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Power Engineering & Energy Solutions

Case Study:

Key Considerations in Choosing Between AC-and DC-Coupling Solar and Battery Energy Storage Solutions

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Executive Summary

The decision between DC-coupled and AC-coupled storage offers distinct advantages and considerations for hybrid projects involving Battery Energy Storage Systems (BESS), such as Solar/BESS, Wind/BESS, or other hybrid combinations. DC-coupled storage typically provides higher energy production rates, while both configurations support grid services and scalable capacity. AC-coupled storage, however, allows for independent operation of the photovoltaic (PV) system and the battery, enabling increased capacity with minimal system modifications.

Choosing between AC and DC coupling is not straightforward and depends on specific project goals and future plans. For projects that require grid charging capabilities—whether standalone BESS or hybrid systems—AC-coupled storage is often the preferred option. Conversely, if maximizing energy production is the primary objective, DC-coupled storage tends to be the better choice.

Ultimately, each project must be evaluated individually, taking into account factors such as land availability, utility regulations, market conditions, and reliability needs to make an informed decision between AC and DC-coupled storage solutions.

Introduction

As the integration of renewable energy sources increases, the need for efficient and reliable energy storage has become crucial. Battery Energy Storage Systems (BESS) play a vital role in stabilizing energy grids, particularly by storing energy for use during peak demand periods. When considering (a) Standalone BESS, (b) Hybrid projects where the BESS is not allowed to charge from the grid and the BESS exclusively charges from the onsite generating facility, and (c) Hybrid projects where the BESS is allowed to charge from the grid as well as from the onsite generating facility, one of the key decisions is between alternating current (AC) and direct current (DC) coupling between the battery and the PV system. This case paper explores the differences between AC and DC design solutions, focusing on cost, efficiency, applications, and flexibility, and providing a comparative analysis to help stakeholders make informed decisions.

Overview of AC & DC Coupling

AC Coupling: AC battery storage systems use an inverter to convert the stored DC energy from the batteries into AC for grid use. This setup allows for modular installations, making it possible to add or remove batteries or inverters independently. AC systems are often integrated after the point of common coupling, enabling direct interconnection with the AC grid.

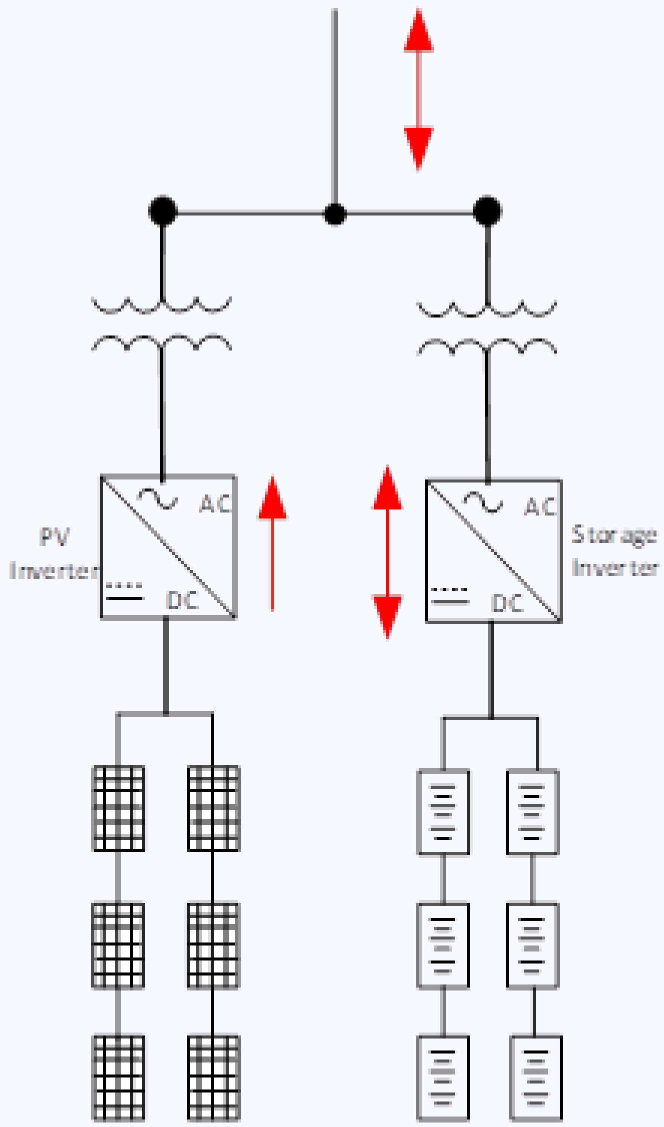

Figure 1: AC Coupled Design

AC Path:

- BESS charging from solar PV:

  PV Array → PV Inverter → AC Grid/Load → Battery Inverter → Battery Bank

- Battery discharging stored energy to grid:

  Battery Bank → Battery Inverter → AC Grid/Load

DC Coupling: DC coupling systems store and discharge DC power directly between the PV system and the battery. This approach typically integrates DC-coupled batteries with solar PV systems, where the energy is stored as DC and doesn't need conversion until it's fed into the grid. DC BESS is often considered for co-located renewable energy projects due to its potential for higher system efficiency. BESS is not allowed to charge from the grid in this case (more often due to a transmission restriction).

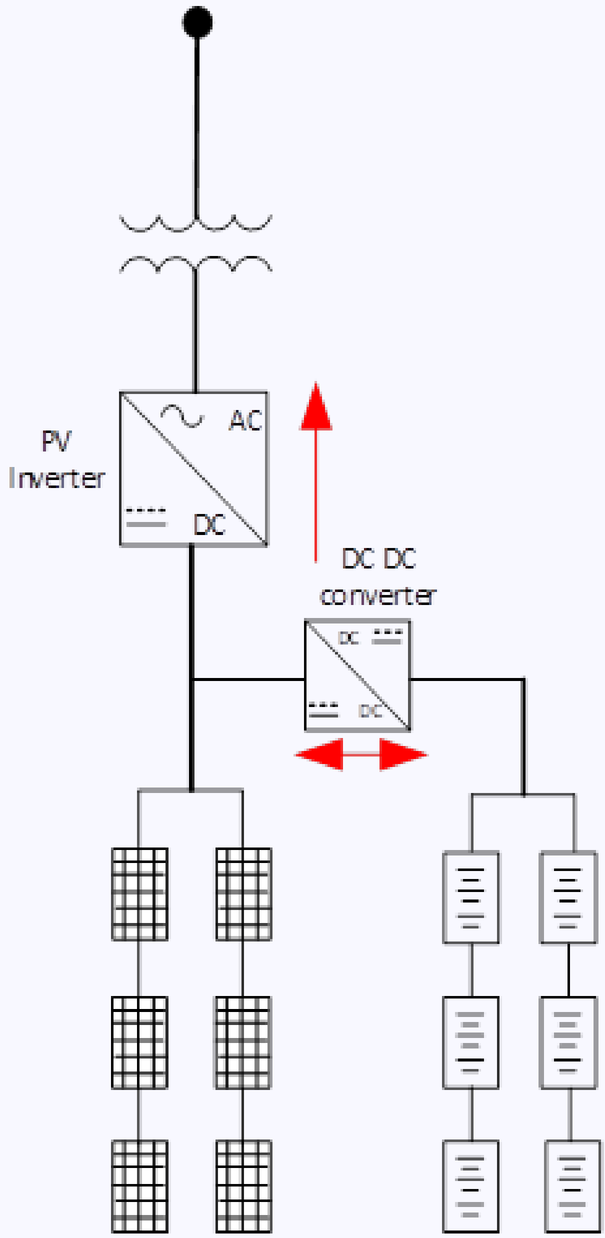

Figure 2: DC coupled Design

DC Path:

- BESS charging from solar PV:

  PV Array ⟶ Charge Controller ⟶ Battery Bank

- BESS discharge/Charge:

  Battery ⟶ Converter ⟶ PV Inverter ↔ AC Grid/Load

Key Considerations in AC vs. DC BESS

Efficiency and Energy Conversion

AC BESS: AC systems require double conversion—once from DC (battery) to AC (grid) and vice versa, which results in energy losses. Conversion losses generally range from 2–5% per cycle, reducing the overall efficiency, especially in applications requiring frequent charge and discharge cycles.

DC BESS: DC-coupled systems, especially when paired with PV, eliminate the need for an initial DC-to-AC conversion, minimizing energy loss. By reducing conversions, DC BESS can achieve slightly higher overall efficiency in PV-integrated applications where the BESS does not typically charge from the grid.

AC or DC Coupled System	Number of Devices to Cross When Charging From PV	Charging From PV Losses	Number of Devices to Cross When Charging From Grid	Charging From Grid Losses
DC	4	8%	6	12%
AC	6	12%	4	8%

Cost Implications

AC BESS: AC BESS is typically modular, making it easier to scale and to integrate into existing infrastructure, though each inverter requires investment, adding to installation costs. When installed independently of renewable generation, AC systems may also involve fewer modifications to existing grid infrastructure, which can lead to cost savings in retrofitting.

DC BESS: DC BESS may have higher upfront costs due to the need for specialized DC infrastructure, such as DC-to-DC converters, which are less common and may require custom configurations. However, in PV-BESS setups, DC systems reduce the number of inverters needed, which can lower costs over time, especially as the scale of energy storage increases.

System Flexibility and Scalability

AC BESS: With modularity and the ability to add batteries or inverters independently, AC systems provide high flexibility, allowing for phased installations and easier upgrades. They're also often compatible with a variety of energy sources and grid configurations, making them well-suited for general-purpose energy storage applications.

DC BESS: DC systems are particularly advantageous in scenarios where they are tightly integrated with DC generation sources, like solar PV farms. However, they're generally less modular than AC systems, and expansions can require significant reconfiguration. This makes DC BESS best suited for projects with a well-defined, upfront energy storage need.

Applications and Use Cases

AC BESS: These systems are often preferred in standalone storage applications and where interoperability with multiple power sources is important, such as commercial and industrial backup power or grid frequency regulation. AC BESS can also be used in various microgrid setups where flexibility in power source connections is critical.

DC BESS: DC systems are most beneficial in co-located PV-plus-storage installations, where they capitalize on the direct coupling of solar energy and storage, reducing conversion losses. DC BESS is advantageous for applications focused on maximizing energy efficiency and for installations with frequent PV cycling, such as peak shaving and renewable load shifting.

Case Findings

In this study, two comparable installations—a 10 MW AC-coupled BESS and a 10 MW DC-coupled BESS integrated with a solar farm—were analyzed over a 5-year period. The DC system demonstrated higher round-trip efficiency by 3%, primarily due to the reduced need for AC conversion. However, the AC system showed greater adaptability to incremental additions and required less specialized maintenance, which contributed to slightly lower long-term operating expenses.

CONCLUSION

Both AC and DC BESS have distinct advantages depending on the specific application, cost constraints, and operational needs. AC systems offer modularity and broad compatibility, making them ideal for standalone storage or sites with mixed energy sources. DC systems, on the other hand, provide higher efficiency in PV-integrated setups and minimize conversion losses, thus making them suitable for co-located renewable installations where efficiency is prioritized over modular scalability.

Ultimately, the choice between AC and DC BESS should align with the project's energy profile, desired flexibility, and cost considerations. As renewable energy and storage technologies continue to evolve, so too will the configurations, bringing new opportunities for optimizing both AC and DC storage solutions.