ISO Smart Grid Roadmap

IS-1 ISO Uses Energy Storage for Grid Operations and Control

Version 2.1

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Approvals:
Signature indicates acceptance of the IS-1 ISO Uses Energy Storage for Grid Operations and Control for Smart Grid Roadmap Project as complete and sufficiently detailed to allow the project to be successfully executed.

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Revision History

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7/14/10	0.1.2	Modified to include more cases	BMoukaddem
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11/05/10	2.1	Section 1 reorganized and focused. Added Functional and Non functional requirements based on CAISO Storage meeting on 10/27/10. Corrected use cases to decouple ADS market dispatches initiated by EMS. Minor grammar and Spelling edits throughout.	Peter Klauer

Table of Contents

1. Use-Case: IS-1 ISO uses energy storage for grid operations and control

The power grid today is a very large and complex “just in time” delivery system that is designed to meet all customers demands for electric energy on a continuous basis. North America Energy Reliability Corporation (NERC) and Western Electricity Coordinating Council (WECC) regional reliability standards are designed to ensure the reliability of this continuous energy supply. These standards cover maintaining adequate transmission capacity and sufficient generation to cover contingencies stemming from forced generator or transmission outages that can happen at any instant of time, as well as, rules related to the scheduling and dispatch of energy between the ISO and it’s neighboring Balancing Authority Areas (BAAs) to keep energy supplies balanced with energy demand and to maintain frequency standards.

As new and increasing amounts of variable and intermittent generation resources, such as wind and solar, are integrated into the grid, the ability to meet these standards for reliability will be more difficult to achieve and maintain. For example, although wind and solar average hourly energy production can be forecasted with reasonable accuracy, they will still produce significant intra-hour and minute-to-minute variability that is inconsistent with today’s grid operations and scheduling procedures. In addition, sudden weather changes can lead to corresponding variations in wind and solar generation output across the service territory and cause significant energy imbalances on the system.

One strategy for mitigating the challenges of intermittent and variable generation impact on grid operations is to utilize storage technologies. Energy storage has the potential to change the current “‘just in time” paradigm by absorbing energy during one period and delivering it within another period based on system conditions. Storage can address the dilemma of continuously matching supply and demand.

Energy storage resources can help grid operators handle the variability of renewable resources and provide the means of shifting excess energy production from off-peak periods to on-peak periods when it is needed. Examples of high capacity energy storage resources that can quickly store or discharge energy include pumped hydro storage, compressed air energy storage, hydrogen fuel cells, batteries, flywheels, ultra-capacitors, and aggregated plug-in electric vehicles. Another means of storage is to use load control devices that can be dispatched to reduce consumption or, in times of excess low-cost renewable generation resources, to increase power consumption.

Energy storage can range from very short-term storage for a few minutes to storage systems that can store hours and days worth of energy. There are two defining characteristics, (1) the power rating which is the rate of charge or discharge of the unit in Megawatts per minute and (2) the amount of energy storage which is measured in the amount of megawatt hours of energy. For example a battery may have a power rating of 10 MWs and an energy capacity of 5 MW-Hrs. This means it can either charge at a 10 MW/min. rate or discharge at a 10MW/min and it could continue to discharge for up to 30 minutes (i.e. 5 MW-Hrs) if the unit was fully charge to at the start.

As can be seen in the table below, energy storage has the capability to provide regulation services, contingency reserves, supplemental energy and fast ramping of energy. It can be used to relieve transmission congestion and transmission overloads and can provide voltage support in transmission constrained areas. It can also be used for major shifting of energy by hours and days for delivery of energy on demand. Also, most energy storage systems do not use carbon based fuels so they can produce these services without contributing to Green-House Gas (GHG) emissions. The major disadvantage of energy storage at this time is the initial cost, which ranges from $1 Million per Megawatt to $4 Million per Megawatt. The $1 Million per Megawatt cost is competitive with the cost of a comparable gas turbine, but in general, storage is a more expensive alternative at the time of publishing this document. It is anticipated that the costs of energy storage will significantly decline in the next 5 years and the Department of Energy (DOE) has set aggressive targets for new energy storage research projects to drive the cost down.

	Market Based Services					
	Seconds to 1 Minute	**1 Minute to 15 Minutes**	**15 Minutes to 60 Minutes**	**1 hour to 4 Hours**	**4 hours to 24 Hours**	**Multiple Days**
Technology	Super Caps Flywheels Batteries	Flywheels Batteries	Batteries Flywheels (15 Min.)	Batteries Compressed Air Energy Storage (CAES)	Batteries CAES Pump Storage	CAES Pump Storage
Service	Distribution Power Quality mitigation due to solar PV	Distribution PQ Grid Frequency	AS Regulation & Contingency Reserves	Supple-mental Energy Dispatch	Supple-mental energy and energy shifting	Supple-mental energy and energy shifting
Value	Potential source for energy injection for grid stabilization	Voltage control and system frequency control	Meet BA control performance standards	Intra-hour energy change needs Transmission congestion	Load following & energy scheduling	Load following & energy scheduling

The benefits of energy storage include fast response ancillary services, improved system reliability, reduced greenhouse gas emissions, reduced costs, and other societal benefits. SANDIA REPORT (SAND2010-0815), published in February 2010, identified 26 benefits associated with the use of electricity storage for electric-utility-related applications. The 26 storage benefits characterized are categorized as follows: 1) Electric Supply, 2) Ancillary Services, 3) Grid System, 4) End User/Utility Customer, 5) Renewables Integration, and 6) Incidental.

The main driver for investment in energy storage is going to be the need to mitigate the variability for the energy supply from wind and solar generation. Although energy storage is not essential for the ISO to handle the variability expected from new wind and solar generation required to meet the 20% RPS in 2013, some amount of storage will clearly be needed to mitigate the operating issues in the 33% RPS scenarios. The amount of storage required was initially studied in 2009 and the operational issues are documented in the KEMA Report for the CEC “Research Evaluation of Wind Generation, Solar

Generation, and Storage Impact on the California Grid" – June 2010[1] The KEMA study and the ISO's previously published report on the integration of renewables[2] both illustrated the amount of regulation resources would approximately double with the major increase in renewables and the intra-hour energy ramps and supplemental energy dispatch would be all be significant issues. The 2007 report also discussed the need for new energy storage resources to assist with the integration of large amounts of renewables.

2. Brief Description:

The scenarios that will be described in this use case document will support using energy storage for grid operations and control concentrating on the use of energy storage for ancillary services, supplemental energy bids, energy shifting and for transmission loading relief. Most of these services will be provided by the market systems but some may be transmission based or an exceptional dispatch.

The goal of this Use Case is to optimize the use of energy storage devices through both the ISO's market based functions and operational driven conditions.

The ISO has identified the following 8 scenarios that demonstrate the use of energy storage devices for grid operations and control

1. **Scenario 1 – Use of energy storage for frequency response:** Real-time mismatch between supply and demand is handled by procuring regulation and dispatching regulating units up and down to meet the fluctuations in the system. Energy Storage devices can be used to provide frequency regulation. In this case, the Energy Storage device will not provide any net energy output, but instead will be dispatched by EMS in response to the frequency component of ACE. The energy storage device will be able to provide higher quality of regulation due to its fast response characteristics
2. **Scenario 2 – Use of energy storage to reduce the intra-hour variability of renewables:** This scenario describes a future where the ISO has more than 6000 MW of wind generation and 3000 MW of solar generation connected to the system. This will result in major intra-hour variability in energy supplies which increases the need for additional regulation services, increases in the supplemental energy dispatches during the real-time operating hour, the need for fast ramping energy resources, and for potential increases in operating reserves. Grid connected and dispatchable energy storage resources will be an essential resource to provide some of these added services. The first use of energy storage is in the Ancillary Services market for regulation service.
3. **Scenario 3 – Use of energy storage for load following:** The CAISO main function is to maintain the reliability of the electrical grid. A major part of this effort is focused on matching supply and demand while using the most efficient resources in meeting this requirement. Long-term needs are managed by committing generating units needed to sustain the total forecasted load in the Day Ahead (DA) Market. Short-term needs are satisfied by committing quick start units and dispatching generation to the proper MW levels to serve the load. Energy storage devices can be used to bridge the gap between DA, Real-time Unit commitment and Real-time economic dispatch. In this case, inter-hour ramping needs not captured in DA and inter-interval ramping needs not provided by RTUC can be satisfied by deploying the proper fast responding energy storage resources

[1] CEC PIER FINAL REPORT - CEC-500-2010-010
[2] CAISO "Integration of Renewable Resources" – November 2007 http://www.caiso.com/1ca5/1ca5a7a026270.pdf

4. **Scenario 4 – Use of energy storage for transmission loading mitigation:** Another main function of the ISO is to maintain the transmission system and extend the lifetime of the equipment comprising the transmission grid. This is where using energy storage devices comes into play where such devices located in critical areas across the network respond to signals from RTD (10-mins ahead) to mitigate congestion on critical transmission assets. This way, more expensive units such has thermal units can be freed up for other tasks instead of ramping them up and down and this will reduce the wear and tear on these units.
5. **Scenario 5 – Use of energy storage for transmission transient stability damping:** The transmission grid is a major asset that should be utilized to its fullest possible extent. Building a 7200MW transmission line and being able to utilize only 4800MW of that capacity at best is not a good use of the existing assets. Energy storage devices in conjunction with intelligent agent and PMU's located ubiquitously across the grid will allow CAISO to utilize that extra capacity without jeopardizing the stability of the grid. PMU's ability to detect electrical anomalies and disturbances and un-damped oscillations across major transmission path provides a window of intervention
6. **Scenario 6 – Use of energy storage for under/over frequency mitigation:** In certain situations, load shedding (or addition) is needed to mitigate under-frequency (or over-frequency) conditions. Energy storage devices can be used to reduce the need for utilizing load shedding (or addition) by providing a better way to respond
7. **Scenario 7 – Use of energy storage for voltage and reactive power support:** One of the main benefits provided by energy storage resources is voltage support. Local distribution of such devices across the network provides the ability to maintain voltage at acceptable levels. Reactive power and Power Factor Correction is an additional bi-product provided by such devices due to their inherent abilities to better control active and reactive power by utilizing converters
8. **Scenario 8 – Use of energy storage for energy or load shifting:** Storage devices can be utilized as a tool to provide energy shifting and peak shaping capability across the grid. In the case of energy shifting, energy storage will be set to charge during off-peak hours when the electricity supply is cheap and abundant and when ample wind and solar generation is available, the stored energy is converted back to electricity during peak hours and during load pickup intervals. Also because energy storage devices act as load, these can be used to flatten the load curve making the troughs and peaks less pronounced. This will intern decrease the need to rely on extra expensive generation to supply the extra load in the system above the base load.

3. Actors

Actor Name	*Actor Type (person, device, system etc.)*	*Actor Description*
Scheduling Coordinator (SC)	Organization	An entity certified by the ISO for the purposes of undertaking the functions specified in ISO Tariff Section 4.5.3. In general these activities include submitting bids, assuring response to dispatches and instructions, and settlements.
Plant Operator	Organization	Entity that operates the energy storage resource and responds to ISO dispatch instructions
ISO Market System	System	Software application(s) that support DAM & RTM where DAM is a financially binding Futures/Forward market that commits Energy and procures Ancillary Services for the following Trade Day and RTM is a five-minute spot market that commits units, ramps generation and procures ancillary services for the imbalance between the Day-Ahead Market and real-time reliability needs. Also, Real-Time Pre-Dispatch (RTPD) and Real-Time Dispatch (RTD) are subsets of the Real-Time Market encompassing the 15 minute (RTPD) commitment / de-commitment and 5 minute generation dispatch of energy and ancillary services.
ISO Energy Management System (EMS)	System	Software application used by ISO to monitor, control, and optimize the performance of the generation and/or transmission system
Energy Storage Device	Device	These are devices that can quickly store or discharge energy for grid operation and control such as pumped hydro storage, compressed air energy storage, hydrogen fuel cells, batteries, flywheels, ultra-capacitors, and aggregated plug-in electric vehicles. The Energy Storage Device assumes the functionality of a secure RTU is embedded.
ISO Dispatch System	System	Automated Dispatch System (ADS) communicates Real-Time commitment and Dispatch Instructions, and Real-Time AS Awards to SCs.
ISO Phasor Visualization/ Monitoring System	System	Software application that supports real-time dynamic monitoring, displays and analyzes synchrophasor data

4. Assumptions

1. In the future, small-scale energy storage devices such as home energy storage devices, plug-in electric vehicles, air conditioning units, etc will be aggregated to perform as participating load or generation resources and then monitored.
2. Energy storage devices participating in the 5-minute balancing energy market must have telemetry capabilities that enable resource monitoring and control of charging and discharging
3. As applicable, energy storage devices will be equipped with intelligent agents in order to alleviate the need for complicated integration technologies to deliver signals to these devices
4. Communications between the ISO's EMS and the secure RTU located at the Energy Storage Device shall adhere to the standards as being established and selected by the National Institute of Standards and Technology (NIST) and the Smart Grid Interoperability Panel (SGIP) under Priority Action Plan (PAP) 7.
5. Communications between the ISO's EMS and the secure RTU located at the Energy Storage Device shall be secure in accordance with CAISO cyber security policy.
6. Future requirement, the system shall support automatic update of operating parameters for new or changed Energy Storage Devices

Day ahead market scenarios require the SC to be responsible for ensuring the storage unit is in the correct state for market activity

5. Preconditions

The following reconditions are applicable across all event flows. Preconditions applicable to specific flows are included within the 'Flow of Events' sections.

1. The Energy Storage Device has successfully gone through the SGIP interconnection process and meet all of the ISO tariff requirements for communications and metering and has a Resource ID
2. The Energy Storage Device has been added to the ISO Market DB and the Network Model and has an associated SCID for the Resource ID
3. If the Energy Storage Device is capable of providing more than 1 hour of energy, then it is certified to provide energy schedules and Supplemental Energy bids in the Day Ahead market for use in real-time.
4. The ISO has modified the EMS AGC signal to provide a regulation signal that is energy neutral over a 15-minute period.
5. The ISO has modified the Market Systems and EMS to model the operating characteristics of energy storage resources, which can have a negative Pmin, the ability to rapidly change from a charge to discharge state, and other characteristics that are unique to energy storage resources.

6. Post Conditions

1. Energy Storage Device has performed as expected per the specific elements of the flow and has been financially settled for services rendered by the ISO.

7. Flow of Events

7.1 Energy Storage for Frequency Response

7.1.1 Basic Flow: Energy Storage Device dispatches up or down based on frequency deviation detected by the device autonomously.

Flow Specific Preconditions:

1. The Energy Storage Device has been certified to provide ancillary services – regulation and/or spinning reserve.
2. Energy Storage Device is capable of detecting frequency deviations autonomously; no real-time communication requirements are required between ISO EMS and the Energy Storage Device

Step#	***Actor***	***Description of the Step***	***Additional Notes***
#	*What actor, either primary or secondary is responsible for the activity in this step?*	*Describe the actions that take place in this step. The step should be described in active, present tense.*	*Elaborate on any additional description or value of the step to help support the descriptions. Short notes on architecture challenges, etc. may also be noted in this column.*
1	ISO Energy Management System	ISO Energy Management System removes the frequency response component from the Area Control Error (ACE) signal based on the telemetry of the storage device being in operation	ACE represents the difference between Net Scheduled interchange and Net Actual Interchange and has both a MW & frequency component. AGC collects the amount of devices on frequency response and accounts for their effect on ACE to eliminate double counting
2	ISO Energy Management System	ISO Energy Management removes the amount of frequency response accomplished by the Energy storage device out of the ACE equation	
3	Energy Storage Device	Energy Storage Device samples/detects frequency deviation	
4	Energy Storage Device	Energy Storage Device absorbs or injects power in response to the deviation of frequency from scheduled frequency as detected from its direct connection to the power grid	The amplitude of the frequency deviation will be used to drive the action taken by the device (absorb/inject)

7.1.2 Alternative Flow A1: Energy Storage Device dispatches up or down based on a signal received from the EMS

Flow Specific Preconditions:

1. The Energy Storage Device has been certified to provide AS – regulation and/or spinning reserve.
2. The Energy Storage Device is capable of receiving a MW dispatch notification.

Step#	Actor	Description of the Step	Additional Notes
#	*What actor, either primary or secondary is responsible for the activity in this step?*	*Describe the actions that take place in this step. The step should be described in active, present tense.*	*Elaborate on any additional description or value of the step to help support the descriptions. Short notes on architecture challenges, etc .may also be noted in this column.*
1	ISO Energy Management System	ISO Energy Management System determines Area Control Error (ACE)	ACE represents the difference between Net Scheduled interchange and Net Actual Interchange and has both a MW & frequency component
2	ISO Energy Management System	ISO Energy Management System sends ACE signal to Energy Storage Device	
3	Energy Storage Device	Energy Storage device automatically responds to ACE signal and absorbs or injects power	

7.2 Energy Storage for Reduction of Intra-Hour Variability of Renewables

7.2.1 Basic Flow: EMS manages Energy Storage Device based on Requirement for Regulation Services

Flow Specific Preconditions:

1. The Energy Storage Device has been certified to provide AS – regulation and/or spinning reserve.
2. The Energy Storage Device is capable of receiving a regulation signal.

Step#	Actor	Description of the Step	Additional Notes
#	*What actor, either primary or secondary is responsible for the activity in this step?*	*Describe the actions that take place in this step. The step should be described in active, present tense.*	*Elaborate on any additional description or value of the step to help support the descriptions. Short notes on architecture challenges, etc. may also be noted in this column.*
1	Scheduling Coordinator	Scheduling Coordinator bids into Ancillary Service (AS) market to provide regulation up/down services	A 50 MW storage device has the ability to provide 100 MW of regulation range (+50 MW up and -50 MW down).

Step#	Actor	Description of the Step	Additional Notes
2	ISO Market System	ISO Market System selects bids in bid stack based on market optimization calculations and sends instructions to EMS	An optimum energy dispatch request occurs every 5 minutes as "load following" type of function.
3	ISO Energy Management System	ISO Energy Management determines the center balancing requirements that should be applied to Energy Storage devices that are associated with selected bids	
4	ISO Energy Management System	ISO Energy Management System manages unit to target through AGC	
5	ISO Dispatch System	ISO Dispatch System issues directives to adjust power by a fixed amount, a go to instruction with a specific time.	
6	Plant Operator	Plant Operator receives dispatch instructions and takes action to adjust power	
7	Energy Storage Device	Energy Storage Device absorbs or injects power in response to plant operator's action	

7.3 Energy Storage for Load Following

7.3.1 Basic Flow: EMS initiates dispatch to Energy Storage Device based on Short Term Energy Requirements

Flow Specific Preconditions:

1. The Energy Storage Device is registered and certified to provide energy.
2. The Energy Storage Device is capable of receiving an energy dispatch signal.

Step#	Actor	Description of the Step	Additional Notes
#	*What actor, either primary or secondary is responsible for the activity in this step?*	*Describe the actions that take place in this step. The step should be described in active, present tense.*	*Elaborate on any additional description or value of the step to help support the descriptions. Short notes on architecture challenges, etc. may also be noted in this column.*
1	Scheduling Coordinator	Scheduling Coordinator bids into Real Time market to provide energy	
2	ISO Market System	ISO Market System selects bids in bid stack based on market optimization calculations and sends instructions to EMS	RTD sends signals 10 minutes ahead for energy dispatch every 5 minutes
3	ISO Energy Management System	ISO Energy Management determines the center balancing requirements that should be applied to Energy Storage devices that are associated with selected bids	
4	ISO Energy Management System	ISO Energy Management System manages unit to target via AGC	
5	ISO Dispatch System	ISO Dispatch System issues directives to adjust power by a fixed amount, a go to	

Step#	Actor	Description of the Step	Additional Notes
		instruction with a specific time.	
6	Scheduling Coordinator	Scheduling Coordinator receives the dispatch instructions and forwards them to the plant operator	
7	Plant Operator	Plant Operator receives dispatch instructions and takes action to adjust power	
8	Energy Storage Device	Energy Storage Device absorbs or injects power in response to plant operator's action	

7.4 Energy Storage for Transmission Loading Mitigation

7.4.1 Basic Flow: Energy Storage device responds to RTD LMP Price Signals

Flow Specific Preconditions:

1. The Energy Storage Device is registered and certified to provide energy.
2. Energy Storage Device is capable of autonomously dispatching energy (up or down) based upon RT price signals.
3. The Energy Storage Device is charged to some capacity deemed valuable by the ISO.

Step#	Actor	Description of the Step	Additional Notes
#	*What actor, either primary or secondary is responsible for the activity in this step?*	*Describe the actions that take place in this step. The step should be described in active, present tense.*	*Elaborate on any additional description or value of the step to help support the descriptions. Short notes on architecture challenges, etc. may also be noted in this column.*
1	ISO Market System	ISO Market System publishes RTD LMP prices	These could be LMPs or congestion component of LMP
2	ISO Energy Management System	ISO Energy Management System provides LMP prices to Energy Storage Device	
3	Energy Storage Device	Energy Storage Device utilizing in-built intelligence to determine whether to absorb or inject power in response to price signals	

7.4.2 Alternative Flow A1: EMS initiates dispatch to Energy Storage Device based on Congestion Mitigation Requirement

Flow Specific Preconditions:

1. The Energy Storage Device is registered and certified to provide energy.
2. Energy Storage Device is capable of responding to energy dispatch signal.
3. The Energy Storage Device is charged to some capacity deemed valuable by the ISO.

Step#	Actor	Description of the Step	Additional Notes
#	*What actor, either primary or secondary is responsible for the activity in this step?*	*Describe the actions that take place in this step. The step should be described in active, present tense.*	*Elaborate on any additional description or value of the step to help support the descriptions. Short notes on architecture challenges, etc. may also be noted in this column.*
1	ISO Market System	ISO Market System detects congestion in real time and calculates dispatch to mitigate congestion. Instructions are sent to EMS	RTD sends signals 10 minutes ahead for dispatch to mitigate congestion
2	ISO Energy Management System	ISO Energy Management determines the center balancing requirements that should be applied to Energy Storage devices within control area based on the congestion mitigation requirement	
3	ISO Energy Management System	ISO Energy Management System manages unit to target via AGC	
4	ISO Dispatch System	ISO Dispatch System issues directives to adjust power by a fixed amount, a go to instruction with a specific time.	
5	Scheduling Coordinator	Scheduling Coordinator receives the dispatch instructions and forwards them to the plant operator	
6	Plant Operator	Plant Operator receives dispatch instructions and takes action to adjust power	
7	Energy Storage Device	Energy Storage Device absorbs or injects power in response to plant operator's action	

7.5 Use of Energy Storage for Transmission Transient Stability Dampening

7.5.1 Basic Flow: Frequency Oscillation Occurs

Flow Specific Preconditions:

1. The Energy Storage Device is of significant scale (capacity of approximately 100 MWs).
2. Energy Storage Device is capable of fast response based on a signal from an Intelligent agent
3. An intelligent Agent exists that is capable of detecting frequency oscillations within a second and is able to send a correction signal to the proper Energy Storage device within a second.
4. Fast and reliable communication exists between the Intelligent Agent, all Energy Storage devices, and all Syncrophasors.
5. The CISO balancing control area has achieved significant phasor measurement unit (PMU) penetration.

Step#	Actor	Description of the Step	Additional Notes
#	*What actor, either primary or secondary is responsible for the activity in this step?*	*Describe the actions that take place in this step. The step should be described in active, present tense.*	*Elaborate on any additional description or value of the step to help support the descriptions. Short notes on architecture challenges, etc. may also be noted in this column.*
1	Intelligent Agent detection system	Intelligent Agent analyzes PMU data readings coming from ISO Phasor System for frequency levels at key locations on the transmission grid and processes logic to detect oscillation	Sampling at 30-60 samples/second
2	Intelligent Agent detection system	Intelligent Agent detects an oscillation and analyzes it. If the oscillation is determined to not dampen without intervention, the agent will determine the best correction to stop the oscillation.	Frequency oscillation occurs.
3	Intelligent Agent detection system	Intelligent Agent determines and issues a correction action to the Energy Storage devices in real-time.	Dampening is an oscillation correction due to inherent system dynamics
4	Energy Storage Device	The Energy Storage Device injects or withdraws energy as dispatched.	
5	Intelligent Agent detection system	Intelligent Agent evaluates the impact of the correction and continues to send corrections to dampen the oscillation until dampening is achieved	This will continue until the Oscillation is dampened
6	Energy Storage Device	After oscillation dampening has been achieved, the Energy Storage Device returns to pre-dispatch levels by energizing or de-energizing (over time) to prepare for the next frequency oscillation event.	

7.6 Under/Over Frequency Load Mitigation

7.6.1 Basic Flow: A Low/High Frequency Event Occurs

Flow Specific Preconditions:

1. The Energy Storage Device has been certified to provide AS – regulation and spinning reserve.
2. Energy Storage Device is capable of detecting frequency needs autonomously; no real-time communication requirements are required between ISO EMS and the Energy Storage Device.

Step#	Actor	Description of the Step	Additional Notes
#	*What actor, either primary or secondary is responsible for the activity in this step?*	*Describe the actions that take place in this step. The step should be described in active, present tense.*	*Elaborate on any additional description or value of the step to help support the descriptions. Short notes on architecture challenges, etc. may also be noted in this column.*
1	ISO Energy Management System (EMS)	ISO Energy Management System gets readings for frequency levels at key locations on the transmission grid.	Sampling at 1-2 samples/second
2	ISO Energy Management System (EMS)	ISO Energy Management System determines that frequencies are lower or higher than an acceptable threshold.	A Low Frequency Event occurs
4	ISO Dispatch System	ISO Dispatch System dispatches Storage Devices to Inject or Withdraw Energy at Appropriate Locations.	
5	Energy Storage Device	The Energy Storage Device injects or withdraws energy as dispatched.	The frequency rises as a result of Energy Storage Device Dispatch. Load shedding is not necessary.
6	Energy Storage Device	The Energy Storage Device returns to pre-dispatch levels by energizing or de-energizing (over time) to prepare for the next Low Frequency event.	

7.7 Voltage and Reactive Power Support

7.7.1 Basic Flow: A Low Voltage or Reactive Power Event Occurs

Flow Specific Preconditions:

1. The Energy Storage Device is registered and certified to provide voltage support and reactive energy.
2. Energy Storage Device is capable of autonomously responding to voltage and reactive power system needs or is capable of providing voltage and reactive power support through existing tariff based system requirements.

Step#	Actor	Description of the Step	Additional Notes
#	*What actor, either primary or secondary is responsible for the activity in this step?*	*Describe the actions that take place in this step. The step should be described in active, present tense.*	*Elaborate on any additional description or value of the step to help support the descriptions. Short notes on architecture challenges, etc. may also be noted in this column.*
1	ISO Energy Management System (EMS)	ISO Energy Management System samples voltage and reactive power at key locations on the transmission grid.	
2	ISO Energy Management System (EMS)	ISO Energy Management System determines that voltage and reactive power levels are not within an acceptable threshold.	A Low Frequency Event occurs
4	ISO Dispatch System	ISO Dispatch System dispatches Storage Devices to Inject or Withdraw Energy at Appropriate Locations.	
5	Energy Storage Device	The Energy Storage Device injects or withdraws energy as dispatched.	The voltage level increases as a result of Energy Storage Device Dispatch.
6	Energy Storage Device	The Energy Storage Device returns to pre-dispatch levels by energizing or de-energizing (over time) to prepare for the next voltage or reactive power event.	

7.8 Energy or Load Shifting

7.8.1 Basic Flow: Energy Storage Device-Responsive Contingency Occurs (Day-Ahead)

Flow Specific Preconditions:

1. The Energy Storage Device is registered and certified to provide energy.
2. Energy Storage Device is capable of responding to energy dispatch signal.
3. The Energy Storage Device has registered operational parameters indicating a long run time of up to eight hours
4. The Energy Storage Devices is well designed for Deep charge and discharge cycles every day several times per day.

Step#	Actor	Description of the Step	Additional Notes
#	*What actor, either primary or secondary is responsible for the activity in this step?*	*Describe the actions that take place in this step. The step should be described in active, present tense.*	*Elaborate on any additional description or value of the step to help support the descriptions. Short notes on architecture challenges, etc. may also be noted in this column.*
1	Scheduling Coordinator	Scheduling Coordinator bids into the Day-Ahead Market	The Energy Storage Device offers into the Day-Ahead and Real-time market like generation resources.
2	ISO Market System	ISO Market System schedules the Energy Storage Device for Energy in the Day-Ahead Market based on optimization (Security Constrained Unit Commitment)	
4	ISO Market System	ISO Market System uses Load / Demand Profile to (On-Peak or Off-Peak) and Locational Marginal Price to commit Energy Storage Device in the Day-Ahead Market	
5	Energy Storage Device	During Off Peak or Low LMP times, Energy Storage Device charges/energizes acting as a load.	
6	Energy Storage Device	During On Peak or High LMP times, Energy Storage Device discharge/de-energize acting as a generator.	

7.8.2 Basic Flow: Energy Storage Device-Responsive Contingency Occurs (Real-Time)

Flow Specific Preconditions:

1. The Energy Storage Device is registered and certified to provide energy.
2. Energy Storage Device is capable of responding to energy dispatch signal.
3. The Energy Storage Device has registered operational parameters indicating a short run time (by energy standards) of approximately two hours
4. The Energy Storage Devices is well designed for continuous charge and discharge every 5 minutes with enough energy to last at least 15 minutes of its rated capacity

Step#	Actor	Description of the Step	Additional Notes
#	*What actor, either primary or secondary is responsible for the activity in this step?*	*Describe the actions that take place in this step. The step should be described in active, present tense.*	*Elaborate on any additional description or value of the step to help support the descriptions. Short notes on architecture challenges, etc. may also be noted in this column.*
1	Energy Storage Device	During the trade day, the Energy Storage Device retains a center-balanced state.	The Center-Balanced state allows the Energy Storage Device the ability to inject or withdraw energy.
2	ISO Market System	ISO Market System during Real-Time Market detects that a contingency occurred such that an Energy Storage Device can respond.	The Energy Storage Device can shift the load to a future time that can be more efficiently and effectively mitigated.
3	Energy Storage Device	The Energy Storage Device injects or withdraws energy or Ancillary Services as directed by Real-Time Operations.	
4	ISO Market System	ISO Market System Real-Time Market detects the Energy Storage Device's injection or withdrawal. The load has shifted to a future time.	The Energy Storage Device can shift the load to a future time that can be more efficiently and effectively mitigated.
5	ISO Market System	In order to manage the shifted load, ISO Market System's RTPD/RTD process commits or de-commits resources to offset the Energy Storage Device's injection or withdrawal.	
6	ISO Market System	ISO Market System's RTPD/RTD process checks to confirm future unit commitment or unit ramping to offset the Energy Storage Device's load shift.	
7	ISO Market System	ISO Market System Real-Time Market s evaluates the contingency status and signals the Energy Storage Device to center-balance.	
8	Energy Storage Device	The Energy Storage Device retains a center-balanced state.	

8. Requirements

#	Business Requirements	Associated Scenario #	Associate Step #
BRQ-001	ISO Energy Management System shall be able to determine an Area Control Error (ACE)	7.1.2	1
BRQ-002	ISO Energy Management System shall be able to send ACE signal to Energy Storage Devices	7.1.2	2
BRQ-003	Energy Storage device shall be able to automatically respond to ACE signal and absorb or inject power accordingly	7.1.2	3
BRQ-004	ISO Energy Management System shall be able to remove the frequency response component from the Area Control Error (ACE) based on the telemetry of the storage device being in operation	7.1.1	1
BRQ-005	ISO Energy Management shall be able to remove the amount of frequency response accomplished by the Energy storage device out of the ACE equation	7.1.1	2
BRQ-006	Energy Storage Device shall be able to sample/detect frequency deviation signals	7.1.1	3
BRQ-007	Energy Storage device shall be able to automatically absorb or inject power in response to frequency deviation signals	7.1.1	4
BRQ-008	ISO Energy Management shall be able to determine the center balancing requirements that should be applied to Energy Storage devices	7.2.1 7.3.1 7.4.2	3 3 2
BRQ-009	ISO Energy Management System shall be able to initiate requests for dispatch of energy storage devices	7.2.1 7.3.1 7.4.2	4 4 3
BRQ-010	ISO dispatch system shall be able to issue directives, to adjust power by a fixed amount on energy storage devices via a go to instruction with a specific time.	7.5.1 7.7.1 7.6.1 7.2.1 7.3.1 7.4.2 7.3.1	4 4 4 5 5 4 7
BRQ-011	Scheduling Coordinator shall be able to receive dispatch instructions and forward them to the plant operator	7.3.1 7.4.2	6 5
BRQ-012	Plant Operator shall be able to receive dispatch instructions and takes action to adjust power	7.2.1 7.4.2 7.3.1	6 6 7
BRQ-013	Energy Storage Device shall be able to absorb or inject power in response to plant operator's action	7.2.1 7.3.1 7.4.2	7 8 7
BRQ-014	Scheduling Coordinator shall bid into Ancillary Service (AS) market to provide regulation up/down services via energy storage devices	7.2.1	1
BRQ-015	ISO Market System shall be able to select least expensive bids in bid stack and request dispatch.	7.2.1 7.3.1 7.8.1	2 2 2
BRQ-016	Scheduling Coordinator shall be able to bid into Day Ahead &Real Time market to provide energy via energy storage devices	7.3.1 7.8.1	1 1

#	Business Requirements	Associated Scenario #	Associate Step #
BRQ-017	ISO Market System shall be able to detect congestion in real time and request dispatch to mitigate congestion via energy storage devices	7.4.2	1
BRQ-018	ISO Market System shall be able to publish RTD LMP prices	7.4.1	1
BRQ-019	ISO Energy Management System shall be able to provide LMP prices to Energy Storage Device	7.4.1	2
BRQ-020	Energy Storage Device shall be able to utilize in-built intelligence to determine whether to absorb or inject power in response to price signals	7.4.1	3
BRQ-021	Intelligent Agent Detection System equipped with high power hardware and software shall be able to analyze PMU data readings coming from ISO Phasor System for frequency levels at key locations on the transmission grid and process logic to detect oscillation	7.5.1	1
BRQ-022	Intelligent Agent Detection System shall be able to detect an oscillation, analyze it and determine whether or not it is not going to dampen on its own	7.5.1	2
BRQ-023	Intelligent Agent determines the best corrective action to take and issues issue it to Energy Storage devices in real-time with full feedback.	7.5.1	3
BRQ-024	The Energy Storage Device shall be able to inject or withdraw energy as dispatched	7.5.1 7.6.1 7.7.1 7.8.2	4 5 5 3
BRQ-025	Intelligent Agent Detection system shall be able to evaluate corrections and continue to issue corrections to dampen the oscillation until dampening is achieved	7.5.1	5
BRQ-026	Energy Storage Device shall be able to return to pre-dispatch levels by energizing or de-energizing (over time) to prepare for the next frequency oscillation event after dampening has been achieved	7.5.1	6
BRQ-027	ISO Energy Management System shall be able to acquire readings for frequency levels at key locations on the transmission grid.	7.6.1	1
BRQ-028	ISO Energy Management System shall be able to determine that frequencies are lower or higher than an acceptable threshold.	7.6.1	2
BRQ-029	ISO Energy Management System shall be able to sample voltage and reactive power at key locations on the transmission grid.	7.7.1	1
BRQ-030	ISO Energy Management System shall be able to determine that voltage and reactive power levels are not within an acceptable threshold.	7.7.1	1
BRQ-031	ISO Market System shall be able to use Load / Demand Profile to (On-Peak or Off-Peak) and Locational Marginal Price to commit Energy Storage Device in the Day-Ahead Market	7.8.1	4
BRQ-032	Energy Storage Device shall be able to charge/energize during Off Peak or Low LMP times acting as a load.	7.8.1	5
BRQ-033	Energy Storage Device shall be able to charge/energize during On Peak or High LMP times discharge/de-energize acting as a generator.	7.8.1	6
BRQ-034	During a trade day, Energy Storage Device shall be able to retain a center-balanced state.	7.8.2	1,8

#	Business Requirements	Associated Scenario #	Associate Step #
BRQ-035	ISO Market System shall be able to detect in real time that a contingency occurred such that an Energy Storage Device can respond.	7.8.2	2
BRQ-036	ISO Market System shall be able to detect in real time the Energy Storage Device's injection or withdrawal. The load has shifted to a future time.	7.8.2	4
BRQ-037	In order to manage the shifted load, ISO Market System's RTPD/RTD shall be able to commit or de-commit resources to offset the Energy Storage Device's injection or withdrawal.	7.8.2	5
BRQ-038	ISO Market System shall be able to evaluate and signal Energy Storage Device to center balance	7.8.2	7
BRQ-039	ISO Energy Management System must be able to read Storage Device Metadata (Dynamic Nameplate)	7.2.1 7.3.1 7.4.2 7.6.1 7.7.1	3 3 2 2 4
BRQ-040	ISO Energy Management System must be able to read current state of Storage Device	7.2.1 7.3.1 7.4.2 7.6.1 7.7.1	3 3 2 2 4
BRQ-041	ISO Energy Management System must be able to send current state of Storage Device to the market systems for Market Dispatch through ADS.	7.2.1 7.3.1 7.4.2 7.6.1 7.7.1	3 3 2 2 4
BRQ-042	ISO Energy Management System must be able to signal directly through AGC, subsets of the Storage Device's capacity	7.2.1 7.3.1 7.4.2 7.6.1 7.7.1	3 3 3 4 4
BRQ-043	ISO Market Systems must be able to signal requests through ADS for subsets of the Storage Device's capacity	7.2.1 7.3.1 7.4.2 7.6.1 7.7.1	5 5 4 4 4
BRQ-044	ISO Market System must be able to retract a bid of an asset from the ISO Market and establish new control authority to ensure unambiguous control (cross check between ISO, IOU, and Plant/Storage Device) (best as a non functional control mechanism?)	7.2.1 7.3.1 7.8.1	1 1 1

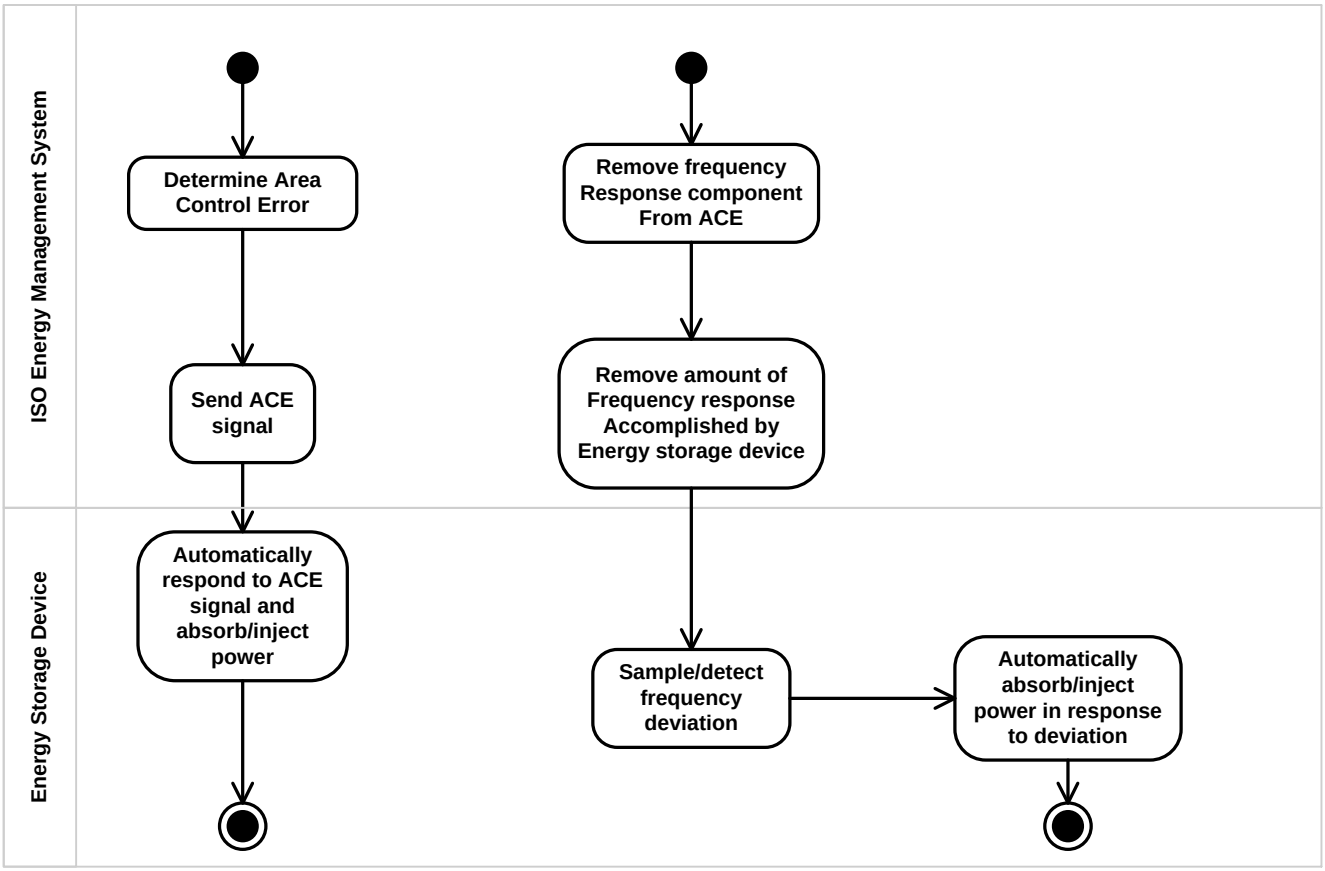
#	Non- Functional Requirements	Associated Scenario #	Associate Step #
NFR-001	The ISO Dispatch System shall be available 24X7X365 with an overall service availability of 99.995%	7.2.1 7.3.1 7.4.2 7.5.1 7.6.1 7.7.1	4 4 4 4 4 4
NFR-002	The ISO Market System shall be available 24X7X365 with an overall service availability of 99.9%	7.2.1 7.4.1 7.4.2	2 1 1
NFR-003	The ISO Energy Management System shall be available 24X7X365 with an overall service availability of 99.999%	7.1.1 7.1.2 7.3.1 7.2.1 7.4.1 7.4.2 7.6.1 7.7.1	1,2 1,2 3,4 3,4 2 2,3 1,2 1,2
NFR-004	The ISO's Dispatch System shall be scalable to handle potential significant increase (TBD) in resources as a result of incorporating energy storage devices	7.2.1 7.3.1 7.4.2 7.5.1 7.6.1 7.7.1	4 4 4 4 4 4
NFR-005	Communication with the ISO for market awards, ISO Dispatch, and telemetry data, must meet the specific ISO technical requirements (example: ADS uses the public internet and 128-bit SSL).	7.2.1 7.3.1 7.4.2 7.5.1 7.6.1 7.7.1	4 4 4 4 4 4
NFR-006	SCs representing Energy Storage Devices & ISO staff must be able to securely access ISO interfaces to carry out their responsibilities	7.2.1 7.3.1 7.4.1	1 1,5 5

#	Non- Functional Requirements	Associated Scenario #	Associate Step #
NFR-007	The ISO's systems shall record access, data creation/modification as well as data receipt/publication by identity for audit purposes	7.1.1 7.1.2 7.2.1 7.3.1 7.4.1 7.4.2 7.6.1 7.7.1 7.8.1 7.8.2	1,2 1,2 1,2,3,4,5 1,2,3,4,5 1,2 1,2,3,4 1,2,3 1,2,3 1,2,3 2,4,5,6,7
NFR-008	Audit data shall be available electronically to the ISO in predetermined formats within predetermined timeframes	7.1.1 7.1.2 7.2.1 7.3.1 7.4.1 7.4.2 7.6.1 7.7.1 7.8.1 7.8.2	1,2 1,2 1,2,3,4,5 1,2,3,4,5 1,2 1,2,3,4 1,2,3 1,2,3 1,2,3 2,4,5,6,7
NFR-009	Data exchanged between the ISO's systems and third party systems shall maintain its authenticity and integrity between the established source and destination	7.1.2 7.2.1 7.3.1 7.4.2 7.6.1 7.7.1 7.8.1 7.8.2	2,3 5,6 5,6 4,5 3,4 3,4 3,4,5 2,3
NFR-010	Storage Resource Asset subsets can vary in number and capacity	All	
NFR-011	Signal Payloads must be represented in CIM	7.1.2 7.2.1 7.3.1 7.4.2 7.6.1 7.7.1	

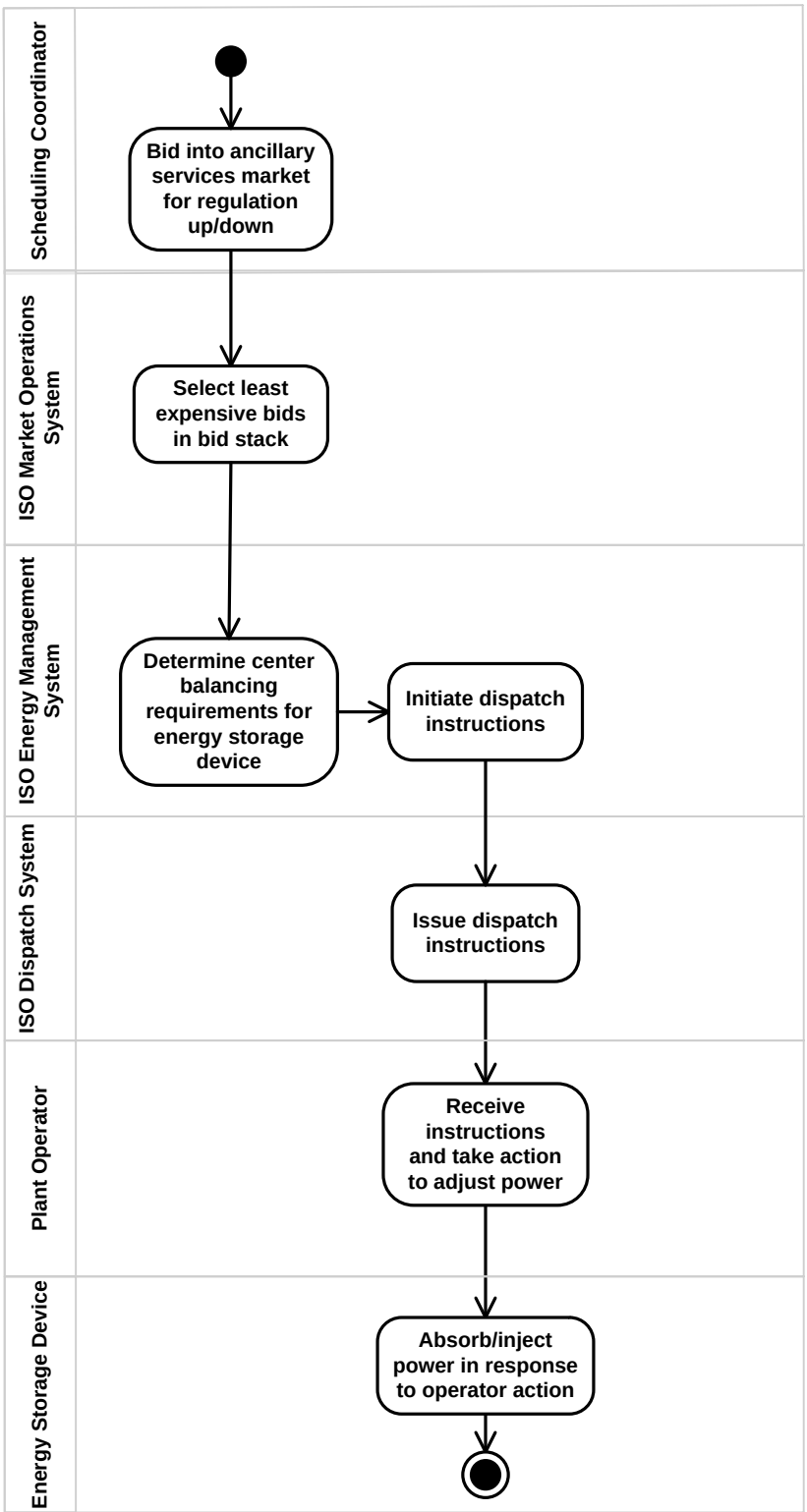
#	Business Rules	Associated Scenario #	Associate Step #
BRL-001	The criteria for eligibility of energy storage devices is similar to generators in terms of agreements, SC representation, metering, telemetry, security, etc	7.2.1 7.3.1 7.4.1	1 1,5 5
BRL-002	Real time dispatches are binding and must be followed.	7.2.1 7.3.1 7.4.2 7.5.1 7.6.1 7.7.1 7.8.2	4 4 4 4 4 4 3
BRL-003	Settlement payment/charges similar to generators shall apply to the SC associated with a Energy Storage device		

9. Activity Diagrams

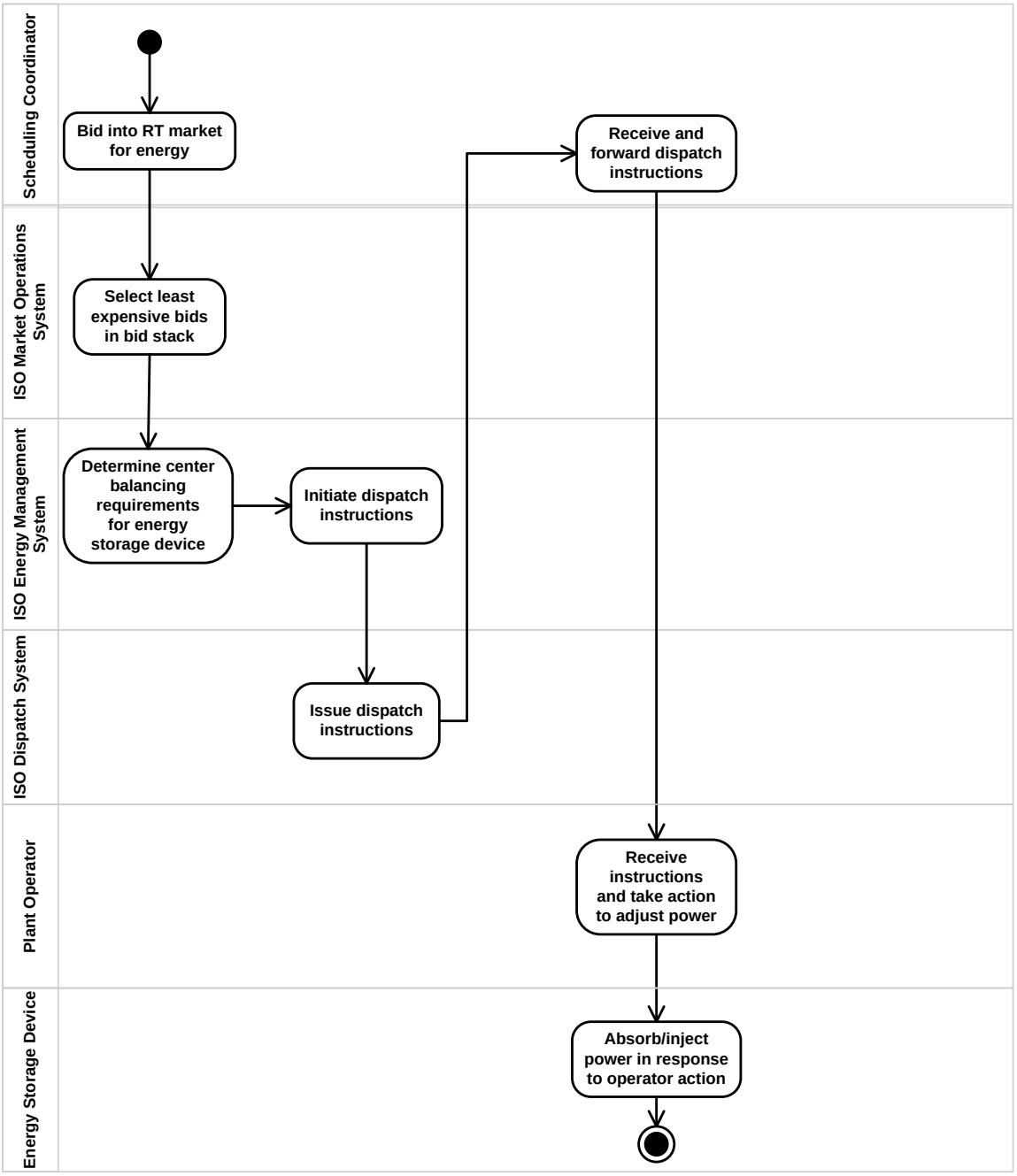
9.1 Energy Storage for Frequency Response



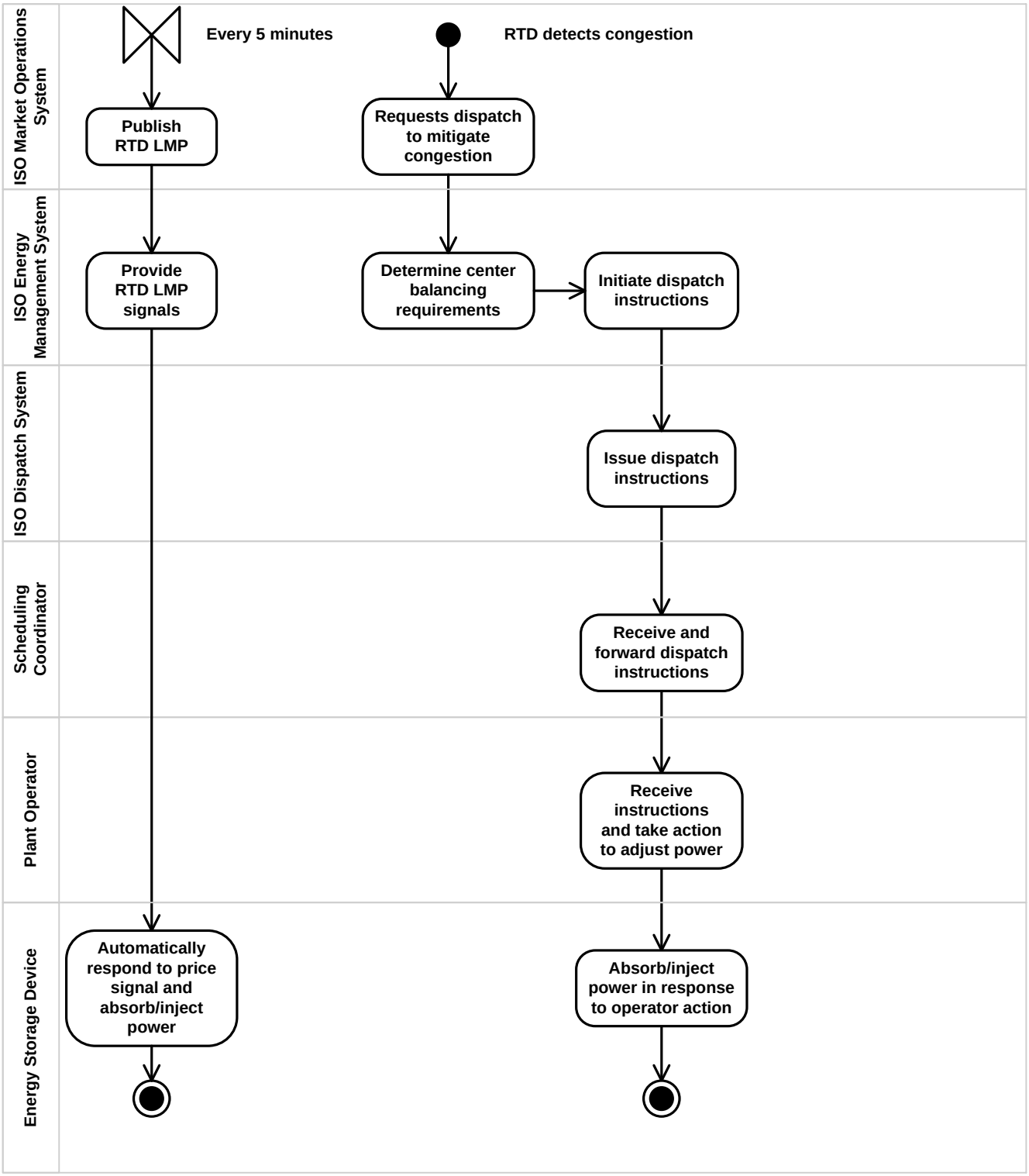
9.2 Energy Storage for Reduction of Intra-Hour Variability of Renewables



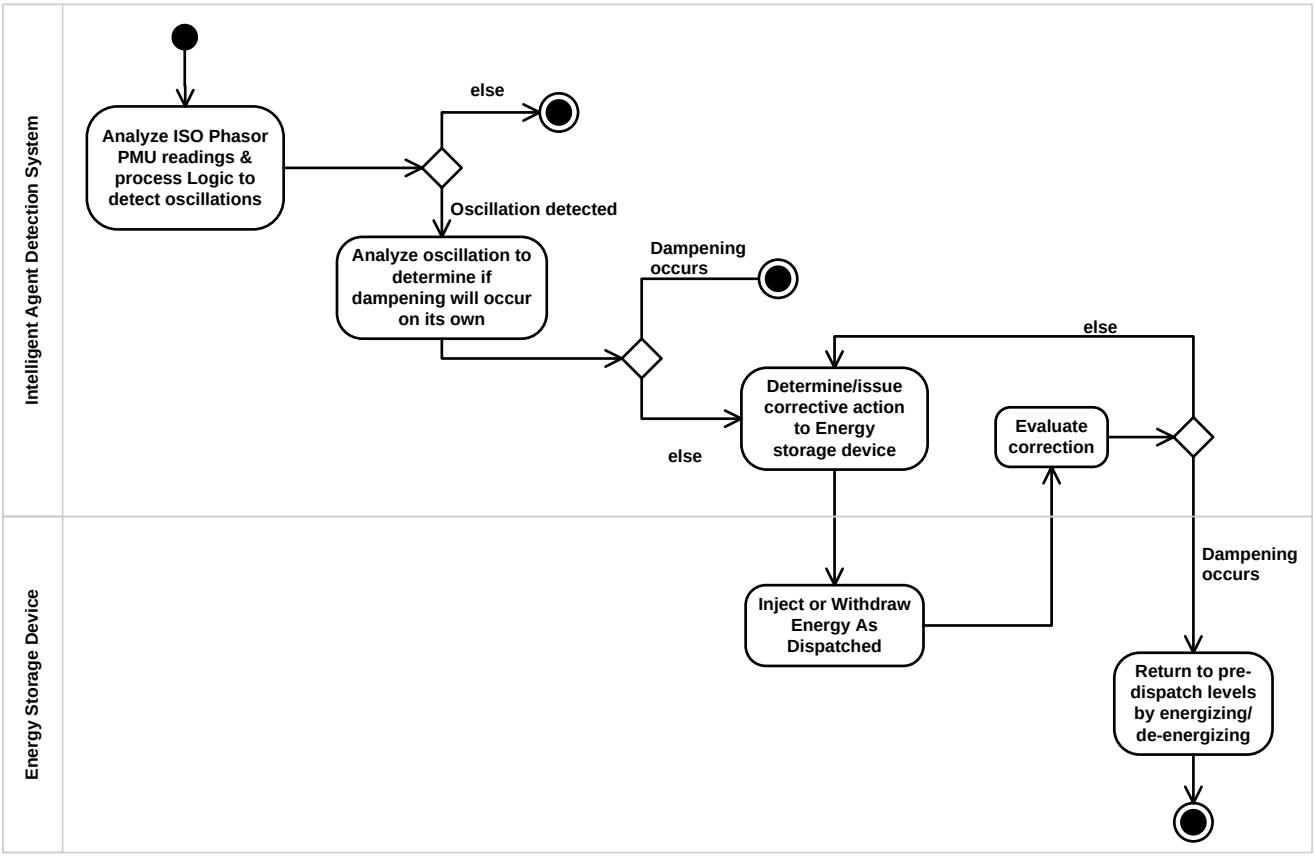
9.3 Energy Storage for Load Following



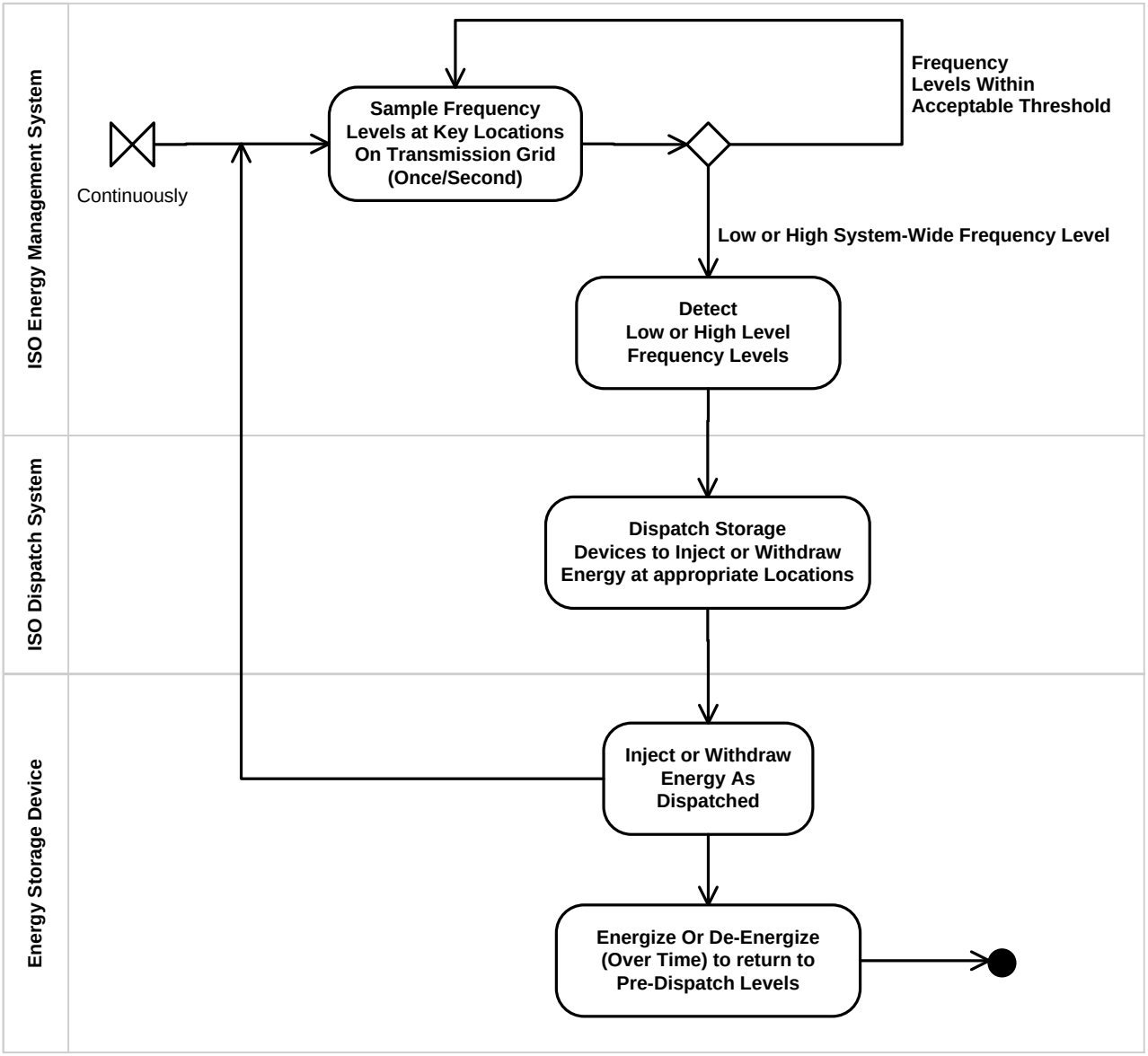
9.4 Energy Storage for Transmission Loading Mitigation



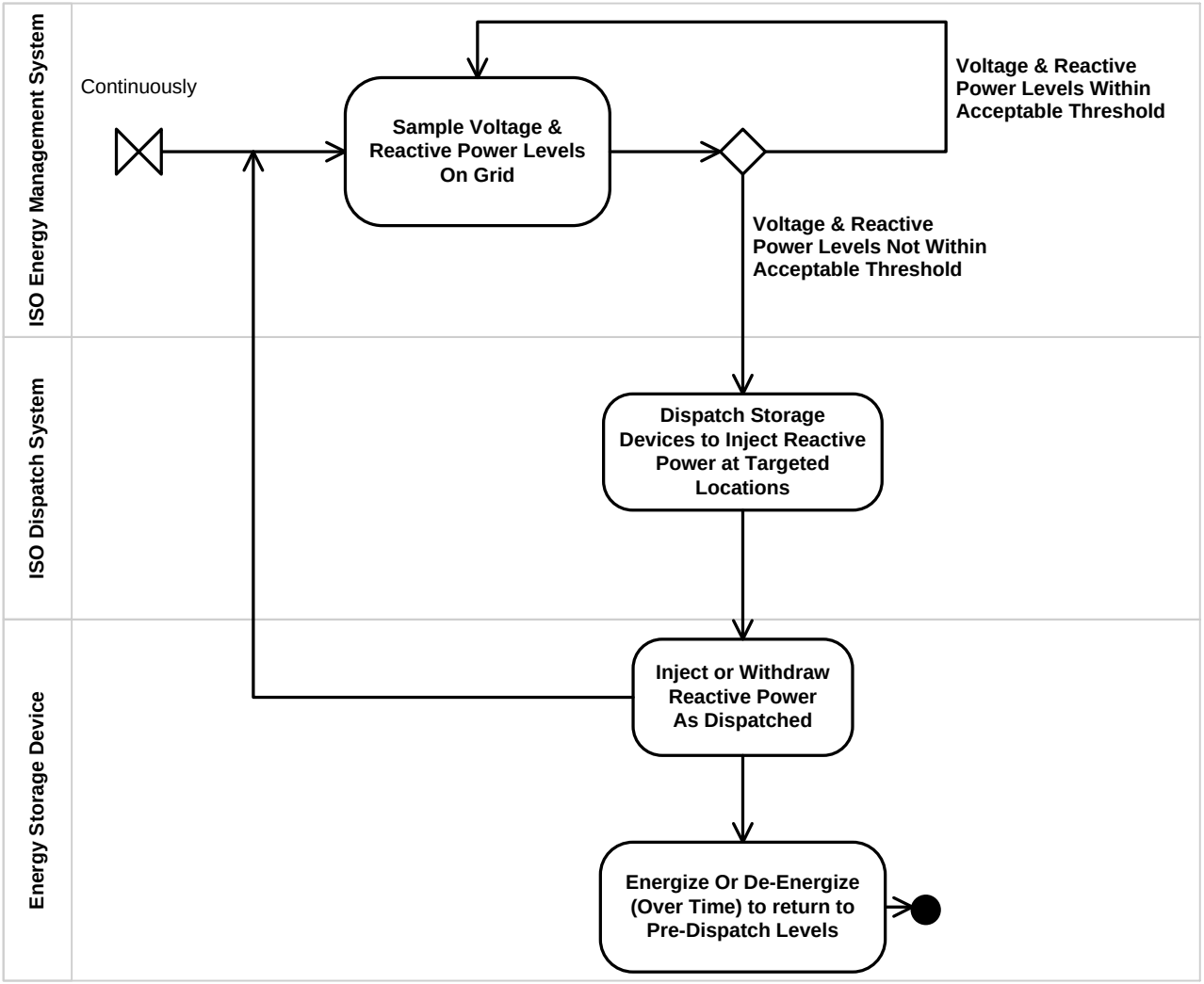
9.5 Energy Storage for Transmission Transient Stability Dampening



9.6 Energy Storage for Under/Over Frequency Load Mitigation

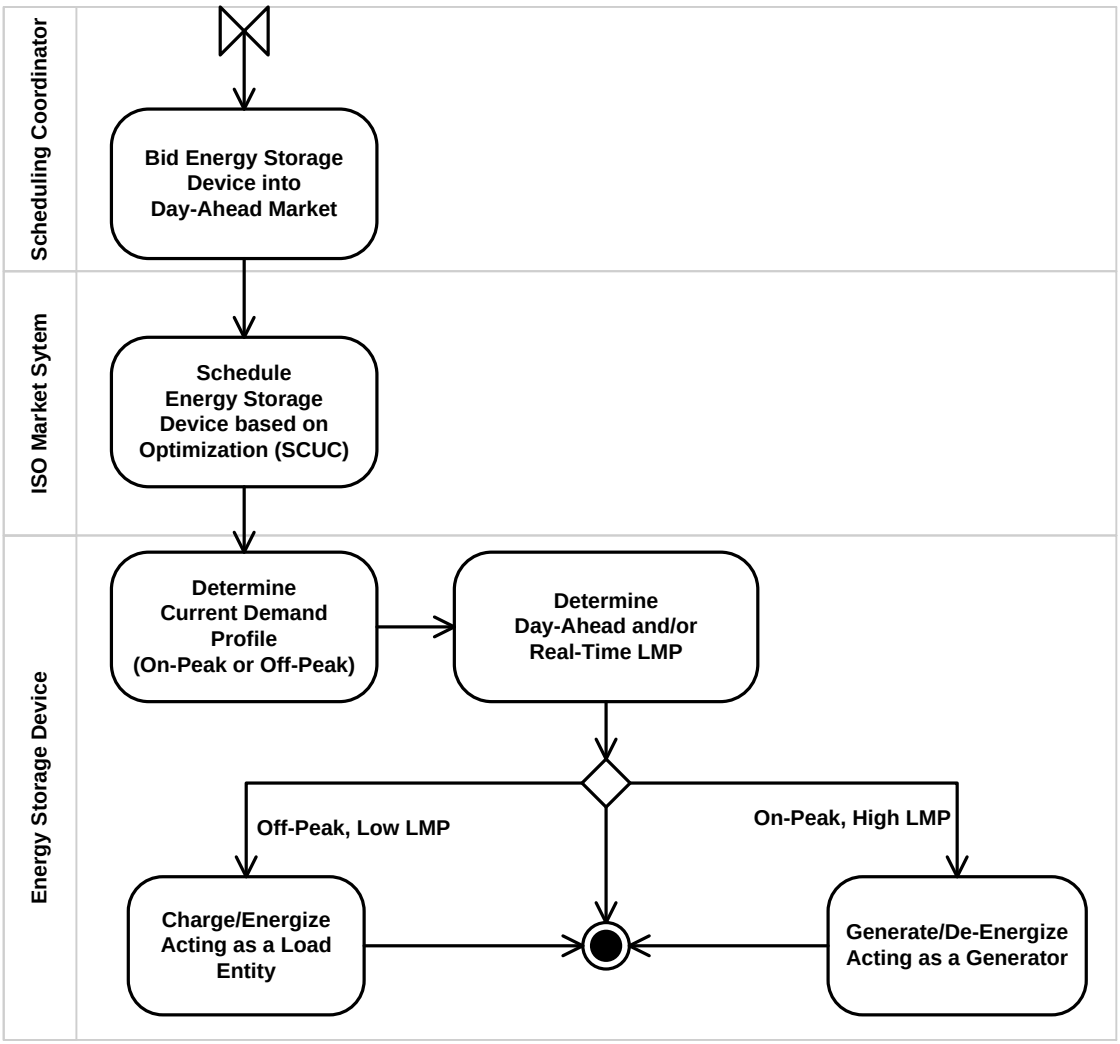


9.7 Energy Storage for Voltage and Reactive Power Support



9.8 Energy Storage for Energy or Load Shifting

9.8.1 Energy Storage for Energy or Load Shifting (Day-Ahead)



9.8.2 Energy Storage for Energy or Load Shifting (Real-Time)