Battery Storage Meets Rising Grid Demand

Battery energy storage systems address the new dynamic of home & utility grid demand from wind, solar, & other renewables

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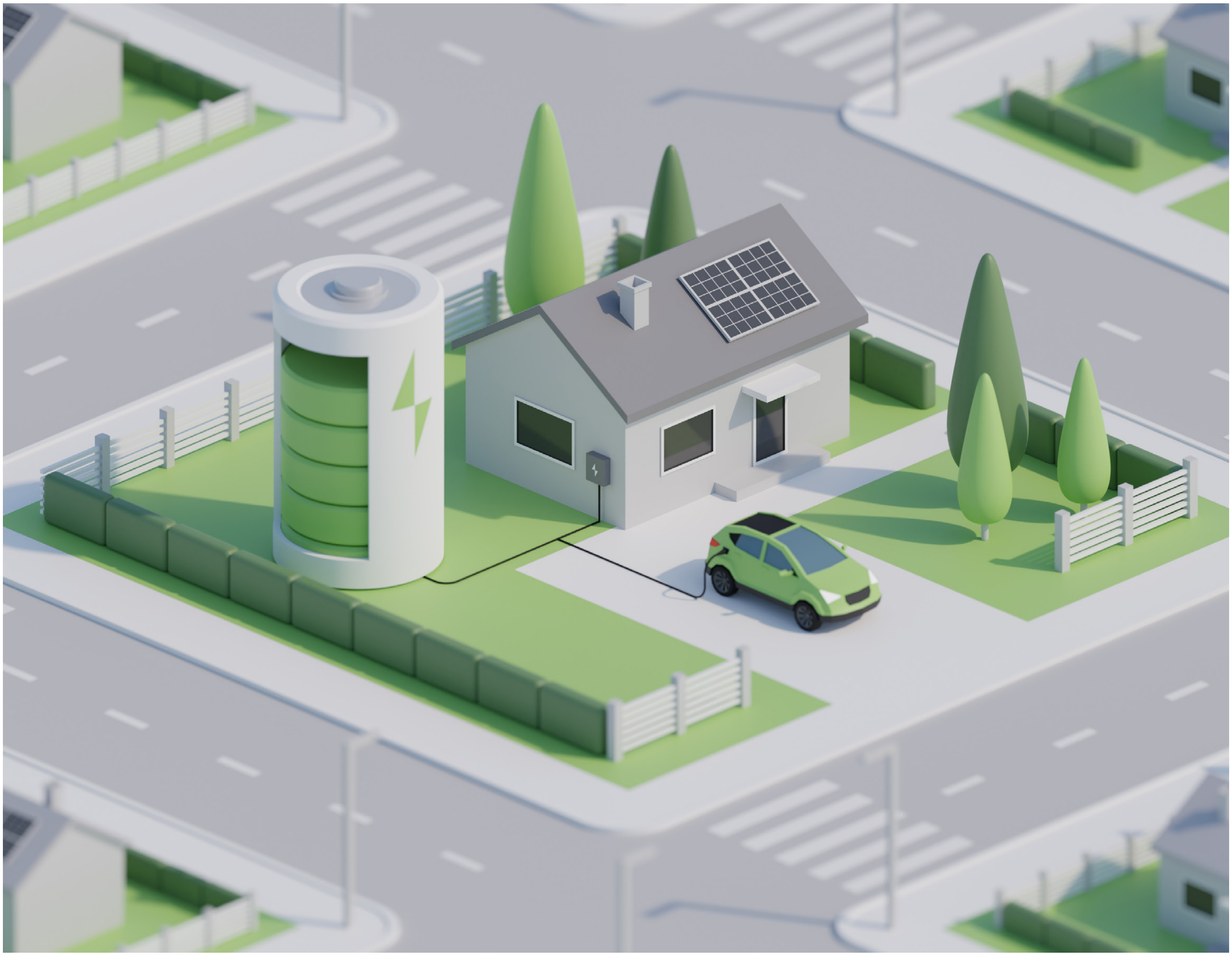

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Governments and energy consumers alike have voiced concerns about the reliability and vulnerability of electrical grids. The dramatic increase in home energy prices, especially in the United States (a price increase of 14 percent from 2022 to 2023) and Europe (2022 European electricity costs hit record highs),[2] is likely to continue as massive investment in artificial intelligence (AI), cryptocurrency, and databases rises.

In the past decade, viable renewable energy alternatives have come into maturity. Renewable energy prices, mainly solar and wind, have now reached and even exceeded parity with fossil fuel grid energy generation. [3]Now, with less centralized (i.e., distributed microgrid) energy solutions available, users and even energy distributors are realizing the full scale of the vulnerabilities of traditional electrical utility grids. Fortunately, the rise of electric vehicles (EVs) and the electrification of many technologies has led to substantial investments in battery electric energy storage technology, which is also an excellent solution for grid-scale and home energy storage. As the residential home energy market continues to grow, with Research and Markets predicting growth from US$2.78 billion in 2020 to US$13.05 billion in 2027,[4] battery electric home energy storage is becoming increasingly viable for energy consumers to reduce peak energy prices, stabilize their personal access to energy, and easily incorporate energy from home solar installations and other renewables with dynamic energy profiles. There are now even incentives provided by some governments, such as US tax credits, [5]that demonstrate the value both governments and consumers are putting into renewable energy and electrical energy storage technologies.

With the advent of lower-cost and more reliable battery electric energy storage technology, grid- and home-energy storage solution businesses are emerging and quickly growing as government subsidies and tax credits enable companies and consumers to embrace renewables and energy storage solutions. This white paper discusses the developing use case of energy storage systems (ESSs) and dives into the advantages of home battery electric energy storage. It also examines the design of battery energy storage systems (BESSs), focusing on these systems' critical components and interconnect requirements.

Energy Storage System Use Cases

ESSs can be divided into two main categories: front-of-the-meter (FTM) and behind-the-meter (BTM). These designations are based on where the energy is stored in relation to the meters on a building. If the ESS is located at the power generation facilities or in a utility-scale energy storage facility, then such an ESS is designated as FTM. FTM ESSs store energy on the producer's side of the utility meter and do not impact the customer's side of the utility meter.

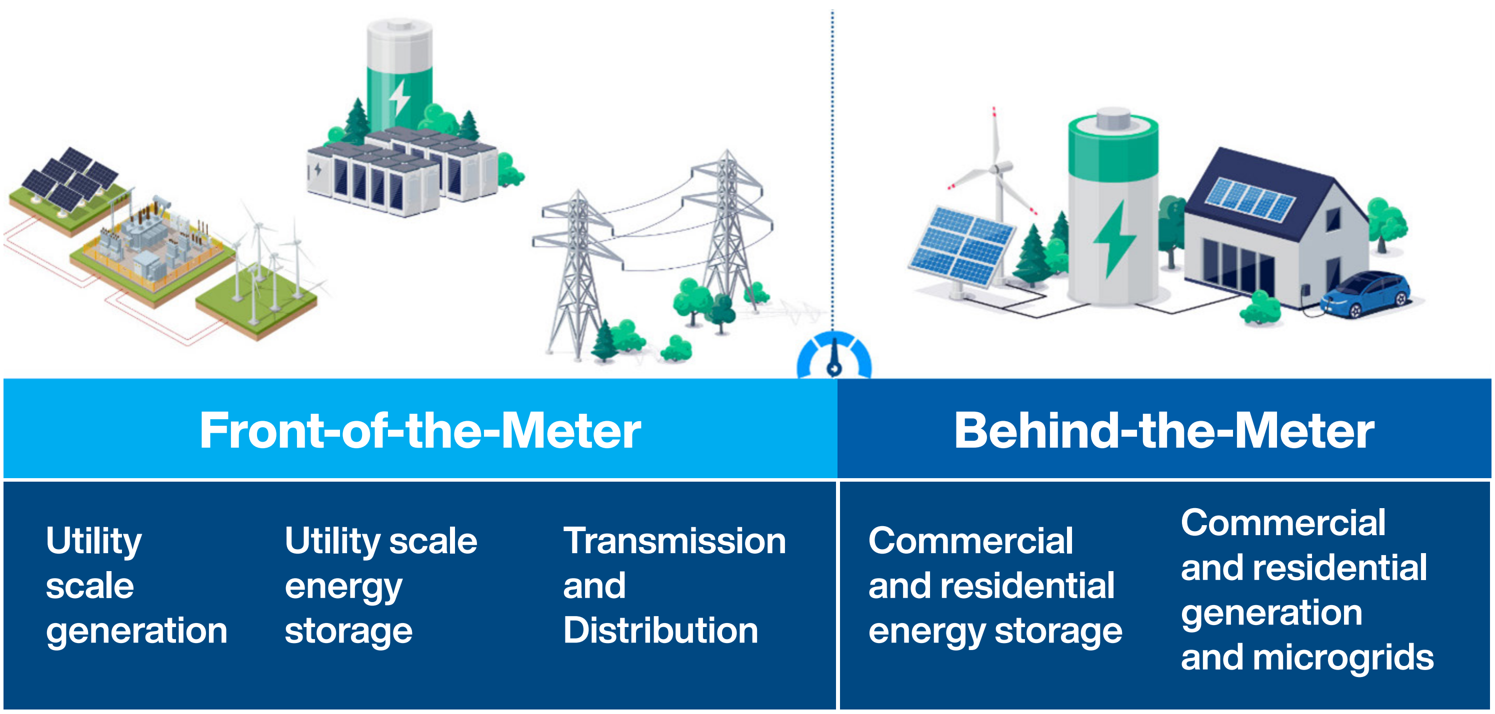

Figure 1: *A diagram depicting FTM and BTM systems. (Source: Mouser Electronics)*

FTM ESSs store energy on the producer's side of the utility meter and do not impact the customer's side of the utility meter.

Examples include ESS installations near wind and solar farms to capture excess energy during periods of high generation. In the case of wind, this could be sustained high winds; or, in the case of solar, this could be clear and bright skies over an extended time when there is less demand than energy production. ESSs installed in this way can be used to balance out the demand as seen from the distributor's side of the grid, where it may be necessary to release energy from these FTM ESSs during periods of low renewable generation. This could happen at night when solar energy generation drops off, during calm wind periods where wind generation softens, or during storms where solar energy is low.

BTM ESSs are located after the utility meter and are not subject to control or provisioning by the utility grid systems. Examples of this include residential battery storage systems. Battery-based ESSs are the most common and most easily accessible to most residential homeowners and even renters. However, other types of residential ESSs exist **(Figure 1)**.

Home Battery Energy Storage Systems

Many governments now provide financial incentives, especially in the United States, encouraging residential homeowners to invest in BTM ESS. [6]Some of the incentives for BTM ESSs are based on how grid energy is priced, and some depend on whether the residence has renewable energy solutions installed. In the case of simply having a BTM ESS, these systems can reduce a consumer's energy bills by peak shaving during high-demand times, typically during midday, and charging their BTM ESS during lower-priced periods, often at night. If renewable energy solutions are available, this could change the dynamic of when to direct energy to the ESS and when to extract the energy.

Moreover, suppose a utility can access substantial renewable energy generation or ESSs. In that case, the distributors may not have more variable incentives or price changes for grid-tied ESSs or renewable energy. In the case of off-grid installations, ESSs are often considered essential for providing energy when residential energy generation isn't available or transient demand exceeds energy generation.

Other trends also contribute to the increased feasibility of battery ESSs for residential use cases, such as the prevalence of smart meter installations in new home builds, meter replacements, or infrastructure upgrades by utilities. Unlike traditional meters, which may be checked once a month or less, smart meters are typically equipped with some type of wireless communication technology and may communicate a residence's energy usage as often as every 15 minutes. Smart meters eliminate the need for estimated bill readings, enabling enhanced intelligence on a given residence's energy usage and ensuring that energy retailers are accountable. With a battery ESS equipped with the intelligence of a smart meter, a residence can become an element of a virtual power plant (VPP), where the intelligent battery ESS is used to optimize electrical energy generation and storage in a distributed fashion.

Fortunately for battery-based ESSs, advances in battery technology, such as new and safer lithium battery chemistries like lithium iron phosphate ($LiFePO_4$) and sodium-ion batteries, are growing battery supply chains and increasing consumer access to large amounts of battery energy storage at more affordable prices. Just as the development of larger wafer sizes, the expansion of silicon integrated circuit (IC) technology supply chains, and competition have led to more affordable and accessible IC technology, the same is occurring for battery technology.

In a more direct way, EV battery systems are also being designed to contribute to residential energy during disrupted utility access, such as power outages from storms. Many of the latest EVs with large battery banks are equipped with optional charging electronics that can also extract energy from the EV batteries and power the home through inverters **(Figure 2)**. Hence, EVs may transform from vehicle-to-load (V2L) to vehicle-to-home (V2H).

Figure 2: *Alternative electric energy storage system in a modern home garage. (Source: inthasone/stock.adobe.com; generated with AI)*

Home Battery Energy Storage System Design

A home battery energy storage system comprises several key components and interconnects for analog, digital, and power electronics **(Figure 3)**. There are many possible configurations of all BESS components, but fundamental requirements exist for interconnection, operation, and tying to the grid, if applicable. The central components of a BESS are the gateway and inverter. At a high level, these devices act as the bridge between the grid, home AC mains, and the BESS. The gateway includes electronics that sense the grid status (if tied to the grid) and can supply energy back to the grid through the utility meter and house service. The inverter is a device responsible for converting the DC energy from the BESS to AC energy usable by the grid and the AC loads of the home.

The BESS, at minimum, includes battery energy storage and the electronics that monitor and control the electrical energy to and from the battery storage, known as the battery management system (BMS). In some configurations, the gateway may also direct AC energy from the grid to the BESS. This configuration also requires battery-charging circuitry that converts the AC energy from the grid to DC energy, which is then controlled and adequately conditioned to charge the battery energy storage.

It is important to have a battery-charging system that is specifically designed for the type of battery used in the BESS to prevent damage to the batteries, optimize battery life, and ensure efficient charging of the batteries. To address these challenges, designers must utilize **energy storage solutions** that balance enhanced power throughout with effective thermal management.

Suppose solar, wind, or other renewables are used also to provide energy to the system. In that case, these energy sources may be directly connected to the BESS or through the gateway. If additional energy sources are available and connected through the gateway, they may require energy-conversion electronics different from the battery-charging circuitry and inverter used in the gateway. These systems also require additional interconnects, including a transfer switch if connected to the home service (such as how a backup generator is connected to a home).

Another example is the energy conversion electronics needed to convert three-phase (typical wind generator configuration) from a wind turbine to the two-phase or single-phase AC used in residential or DC to energize a BESS. A solar power installation may require additional conversion electronics, such as an inverter that converts the DC from solar to either AC for the home or a DC-DC converter for energizing the BESS. In some cases, the inverter used to convert the DC provided by the BESS may also be used for solar energy conversion.

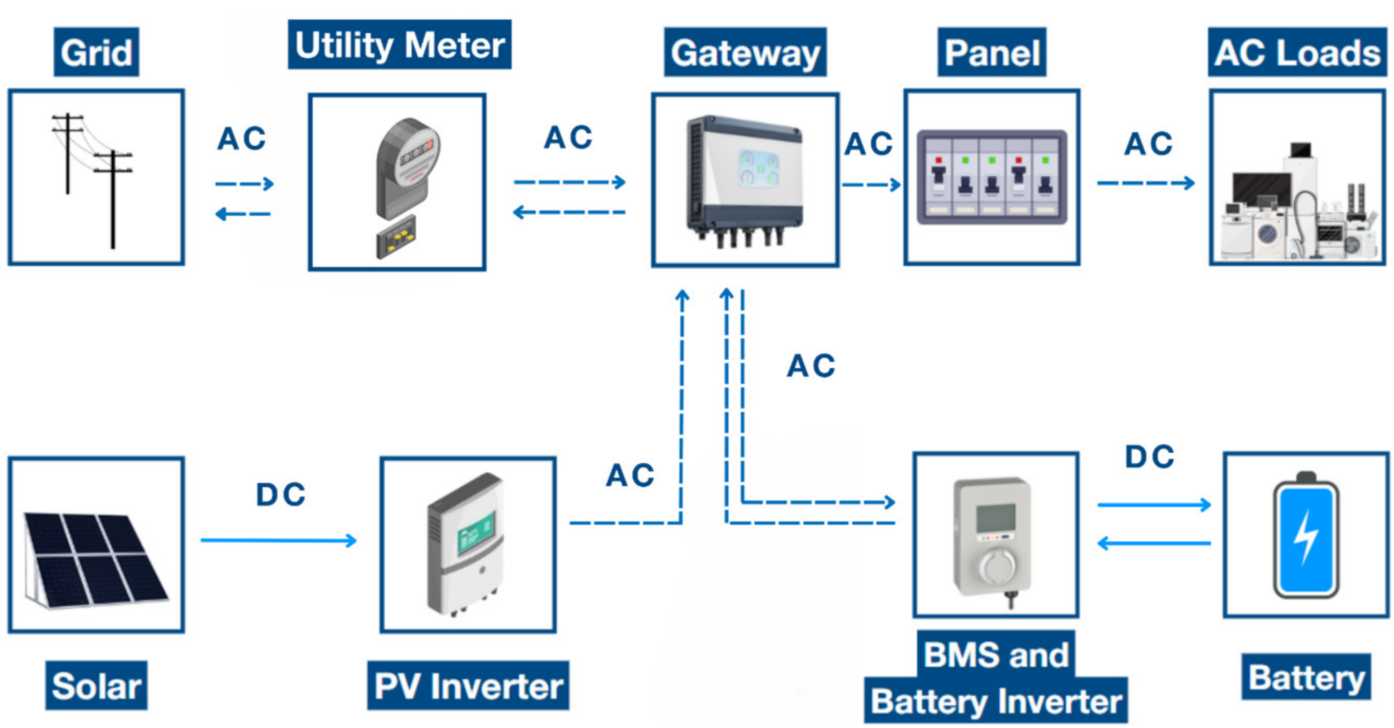

Figure 3: *Diagram of a residential BESS, optional solar connection, and grid-tie. (Source: Mouser Electronics)*

As mentioned earlier, some automakers are also releasing EV charging electronics that can be tied to a home service, much like a backup generator. These systems can be used to charge the EV and supply the home with AC when the grid fails. In future cases, this vehicle-to-grid (V2G) connection may also use the EV battery as a full BESS—the EV battery used to reduce energy bills using smart control. Hence, smart homes with BESSs of the future may include solar or wind power, EV BESS, a home BESS, and the necessary systems to integrate these renewables and battery energy storage technologies in an optimized home energy system that minimizes home energy costs and ensures reliability even in severe weather or outages.

To achieve this, however, designs will need to achieve high levels of efficiency, reliability, and performance while mitigating environmental challenges such as temperature extremes, high winds, moisture ingress, pests, and corrosives. Designers must protect these electronics from the ambient environment while ensuring an optimal local environment for the electronics.

For these reasons, home BESSs and other home energy electronics must be located within protective enclosures that often include thermal management solutions. Within these enclosures, there are a variety of interconnect types. These include terminal blocks, many types of electrical wiring, varieties of connector types, and busbars. There are also several types of interconnects and conduits used to connect the different home energy electronics enclosures.

Designers must select these interconnects to conform to regional building codes and to ensure the safety and performance of these systems. In addition to reliability, interconnect considerations must also account for the interconnect adding resistance, inductance, and capacitance, which may be affected by environmental conditions and could impact the operation of the electronics in the system.

As shown in **Figure 4**, the typical connector requirements for a BESS include the following:

1. SW1 Connectors
2. Terminal Blocks
3. Mini-Fit Connectors
4. Off-the-Shelf Power and Signal Discrete Wire Cable Assemblies
5. Nano-Fit Connectors
6. Busbars
7. PowerPlane Busbar Connectors
8. Mega-Fit Connectors

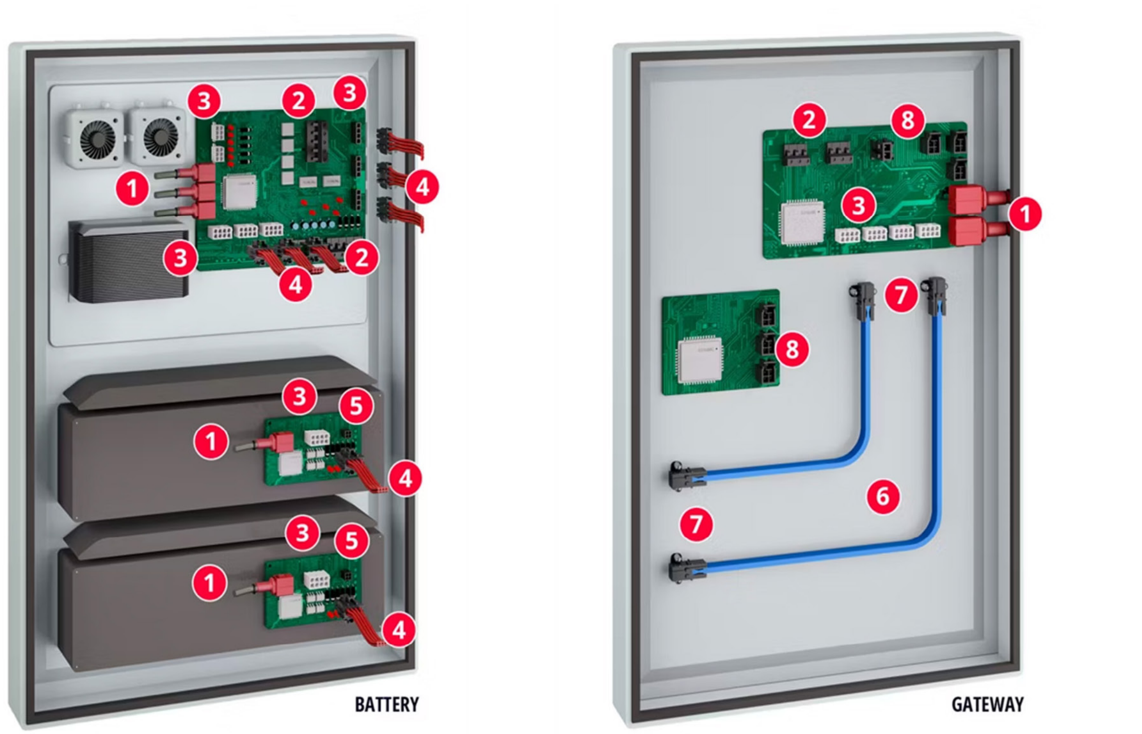

Figure 4: *Typical connector requirements for a BESS. (Source: Molex)*

The ease of installation and troubleshooting of the interconnect cabling and connectors are important considerations, as this can directly impact the initial installation costs and maintenance over time. Additional considerations for BESSs may be specific to the energy storage type. For instance, with some lithium-ion battery chemistries, thermal runaway can be triggered by extreme temperatures, battery aging, and shorts. This could lead to fires and expensive damage to a home or other BESS electronics, which is why test standards such as UL9540A and NFPA 855 are used to mitigate hazards associated with ESSs.[7,8]

Conclusion

Battery energy storage systems and future V2G technologies are viewed by many as a necessary step to enhancing the reliability of electric grids via decentralization and battery energy backup. There are numerous hurdles to overcome in designing these systems, many of which involve selecting reliable and high-performance interconnects that ensure communication, sensing, and power transfer among the various circuits in residential BESS.

Sources

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