510 kWh off-grid energy storage

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This study limits its scope to developing economies that rely heavily on off-grid renewable energy systems to improve access to electricity. Batteries considered are the lead-acid and the lithium technologies. These technologies are matured and have been successful ones in the industry for many years. The study does not cover battery technologies for mobile devices, automotive and electric vehicle applications.

The review type adopted in this study was mixed studies review which combined both literature review and mixed studies [4]. Relevant articles were downloaded from Scopus database and google scholar database. A total of 200 peer-reviewed articles were downloaded. Thereafter, 70 were discarded and 130 were used for the study. Among the articles used were book chapters, conference proceedings, as well as research articles.

While renewable energy sources offer a clean and sustainable solution to the global energy crisis, their inherent variability and intermittency pose challenges to their harvesting and utilization. They are prone to variability in energy production due to the time of day, weather conditions [5], and the effects of climate change. For example, a solar power plant produces energy that is closely correlated with the presence of sunshine during the day. Variations in the sun"s position, cloud cover, and seasonal weather cause fluctuations in solar energy output. The same variations in output are also true for wind turbines concerning the availability of wind resources.

To ensure steady and reliable energy supply to load centers, grid operators must manage the challenges posed by fluctuation and intermittency. Mismatches between energy supply and demand may result in abrupt declines or spikes in the output, which might potentially cause blackouts or grid instability. When renewables are integrated into the grid, variability and intermittency create instability, making energy storage a desired solution [6]. In the case of off-grid systems, energy storage systems are deployed to store excess energy when production is at its peak for use when generation is low or not available [7]. They mitigate the erratic nature of renewable energy generation, thereby enabling the efficient and effective utilization of energy produced at peak periods or seasons.

It is indisputable that energy storage is crucial for reducing the unpredictability and intermittent nature of renewable sources. Energy storage technologies not only solve the problem of intermittency but also support the deployment of renewable energy at scale, in line with global efforts aimed at carbon footprint reduction and combating climate change [11]. As theworld moves closer to a low-carbon energy future, energy independence and improved grid dependability, the global transition to a resilient and sustainable energy landscape can be facilitated, in part, by the integration of storage solutions into renewable energy systems.

Lead-acid batteries are one of the oldest and most widely used rechargeable battery technologies [14]. They are renowned for their high reliability and cost-effectiveness. The chemistry of lead-acid batteries involves reversible electrochemical reactions that occur within cells. During discharge, chemical energy converts to electrical energy, and during charging, the reverse occurs. This chemistry involves reversible reactions between lead oxide (PbO2), lead (Pb), and sulfuric acid (H2SO4) in an aqueous electrolyte [15,16,17,18,19], illustrated in Fig. 1.

Lead-acid battery chemistry [19]

The cathode, positive plate, is made of lead oxide while the anode, negative plate, is made of sponge lead material. Chemical reactions take place at the two electrodes during discharge and charge cycles as shown in Eqs. 1-6.:

Discharge reactionat the (lead oxide) Cathode.

Lead oxide(PbO2), goes through reduction reaction:

Discharge reaction at the (lead) Anode.

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