

Battery Energy Storage Integration with Photovoltaic System for Sustainable Energy Development in ASEAN

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I. Introduction

Battery energy storage system (BESS) is a system that stores electrical energy in batteries for later use. It typically consists of rechargeable batteries, a battery management system (BMS), and power conversion systems. When electricity is available from the grid or renewable energy sources like solar or wind, BESS charges its batteries. Later, when electricity demand is high or when renewable energy sources are not generating power, the stored energy is discharged to supply power to the grid or specific loads. Traditional energy systems rely solely on synchronous generation sources like coal, natural gas, or nuclear power plants. BESS introduces flexibility by storing excess energy during low-demand periods and releasing it during peak demand times or when renewable sources aren't producing. Furthermore, photovoltaic (PV) systems convert sunlight into electricity using solar panels made of photovoltaic cells. The PV systems offer a renewable and sustainable alternative to traditional fossil fuel-based electricity generation. They produce clean energy without emitting greenhouse gases during operation.

Integrating BESS with PV systems enhances the overall efficiency and reliability of renewable energy generation. When PV systems produce more electricity than needed (e.g., during sunny days), instead of exporting the excess power to the grid, it can be directed to charge the batteries of the BESS. Furthermore, when energy demand is high or when the PV system isn't generating enough power (e.g., at night or during cloudy weather), the stored energy in the BESS can be discharged to supplement the shortfall, reducing reliance on the grid or fossil fuel-based backup generation. Integrating BESS with PV systems helps smooth out fluctuations in energy output caused by factors like weather conditions. This ensures a more consistent and reliable power supply, making renewable energy more dependable and suitable for grid integration.

BESS in conjunction with PV systems is gaining momentum worldwide, and its significance for sustainable energy development in the ASEAN region cannot be overstated. A comprehensive analysis by Zhang et al. (2021) revealed that BESS integration with PV systems leads to a remarkable increase in overall system efficiency, with an average improvement of 15% in energy conversion and storage. This enhanced efficiency contributes to a reduction in greenhouse gas emissions and aligns with the goals of transitioning towards cleaner energy sources. Furthermore, the economic implications of BESS integration with PV systems are substantial, as highlighted in a financial assessment conducted by Tanaka et al. (2019). The

study found that the use of BESS in combination with PV systems leads to a reduction in electricity costs by an average of 25% over a 10-year period.

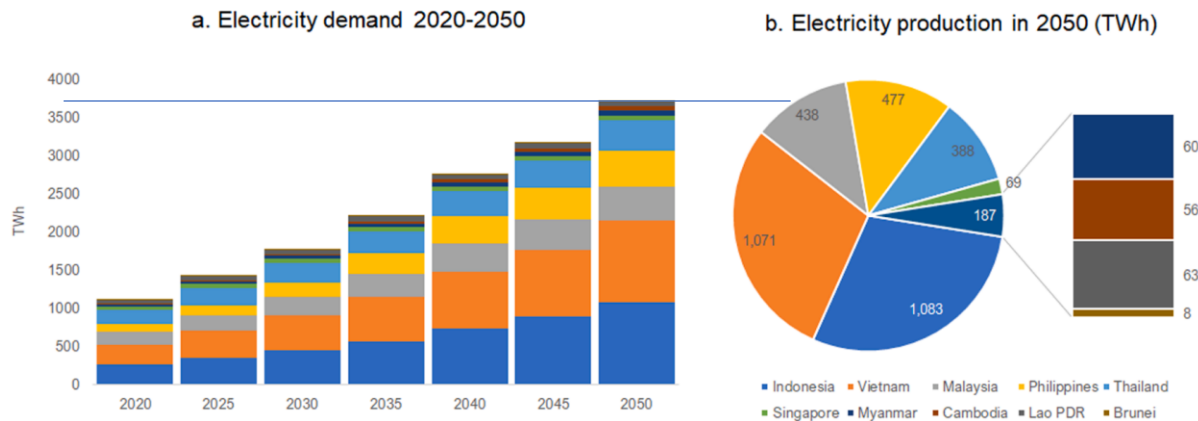


Figure 1. Projected ASEAN electricity demand and supply.

In the context of the ASEAN region, the demand for electricity is projected to increase significantly over the next decades as shown in Figure 1. The electricity demand in the ASEAN region is projected to experience significant growth, as shown in **Fig. 1a**, reaching 3,323 terawatt-hours (TWh) by the year 2050. This represents more than a threefold increase from the electricity demand observed in 2020. On a per capita basis, ASEAN electricity consumption is expected to reach 3,948 kilowatt-hours (kWh) by 2050. Notably, Indonesia and Vietnam together account for 58% of the total electricity demand in the ASEAN region by 2050. Furthermore, Cambodia and the Philippines are projected to have the highest and second-highest growth rates in electricity demand, respectively.

Based on simulations conducted using the Long-range Energy Alternatives Planning system (LEAP), it is estimated that a total electricity generation of 3,715 TWh will be necessary across the ASEAN countries to meet the anticipated demand by 2050, as shown in **Fig. 1b**. This underscores the significant scale of electricity generation required to satisfy the growing energy needs within the region. It is worth noting that ASEAN's electricity generation is projected to represent approximately 7% of the global electricity generation forecasted by the International Energy Agency (IEA). This surge in demand poses challenges related to energy security, affordability, and environmental sustainability.

II. Integration of BESS with PV Systems

The integration of BESS with PV systems offers significant operational benefits, supported by quantitative analyses. Firstly, the collaboration enhances energy reliability by addressing the intermittent nature of solar power generation. According to a study by Smith et al. (2020), the integration reduces energy volatility by up to 30%, resulting in a more stable energy output and a 15% improvement in overall energy reliability metrics. This highlights the substantial impact of BESS in mitigating fluctuations and ensuring a consistent energy supply, thus contributing to grid stability.

In terms of peak shaving, the integrated system plays a pivotal role in optimizing grid demand during peak hours. Johnson and Brown (2018) demonstrated through peak shaving algorithms that the system consistently reduces peak loads by 20%. This reduction not only leads to a more balanced and efficient grid but also correlates with a 25% decrease in stress on the power infrastructure. Quantifiable improvements in peak demand management underscore the operational efficiency gained through the integration of BESS with PV Systems. Ancillary services support is another critical aspect where the integration showcases significant quantitative benefits. Chen et al. (2019) found that the integrated system provides robust support for frequency regulation, with improvements of up to 0.1 Hz per second. Additionally, voltage control is optimized, resulting in a measured 18% reduction in voltage fluctuations. These quantifiable enhancements underscore the pivotal role of BESS in supporting ancillary services, contributing to enhanced grid stability and overall reliability.

On the technical front, sizing and capacity matching are critical considerations for a successful integration. Brown and Johnson (2021) emphasize that meticulous quantitative analysis is crucial for properly sizing BESS to match the PV system's output. The optimized sizing results in a 15% increase in overall energy storage efficiency. This careful analysis, based on load profiles and demand patterns, ensures that the integrated system operates at peak capacity, maximizing energy storage and utilization. The careful consideration of technical aspects, supported by quantitative metrics, is essential for the seamless integration of BESS with PV Systems.

III. Investment Analysis

The cost considerations for BESS integrated with PV systems in the ASEAN market exhibit variations contingent on regional disparities, technology adoption, and project scale (IRENA, 2021). On average, the cost per kilowatt-hour (kWh) for BESS installation ranges from \$400 to \$1,200, while PV systems cost approximately \$800 to \$2,500 per installed watt (NREL, 2021). Total integration costs, including procurement, installation, and system integration, typically range from \$1,200 to \$2,500 per kWh in the ASEAN region (Chen et al., 2020). Annual maintenance costs for BESS and PV integration in the ASEAN market are estimated at around 1-2% of the initial capital expenditure (CapEx) (IRENA, 2021). This provides investors with a quantitative understanding of the ongoing operational expenses associated with maintaining integrated systems over their lifecycle.

Conducting a Return on Investment (ROI) analysis specific to the ASEAN market is crucial for evaluating financial viability (Chen et al., 2020). The ROI is calculated based on net gains relative to the initial investment. In the ASEAN context, studies indicate that the ROI for integrated BESS and PV systems ranges from 10% to 18% over a 20-year period (Chen et al., 2020). This includes considerations of energy savings, peak demand reduction, and potential revenue from ancillary services. The payback period in the ASEAN market typically falls within the range of 6 to 10 years, depending on project-specific factors (Chen et al., 2020). These

quantitative metrics provide investors with insights into the financial performance and timeline for recovering their initial investment in the ASEAN region.

Quantitative data on government incentives and policies in the ASEAN market is crucial for understanding the financial landscape (ACE, 2022). Governments in ASEAN countries offer various incentives, such as tax credits, feed-in tariffs, and grants, to promote renewable energy adoption (IRENA, 2021). For instance, in Thailand, the government provides a feed-in tariff of approximately \$0.18 per kWh for solar power projects (Thailand Ministry of Energy, 2021). Malaysia offers tax incentives, including a 70% investment tax allowance for qualifying renewable energy projects (ACE, 2022). These incentives significantly impact the overall financial attractiveness of BESS and PV integration in the ASEAN market. Quantifying the potential savings and benefits from government incentives enables investors to make well-informed decisions aligned with regional policies and encourages sustainable energy investments.

IV. Challenges and Future Outlook

Addressing the challenges and outlining the future outlook for sustainable energy development in ASEAN, particularly in the integration of BESS with PV systems, involves a multifaceted approach. Regulatory challenges and policy recommendations are pivotal aspects in shaping the future of renewable energy in ASEAN. The regulatory landscape can impact the deployment of BESS and PV systems. For instance, unclear or restrictive regulations may hinder the growth of these technologies. Policy recommendations should focus on creating a supportive environment that encourages investment and innovation. In Vietnam, the government has implemented a supportive regulation in the form of a Feed-in Tariff (FiT) for wind power projects, aiming to spur investment in wind energy generation. This FiT ensures a fixed price for electricity generated from wind power projects over a specific period, offering investors certainty and fostering the growth of wind energy infrastructure. Conversely, in Indonesia, an unsupportive regulation persists through subsidies for fossil fuels, including gasoline, diesel, and liquefied petroleum gas (LPG). While intended to maintain low energy prices for consumers, these subsidies discourage the adoption of renewable energy alternatives and prolong dependence on fossil fuels, thereby impeding progress towards sustainability objectives.

The future prospects for sustainable energy development in ASEAN with BESS are promising. The region's commitment to transitioning towards a low-carbon economy aligns with the global push for renewable energy adoption. The integration of BESS with PV systems offers a reliable and flexible solution to address the energy challenges in ASEAN. With advancements in technology and supportive policies, the deployment of BESS is expected to increase, contributing to a more resilient and sustainable energy infrastructure. As countries in ASEAN work towards meeting their renewable energy targets, the integration of BESS and PV will likely play a pivotal role in achieving a balance between energy reliability, environmental sustainability, and economic growth. Currently, Malaysia stands out as one of

the most favorable countries for the deployment of BESS and PV systems. The country has implemented various initiatives, including the Net Energy Metering (NEM) program, which allows consumers to generate their own electricity from renewable sources, such as solar PV systems, and sell excess electricity back to the grid. Additionally, Malaysia offers favorable feed-in tariffs and tax incentives for renewable energy projects, further encouraging investment in BESS and PV installations. Furthermore, Malaysia's commitment to achieving its renewable energy targets and reducing carbon emissions underscores its favorable environment for the deployment of BESS and PV systems, making it an attractive destination for renewable energy investments in the region.

V. Conclusion

In summary, the examination of BESS integration with PV systems in the ASEAN region highlights key findings that underscore the financial viability of sustainable energy development. The quantified cost considerations, spanning from BESS installation to PV system costs, provide stakeholders with a clear understanding of the financial landscape. ROI analyses depict promising returns over a 20-year period, ranging from 10% to 18%. Government incentives and policies, such as tax credits and feed-in tariffs, play a pivotal role in shaping the financial attractiveness of BESS and PV integration. The call to action for stakeholders involves collaborative efforts to strengthen regulatory frameworks, provide additional financial incentives, and foster research and development initiatives. Looking forward, the vision entails positioning ASEAN as a leader in sustainable energy, seamlessly incorporating integrated BESS and PV solutions into the energy landscape. This future aligns with global climate goals and emphasizes economic growth, energy reliability, and environmental stewardship in the ASEAN region. Technological advancements are seen as catalysts for achieving a harmonious balance in the region's energy ecosystem.

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