Solar Plant Full SCADA System

Table of Contents

Chapter 1. Project Origin, Grid Authority, and Objectives

1.1 Project Sponsor and Grid Authority

This project is defined as originating from a utility-scale power system stakeholder operating within a North American bulk electric system. The project sponsor is assumed to be either a regulated electric utility or an independent power producer developing a grid-connected solar generation facility with hybrid energy storage.

The system is designed to operate under the authority and operational oversight of an Independent System Operator. The grid authority is responsible for maintaining system reliability, balancing generation and load, and enforcing operational requirements at the transmission level. The plant described in this document is required to comply with dispatch, ramping, and reporting obligations imposed by such grid authorities.

The design basis explicitly considers operating environments governed by CAISO and ERCOT, recognizing that while specific implementation details may vary by region, the core control and compliance expectations are similar.

1.2 ISO Operated Grid Context

In an ISO-operated grid, generation resources are dispatched to meet system demand while maintaining stability and reliability. Resources connected to the transmission system are expected to behave as controllable assets, responding predictably to dispatch instructions and operating within defined technical limits.

Within this context, the solar power plant is treated as a single aggregated resource at the point of interconnection. The grid authority does not interact with individual inverters, storage devices, or internal plant equipment. Instead, it evaluates compliance based on the net real power delivered to the grid and the plant's ability to follow dispatch instructions without violating ramp rate or safety constraints.

The system described in this document is therefore designed to abstract internal complexity and present a unified, controllable interface to the grid operator.

1.3 CAISO and ERCOT Operating Environment

The design explicitly accounts for operating expectations typical of both CAISO and ERCOT managed systems. These environments impose requirements related to dispatch tracking, ramp rate control, and predictable behavior during normal and abnormal conditions.

While market participation rules, pricing mechanisms, and certification processes differ between CAISO and ERCOT, both environments require that utility-scale resources:

- Accept externally issued real power dispatch commands
- Enforce ramp rate limits at the point of interconnection
- Maintain stable operation during changing grid conditions
- Provide accurate and timely measurement of delivered power
- Transition safely during faults or loss of communications

This system design focuses on the control, coordination, and supervisory behaviors necessary to meet these operational expectations without claiming regulatory certification or market participation authority.

1.4 System Objectives

The primary objectives of the system are as follows:

- To operate a utility-scale solar power plant with hybrid energy storage as a controllable grid resource
- To track grid-issued dispatch commands at the point of interconnection within defined tolerances
- To coordinate solar generation and energy storage assets to meet dispatch and ramp requirements
- To enforce operating limits and safety constraints under all conditions
- To provide operators and grid stakeholders with clear visibility into plant status and performance

All subsequent system requirements, control logic, and implementation deliverables are derived from these objectives.

1.5 Definition of Success

The system shall be considered successful if it satisfies the following conditions:

- All defined system requirements are met under normal operating conditions
- Dispatch commands are followed without violation of ramp rate or power limits
- Loss of assets or communications results in deterministic and safe fallback behavior
- Fault conditions override dispatch objectives and place the system in defined safe states
- The system design can be implemented using industrial control platforms and validated through simulation and testing

Meeting these criteria demonstrates that the system behaves in a manner consistent with expectations for ISO-connected utility-scale generation facilities.

Chapter 2. System Requirements and Design Basis

2.1 Required Power Capacity

The plant shall be designed as a utility-scale resource capable of delivering controllable real power to the grid at the point of interconnection.

The required power capacities are defined as follows:

- Solar generation nameplate capacity: **100 MW**
- Maximum continuous real power delivery at the point of interconnection: **100 MW**
- Maximum controllable real power delivery using energy storage during non-solar periods: **50 MW**

The control system shall ensure that total plant output does not exceed the maximum allowable real power at the point of interconnection under any operating condition.

The plant shall be capable of sustained operation at any dispatch level between zero and one hundred megawatts, subject to resource availability and operating constraints.

2.2 Required Energy Capacity

The plant shall include hybrid energy storage consisting of two distinct storage technologies with complementary operating characteristics.

Lithium Ion Battery Storage System

- Maximum charge power: **50 MW**
- Maximum discharge power: **50 MW**
- Total usable energy capacity: **200 MWh**
- Minimum allowable state of charge: **10 percent**
- Maximum allowable state of charge: **90 percent**

The lithium ion system shall be capable of delivering its rated discharge power continuously for a minimum of four hours under nominal operating conditions.

Flywheel Energy Storage System

- Maximum charge power: **10 MW**
- Maximum discharge power: **10 MW**
- Total usable energy capacity: **2 MWh**

The flywheel system is intended for short-duration power smoothing and rapid response and shall not be relied upon for sustained energy delivery.

2.3 Dispatch Requirements

The plant shall comply with dispatch requirements consistent with ISO-operated grid environments, including those governed by CAISO and ERCOT.

Dispatch requirements are defined as follows:

- Dispatch commands expressed as real power setpoints in megawatts
- Dispatch command resolution: **1 MW**
- Dispatch update interval: **60 seconds**
- Allowable dispatch range: **0 to 100 MW**

The dispatch command shall be treated as the authoritative operating target, subject to safety, availability, and operating constraints.

If the dispatch command exceeds available plant capability, the system shall deliver the maximum achievable output and indicate a dispatch tracking limitation.

2.4 Ramp Rate Requirements

To maintain grid stability and limit stress on plant equipment, the plant shall enforce ramp rate limits at the point of interconnection.

Ramp rate requirements are defined as follows:

- Maximum allowable increase in output: **10 MW per minute**
- Maximum allowable decrease in output: **10 MW per minute**

Ramp rate limits shall apply regardless of the cause of output change, including dispatch commands, solar variability, or storage behavior.

The control system shall coordinate internal assets to ensure that ramp limits are enforced at the plant level under all operating conditions.

2.5 Availability and Reliability Requirements

The system shall be designed to meet the following availability targets during normal operation:

- Solar generation availability during daylight hours: **greater than 98 percent**
- Lithium ion storage availability: **greater than 97 percent**
- Flywheel storage availability: **greater than 97 percent**
- Plant control and supervisory system availability: **greater than 99.5 percent**

Failure or unavailability of any single storage subsystem shall not prevent continued operation of remaining available resources, provided safety constraints are met.

2.6 Operating Constraints

The system shall operate under the following mandatory constraints:

- No asset shall be commanded beyond its defined power or energy limits
- Equipment-level safety interlocks shall override all dispatch objectives
- Protection or fault conditions shall force the plant into predefined safe states
- Loss of dispatch or supervisory communications shall result in a defined fallback operating mode
- Operator actions shall be constrained by defined authority levels and operating modes

These constraints are enforced regardless of grid operating conditions or dispatch objectives.

2.7 External Interfaces and Non-Owned Functions

Certain functions affecting plant operation are governed by external systems, regulatory frameworks, or equipment-level controls and are not directly implemented within the plant control system described in this document.

These functions include:

- **Market Operations and Pricing**
  Dispatch commands are assumed to originate from external market and grid operations systems. The plant control system consumes dispatch signals but does not generate bids, pricing decisions, or market settlements.

- **Reactive Power and Voltage Regulation**
  Voltage control and reactive power behavior are governed by inverter-level controls and grid interconnection requirements. The plant control system shall operate within externally imposed limits and shall not override inverter protection or voltage control functions.

- **Protection Systems and Relay Coordination**
  Electrical protection systems operate independently and have authority to override plant control commands. The plant control system shall respond deterministically to protection trips, breaker openings, and fault indications.

- **Regulatory Certification and Commissioning**
  Formal grid certification, interconnection approval, and witnessed commissioning activities are external processes. This design focuses on control logic behavior and pre-deployment validation.

Explicit recognition of these interfaces ensures correct integration with grid operator expectations while maintaining clear ownership boundaries.

Chapter 3. Grid Interface and Compliance Model

3.1 ISO Dispatch Model

The plant shall interface with the grid through a dispatch-based operating model consistent with ISO-operated transmission systems. Under this model, the grid authority issues real power dispatch commands that specify the desired net output of the plant at the point of interconnection.

The dispatch command represents a plant-level requirement and does not reference individual generation or storage assets. The plant control system is responsible for translating this command into coordinated actions across internal resources while maintaining compliance with all operating constraints.

The dispatch model assumes:

- A single real power setpoint representing total plant output
- Periodic updates at a fixed dispatch interval
- Authority of dispatch commands over normal operating behavior, subject to safety and availability limits

The plant shall behave as a predictable and controllable resource from the perspective of the grid, regardless of internal asset composition or operating state.

3.2 CAISO and ERCOT Dispatch Characteristics

While specific implementation details vary by region, dispatch characteristics used by CAISO and ERCOT share common control expectations that are addressed by this system design.

These characteristics include:

- Dispatch commands issued as real power setpoints rather than direct equipment commands
- Enforcement of ramp rate limits at the point of interconnection

- Evaluation of compliance based on measured plant output rather than internal asset behavior
- Requirement for deterministic and stable response to dispatch changes

The system described in this document is designed to meet these shared characteristics without relying on region-specific market rules or certification procedures.

3.3 Point of Interconnection Definition

The point of interconnection is defined as the single electrical boundary between the plant and the transmission system. All grid-facing measurements, dispatch compliance evaluations, and operating limits are assessed at this location.

From the grid authority's perspective, the plant is treated as a single aggregated resource. Internal distribution of power among solar generation and storage assets is not visible outside the plant boundary.

The control system shall regulate net real power at the point of interconnection such that:

- Measured output tracks the dispatch command within defined tolerances
- Ramp rate limits defined in Chapter 2 are enforced at the point of interconnection
- Any loss of generation or storage capacity is immediately reflected in measured output

The point of interconnection measurement serves as both the feedback signal for control and the authoritative value for grid compliance.

3.4 Measurement and Telemetry Requirements

The plant shall provide continuous measurement of real power at the point of interconnection. This measurement is used for both internal control feedback and external reporting.

At a minimum, the following measurements and status indicators shall be available to the supervisory system:

- Real power delivered at the point of interconnection
- Plant online or offline status

- Current operating mode
- Dispatch tracking status

Internal asset measurements, including solar availability and storage state, are used by the control system to coordinate resources but are not required for grid-facing telemetry within the scope of this design.

All measurements relevant to dispatch compliance shall be updated at a rate sufficient to support the defined dispatch interval and ramp rate enforcement.

3.5 Grid Imposed Operating Modes

The grid authority may impose operating modes that constrain or override normal plant behavior. These modes are treated as external requirements and shall be enforced by the plant control system.

The supported grid-imposed operating modes include:

Normal Dispatch Mode
The plant tracks the issued dispatch command while enforcing all operating constraints.

Curtailment Mode
The plant limits output below available generation. Excess solar production may be curtailed or diverted to storage charging if capacity is available.

Reduced Capability Mode
One or more plant assets are unavailable. The plant continues operation using remaining resources and reports reduced capability.

Offline Mode
The plant is disconnected from the grid and delivers zero real power at the point of interconnection.

Transitions between operating modes shall be deterministic, controlled, and clearly observable through the supervisory system.

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The dispatch model assumes:

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Chapter 4. Control Architecture and Authority Hierarchy

4.1 Control Layer Separation

The control system is structured as a layered hierarchy to ensure deterministic behavior, enforce safety, and maintain clear ownership of responsibilities. Each control layer operates within a defined scope and authority boundary, and no layer may bypass the constraints of another.

The architecture is organized into the following functional layers:

- Grid interface and dispatch authority
- Plant-level coordination and control
- Equipment-level control and protection
- Supervisory monitoring and operator interaction

This separation ensures that high-level dispatch objectives are translated into actionable commands while preserving equipment safety and protection integrity.

4.2 Power Plant Controller Responsibilities

The Power Plant Controller is responsible for coordinating all plant assets to meet grid-imposed dispatch and ramp requirements at the point of interconnection.

Its responsibilities include:

- Receiving grid-issued dispatch commands
- Determining required total plant output
- Allocating power commands among available generation and storage assets
- Enforcing plant-level ramp rate limits
- Managing transitions between operating modes
- Detecting and reporting dispatch tracking limitations

The Power Plant Controller operates on aggregated plant measurements and asset availability signals. It does not directly actuate equipment and does not bypass equipment-level safety logic.

All decisions made by the Power Plant Controller are subject to validation and enforcement by lower control layers.

4.3 PLC Responsibilities

The PLC layer is responsible for direct interaction with physical plant equipment and serves as the final authority on whether a commanded action may be executed.

PLC responsibilities include:

- Enforcing equipment-level permissives and interlocks
- Executing start-up and shutdown sequences
- Monitoring equipment status and fault conditions
- Latching faults and enforcing reset requirements
- Rejecting or limiting commands that violate safety or operating constraints

PLC logic executes deterministically and independently of supervisory or plant-level coordination logic. In the event of conflicting commands, PLC safety logic takes precedence.

4.4 SEL RTAC Role and Responsibilities

The SEL RTAC functions as a real-time coordination and communication layer between plant-level control and grid-facing systems. It provides deterministic processing, protocol handling, and time-aligned data exchange.

Primary responsibilities include:

- Acting as a secure interface between grid communications and plant control
- Aggregating measurements and status information
- Relaying dispatch commands to the Power Plant Controller
- Providing time-synchronized data for monitoring and analysis

- Supporting redundant or fallback communication paths

The RTAC does not replace the Power Plant Controller or PLC logic. Instead, it facilitates reliable, deterministic communication and coordination across the control hierarchy.

This role is commonly implemented using platforms such as those provided by Schweitzer Engineering Laboratories.

4.5 Authority, Overrides, and Safety Priority

Authority within the control system follows a strict priority order:

1. Protection systems and hardwired interlocks
2. PLC safety and fault logic
3. Plant-level control coordination
4. Supervisory and operator commands

At no point may a higher-level control function override a lower-level safety or protection constraint.

Dispatch objectives are always subordinate to equipment safety, protection trips, and fault conditions. Operator commands are further constrained by defined authority levels and operating modes.

This priority structure ensures predictable and safe behavior under all operating conditions.

4.6 Fallback and Loss of Communications Behavior

The system shall define deterministic fallback behavior for loss of communications or control authority.

In the event of loss of dispatch communications:

- The plant shall transition to a predefined fallback operating mode
- Output shall be limited to a safe and stable level
- Dispatch tracking shall be suspended and reported

In the event of loss of supervisory or operator communications:

- Automated control functions shall continue to operate
- Safety and protection logic shall remain fully active
- Operator visibility may be reduced but control integrity shall be maintained

These fallback behaviors ensure continued safe operation even under degraded communication conditions.

Chapter 5. Asset Models and Control Logic

5.1 Solar Generation Asset Model

The solar generation asset represents the aggregated output of all photovoltaic inverters within the plant. From the perspective of the control system, solar generation is modeled as a single controllable resource with variable availability.

The solar asset model shall include the following characteristics:

- Maximum available power limited by environmental conditions
- A fixed nameplate capacity defined in Chapter 2
- Ability to curtail output below available power when required
- Zero capability during nighttime conditions

Solar generation is treated as non-dispatchable in the positive direction. The control system may reduce solar output through curtailment but may not command output greater than available power.

The solar asset provides the Power Plant Controller with a real-time estimate of available power and accepts curtailment commands within its operating limits.

5.2 Lithium Ion Battery Storage Asset Model

The lithium ion battery storage asset is modeled as a dispatchable energy resource capable of sustained power delivery within defined energy limits.

The model includes:

- Maximum charge and discharge power limits
- Total usable energy capacity
- State of charge boundaries
- Charge and discharge efficiency

- Dynamic state of charge calculation based on commanded power

The lithium ion system may be commanded to either charge or discharge, but not both simultaneously. Commands that would violate power limits or state of charge constraints shall be rejected or limited by the control logic.

This asset is intended to provide sustained energy delivery during periods of insufficient solar generation and to absorb excess generation when available.

5.3 Flywheel Storage Asset Model

The flywheel storage asset is modeled as a fast-response, short-duration energy buffer.

The model includes:

- High allowable ramp rates
- Limited total usable energy capacity
- Rapid charge and discharge capability
- Continuous tracking of stored energy

The flywheel system is prioritized for fast transient response and ramp rate enforcement rather than long-duration energy delivery. It is expected to cycle frequently and operate near the center of its energy range under normal conditions.

Commands to the flywheel asset shall be constrained to prevent energy depletion or saturation.

5.4 Power Allocation Logic

Power allocation logic determines how the total plant output required by the dispatch command is distributed among available assets.

The Power Plant Controller shall compute the required net plant output at the point of interconnection and allocate contributions according to the following priorities:

1. Use available solar generation up to the required output
2. Apply lithium ion storage to supply or absorb remaining power as needed

3. Use flywheel storage to manage rapid changes and transient mismatches

If available resources are insufficient to meet the dispatch command, the system shall deliver the maximum achievable output and indicate a dispatch tracking limitation.

Power allocation decisions are recalculated continuously based on asset availability, state of charge, and operating constraints.

5.5 Ramp Enforcement Logic

Ramp enforcement logic ensures that changes in plant output do not exceed the ramp rate limits defined in Chapter 2.

The control system shall:

- Monitor the rate of change of output at the point of interconnection
- Limit changes in commanded power to remain within allowable ramp rates
- Use fast-response assets to absorb rapid fluctuations
- Smooth transitions between dispatch setpoints

Ramp enforcement is applied at the plant level rather than at individual asset levels, allowing internal coordination to meet external requirements.

5.6 Energy Management Constraints

Energy management logic ensures that storage assets remain within acceptable operating ranges over time.

The control system shall enforce:

- Minimum and maximum state of charge limits
- Reserve margins to support future dispatch requirements
- Prevention of sustained operation at energy extremes

Energy management decisions may temporarily limit dispatch tracking in order to preserve long-term operability and system stability.

These constraints ensure that the plant remains capable of responding to future grid requirements while maintaining asset health.

Chapter 6. SCADA, Monitoring, and Operator Interaction

6.1 Required Measurements and Visibility

The SCADA system shall provide continuous visibility into plant operation at a level appropriate for both operators and grid stakeholders. Visibility is centered on plant-level performance rather than individual device internals, while still allowing drill-down for troubleshooting.

At a minimum, the following measurements and status indicators shall be visible:

- Real power delivered at the point of interconnection
- Current dispatch setpoint
- Dispatch tracking status and error
- Active operating mode
- Solar generation availability and output
- Lithium ion storage power and state of charge
- Flywheel storage power and energy state
- Asset availability and fault status

All displayed values shall be updated at a rate sufficient to support dispatch monitoring and ramp compliance verification.

6.2 Alarms and Event Handling

The SCADA system shall provide structured alarm and event handling to ensure abnormal conditions are clearly identified and actionable.

Alarm requirements include:

- Distinction between alarms and informational events
- Priority classification based on operational impact

- Clear textual descriptions of alarm conditions
- Time-stamped recording of alarm occurrence and clearance

At a minimum, alarms shall be generated for:

- Dispatch tracking limitations
- Ramp rate violations or near violations
- Loss of asset availability
- Loss of communications
- Protection trips or fault conditions

Alarm handling shall support acknowledgment, logging, and post-event review.

6.3 Trending and Historical Data

The SCADA system shall record historical data sufficient to evaluate system performance, investigate events, and demonstrate compliance with operational requirements.

Required historical data includes:

- Point of interconnection real power
- Dispatch setpoints and changes
- Storage state of charge
- Asset availability and fault states
- Operating mode transitions

Trending tools shall allow operators and engineers to review time-aligned data over configurable time ranges. Historical data retention shall be sufficient to support operational analysis and acceptance testing review.

6.4 Operator Authority and Control Modes

Operator interaction with the system shall be constrained by defined authority levels and operating modes to prevent unsafe or unauthorized actions.

Operator capabilities may include:

- Acknowledgment of alarms
- Selection of operating modes within allowed limits
- Initiation of start-up or shutdown sequences
- Requesting transitions between normal and fallback modes

Operators shall not be permitted to override equipment-level safety interlocks, protection logic, or hard limits enforced by lower control layers.

All operator actions shall be logged with timestamps and operator identification.

6.5 Grid and Utility Visibility

The SCADA system shall support visibility appropriate for grid operators and utility stakeholders. This includes providing accurate representation of plant output, availability, and operating status without exposing internal control complexity.

Grid-facing visibility focuses on:

- Point of interconnection real power
- Plant online or offline status
- Active operating mode
- Dispatch tracking capability

This separation ensures that grid stakeholders receive clear and consistent information while internal plant operations remain abstracted.

Chapter 7. Implementation Deliverables and Artifacts

7.1 Power Plant Controller Implementation

The Power Plant Controller implementation represents the plant-level coordination logic responsible for dispatch tracking, ramp enforcement, and operating mode management.

The PPC implementation shall include:

- Dispatch setpoint intake and validation
- Plant-level power target calculation
- Power allocation across solar generation, lithium ion storage, and flywheel storage
- Ramp rate enforcement at the point of interconnection
- Operating mode handling including normal dispatch, curtailment, reduced capability, and fallback modes
- Detection and reporting of dispatch tracking limitations

The PPC logic shall operate deterministically and shall not directly actuate physical equipment. All PPC commands are subject to validation by lower control layers.

Deliverables include:

- PPC functional logic description
- PPC control logic implemented using function blocks
- Parameter configuration files
- Dispatch tracking and ramp enforcement test results

7.2 PLC Control Logic Implementation

The PLC implementation is responsible for equipment-level control, safety enforcement, and sequencing.

The PLC logic shall include:

- Equipment permissives and interlocks
- Start-up and shutdown sequencing
- Asset availability determination
- Fault detection, latching, and reset logic
- Validation and limiting of commands received from the PPC

PLC logic executes independently of supervisory systems and shall always prioritize safety and protection conditions over dispatch objectives.

Deliverables include:

- PLC ladder logic and function block diagrams
- I/O mapping and signal definitions
- Fault and interlock logic documentation
- Equipment sequencing descriptions

7.3 SEL RTAC Configuration and Integration

The SEL RTAC implementation provides real-time coordination and communication between grid-facing systems, the PPC, and plant equipment.

The RTAC configuration shall include:

- Dispatch signal intake and forwarding
- Measurement aggregation and time alignment
- Secure and deterministic communications
- Redundant or fallback communication paths
- Status and alarm forwarding to supervisory systems

The RTAC serves as an integration and data-handling layer and does not replace PPC or PLC logic.

Deliverables include:

- RTAC configuration files
- Signal mapping documentation
- Communication flow diagrams
- Time synchronization configuration

This role is representative of platforms provided by Schweitzer Engineering Laboratories.

7.4 SCADA Implementation

The SCADA implementation provides supervisory monitoring, alarm handling, historical data, and operator interaction.

The SCADA system shall include:

- Plant overview displays
- Dispatch and operating mode visualization
- Alarm and event handling configuration
- Trending and historical data views
- Operator control interfaces consistent with defined authority levels

SCADA does not execute real-time control logic and does not bypass PPC or PLC constraints.

Deliverables include:

- Screen layouts and navigation structure
- Alarm lists and priorities
- Trend definitions
- Operator interaction documentation

7.5 CODESYS Project Structure

The control logic described in this document shall be implemented and simulated using the CODESYS development environment.

The CODESYS project shall be structured as follows:

- Separate tasks for PPC logic, PLC logic, and supervisory simulation
- Modular function blocks for each asset model
- Parameterized constants reflecting Chapter 2 requirements
- Clearly defined interfaces between control layers

This structure supports readability, testing, and reuse.

Deliverables include:

- CODESYS project files
- Function block definitions
- Task and execution rate configuration

7.6 Simulation Environment and Test Harness

A simulation environment shall be implemented to support verification and acceptance testing.

The test harness shall include:

- Simulated dispatch signal generator
- Solar availability simulator
- Storage asset simulators
- Fault and communication loss injection mechanisms

The simulation environment enables repeatable and deterministic testing without physical hardware.

Deliverables include:

- Test harness logic
- Simulation configuration files
- Test execution instructions

7.7 Delivered Artifacts

The final delivered artifacts for this project include:

- System design document
- PPC control logic implementation
- PLC control logic implementation
- RTAC configuration artifacts
- SCADA configuration artifacts
- CODESYS project files
- Verification and test results

These artifacts collectively demonstrate compliance with system requirements and readiness for field deployment pending hardware integration and commissioning.

Chapter 8. Verification and Acceptance Testing

8.1 ISO Style Dispatch Compliance Tests

These tests verify that the plant behaves as a controllable resource under an ISO-style dispatch model.

Test Objective
Verify that the plant tracks dispatched real power setpoints at the point of interconnection while respecting operating constraints.

Test Method

- Apply step and ramped dispatch commands within the allowable range.
- Observe measured real power at the point of interconnection.
- Log dispatch tracking error and response time.

Acceptance Criteria

- Plant output converges to the dispatch setpoint without instability.
- Dispatch tracking error remains within defined tolerance.
- No violation of ramp rate or power limits occurs.
- Dispatch tracking limitations are correctly indicated when capability is insufficient.

These tests are representative of expectations imposed by ISO-operated grids.

8.2 CAISO and ERCOT Ramp Compliance Tests

These tests verify compliance with ramp rate requirements typical of CAISO and ERCOT.

Test Objective
Verify that changes in plant output do not exceed the maximum allowable ramp rates at the point of interconnection.

Test Method

- Apply dispatch step changes exceeding allowable ramp limits.
- Observe plant output response and internal asset coordination.
- Measure rate of change of output at the point of interconnection.

Acceptance Criteria

- Output ramps at or below the specified megawatts per minute limit.
- Fast-response storage assets absorb transient mismatches.
- Ramp enforcement occurs at the plant level regardless of asset behavior.

8.3 Normal Operation Test Cases

These tests validate correct system behavior under expected operating conditions.

Test Scenarios

- Daytime operation with high solar availability.
- Transition from solar-dominated operation to storage-supported operation.
- Evening operation with storage discharge.
- Dispatch changes within normal operating range.

Acceptance Criteria

- Stable dispatch tracking is maintained.
- Storage state of charge evolves correctly over time.
- No unnecessary curtailment or oscillatory behavior occurs.
- Operator displays and trends reflect accurate system state.

8.4 Degraded and Faulted Operation Test Cases

These tests verify graceful degradation and safe behavior when assets or communications are unavailable.

Test Scenarios

- Loss of lithium ion storage availability.
- Loss of flywheel storage availability.
- Reduced solar availability due to environmental conditions.
- Loss of dispatch communications.

Acceptance Criteria

- Remaining assets are reallocated appropriately.
- Dispatch tracking degrades predictably without instability.
- Fallback operating modes are entered correctly.
- System state and limitations are clearly indicated.

8.5 Fault and Protection Test Cases

These tests validate correct response to protection and fault conditions.

Test Scenarios

- Protection trip indication asserted.
- Breaker open condition detected.
- Equipment fault latched at the PLC level.

Acceptance Criteria

- Dispatch objectives are immediately overridden.
- Plant transitions to defined safe states.
- Fault conditions are latched and require explicit reset.

- Alarms and events are generated and logged correctly.

These tests demonstrate that safety and protection have absolute priority over control objectives.

8.6 Acceptance Criteria

The system shall be considered acceptable if all test cases meet their defined acceptance criteria.

At a minimum, acceptance requires:

- No violation of power or ramp rate limits.
- Deterministic response to dispatch and fault conditions.
- Correct enforcement of authority hierarchy and safety priority.
- Accurate monitoring, alarming, and historical data capture.
- Repeatable test results under identical conditions.

Successful completion of these tests demonstrates that the control system meets the functional expectations of an ISO-connected utility-scale resource.