POWERING SUBSTATIONS: A COMPARATIVE ANALYSIS

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ABSTRACT

The transmission grid consists of interconnected substations and power lines enabling the flow of energy from generation sources to distribution centers. Auxiliary services, essential for the supervision, control, and protection of the transmission network, are typically powered by internal sources (tertiary winding), external sources (distribution grid) or by diesel generators. This work presents a comparative analysis between the traditional diesel generator and an innovative solution consisting of lithium-ion batteries coupled with photovoltaic generation. Employing HOMER PRO, technical and economic assessments were conducted. Although the renewable system incurs a higher initial investment, it exhibits significantly lower operational costs and environmental impact. This alternative offers great potential for use, especially in substations without availability of internal power sources or those far from the distribution grid.

Keywords: Auxiliary Services; Battery Energy Storage; Lithium-Ion; Photovoltaic Generation; Transmission Substations.

INTRODUCTION

Brazil's National Interconnected System (SIN) connects generation sources and transmission grids, enabling energy exchange and ensuring a reliable supply to consumers [1]. The National Electric System Operator (ONS) operates the SIN under the regulation and supervision of the National Electric Energy Agency (ANEEL).

Electric systems are susceptible to various types of disturbances during real-time operation. Some of these disturbances result in power supply interruptions, with the severity of the impact depending on factors including the cause, duration, and extent of the affected area [1].

ANEEL's Transmission Service Rules [2] stipulate that service quality is measured based on the availability and operational capacity of transmission lines (TLs) and substations (SSs). A variable fee is linked to the operational performance, imposing a financial penalty on the company.

High-voltage SSs play a fundamental role in the SIN. Equipped with switching, control, and protection devices, they constitute the endpoints of TLs, enabling the flow of electric power throughout the network. Substations are also capable of voltage regulation, by stepping up or down the voltage level of the transmitted energy [3]. Their routine operation is ensured by a set of panels and equipment known as auxiliary services (SAux). Under restricted conditions, these systems must maintain the supply of essential loads to ensure operational continuity until maintenance teams restore normal operation [4].

The Institute of Electrical and Electronics Engineers (IEEE) recommends using tertiary windings, busbars, distribution lines, or emergency generators for auxiliary systems [5]. Brazilian regulations require at least two alternating current (AC) sources, with one external from the distribution grid and one internal to the substation, or two internal sources. If this is not possible, an alternative with two independent AC power supply sources must be proposed to the ONS [3].

Diesel generators (DGs) are commonly used as emergency power sources. In substations situated in remote areas, lacking a distribution grid (external source) or transformer element (internal source), DGs can serve as both the primary and backup source for auxiliary services. Considering the absence of transformers in 238 SIN substations (EPE [6]), renewable energy storage offers a sustainable alternative for auxiliary power, mitigating the carbon emissions.

This article aims to simulate and compare two alternative power supply sources for substation auxiliary services, using a Brazilian transmission company as a case study. Load profiles and sizing aspects will be addressed. Financial parameters and electrical data of a diesel generator and a lithium-ion battery energy storage system (LiBESS) with coupled photovoltaic generation will be compared. The simulation also provides insights into fuel consumption and greenhouse gas (GHG) emissions avoided by utilizing the renewable source instead of DG.

MATERIALS AND METHODS

Official information from Brazilian electricity sector regulators and specialized literature was consulted. Data from PD-07351-0001/2022 research and development (R&D) project, registered with ANEEL, were used.

The electrical load from Firminópolis Transmission control house, at Trindade substation (Goiás-Brazil), was obtained from company's executive project and measured using a Fluke 435-II power quality and energy analyzer.

The HOMER PRO software simulated electrical schemes, evaluating the LiBESS-PV system installation in a new substation and using data from an existing substation as a reference. Economic parameters adopted were discount rate of 10.25% (SELIC), inflation of 4.5% (IPCA), and 25-year horizon. Financial results and electrical data are presented and discussed in the next section.

RESULTS AND DISCUSSION

According to the Firminópolis project, the installed loads are 25.45 kVA (essential) and 6.49 kVA (non-essential). The average power and daily consumption measured in field were 5.23kW and 125.50kWh/day, respectively. To ensure adequate power supply for the full load of the Saux, the diesel generator must have a nominal power greater than 48kVA.

The battery bank capacity was calculated to meet the daily energy demand of the SAux, assuming a 90% depth of discharge (DoD) and 10% internal losses. For a 36-hour autonomy, the LiBESS must have a storage capacity of 233.00kWh.

The photovoltaic (PV) system must generate sufficient energy to fully charge the batteries during each solar cycle. The total power of the PV modules, calculated based on local solar irradiance data, must be at least 53.00kWp. The nominal power of the photovoltaic inverter will be 40.00kW for an inverter sizing factor of 0.75.

Considering that the power converter system (PCS) will operate in grid-forming mode for islanding operation, a 75.00kW output power PCS was selected. This power rating not only meets the load demand but also exceeds the peak production of the PV system, preventing overvoltage and overfrequency issues.

In addition to technical parameters, financial data in “**Table 1**” were considered for the simulation of a new installation. Replacement of an existing source requires case-by-case assessment of electrical adjustments to the auxiliary service panel. Market quotations were used to define the cost of the DG and the PV system. LiBESS and PCS were priced at BRL 4,000.00/kWh [7], detailed in [8]. A reinvestment of 50% of the initial cost every 15 thousand hours was assumed for DG, discounting the residual value. Replacement for LiBESS and solar inverter occurs every 13 years, valued at BRL 2,800.00/kWh [7], [8] and market rates. The fuel cost used was BRL 5.86/liter, based on the April 2024 averages for Goiás-Brazil.

Table 1. HOMER PRO inputs for financial analysis.

Equipment	DG 50kW	BESS 233kWh	PCS 75kW	PV 53kWp
Capex	70.00k BRL	516.60k BRL	415.40k BRL	200.50k BRL
Replacement	35.00k BRL	326.20k BRL	-	25.00k BRL
O&M per year	44.50k BRL	2.60k BRL	2.10k BRL	2.70k BRL

Two independent scenarios for powering SAux loads were simulated using HOMER Pro. “**Fig. 1**” shows the connection topology and electrical results for the first scenario, with DG as the main source (DGP). Due to 240-hour maintenance intervals, a backup device (DGR) was included. However, deployment costs were limited to a single generator. The upper graph shows the AC load and power output from DGP. On July 2, the main generator was shut down for preventive maintenance, shifting the load to the backup generator, as shown in the lower graph. After the maintenance, both units failed, dropping the AC load to zero in the upper graph, while in the lower graph displays the unserved load with a power spike.

“**Fig. 2**” shows the schematic diagram and load supply results for the second scenario, with LiBESS coupled with photovoltaic generation (LiBESS-PV) as the main source, without backup equipment. The upper graph displays AC load, and the electrical power from the PV system and LiBESS. On May 28, the state of charge (SoC) of LiBESS drops to zero, leaving the batteries completely discharged. At the same time, no electrical power is generated by the PV system, indicating the absence of solar irradiation. Consequently, the unserved load is indicated by a spike until photovoltaic power is generated, serving both the load and recharging the batteries.

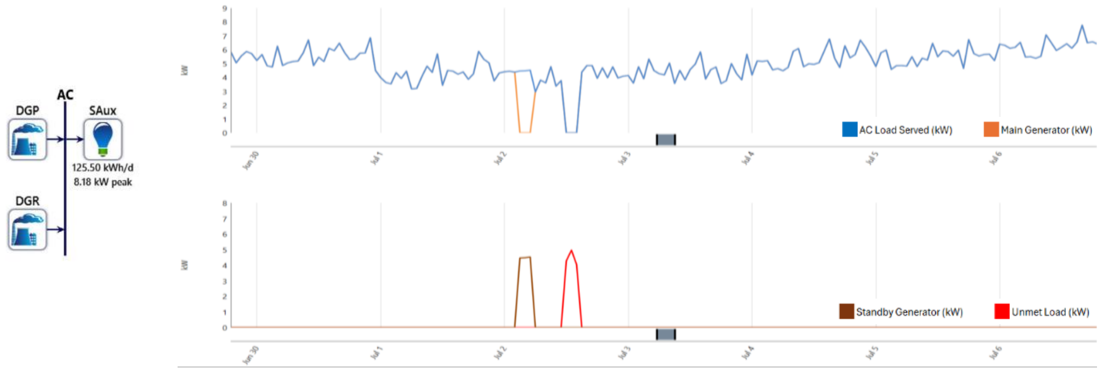

Figure 1. DG as the main source of SAux.

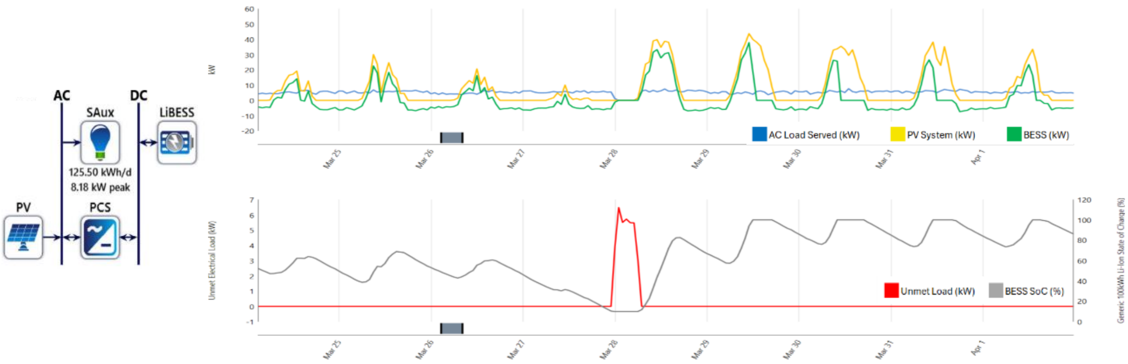

Figure 2. LiBESS-PV as the main source of SAux.

The "**Table 2**" presents simulation results, demonstrating that the LiBESS-PV Levelized Cost of Energy (LCOE) is more attractive than the diesel generator. The Net Present Cost (NPC) of the DG increased by his operational expenses (OPEX) – fuel consumption and maintenance costs – exceeded the LiBESS-PV system by a factor of 2.50. A consumption of 26,951 liters of diesel during the analysis period was observed, considering both main and standby generator. The resulting GHG emissions, in kilograms per year (kg/yr), are shown in the table below.

Table 2. Simulation results.

	Financial Results				GHG Emissions			
Item (unit)	LCOE (BRL/kWh)	NPC (BRL)	CAPEX (BRL)	OPEX (BRL)	CO2 (kg/yr)	CO (kg/yr)	SO2 (kg/yr)	NOx (kg/yr)
DG	5.84	3,586.00k	0.07k	262.18K	70,554.00	440.00	173.00	414.00
LiBESS PV	2.28	1,397.95k	1,132.84k	19.78K	-	-	-	-

For future research, simulating the LiBESS-PV system in association with a second power source, could provide valuable insights into the optimal configuration for main and emergency power supply. This analysis would help determine the most cost-effective and environmentally friendly arrangement.

CONCLUSION

This study compared the use of a diesel generator (DG) and a lithium-ion battery energy storage system with coupled photovoltaic generation (LiBESS-PV) for powering the auxiliary services (SAux) in a transmission substation. The LiBESS-PV system demonstrated a significantly lower Levelized Cost of Energy (LCOE) (2.28 BRL/kWh vs. 5.84 BRL/kWh) over a 25-year period. This reduction is primarily due to lower operational expenses associated with eliminating fossil fuel consumption, offsetting the higher initial investment. The LiBESS-PV solution is particularly attractive in substations without an internal source or those far from the distribution grid, where investment in network extension is technically or financially unfeasible.

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