INVESTIGATION CHALLENGES FACING THE INTEGRATION OF THE 33 MW EZRA DIESEL POWER PLANT AND TWO 20 MW SOLAR PHOTOVOLTAIC (PV) GENERATION INTO THE DISTRIBUTION SYSTEM IN JUBA CITY

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Abstract

Solar photovoltaic (PV) generation is significant in sustainability and transitioning from diesel to clean energy. Integrating solar photovoltaic (PV) generation into the distributed networks improves energy balance, pollution mitigation, and cost reduction. South Sudan is an African country with frequent power outages and a lack of load reliability. The country's electricity demand stands at 300MW, with an installed capacity of around 252.4M. The gap in installed capacity is due to insufficient funds to build new electricity facilities. Two power plants were constructed between 2019 and 2025. Ezra's diesel power plant, which had a capacity of 33 MW, was built in 2019, while two solar PV plants with a capacity of 20 MW were commissioned between 2023 and 2025. The two Juba Solar PV plants aim to increase the current installed capacity of 33 MW to 73 MW, contributing to economic growth and job opportunities. The electricity tariff will be reduced gradually as the wattage amount increases. The paper investigates the challenges of integrating the 33 MW Ezra Diesel Power, Ezra 20 MW Solar hybrid solution and 20 MW Nesitu Solar PV plant. Factors such as weather conditions, energy intermittency, and unequal load will be investigated. Inverters, energy storage systems, and sensors can stabilise the energy flow between PV solar panels and the grid. Ezra and Nesitu Power Plants case studies will be shared and discussed in detail. Integrating two solar PV plants will reduce dependency on thermal generation and promote renewable energy generation.

1 Introduction

Juba, the capital of South Sudan, faces significant challenges in meeting its growing electricity demand. Since 2019, the city's power supply has primarily depended on a 33MW diesel power plant [1]. However, the heavy reliance on diesel-based generation has led to concerns about the power supply's sustainability, reliability, and affordability. Recently, a growing interest has been in harnessing renewable energy sources to diversify the energy mix and address the city's energy poverty. The Nesistu 20 MW solar power plant commissioned in 2022 and the Ezra 20 MW Solar hybrid solution completed in 2025 represent significant steps toward integrating renewable energy into the Juba power system [2].
The successful integration of the two solar PV plants with the existing 33 MW diesel power plant would create a hybrid power system, potentially offering a more reliable, sustainable, and cost-effective electricity supply for Juba City. Small-scale diesel power plants and solar PV generation integration have no serious operation issues. However, integrating a large-scale diesel power plant and a solar PV plant represents a unique set of technical, operational, and regulatory challenges that must be carefully investigated and addressed. Factors such as grids' stability, power quality, dispatch coordination, and energy storage requirements must be thoroughly examined to ensure sufficient operation of hybrid power system [2].

This paper investigates the key challenges and strategies for integrating the 33 MW Ezra Power Plant and the 40 MW Nesitu and Ezra solar PV power plants in Juba. The study will explore the technical, operational, and regulatory considerations and propose comprehensive recommendations to facilitate the successful integration of the hybrid system, ultimately contributing to enhancing Juba's energy security and sustainability.

2 Methodology

The research adopts a case study approach, focusing on the Juba Solar PV Park, Ezra diesel, and solar hybrid plants. The Nesitu Solar Parks Park's specifications include a 20 MW Solar PV system capacity with 35 MWh battery storage. The Solar hybrid plant specifications include 20 MW and 14 MWh, while the Ezra diesel power plant has a capacity of 33 MW. The research utilises data from the South Sudan Ministry of Energy and Dams, the specifications of the Solar PV generations and the Ezra diesel power plant. The collected data is analysed by reviewing the current electricity generation and distribution system and assessing the technical challenges facing integrating solar PV generation and the Ezra diesel power plant in Juba City. In addition to the advantages and disadvantages of solar energy generation.

3 Result

Investigation challenges facing the integration of the 33 MW Ezra diesel power plant and the two 20 MW solar photovoltaic (PV) into the distribution system in Juba City has the potential to contribute to sustainability, energy balance, pollution mitigation, and cost reduction. The two solar generation projects aim to increase the installed capacity in Juba City from 33 MW to 73 MW. The new capacity is expected to serve 116000 residents and save 26000 tons of carbon dioxide (CO2) annually. This research contributes to understanding the benefits and challenges of integrating renewable energy sources into a distribution system. It emphasises the significance of sustainable energy solutions in transitioning from fossil fuels to clean energy. The investigation challenges facing the integration of the 33 Ezra diesel power plant and two 20 MW solar PV generation into the distribution system in Juba City hold promise for improving the reliability and sustainability of the electricity supply. With their increased capacities and reduction in carbon emissions, the Juba Solar PV Park and Ezra solar hybrid plant represent a positive step towards achieving energy transition goals.

4 Current Status of Electricity Generation and Distribution in South Sudan

The current electricity generation demand is 300 MW; however, the installed capacity is around 252.4 MW. Insufficient funds are the reason for the limited generation demand and the need to build extra electricity facilities. In 2015, the Ministry of Energy and Dams and the Ezra Construction and Development Group initiated a 100 MW Ezra Power Plant project, which started construction in 2017 and was launched with a capacity of 33 MW as the first phase of operation in 2019 in Condokoro, east of the River Nile. The generated electricity is transmitted and distributed to consumers through 132kV and 33 kV/0.415kV [3]. Nevertheless, the electricity supply in Juba City remains unstable and is faced with frequent power outages and load shedding throughout the year. Table 1 below shows the current electricity generated and distribution in the country. Most of these power plants are diesel-based generation. The Roseires hydropower plant supplies the Renk town on the border with Sudan. However, the substation to distribute electricity in the town is not operational due to a lack of spare parts and technical issues. South Sudan has the potential to generate electricity from the hydro but a lack of funds remains an obstacle. The only two plants based solar generations are the Nesitu solar parks and the Ezra hybrid solar plant. Solar energy is also abundant in the country. The most considerable capacities are generated in the oilfields of the Upper Nile State, Unity State, and Ruweng Administrative area. Two towns, Bentiu in Unity State and Melut in Upper State, are supplied with sustainable electric power [2].

Table 1 Operational and Non-Operational Diesel and Solar Power Plants in South Sudan

Location	Fuel	Capacity (MW)	Status	Year
Ezra Power Plant Juba	Diesel	33	Operational	2019
Malakal Power Plant	Diesel	4.8	Not Operational	1982
Wau Power Plant	Diesel	5.6	Operational	2008
Bor Power Plant	Diesel	3	Not Operational	2009
Rumbek Power Plant	Diesel	3	Not Operational	2009
Yambio Power Plant	Diesel	3	Not Operational	2009
Renk Interconnection Substation	Water	5	Not Operational	2007
Paloch Power Plant	Diesel	97	Operational	2005
Tharjath Power Plant	Diesel	58	Operational	2005
Nesitu Solar Plant	Solar	20	Not Integrated	2022
Ezra Solar Hybrid Plant	Solar	20	Integrated	2023
Total		252.4		

There are two large-scale solar PV generation plants in Juba City. The first is in the Nesitu area, 20 km south of Juba City. Construction started in 2022 and was completed in 2023, and it waited for integration into the electricity distribution system. The second PV solar generation started its construction in 2023 and was commissioned in 2025 by Ezra Construction and Development Group. This solar hybrid plant is located within the area of Ezra Power Plant in the Condokoro area, east of the River Nile [2], [4]. This increase in the generating capacity will stabilise the electricity supply in Juba City, however, the kilowatt hour (kWh) price is still an issue that residents complain about.

5 Integration of Solar PV into Existing Diesel Generation-Based System

Renewable energy sources such as solar PV and others can be integrated into an electrical power system with low and medium voltages. The electric power generated by solar PV can be incorporated into the grid or in a stand-alone system. Solar panels, power electronics devices, and battery storage systems are components of the solar PV system. These components are necessary to convert the generated electricity from DC to AC or vice versa. Solar radiation and the tilt of PV panels are crucial for electricity production [5], [6]. Power quality stability, reduction in energy conversion losses, and improved reliability are the main advantages of Solar PV generation and its integration into power systems. Adequate load quality should characterise the reliability of distributed generators by timely maintenance to reduce annual power outages [7]. Other advantages of PV systems are that they are emissions-free and have low maintenance and operation costs. However, Solar PV has environmental concerns and can affect biodiversity and land [8].

6 Challenges Facing the Integration of a 33 MW Ezra Diesel and Two 20 Solar PV Generation in Juba City

6.1 Ezra diesel power plant and solar hybrid plant

The Ezra Construction and Development Group constructed and launched a 33MW diesel power plant between 2017 and 2019. It was a phase one operation; the remaining phases included 30 MW, 20 MW, and 20 MW. However, this diesel power plant faces outage challenges regarding sustainable power supply and reliability. In 2023, Ezra started constructing a 20MW solar hybrid plant in the same compound as the current diesel power plant with a 14 MWh battery energy storage system to overcome the plant's drawbacks [2], [4]. Thus, hybrid power plants integrate and operate renewable energy, controllers, and energy storage systems. Such plants can provide a continuous electricity supply and maintain the load without interruption [9]. However, solar hybrid plants depend on weather conditions, which may affect energy intermittency and unequal load demand. Advanced technologies such as inverters, sensors, and energy storage systems are crucial in optimising energy generation for a sustainable electricity supply. For instance, advanced inverters can manage the energy flow between solar PV panels and the grid, and sensors provide real-time data on weather conditions and energy consumption patterns [10].

A single energy storage system for a high steady-state power supply may need an ample energy storage system, which is costly. Such a storage system is only suitable for low power supply, and vice versa; it is usually considered a temporary solution. Therefore, a hybrid energy storage system has proven more effective. A system that combines two or more energy storage methods cooperating and delivering continuous power supply [11]. At the moment, the desired energy storage technology is the electrochemical devices. These types of batteries require constant maintenance and have a shorter lifespan, presenting environmental risks due to lead and sulfuric acid use. The latest study proved that the effectiveness of electrolysis's hydrogen-based electrical energy storage systems does not emit polluting gases [12].

The Ezra solar hybrid solution will serve around 16000 households or 57000 residents in Juba city and save 42,000 tons of carbon dioxide emission per year. With the completion of the solar hybrid plant in 2025, Ezra mixed power generation reached 53 MW of the 100 MW project, and the challenge is still how to add the unutilised 47 MW to complete a 100 MW power plant as it was designed. The plant does not need transmission lines to distribute its generated power; it can use the existing distribution system in Juba City. However, integrating the Ezra diesel power generation and the solar hybrid generation is a challenge that needs careful addressing [2], [4].

6.2 Nesitu Solar PV power plant

In 2019, the Ministry of Energy and Dams contracted an Egyptian company, Elswedey Electric, to construct a Solar PV plant in the Nesitu area, 20 km south of Juba City. The plant’s construction started in 2020 and was completed in 2023. PV solar panels tilted at an angle of 8 degrees south orientation are shown in (Fig. 1) [2]. The schematic system diagram, including PV panels, battery storage system, inverters, and energy management system, is shown in (Fig. 2). The PV system, which cost US$ 45 million, will be connected to the current grid in Juba City; however, before integrating into the grid, Elsewedy Egyptian Company Juba Solar PV park to construct a 33kV transmission line and a Ring Medium Unity (RMU) for a distance of 20 km. The obvious challenges facing the plant include the clearance of the financial obligation by the government of South Sudan, the construction of the transmission line, and the integration into the existing electrical power system in Juba City. Environmentally, the plant is set to serve 59,000 residents in Juba, save 10,888 tons of carbon dioxide annually and reduce greenhouse gas emissions.

Fig. 1. PV panels' fixed mounting structure tilt angle is 8 degrees south orientation.

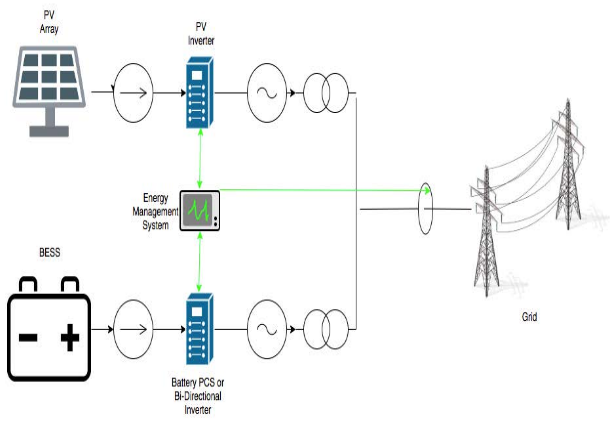

Fig. 2. Solar PV park system schematic diagram

6.3 Integration process steps

Procedures, standards, regulations, and laws must be carefully considered before integrating the Ezra diesel power plant and solar PV systems [13]. Improper integration might affect the protection system and cause faults in the distribution system. The solar PV system supplies power in both directions, which may cause over and under-generation in the distribution system. Solar radiation forecast tools and an energy storage system are measured to avoid an imbalance in the distribution system [14].

Two scales of PV solar systems are involved: small scales ranging from 1-25kW and larger ones above 10 MW. A solar PV system of 1-25kW generates electricity of a low voltage of 600 V and below, which can be used to develop distributed systems. The benefits of such arrangements are the absence of transmission lines and the mitigation of load reliability connected to the new distribution system. This set-up system is relevant to the standby capacity that provides stable power at a low power supply. A large-scale solar PV system is needed for electrical power systems that are far from the customers and require transmission lines. Such a system involves costs and line losses, which result in energy loss during conversion [14], [15].
Organisations that offer standards and codes for the integration process exist, including the Electric Power Research Institute (EPRI) and the International Council on Large Electric Systems (CIGRE), the Institute of Electrical and Electronics Engineers (IEEE), and the International Energy Agency (IEA) [16]. The EPRI details integrating a few kW solar PV system up to 50 MW and its energy storage stations near the substation. CIGRE compares generation systems between 50 MW and 100 MW capacities connected to a centralised network [17], [18]. The IEEE deals with electricity generation from infrastructure near power system stations, and the IEA regulates the integration of distribution generators into grids [19], [20]. All the above standards, regulations, and laws must be carefully implemented when integrating Ezra's diesel power plant and solar PV generations in Juba City. This is to ensure the safe integration and reliability of the power supply.

7 Conclusion

Two 20 MW solar PV solar parks were constructed between 2019 and 2025 in Juba. The existing 33 MW Ezra diesel power plant was also built in 2017 and has been operational since 2019 in Juba City. The 40 MW solar PV and 33 MW thermal generation will bring the total power capacity to 73 MW in Juba City. However, the Nesitu Solar PV plant is not operational due to incomplete financial obligations with the Egyptian Elsewedy Electric. The Ezra Solar Hybrid Plant has been newly integrated into the distribution system. The 40 solar PV generation will contribute to reducing the high electricity tariffs and serve 116000 residents in Juba City. Around 26000 tons of carbon dioxide emissions will be saved annually. As such, there has been an increase in the incorporation of renewable energy into the distribution system in Juba City since 2019.

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