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Evaluating Energy Storage System Efficiency

UNDERSTANDING EFFICIENCY & ITS FINANCIAL IMPACT

Efficiency is the yardstick by which we measure how effectively an energy storage system converts input energy into useful “work” or output. This concept is akin to evaluating the gas mileage of a car – it tells us how far we can go on a gallon of fuel. However, in the complex world of energy storage, efficiency is not a fixed value; it's a dynamic metric influenced by various factors.

Efficiency serves as a comparative tool, allowing us to rank power and energy conversion systems based on their ability to conserve resources and save money. It can be used to evaluate a wide range of systems, from power plants that turn fuel into electricity to battery chargers that deliver direct current (dc) power to a battery.

Grid-scale energy storage systems, in particular, are intricate collections of subsystems, each playing a role in converting power or energy from one form to another through a multi-stage process. Assessing the efficiency of such overall systems involves a comprehensive understanding of these processes and the impact of operating conditions on each one.

A battery-based energy storage system involves an alternating current to direct current (ac/dc) power conversion, an ac/ac transformer, auxiliary power systems, controls, wiring, disconnects, fuses, circuit-breakers, a battery and temperature management systems. Energy flows from the source, undergoes multiple conversions and gets stored as chemical energy in the battery. During this process, some power is utilized to maintain optimal operating temperatures for the battery and conversion equipment.

Round-Trip Efficiency

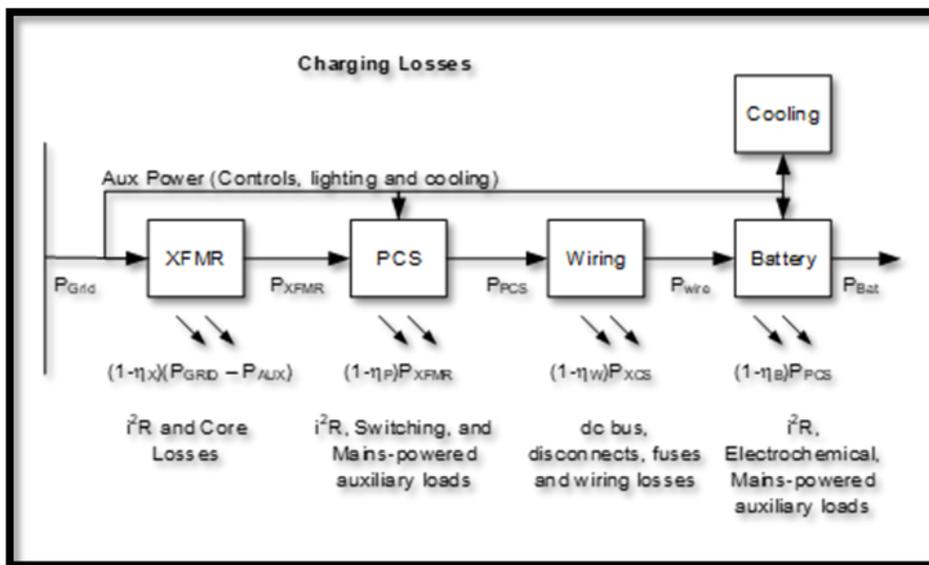
Round-trip efficiency (RTE) quantifies the energy discharged at the system's terminals in relation to the energy used to charge it at a specified rate. This calculation assumes that the battery begins and ends the cycle at the same state. Charging energy encompasses all the power required to maintain the system during the charge, including heating, cooling and controls. In contrast, discharged energy

needs to discount temperature management and control power during the discharge cycle.

System-specific nuances and the complexities of conversion pathways make efficiency calculations intricate. Nonetheless, there is a method to generalize total system efficiency by considering individual subsystem efficiencies and relative auxiliary power loads.

Power Flow

The power flow diagram below illustrates energy losses within a typical energy storage system during a charge half-cycle.



In this diagram, auxiliary power is sourced directly from the grid. Although it's possible to derive auxiliary power from other sources, when assessing the system as a whole, we can combine auxiliary power and grid power into one input power for the system. Thus, the energy going into the battery equals the grid power minus auxiliary power, adjusted by one-way efficiencies between the input and battery, and the charging time.

Battery Cell Efficiency

When we force current into a battery cell, most of the energy gets stored chemically, but some is lost as heat. Lithium-ion cells are quite efficient, with round-trip efficiencies ranging from 90% to 98%, depending on their design.

LFP cells, a variant of lithium-ion batteries, exhibit additional losses due to hysteresis between charge and discharge voltage curves. Even at low rates, these losses can amount to about 1.5%, resulting in round-trip efficiencies of approximately 95% to 96.5% for LFP cells designed for one- to four-hour cycles.

Wiring Efficiency

Efficiency in wiring is critical because it impacts energy losses. Typically, we aim to limit conductive wiring losses in a system to less than 1%, as losses generate heat, which needs to be managed.

PCS Efficiency

Power conversion systems (PCS) play a vital role in energy conversion. Modern PCS are highly efficient, with one-way efficiencies of around 98.5%. Next-generation PCS using silicon-carbide components can achieve even higher efficiencies, some exceeding 99.3%.

Transformer Efficiency

Transformers, too, contribute to energy losses. Large transformers conform to efficiency regulations and can achieve one-way power efficiencies greater than 99.2%. High-voltage transformers often exceed 99.7% efficiency.

Temperature Management and Auxiliary Power Losses

These losses are a catch-all category, including power needed for controlling battery and equipment temperatures. Cooling systems, for instance, are critical for preventing overheating but can also add to auxiliary power consumption, typically ranging from 5 to 10 kW for a 4 MWh battery.

The Effects of Cycle Profile on Efficiency

Efficiency is not static; it can vary depending on how often the battery is cycled and the site's conditions. Idle times between cycles can introduce auxiliary loads, affecting the effective round-trip efficiency. To calculate this, we consider factors such as average auxiliary power during a charge cycle, average power during idle periods and the ratio of idle time to discharge time.