Optimizing Off-Grid Energy: A Case Study on Hybrid BESS Integration for Resilient Off-Grid Telecommunication Tower in Malaysia

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A Joint Paper by EDOTCO Group and Universiti Kebangsaan Malaysia

1. Company at a Glance: EDOTCO Group

As a pioneer of the tower industry in Asia, EDOTCO Group places sustainability at the core of its business by not only encouraging co-location to reduce emissions, but also adhering to its Sustainability Policy. The Group's 2024 operations underscore a commitment to becoming a top five global TowerCo by 2030, driven by a strategic mandate to reduce its carbon footprint via its Carbon Neutral target by 2030. In Malaysia, nearly 82 off-grid sites are currently powered by conventional diesel generators (genset), which are known to release significant carbon emissions. This reliance on fossil fuels hindered EDOTCO's progress toward its carbon reduction targets. To address this, EDOTCO is engaging with supply chain partners to lease and integrate Hybrid BESS (Battery Energy Storage Systems) at these off-grid locations. By implementing these hybrid systems, the partners maximize resource efficiency while EDOTCO reduces industry-wide emissions, all while bridging the digital divide for underserved communities across Malaysia. Ultimately, EDOTCO ensures that the future of connectivity remains inclusive and resilient, reflecting a harmonious balance between technological innovation and the preservation of the planet for generations to come.

2. The Objective: Case Study Overview

This case study report is co-written by EDOTCO and Universiti Kebangsaan Malaysia (UKM). It presents a comprehensive analysis of a Battery Energy Storage System (BESS) hybrid power system, comparing its performance against a modeled, genset-only baseline scenario. The primary objective of this project was to validate the system's ability to reduce diesel fuel consumption and carbon emissions, thereby enhancing operational efficiency and environmental sustainability. The analysis is based on raw operational data of charge and discharge cycles, genset run time, and site power demand.

The key findings of this assessment demonstrate a significant and measurable improvement across all key performance indicators. Over the analyzed period, the hybrid system achieved a substantial reduction in diesel consumption, directly translating to a considerable financial saving in fuel costs. This reduction in fossil fuel usage resulted in a quantifiable decrease in carbon emissions, positioning the system as a critical component of a sustainable energy strategy. Furthermore, the intelligent energy management system's ability to reduce genset run hours not only conserved fuel but also mitigated the risk of operational and maintenance issues, such as "wet stacking," thereby extending the life of the genset and reducing long-term maintenance expenditures. The case study report concludes that the integration of the battery energy storage system (BESS) provides a clear economic and environmental advantage. It is recommended that the site's energy management strategy be continuously refined based on ongoing data to maximize efficiency. The quantified emissions reductions also prepare the organization for future participation in emerging carbon markets, offering a potential new revenue stream and reinforcing a commitment to corporate social responsibility.

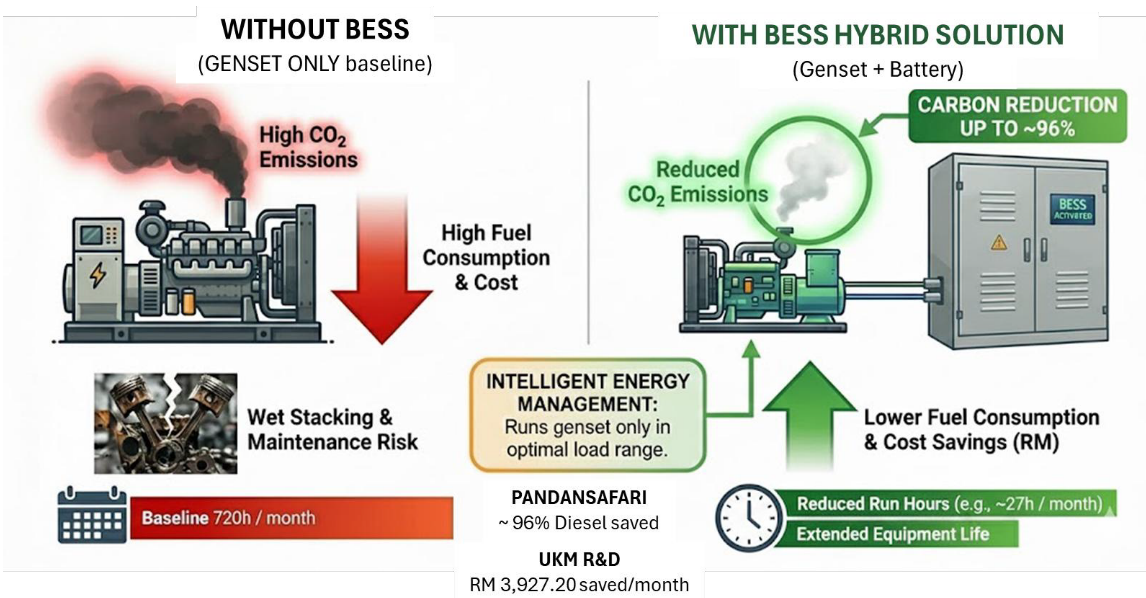


Figure 1 Visual summary of the BESS hybrid solution benefits

3. The Challenge: Inefficiencies of Standalone Gensets

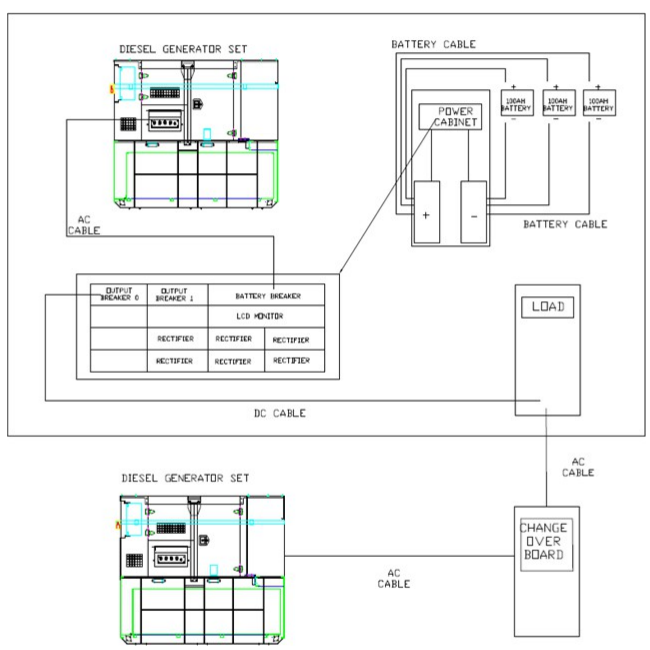
The widespread reliance on gensets for off-grid or backup power presents a well-documented challenge related to operational efficiency and environmental impact. A fundamental inefficiency of conventional gensets is their varying fuel consumption rates depending on the electrical load. Diesel engines are designed to operate most efficiently within a specific load range, typically at 75% to 80% of their rated capacity. When operated at a low load, particularly below 30% to 40% of their capacity, their fuel efficiency plummets, resulting in a disproportionately high specific fuel consumption (SFC), measured in Liters per kilowatt-hour (L/kWh) or grams per kilowatt-hour (g/kWh). Beyond the immediate financial cost of wasted fuel, prolonged low-load operation leads to a critical maintenance issue known as "wet stacking". This condition occurs when the engine's combustion temperature is insufficient for a complete burning diesel fuel. The unburned fuel, along with carbon particles and moisture, accumulates in the exhaust system, forming a dark, oily substance. Wet stacking is not merely an aesthetic problem; it can cause significant internal damage to the engine. The unburned fuel can dilute the engine's lubricating oil, leading to increased wear on components like cylinder walls and piston rings, and can also damage injectors and exhaust valves. Manufacturers' warranties often do not cover damage resulting from this preventable condition. Consequently, operating a genset at low loads for extended periods shortens its operational life, increases the frequency of maintenance, and drives up long-term operational costs.

4. The Solution: BESS Hybrid Integration

The integration of a Battery Energy Storage System (BESS) directly addresses these core inefficiencies. The hybrid system operates on a dual-mode principle designed to keep the genset in its optimal efficiency range. During periods of low energy demand, the genset is turned off entirely, and the battery provides power to the site. This eliminates the inefficient and damaging low-load operation of the diesel engine. When the battery's state of charge (SOC) drops below a defined threshold or when the site's energy demand exceeds the battery's power output capability, the genset automatically starts. Once started, the genset operates at a high, stable load, simultaneously powering the site and recharging the battery with its surplus energy. This operational strategy ensures that the genset runs less frequently and, when it does, it operates at its most efficient point, reducing fuel consumption and avoiding the detrimental effects of wet stacking. The strategic combination of these components provides a more resilient, cost-effective, and environmentally friendly power solution.

4.1 System Configuration

The technical configuration of a BESS hybrid power system is illustrated below. This setup combines diesel genset with a battery energy storage system (BESS) to provide a resilient and flexible power supply to a load. In this configuration, the gensets is turned off automatically during periods of low demand, with the battery taking over to power the load. The gensets are then used to recharge the battery and power the site when the battery's charge is low or when the power demand is high.



A Proof-of-Concept (POC) was initiated across 4 distinct off-grid sites. Each site was initially powered by mutual 2 x 20 kVA gensets operating in tandem.

4.2 Installation Sites

Site Name	Site ID	Region	Date of installation	Average load (A)
PANDANSAFARI	e.coMY002940WW	Central	20/3/2025	3.7
UKM R&D	e.coMY003437BB	Central	20/4/2025	41.3
KEM GEMAS 3	e.coMY003283NN	Eastern	22/2/2025	15.9
RAMO TNB ULU JELAI	e.coMY003153CC	Eastern	20/4/2025	13.8

1. PANDANSAFARI (e.coMY002940WW)


2. UKM R&D (e.coMY003437BB)

3. KEM GEMAS 3 (e.coMY003283NN)

4. RAMO TNB Ulu Jelai (e.coMY003153CC)

5. Operational Performance Metrics

Data was systematically collected over a period of month to validate the system's ability to meet a set of mutually agreed-upon key performance indicators (KPIs), which included:

a) Battery operation exceeding 12 hours a day
b) Genset operation for battery charging and equipment power
c) A minimum 15% reduction in diesel consumption
d) A minimum 15% reduction in carbon emission

A rigorous methodology was applied to analyze the raw data from the BESS hybrid system to derive meaningful insights. The initial step involved the aggregation and normalization of the raw data, which included time-series logs of genset run time, battery state of charge (SOC) and charge/discharge rates.

a) Battery operation exceeding 12 hours a day

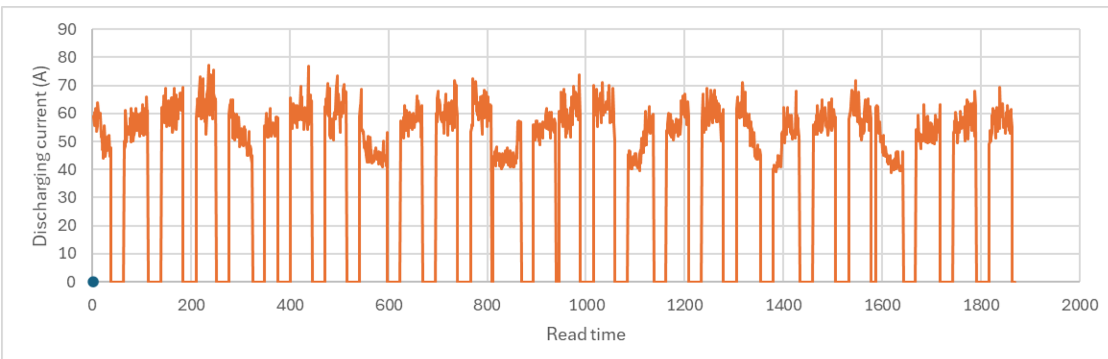


Figure 2 Weekly Discharging Current Profile of the BESS Hybrid System at the UKM R&D Site (highest load)

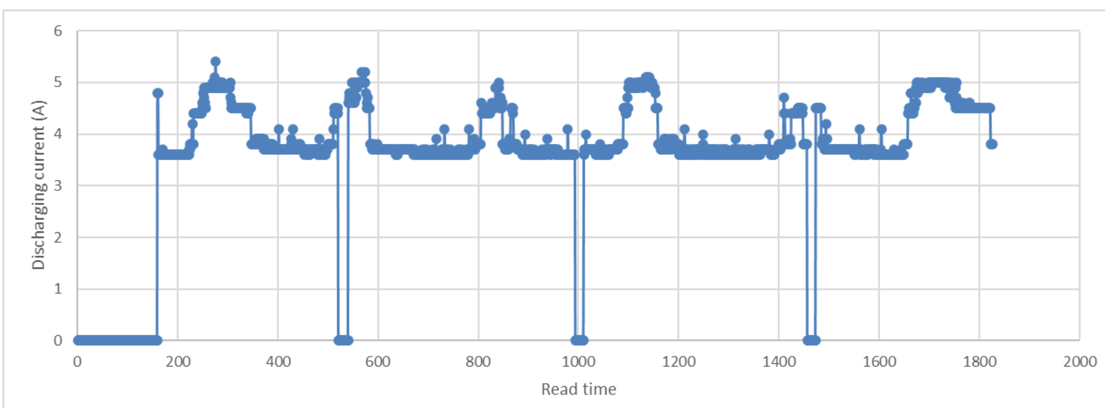


Figure 3 Weekly Discharging Current Profile of the BESS Hybrid System at the PANDANSAFARI Site (lowest load)

Figure 2 & 3 illustrates the battery's discharging current over time. The periods of high current (the peaks in the orange line) show when the battery is actively powering the site's load. The flat, zero-current sections indicate that the battery is not discharging, corresponding to the times when the genset has taken over to power the site and recharge the battery. Over the course of the week, for the site with highest load, the battery operated for a total of approximately 102.8 hours, averaging 14.68 hours per day. While for site with lowest load, the battery operated for a total of approximately

b) Genset operation for battery charging and equipment power

Figure 4 Daily genset running at RAMO TNB ULU JELAI

Figure 4 shows that after each period of genset operation (the blue flat line), the battery's discharging cycle resumes with high current. This proves that while the genset was running, it was not only powering the equipment but also simultaneously recharging the battery, allowing it to take over the load once again.

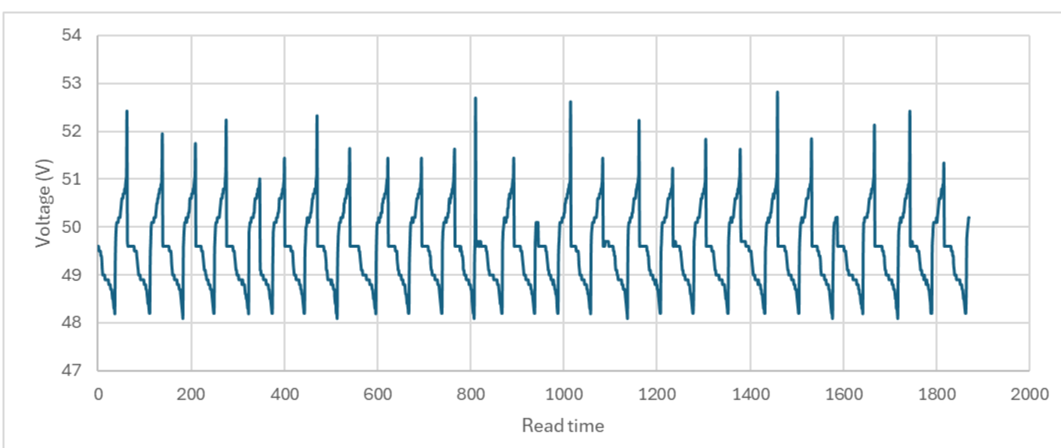


Figure 5 The charge-discharge cycle

Each time the graph shows a gradual, steady decrease in voltage, it represents a discharge cycle. This is the period when the battery is actively powering the site's equipment. As the battery supplies energy to the load, its State of Charge (SOC) drops, which is directly reflected as a decline in its voltage. This continues until the battery reaches a predefined low voltage threshold.

As depicted in Figure 5, the sharp rise in voltage signifies a charging event. This occurs when the genset automatically turns on. The genset's role is not just to power the site but also to quickly recharge the battery with surplus energy. The steepness of the line indicates a rapid and efficient charging process. Once the battery reaches a satisfactory SOC, the genset turns off, and the system returns to its battery-powered mode.

6. Comparative Analysis: Hybrid vs. Baseline (Genset only)

6.1 Diesel consumption

Diesel consumption is heavily dependent on a site's load, with higher-load sites consuming more than lower-load sites. The total diesel consumption over a three-month period was observed at the highest and lowest load sites.

a) PANDANSAFARI

The approximate consumption rates are: At ¼ Load: 2.3 liters per hour

Genset only,
Total genset running hour per month: 720h

With BESS hybrid system,
Total genset running hour per week: 6h 45min
Total genset running hour per month: 27h

Month	Diesel consumption (L/month) Genset only	Diesel consumption (L/month) BESS Hybrid
Jan	1,656	-
Feb	1,656	-
Mac	1,656	-
April	-	62.1
May	-	62.1
June	-	62.1

b) UKM R&D

The approximate consumption rates are: At ¼ Load: 2.3 liters per hour

Genset only,
Total genset running hour per month: 720h

With BESS hybrid system,
Total genset running hour per week: 65.25h
Total genset running hour per month: 261h

Month	Diesel consumption (L/month) Genset only	Diesel consumption (L/month) BESS Hybrid
Feb	1,656	-
Mac	1,656	-
April	1,656	-
May	-	600.3
June	-	600.3
July	-	600.3

6.2 Carbon Emissions Reduction

A significant environmental benefit of the hybrid system is the reduction in greenhouse gas emissions. The carbon emissions saved were quantified by converting the volume of diesel fuel conserved into a corresponding mass of carbon dioxide (CO_2) emissions. Typical standard diesel emissions factor is approximately 2.68 kg CO_2 per liter of diesel.

Formula: CO_2 Saved (kg) = Diesel Saved (L) × Diesel Emissions Factor (kg CO_2/L)

Site	Diesel saved per month (L)	CO_2 saved per month (kg)
PANDANSAFARI	1,593.90	4,271.65
UKM R&D	1,055.70	2,829.28

This analysis shows that the hybrid system avoided the emission of a significant number of metric tons of CO_2 over the observation period.

6.3 Financial Savings

The most immediate and tangible benefit is the reduction in diesel fuel costs. Based on the calculated savings in diesel volume from the comparative analysis, a monetary value can be determined using local fuel prices. The rate of diesel is RM 3.72 per liter.

Site	Diesel saved per month (L)	Cost saved per month (RM)
PANDANSAFARI	1,593.90	5,929.30
UKM R&D	1,055.70	3,927.20

In addition to fuel savings, a critical component of the financial analysis is the reduction in operational and maintenance (O&M) costs. Reduced genset run time directly correlates to extended maintenance intervals, such as fewer oil changes, filter replacements, and general servicing. Furthermore, by preventing the damaging effects of low-load operation and wet stacking, the hybrid system helps to prolong the genset's overall lifespan and increase its resale value. This leads to a lower Total Cost of Ownership (TCO) over the asset's lifetime. The long-term financial viability of the hybrid system is also robust when accounting for the initial capital investment and the eventual cost of battery replacement. Although the initial investment in a BESS can be substantial, the operational savings from reduced fuel and maintenance costs typically provide a positive net present value over the system's lifetime.

7. Strategic Conclusion & Recommendations

The analysis of the BESS hybrid system definitively proves its effectiveness in reducing diesel consumption and carbon emissions. The system's intelligent energy management strategy addresses the core inefficiencies of traditional gensets by avoiding low-load operation and keeping the genset in its optimal efficiency range. This results in significant and measurable reductions in both fuel costs and environmental impact, along with a decrease in long-term operational and maintenance expenses.

Based on the findings of this case study report, the following strategic recommendations are provided to further optimize the system's performance and leverage its full potential:

- **Refinement of the Energy Management System (EMS):** The collected data provides an excellent foundation for refining the system's control logic. Further analysis of the time-series load profile and battery State of Charge (SOC) can inform adjustments to the genset's start/stop thresholds and charging parameters to maximize efficiency. This continuous refinement transforms a static system into an adaptive one, constantly improving its performance over time.
- **Assessment of System Sizing and Scalability:** The site's energy demand patterns should be regularly reviewed. A detailed understanding of peak and low loads can inform decisions on the optimal sizing of both the genset and the battery for future needs. For larger installations or remote sites with long-distance power distribution, it may be beneficial to explore the use of high-tension genset, which can significantly reduce energy loss and cable costs when transmitting power over distance.
- **Implementation of Continuous Monitoring:** To maintain peak performance and identify potential issues before they become critical, the implementation of a real-time remote monitoring system is highly recommended. Platforms such as Cummins Power Command Cloud or DEIF Insight provide customizable dashboards, event-based logging, and real-time alerts, which enable proactive maintenance and remote optimization.
- **Strategic Positioning and Futureproofing:** The proven emissions reductions should be leveraged in the company's sustainability reporting. By quantifying the environmental impact now, the organization is prepared to participate in Malaysia's emerging carbon market, should it choose to, and to meet potential future regulatory requirements. This positions the project not just as a financial success but as a forward-thinking investment in the company's long-term sustainability and market leadership.