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King Abdullah Petroleum Studies and Research Center

Commentary

The Impact of High Temperatures on Battery Performance in Solar-PV Systems With Storage

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Introduction

The World Bank estimates that nearly 1 billion people globally have no grid electricity access. Diesel generators are the default source of energy for locations lacking access to the grid. The falling costs of solar photovoltaic (PV) generation and battery storage systems will enable fully renewable, reliable, and economic off-grid generation. Off-grid systems do not need expensive transmission lines, their users are less vulnerable to fluctuating diesel prices, and they are less polluting and quieter than traditional means of off-grid generation.

The power output of solar PV panels depends mainly on their efficiency, angle of installation, and ambient temperature. Analyzing the annual degradation rate of solar panels gives a more accurate estimate of their output over a project's lifetime. However, these factors have little effect on the lifetime of solar panels. Their lifetime does not depend on how much power they generate, and it is customary to get warranties of 25 years from solar PV manufacturers.

However, the situation regarding battery lifetimes is starkly different. The temperature in which batteries operate and their (dis)charging patterns are factors that affect battery lifetimes significantly. Both factors can reduce the lifetime of batteries by more than half.

The state of charge and temperature

One of the most important factors that affects the lifetime of a battery is the 'state of charge' (SOC). The SOC is the level of charge a battery has relative to its capacity. If a battery only has 20% of its energy capacity left, it has a 20% SOC. To optimize battery lifetimes, manufacturers generally recommend that their SOCs do not fall below 50%.

Ensuring that batteries installed to store energy generated from solar panels do not drain below a 50% SOC level requires a large battery bank (and hence increased costs). On the other hand, if the batteries are allowed to discharge to lower SOC values, a lower number of batteries are required in the bank to store energy. However, allowing batteries to reach low SOC levels results in faster wear and tear of the battery terminals, which shortens the batteries' lives. Shorter battery lives have financial implications as the batteries will need to be replaced more frequently. As such, there is an economic trade-off between stipulating a minimum SOC and the size of the battery bank that would be required to meet this constraint. Most manufacturers recommend against letting SOC levels drop below 10% as this can cause permanent damage to the battery terminals.

The temperature in which the batteries function is a key factor that significantly affects the performance and lifetime of batteries, and hence the economics of solar storage systems. At high temperatures (around 40 degrees Celsius), battery capacities can increase by 20%. Countering this capacity increase, their maximum capacities degrade with each cycle. Due to the complexity of temperature effects, they are mostly ignored when designing solar storage systems.

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Quantifying the financial implications of operating batteries in hot climates

KASPARC developed a detailed model that takes into account the effect of temperature on battery performance. This showed an increase in the net present cost of diurnal (daytime) loads of at least 73%. Furthermore, the net present cost at least doubles when accounting for temperature effects for mostly nocturnal loads.

Most of the literature on solar-storage systems recommends that solar-storage systems should be designed while ensuring that the SOC does not fall below 50%. The KAPSARC study finds that specifying a lower minimum SOC (i.e., 20% to 30%) in hot climates can still satisfy the reliability constraints while achieving a lower net present cost. The cost decreases because the battery capacities increase at higher temperatures, i.e., more energy is stored to meet the load. The additional available energy means fewer batteries are required in the bank, which reduces costs significantly. In other words, it is more cost effective (from a net present value perspective) to allow the battery bank to discharge to lower-than-typical SOC levels and replace a smaller number of batteries more often, compared with a case where we limit the SOC to a higher value and replace a larger number of batteries less often.

Representing battery performance more realistically by incorporating temperature effects shows an increase in the net present cost of at least 73% when loads are mainly diurnal.

Key takeaways

- The minimum allowed SOC, and the temperature in which batteries operate significantly affect their lifetimes and performance levels.
- Most manufacturers advise against batteries reaching an SOC below 50%, to prevent damaging their terminals and shortening their lifetimes. Our study finds that specifying a lower SOC (i.e., 20% to 30%) in hot climates can still satisfy the reliability considerations while achieving a lower net present cost.
- Representing battery performances more realistically by incorporating temperature effects increases their net present cost by at least 73% when the load is mainly diurnal and by 100% when the load is mainly nocturnal.

For more information, please refer to Elshurafa, Amro M., and Mohammad H. Aldubyan. 2019. “State-of-Charge Effects on Standalone Solar-Storage Systems in Hot Climates: A Case Study in Saudi Arabia.” *Sustainability* 11(12): 3471.

About KAPSARC

The King Abdullah Petroleum Studies and Research Center (KAPSARC) is a non-profit global institution dedicated to independent research into energy economics, policy, technology and the environment, across all types of energy. KAPSARC's mandate is to advance the understanding of energy challenges and opportunities facing the world today and tomorrow, through unbiased, independent, and high-caliber research for the benefit of society. KAPSARC is located in Riyadh, Saudi Arabia.

About the commentary

This commentary series is part of KAPSARC's continuing effort to disseminate its work on Electricity Market Analysis within the Energy Transitions and Electric Power research group.

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