Design and Energy analysis of Photovoltaic Biomass Hybrid Energy Power System to Supply a rural health facility in Uganda

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Abstract: *The design and execution of a photovoltaic (PV) biomass renewable energy system for rural health clinics in Uganda is presented in this research. The goal of this research is to provide a sustainable and dependable supply of electricity for health facilities in rural places where grid power is limited or unavailable. The system combines solar PV panels and biomass gasification technology to provide electricity for lighting, medical equipment, and other critical needs in health care facilities. The system was designed using a thorough methodology that includes site assessment, load analysis, system sizing, component selection, installation, and performance evaluation. The study's findings showed that deploying a PV biomass renewable energy system for rural health institutions in Uganda is feasible, with beneficial effects on the quality of healthcare services supplied. The system performance analysis revealed that it was capable of meeting the electrical demand of the health facilities and contributed to reducing dependency on diesel generators, hence lowering greenhouse gas emissions. The study's findings highlight the potential of PV biomass renewable energy systems as a viable solution for providing long-term energy access to rural health facilities in Uganda and other similar settings, thereby contributing to improved healthcare services and environmental sustainability. The hybrid energy system has been viewed as an outstanding alternative for rural health facility electrification where national grid expansion and extension are both important and economically unviable. Because of limited fossil fuel supplies, wars, and worldwide environmental concerns, the use of renewable energy sources for electrical power generation, transmission, distribution, and use is becoming increasingly important. Solar energy is the most common type of Renewable Energy Technologies RETS in Ugandan rural areas due to the weather conditions. This is due to the sunrise occurring between 2408 and 4383 hours each year, with average insulations of 5-7 kwh/m2/day in all regions of Uganda. In addition, photovoltaic (PV) power and energy systems are among the most commonly utilized technologies for converting solar power into electricity. Furthermore, biomass resources in Uganda that can be used for energy production are classed as non-plantation biomass, fuel crops (energy plantations), and urban garbage. The total amount of biomass expected is in the order of 50 million ton/y; their gross calorific value is around 800 million GJ, equating to approximately 18 million toe/y. On the other side, energy storage is also combined, which could help to lower peak electricity consumption while smoothing out differences in power supply by fluctuating solar power. The hybrid system considers solar PV and biomass with batteries and converter. A case study was conducted in a distant rural south western districts in Uganda. The primary responsibility is to determine the right component size, reliability, operation, and availability strategy for the system, which will lead to the design and planning of a hybrid energy system for rural health facilities in Uganda.The aforementioned problems prompted a desire to research the possibility of a PV-biomass-battery storage-based generator connected to the grid. A study was undertaken by gathering solar radiation data, comparing average yearly solar radiation, and performing a ranking system. This technology has several advantages over traditional energy producing processes. This study depicts the various system components and their optimal combination for effective power generation utilizing locally available materials. In this research, a proposed strategy for developing PV-biomass energy systems on the electrical loads of rural medical facilities in Uganda is given and used. This approach covers modeling, sizing, and assessing the generation of PV-biomass-battery storage systems that interface with the electrical grid. In addition, a proposed model is presented and used to evaluate the influence of this generation on the capacity, energy, and load displacement of traditional power supply systems, reduction in pollution levels, and energy demand charges of the study electric utility. The learning method makes use of a reference model that describes the system's expected performance. Finally, a comparison analysis of the two created controllers is performed. It outlines the benefits and drawbacks of each controller algorithm.*

Keywords PV, Biomass, Hybrid power system, Renewable energy technologies, Health facility, Uganda

1. Introduction

Access to dependable energy is critical for providing high-quality healthcare in remote locations. However, many health institutions in Uganda and other poor nations experience intermittent or non-existent grid energy, which can lead to inadequate healthcare delivery and impaired patient care. Renewable energy solutions, such as solar PV and biomass gasification, have been identified as potential options for meeting the energy requirements of rural health care institutions [1]. A PV biomass renewable energy system is planned and deployed in this project to offer sustainable electricity to Ugandan health facilities. The study's goal is to evaluate the system's viability, performance, and influence on healthcare services and environmental sustainability. Currently, the demand for electrical energy is increasing quickly over the world. Furthermore, 70% of the population lives in rural areas. In general, the creation of electrical energy is dependent on fossil fuels. As a result, CO2 emissions increase, which is not good for the environment. As a result, we should use hybrid systems to implement renewable energy [2].For the hybrid system, solar PV and biomass with battery and converter are being investigated. The integrated biomass solar town concept promotes the local community to use biomass waste [3]. A geothermal-biomass hybrid renewable energy system is a suggested transformative energy plan to reduce fossil fuel consumption and CO2 emissions cheaplyOn the other hand, energy storage is included, which might help reduce peak electricity consumption while also smoothing variances in power supply from variable solar power. The key job is to determine the appropriate component size and system operation strategy, which will lead to the design and planning of an optimal hybrid energy system [4].As a result, this study discusses an Integrated Biomass Solar Town for an ECUREI renewable energy village in Uganda. In addition, the article seeks to construct a comprehensive model for determining the best hybrid system combination of renewable energy resources for a rural community while ensuring power supply stability in all rural health facilities. Different operating strategies can be applied to the various combinations [5]. The energy stored in the battery can be used during the night to ensure the system's best operation. The purpose of optimal operation is to reduce costs while operating a system to achieve the best feasible system performance, where cost and performance are inextricably related. This is owing to the fact that component sizing is tied to the system's operation strategy.

HYBRID ENERGY SYSTEM

The design of an ideal hybrid system is complicated since renewable energy supplies are not stable and fluctuate based on seasonal and geographical factors. The fixed output from each scheme participating in the system is not consistent [3]. The demand for an efficient hybrid system while ensuring reliable operation is reliant on component size and its properties in conjunction with the ideal operation approach.

In this strategy, the parallel configuration of these different schemes in a hybrid system is used with the battery and converters for additional backup, particularly for the output from solar panels. The elements responsible for selecting the most optimal hybrid system combination of the proposed site are flexibility, efficiency, reliability, and economics. Solar PV and biomass, with a battery and converter for backup throughout the night.

CASE STUDY

This research is centered on a typical farming settlement in south western districts of Uganda. The off grid will be connected to the rural health facilities and then the households. This hybrid energy technology is being developed to reduce electric grid demand.

The hybrid system under consideration consists of a gasifier integrated network system, Photovoltaic arrays and a battery bank. The power output of the PV module is determined by the available solar resource at the location. The system consists of a gasifier-integrated network connected to the AC bus and solar units connected to the DC bus. The hybrid system's sizing primarily tries to determine the ratings of the generation units (photovoltaic arrays and the gasifier integrated network) as well as the capacity of the battery bank. The software tool etap and HYSIZEis used to perform thorough system simulation. The village's yearly average consumption is 4000 kWh per day, with a peak demand of 295 kW.

2. METHODOLOGY

The PV biomass renewable energy system was designed and implemented using a comprehensive process that includes the following steps:

Site Survey and evaluation: A thorough evaluation of the health facilities' location and energy requirements was carried out, including data gathering on solar radiation, biomass availability, and electricity usage.

Analysis of the Loads: A complete analysis of the health facilities' energy demand was performed, including an assessment of power use for lighting, medical equipment, refrigeration, and other critical loads.

Sizing of the system: Based on the load analysis and site evaluation, the PV biomass renewable energy system was sized to fulfill the health facilities' electricity need. The ideal capacity of PV panels, biomass gasifiers, battery storage, and other system components had to be determined.

Selection of the Components: PV panels, biomass gasifiers, batteries, and inverters were chosen based on technical requirements, availability, and economic factors.

Installation: The system components were installed at the health institutions in accordance with the design specifications and best practices, which included proper wiring, mounting, and safety precautions.

Performance evaluation: Over time, the system's performance was monitored and analyzed to measure its dependability, efficiency, and efficacy in serving the energy needs of the health facilities.

The grid-connected electricity is imported into the etap software program, and the average electricity load per day and peak load are calculated.

- PV sizing was calculated using solar radiation and various de-rating factors.
- An appropriate biomass generator was chosen, and it was assumed that 1 ton of biomass is available each day. The biomass generator was sized in accordance with the power supply aim.
- HPS integration into off grid system to supply electricity to off grid-connected loads

SYSTEM DESIGN

The PV biomass renewable energy system is a hybrid system that combines solar PV panels and biomass gasification technology. PV panels were installed on the roofs of the health facilities to capture solar energy throughout the day. The biomass gasifier was designed to generate gas from locally accessible biomass, such as agricultural leftovers, which is then utilized to generate electricity [6]. The gasifier was linked to an electric generator or engine, which was integrated into the whole system. A battery storage system was installed to store extra electricity generated during the day for usage at night or when solar radiation or biomass availability is low. The average solar irradiation at the site is 6.7 kWh/m2/day [7]. The facility has access to biomass. Rice husk, cotton stalk, mustard stalk, chicken litter, and bagasse are examples of biomass materials that have been utilized to generate electricity. The calorific value per kilogram is 4000 kJ. Gasification of biomass turns solid biomass into a more convenient gaseous state.

Solar Panel

The choice of solar panels is an important stage in the construction of a PV biomass renewable energy system. Solar radiation, panel efficiency, and durability are all important considerations. A site evaluation is carried out to establish the availability of solar radiation at the location of the health facilities. Based on this information, solar panels of sufficient capacity and efficiency are chosen to maximize energy output from solar radiation [8]. Because the system would be exposed to diverse weather conditions in rural locations, panel durability is especially critical. To ensure dependable and long-lasting performance, high-quality solar panels with sturdy designs and warranties are desired.

The Solar Atlas provides the average daily solar energy input across the year, which ranges from 5.4 to 7.1 kWh/m2/day depending on the area of operation [9]. PV has a rated capacity of 200 kW, is operational for 4,385 hours per year, and generates 358,686 kWh per year. The demand is used to calculate the quantity of solar panels needed.

Panels

$$P_{pv} = pv \times N_{pvp} \times N_{pvs} \times V_{pv} \times I_{pv} \ldots\ldots\ldots\ldots..(1)$$

where pv represents the PV module's conversion efficiency, V_{pv} the module's operating voltage, $I_{pv}$the module's running current, and N_{pvp}, N_{pvs} the number of parallel and series connected solar cells

Battery

Battery storage is a critical component of the PV biomass renewable energy system because it stores energy for usage during periods of low solar radiation or biomass availability. The proper battery selection is crucial for system performance and dependability. Battery capacity, voltage, cycle life, and safety features must all be considered. Battery capacity should be calculated based on the energy demand of the health care facility and the projected length of low solar radiation or biomass availability [10]. Higher voltage batteries are preferred to reduce energy losses during the DC-to-AC conversion process. Cycle life, or the number of charge and discharge cycles a battery can withstand, is critical for battery lifespan. For dependable and safe operation, batteries with a longer cycle life and safety features such as overcharge prevention and temperature sensors are preferable[11].

Converter

Converters are used to convert the DC electricity generated from the solar panels and batteries into AC electricity for use in the health facilities. Selection of appropriate converters is important for efficient and reliable energy conversion. Factors such as converter efficiency, input and output voltage range, and protection features need to be considered. Higher converter efficiency ensures maximum energy conversion, reducing energy losses [12]. The input and output voltage range of the converters should match the specifications of the solar panels, batteries, and the health facilities' electrical loads. Protection features, such as overvoltage protection, short-circuit protection, and temperature protection, are important for safe and reliable operation of the converters.

PV power generation varies with the amount of sunshine shining on the panels at any one moment, resulting in a shortage of power output throughout the night and in overcast weather. In such cases, a battery bank is required to deliver smooth power to the load[13] .Charges when extra electricity is generated by the PV module and discharges when demand occurs. The largest peak charge occurred between 12 and 17 p.m. A total of 133584 kWh/yr energy was injected into the battery, while 107,066 kWh/yr energy was consumed by discharging the battery.

The converter output connected to the PV module converts direct current (DC) to alternating current (AC). For 200 kw of PV module, a rated capacity 200 kw converter was used [6]. The converter was operational for 6649 hy/yr, with a total energy production of 401,530 kWh/yr and a system energy output of 361,378 kWh/yr. As a result of the system failure, an energy loss of 40,152 kWh/year occurred [14].

Biomass generator

The biomass generator is linked into the PV biomass renewable energy system to produce electricity using locally available biomass as fuel, such as agricultural wastes. The choice of a suitable biomass generator is crucial for efficient and dependable energy generation. Consider factors such as generator capacity, fuel consumption, and emissions [6]. The generator capacity should be selected depending on the energy demand of the health care facilities during peak periods.

Biomass generators mostly use agricultural waste, firewood, animal manure, cattle dung, and human waste [15].The system was obliged to operate a rated capacity of 30 kW biomass-based generator all of the time. It is clear from Figure 2 that the biomass generator was used to its full capacity at all times. A total of 8,760 hours/year were employed to generate a total output of 263,000 kWh/year, with a bio-feed consumption of 124 tons/year. The rate of fuel F consumed by a biomass generator to generate power P is given by:

$F = aP^2 + bP + C$…………………………(2)

Where a, b and c are coefficients for generator

APPLICATIONS

Because the energy density of the network is significantly higher than that of solar PV and biomass, the number of PV modules and biomass generator capacity are gradually increased until the ideal system is obtained. The ideal hybrid system is the one with the highest reliability and the lowest cost of energy per unit (KWh). Figure 1 depicts the hourly solar insolation as well as the power demand. As a result, the total power generated by the hybrid system at any given time is:

$p(t)\ P_b = \sum_{n=1}^{N_n} P_n + \sum_{s=1}^{N_s} P_s + \sum_{b=1}^{N_b} P_b$…………………………………..(3)

Where P_n is the network energy.

Figure 2 displays the distribution of sources under various scenarios. It demonstrates that the power from solar photovoltaic is fully utilized to provide the load demand as well as charging the battery during the day. This figure also demonstrates that the maximum demand of 221 kW occurs at 8:00 am is fulfilled by all energy sources. During this time, any excess power generated by the hybrid energy system is used to charge the battery bank. Figure 3 depicts the monthly average electric production of each power system in an HPS.

The annual production of PV and generators is 320,830 kWh/yr and 263,000 kWh/yr, respectively, with a total percentage contribution to electrical load of 40% and 33%. Furthermore, battery storage is shared by 6%, but the remaining unmet electricity is purchased from other energy alternatives. i.e. a total of 170,000 kWh/year of electricity, or 21%. The remainder of the electricity is drawn from the grid. Table 2 is a block diagram of a potential hybrid solar PV/biomass energy plant.

Furthermore, the biomass gasifier and SPV systems are operational during the day, from 6:00 AM to 9:00 PM (15 hours per day). During the night, power is supplied via the utility grid. It is predicted that the running costs of the biomass gasifiers will be significantly reduced. Figure 5 depicts the cash flow summary for each system.

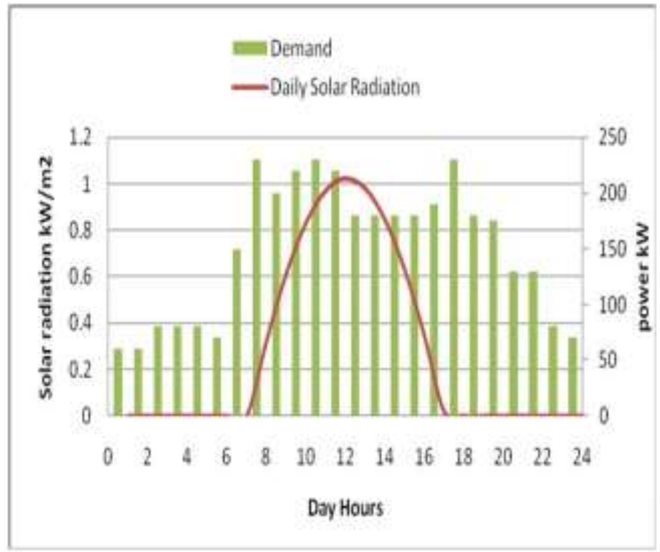

Figure 1. The hourly solar insolation and the power demand

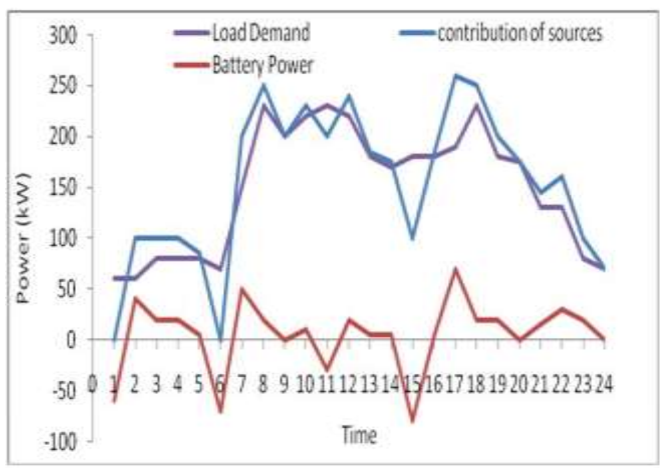

Figure 2. Optimal allocation sources

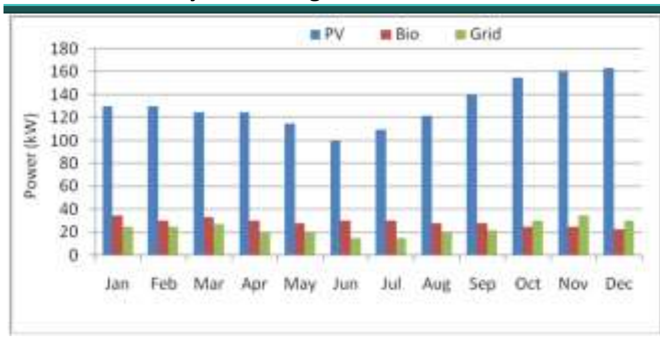

Figure 3. Average monthly electric production

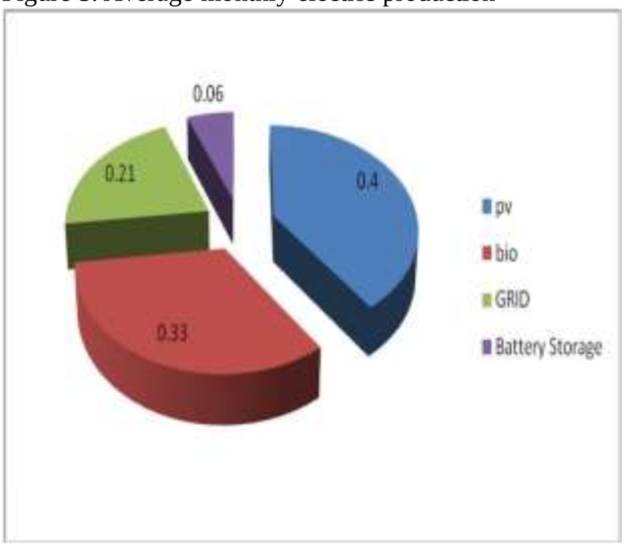

Figure 4. Annual contribution of different sources and storage

Table 1 Block diagram of a proposed Solar PV/biomass hybrid energy system.

Production	%	KWh/yr
PV array	0.4	**320830**
Biomass Generator	0.33	**263000**
Grid	0.21	**170000**
Battery Storage	0.06	**55800**

Energy Analysis Using Hysize Results

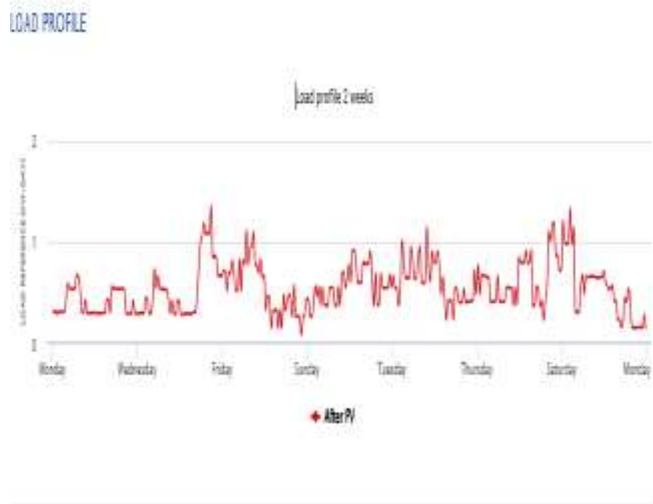

Figure 5: Energy Load flow of the designed system per week

Figure 6: Energy Consumption rate per source

Conclusions

A hybrid energy system is an ideal alternative, particularly for electrifying isolated rural health facilities. Where grid extension is both difficult and expensive. In this study, an analysis of a systematic approach for planning a PV-Biomass hybrid system and its economic analysis, including computation of percentage savings and payback time analysis, is provided.

An attempt has been made to design HPS in order to investigate the possibilities of utilizing solar energy and biomass to meet the power load need for rural health facilities in Uganda as an ECUREI Renewable Energy Village Model. The feasibility analysis found that for annually fluctuating electricity load, an off grid-connected HPS system might be cost-effective. Environmentally friendly and feasible option. As previously stated, the incorporation of a biomass gasifier into the system makes the system more sustainable, and the use of a battery system for storage has increased the use of renewable energy in Uganda.

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