Battery Energy Storage Systems: Topology Selection Depends On Application Needs

by Kane Jia, onsemi, Shanghai, China

Batteries can be used to store the energy produced from renewable sources like solar and wind at peak times, allowing them to be drawn upon when environmental conditions are less favorable for energy production. This article reviews power conversion topologies for residential and commercial battery energy storage systems (BESSs) with details on the different topology options for different systems and the design tradeoffs among those topologies.

This article begins with an overview of the benefits provided by BESSs, and describes their key building blocks. The role of power conversion in these systems is then discussed, first with regard to residential systems and then for commercial systems. The two approaches to energy storage in these systems—ac-coupled and dc-coupled—are explained, and the different power supply topologies used in these systems are discussed.

BESS Advantages

The four most commonly used energy storage methods are electrochemical, chemical, thermal, and mechanical. Lithium-ion batteries, the most recognizable electrochemical storage system, exhibit high power density and efficiency, compact form factors, and modularity. In addition, Li-ion is a mature battery technology making it reliable and low-cost. The continuously falling price of Li-ion batteries contributes to their growing use in energy storage systems.[1]

Using on- or off-grid solar inverter systems together with battery storage offers many benefits for residential and commercial users. First, there is pricing. Storing energy reduces electricity costs when the price of electricity from utility providers is higher. Second is self-sufficiency as storing energy reduces (or eliminates) dependence on the grid. Finally, stored electricity offers an alternative in case of a mains power failure, providing a backup power source.

BESS Main Building Blocks

A BESS typically includes four main building blocks:

- Rechargeable battery module: This comprises rack-mounted battery cells with a nominal voltage ranging from 50 V to over 1000 V.
- Battery management system (BMS): The BMS protects and manages rechargeable batteries, ensuring they operate inside safe operating parameters.
- Power conversion system (PCS): The PCS connects the battery pack to the grid and load and is a significant factor in a BESS's cost, size, and overall performance.
- Energy management system (EMS): This software monitors, controls and optimizes the generation or transmission system.

The first three blocks are pictured in Fig. 1.

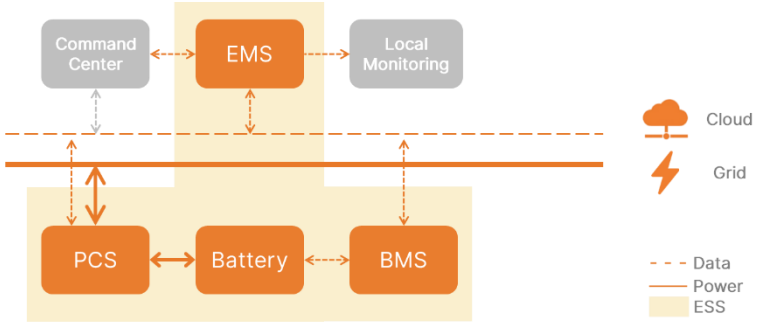


Fig. 1. Overview of a BESS implementation.

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Residential BESS

Power conversion systems used with BESSs are categorized by how they couple energy (ac or dc) and also by power level (residential or commercial). A dc-coupled system, or hybrid inverter, requires only one power conversion step (Fig. 2).

However, while ac-coupled energy storage is an easy upgrade for existing solar or wind generating systems, it requires an additional power conversion step to charge and discharge the battery and therefore, more power can potentially be lost. For example, a residential power conversion system can be added to an existing solar inverter system to allow generated energy to be used to charge a backup battery or power home appliances.

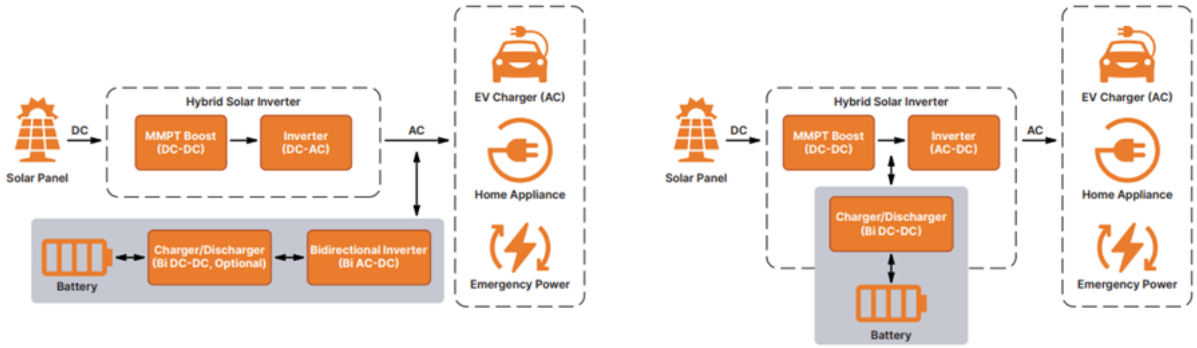


Fig. 2. Residential ac-coupled (left) and dc-coupled (right) ESS.

In a dc-coupled system, a bidirectional dc-dc converter connects a battery pack and the dc link. The bus voltage of a single-phase system is usually less than 600 V while charging and discharging power does not exceed 10 kW. Here, a buck-boost converter is the most common bidirectional dc-dc topology because it requires fewer components and is easy to control.

Two 650-V IGBTs or MOSFETs with parallel diodes are adequate in a bidirectional system of this type. For example, onsemi's FGH4L75T65MQDC50 650-V FS4 IGBT with integrated SiC diode offers low conduction and switching losses in this application. A wide-bandgap (WBG) switch is an alternative option to enhance power density and thermal management (Fig. 3).

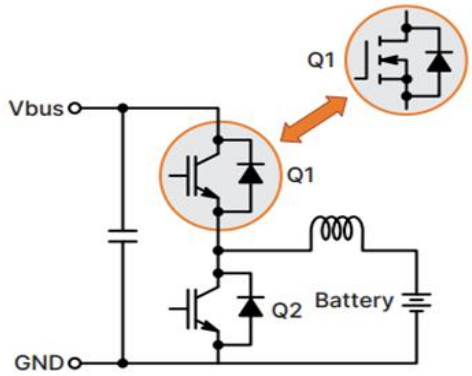


Fig. 3. Buck-boost for bidirectional dc-dc.

Isolation can ensure the safety of BESS users, and the dual active bridge (DAB) converter and CLLC topologies offer isolated bidirectional dc-dc converter solutions for BESSs. A cascaded front-end buck-boost circuit can deliver a broader range of input and output voltages in the event of a significant variation in the battery voltage. This approach also lowers the amount of reactive power and increases the size of the soft-switching zone.

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Three-phase is the standard power source in commercial and business premises and homes with higher power demands. Power switches in three-phase applications must withstand operating voltage and currents capable of delivering up to 15 kW and a higher dc-link voltage than residential installations (up to 1000 V).

This can be implemented by replacing the 650-V switches considered previously with 1200-V devices, potentially as part of a three-level symmetric buck-boost topology. This offers lower switching losses as only half of the output voltage appears at the switches and diodes. This also has the advantage of requiring smaller inductors and exhibits improved EMI performance. Unfortunately, this approach requires more components, increasing design complexity, control and system cost.

Commercial BESS

A commercial energy storage system's input and output power range is typically between 100 kW and 2 MW. These large installations may consist of several three-phase subsystems ranging from dozens of kilowatts to over 100 kW. Here, the maximum dc voltage, which depends on the bus voltage of the existing solar system or battery voltage, is a critical specification.

The dc bus voltage of standard commercial solar inverters is typically 1100 V but can be up to 1500 V in a utility-scale system. For a given power level, increasing the dc-bus voltage reduces the current and therefore lowers the cost of the interconnection cable.

Ac-coupled systems are more commonly used in commercial BESSs because they can be easily added to an existing design. Meanwhile dc-coupled systems have relatively high requirements on electrical retrofit especially for commercial cases because they have to be connected to a dc bus, which is usually inside the original system and has high voltage and current.

The three-level I-NPC is a topology commonly used with inverters in high-power industrial applications. This has four switches, four inverse diodes, and two clamping diodes per phase with a breakdown voltage lower than the actual dc-link voltage meaning 650-V switches are sufficient in an 1100-V system (Fig. 4). To make the system capable of delivering power in both directions, the inverse diodes need to withstand higher current. In practice, multiple diodes are generally used in parallel to increase the current capability, and designers must pay close attention to the heat dissipation of the diodes to ensure they stay within their operating limits.

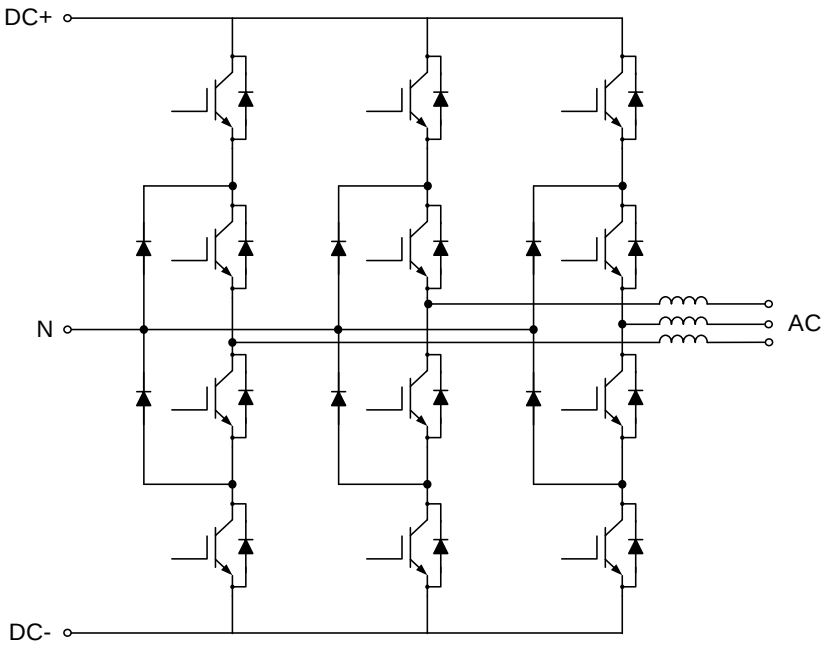


Fig. 4. Three-phase I-NPC topology.

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In general, power converters, and in particular their topologies, are optimized for one use case and one direction of the power flow through the selection and relative sizing of the switches and diodes. Even dc-ac topologies designed to be bidirectional will perform better in one direction than in the other. So, it is important to bear in mind what will be the most common use case.[2]

There are several advantages to using three-level topologies. First, they have lower switching losses (proportional to the square of the voltage applied to switches and diodes). Secondly, they exhibit lower current ripple and, the peak-to-peak voltage is half the total output, making it easier to filter using a smaller, lower-cost inductor. Finally, conducted EMI, linked to the current ripple, is reduced, as are radiated emissions.[2]

Upgrading to an A-NPC topology offers even better performance because it replaces two clamping diodes with two lower-loss active switches (Fig. 5). What's more, these two switches provide flexibility in that they expand the number of PWM strategies that may be used, which can solve the loss-balancing issue of I-NPC[3] in a high-power system. Nevertheless, for this arrangement, the use of more active switches and drivers will increase the cost, as well as control complexity. Designers should choose the most appropriate topology in terms of the application requirements.

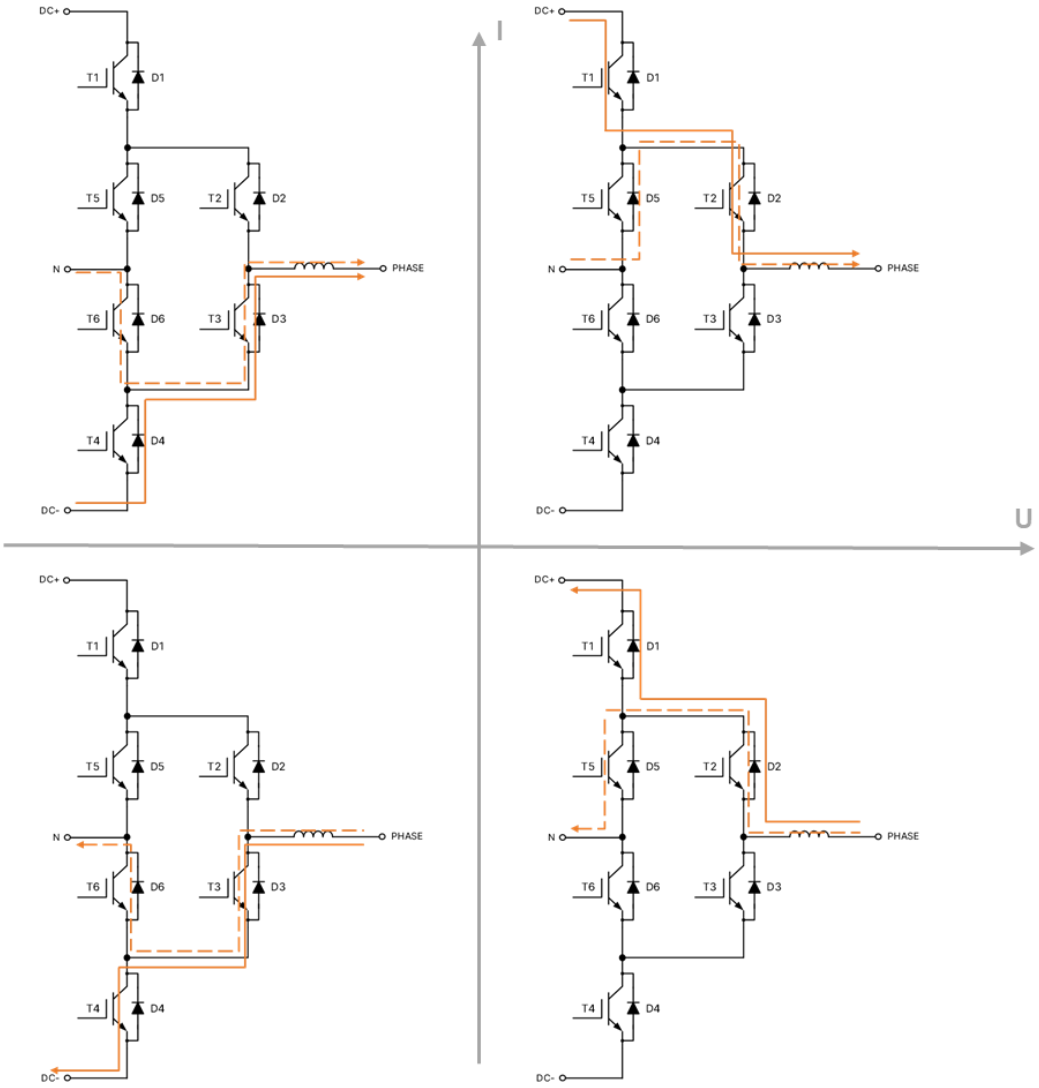


Fig. 5. An A-NPC topology operating in four quadrants.

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About The Author



Kane Jia is an application marketing engineer for the onsemi strategic technical application marketing team. In this role, Kane leads the global promotion of energy infrastructure applications like solar inverter, dc EV charger, and others.

For more on design of power converters in renewable energy applications, see How2Power's Design Guide, locate the "Application" category and select "Renewable Energy Systems".

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