ZOE AI-EMS

Advanced Energy Optimization Playbook

The Intelligence Behind Every Energy Decision

Turning Every Energy Decision into Maximum Value

Index

1. Document Overview & Scope

1.1 Scope and Purpose

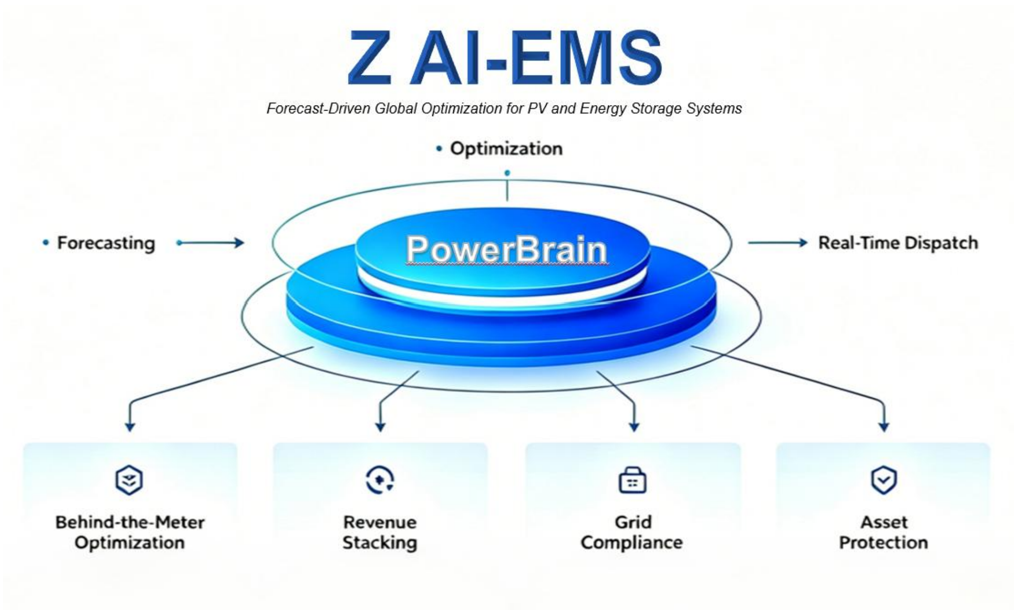
This document describes the control philosophy, optimization logic, and asset protection mechanisms of the ZOE AI-EMS. At the core of the system is ZOE PowerBrain, ZOE's AI-driven optimization engine. By combining forecasting, multi-objective optimization, dynamic strategy adaptation, and real-time dispatch execution, ZOE PowerBrain continuously determines the optimal operating strategy for PV and battery energy storage systems.

Unlike traditional rule-based EMS platforms that rely on fixed schedules and predefined control priorities, ZOE PowerBrain continuously evaluates future operating conditions, competing economic opportunities, and operational constraints before generating dispatch decisions.

This document explains:

- How PowerBrain makes decisions;
- Which optimization objectives are evaluated;
- Which operational constraints are enforced;
- How economic performance and asset protection are balanced

Detailed configuration procedures and user operations are provided separately in the EMS User Manual.



1.2 Target Audience

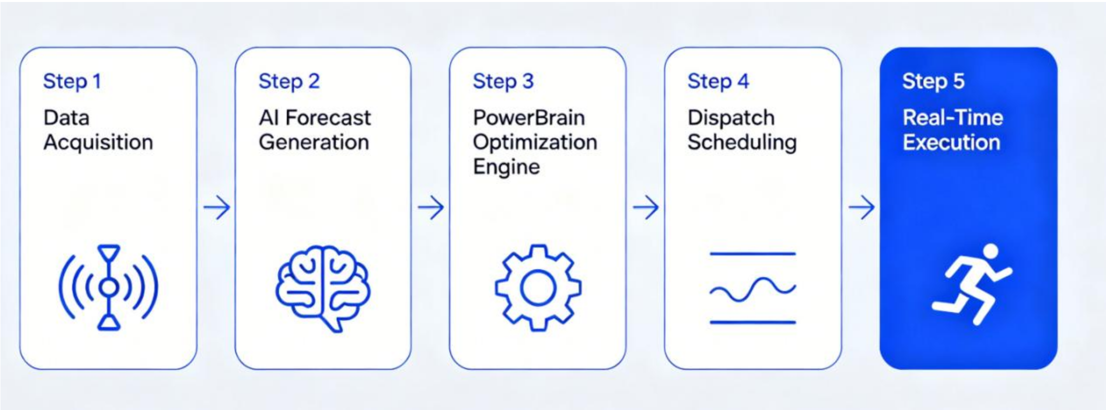
This document is intended for:

- Solution Architects
- EPC Contractors
- System Integrators
- Asset Owners / Operators
- Energy Aggregators
- Technical Due Diligence Teams

2. **ZOE AI-EMS Decision Framework**

2.1 **ZOE PowerBrain Architecture**

ZOE PowerBrain serves as the intelligence layer of the ZOE AI-EMS. It transforms operational data into executable dispatch decisions through a continuous optimization process.



ZOE PowerBrain Decision Flow

The objective is not to maximize a single strategy, but to continuously identify the operating strategy that delivers the highest overall system value while maintaining operational safety and compliance.

2.2 **Forecast-Driven Decision Making**

Traditional EMS platforms typically execute predefined schedules or threshold-based rules. ZOE PowerBrain adopts a forecast-driven control philosophy. Instead of reacting to events after they occur, the system continuously predicts future operating conditions and proactively adjusts dispatch decisions.

Typical forecast inputs include:

- Site Load Forecast
- PV Generation Forecast
- Electricity Price Forecast
- Weather Forecast
- Market Signals

Forecast availability depends on project configuration, data accessibility, and market conditions.

2.3 **Multi-Objective Energy Optimization**

Energy storage assets rarely operate with a single objective, and traditional EMS platforms often execute independent strategies according to fixed, rigid priorities. A battery reserved exclusively for energy arbitrage may be unavailable for peak demand reduction, while a strategy focused solely on demand charge management may miss lucrative market opportunities.

To resolve these conflicts, ZOE PowerBrain incorporates load/PV generation/electricity prices forecasting, market opportunities, and operational constraints into a single, unified optimization framework. The engine evaluates all available opportunities simultaneously rather than optimizing individual strategies independently.

Typical optimization objectives include:

- PV Self-Consumption Optimization
- Peak Shaving & Demand Charge Management
- Energy Arbitrage
- Negative Price Response
- Renewable Curtailment Recovery

All optimization decisions are strictly constrained by:

- Battery SoC Limits
- Thermal Limits

- Warranty Constraints
- Grid Import Limits
- Export Restrictions
- Grid Connection Agreements
- Asset Protection Policies

By continuously balancing these competing objectives and operational constraints within a single optimization process, ZOE PowerBrain determines the operating strategy that delivers the highest overall system value under current and conditions forecasting. This enables the system to dynamically co-optimize self-consumption, peak demand reduction, and battery asset preservation.

2.4 **Dynamic Strategy & Real-Time Dispatch**

Operating conditions continuously evolve throughout the day. Electricity prices fluctuate. Weather forecasts change. PV production deviates from predictions. Load patterns shift. Market opportunities emerge and disappear.

To respond to these dynamic shifts, ZOE PowerBrain continuously re-evaluates forecasts and translates optimization results into real-time dispatch execution. ZOE PowerBrain does not operate strategies independently; all economic objectives are balanced simultaneously within the unified optimization framework to generate live control commands.

The resulting real-time dispatch commands ensure that the system always executes the highest-value operating decision at any given second, while respecting all applicable operational constraints and project-specific weighting models.

3. **Behind-the-Meter Economic Optimization Strategies**

The following sections define the core behind-the-meter economic optimization pillars continuously evaluated by ZOE PowerBrain. These strategies focus on maximizing immediate on-site cost savings and localized asset returns.

3.1 **PV Self-Consumption Optimization**

ZOE PowerBrain prioritizes the utilization of locally generated PV energy within the facility. Available solar generation is supplied to local loads first, while surplus energy is directed to the battery before importing electricity from the grid. By maximizing on-site renewable energy utilization, this strategy reduces dependence on purchased electricity, improves energy self-sufficiency, and enhances overall project economics.

Typical applications include commercial buildings, logistics parks, industrial facilities, and manufacturing sites.

3.1.1 Renewable Curtailment Recovery

When PV production exceeds both local site demand and grid export capacity limits, ZOE PowerBrain evaluates available battery capacity, forecasted load, and future charging opportunities to automatically capture and store surplus renewable energy that would otherwise be lost to inverter curtailment. By recovering this stranded energy, the system increases total renewable utilization and maximizes the financial return on the on-site generation investment.

3.2 **Peak Shaving & Demand Charge Management (DCM)**

ZOE PowerBrain utilizes historical operating data, predictive analytics, and real-time power monitoring to suppress facility demand peaks at the Point of Common Coupling (PCC). This predictive framework simultaneously addresses two distinct dimensions at the PCC: Physical Infrastructure Protection (Peak Shaving) and Tariff Cost Optimization (DCM).

- Peak Shaving (Physical Overload Protection): Operates through high-speed local control to respond rapidly to load fluctuations and prevent infrastructure overloads. It serves as an instantaneous physical safeguard against sudden power surges caused by heavy machinery startups, large motor loads, or other high-power events. By dynamically discharging the battery to maintain site demand below the available connection capacity, the system helps avoid breaker trips and costly grid infrastructure upgrades.
- Demand Charge Management (Financial Tariff Optimization): Operates within the global optimization framework using forecasted load profiles and utility-defined demand billing intervals. PowerBrain utilizes AI-driven load forecasting to identify potential billing peaks in advance and strategically reserves battery capacity to reduce demand charges. Instead of discharging prematurely, the system optimizes battery utilization across the applicable

billing interval to minimize recorded peak demand while preserving flexibility for other value streams.

Typical applications include industrial parks, data centers, and high-load commercial manufacturing sites.

3.3 **Energy Arbitrage**

ZOE PowerBrain evaluates electricity price forecasts and automatically schedules battery charging and discharging cycles to capture energy cost differentials across varying time periods. Rather than relying on rigid, time-of-use schedules, dispatch decisions are continuously dynamic—optimizing based on volatile day-ahead markets (DAM), intraday markets (IDM), or dynamic retail tariff programs to minimize net energy procurement costs.

3.3.1 Negative Price Response

When wholesale electricity prices drop into negative territory, PowerBrain automatically determines whether charging the battery yields net-positive economic value. The algorithm factors in wholesale energy credits, applicable network charges, future dispatch requirements, and battery availability. Where dynamic pricing contracts are active, the system automates charging during qualified negative-price windows, subject to local tariff eligibility and project configuration, while safeguarding overall asset health and future operational flexibility.

4. **Future-Ready Revenue Stacking (VPP & Grid Interactivity)**

Beyond on-site optimization, the ZOE AI-EMS architecture provides a secure bridge to external revenue opportunities. Through advanced integration interfaces, the system enables coordination with utilities, aggregators, Virtual Power Plants (VPPs), and grid operators, allowing battery assets to evolve from passive energy consumers into active participants in modern electricity markets.

4.1 **Demand Response & Flexibility Programs**

ZOE PowerBrain supports participation in utility-led Demand Response (DR) programs and emerging local flexibility markets through secure external dispatch interfaces.

When grid operators, utilities, or flexibility service providers request temporary load reduction or power injection during periods of network stress, the EMS automatically evaluates available battery capacity, site operating conditions, and existing optimization objectives before executing the requested response.

Rather than treating flexibility events as isolated commands, PowerBrain incorporates these signals into its unified optimization framework, balancing flexibility revenues against on-site energy costs, battery availability, and operational constraints.

This capability enables asset owners to unlock additional revenue streams while supporting grid reliability and renewable energy integration.

Typical applications include:

- Utility Demand Response Programs
- Local Flexibility Markets
- Distribution Network Congestion Management
- Peak Demand Reduction Programs
- Capacity Market Participation

Typical market examples include flexibility programs in the United Kingdom, local congestion management schemes in the Netherlands, and emerging distributed flexibility initiatives across Europe. ZOE PowerBrain continuously evaluates the economic value of flexibility events against all other available opportunities to ensure participation remains aligned with overall asset value maximization.

4.2 **VPP Participation & Ancillary Services**

The ZOE AI-EMS architecture supports integration with Virtual Power Plant (VPP) platforms, enabling decentralized energy storage assets to be aggregated into coordinated energy portfolios.

Through secure and low-latency communication interfaces, PowerBrain can receive dispatch instructions from aggregators and market operators while continuously maintaining local operational constraints and optimization priorities.

Supported communication interfaces may include:

- IEC 60870-5-104
- Modbus TCP
- OpenADR
- REST APIs
- Utility-specific communication protocols

Once integrated into a VPP portfolio, battery assets may participate in ancillary service markets and flexibility programs, creating additional revenue opportunities through grid-support services.

Typical applications include:

- Frequency Containment Reserve (FCR)
- Automatic Frequency Restoration Reserve (aFRR)
- Manual Frequency Restoration Reserve (mFRR)
- Aggregated Distributed Energy Portfolios
- Multi-Asset Revenue Stacking Programs

Participation requirements depend on local market regulations, aggregator qualification processes, and project-specific configurations.

5. Grid Compliance & Interconnection Strategies

5.1 PV Output Smoothing

ZOE PowerBrain coordinates battery dispatch to mitigate short-term PV output fluctuations and improve power stability at the grid connection point. By smoothing renewable generation variability, the system can improve generation predictability, reduce output volatility, and support stable operation of the local distribution network.

Typical applications include utility-scale PV plants and large commercial PV installations.

5.2 Zero Export Control

ZOE PowerBrain enforces export limits at the Point of Common Coupling (PCC) in accordance with local interconnection requirements. When PV generation exceeds site demand, surplus energy is first directed to battery charging. If battery charging capacity is unavailable, remaining generation may be curtailed at the inverter level to maintain compliance with export limits. This strategy helps ensure compliance with non-export agreements and distribution network restrictions.

Typical applications include non-export grid connections and export-constrained projects, including installations subject to Spain's UNE 217001 requirements.

6. **Asset Protection & Operational Constraints**

Asset protection always takes precedence over economic optimization.

6.1 **SoC/DoD Protection**

ZOE PowerBrain enforces configurable upper and lower operating limits for battery State of Charge (SoC) and Depth of Discharge (DoD). These limits are continuously incorporated into optimization decisions and cannot be overridden by economic objectives, ensuring battery health, cycle-life preservation, and manufacturer warranty compliance.

6.2 **Dynamic Power Derating**

ZOE PowerBrain continuously monitors battery operating conditions, including thermal status, cell voltage imbalance, and system health indicators. When predefined operating thresholds are approached, allowable charging and discharging power is automatically reduced to maintain safe operation and prevent complete system shutdowns.

6.3 **Anti-Deep-Discharge**

Auto-Charging If battery charge falls below a predefined threshold due to cell self-discharge or auxiliary electronic overhead, a recovery charge is automatically initiated from available grid or PV sources. This function helps prevent irreversible deep discharge damage during prolonged standby periods.

6.4 **Intelligent Thermal Management Synergy**

Where supported by system architecture and available interfaces, PowerBrain establishes a predictive, feed-forward loop to exchange operating forecasts and dispatch schedules with thermal management systems. This predictive coordination can improve thermal efficiency, optimize HVAC energy consumption, and reduce thermal derating events.

6.5 **Islanding Operation Protection**

Where supported by PCS capabilities and project configuration, ZOE PowerBrain supports supervisory coordination of island operation. The EMS assists with post-transition energy balancing and generation-load stabilization after the PCS executes the grid-to-island transfer.

6.6 **Emergency Shutdown (ESD)**

Control The EMS supports coordinated emergency shutdown procedures during critical fault conditions.

Trigger sources may include:

- Site fire detection systems
- Physical emergency stop buttons
- Ground fault detection systems
- Insulation monitoring devices
- Critical system alarms

The objective is to protect personnel, equipment, and surrounding infrastructure.

7. **Control Philosophy Summary**

ZOE PowerBrain continuously evaluates three categories of information:

Future Conditions Forecast:

- Load Forecast
- PV Forecast
- Electricity Price Forecast
- Weather Forecast
- Market Signals

Economic Objectives:

- PV Self-Consumption Optimization (including Curtailment Recovery)
- Peak Shaving & Demand Charge Management (DCM)
- Energy Arbitrage (including Negative Price Response)
- Demand Response & Flexibility Programs
- VPP Participation & Ancillary Services

Operational Constraints:

- SoC Limits
- Thermal Limits
- Warranty Constraints
- Grid Import Limits
- Export Restrictions
- Asset Protection Policies

By combining AI forecasting, multi-objective optimization, and real-time dispatch execution, ZOE PowerBrain enables the ZOE AI-EMS to continuously identify and execute the highest-value operating strategy for each moment of system operation.

Rather than simply executing predefined rules, ZOE PowerBrain continuously determines what action should be taken, when it should be taken, and how available battery capacity should be allocated across competing opportunities to deliver the highest overall system value.