Connector and cable considerations

Utility-scale energy storage battery racks

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Learn more about

- Providing peace of mind in a grid event
- The benefits associated with utility-scale energy storage systems
- The need for drivers, trends, consumer expectations, and market challenges, which in turn influence the selection of connectors and cables used in battery racks for utility-scale energy storage systems

Introduction

Electricity in our daily lives is an unconscious convenience until it is not available. Planned, unplanned, and controlled outages in the form of blackouts cause disruption. Climate change-inducing extreme weather events that contribute to outages are making energy storage more important than ever. This white paper will investigate the role that connectors and cables play in energy storage systems.

Today, ethical and sustainable considerations influence the decisions of many more consumers than they did a decade ago. Additionally, consumers today are more technology-savvy than ever before. Early adopters of home energy storage systems naturally expect these technology-driven products to make a comfortable and secure, yet sustainable, lifestyle entirely possible.

Figure 1: Climate change effects

Energy storage system (ESS) contribution to sustainability

Solutions to integrate various renewable energy sources have evolved over the years. However, many are intermittent renewable energy sources (IRES), as their power sources fluctuate in nature. For example, wind power relies on wind speeds and air density, among other factors, and solar power production is impacted by latitude location and climatic conditions.

Synergies among these different innovations to create a comprehensive and sustainable energy solution are continually evolving. More renewable energy will result in a greener grid. For more than 20 years, renewable energy such as wind and solar have become more integrated into the utility grid; the next evolution is to store that energy to maintain grid production.

ESS use case examples are grid stability (grid production directly corresponds with the energy consumption); peak shaving (managing demand spikes); uninterruptible power supply (backup power during interruption); and refluxuation compensation (reduce intermittency and enables frequency regulation).

Using a storage solution such as batteries has many sustainable benefits and enables the decarbonization of the network through greater consumption of renewable energy. Battery energy storage systems (BESS) are among the most integrated energy storage technologies for electricity generation. Pairing or co-locating batteries with renewable energy generators is increasingly common and expected to rise due to high-cycle efficiency and fast response times favorable for grid-support applications.

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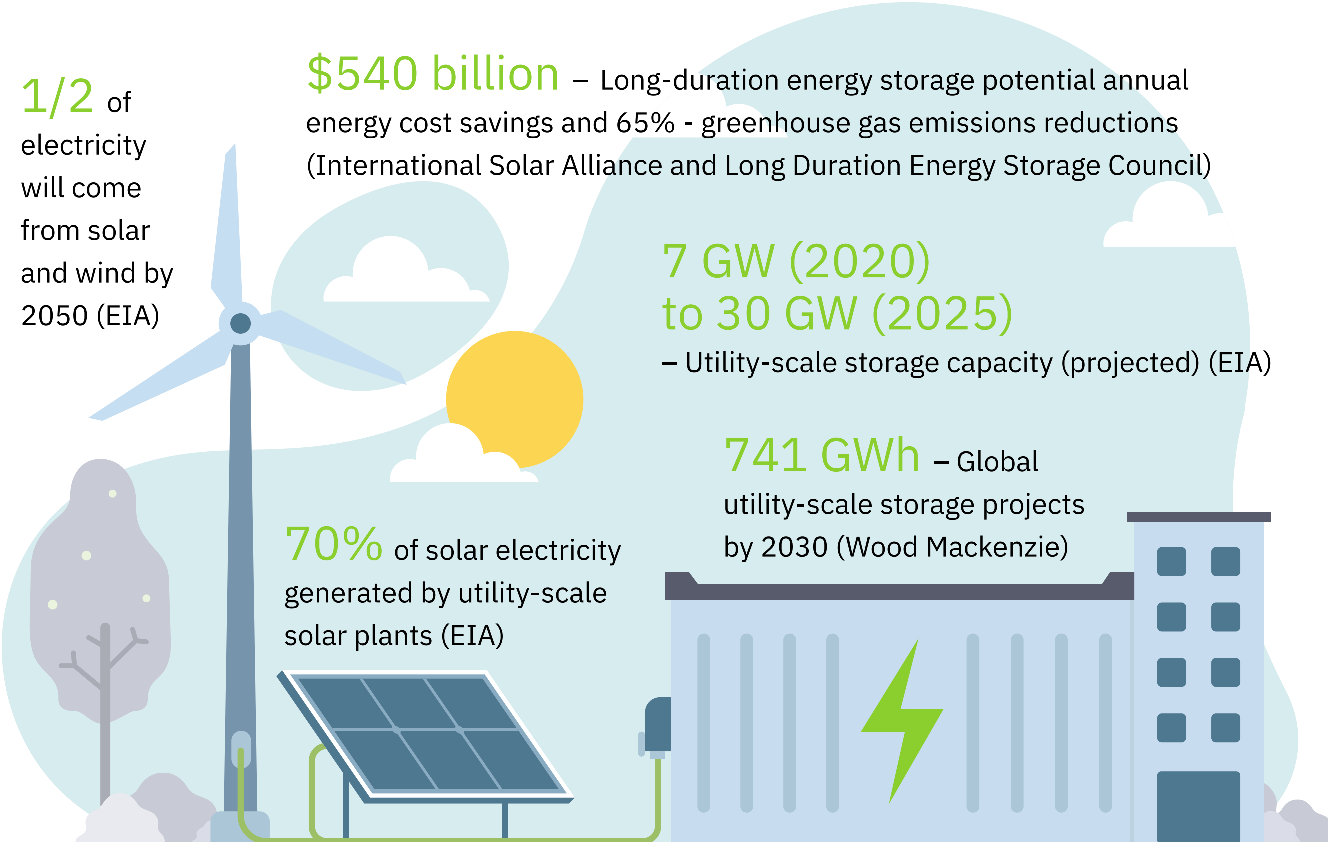

The electric power sector is transforming due to higher levels of renewable energy, greater amounts of distributed energy resources, and shifting demand patterns resulting from the electrification of the economy. Sector coupling is “the idea of interconnecting the energy consuming sectors – buildings (heating and cooling), transport, and industry – with the power producing sector” (Wettengel). The transformation presents new challenges and opportunities in operating and maintaining a reliable power system.

Energy storage technologies have the potential to aid these challenges by increasing the flexibility and reliability of the utility system. In 2022, the Inflation Reduction Act modified and extended the Clean Energy Investment Tax Credit, which provides up to a 30 percent credit for qualifying investment in renewable projects. This demonstrates the country’s readiness for utility energy storage to further support this evolution. ■

Battery Energy Storage System (BESS) segments

A BESS is a type of energy storage device that uses batteries as its storage technology. A BESS requires additional components that allow the system to be connected to electrical networks and, in turn, to the utility. BESSs use different types of batteries with unique designs and optimal charging and discharging specifications. The majority of U.S. utility-scale BESSs use lithium-ion batteries, which have performance advantages for utility grid-support applications.

Highlighting some of the critical segments will demonstrate the complexity of these systems. Most importantly, the connector and cable selection play an integral part in successful deployment. Considerations include electrical (ampacity, temperature ratings, cable strand count, metallurgy, shielding) and mechanical (tolerances, routing, flexibility, quick connection/disconnect, audible, color coding, polarization, touch safe, IP rating) required for UL 1973 system certification. ■

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Figure 2: Battery Energy Storage System (BESS)

Battery rack/pack systems

Battery rack/pack systems are intricate because of the number of parameters to consider. A pack system can be connected in series, parallel, or commonly both to reach the BESS's required voltage and current. The racks are comprised of various subsystems configured for specific applications. This flexibility allows the BESS to scale to fulfill energy demand fluctuations easily.

The modularity of the battery racks requires cable and connector connections for power and communications among the various components. For front connection applications, the racking system provides a structure with defined dimensions that allow for premade cable assemblies that can be factory-overmolded, which results in consistent, robust assembly. Optimized connectors and cables can enable quick and safe installation of rack system components. Connectors with push-on locking with audible clicks can ensure quick, proper installation with no tooling. Conversely, a traditional lug and bolt requires the installer to carefully position the loose hardware and torque to a specification, consuming valuable assembly time. Phoenix Contact calculates that a push-on locking, battery pole connection is roughly 80 percent faster than a traditional lug-and-bolt connection.

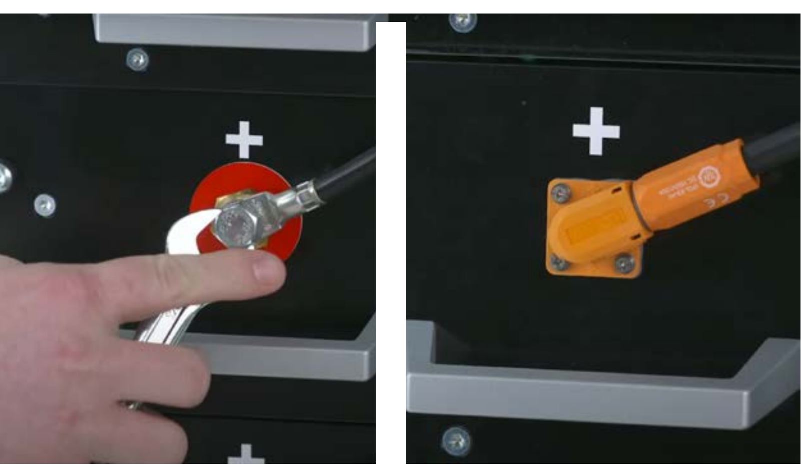

Figure 3: Screw connection versus plug connection

A 360-degree rotation feature when cable and receptacles are mated allows easier installation and cable routing. Lugs and bolts are not rotatable, exerting strain on the connection and cable. Battery-pole connectors provide increased installer safety because the connectors are touch-proof, while a screw connection is not. When considering a battery storage system in a container, Phoenix Contact calculates roughly 200 power connections are needed to connect the complete container. At one minute per screw connection, using push-on connectors can save approximately two and a half hours of assembly time.

High-power applications may require a connector position assurance (CPA) feature, such as the latch-locking feature on the Phoenix Contact 350-amp BPC cable plug. This ensures that once locked in place, the cable assembly cannot become unplugged unless the locking feature is disengaged, adding additional safety features. ■

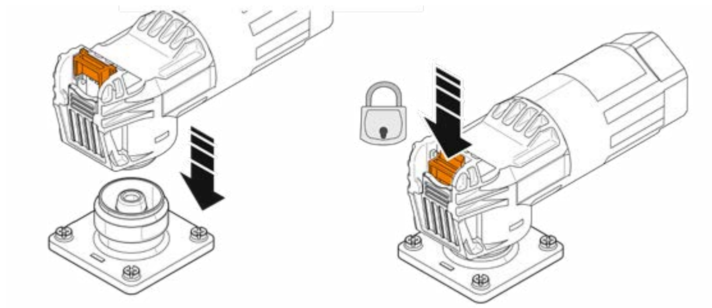

Figure 4: Battery Pole Connector position assurance

BESS controller

The controller/de-stage controller power module (DCPM) is "the brain of the entire BESS. It monitors, controls, protects, communicates, and schedules the BESS's key components. The controller communicates with BESS components and "with external devices such as electricity meters and transformers, ensuring the BESS is operating optimally." The controller can integrate with third-party operating systems (OS), SCADA (Supervisory Control and Data Acquisition), and EMS (Energy Management System) for complete data acquisition and energy management (Power-Sonic).

Since everything connects to the controller, there are many considerations for routing power and communication cable assemblies. A UL 9540 BESS certification requires the use of UL 3817-approved cable. However, when routing power cables external to the enclosure, NEC standards may apply.

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The NEC standards have ampacity derating values depending on whether cables are routed separately or multiple cables are routed in a bundle. Connector rotational features on the battery power cable assemblies are essential for routing cables that ensure access to the battery modules.

The continuous exchange of extensive information is essential to ensuring stable grid operation. However, standard communication protocols for BESSs are still being considered, as there is a requirement for a higher level of interoperability among intelligent electronic devices. The automotive industry has traditionally used Controller Area Network (CAN) protocol for electric vehicles. This communications protocol has also become popular in the battery energy storage market space.

CAN is a two-wire (twisted pair), bidirectional serial bus communication method that allows electronic subsystems to be linked together and interact in a network (Zerynth Documentation). Various connector and cable options are viable for this communication standard. M12 connectors and cables are considered standard interfaces due to the extensive portfolio, installer familiarity, and IP rating. The product offering includes panel-mount with flying leads, panel-mount to Ethernet, and PCB-mount for the device side. On the cable/plug side, there are threaded versions, as well as push-pull for faster connection. The right-angle orientation is desired for shorter protrusion and is less susceptible to being sheared off if hit from the side. M12 connectors have options for integrated shielding and advanced shielding technology on the cable if factory-overmolded.

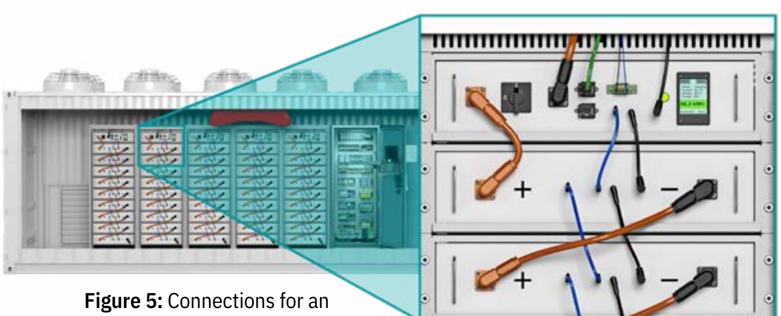

Figure 5: Connections for an energy storage rack

Another option for a CAN communication connector interface is the industrial Single-Pair Ethernet (SPE) connector and cable. SPE has been used for many years in the automotive industry and is a proven technology. It is designed for bidirectional communication with an IP interface and uses shorter contacts that prove beneficial for better signal quality. Additionally, SPE has a smaller connector footprint and cable diameter than M12 or Ethernet. ■

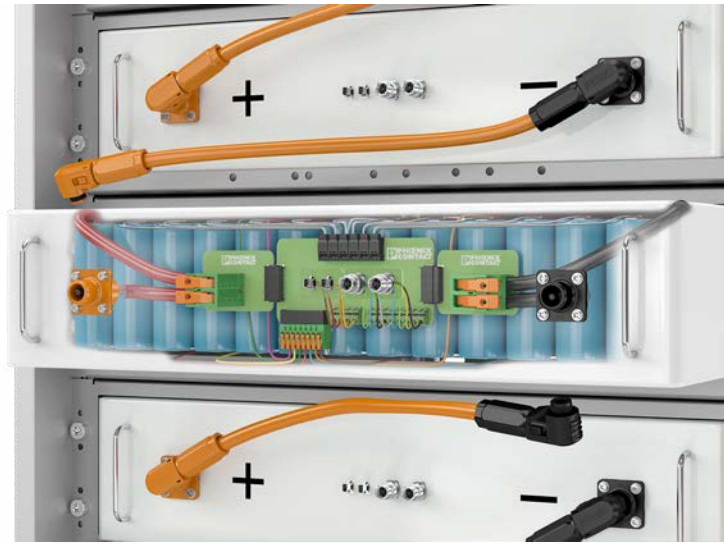

Figure 6: Battery module connections

Battery Management System (BMS)

A battery management system (BMS) ensures "that the battery operates within predetermined ranges for several critical parameters, including state of charge (SoC), state of health (SoH), voltage, temperature, and current." Additional functions of the BMS could include real-time monitoring and protection of the battery at the cell level, module, string, and system level. "The BMS constantly monitors the status of the battery and uses application-specific algorithms to analyze the data, control the battery's environment, and balance it. This is critical for the thermal management of the battery and life of the cell" (Power-Sonic).

Communication in some BMS applications lends itself to safety and noise efficiencies with a bidirectional interface over a single twisted pair of wires. The layout of signal lines plays a significant role in maximizing the immunity of a circuit within a BMS. Layout guidelines recommend the transformer should be placed as close as possible to the cable connector. Shielding of this pair of signals may be optional, depending on proximity to noise emissions from other elements, such as power cables. Therefore, a smaller connector and cable interface would be ideal for these applications.

The SPE connector and cable from Phoenix Contact is an example of a communication connector for this application. As mentioned earlier, SPE has traditionally been used in automotive applications. With EV technologies now trending in industrial applications with energy storage, SPE lends its efficiencies to the Energy Storage market. ■

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Battery module

Figure 7: Battery pole connectors and cables

The battery module "is a crucial component within the BESS; it stores the energy ready to be dispersed when needed." The battery is comprised of battery "cells wired in series and parallel within a frame to create a module" (Power-Sonic).

Battery-cell compilation is the heart of the BESS. Slight variations in single-cell (SC) compilations could drastically influence the overall assembly performance and durability. The cell's imbalance, configuration, voltage response, degradation, aging differences, and temperature distribution are just some of the parameters to consider.

The battery modules are connected in series in the battery rack. Internal connection options include lug, busbar, or crimp for reliable panel feed-through connections. External connection polarization and color-coding of the connector and cable will ensure error-free installation. Shorter distance cable connections from battery module to module with large rigid cable require tolerance analysis. Combined 360-degree rotational and vertical force analysis is beneficial for long-term reliability.

Battery connection receptacle protection caps may be required for connector protection during transportation or for unused receptacles. This will protect the connection point and maintain an IP rating if required. Cooling the battery module can help prolong its lifecycle. The connector and cable's IP ratings are important to protect the electronics if the cooling system becomes damaged and leaks.

Cell-sensing communication from the battery module to the BMS is valuable for reporting the state of health (SoH) for each cell. Due to the proximity to the power connections, these signals are vulnerable and need protection from potential electromagnetic interference. Utilizing high-speed, shielded connectors, such as shielded FP 0.8 board-to-board connectors from Phoenix Contact, to bring the signals to the processor can ensure accurate data transmission. ■

Additional segments of BESS

There are several other important BESS segments that are beyond the scope of this paper, including:

- HVAC
- Fire suppression
- Supervisory Control & Data Acquisition System (SCADA)
- Energy management system (EMS), DC-DC converter, AC-DC converter

We encourage you to research these segments when selecting your BESS. ■

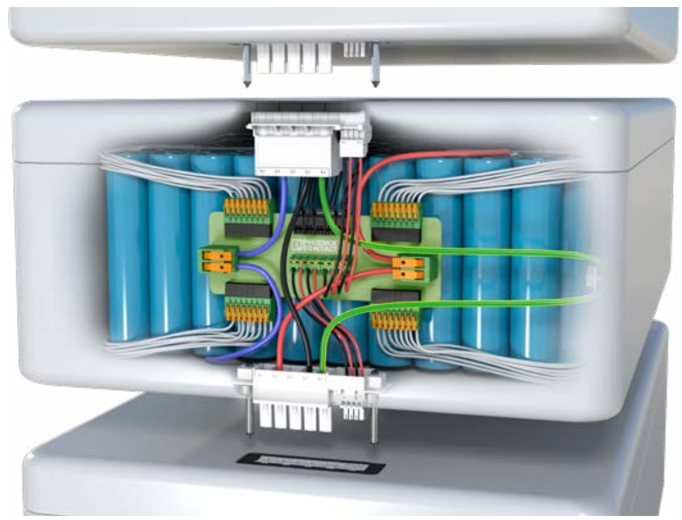

Figure 8: Cell-sensing connections

Conclusion

BESS connector and cable considerations

Clean, affordable, and renewable energy, and energy storage are more important than ever before. Energy storage is invaluable and has arrived at the right time, as this technology will help stabilize the gird and supply reliable power.

A BESS requires numerous connections for signals, data, and power. Connectors and cables are critical components in a utility-scale energy storage battery rack. Key

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considerations in selection are: voltage and current ratings; material and durability, cable sizing and length, flexibility and bend radius; installation and maintenance; environmental sealing; safety standard compliance. Modifying or customizing connector and cable solutions may be needed to optimize fulfilling these requirements. By carefully considering these factors, engineers can design robust and reliable utility-scale energy storage battery racks with connectors and cables that meet the specific needs of the application. Choosing the right connector technology will ensure that BESSs operate safely, reliably, and efficiently. ■

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