Building a smarter BDU/PDU: A layer-by-layer guide to sensing, switching and protection

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Specifying a battery disconnect unit (BDU) or a power distribution unit (PDU) for a modern electric vehicle (EV) is, in practice, both a supply chain and an engineering problem. The sensing, switching, protection and mechanical integration functions that a BDU/PDU must perform each draw from a different supply chain — a current sensor supplier, a contactor supplier, a resistor supplier, a busbar fabricator and a controls supplier.

Each has its own qualification timeline, interface specification and thermal assumptions. When those assumptions prove incompatible, the integration problem falls on the BDU/PDU manufacturer.

Luckily, Isabellenhütte's portfolio of precision resistive components, sensing electronics, contactors and busbar assemblies covers the complete stack.

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What goes inside a modern BDU/PDU

The terms BDU and PDU are often used interchangeably, and in many vehicles, are part of the same enclosure. The difference lies in functionality: a BDU safely disconnects the battery in the event of an accident or short circuit, while a PDU takes power from the battery and distributes it to critical vehicle subsystems such as the drivetrain inverter, DC/DC converter, onboard charger (OBC), HVAC, steering and thermal management (Figure 1).

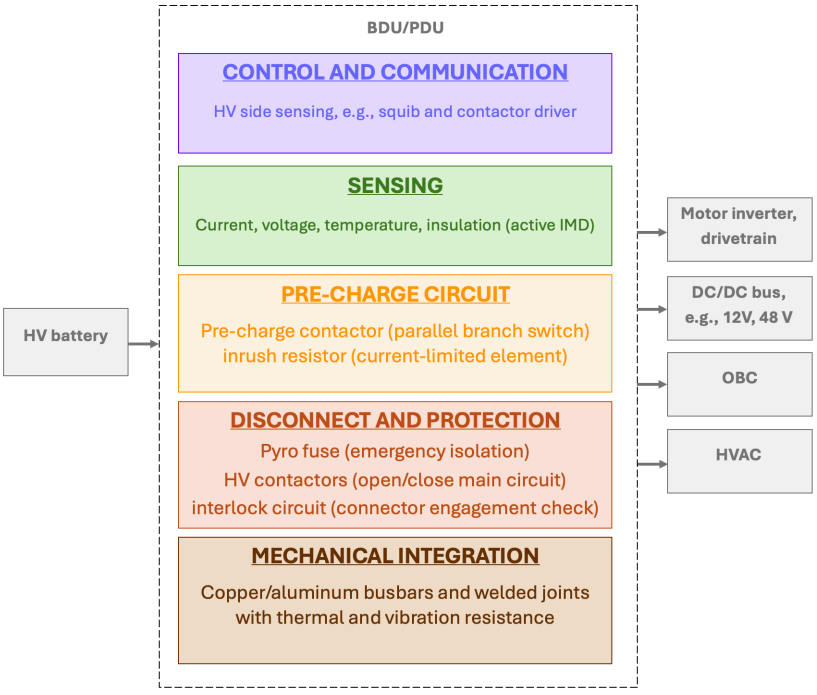


Figure 1: BDU/PDU functional layers (sensing: Current, voltage, temperature and insulation).
Source: Isabellenhütte

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Regardless of the label or enclosure, functionality can be broken down into several key layers:

- **Sensors:** These measure parameters like current, voltage and temperature across multiple circuit nodes and mechanical joints. An optional insulation monitor (IMD) will measure the resistance between the high-voltage circuit and chassis ground to assess insulation integrity.
- **A disconnect and protection layer:** Pyro fuses are used for emergency isolation, high-voltage contactors to open and close the main circuit and an interlock system that runs through all high-voltage connectors to verify that they are properly engaged.
- **A pre-charge circuit:** often placed in a parallel branch with its own contactor and current-limiting resistor, it slowly charges the capacitors in the motor inverter before the main contactors close, preventing destructive inrush current events.
- **A control and communication layer:** These often rely on separate modules. One controller module aggregates sensor data and exchanges status and measurement data with the vehicle's battery management system (BMS) via CAN bus protocol. The contactor control and pyro triggering is typically done via analog signals that come from a separate control module (e.g., squib and contactor drivers).
- **Mechanical integration:** Copper or aluminum busbars connect every component to reliably distribute power with minimal resistive losses and enough durability to survive the vibration and thermal cycling within a vehicle's lifetime.

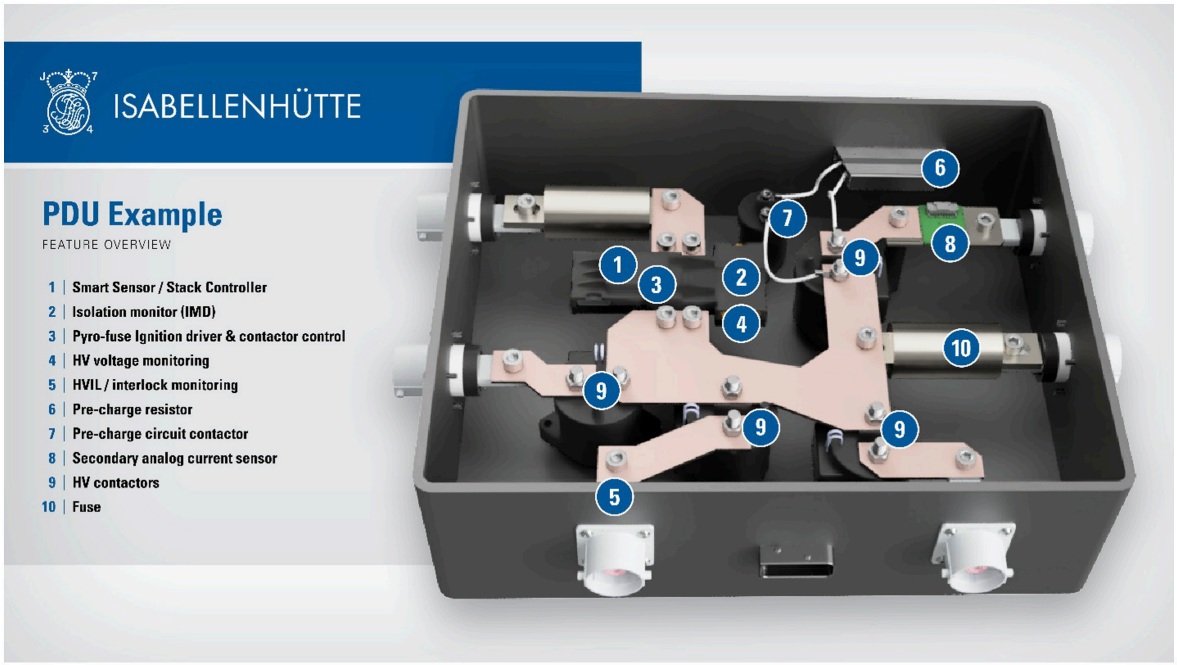


Figure 2: A PDU example highlighting each functional layer. Source: Isabellenhütte

Sensing

All BDU/PDU functions critically rely on sensor data. Precision resistors act as shunt-based current sensors that effectively use Ohm's law (V=IR) to measure current accurately. Shunt-based current measurements are preferred over Hall-effect in automotive applications, as they avoid the nonlinearity and temperature sensitivity in magnetic field sensing, especially at high currents on the order of thousands of amps (Figure 3).

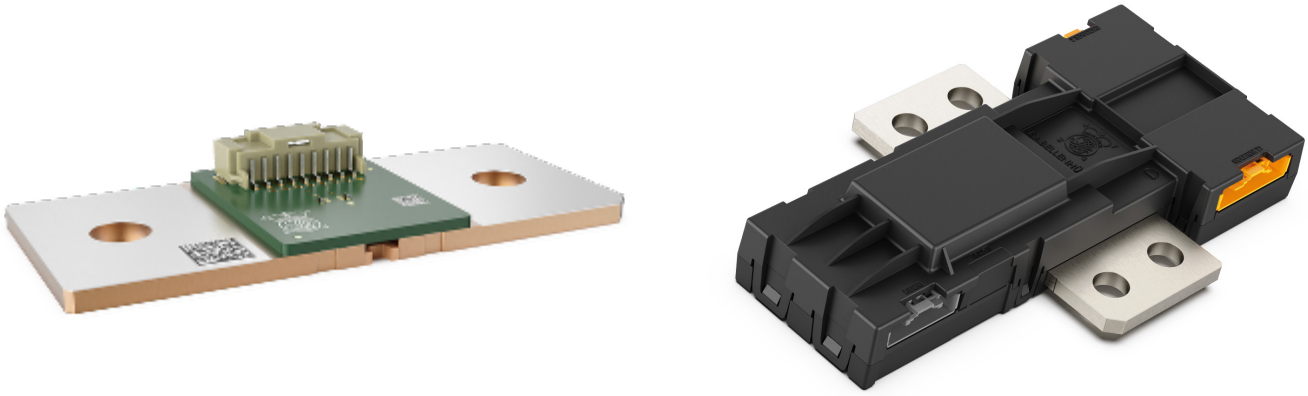


Figure 3: BSN (left) and IVT-3-Pro (right) precision current sensors. Source: Isabellenhütte

Isabellenhütte's position in precision current sensing is built on in-house alloy production, engineered specifically for a low temperature coefficient of resistance, minimal thermal EMF relative to copper traces and long-term stability under continuous high-current load. These properties matter at the system level, as a shunt that drifts with temperature or degrades over time introduces measurement error that compounds into BMS and BDU/PDU decisions about state-of-charge (SOC), fault-detection thresholds and contactor-control timing.

However, the current information alone is not enough to manage the BDU/PDU safely; the controller needs voltage data, as well, to achieve the following:

- Perform pre-charge sequencing by measuring voltage on both sides of the main contactor to determine whether it's safe to close the main contactor
- Conduct insulation monitoring (IMD) by injecting a known signal and measuring the response
- Understand the state of the circuit (e.g., whether or not the contactors have actually opened and closed as commanded)
- Detect an overvoltage condition

Disconnect and HV protection

Contactors

Contactors are the electromechanical switches that open and close the high-voltage circuit on command from the control layer. Contact resistance is a particularly important parameter for these components: resistance in the tens of milliohms at currents in the hundreds of amperes produces heat that must be managed within the PDU thermal budget.

The ICC contactor series (Figure 4) was developed to pair with Isabellenhütte's shunt-based sensing products. Several specifications are available, including:

- 150 A continuous at 1,000 V DC (35 mm^2 conductor) for pre-charge and auxiliary circuit positions
- 500 A continuous at 1,000 V DC (127 mm^2 conductor) with a one-minute overload rating of 1,000 A, for main HV+ and HV− switching

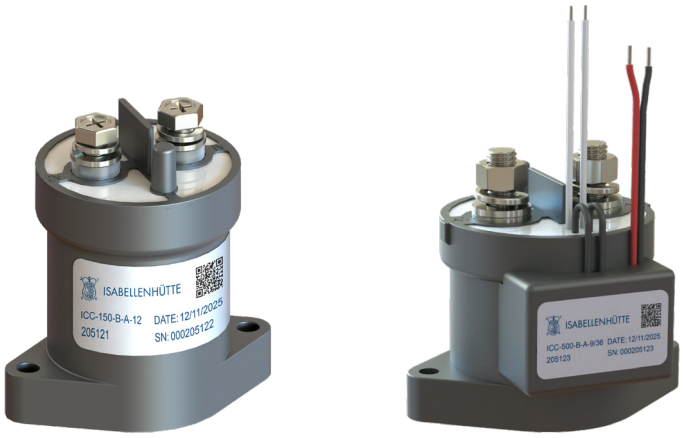


Figure 4: ICC-150 (left) and ICC-500 (right) contactors are hermetically sealed beyond IP69 with contact resistance ≤ 0.4 mOhms and rated for a 500,000-cycle life. Source: Isabellenhütte

Because the controller module and the ICC contactors are developed within the same product family, the control interface between them — coil drive timing, diagnostic feedback and fault response sequencing — does not require the OEM to bridge two independently specified systems.

Pre-charge protection

Large motor inverter filters will require pre-charge circuits to limit the high inrush currents from capacitive loads during power-up. Motor inverters, in particular, require a large input filter capacitor to prevent HV ripple from reaching downstream equipment. In fact, a capacitor bank can take up 30% of the space in a motor inverter. The pre-charge circuit prevents these large current spikes on the order of thousands of amps, which can create arcs when contactors close. If the main contactor closes directly onto a discharged capacitor bank at 400 V or 800 V, the resulting inrush current can weld contactor contacts, damage capacitor banks and destroy semiconductor devices in the inverter.

The pre-charge resistor is the limiting element in this circuit, effectively adding impedance to this path (thus limiting current) and absorbing the energy pulse repeatedly over the vehicle's lifetime, despite temperature extremes and vibrational strain. Figure 5 shows Isabellenhütte's ARV/ARH series. These are AEC-Q200-qualified, wire-wound, aluminum-clad resistors specifically designed for pre-charge circuitry.

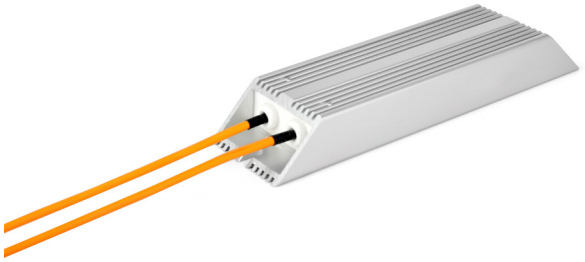


Figure 5: The ARV/ARH series of AEC-Q200 qualified, wire-wound resistors designed for pre-charge circuitry. Source: Isabellenhütte

Controller

The BMS itself handles low-voltage, cell-level functions — balancing, individual cell monitoring and SOC estimation. A separate stack controller, typically housed inside the BDU or PDU, handles the HV side: contactor control, pyro fuse triggering, total stack current sensing, voltage monitoring and insulation monitoring. This is one common design approach — particularly prevalent in commercial vehicles and heavy machinery — though not all PDUs include this level of integrated intelligence. This stack controller requires two things from its intelligence layer:

- Knowledge of the state of the circuit at all times
- The ability to change that state at speed in the event of a fault

Knowing the state means measuring current, voltage across multiple circuit nodes, temperature at mechanical joints and the integrity of the insulation barrier between the HV circuit and chassis ground. Traditionally, these functions are handled by multiple discrete components — a current sensor reports over a communication bus to a controller, which then issues commands, while contactor control and pyro fuse triggering are handled separately through dedicated analog outputs.

The controller module (Figure 6) consolidates all of this into a single device. It reports sensing data — current, voltage, temperature and insulation status — to the BMS via CAN, while controlling contactors and firing pyro fuses directly through its own analog outputs, without routing those commands through the BMS.

Measurement and protective action occur within the same processing cycle. In other words, when the module detects a short circuit at a combined charging system or megawatt charging system inlet, it can fire the pyros and open contactors within hundreds of microseconds, achieving an open circuit in under one millisecond. The same module concurrently helps handle pre-charge sequencing and provides active IMD, monitoring voltage on both sides of the contactor to determine when it is safe to close.

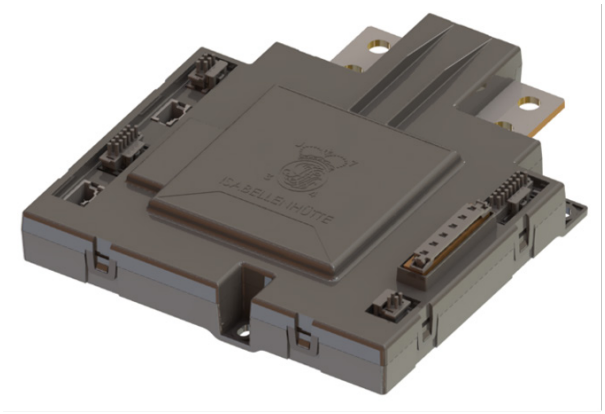


Figure 6: A stack controller with sensing capability that spans the functional scope of a BDU/PDU. Source: Isabellenhütte

All of this can then be communicated to the BMS via a centralized point, rather than through a distributed architecture. In architectures where multiple battery stacks are distributed along the vehicle frame, each with a separate BDU/PDU — such as in commercial fleet vehicles and heavy machinery — it can operate as an autonomous local node, acting on local fault conditions independently while remaining networked to the central system.

Mechanical integration

Busbars are the current-carrying conductors that connect all components within a PDU. In most designs, they are among the last elements to be finalized, but their geometry and material choices affect the thermal and electrical performance of every component they connect:

- A busbar joint with higher-than-anticipated resistance raises temperatures at the adjacent shunt or contactor terminal
- A busbar routed without consideration of component placement creates mechanical stress at connection points

The material selection for automotive busbars has shifted in recent years. Copper has excellent conductivity but is expensive and heavy. Aluminum is lighter and significantly cheaper, and as pressure on battery system costs has intensified, more OEM specifications have shifted to aluminum busbars. The problem is that most sensing and switching components — shunt resistors, contactors — retain copper terminations. Connecting copper to aluminum with mechanical fasteners is workable but introduces several long-term reliability concerns.

Welding copper directly to aluminum eliminates the mechanical joint entirely. The weld produces a lower-resistance connection than a fastened alternative, removes the assembly labor associated with torque validation and eliminates the long-term risk of fastener relaxation under vibration. Isabellenhütte has developed this capability and can deliver shunts, contactors and busbars as a pre-assembled, pre-validated subassembly. With this addition to Isabellenhütte's capabilities, the PDU manufacturer's integration task is effectively reduced to placing the assembly in the housing and connecting the low-voltage wiring harness.

Conclusion

The engineering complexity of a modern BDU or PDU is distributed across every layer of the unit — disconnect and protection, pre-charge circuit, sensing, control/communication and mechanical integration. Each layer has historically required a separate supplier relationship, with integration risk accumulating at every interface.

Isabellenhütte's core competency is precision current measurement in demanding automotive environments, built on proprietary resistive alloys and decades of qualification experience. The controller module extends that foundation into contactor and pyro control. The ICC contactor series, the BSN redundant shunt, the ARV/ARH pre-charge resistors and custom-welded busbar assemblies address the remaining layers. This covers the full functional scope of the BDU/PDU from a single supplier; and since the products are developed to work together, system-level validation is dramatically reduced.

Integration between sensing and switching components is also an active direction of development. Future product generations are expected to bring about closer physical integration of shunt and contactor functions, further reducing the component count and simplifying the PDU manufacturer's assembly process.

Contact Isabellenhütte to learn more.

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Today, Isabellenhütte is one of the world's leading manufacturers of precision measurement systems, resistance, and thermo alloys as well as high power resistors. We call this journey "Innovation by tradition." Isabellenhütte USA is a wholly owned subsidiary of Isabellenhütte Heusler GmbH KG, located in Dillenburg, Germany.