Enhancing Power Reliability in Critical Infrastructure with Battery Backup Units (BBUs)

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Abstract

With the growth of cloud computing and online storage, data centers have become essential to almost every part of the global economy. With equipment typically in rows of racks used for storing, processing and sharing data, modern data centers need backup power that is reliable, efficient and compact. Battery Backup Units (BBUs) using 48V lithium-ion batteries are rapidly replacing traditional systems because they offer higher energy storage, longer life span and support real-time monitoring. This paper explains the role of BBUs in modern data center architectures, along with benefits and key design components. The use of wide-bandgap devices offers an effective approach for high-voltage (HV) BBU applications, addressing critical constraints related to weight, volume and efficiency.

BBUs are critical subsystems used to provide uninterruptible power to electronic equipment, particularly in data canters, telecom infrastructure and other industrial systems. Their primary objective is to maintain power continuity during outages or grid instability, ensuring operational reliability and data integrity.

BBU Configurations

- **Centralized BBU:** Serves multiple racks/systems, commonly used in large-scale data centers
- **Distributed BBU:** Each rack or system has its own dedicated BBU, enabling modular scalability and fault isolation
- **Hybrid BBU:** Combines batteries with capacitors for fast transient response and long-duration backup

Typical Applications

- **Hyperscale and enterprise data centers:** For critical backup and uninterrupted operation
- **High-performance computing (HPC) racks:** Supports power-hungry compute nodes during outages

- **Edge servers with isolated HVDC bus:** Enables decentralized backup for high-efficiency architecture for longer battery life
- **Next-generation AI cluster power backup:** Provides fast, reliable backup for GPU/AI accelerators under high load

Conventional Power Architecture

As shown in Figure 1, the traditional data center power architecture uses a 12V bus to supply power to key components like processors and memory. This low-voltage distribution leads to high conduction losses. Moreover, placing the BBU on the high-voltage AC side adds extra power conversion stages, reducing overall system efficiency. A BBU is part of an UPS-like (uninterrupted power supply) architecture designed mainly for short-term backup.

Limitations

- Multiple conversion stages reduce efficiency
- Lack of advanced real-time control and predictive maintenance
- Increased component count

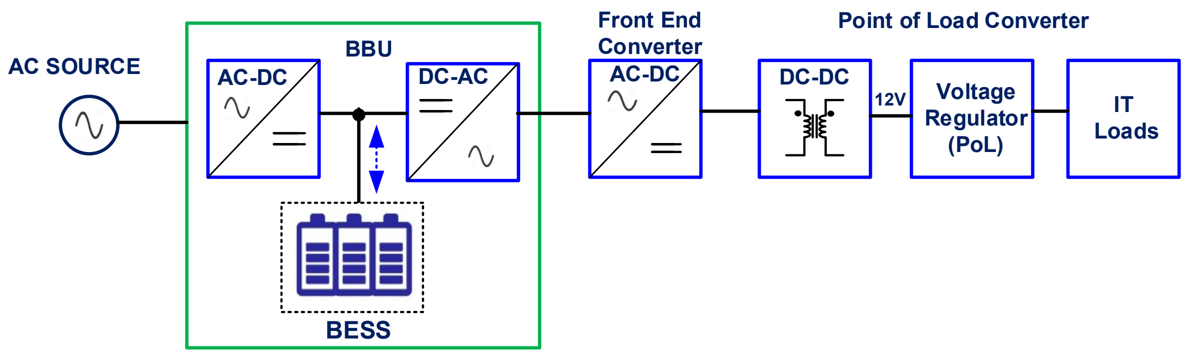

Figure 1: UPS Based Approach in Standard Server Architecture

48V Improved Power Architecture

The improved power architecture, shown in Figure 2, introduces a 48V distribution bus and eliminates the need for an online UPS, resulting in improved efficiency and simplified power flow. Supported by the Open Compute Project (OCP), this design aligns battery voltage with the power supply output for better reliability and power density.

The architecture aims to:

- Minimize losses due to reduced power conversion stage
- Enhance system efficiency
- Support higher power densities in compact rack-mounted form factors

- Enable modularity for easy scaling and maintenance
- Improve monitoring and control through digital interfaces

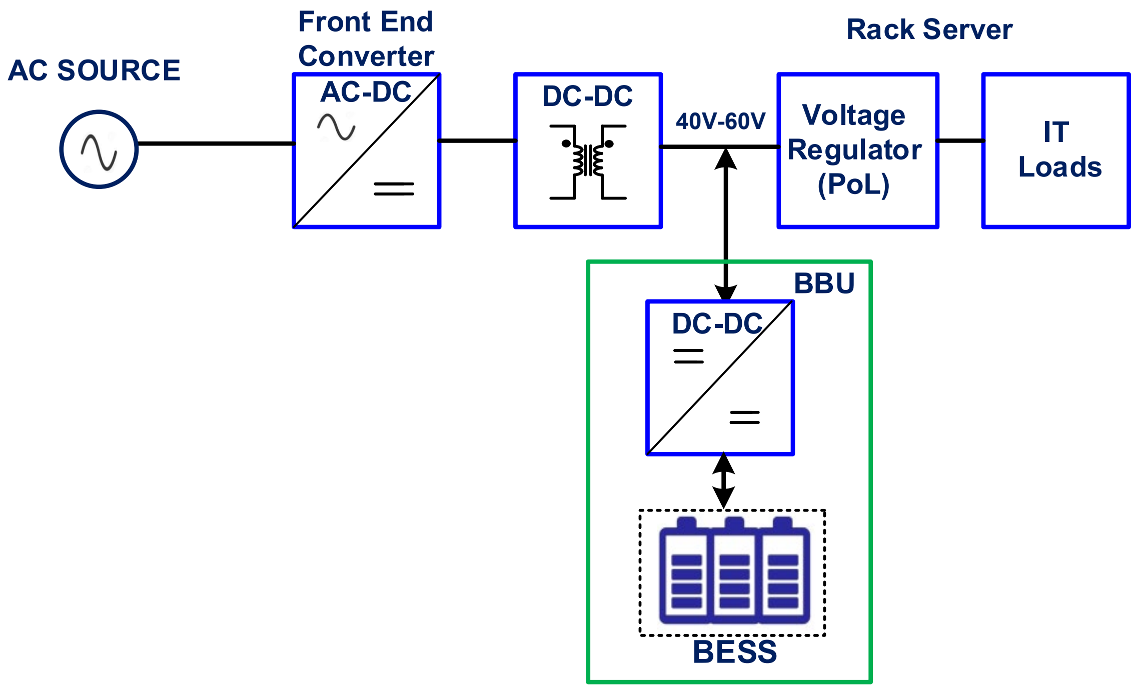

Figure 2: 48V Improved Power Architecture

48V BBU Architecture (Buck-Boost)

For a 48V server BBU system as shown in Figure 3, a quad-switch bi-directional buck-boost is the most common and robust option to manage varying input/output conditions and ensure reliable power to the load. Current balancing for parallel power paths should be deployed if multiple phases are used.

Topology Leverages Buck-Boost Operation:

- Boost operation when battery State of Charge (SoC) is low (charging 38V to 48V)
- Buck operation when battery SoC is high (54V to 48V)
- Ensures reliable power to the server DC bus

Features

- Enables peak transient power sharing and maintains a fixed 48V output, enhancing overall system efficiency.
- Eliminates redundant UPS stages, reducing complexity and losses.
- Facilitates natural, streamlined power flow.
- Simplifies power conversion stages.
- Improved system reliability and modularity.

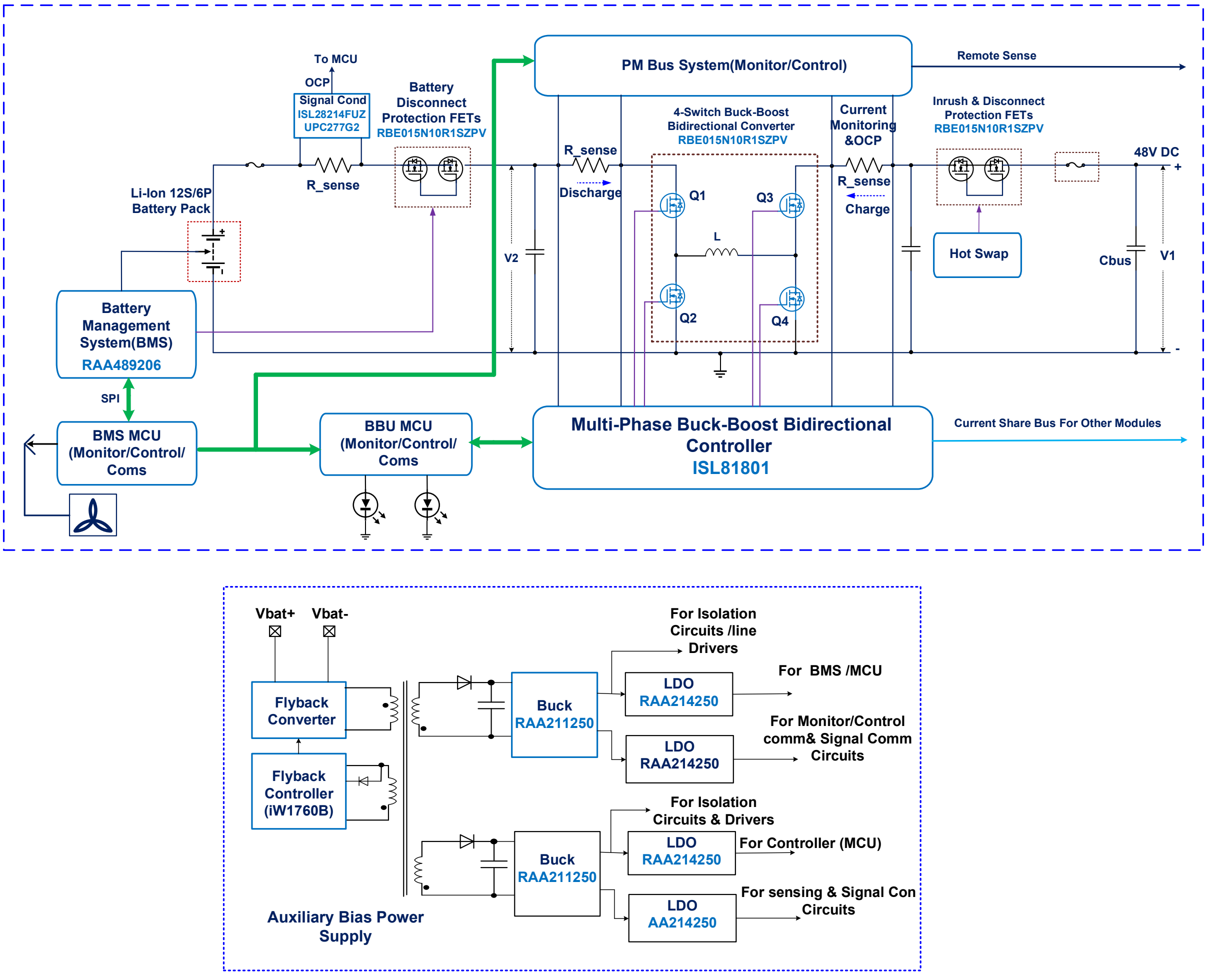

Figure 3 48V Buk-Boost Server BBU System Architecture

Table 1: Key Specifications

Parameters	Specifications
Topology	Bi-directional Buck-boost
Battery voltage range	36V to 60V (Li-ion battery)
Bus voltage	48V
Output power	Up to 12kW in multiphase depends on server load
Switching frequency	100kHz to 400kHz
Efficiency	≥97% (multi-phase)
Control	Voltage and current control with digital supervisory control
Buck or Boost controller	ISL81801 dual-phase bi-directional, up to 80V input, ideal for BBU
Switching devices	150V Renesas REXFET MOSFETs
Aux Power supply	iW1760B, RAA211250, RAA214250 resonant flyback/dual-switch flyback

48V BBU Architecture (Buck or Boost)

For a 48V Server BBU system shown in Figure 4, bi-directional buck or boost converters are an ideal and often essential solution particularly when the system must both charge and discharge a battery pack to ensure reliable power to the load. The buck/boost topology supports bi-directional energy flow.

Topology Uses Buck or Boost Operation

- Boost operation (discharging), battery is discharged and supplies power to server bus V_{bat} > 48V
- Buck operation (charging), battery gets charged from a server bus when V_{bat} < 48V
- Ensures reliable power to the server DC bus

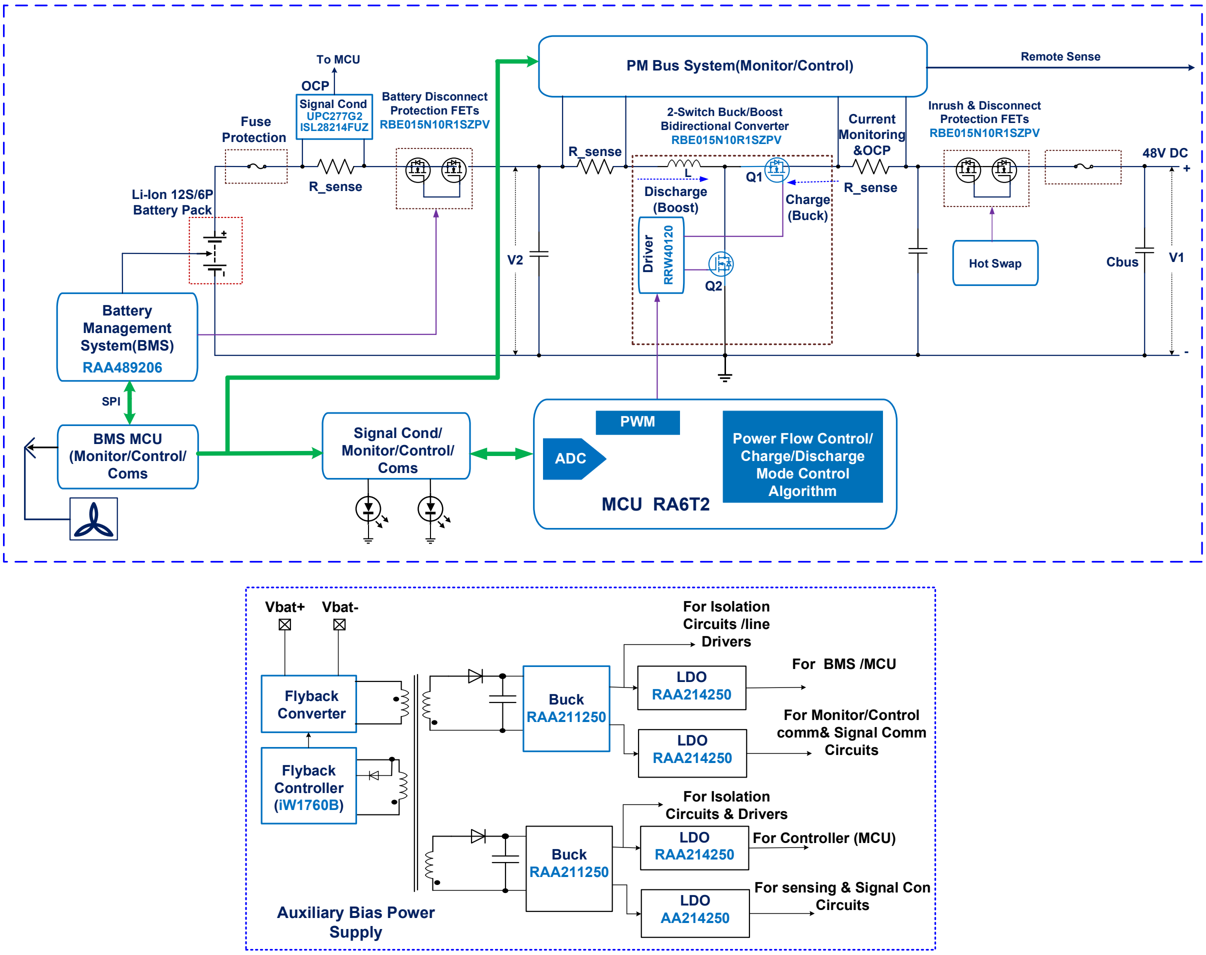

Figure 4: 48V Server BBU System (Buck or Boost)

Table 2: Key Specifications

Parameters	Specifications
Topology	Bi-directional Buck or Boost
Battery voltage range	36V to 60V (Li-ion battery)
Bus voltage	48V
Output power	Up to 5kW multi-phase dependent on server load
Switching frequency	100kHz to 800kHz
Efficiency	≥96%
Control	Voltage and current control with digital supervisory control
Buck or Boost controller	RA6T2 digital MCU manages bi-directional power flow and mode transition (charge/discharge)
Switching devices	150V Renesas REXFET MOSFETs or 100V GaN FETs
Aux power supply	iW1760B, RAA211250, RAA214250 resonant flyback/dual-switch flyback

HV BBU Architecture

AI data centers are increasing computing density by transitioning from traditional low-voltage distribution to 800V HVDC bus architectures, reducing conduction losses, minimizing cable size and improving power conversion efficiency to meet massive AI workload demands. To address high-power demands for data centers and AI infrastructure, the power system must be designed to be scalable and efficient. An 800V BBU shown in Figure 5 is a high-voltage backup energy storage system designed to provide short-term backup and power conditioning to the data center's power infrastructure, especially during grid interruptions or transitions.

Features

- High power density
- Improved system efficiency
- Reduced copper losses
- Supports fast transient load demands
- Lower component count

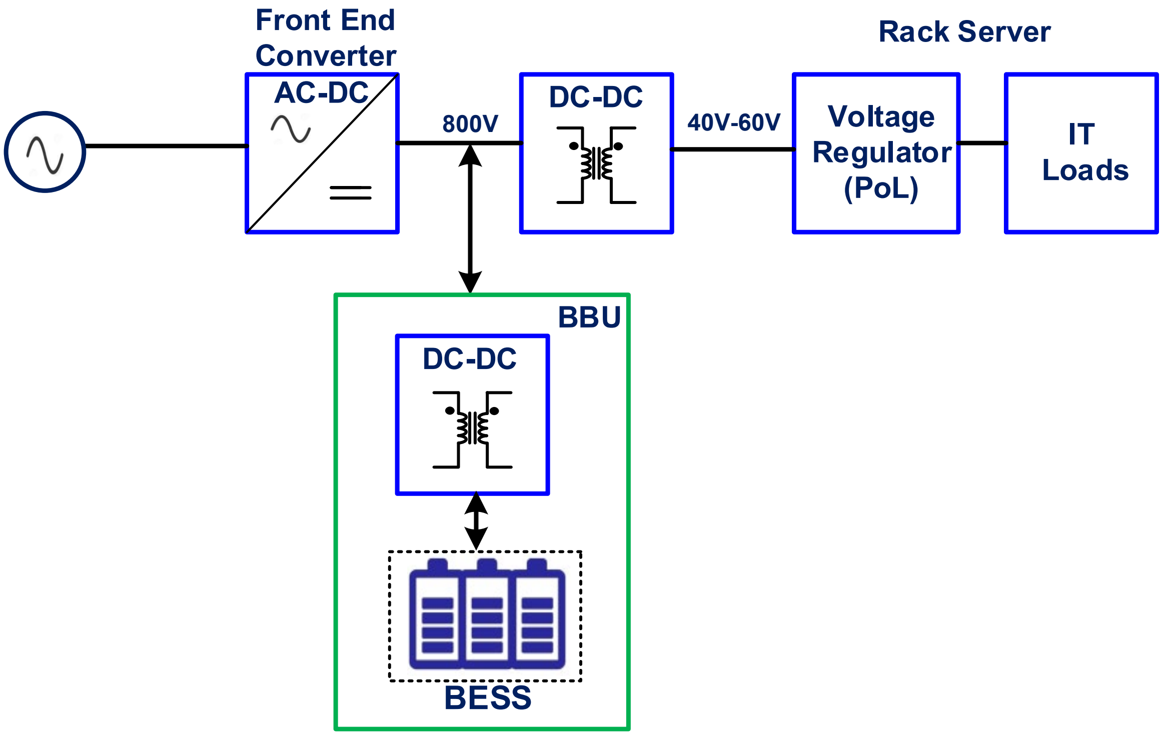

Figure 5: High Voltage Battery Backup System Architecture

800V BBU Architecture (Isolated Bi-directional)

In high-voltage server BBU systems operating at 800V DC bus shown in Figure6, the isolated bi-directional DC/DC converter serves as a high-efficiency and fast backup switching (<5 ms), next-generation power conversion architecture.

Advantages of Bi-directional Isolated LLC Resonant Converter

- Suitable for ultra-wide voltage gain range applications
- Soft switching can be realized within entire voltage and load range
- High efficiency and power density
- Eliminates higher voltage rating device as stacked half-bridge or multi-level topologies allow use of 650V-rated power switches, which have significantly better figure of merit compared to 1200V-rated devices
- Reduced resonant design complexity

Topology Leverages Bi-directional Operation

- Battery is charged from a server bus when $V_{bat} < 48V$
- Battery is discharged and supplies power to server bus $V_{bat} > 48V$
- Ensures reliable power to the server DC bus

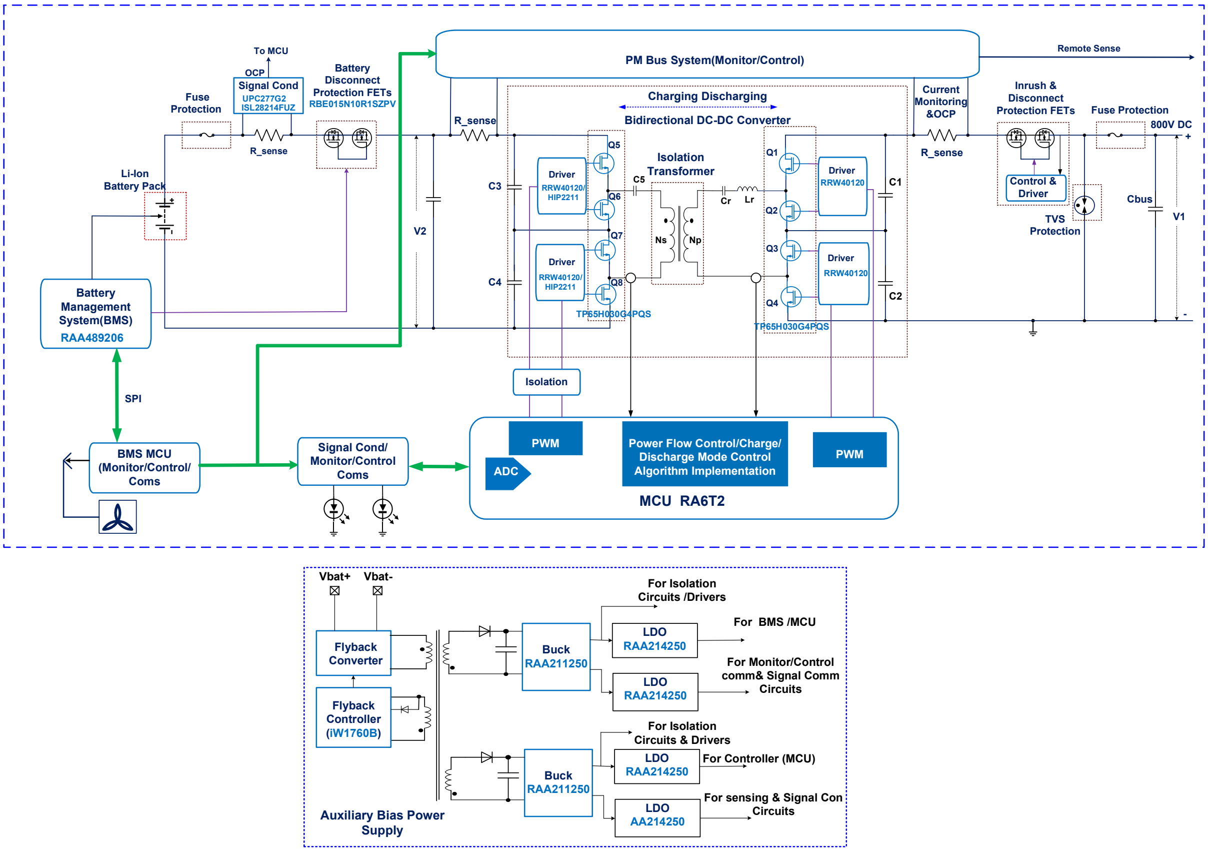

Figure 6: 800V HV BBU System (Isolated Bi-directional DC/DC Converter)

Table 3: Key Specifications

Parameters	Specifications
Topology	Isolated bi-directional LLC
Battery voltage range	36V to 60V (Li-ion battery) for low voltage 300V to 400V for high voltage
Bus voltage	700V to 900V (nominal 800V)
Output power	6kW to 12kW dependent on server rack
Switching frequency	100kHz to 800kHz
Soft switching	ZVS (primary), ZCS (secondary)
Efficiency maximum	98%
Control	Voltage and current control with digital supervisory control
Controller	RA6T2 digital MCU manages bi-directional power flow and mode transition (charge/discharge)
Switching devices	TP65H030G4PQS GaN FETs and 150V Renesas REXFET MOSFETs
Aux power supply	iW1760B, RAA211250, RAA214250 resonant flyback/dual- switch flyback

Key Components Description

- **Battery Pack:** Typically composed of Lithium-ion (Li-ion) cells arranged to deliver a 48V/800V nominal output bus voltage
- **DC/DC Power Converter:** Manages energy flow between the battery and the system/load, regulating output voltage and current to ensure stable and reliable power delivery. Topology and design vary depending on the system voltage (e.g., 48V or 800V), isolation requirements, bi-directional power flow and efficiency needs.
- **Battery Management System (BMS):** Monitors and manages cell voltages, temperatures, current, state of charge (SoC) and state of health (SoH) to ensure safe and efficient battery operation. Provides protection against over-charge, over-discharge, thermal overload and short circuits.
- **Digital Control and Monitor with MCU:** Executes and supervises real-time control algorithms, datalogging, system monitoring, communication and safety protocols
- **Communication Interface:** Protocols like RS485, CAN or Ethernet enable the BBU to interface with power distribution units, energy management systems and data center controllers for real-time monitoring, control and status reporting.
- **Protection:** Protection such as OCP, OVP, OTP etc., must be implemented at multiple levels as battery, converter, communication and system interfaces

Design Challenges

Designing a BBU for data centers includes challenges such balancing efficiency, reliability, size and cost, as well as safety limits while addressing fast switching topology, battery health monitoring and EMI/EMC compliance.

- **Bi-directional Conversion:** High-efficiency converters needed for both charging and discharging
- **Battery Safety:** Demands precise SoC/SoH monitoring and thermal/fault protection
- **Thermal and Space:** Compact design must manage heat effectively in tight rack spaces
- **EMI/EMC:** Fast switching requires robust filtering and EMI/EMC shielding
- **Voltage/Current Stress:** 48V for high current, 800V for high isolation and safety needs
- **Fast Response:** Must deliver immediate backup during power loss
- **Reliability:** Long-life, fault-tolerant components critical for 24/7 uptime
- **Cost and Supply:** Balancing performance with supply chain constraints

Table 4 shows a brief comparison of the design factors and challenges between 48V and 800V bus architectures.

Table 4: Design Challenges of 48V versus 800V Bus Architecture

Challenge	48V	800V
Power conversion	Simple Buck/Boost	Complex isolated (CLLC, DAB)
Bi-directional flow	Adds complexity	Robust bi-directional design needed
Current distribution	Very high current, large busbars, I^2R losses	Lower current, thinner busbars, better efficiency
Scalability	Limited, bulky wiring	Better scalability with centralized HV distribution
Layout constraints	Wide traces for current	High-voltage spacing, insulation barriers
Protection circuitry	Overcurrent, thermal, fuse	Surge, inrush, arc fault protection
Safety and insulation	Simpler, lower risk	Needs reinforced insulation (per IPC-9592B)
Cost trade-off	Lower cost, lower voltage components	Higher initial cost, higher voltage-rated parts

Summary

Renesas offers comprehensive BBU solutions for both 48V and 800V Data center architectures, supporting power ratings from a few kilowatts up to 12 kW. These solutions integrate advanced power conversion topologies using Renesas MOSFETs, GaN devices, gate drivers, BMS solutions, auxiliary bias circuit controllers and MCUs for real-time monitoring and power flow control. Along with delivering a strong price-to-performance ratio, Renesas offers extensive design support resources including reference designs, firmware libraries, design tools and technical assistance to streamline development and ensure industry compliance and protection. Visit renesas.com/power to learn more.

References

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