these resources, their combination is a preferred approach to minimize the unpredictability of variable renewable energy (VRE) generation. The availability of wind and solar resources complements one another extremely well. The sun shines for just a few hours each day, but wind can blow at any time of the day, though it is usually fiercest in the evenings and at night. Additionally, the forecast uncertainty for these resources poses a significant obstacle to the predictability of their power output, creating a significant challenge for the dispatch of electricity from these resources as it prevents the precise matching of power production and demand (Hussain et al., 2022).

Additionally, higher wind speeds are frequently experienced on cloudy days when solar photovoltaic production is decreased due to shading losses (Waterworth, & Armstrong, 2020). As a result, combining the two resources can increase and stabilize the availability of renewable energy.

In comparison to single variable renewable energy (VRE) systems, the generated power can experience less fluctuation when solar and wind energy are integrated into hybrid power generation systems. This enhances the performance and reliability of the system as a whole. As a result, the amount of storage needed in the system can be greatly decreased, resulting in significant cost savings (Boza & Evgeniou, 2021).

2.13 Batteries Energy Storage System in microgrid

Electrochemical batteries protrude as one of the most often utilized storage technologies in commercial and residential power systems, microgrids, and nanogrids (Olabi, A. G., Onumaegbu, Wilberforce, Ramadan, Abdelkareem, & Alami, 2021). In order to meet both any backup needs and the target application's peak power requirements for islanding mode operation, the electrochemical battery's energy and power ratings must be determined (Nastasi, Mazzoni, Groppi, Romagnoli, & Garcia, 2021).

Numerous stationary and mobile applications, such as those for electric cars, submarine missions, and aircraft operations, utilise battery energy storage devices. Batteries are utilized as support systems in a variety of power system components, including the systems for power production, transmission, and distribution. These advantages make batteries popular for use in power generation, transmission, and consumption (Nadeem, Hussain, Tiwari, Goswami, & Ustun, 2018).

Two electrodes are used in batteries. Batteries transform chemical energy into electrical energy through an electrochemical process, which includes transporting electrons from one substance to another across an electrical circuit. A single cell requires the flooding of the anode and cathode into the electrolyte component, which acts as the medium for the transfer of charge. The electrochemical reaction then takes place as the anode is oxidized and the cathode absorbs electrons from the external circuit while releasing them to it (Dwivedi, 2020).

The main issue limiting the battery's life is the voltage imbalance at the cell level inside a particular battery module. Passive or active cell balancing procedures are required to provide an equal distribution of voltages that enhances battery lifetime and state of health (Omariba, Zhang & Sun, 2019). These devices frequently go through charge and discharge cycles in order to supply the need for immediate power (Garca et al., 2018). Additionally, the battery's longevity is adversely impacted if the charge/discharge levels are higher than those specified (Jin, Zeng, Chen, Feng, & Liu, 2019).

The temperature management of the batteries is a serious obstacle to safe operation under high power demands. In order for the batteries to produce the appropriate power under optimal conditions, they actually need to be adequately cooled in high-temperature settings but they also need to warm up in low-temperature surroundings (Xiong, Cao, & Yu, 2018). The transient response (di/dt) of batteries is often constrained since large transient variations might harm the device's performance (Sun et al. 2017).

2.14 Grid connected in microgrid

For usage in the built environment, hybrid power systems that are linked to the grid have grown in popularity. In grid-connected systems, a grid is used as a backup power source or as an excess power absorber. Using inverters, which convert DC power into AC electricity, the grid (Goel & Sharma, 2017).

In modest systems, such those found in residential houses, where the produced power from the hybrid is sent into the grid or utilized to power AC equipment, inverters are linked to distribution boards. Theoretically, these systems do not require batteries since they are linked to the grid, which acts as a buffer into which extra hybrid power is delivered (Rauf & Khan, 2017).

The grid also supplies electricity to the residence when hybrid power generation is not enough. However, more and more grid-connected systems are including batteries to increase self-consumption, or the amount of hybrid-generated power utilized by the household (Li, 2019)

2.15 Summary

This chapter has discussed the critical literature review on microgrids with a focus on the current research trends in this area, needs and their approaches. It has also presented a detailed discussion on future of renewable energy in Ghana, renewable master plan, renewable potentials in Ghana and barriers to renewable energy implementation in Ghana. Moreover, it also provided a detailed discussion on concept of microgrid and benefit of microgrid. Also, the chapter continued to discussed hybrid AC/DC microgrid structure configuration and power management techniques, control methods used for hybrid microgrid operation. In addition to, the chapter provided detailed discussion on hybrid energy in the system, batteries energy storage system and grid connected in microgrid system.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter discusses the methodology employed in undertaking the research. It consists the following sub-heading: description of the educational institution and site, data survey of the educational institution, data collection, modeling of hybrid microgrid systems components, modelling of environment parameters, economic analysis, control strategies, technical and economic input and Schematic of hybrid microgrid system.

3.2 Description of the educational institution and site

The Ghana Secondary Technical School is a high school with a focus on science and technology that is situated in Takoradi on Ghana's west coast (4°53.8'N, 5°45.0'W). The oldest "non-missionary" high school in Ghana, it is the third-oldest high school overall. GSHTS is a male school that offers courses such as General Arts, Technical and Science. GSHTS has around 2500 + students and has many strict teachers but very good in teaching their subjects. The school has an administration just at the entrance which is complex, which host a number of administrators. Just opposite the administration is a school library and a staff common room.

Also, there is a school field that sit at the center of the school, backet ball, volley ball court that sit on the mother end of the field. There are ten dormitory blocks starting from house One to house Ten, also have house 11 and 12 which yet to be renamed. The school has a large multi-purpose, ultra-modern assembly hall that sit at the southern end of the school field. There are several bungalows to accommodate teachers and staff of the school, as a bungalow is attached to each house for house masters. The school dining hall and kitchen are also adjacent to the classrooms. Moreover, the school has ultramodern school clinic and science laboratories, also has well equipped technical workshops. Furthermore, due to the school's location in Sekondi-Takoradi, the area has a hot, gloomy rainy season that lasts the entire year. The average annual temperature ranges from 740 to 880 degrees Fahrenheit, seldom falling below 720 or rising over 910 degrees. the wind vector (speed and direction) at 50 meters above the ground for the whole area every hour. Over the course of the year, Sekondi-average Takoradi's hourly wind speed shows some seasonal fluctuation.

Figure 3.1; Geographical area of the Educational Institution

3.3 Data Survey of the selected educational institution

For the power evacuation, knowledge of the power demand of the educational institution to be electrified is needed. The power consumption within six months of the educational institution was taken from the account office which includes the expenditures on energy consumption every month. In the second cycle educational institutions in Ghana all the fund spent on utility are forwarded to the government in form of refund of utility charges and the government will pay all the expenses. The annual average monthly energy consumption of the educational institution.

Table 3.1; Annual Average Monthly Energy Consumption

S/N	Month/Year (2021)	Energy Consumption (KWh)
1.	January.	8574.60
2.	February.	7574.60
3.	March.	9574.60
4.	April	8524.40
5.	May	8624.80
6.	June	11906.25
7.	July	15791.45
8.	August	6266.45
9.	September	4574.51
10.	October	4135.86
11.	November	8773.03
12.	December	8574.60
Total		**102895.18**

The monthly average daily energy consumption is calculated using the equation below;

$$E_{Avg.\frac{con}{mth}} = \frac{E_{tot,con}}{N_{mth}} \qquad (3.1)$$

Where; $E_{Avg.con/mth}$ is average monthly energy consumption, $E_{tot,con}$ is annual energy consumption and N_{mth} is the number of months.

The seasonal profile for the selected educational institution was employed from HOMER software, at monthly base for the year 2021 as shown in figure 3.1.

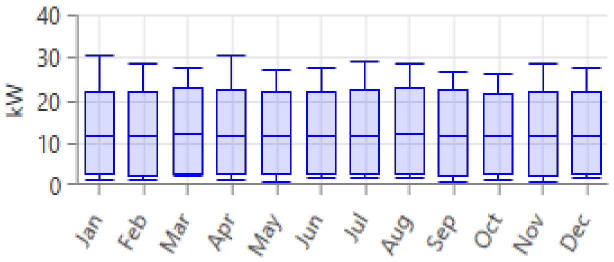


Figure 3.1; Seasonal Profile of energy consumption.

The daily profile for the selected educational institution was retrieved from HOMER software, at an hourly base for the year 2021 as depicted in figure 3.3.

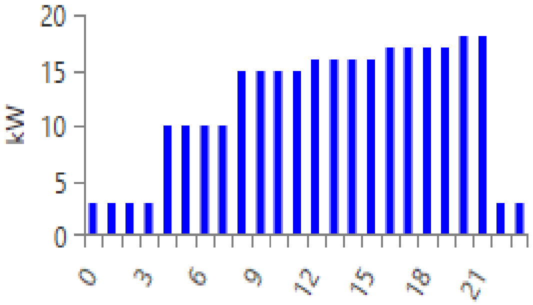


Figure 3.2; Daily profile of energy consumption.

The research observed that the peak hour in the educational institution is from 20.00 – 21.00 which is due to student activities during preps and teacher activities in their bungalows.

3.4 Data collection

3.4.1 Solar Radiation Data collection

The monthly solar radiation given by HOMER software is depicted in figure 3.3 below

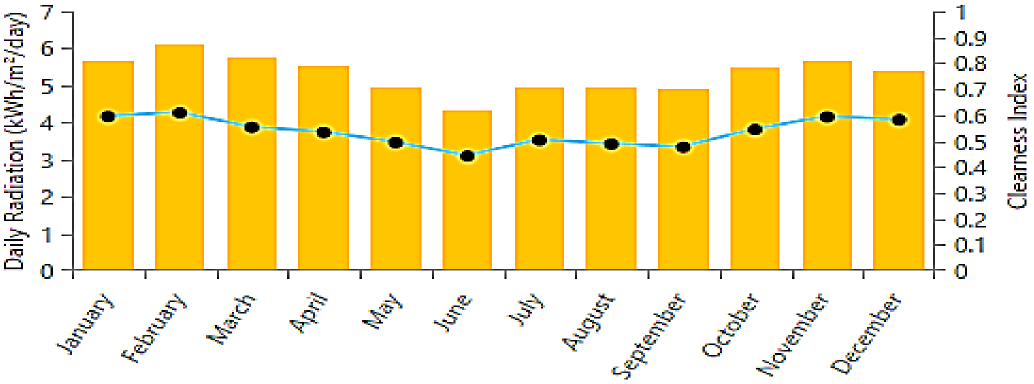


Figure 3.3; Monthly solar radiation.

A high of 6.090 kWh/m^2/day of estimated solar radiation is recorded in February, a minimum of 4.330 kWh/m^2/day in June, and an average of 5.31 kWh/m^2/day throughout the course of the year. The program also displays the clearness index at the target location, with high values during the winter (April through August) when skies are clear and low values during the summer (September through March), when skies are clouded for the majority of the time.

Wind Data Collection

The monthly wind speed distribution along the year given by HOMER software is, as presented in Figure 3.4 below.

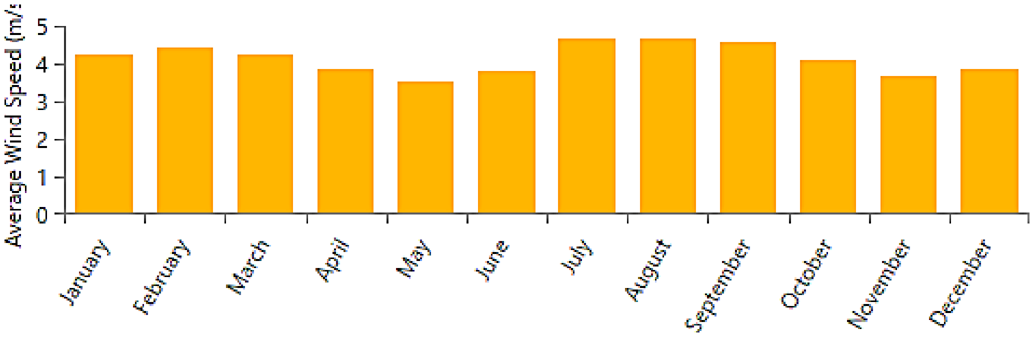


Figure 3.4; Monthly wind speed

According to the aforementioned graph, Sekondi-Takoradi experiences an average yearly wind speed of 5.02 m/s, with a maximum estimated mean monthly wind speed of 4.690 m/s in July and a lowest value of 3.510 m/s in May.

3.5 Component Modeling of Hybrid Microgrid Systems

The Hybrid Optimization Model for Electric Renewables was created by NREL, USA, to design and optimize hybrid systems for a range of applications. In this investigation, HOMER Pro is utilized. To evaluate various power generating alternatives, it mimics the technical and economic behavior of hybrid energy systems. It also aids in comprehending and calculating the impacts of input uncertainty. It can simulate both grid-connected and off-grid power systems, which include solar panels, wind turbines, small hydropower, biomass energy, reciprocating engine generators, microturbines, fuel cells, batteries, and hydrogen storage to meet electric and thermal load requirements.

Simulation, optimization, and sensitivity analysis are all performed using HOMER. In the simulation process, it simulates the hourly performance of a power production system configuration for the system's techno-economic analysis. The optimization technique simulates several potential system configurations in order to identify the ideal configuration that fulfills the technical restrictions at the lowest net current cost. This software executes several optimizations for a variety of assumptions of a single input throughout the sensitivity analysis process to evaluate the implications of uncertainty in variables like average solar radiation, average wind speed, or the future fuel.

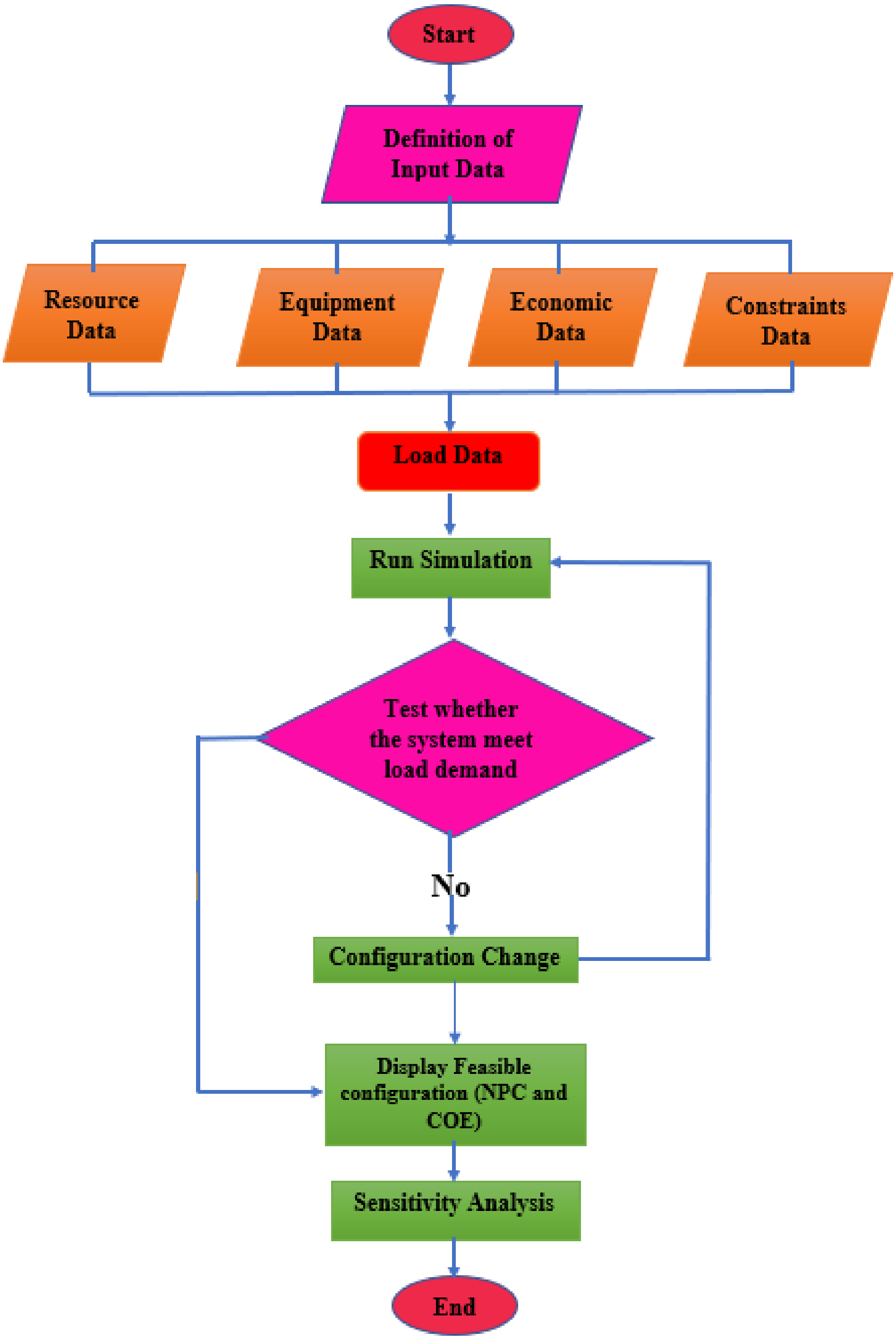


Figure 3.5; Framework of HOMER optimization procedure.

Figure 3.5 depicts the flowchart for developing the hybrid microgrid system, which begins with defining the input data, which includes resource data, equipment data, economic data, and constraints data. The next step is to input data, run simulations, and determine if the system can handle the load requirement load data. Then, modify the configuration and run the simulation for the system. HOMER software will display feasible configurations according to minimum NPC and COE. The final stage is the sensitivity analysis, which determines varying factors.

3.5.1 Modeling solar PV

Solar panels are linked in series or parallel to provide electricity in a solar system. The output power produced by solar panels is given in equation (3.2).

$$P_{PV} = M_{pv} f_{pv} x \left(\frac{I_T}{I_S}\right) x \; [1 + \beta_T \left(T_C - T_{ref}\right] \qquad (3.2)$$

Where the solar radiation is given as G (W/m^2) and the solar radiation at a standard temperature is G_{ref} (G_{ref} =1000W/m^2), respectively, depends on the output power of the photovoltaic cells, P_{pv-out}. The temperature of the cell in standard conditions is provided asT_{ref} $(25^0 C)$, and the temperature coefficient is given as K_T, where T_C is the ambient temperature.

3.5.2 Wind Turbine Model

The wind pushes the blades, which spin the wind turbine's generator, providing electrical energy. This is a mechanical process that produces the electricity from of the wind turbine. The wind turbine power is determined using equation (3.3).

$$P_m = \frac{1}{2} \rho \pi R^2 C_P V_w^3 (\lambda, \beta) \times \eta t \times \eta g \qquad (3.3)$$

A (πR^2) is the swept area, while C_p is the power coefficient. Air density is, wind speed isV_w , wind turbine efficiency is ηt, and generator efficiency is ηg

3.5.3 Diesel generator modeling

In instances where the weather is adverse and the battery is unable to supply the load, the diesel generator is employed to boost the efficiency of the hybrid system. Performance is often described by the generator efficiency, how much fuel it uses, and what kind of fuel it uses. The kind of gasoline being used often affects fuel consumption. The hourly fuel consumption of a DG set is represented by equation (3) as a linear.

$$\mathrm{F.t} = mY_{dg} + nP_{dg}.t \qquad (3.4)$$

Where P_{Rdg} is the rated DG power, $P_{DG}(t)$ is the actual power generated by the DG at a time t, m and a are connected the DG in litre/KW and they depend on the DG rated capacity.

3.5.4 Battery modeling

The battery is included in the system's design as a storage system; it stores energy that may be used if the renewable energy system is unable to supply electricity because of environmental reasons. The energy stored in the battery is utilized to power the load when solar radiation is insufficient to do so at night and a backup generator may be needed. This will occur in accordance with the battery's capacity, rate of charge and discharge, and state of charge (SOC). The nominal capacity of the battery is given in equation (3.5).

$$Q = I_n + T_n \qquad (3.5)$$

Where, I_n is constant discharge current, amp and T_n is discharge time, h

The battery storage capacity is given in equation (4).

$$C_{tot,batt} = \frac{E_L \times N_{day}}{V_{batt} \times \eta_{batt} \times \eta_{cable} \times DOD} \qquad (3.6)$$

Where; $C_{tot,batt}$ is total required capacity of the battery bank, DOD is the battery depth of charge the battery, η_{batt} is battery efficiency , V_{batt} is battery voltage and η_{cable}, N_{day} is the day of autonomy and E_L is the daily average load energy.

The total number of batteries required is calculated in the given equation;

$$N_{batt} = \frac{C_{tot,batt}}{C_{single,batt}} \qquad (3.7)$$

Where; N_{batt} is the number of batteries and $C_{single,batt}$ is the capacity of a single battery.

The total number of strings required is calculated according to the given equation;

$$N_{string} = \frac{N_{batt}}{V_{DCbus}/V_{batt}} \qquad (3.8)$$

Where; N_{string} is the number of strings of the battery, N_{batt} is the number of the batteries required, V_{DCbus} is the DC bus voltage and V_{batt} is the battery nominal voltage.

3.5.5 Modeling of grid

An electrical grid is a network of power plants, high-voltage transmission lines, and distribution lines that is connected and used to distribute electricity to customers. The grid is simulated by HOMER as a source of power from which the system may buy ac electricity and from which the extra electricity can be sold. The software also contains net metering, which requires the customer to pay the bill for net grid purchases if purchases exceed sales, but rewards the consumer for net grid sales if sales exceed purchases. Maximum power sales and maximum grid demand serve to quantify the system's capacity. Depending on the source of power generation, it uses an emission coefficient to determine the pollution emissions as a consequence of grid power purchases.

3.5.6 Modelling of Converter

In the inversion and rectification processes, a converter is a device that converts electric power from DC to AC. HOMER suggests that the device can take the load for as long as necessary and that the inverter and rectifier capabilities are continuous rather than surged. The grid or another AC power source, such as a generator, can both be used in parallel with the inverter. The converter's final physical characteristics, which HOMER anticipates will not change, are its inversion and rectification efficiency.

3.5.7 Modelling of Charge Controller

In order to prevent overcharging, a charge controller is used to determine when a battery is fully charged and to stop or restrict the flow of energy from the energy source to the batteries. The mathematical model of the charge controller is calculated using the equations below;

$$E_{cc,out}.t = E_{cc,in}.t \times \eta_{cc} \qquad (3.10)$$

$$E_{cc,in} = E_{rec,out}.t + E_S.t \qquad (3.11)$$

Where$E_{cc,out}$ represents the output energy from the charge controller (kWh), $E_{cc,in}$ represent the input energy from the charge controller (kWh), η_{cc} represent the charge controller efficiency, $E_{rec,out}$ represent the output energy from the rectifier (kWh), E_S represents the available surplus energy from DC source.

3.5.8 Modelling of Environment parameters

Total GHG emissions from the power plant are calculated in order to assess environmental viability. These gases and other pollutants raise the harm that environmental pollution poses to both human and animal

Emission factor

It is a metric that relates the amount of pollutants discharged into the environment for each unit of energy generated. In this work, emission is calculated as:

$$E\left(\frac{\text{kg}}{\text{kWh}}\right) = G_{cap} x E_f (1 - \eta_r) \tag{3.12}$$

Where, G_{cap} is the total generation capacity, E_f is the emission factor, η_r is the overall pollutant reduction efficiency of the system.

3.6 Economic Analysis

The annual real interest rate and project lifespan are two crucial economic input factors required for HOMER simulation. At the conclusion of the simulation, HOMER ranks the sum of the net present costs of all systems in descending order. Aside from that, the levelized cost of energy is also taken into account to produce a practical yardstick for comparison in order to determine the best outcomes of various system designs. All these economic factors will be covered in the section that follows.

3.6.1 Interest Rate

The annual real interest rate, sometimes called the real interest rate or simple interest rate, is one of the inputs that HOMER uses. It is the discount rate applied when turning one-time expenses into yearly expenses. The nominal interest rate and yearly real interest rate are linked by the formula below.

$$i = \frac{i - f}{1 + f} \tag{3.13}$$

Where i = nominal interest rate [%] and f =yearly inflation rate [%]

3.6.2 Levelized Cost of Energy (LCOE)

According to HOMER, levelized cost of energy (LCOE or COE) is the average cost per kWh of useable electrical energy generated by the system. This quantity is calculated from the following equation

$$COE = \frac{TAC}{L_{prim}AC + L_{prim}DC + E_{grid,sales}} \tag{3.14}$$

Where: TAC is total annualized cost (\$/year), L_{prim} is primary AC load (kWh/year), L_{prim} is primary DC load served (kWh/year) and $E_{grid,sales}$is total grid sales (kWh/year) (E_{gr},sales).

3.6.3 Net Present Cost (NPC)

The present value of all of the system's expenses minus the present value of all of the money it generates over its lifetime is the total net present cost (NPC) of the system. Included in the costs are capital outlays, replacement costs, operation and maintenance costs, fuel prices, fines for pollution, and the cost of using the grid to get power. Two sources of income are grid sales revenue and salvage value. According to the below equation, the total discounted cash flows for each year of the project's life cycle are added to determine the total NPC.

$$C_{NPC} = \frac{TAC}{CRF(i, Tproj)} \tag{3.15}$$

Where C_{NPC} is net present cost [\$], TAC is total annualized cost [\$/year], $CRF$is capital recovery factor,T_{proj} is project lifetime [year] and i is nominal interest rate [%]

The system's lifetime in this research is 25 years, and a ratio called the capital recovery factor is employed to evaluate an annual present value which is a series of equal annual cash flows. The capital recovery factor’s equation is as follows

$$CRF(i,t) = \frac{i(1+i)^t}{(1+i)^t - 1} \qquad (3.16)$$

Where t = lifetime of the system [year]

3.6.4 Salvage Value

Salvage value is the price of a power system component that is still functional at the end of the project's lifecycle. This equation is used by HOMER to determine the value of each component at the end of the project's life cycle.

$$S = C_{rep} \frac{T_{comp} - [T_{proj} - (T_{comp} \times \beta(\frac{T_{proj}}{T_{comp}})}{R_{comp}} \qquad (3.17)$$

Where; S is salvage value [\$], C_{rep} is component replacement cost [\$], T_{rem} is component remaining life [year], T_{comp} is component lifetime [year] and β is a function that round down a real number to the nearest integer.

3.6.5 Internal Rate of Return

Internal rate of return is the discount rate at which the reference case and the optimized system have the same net present cost. The internal rate of return is calculated using HOMER by dividing the present value of the difference between the two cash flow sequences by the discount rate.

3.6.6 Return on Investment

The cost reductions over time versus the initial expenditure is known as return on investment. The return on investment is calculated by multiplying the variation in capital costs by the typical annual variation in nominal cash flows throughout the duration of the project.

To calculate the return on investment, use the following equation.

$$R_{OI} = \frac{\sum_{i=0}^{T_{proj}} C_{i,ref} - C_i}{T_{proj}(\, C_{cap} - C_{cap,ref})} \tag{3.18}$$

Where; R_{OI} is nominal annual cash flow for reference system [$], $T_{proj}$is project lifetime [year], $C_{i,ref}$ is nominal annual cash flow for reference system [$], C_i is nominal annual cash flow for current system [$], $C_{cap}$is capital cost of the current system [$], and $C_{cap,ref}$ is capital cost of the reference system [$].

3.6.7 Simple Payback

Simple payback is the amount of years necessary for the aggregate cash flow difference between the case-reference system and the improved system to become positive. The payback period is the length of time required to recoup the investment cost variance between the reference case and improved solutions.

$$T = \left(\frac{C}{S}\right) \tag{3.19}$$

Where T is the payback period, C is the project cost and S is the savings of the project.

3.6.8 **Total Annualized Cost**

The entire cost that, if distributed equally over the length of the project, would have a net present cost equal to the component's actual cash flow sequence is represented by the sum of its annualized costs. One may calculate the annualized cost by dividing the net present cost by the capital recovery factor, as shown in the equation below:

$$TAC = CRF\left(i, T_{proj}\right) \times C_{NPC,tot} \tag{3.20}$$

WhereTAC is total annualized cost [$/year], CRF is the capital recovery factor

T_{proj} is the project lifetime [year], $C_{NPC,tot}$ is the total net present cost [$] and i is the nominal interest rate [%].

3.7 Technical and Economic input

The technical analysis for the research, sizing, simulation, and data analysis of full hybrid microgrid systems will be carried out with HOMER Pro's assistance. The program simulates the operation of the hybrid microgrid system while taking into account the numerous potential losses. It contains a large library of meteorological data for various locations, system components, and their specifications from manufacturers

3.7.1 Solar PV cost

Generic flat plate type PV panels were selected after comparing several options with a focus on the price offered. As long as efficiency is not a major concern in this situation, the rationale for picking the goods from the mentioned firm is its inexpensive cost of delivery. Through market survey, the capital cost 1kW panel is $3000 and the replacement cost is $ 2500 and operation and maintenance is $10/year. These panels have 25 years of life along with 80% derating factor. Different capacity variation for the solar PV panels (0, 30, 40, 50kW).

3.7.2 Wind Turbine Size and Cost

The limiting factors for choosing a wind turbine include the number of turbines, their lifespan, their hub height, their cost, the sort of power they provide, and their reduction in wind speed. To meet the needs of consumer products with AC loads, the chosen turbines may produce energy of the AC type. The wind turbine taken for this research work is Generic 3kW, Quantities [0,2,3,4,6], Capital cost, $18000, Replacement cost, $16200, Operation and Maintenance, $180/year, Lifetime-20, hub height 50m meters.

3.7.3 Cost and Size of Batteries

Cost and battery count are input parameters that are entered into the program, just like with the other parts of the power system. Hoppecke 24 OPzS, which is available in the HOMER tool collection, was the storage battery of choice. The capital cost, replacement cost and O&M costs for one unit of this battery is considered as $2171, $2000, and $20 respectively. Quantity of Batteries considered [400,600,800] 12 per string.

3.7.4 Diesel Generator Size and Cost

Diesel generators are used as a backup power source in hybrid microgrid systems rather than as the primary power source. When solar PV-wind hybrid systems are unable to fully meet the load requirement, a diesel generator is used to supply electricity to the load. Although there is a large selection of diesel generators, it might be difficult to evaluate because various vendors offer varying cost justifications. The AC generator has a capacity of 10 kW. Its initial capital cost is $5000 and its replacement costs are $4000. The operation and maintenance cost is $0.03 per hour. The life time of the generator is estimated at $15000 operating hours. Diesel is priced at $1.02 per liter based on an exchange rate of $1.00 = 14.0013 Ghana cedis (October, 2022). Sensitivity [1.5,1.7,2.0,2.2] and limited consumption is 5000L/year.

3.7.5 Grid

Grid is the primary source of electricity in hybrid microgrid systems. The single rate of the national grid for commercial load is GH¢0.76/kWh ($0.057) [$0.057, 0.07,0.1 /kWh] (ECG bill), sellback, Supply power price is $0.057/kWh and Demand charges at $0.50/kW/month are based on an exchange rate of $1.00 = 14.0013 Ghana cedis (October, 2022).

3.7.6 Converter

The converter size that is used in this system is 100kW. The initial capital cost is considered as $600/kW and its replacement cost is $450. The operation and maintenance cost is estimated as $100 per one year and lifetime is 15years. The inversion efficiency is 90%, rectification efficiency 85%. Efficiency 85%, to operate parallel with diesel generator. Different capacities of converters [0, 50, 100,150kW] to feed the defined load.

3.7.7 Economic Inputs

The real interest rate is the difference between the nominal interest rate and the inflation rate. The modeling tool would take into account the following extra inputs to compare the economics of the power system setup using renewable and non-renewable energy sources. The lifetime of the hybrid microgrid system is designed to end for 25 years long with generating capacity to meet the demand and the annual real interest rate in Ghana is taken as 24.5% (October, 2022) that is used to calculate the NPC of the project and system fixed capital cost is $ 6000.

3.7.8 Constraint Inputs

The capacity shortfall of any power system architecture may be determined annually using HOMER. Excess electricity is generated when there is either an overabundance of power coming from renewable sources relative to load demand or when a battery bank is completely charged and therefore unable to store the energy generated. The following constraint inputs are taken into account for this study example, and no consideration is made for the location of interest's thermal load. Maximum annual capacity shortage [0%, 10%], operating reserve is 10% and annual peak load is 0%, solar power output is 80% and wind power output is 50%.

3.8 Model of Hybrid Microgrid System

The system is made up of the components listed above: solar PV modules, batteries for wind turbines, diesel generators, grid, charge controllers, converters, and all necessary wiring and safety equipment. Using HOMER software, the system feasibility analysis was carried out. A computer model called HOMER makes it easier to assess different on- and off-grid power system design alternatives for educational institutions. The hybrid microgrid's daily energy consumption is 286 kWh, with a peak demand of 30.79 kW, as shown in Figures 3.5 and 3.6. The DC bus is connected to a 1kW solar PV system with Hoppecke 24 OPzS batteries; the converter serves as both a rectifier and an inverter. The grid, a 3 kW wind turbine, and a 25 kW diesel generator are all linked to form the AC bus.

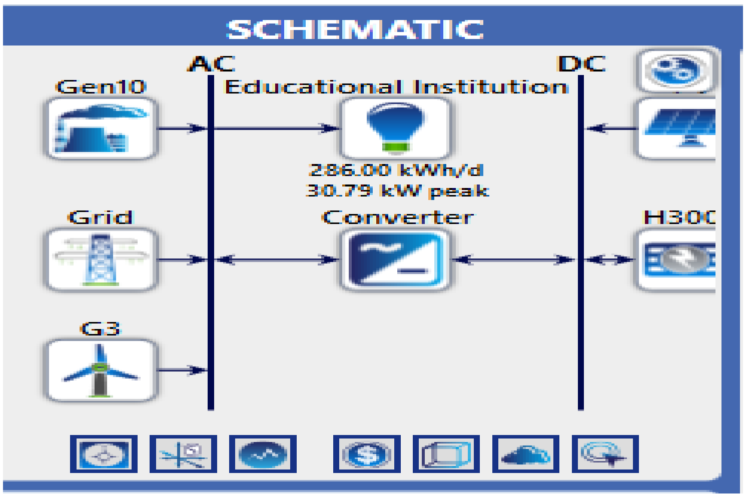


Figure 3.6; Schematic diagram of proposed system

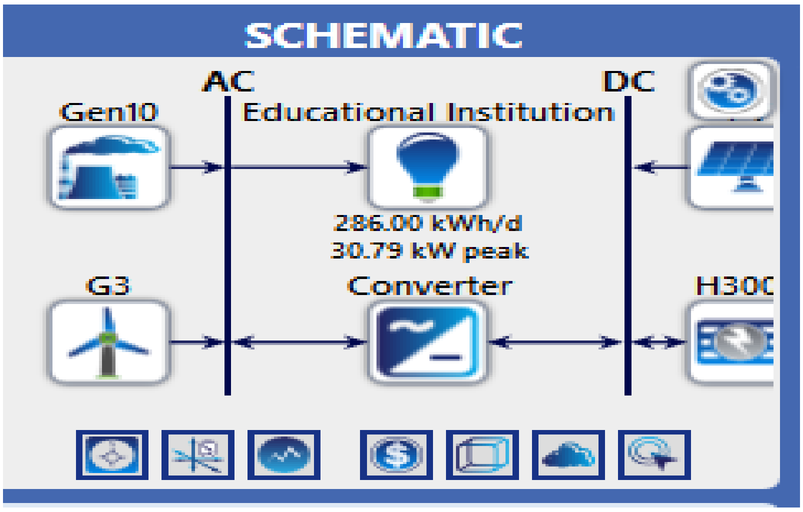


Figure 3.7; Schematic diagram of off-grid microgrid.

The software program runs a simulation that includes calculations of energy transfer between electrical buses and economic evaluations over a certain period using the pertinent information given by the researcher. The government may then make a choice based on the offered solution by identifying the most practical mix of power sources and storage components from the simulation results.

CHAPTER FOUR

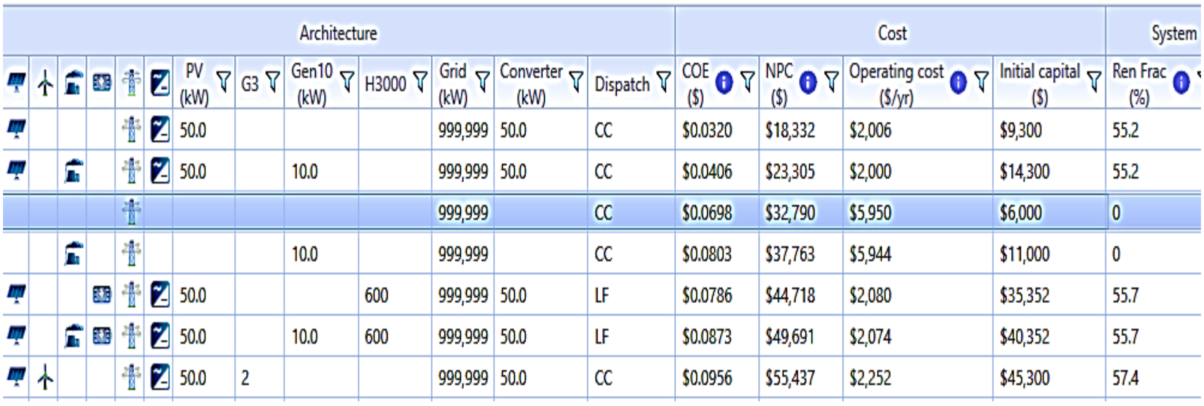
DATA PRESENTATION AND ANALYSIS

4.0 Introduction

This chapter presents the results and discussions for the simulation based on the above input data for a 25-year analysis period. The optimal system is selected by the HOMER program among the other sizes. Grid system, Grid connected hybrid microgrid system and Standalone hybrid system are compared in this segment. The hybrid system is optimized in order to meet demand for the educational institution. The assessment covers both the technical and economic system performance for 25 years lifetime, environment impact, control strategy employed and sensitivity analysis.

4.1 Analysis of Optimization results of Grid connected Hybrid microgrid.

The systems are arranged in increasing order by their NPC and COE. Out of 12,000 computer simulations, only 9,280 were feasible, and the best five systems of each configuration are analyzed. The hybrid microgrid configurations are PV/Grid, PV/Grid/DG, Grid, DG/Grid, and DG/Grid/Battery. The most optimal system is the Hydro/DG/Battery system with a 50 kW PV, 50 kW Converter, and CC dispatch strategy. It has an NPC of $18,332 and a COE of $0.0320. It has the second-lowest operating cost of $2,006/year and has second-lowest initial capital of $9,300. The optimal system is PV/Grid/DG which has an NPC of $23305 and a COE of $0.0406. It has an operating cost of $5,950/year and initial capital of $14,300. Also, it can be seen that the third optimal system is the Grid which has an NPV of $32,790 and a COE of $ 0.0698. It also has operating cost of $5,950/year and lowest initial capital of $600. It is revealed that the fourth optimal system is DG/Grid which has an NPC of $37,763 and a COE of 0.0803. It also has an operating cost of $5,944/year and initial capital of $11000. It can be deduced from the figure 4.1 that the five is DG/Grid/battery which has an NPC of $44,718 and a COE of 0.0786. It has an operating cost of 2,080/year and initial cost of 35,352. Compared to the fourth-best performing system, which is a DG/Grid system, adding the battery helps to bring down the cost of the system. And so, it fetched out that as the number of the systems are increasing COE also increased with the exception of DG/Grid/battery system. The optimal results are depicted in the figure 4.1 below;

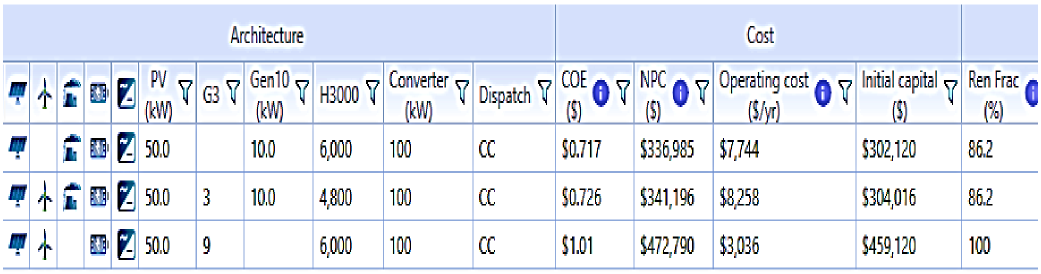


Architecture													Cost				System
						PV (kW)	G3	Gen10 (kW)	H3000	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)
✓				✓	✓	50.0				999,999	50.0	CC	$0.0320	$18,332	$2,006	$9,300	55.2
✓		✓		✓	✓	50.0		10.0		999,999	50.0	CC	$0.0406	$23,305	$2,000	$14,300	55.2
				✓						999,999		CC	$0.0698	$32,790	$5,950	$6,000	0
		✓		✓				10.0		999,999		CC	$0.0803	$37,763	$5,944	$11,000	0
✓			✓	✓	✓	50.0			600	999,999	50.0	LF	$0.0786	$44,718	$2,080	$35,352	55.7
✓		✓	✓	✓	✓	50.0		10.0	600	999,999	50.0	LF	$0.0873	$49,691	$2,074	$40,352	55.7
✓	✓			✓	✓	50.0	2			999,999	50.0	CC	$0.0956	$55,437	$2,252	$45,300	57.4

Figure 4.1; Optimization of Grid connected hybrid microgrid

4.2 Analysis of Optimization results of Standalone Hybrid microgrid.

The input data are methodically evaluated, described, and tabulated in order to find the most economical hybrid system of the five hybrid systems suggested in this study using the HOMER software. Specifically, the first system, the PV/DG/battery-power converter hybrid microgrid system, was discovered to be the most cost-effective system among the hundreds of PV-wind batteries-power converter hybrid systems studied with the HOMER software. A comparison of this system with a chosen representative of each of the five systems is provided in the figure. Which has an NPC of $336,985, a COE of $0.719 and an operating cost of $7,744 as depicted in figure 2. It can be unveiled from the figure that the COE of each system increases when the system capacity increases or when there is additional component.



Architecture											Cost				
					PV (kW)	G3	Gen10 (kW)	H3000	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)
●		●	●	●	50.0		10.0	6,000	100	CC	$0.717	$336,985	$7,744	$302,120	86.2
●	●	●	●	●	50.0	3	10.0	4,800	100	CC	$0.726	$341,196	$8,258	$304,016	86.2
●	●		●	●	50.0	9		6,000	100	CC	$1.01	$472,790	$3,036	$459,120	100

Figure 4.2; Optimization of Standalone hybrid microgrid

4.3 Economics, Technical and Environmental analysis of system options

4.3.1 Grid System

The main grid can handle the full load demand and where RF is almost 0%. The total NPC is deducted from the main grid and is calculated to be $ 32,790 over the lifetime of the 25 projects as indicated in figure 4.1. At the assigned electricity tariff, which includes operating expenses and fossil fuel prices, a total amount of energy purchased from the main grid each year is 104,390 kWh. On the basis of the assigned load, the annual harmful CO_2 emission for the selected the educational institution is 66,400 kg. 65,974g/kWh of carbon dioxide, 286g/kWh of sulfur dioxide, and 140 g/kWh of nitrogen oxides are the harmful emissions as in table 4.1 below.

Table 4.1; Emission of Grid system

Quantity	**Value**	**Unit**
Carbon Dioxide	65974	Kg/yr
Carbon Monoxide	0	Kg/yr
Unburned hydrogen	0	Kg/yr
Particulars of matter	0	Kg/yr
Sulfur Dioxide	286	Kg/yr
Nitrogen	140	Kg/yr

Table 4.2; Annual Electricity Production

Component	Production (kWh/yr)	Percent
Grid Purchases	104,390	100
Total	**104,390**	**100**

It can be deduced from the table that the annual electrical energy purchased from the is 104,390 kWh. Due to the energy situation in the country, grid system only cannot give secured power supply.

4.3.2 Grid connected Hybrid Microgrid system (PV/Grid)

The Grid connected Hybrid Microgrid system has a RF of 55.2%, with total NPC estimated as $ 18,332, levelized COE which is also estimated as $0.0320 and operating cost which is estimated as $2,006 over the course of the 25 projects as deduced from the optimized results in figure 4.1. The total annual energy purchased from the main grid is 57,102 kWh which contributed to 42.2%, at the assigned electricity tariff and total annual energy from the hybrid renewable system is 78,100kWh which also contributed to 57.8%. The annual harmful CO_2 emission for the selected, educational institution is based on the assigned load, is 36,088 g/kWh of carbon dioxide, 156 g/kWh of sulfur dioxide, and 76.5g/kWh of nitrogen oxide as in table 4.2.

Table 4.3; Emission Grid Connected Hybrid microgrid

Quantity	Value	Unit
Carbon Dioxide	36,088	Kg/yr
Carbon Monoxide	0	Kg/yr
Unburned hydrogen	0	Kg/yr
Particulars of matter	0	Kg/yr
Sulfur Dioxide	156	Kg/yr
Nitrogen	76.5	Kg/yr

Table: 4.4; Annual Electricity Production

Component	**Production (kWh/yr)**	**Percent**
Generic flat plate PV	78,100	57.8
Grid Purchases	57,102	42.2
Total	**135,202**	**100**

Electricity production from the grid connected system has been mainly from the PV, the grid generated 78,100kWh of electricity annually representing 57.8%. The grid also produced 57,102kWh of electricity per year representing 42.2% of the total electricity produced by the grid connected system. Table 4.4 above depicts the monthly electricity production from the grid connected.

4.3.3 Standalone Hybrid microgrid system (PV/DG/Battery)

According to the optimized outcomes, standalone Hybrid Microgrid system has a RF of 86.2%, a total NPC which is estimated as $ 336, 985 levelized COE which is estimated as $0.717, and an operating cost which is estimated as $7,744 over the 25 projects as depicted in figure 4.3. The total energy produced by the Hybrid renewable system is 92,487kWh. Using the assigned load as a basis, the annual harmful CO_2 emission for the chosen educational institution is calculated to be 13,060g/kWh of carbon dioxide, 98.8 of carbon monoxide ,3.6 of unburned hydrogen, 5.99 of particular matters, 32.0 g/kWh of sulfur dioxide and 112 g/kWh of nitrogen oxide as in table 4.5below;

Table 4.5; Emission of hybrid microgrid

Quantity	Value	Unit
Carbon Dioxide	5,453	Kg/yr
Carbon Monoxide	34.0	Kg/yr
Unburned hydrogen	1.5	Kg/yr
Particulars of matter	0.204	Kg/yr
Sulfur Dioxide	13.4	Kg/yr
Nitrogen	32.0	Kg/yr

Table 4.6; Annual Electricity Production

Component	Production (kWh/yr)	Percent
Generic flat plate PV	78,100	84.4
Generic 10kW Fixed Capacity Genset	14,387	15.6
Total	**92,487**	**100**

Electricity production from the grid connected system has been mainly from the PV, the PV generated 78,100kWh of electricity annually representing 84.4%. The Gen25 also produced 14,387 kWh of electricity per year representing 15.6% of the total electricity produced by the grid connected system. It can be figured out from the table 4.6, that the PV renewable potential at the area is very high compared to wind energy and provide reliable power supply.

4.4 Summary of NPC and Annual of the Hybrid Microgrid System options

4.4.1 Grid system only

Table 4.7; Breakdown of annualized cost

Name	Capital	Operating	Replacement	Salvage	Resource	Total
Grid	$0.00	$26,790	$0.00	$0.00	$0.00	$26,790
Other	$6,000	$0.00	$0.00	$0.00	$0.00	$6,000
System	$6,000	$26,790	$0.00	$0.00	$0.00	$32,790

Table 4.8; Breakdown of annualized cost

Name	**Capital**	**Operating**	**Replacement**	**Salvage**	**Resource**	**Total**
Grid	$0.00	$5,950	$0.00	$0.00	$0.00	$5,950
Other	$1,333	$0.00	$0.00	$0.00	$0.00	$1,333
System	$1,333	$5,950	$0.00	$0.00	$0.00	$7,283

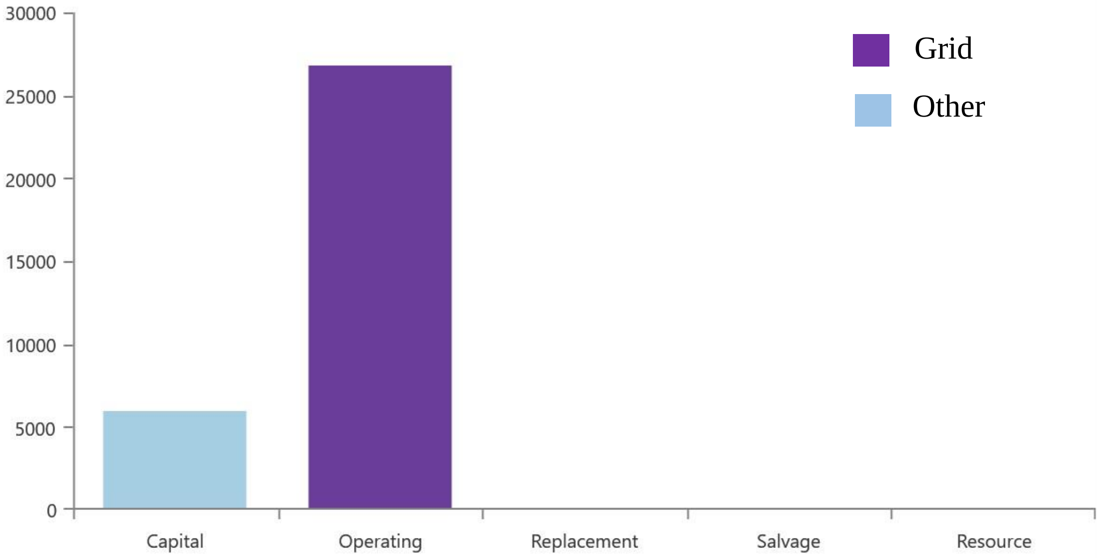


Figure 4.3; Cost summary of Grid system

4.4.2 Grid connected hybrid Microgrid (PV/Grid)

Table 4.9; Breakdown of Net Present Cost

Name	**Capital**	**Operating**	**Replacement**	**Salvage**	**Resource**	**Total**
Generic flat plate PV	$3,000	$45.02	$0.00	$0.00	$0.00	$3,045
Grid	$0.00	$8,751	$0.00	$0.00	$0.00	$8,751
Other	$6,000	$0.00	$0.00	$0.00	$0.00	$6,000
System Converter	$300.00	$225.11	$11.31	-$0.514	$0.00	$535.91
System	$9,300	$9,021	$11.31	-$0.514	$0.00	$18,332

Table 4.10; Breakdown of Annualized cost

Name	**Capital**	**Operating**	**Replacement**	**Salvage**	**Resource**	**Total**
Generic flat plate PV	$666.33	$10.00	$0.00	$0.00	$0.00	$676.33
Grid	$0.00	$1,944	$0.00	$0.00	$0.00	$1,944
Other	$1,333	$0.00	$0.00	$0.00	$0.00	$1,333
System Converter	$66.63	$50.00	$2.51	-$0.114	$0.00	$119.03
System	$2,066	$2,004	$2.51	-$0.114	$0.00	$4,072

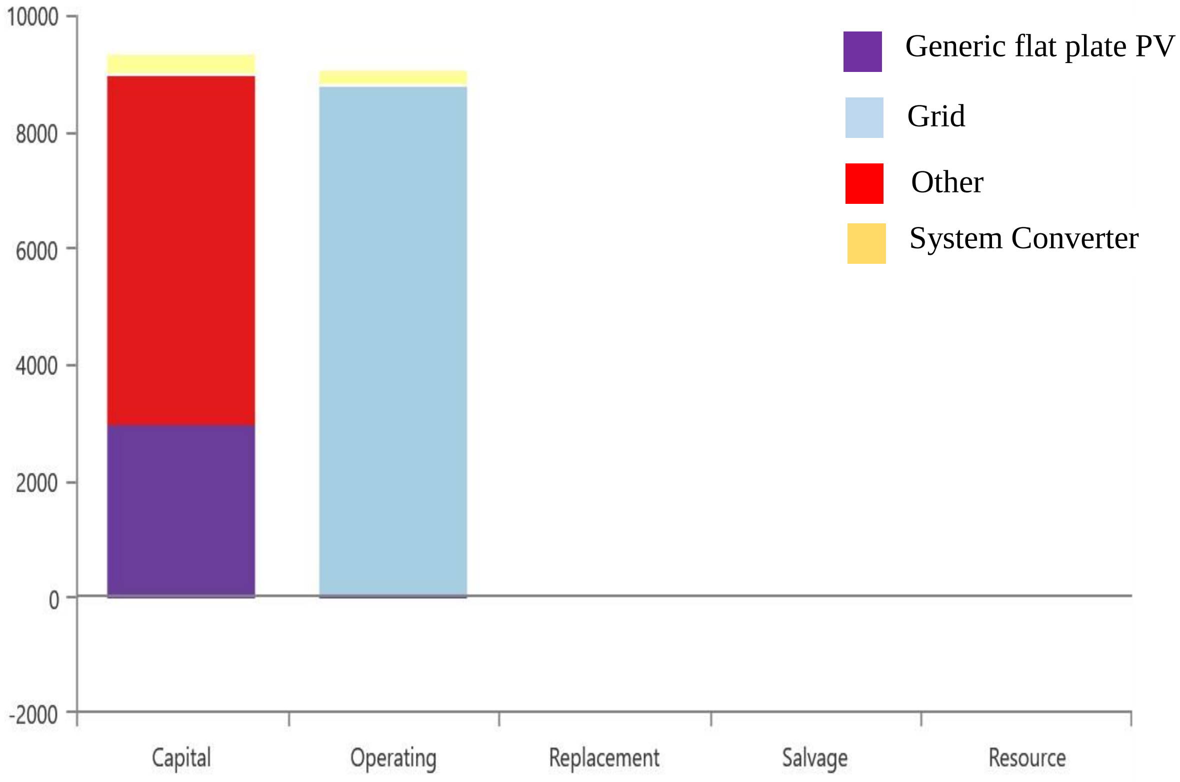


Figure 4.4; Cost summary of Grid connected microgrid

4.4.3 Standalone Hybrid microgrid (PV/DG/Battery)

Table 4.11; Breakdown of Net Present Cost

Name	Capital	Operating	Replacement	Salvage	Resource	Total
Generic 10kW Fixed Capacity Genset	$5,000	$2,488	$975.39	-$25.49	$27,008	$35,446
Generic flat plate PV	$30,000	$450.23	$0.00	$0.00	$0.00	$30,450
Hoppecke 24 OPzS 3000	$260,520	$0.00	$4,836	-$1,339	$0.00	$264,017
Other	$6,000	$0.00	$0.00	$0.00	$0.00	$6,000
System Converter	$600.00	$450.23	$22.63	-$1.03	$0.00	$1,072
System	$302,120	$3,388	$5,834	-$1,365	$27,008	$336,985

Table 4.12; Breakdown of Annualized cost

Name	Capital	Operating	Replacement	Salvage	Resource	Total
Generic 10kW Fixed Capacity Genset	$1,111	$552.60	$216.64	-$5.66	$5,999	$7,873
Generic flat plate PV	$6,663	$100.00	$0.00	$0.00	$0.00	$6,763
Hoppecke 24 OPzS 3000	$57,864	$0.00	$1,074	-$297.33	$0.00	$58,641
Other	$1,333	$0.00	$0.00	$0.00	$0.00	$1,333
System Converter	$133.27	$100.00	$5.03	-$0.228	$0.00	$238.06
System	$67,104	$752.60	$1,296	-$303.22	$5,999	$74,848

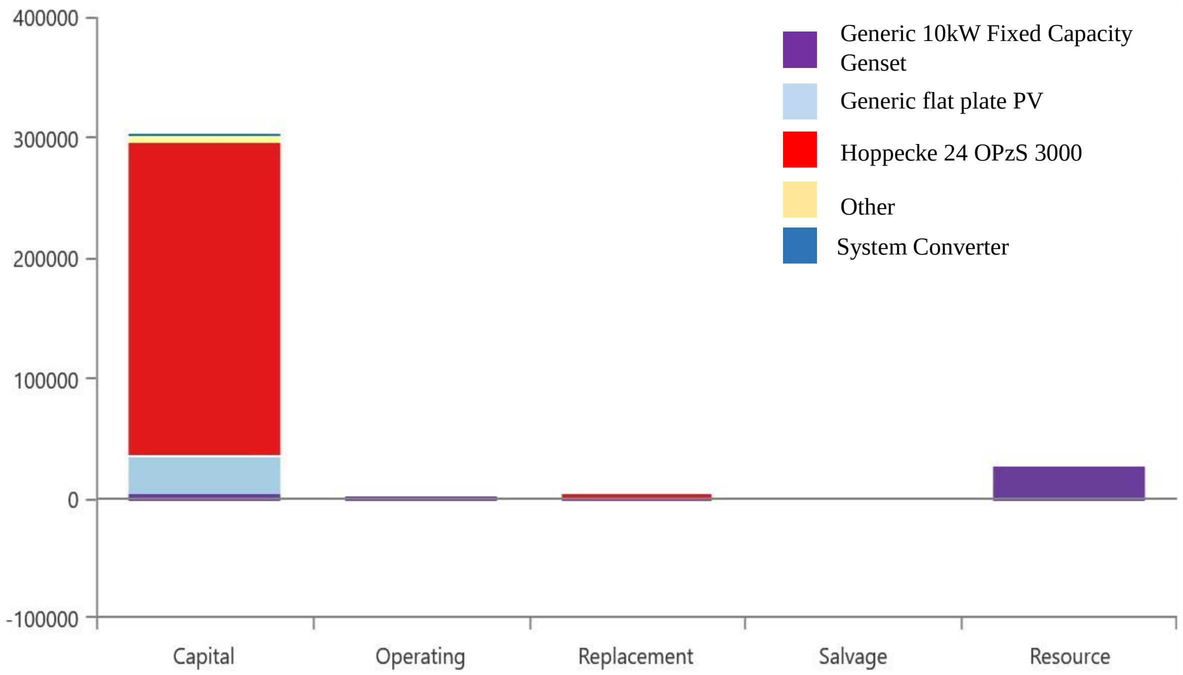


Figure 4.5; Cost summary of Grid connected microgrid

4.5 Discussion of findings

4.5.1 Economic comparative analysis of hybrid system options

The optimization approach is based on net present cost, which is the sum of all capital costs, operating and maintenance costs, replacement costs, and salvage costs for all hybrid microgrid system components throughout the course of the project.

It is unveiled from the simulation results that grid system only has the lowest NPC which is estimated as $32,790 and levelized COE which is estimated as $0.070, due to it low operating and maintenance cost. The implies grid system is the third optimal system for electrification of the educational institution at third-lowest energy production.

More so, it is clear from the optimization results that grid connected hybrid microgrid (PV/Grid) is the feasible system since it has the lowest NPC which is estimated as $18,332 and levelized COE which is estimated as $0.0320 due to its second-lowest cost of operation and maintenance compared to standalone hybrid microgrid as indicated in figure 4.2. It reduces the amount of money the educational institution spends on energy consumption because some of the energy is also sold to the grid. It is the best solution to the chronic intermittency of renewable energy source. Although, Grid connected hybrid has higher CO_2 emission of gasses compared standalone hybrid microgrid but yet still grid connected microgrid is the one we thumb up for the educational institution electrification.

In addition to, it can be fetched out from the analysis that, standalone hybrid microgrid (PV/DG/battery) has the highest NPC which is estimated as $336,985 and levelized COE which is estimated as $0.717 because it has a high capital cost especially the cost of battery storage. It has the lowest CO_2 emission among other due to high renewable factor. This implies the standalone hybrid microgrid is feasible system for the electrification of the educational system. Despite the fact that standalone is optimal system for the electrification education institution, it is produced from only PV and DG so if the fuel price increased and the educational institution cannot afford, and also when there is climate variation meaning the educational institution is going to face power outage.

4.5.2 Technical comparative analysis of the hybrid system options

In the grid system, the energy purchased the from grid is 104,390 kWh at a cheap price. However, grid system also has high emission of gases and not considering its uncertainty and interrupted of power supply in Ghana.

Also, In the grid connected system (PV/Grid) the electrical energy purchased from the grid is 57,102 kWh and the energy produced from the hybrid renewable energy is also 78,100 kWh. Since is grid connected, the energy sold to the grid is 23,002 kWh. There will be no power outage in case of maintenance, grid uncertainty and interrupted power supply and renewable intermittency.

More so, in standalone hybrid microgrid system (PV/DG/battery), the energy produced from the system is 92,487kWh which is not up to the energy consumption. Standalone hybrid is green technology in which the whole world is promoting now. Despite its benefits, such as its non-depleting and non-polluting nature, better load matching, and greater usage of renewable energy, the initial cost of battery storage for the educational institution is considerable, and renewable energy is intermittent.

In a nut shell, based on the optimization results, one can summarize that grid connected (PV/Grid) is the best hybrid microgrid systems viable to power the educational institutions. Grid connected is the most cost-effective system and also provides more reliable power. Grid connected hybrid microgrid (PV/Grid) is more environment friendly than grid system and provides secure power than standalone hybrid microgrid system.

4.6 Environmental comparative analysis of hybrid system options

Due to the usage of renewable energy technology, the hybrid microgrid architecture reduces large amounts of CO_2 emissions. Diesel fuel is injected into the combustion chamber of a diesel generator in a mixture with compressed air as its basic working principle. Unburned hydrocarbon and other harmful particles, such CO_2 and NO_2, are produced when this combination burns and are particularly toxic to our lungs. The detailed pollutant emissions of most of the possible are listed in Table 4.1, which shows that grid only has lower value for RF which is 0%, since RF lowers hazardous emissions. RF plays a significant role in reducing harmful emissions, implies that the grid system produced higher emissions comparing with other configurations. Also, Table 4.2, indicated that the RF of grid connected (PV/Grid) is 52.2% which has higher emissions compared to the standalone (PV/DG/battery). More so, the table 4.3 shows that the RF of standalone is 84.2% which is lowest emission among the others.

4.7 Power control strategy Analysis Grid connected hybrid microgrid

Table 4.13; Control Strategy for PV/Grid System

Quantity	Value	Units
Excess Electricity	0	kWh/yr
Unmet Electric Load	0	kWh/yr
Capacity Shortage	0	kWh/yr

It can be unveiled from the table 4.10 above that, excess electricity, unmet load and capacity shortage are all 0kWh/yr. This means that, the energy generated by the PV was used to serve the load during normal operation. When the energy generated exceeded the demand for the load, the remaining energy was sold to the grid. The system will automatically start purchasing the energy from the grid to supply the load if the PV generation is unable to meet demand during peak load. It can be point out from figure 4.1 that the dispatch strategy used was Circle charging (CC).

Table 4.14; Control strategy for PV/Grid/ battery system

Quantity	Value	Units
Excess Electricity	914	kWh/yr
Unmet Electric Load	0	kWh/yr
Capacity Shortage	0	kWh/yr

It can be seen from the table 4.11 above that, excess electricity is estimated as 914kWh/yr, unmet load which is electrical load that the power system is unable to serve is estimated as 0kWh and capacity shortage is also estimated as 0kWh/yr. This implies that PV was used to serve the load during normal operation. When the energy generated exceeded the demand for the load, the remaining energy was used to charge the batteries to 100% charge. The excess energy from these sources was routed to the grid. The system will automatically start purchasing the energy from the grid to supply the load if the PV generation is unable to meet demand during peak load; however, the grid does not charge the battery. It can could be seen from figure 4.1, that the dispatch strategy used was Load follow (LF).

Moreso, comparing the optimized system which is the PV/Grid and the fifth optimized system which is also PV/Grid/battery system, it can be deduced from figure 4.1 that the circle charging strategy is preferable than load follow (LF) in terms of COE and NPC. The circle charging (CC) strategy is more economical than load follow (LF) in terms cost effective due to the additional battery cost of the system. Even though PV/Grid/battery system have batteries and excess electricity that can provide a more dependable power supply than PV/Grid systems, since PV/Grid is a feasible system, it will be used to electrify educational institutions.

4.8 Sensitivity analysis

Sensitivity analysis is crucial because it enables us to foresee how the system will behave in various scenarios. The rise in grid power prices ($0.057, 0.07, 0.1/kWh) has a significant impact on the financial sustainability and operational efficiency of PV/Grid connected systems in educational institutions. The total net present cost (NPC) of implementing these systems increases proportionately, indicating a higher investment requirement. This raises financial challenges for institutions with limited budgets, potentially hampering the implementation of renewable energy solutions. The levelized cost of electricity (COE) also increases, affecting the institution's annual budget and potentially diverting resources away from other essential needs. This research highlights the need for proactive strategies and policy interventions to address these financial challenges. Policymakers, administrators, and stakeholders must collaborate to reduce initial setup costs, explore government incentives, subsidies, or financing schemes tailored to educational facilities, invest in energy-efficient technologies, adopt smart grid solutions, and promote energy conservation practices. Additionally, partnerships with renewable energy providers and community initiatives can help reduce overall energy expenses.

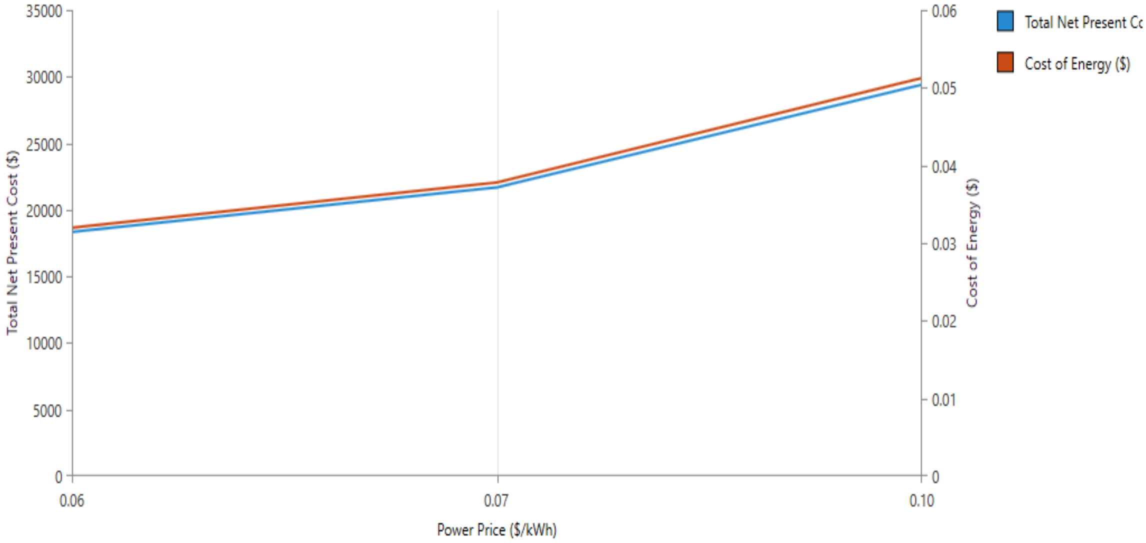


Figure 4.6; Rise in grid power prices

CHAPTER FIVE

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

This chapter is an overview of all that has been done on feasibility analysis of hybrid microgrid system for the electrification of educational institutions in the Western of Ghana. The summary of the research findings, conclusion, recommendations, suggestion for further research are presented in this chapter.

5.1 Summary of the research findings

This work offers a comprehensive feasibility analysis of a hybrid microgrid system for electrifying second-cycle educational institutions, with Ghana Senior High Technical School in Western Ghana serving as a case study. In addition, hybrid microgrid energy systems are very important for reducing emissions from traditional power plants by employing renewable energy and for lowering the high cost of delivering electricity to educational institutions in Ghana. The durability of hybrid microgrid energy systems have enhanced. Microgrids can momentarily separate from the central grid while continuing to deliver electricity from their own generating sources or battery storage during an outage.

Grid linked hybrid microgrid systems are an ideal technology to lower fuel consumption and environmental risks because the price of fossil fuel is not constant and will undoubtedly increase owing to the devaluation of the Ghana cedi versus the dollar. In educational institutions, a hybrid microgrid energy system is used to support peak demand. To determine the optimal option, HOMER software was utilized to simulate and analyze the potential choices. The investigation mentioned in this research was conducted at a school in Ghana's Western Region.

Furthermore, once a critical analysis was made between the grid, grid connected hybrid microgrid system (PV/Grid) and standalone, hybrid microgrid system, it was concluded that the grid connected hybrid microgrid system (PV/Grid) appears to be more technically and economically feasible, because of the lowest COE the grid system ($0.0320) and lowest NPC of the system ($18,332). Also, it has second-lowest operating cost of the hybrid microgrid system ($9,300) and also has a higher renewable fraction (55.2%) compared to grid system.

Despite the fact that the annual cost of the electricity production and emissions of gases have been reduced in hybrid microgrid system (PV/Grid) and there will be no power blackout through the year thus, enhance better performance of the academic institutions, for the financial capabilities of educational institutions in Ghana's Western Region, it is still an intolerably expensive investment. Since even in all the educational institutions are covered by the national grid (supplied by ECG), the cost of electricity for commercial use is about $0.057 /kWh. The government, however, is in charge of providing power to educational institutions. Therefore, for the implementation of hybrid microgrid electrification projects, the Government of Ghana and cooperating partners provide funding. Then, it is up to the involved PTA and OSA to contribute and ensure the necessary local maintenance and operation-supporting procedures to keep the system properly running and to sustain the longevity of the equipment.

5.2 Conclusion

This research boosted dependability and energy services, decreased emissions and pollutants, sustained power supply, and increased operating life, in our educational Institutions, situated very close to coast of Western Ghana. This is accomplished by implementing a microgrid that uses readily available renewable energy sources, such as solar, and that was optimally designed using HOMER software with the goal of lowering power supply costs, reducing carbon emissions, minimizing power losses, and ensuring better utilization of renewable energy sources while eliminating power outages.

5.3 Recommendations

With regard to the finding and conclusion, the following recommendation are outlined to rectify the unsatisfactory situation.

- Investments in hybrid microgrid systems are typically marked by high initial costs and protracted payback periods, which act as a barrier to their integration. Government subsidies to guarantee the viability of the projects were proposed as a solution to this problem.
- Governments should incorporate aspects of the hybrid microgrid's deployment into their electrification plans, including the choice of technology and what occurs when the main grid arrives at the educational facility.
- The primary barriers to integrating a hybrid microgrid should be clear and open rules.
- In order to sustain the operation of the hybrid microgrid system, we need take project financial feasibility into account.

5.4 Suggestion for further research

The researcher hopes that additional study will examine these techniques in order to better understand how satisfied educational institutions are with hybrid microgrid systems, which has an influence on how well these systems are received.

Further study may examine the usage of hybrid microgrid systems with two or more renewable energy sources and enough battery storage capacity to meet load demand when renewable energy supply is insufficient. This would make these systems even more sustainable for educational institutions in Western Ghana by reducing the need for fuel and the grid owing to grid unpredictability.

Additionally, because the weather at a specific location might change at any time and can vary from place to the other, direct measurements of an interested site should be carried out and analyzed before embarking on set up of plants.

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APPENDIX

System Simulation Report

www.homerenergy.com

File: Research Work

Author: Paul Kusi

Location: V7X2+956, Takoradi, Ghana (4°53.8'N, 1°45.0'W)

Total Net Present Cost: $18,332.01

Levelized Cost of Energy ($/kWh): $0.0320

Notes: FEASIBILITY ANALYSIS OF HYBRID MICROGRID SYSTEM ELECTRIFICATION IN THE EDUCATIONAL INSTITUTIONS. (A CASE STUDY GHANA)

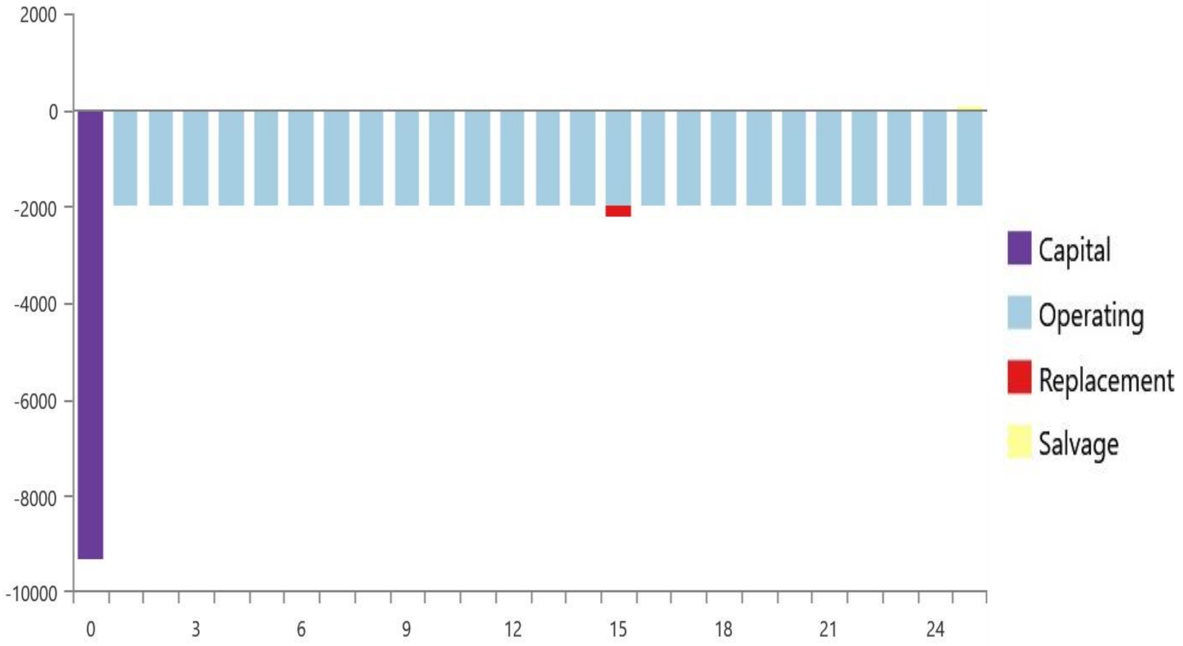
Sensitivity variable values for this simulation

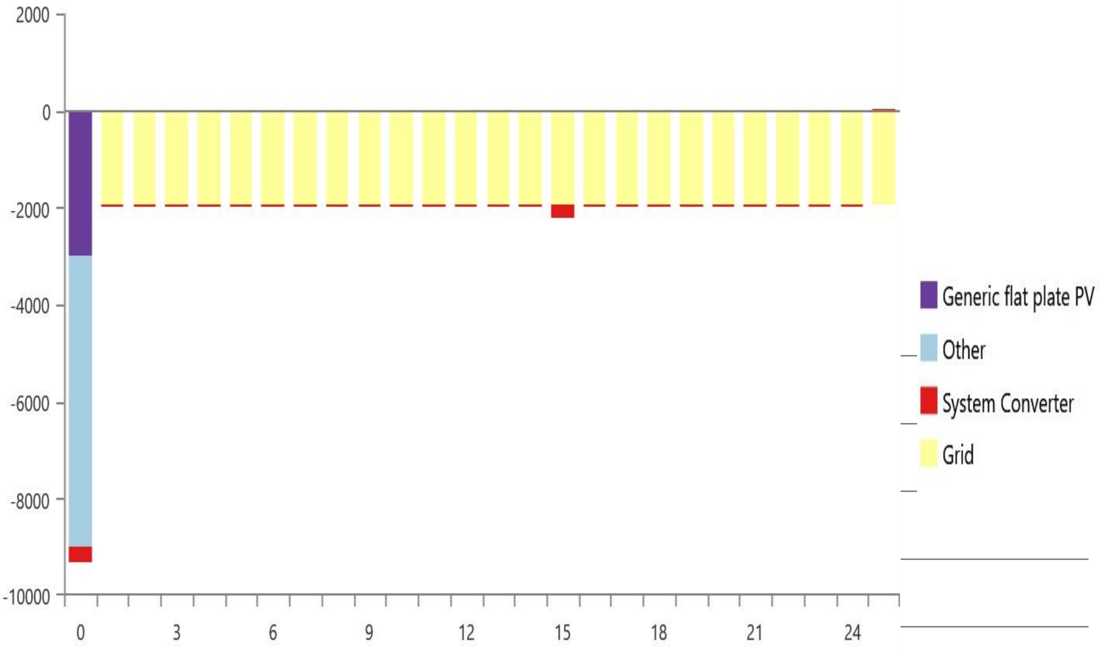
Variable	Value	Unit
Diesel Fuel Price	1.20	$/L
Capacity Shortage	0	%

System Architecture

Component	Name	Size	Unit
PV	Generic flat plate PV	50.0	kW
System converter	System Converter	50.0	kW
Grid	Grid	999,999	kW
Dispatch strategy	HOMER Cycle Charging		

Cash Flow





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PV: Generic flat plate PV

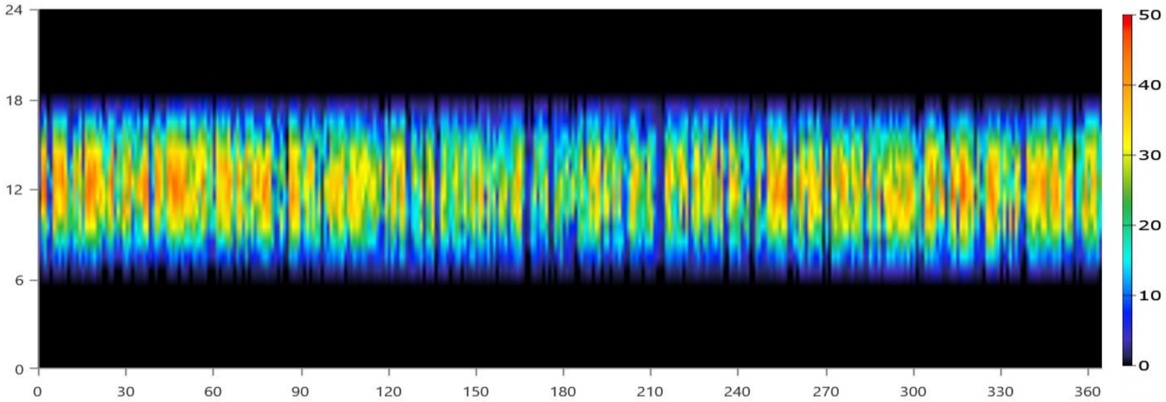
Generic flat plate PV Electrical Summary

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	48.3	kW
PV Penetration	74.8	%
Hours of Operation	4,380	hrs/yr
Levelized Cost	0.00866	$/kWh

Generic flat plate PV Statistics

Quantity	Value	Units
Rated Capacity	50.0	kW
Mean Output	8.92	kW
Mean Output	214	kWh/d
Capacity Factor	17.8	%
Total Production	78,100	kWh/yr

Generic flat plate PV Output (kW)

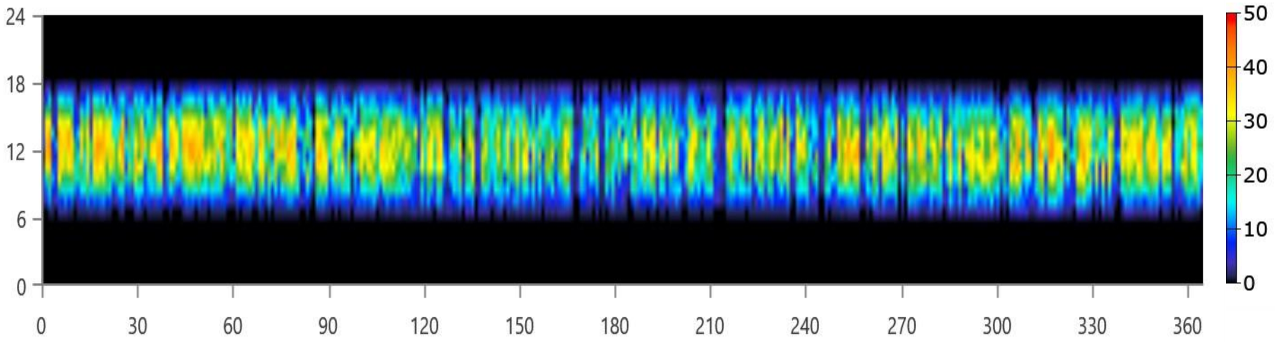


Quantity	Value	Units
Hours of Operation	4,380	hrs/yr
Energy Out	70,290	kWh/yr
Energy In	78,100	kWh/yr
Losses	7,810	kWh/yr

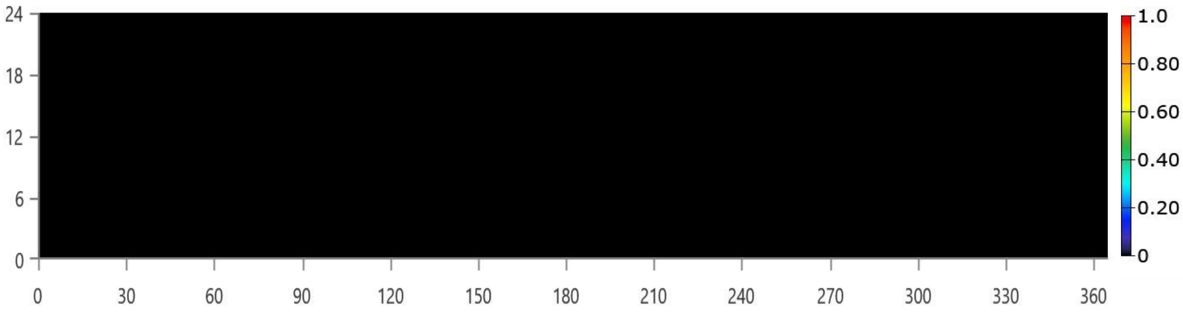
System Converter Statistics

Quantity	Value	Units
Capacity	50.0	kW
Mean Output	8.02	kW
Minimum Output	0	kW
Maximum Output	43.5	kW
Capacity Factor	16.0	%

System Converter Inverter Output (kW)

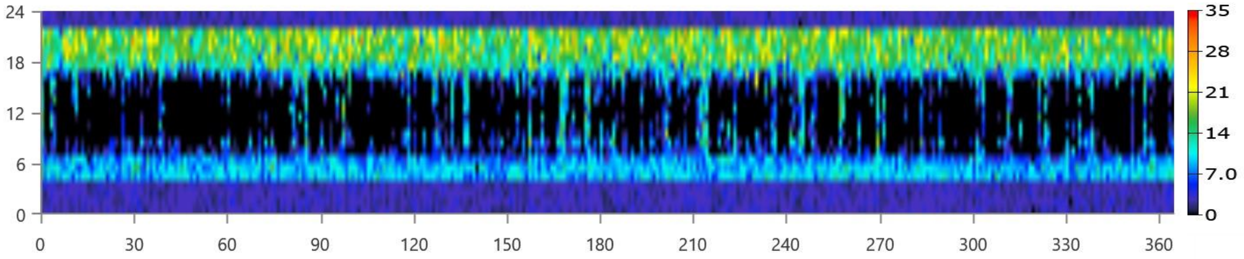


System Converter Rectifier Output (kW)

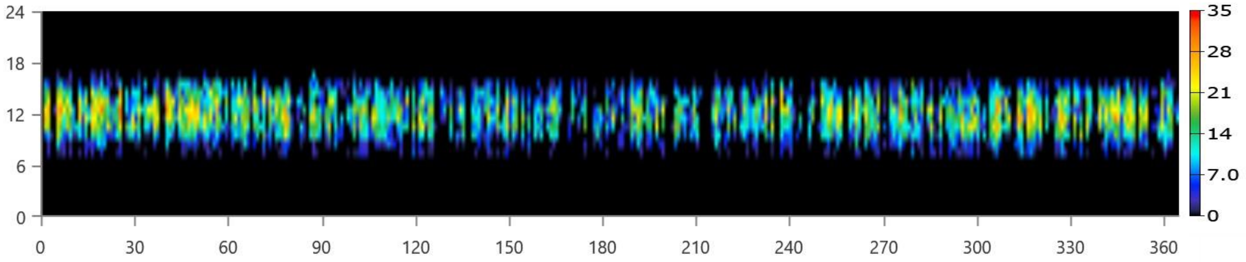


Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge	Demand Charge
January	4,732	2,559	2,173	30.7	$123.87	$0.00
February	3,933	2,438	1,495	28.7	$85.21	$0.00
March	4,808	2,160	2,649	26.8	$150.98	$0.00
April	4,587	1,878	2,709	30.8	$154.39	$0.00
May	4,798	1,536	3,262	27.3	$185.93	$0.00
June	5,213	1,106	4,108	27.9	$234.13	$0.00
July	4,914	1,508	3,406	29.0	$194.16	$0.00
August	5,252	1,534	3,717	27.7	$211.89	$0.00
September	5,066	1,665	3,401	26.8	$193.88	$0.00
October	4,564	2,033	2,531	25.5	$144.29	$0.00
November	4,496	2,412	2,084	28.9	$118.76	$0.00
December	4,739	2,174	2,565	27.8	$146.20	$0.00
Annual	57,102	23,002	34,100	30.8	$1,944	$0.00

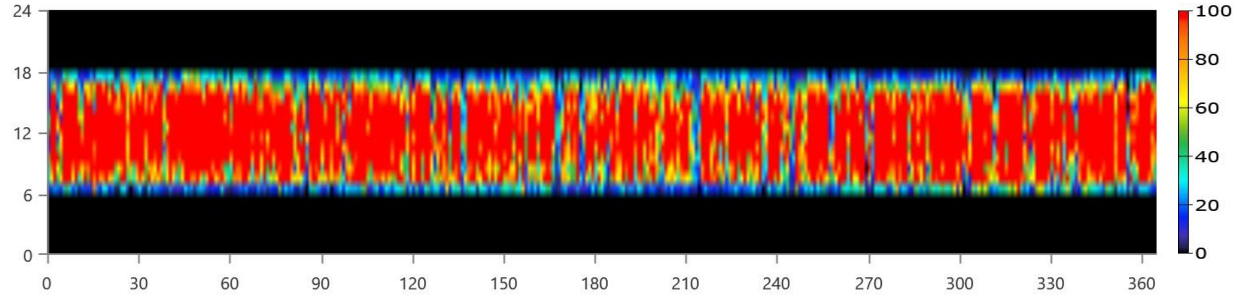
Energy Purchased From Grid (kW)



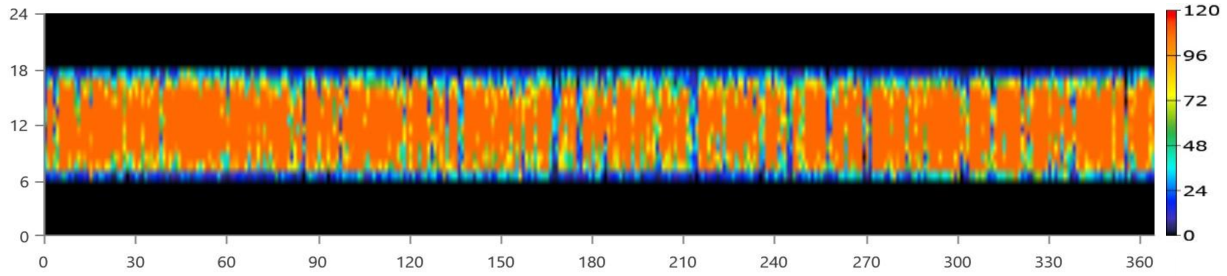
Energy Sold To Grid (kW)



Instantaneous Renewable Output Percentage of Total Generation



Instantaneous Renewable Output Percentage of Total Load



100% Minus Instantaneous Nonrenewable Output as Percentage of Total Load