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Review On Solar Photovoltaic and Battery Storage Systems for Grid-Connected in Urban: A Case study of University of Juba

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***Abstract*— Currently, Solar PVs are gaining considerable acceptance because of their ability to directly convert sunlight into electric power. Nevertheless, photovoltaic-generated electricity may fail to satisfy the ever-increasing energy demand because it does not provide a consistent supply that aligns with the needs of consumers. To solve this problem, energy storage has recently gained importance in grid-connected Photo Voltaic (PV) plants. This helps in managing loads more flexibly and overcoming problems related to power quality faced by grid-distributed networks, thereby making PV plants valuable and appealing. To effectively integrate PV plants and storage systems into the power grid, various techniques for battery management have been developed to create a demand that is more responsive to prices. The wider deployment of PV systems is hindered by the lack of supporting policies. This study reviews different techniques of configuration and modeling employed for the optimal operationalization of PV grid-tied systems with battery storage. We examined numerous optimization methods and dispatch mechanisms for energy stored that capitalize on the monetary worth of battery-operated PV systems. We also discuss the grid-connected PV system-related power quality and control technology challenges. Finally, we explored several functioning and maintenance concerns of battery-operated PV systems and highlighted the financial and ecological advantages of PV grid-tied configuration. The goal of this study was to review several technical issues related to the condition of PV systems. These issues include energy regulation, various cell technologies, energy management and scheduling methods, reliability, and power quality. We also discuss whether findings from the University of Juba should be adopted.**

Keywords*— *Solar PV, Grid-connected system, battery, storage system

I. Introduction

Currently, the world is facing significant challenges related to rising energy demands and reliance on non-renewable energy sources. As a result, there is a growing trend toward utilizing Renewable Energy Sources (RES) as a solution for electricity generation. Solar energy has emerged as a compelling option for numerous countries to shift away from fossil fuels and adopt a more sustainable energy source among all available renewable energy sources [1-2]. Approximately 93% of people on Earth live in nations with solar PV energy potentials between 3.0 and 5.0 kWh/kWp on a daily average. Almost 70 countries have excellent solar PV conditions, with daily average output exceeding 4.5 kWh/kWp, enough to boil roughly 25 liters of water.

From 2010 to 2015, the Solar PV installation capacity increased consistently and has since witnessed a substantial surge. Solar PV generation has reached a historic high of over 1,000TWh, with a remarkable increase of 22% or 179TWh. This achievement marks the second fastest growth in renewable technologies, after wind energy, in absolute generation growth as of 2021 [3]. China is expected to maintain its lead as the world's major PV market leader by 2050, with a projected share of more than 37% of its worldwide capacity. [4-5].

Photovoltaic energy sources have diverse uses, such as powering water pumps, charging batteries, providing electricity to homes, illuminating streets, cooling systems, heating swimming pools, running hybrid vehicles, supporting telecommunications, operating satellite power systems and military spaces, and generating hydrogen. Two categories of systems make up the global market for these energy sources: decentralized systems, which make up approximately 60% of the market, and centralized or utility-scale systems, which make up approximately 40% of the market. Off-grid or Stand-alone schemes, which formerly dominated the market, now account for roughly 1% of the market. Currently, modules of crystalline silicon (c-Si) control the majority of the PV market, accounting for approximately 90% of the total. The market share for Thin Films (TF) of all kinds is currently only approximately 10%, a decrease from 16% in 2009, while the market share for Concentrating Photo Voltaic (CPV) technology is still less than 1% despite its rapid rise [4].

Similar to wind energy, solar energy is dependent on weather patterns, which pose a major challenge. The limited capacity for PV energy production stems from the inconsistent and erratic characteristics of PV energy generation, which make it difficult to operate the grid. As a result, a fundamental challenge for PV systems is coordinating intermittent energy production with ever-changing power demand [6]. One approach to address the

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issue of irregular power sources is to integrate a storage element.

Although the importance of storage has been acknowledged, more research in a practical setting is required to better understand and assess the distribution of stored energy. This allows us to financially maximize the advantages of renewable energy production and storage arrangements [7-8]. To maximize the financial benefits of PV battery systems, a number of retail pricing models, including Critical Peak Pricing (CPP), Real-Time Pricing (RTP), and Time-Of-Use (TOU), have been advocated in academic literature. These programs are designed to encourage customer involvement in demand response. [9-10] investigated how it can increase the system output efficiency, streamline the process, and produce electrical energy of higher quality.

The evaluation of battery-operated Solar PV schemes for urban grid connections has substantial value for several reasons, with an emphasis on applying the findings to the University of Juba. First, it offers insightful information on how well these systems can accommodate the increasing energy demand of cities. Energy needs are increasing along with the urban population, and sources of renewable energy like solar photovoltaics have the ability to supply these needs sustainably. Second, the evaluation offers a deeper understanding of the technological elements of Solar PV and battery systems, including their constituent parts, installation, functioning, and maintenance. These data are fundamental for policymakers, energy strategists, and investors who aim to boost the use of battery-operated Solar PV systems in metropolitan regions. Finally, the assessment also analyzes the difficulties and impediments to the installation of solar PV and battery systems in urban locations. This study can assist stakeholders in creating successful strategies and policies to address these issues and encourage the general adoption of these systems by drawing attention to these concerns.

II. Literature Review

A. *PV cell technologies*

Currently, c-Si panels, which are categorized as first-generation solar cells, are used to fabricate the majority of solar cells. Owing to their affordability and greatest efficiency level, these panels, which are composed of crystalline silicon, comprise 85-90% of all photovoltaic module sales globally. sc-Si and mc-Si are common varieties of c-Si panels. Although there are numerous manufacturers of c-Si solar cells, and the technology is a mature and well-established PV technology, the cost of the raw ingredients required to make them is high. Although costs have come down recently, it is unclear whether further cost cuts will allow c-Si to successfully compete with less expensive solar resources in the wholesale power-generating sector. [4][11].

The second-generation photovoltaic technologies, which currently make up between 15% and 20% of the market, are referred to as thin-film PV technologies. Because of the low cost of materials and manufacturing, these technologies are desirable. However, it is important to consider the fact that they are less efficient and have elevated mounting costs and space requirements compared to c-Si cells. TF technologies still hold a significant market share, with the exception of utility-scale systems, although they are not as developed as c-Si PV cells. TF still have to contend with a number of issues, such as toxicity, availability, and durability of the materials, particularly in the case of cadmium. In addition, the prices of c-Si modules represent a significant threat to TF technologies [11-12].

Third-generation PV technologies, such as concentrator photovoltaic (CPV), advanced thin-film (TF), and organic cells, are still being studied and developed at this time. By using innovative conversion processes, methodologies, and cutting-edge materials, these technologies have the potential to attain higher conversion efficiency. Because they haven't yet been commercialized, their exorbitant price is still a mystery. They continue to be improved at the R&D stage right now [4], [11].

B. *Off-grid and grid-tied systems classification*

PV systems are divided into two groups: utility-interactive, commonly referred to as grid-linked systems, and standalone systems. Its operational and functional requirements, component layouts, and connectivity to other sources of power and electrical loads all affect how they are classified. PV systems offer AC and/or DC power services and can operate either independently or tied to the utility grid[13].

PV systems that are built to function with the electric utility grid are integrated with the grid and cooperate with it. These PV systems' power conditioning device, commonly referred to as an inverter, is their most important component. The inverter serve to convert the electricity generated by the PV array from DC to AC power that complies with the utility grid's specifications for voltage and power quality. The power conditioning device will automatically stop sending electricity to the grid in the situation of a malfunction of the electric utility grid. [14]. The Fig.1 shows the grid connected solar PV system.

Fig. 1. Grid-connected solar PV system [15].

The photovoltaic (PV) system features a two-way connection that enables the electricity it produces to be either used for on-site electrical needs or transferred back to the power grid in situations where the PV system produces more electricity than is required on-site. When the output of the PV system is insufficient to handle the electrical load, such as during periods of low output, as on cloudy days or at night, the required amount of power is purchased from the utility[14].

PV systems that are linked to the grid and do not have an energy storage backup are considered ecologically friendly and are commonly favored by individuals due to their low maintenance and cost-effectiveness. However, these systems rely on grid power and in cases of power outages during the

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night or on cloudy days, they will cease to function until grid power is restored.

It is common for PV systems equipped with energy storage backup to be connected to utility grids. This type of design has several benefits such as the ability to sell any excess electricity produced by the PV system back to the grid, charging the battery during non-peak periods, and purchasing power from utility grid to support the loads in situations where the battery-operated PV power are insufficient[14].

Independent photovoltaic (PV) systems work autonomously and are not connected to the electric utility grid. These systems operate in isolation and are usually used to supply electricity to a DC and AC load that is appropriately sized. They are powered by either a PV array alone or a hybrid PV system, which amalgamate PV array with a diesel generator acting as an additional source of power. Off-grid systems of this type typically contain an inverter, which transforms the DC voltage produced by the PV modules into AC voltage that can be utilized by appliances directly [13]. Some significant characteristics of PV technology are outlined in the table 2 below [13]:

TABLE I. AN OVERVIEW OF SOME KEY ASPECTS OF PV TECHNOLOGY

Characteristics	Exposition
Range of operation	1 kW-300 MW
Fuel	Sun
types of applications	household, utility scale, and business
Efficiency	For crystalline silicon, the percentages are 12–16%, for thin films, 11-14%, and for organic cells, 18–20%.
Ecological effect	There are no direct emissions of CO2, NOx or CO.
Advantages	Modular construction, zero direct emissions, and environmentally friendly technologies.
Downsides	Additional costs for setup, variable power output due to unreliable weather, need for mechanical and electronic monitoring devices and need for additional storage for best results.

C. Techniques for design, size, and modeling

Creating models in a streamlined manner to operate photovoltaic components could boost the productivity of the entire photovoltaic system. This encompasses constructing models for the photovoltaic electricity generator, interface of power electronic, storage equipment, and the devices that consume power. Various models for solar cells are available, including a basic model for PV cells, a more precise model known as two-diode model, and moderate one-diode model that is commonly used in modelling PV panels [13]. The table below illustrates the approaches used in designing PV and storage components.

D. Scheduling methods and energy management

Designing effective scheduling techniques is challenging because of the unpredictable availability of solar energy resources. An efficient approach would be to combine a storage system for energy with the photovoltaic panels to achieve better results. Another solution is to use Demand Side Management (DSM) technology, which utilizes dynamic pricing strategies to change consumption of energy from peak to non-peak times, thereby achieving power balancing and reducing expenses [13]. A plan for a photovoltaic lighting system that includes energy management has been suggested [29]. The findings indicated that the efficiency of the system was enhanced by solar batteries MPPT control. A strategy for energy management was optimized [30] by converting the production of photovoltaic energy, which depends on solar irradiance, into a constant output per hour. This approach enabled photovoltaic power plants to participate in electricity markets with minimal additional costs associated with the incorporation of a storage system of energy. [29-31] study involved the creation and testing of algorithms that regulate the flow of energy in PV lighting systems used in public areas. The objective was to ensure that the system remained operational during power outages while minimizing overall energy expenses. The table provided below summarizes the various methods for managing the energy of PV battery systems. An efficient power flow management system may consist of distinct stages such as prediction, optimization, and local control.

E. PV system storage problems

As previously mentioned, PV renewable energy sources are causing increasing concern in power systems because of their significant intermittency. This could result in complications, such as instability, difficulties in regulating voltage, and other power quality problems. In order to address these issues, storage systems of energy remain being extensively employed in electrical systems.To handle the unpredictable and fluctuating attribute of photovoltaic (PV) energy in power systems, various types of energy storage systems including thermal storage, electrochemical, electrical, and mechanical are employed. It is essential to compare these systems based on their applications, advantages, initial cost, and overall lifespan. The table 4 presented underneath displays the distinctive characteristics of various devices for electric storage that can combine with Solar PV, along with an analysis of their benefits and drawbacks.

F. Policy in Energy

Satisfying the current and forthcoming energy demands while minimizing negative impacts on the environment is an extremely challenging issue. Consequently, renewable energy sources are being considered as potential solutions. Several countries have implemented incentive policies to support the development of alternative energy sources, with Europe being the notable leader in photovoltaic (PV) deployment until 2012. However, recently, this technology has expanded beyond Europe, primarily in Asia, and particularly in China. Despite this dramatic shift, several economic and non-economic barriers must be overcome to achieve the International Energy Agency's vision. As a result, in order to overcome potential obstacles, it is crucial to develop new recommendations for system integration, technical, legal, and regulatory challenges.

In their study, [47] examined the policies implemented in various countries to advocate for the utilization of PV

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technology.The authors emphasized that to support the continued expansion of the market and user base,retail financing terms must be adaptable and accommodating. The incorporation of grid-tied renewable energy storage system is limited by regulations, which act as constraints. To speed up wider PV system adoption, which will hopefully lead to lower deployment costs in the near future, various state policies are required to provide economic incentives that compensate for the high investment costs.Various strategies are implemented to encourage the adoption of PV renewable energy, including trading mechanisms, feed-in-tariffs, investment tax credits,renewable portfolio standards, pricing regulations, quota mandates, production incentives, and other relevant policies. These policies' main goals include reducing reliance on non-renewable energy sources, promoting the development of new industrial sectors, and mitigating the environmental effects of the energy industry. The most popular policies thus far are the RPS and FIT, but countries should choose the policy that best suits their circumstances and objectives [47].

While investment and finance are crucial for creating effective policies, it has been observed that clear and trustworthy signals from policymakers can decrease risks and boost confidence. However, if policies are inconsistent and send mixed messages, they can result in higher costs for consumers and investors in the financial and energy sectors.

III. Case Study: University Of Juba, South Sudan

The Republic of South Sudan, situated in the central and eastern part of Africa, is a nation bordered by nearby countries including Sudan, Ethiopia, Uganda, CAR, DR Congo, and Kenya. The population of the country is estimated to be around 11.19 million people in 2020. Juba is both the capital and the biggest city in South Sudan.South Sudan has the lease electricity access rate in African continent, with only 7.24% of the population having access as of 2020 [2]. The current state of energy in this country is closely tied to recent conflicts. Despite the ample potential for solar energy and hydropower, the majority of electricity is generated through thermal sources, and the supply is restricted to only a handful of communities.

South Sudan experiences approximately 8 hour of sunlight every day, with horizontal surface radiation between 5 and 6 kW/m2 per day, primarily in the northern and eastern regions. The highest level of global horizontal irradiation in South Sudan is 2264 kWh-2, which is comparable to Sahara's peak of 2702 kWh-2, making it a suitable location for solar-energy production. The Fig.2 shows the Map of South Sudan depicting the feasibility of solar energy potential.

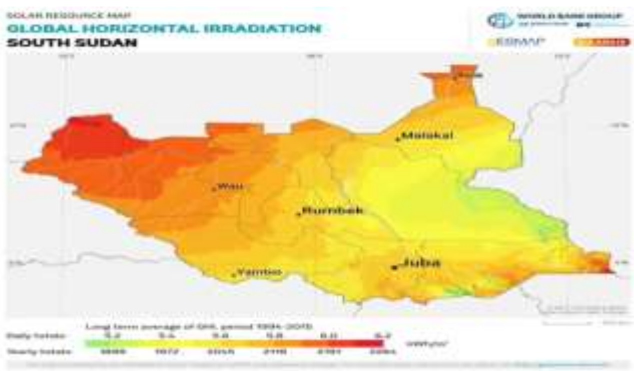

Fig. 2. Map of South Sudan depicting the feasibility of solar energy potential [2].

Despite this, the primary source of energy in South Sudan is mainly focused on oil, and the capital city relies on a power plant that runs on diesel fuel. However, this power plant experiences frequent interruptions in the electricity supply [48]. Diesel-powered power plants provide the vast majority (73%) of electricity access rate. Electricity from renewable energy sources, mainly solar PV, accounts for the remaining 27% of total access [49]. The limited availability of electricity has a negative impact on various sectors in the country, including education, agriculture, and healthcare, thereby reducing their effectiveness.

Grid-connected photovoltaic (PV) systems offer a practical solution to address electricity blackouts in Juba, achieve zero-energy buildings, and reduce the cost of solar energy generation. These systems can significantly improve the energy efficiency of a building. Many universities worldwide have ample unused areas on their grounds and buildings, making them ideal locations for installing grid-connected PV systems on rooftops and the ground. This presents a significant opportunity to expand the use of solar-power technology [50].Electricity is an essential requirement for most institutions, including universities, to perform daily activities.The University of Juba is the largest university in South Sudan and serves as a focal point for academic and research activities.

As with many other institutions in the region, it has faced significant challenges with electricity supply owing to unreliable and expensive grid infrastructure. Consequently, the university has invested in solar PV and battery storage systems to supplement its energy needs [51]. Solar PV and battery storage systems were installed on the rooftops of several buildings on a university campus. The PV system consists of 528 solar panels with a total capacity of 150 kW, whereas the battery storage system has a capacity of 468 kWh. The systems were designed and installed by a local contractor in collaboration with the engineering team of the university. To evaluate the effectiveness of the systems, data on energy production and consumption were collected over a period of one year. The data were analyzed to determine the percentage of energy supplied by the solar PV system and the percentage of energy stored in the batteries. The cost savings achieved through the use of solar PV and battery storage systems were also evaluated [52].

The solar PV system generated 221,520 kWh of electricity over a one-year period, which was equivalent to 19% of the total energy consumed by the university during that time. The battery storage system stored 190,080 kWh of energy, which was equivalent to 16% of the total energy consumed. The use of solar PV and battery systems resulted in a cost savings of $120,000 USD over the one-year period. This represents a significant cost reduction for the university, as it previously relied solely on diesel generators for its energy requirements [51].The investment of the University of Juba in solar PV and battery storage systems has proven to be a successful strategy for addressing its energy challenges. These systems have significantly reduced the university's reliance on diesel generators and have resulted in substantial cost savings. The system has improved power reliability, reduced electricity bills, and a positive impact on the environment [52].

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IV. Results And Discussion

Solar PV systems have been increasingly utilized in urban and city environments for grid-connected applications, with battery storage systems playing a crucial role in ensuring continuous power supply. The global solar PV market has witnessed significant growth over the past decade [29-52], with China being the primary global market leader, accounting for almost 37% of its global capacity.

TABLE II : Illustrate The Approaches Used In Designing Pv And Storage Components

System used energy generation system	Aims	Engineering design and simulation	Findings	References
PV Hybrid system	• PV-AC grid system sizing. • Sizing & energy dispatch PV-diesel-battery power Systems.PV-wind system sizing	• Models of the PV, converter, and battery with Homer. • Model for simulating size with RETScreen® that is based on a spreadsheet.Component size optimization using Homer.	• Most affordable net present cost • Analyzing the economic impact of energy performance • Cost reduction for dependable autonomous system	[16] [17] [18]
Solar photovoltaic system	• Net Present Value-based Rightsizing (NPV). • Modelling and simulation. • Parametric analysis. • Operation and modelling. Modelling and simulation. • Design, modelling, and simulation. 1.0 Sizing a standalone PV system using regression.	• Combining demand response with the Monte Carlo method for sizing. • PV model parameterization using Simulink and Simpower. • System sizing accounting for the duration of the load and the charging low voltage disconnect. • Model of PV array-inverters operating in master mode using Simulink and MATLAB. • Single diode model with MATLAB & Simulink. • PV mathematical models, DC-DC boost converters, and comprehensive converter designs.	• NPV based-appropriate sizing of a PV system with consideration for sellback prices. • Long-term grid-tied functional modeling strategy. • Helps a PV designer determine the ideal system specifications and charge controller settings. • Improved power system voltage and frequency regulation. • Output current calculation. • PV-based power system setup for testing using a DC-DC converter.	[19] [20] [21] [22] [23] [24]
Solar-plus-storage system	• Optimum scale. • Hybrid storage technology sizing optimization	• Sensitivity investigation and direct search methodology. • Design of a hybrid system that maximizes the number of batteries, the tilt of the PV modules, and the number of solar panels.	• Optimal sizing using a systematic algorithm. • Optimal size based on utility properties.	[25-26] [27]
Grid-tied PV system	• PV performance study. • Synchronizing the inverter with MPPT and connecting to the grid.	• The utilization of MATLAB & Simulink in constructing models for PV panels, inverters, converters, filters, MPPT, and units for control & protection. • The utilization of MATLAB & Simulink for creating a model of a PV array, MPPT, and an inverter connected to the power grid.	• Adequate design control for PV system. • Improved PV system modeling and control design techniques.	[13] [28]

The PV market is primarily dominated by crystalline silicon (c-Si) modules, which constitute roughly 90% of the market share, with both single-crystalline (sc-Si) and multi-crystalline (mc-Si) modules being widespread. The market share of thin films (TF) has decreased from 16% in 2009 to only 10% today. Similar to that, concentrated photovoltaic (CPV) technology only makes up less than 1% of the market.

A. Battery Storage Systems and their Role inSolar PV

Battery storage systems play a crucial role in ensuring continuous power supply and mitigating the challenges posed by weather conditions. Lithium-ion (Li-ion) batteries are currently the most broadly utilized technology for stationary energy storage applications, with lead-acid batteries being the second most commonly used. Other types of batteries include sodium-sulfur (NaS), flow, and redox flow batteries. These batteries provide several benefits such as grid stabilization, load management, and ancillary services.

B. Battery storage and solar power applications

Solar photovoltaic (PV) and energy storage systems utilizing batteries are adaptable and can be utilized for a variety of tasks, including powering water pumps, charging batteries, illuminating streets, providing electricity to homes, heating swimming pools,refuelling hybrid cars, supporting communication networks, supplying power to military and space equipment, and producing hydrogen. These schemes are typically used for either centralized, accounting for about 40% of the market, or decentralized systems, which account for about 60% of the market.

C. Challenges and Future Directions

The adoption of solar PV and battery storage systems faces several challenges, such as high initial costs, technological limitations, and lack of policies and regulations to promote their use. However, advancements in technology, coupled with favourable government policies and regulations, have contributed to their widespread adoption. Furthermore, the amalgamation of solar PV and battery storage systems with other sources of renewable energy such as hydropower and wind power, can provide a balanced portfolio of renewable energy resources.

Solar PV and storage systems have the potential to become the leading source of electricity by 2040, with several countries already investing heavily in their adoption. The combination of PV and storage systems with other renewable energy sources can provide a sustainable solution

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for meeting the rising energy demands and shifting towards sources of renewable energy.

V. Conclusion

The advances of PV technology have resulted in a potentially viable solution to the world's energy dilemma and the negative environmental effects of energy production. These problems can be greatly addressed by this renewable energy source. However, the incorporation of PV technology into the electrical grid presents several technological challenges, such as fluctuations in power, instability in voltage, and storage issues. Energy storage systems such as electrochemical batteries can be employed to address the intermittent nature of PV energy in power systems. Furthermore, the implementation of effective energy policies is crucial for supporting the continued expansion of the PV market and user base. Various strategies are implemented to encourage the adoption of photovoltaic (PV) renewable energy, including trading mechanisms, feed-in-tariffs, investment tax credits, renewable portfolio standards, pricing regulations, quota mandates, production incentives, and other relevant policies. These policies' main goals include reducing reliance on non-renewable energy sources, promoting the development of new industrial sectors, and mitigating the environmental effects of the energy industry. The high initial costs associated with PV technology pose a significant challenge for renewable energy sources and energy efficiency improvements. This is because these expenses are mainly incurred upfront. Therefore, the introduction of PV technology into electrical grid requires a multifaceted approach that involves addressing technical challenges, implementing effective energy policies, and overcoming financial and non-financial barriers to achieve the International Energy Agency's vision of sustainable energy for all.

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