Technical Article

Designing a data center power architecture with supply and processor rail-monitoring solutions

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Machine intelligence enables a new era of productivity and is becoming an integral part of our lives and societies across many disciplines and functions. Machine intelligence relies on computing platforms that execute code, decipher data, and learn from trillions of data points in fractions of a second. The computing hardware for machine intelligence needs to be fast, extremely reliable, and powerful. Designers must combine solid design practices with self-diagnostics and continuous monitoring schemes to prevent or manage potential faults such as data corruption or communication errors in the system.

An essential element in such monitoring systems is the supervision and monitoring of power rails throughout the system. In this article, I'll examine and describe some of the best practices for designing supply and processor rail-monitoring solutions in enterprise applications.

Understanding power architectures

Enterprise computing relies upon a complex power architecture that delivers energy from AC sources to every point of load in the system. Figure 1 is a high-level illustration of elements in a server rack.

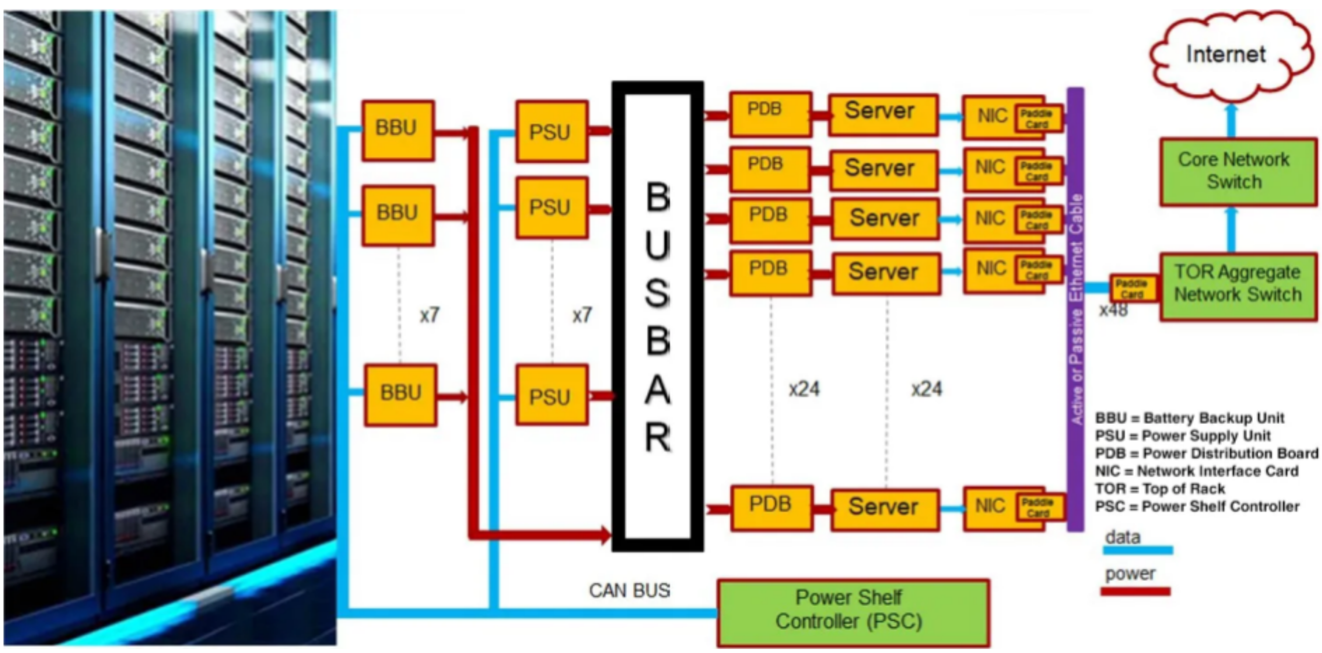

Figure 1. High-level server rack diagram with distributed battery backup units (BBUs) and power supply units (PSUs) connected to a busbar that then distributes AC power thought to the rack. Source: Texas Instruments

A high-efficiency—typically >91% for a titanium-grade design—PSU converts and then distributes AC power (208V or 240V) to 48V throughout the rack. The power distribution board (PDB) then converts DC power to various voltages, typically 12V, 5V, and 3.3V, for feeding to subsystems including the motherboard, storage, network interface cards (NICs), and switches, and system cooling. Each of these subsystems, in turn, has its own locally managed power architecture. A battery backup unit (BBU) maintains system power during any AC line disruptions.

Designing for durability

Each subsystem requires a reliable power design and monitoring. Let's examine some of these subsystems further.

The PSU

PSUs have several types of monitoring to ensure reliable operation and delivery. They monitor the AC mains' output voltage while also detecting internal temperature, over- and under-voltage conditions, and short circuits.

Server designs also require N+1 redundancy: "N" represents the minimum number of necessary PSUs to meet server power needs. An additional PSU ("+1") is available if one of the other PSUs encounters a temporary or permanent fault or failure.

The PDB

As mentioned earlier, the PDB converts a 48-V input to several DC rails, including 12V, 5V, and 3.3V. Although comparators with simple shunt references can be used to monitor each of these rails for overvoltage and undervoltage conditions, modern-day voltage supervisors offer a small footprint and ease of design and provide additional benefits such as hysteresis and input-sense delay for noise immunity, an adjustable output delay to avoid false triggers during power up, and higher accuracy for the highest detection reliability.

Many new voltage supervisors, such as the Texas Instruments (TI) TPS3760, are rated for voltages as high as 70V, and can monitor 48V and other bus voltages directly without needing a low-dropout regulator or dedicated power rail. In addition to real-time supervision, advanced monitoring integrated circuits can provide telemetry data on the most vital rail voltages to enable predictive maintenance and historical fault analysis, significantly reducing system downtime.

Another design consideration is early power failure detection. These circuits monitor specific supply rails for sudden voltage drops and alert the host or processor to take swift action in anticipation of a power loss. A high-speed and precise undervoltage supervisor performs this function. Figure 2 illustrates an example of this type of design and its timing diagram.

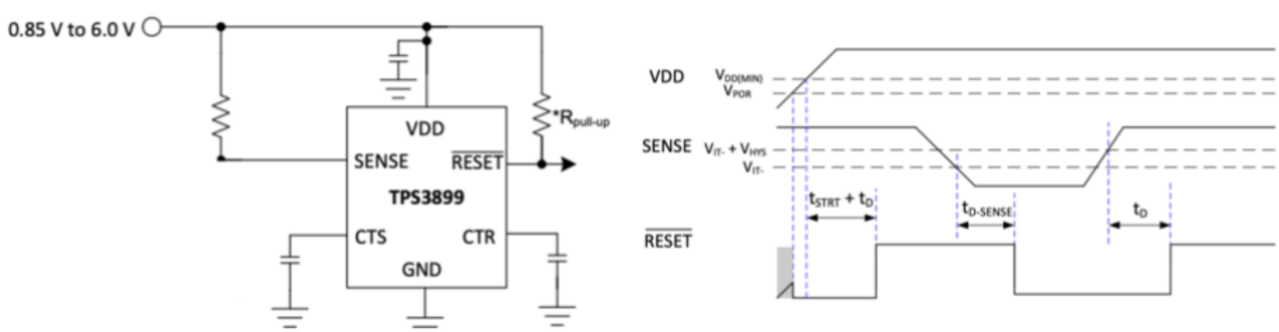

Figure 2. A voltage supervisor example with a timing diagram, monitoring the 0.85 to 6.0V supply rail for sudden voltage drops to take action in the event of a power loss. Source: Texas Instruments

The motherboard

Motherboard power rails present designers with a different set of challenges, which I'll examine in more detail in this section.

Processor rail monitoring

Modern processors are very sensitive to variations in their power supply rails. There are many reasons for this, but it is mostly because these processors operate at voltages as low as 0.7V with reduced tolerance for voltage fluctuations and utilize features such as dynamic voltage and frequency scaling.

Consequently, the processors require high-precision window voltage supervisors. Window supervisors monitor the supply voltage for both overvoltage and undervoltage conditions. Devices targeted for these applications, such as TI's TPS389006, have an accuracy of ±6mV. Designers can adjust the glitch filter up to 650ns through the I^2C registers.

Another essential aspect of power-rail design is the system's ability to maintain stability during rapid load transients. Modern processors can shift from idle to full load in microseconds, causing sharp voltage droops or overshoots if the power supply and monitoring systems are not designed with fast loop responses and the appropriate output capacitance.

Proper power-up and power-down supply sequencing is also essential for the motherboard and processor. Sequencing ensures proper system initialization—for instance, a processor may require that the memory controller be operational before executing instructions. Sequencing also prevents large inrush currents and voltage spikes during power-up. During power-down, sequencing maintains data integrity by giving memory and storage devices enough time to save data or complete operations before losing power.

Figure 3 provides a design example for the monitoring and sequencing of the supply rails.

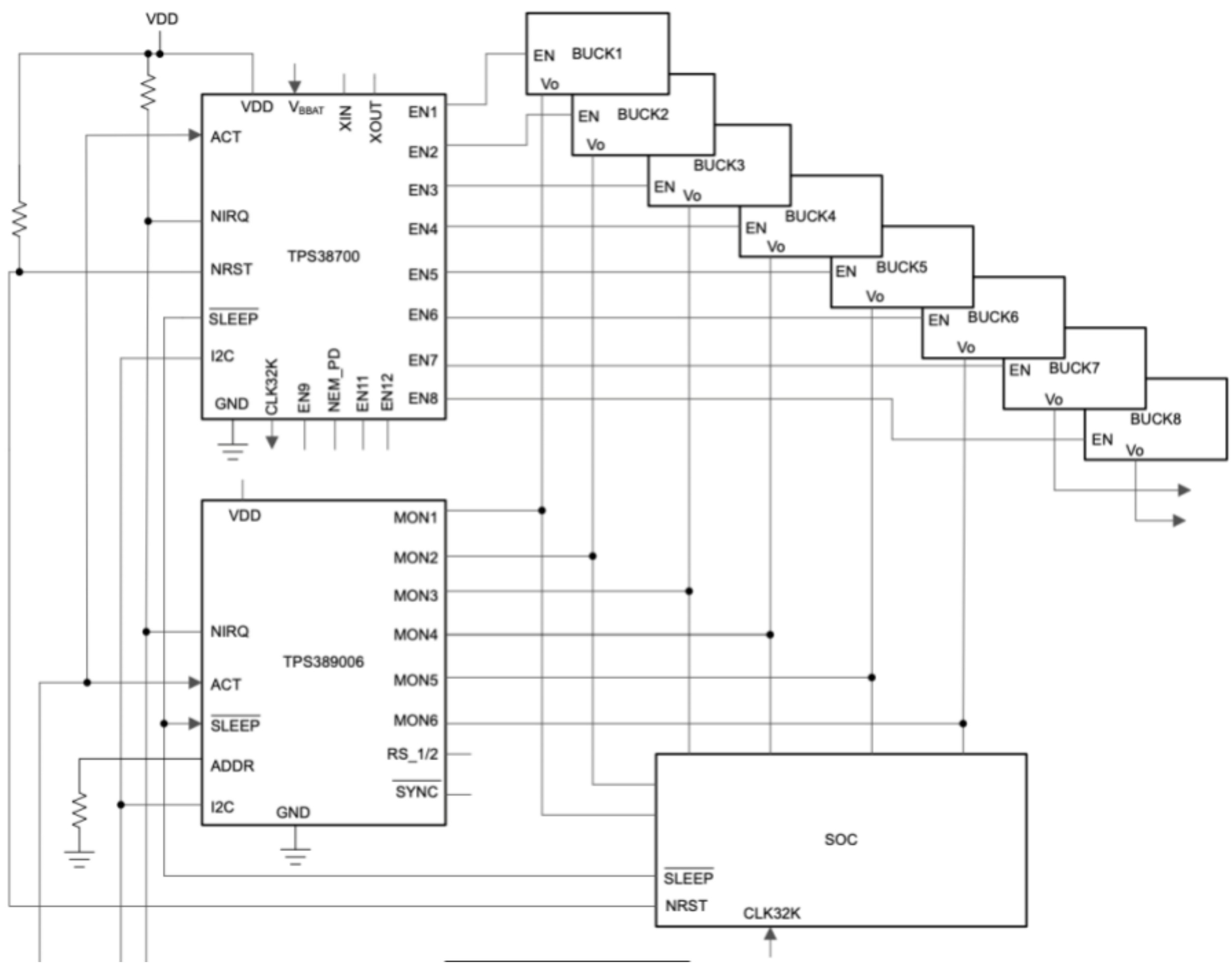

Figure 3. Supply-rail monitoring and sequencing examples for proper system initialization. Source: Texas Instruments

Finally, managing inrush current is vital for systems with hot-swappable components to avoid tripping circuit protection or destabilizing the power bus. Hot-swap controllers equipped with integrated current limiting and fault detection ensure smooth insertion and removal without disrupting other active subsystems.

Future trends

The enterprise industry is poised to transition to a $400V_{DC}$ power-distribution system, which would increase efficiencies by eliminating redundant power-conversion stages and I^2R losses and reduce copper usage and costs. Such high-voltage systems will demand even more high-powered rail monitoring, with faster fault detection and isolation, to maintain safety and system uptime. A new generation of high-voltage monitoring solutions is emerging to address the future design needs in this space.

Compelling power architectures are essential for ensuring reliable and uninterrupted operation in enterprise systems. Combining solid power-design practices with real-time monitoring and early fault detection helps prevent unexpected failures and protects critical workloads. As system complexity grows and power architectures evolve, especially with the shift toward higher voltage distribution, careful planning and rail supervision will continue playing a role in delivering safe and efficient performance.

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