Programmable Battery Systems

Introduction

Modern energy systems are strongly coupled, where voltage, current, temperature, and internal resistance interact continuously. Yet conventional architectures attempt to manage these interactions using separate, sequential control loops, typically implemented through software-based battery management systems (BMS). While these systems improve monitoring, they do not address the root limitation: the electrical topology remains fixed and slow to adapt. This mismatch between system behavior and control architecture is the underlying cause of instability, inefficiency, and thermal runaway.

The Need for Programmable Systems

- Electrochemical systems cannot be effectively controlled through delayed, parameter-based correction alone.
- When abnormal conditions arise—such as rapid load changes, imbalance between cells, or localized heating—traditional systems respond reactively, often too late.
- A new approach is required.

Programmable Battery Operating Systems (BOS) introduce a paradigm shift:

- Instead of treating batteries as static assemblies, BOS treats them as dynamic, relational networks that can adapt structurally in real time.
- This approach is grounded in a unifying principle:

Strongly coupled systems must be governed through a single coherent action, not sequential corrections.

By enabling real-time reconfiguration of electrical connectivity, BOS allows the system to:

- redistribute electrical and thermal stress
- isolate unstable nodes
- balance energy conditions dynamically
- route power efficiently between source, storage, and load

This transforms the battery from a passive component into an active energy routing system.

The Single-Action Principle (SAP): A Unified Control Framework

At the core of BOS lies the Single-Action Principle (SAP).

SAP states that in a strongly coupled system, control must be executed as a single, unified action derived from the full system state, rather than as multiple sequential corrections.

- In BOS, this is implemented physically through topology reconfiguration based on the rate of change (dx/dt) of key system variables.
- However, SAP is not limited to energy systems.
- SAP defines a broader framework within Relational Dynamics, where system behavior is governed by relationships and interactions rather than isolated variables.
- This establishes SAP as a bridge between physical systems (energy) and computational systems (intelligence):
    - In energy systems, SAP manifests as real-time topology switching (BOS)
    - In intelligent systems, SAP can manifest as unified decision layers that replace multi-step orchestration

Thus, SAP provides a common foundation for:

- Battery Operating Systems (BOS)
- AI orchestration systems (e.g., Vantage State Intelligence)
- Future programmable infrastructure systems

The BOS Architecture

The Battery Operating System (BOS) introduces a hardware-governed control architecture for programmable energy systems.

US11,398,735B2 – Plasmic Control (Digital/Analog)
US 11,799,301 B2 – Node Fusion

In BOS-based systems:

- sources, storage elements, and loads are represented as nodes
- a programmable switching topology dynamically interconnects these nodes
- control is achieved through topology reconfiguration, not delayed parameter adjustment

Instead of reacting after instability occurs, BOS evaluates the rate of change (dx/dt) of key variables—voltage, current, temperature, and internal resistance—and reconfigures the network proactively.

This enables:

- sub-millisecond response to instability
- prevention of thermal runaway before it begins
- stable operation under dynamic conditions

In this architecture, intelligence is embedded directly in hardware, enabling real-time reflexive control without software latency.

From Battery Packs to Energy Routers

The BOS framework transforms batteries into programmable energy routers.

Rather than operating as fixed storage units, BOS-based systems dynamically route energy between:

- renewable sources (e.g., solar)
- grid inputs
- storage elements
- end-use loads

Simultaneous Parallel Charging in Uninterruptible Series Discharging energy storage systems (Pat. No. US12,266,969 B2), this enables:

- power delivery **even when source voltage is lower than the load**
- simultaneous charging and discharging
- dynamic voltage and current adaptation through topology
- elimination of intermediate conversion stages

By removing the need for DC-DC converters, MPPT controllers, and inverter stages, BOS simplifies system architecture while improving efficiency and safety.

System Advantages

BOS-based systems offer a fundamentally different performance profile:

- Predictive stability through unified control of strongly coupled variables
- Hardware-native intelligence with sub-millisecond response
- Prevention of thermal runaway, not just protection after detection
- Topology-driven control, replacing fragmented subsystems
- Reduced system complexity through elimination of conversion stages
- Improved efficiency by minimizing switching and conversion losses

Extending BOS to Intelligence Systems

The principles underlying BOS extend beyond energy systems.

Conventional AI and software systems rely on multi-step orchestration, where tasks are decomposed into sequences of actions. This approach introduces latency, inconsistency, and inefficiency.

By contrast, applying SAP enables:

- unified decision-making based on full system context
- reduction of iterative loops
- coherent system-level behavior

This establishes a pathway toward hardware-native intelligence and relational AI systems, where computation is aligned with the same principles governing physical systems.

In this sense, BOS represents the physical implementation of SAP, while future intelligent systems represent its computational extension.

SWITCHING BATTERY®
Someday, Every Battery will be a Switching Battery