MESA DER Use Case:

Energy Arbitrage by Shifting Energy Production Among DER

1. Use Case: Energy Arbitrage by Shifting Energy Production among DER

1.1. Use Case Name: Energy Arbitrage by Shifting Energy Production among DER

Energy arbitrage is the shifting of energy production from lower price to higher priced times, and the corresponding shifting of energy use from higher price to lower priced times.

In wholesale energy markets enabled by energy storage devices, energy arbitrage refers to purchase of energy when the prices are low and resale of purchased energy when the prices are high.

In the distribution system, energy arbitrage is exercised by the utility through tariffs that depend on the time of day and encourage consumers to shift their energy use from higher priced times to lower priced times.

It is therefore important to state that the Energy Arbitrage Use Case described in this document refers more to the use of energy storage devices to shift energy from one time of day to another and is thought to be the primary use case for energy storage devices especially when combined with a renewable energy source.

1.2. Background information

Energy arbitrage, in addition to involving generation, may involve the consumption of energy for storing energy in an Energy Storage System (ESS) during lower price times then discharging (generating) this stored energy during higher price times. Energy arbitrage now must take into account additional factors:

- Demand Response is now just viewed as one strategy within energy arbitrage methods.
- Energy arbitrage is primarily day-ahead management of exporting and importing active power to optimize revenue, while demand response may be seen more for reducing loads hours-ahead to possibly day-ahead.
- Prices for exporting energy may or may not be the same as for importing energy.
- Locational marginal pricing (LMP) reflects the location of the DER plant and can vary in real-time, every 15-minutes, every hour, etc. Energy imbalance typically drives spot-market prices within the hour
- If a plant consists of Renewable Generation plus Storage, then the storage can be used to reach optimal energy export and import for each hour by scheduling the Generation Following function.

However, DER plants usually must or can provide other grid support functions (mandatory or market-driven). Some of these functions might only impact reactive power, but even those might limit some active power choices. These additional grid support functions would have to be balanced in conjunction with the energy arbitrage requirements and could include:

- **Mandatory grid support functions**: IEEE 1547 and California's Rule 21 include some mandatory functions, such as frequency and voltage ride-through, volt-var control, volt-watt control, frequency droop, power factor management, etc.
- **Active power smoothing**: Minimizing changes in net active power during ramping up and down of PV.
- **Load following**: The DER are used to reduce net load not just for energy arbitrage reasons but for grid support or contractual reasons.
- **Generation following of external plants**: The DER in one plant has a contract to support generation at a separate plant.
- **Frequency regulation**: the DER is used for primary frequency regulation (droop – mandatory in IEEE 1547), secondary frequency regulation (automatic generation control (AGC), and/or tertiary frequency regulation (spinning reserve or operational reserve).
- **Frequency smoothing**: The DER is used for artificial inertia by countering spikes and dips in frequency.
- **Frequency emergency response**: The DER is used to rapidly inject (or remove) active power from the grid if the frequency exceeds its low (or high) limits.
- **Voltage support**: The DER is used to maintain voltage levels via active power and reactive power changes.
- **Providing operational reserve**: The DER retains energy in case it needs to provide operational reserve.

Therefore, part of energy arbitrage consists of optimizing the traditional cost savings from shifting of active power loads to different times with gaining revenue from providing ancillary services with DER. For example, if the stored energy comes from renewable sources, then the actual cost to store this energy is minimal, while using stored energy to smooth the export of PV generation may improve revenues. Thus the energy arbitrage use case is more than demand response but must take these competing requirements into account.

1.3. Brief Narrative of basic energy arbitrage use case

1.3.1. Components of the Energy Arbitrage Use Case

For this basic Energy Arbitrage Use Case, the DER Plant contains:

- PV system (PV)
- Battery Energy Storage System (ESS)

Only three functions are included:

- Active Power (Generation) Following (ESS follows PV)
- Coordinated Charge/Discharge (ESS reaches a target State of Charge by a specified time)
- Charge/Discharge (ESS active power charge and discharge are managed)

Additional capabilities include:

- Input from external sources
- Schedules
- Management applications that take all the relevant inputs and, acting as “black boxes”, develop the results.

1.3.2. Brief Description of Key Activities in the Energy Arbitrage Use Case

Background: The DER Plant includes both PV generation and energy storage capabilities. The price of energy is provided by the Balancing Authority (e.g. CAISO) for each location (Locational Marginal Pricing (LMP)) and for each period during different time frames: typically hourly periods for week ahead, day ahead, and hour ahead, but may be as short as 5 minutes. In this Use Case, a period of 15 minutes is used.

Planning: The DER DERMS develops a plan for the export of active power from the plant for each pricing period, based on the energy prices, the forecast of the PV generation, the storage capabilities, and the other expected uses of these DERs for meeting loads or providing ancillary services (Plant Schedule). The DER DERMS also develops a schedule for the charging and discharging of the ESS. Based on Generation Following and Coordinated Charge/Discharge functions. This ESS schedule is based on priorities, ideal, maximum, and minimum settings for each of the requested functions. *Although the DER DERMS may develop schedules for other DER actions (limit active power, peak power shifting, volt-watt function, frequency-watt artificial inertia, etc.), these other uses are not included in this Use Case.*

Operation: During each pricing period, the Plant and ESS schedules are followed. If power system contingencies arise involving mandatory immediate or short-term actions, or if the ESS or PV resources must change their operational capabilities due to equipment failures or human-invoked maintenance or safety actions, the schedules are updated.

Coordination due to other uses of the DER: If modifications to expected uses of the DERs are requested, the DER DERMS assesses the impact on energy arbitrage, and modifies any affected schedules based on priorities, ideal, and maximum/minimum settings.

1.4. Assumptions for this Basic Energy Arbitrage Use Case

DER capabilities: The plant is a “PV Plus ESS” Plant. Generation is provided by PV systems and ESS is provided by battery systems. No load is included other than charging the battery. For this use case, if multiple batteries are involved, they are treated as a single unit (e.g. allocation of active power discharging or charging is handled as if the batteries were a single unit). All PV and ESS nameplate and operational settings are already available in the DER DERMS.

Pricing information: 15-minute LMP information on the price of energy for the current day has been provided the day before for the electrical location of the plant. Spot Market or updated prices may be provided during the current day.

Grid status: The grid is in a normal state with no active power constraints.

PV forecast: The forecast of PV active power output for the entire day is available day ahead and is updated periodically during the day.

Battery charging: The ESS can only be charged using PV generation.

Daily Plant Active Power Output Schedule: The *Plant Schedule* of total plant active power output at the PCC is created for the entire 24-hour day, based on 15-minute prices of energy, the PV active power output forecast, and the battery charging constraints. The creation of this schedule is a "black-box" algorithm that optimizes revenue while taking into account the various constraints. Each scheduled active power output is the target that the Generation Following function seeks to achieve, while the Coordinated Charge/Discharge function may override (higher priority) if the battery state of charge target is not being met in a timely manner. This Plant Output Schedule may be updated during the current day based on changes in PV forecasts and pricing information via the DERMS HMI or autonomously.

Primary functions: The *Generation Following function* (Active Power Response Mode #2) (ESS following PV active power output) is the primary method of determining what the total active power output of the plant should be in real-time. The function monitors the PV active power output and determines the delta generation or consumption that should be provided by the ESS to meet the Plant Schedule. The *Charge/Discharge Mode* then commands the ESS to provide that amount of generation or consumption (as a percentage of WMax).

Additional function: The *Coordinated Charge/Discharge mode* is used to ensure that the ESS achieves a set State of Charge target by the end of the (Plant Schedule) day.

Monitored data: The focus of the Use Case is the identification of MESA data exchange requirements for performing energy arbitrage related to active power. Therefore, the data exchanges of PV and ESS in this Use Case cover only those requirements and do not include other data exchanges such as monitoring of reactive power, allocation of commands to different storage units, handling of alarms, retrieval of maintenance data, etc. This monitored data is available to be viewed through the DERMS HMI.

Commands: The assumption for this Use Case is that the DERMS will provide the Power Resource Manager with the Generation Following parameters and schedule as well as the Coordinated Charge/Discharge parameters, and that the Power Resource Manager will then combine all requested actions with respect to the ESS to issue a net result. This assumption allows these interactions to be clearly modeled using MESA.

Metered data: The actual Plant active power output is metered as net energy measurements for every (1, 5, or 15?) minutes, while internal metering captures the PV output energy and the ESS net energy for each (1, 5, or 15?) minutes. (Metering is not included in this Use Case).

Error or failure conditions: This Use Case does not address errors, loss of communications, equipment failures, or any other types of abnormal conditions. These situations are extremely important to cover, however, and additional (sub) Use Cases should add the handling of these conditions.

2. Actors (Roles)

2.1. Diagram of Actors in Energy Arbitrage Use Case

The actors for this Energy Arbitrage Use Case are shown in Figure 1.

- The **stick figures** are actors or "roles". In this document, these two terms are used interchangeably.
- The **colors** reflect the categorization of different roles in the IEC 61850-7-420 information model: Resources are brown, electrical connection points are blue, operational functions are pink, scheduling is green, "black box" power resource management system are yellow, and external entities that provide input but whose functionality is not part of this use case are purple.
- The **arrows** reflect modeling constructs: the dotted arrows show information flows, while the solid arrows show "generalization" which just means that specific actors point to a general type of actor. For instance, the pink Active Power Following actor is a specific type of the general actor, Operational Function.

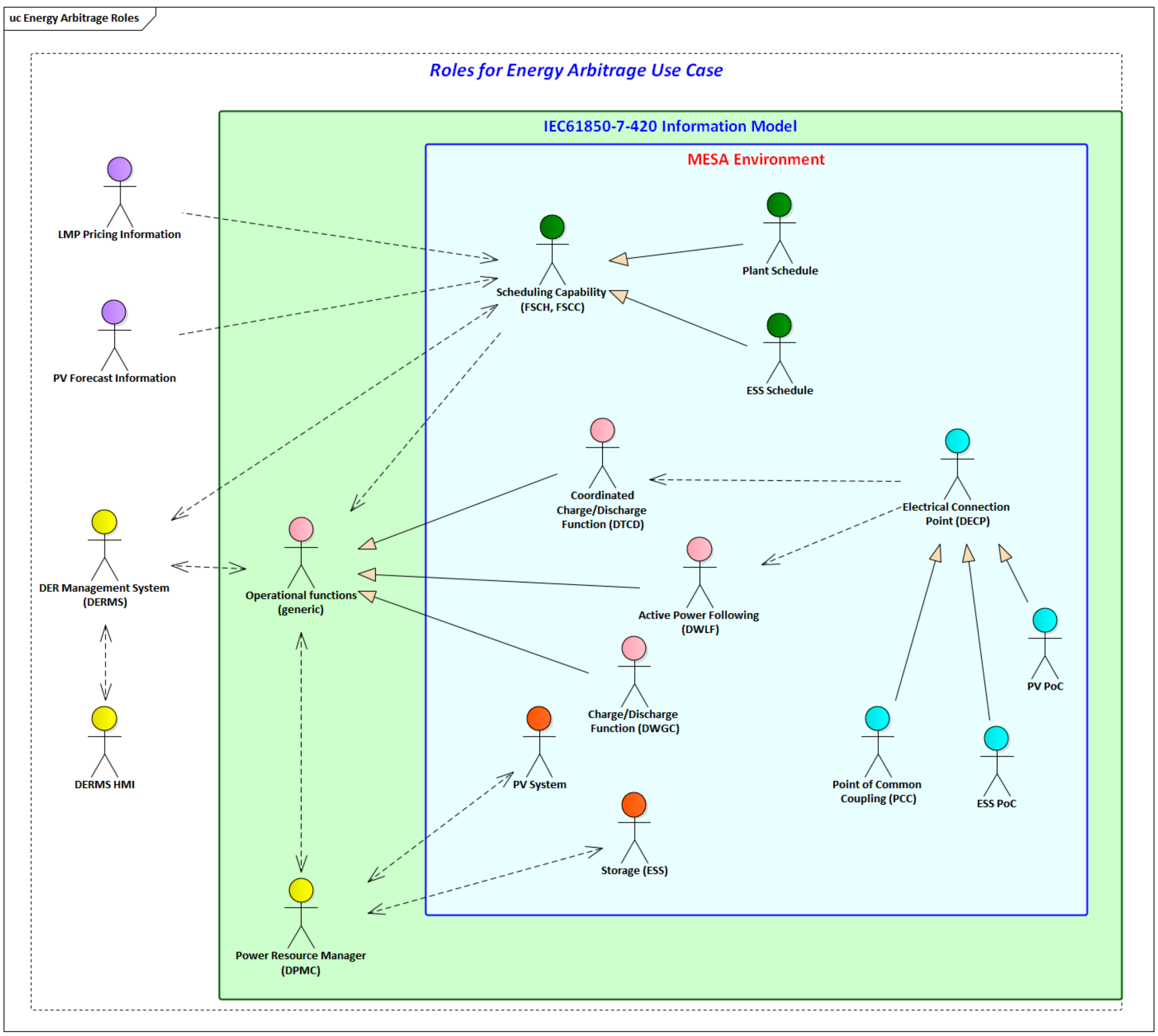

Figure 1: Roles for Energy Arbitrage Use Case

2.2. System Actors

The system actors in this Use Case are:

- Location Marginal Pricing (LMP) information source
- PV system (PV) forecasting source
- DER Facility DERMS (DERMS) (for optimizing inputs to determine and manage schedules)
- DERMS HMI (HMI) (for viewing schedules and manually updating settings)
- Plant Schedule (data used by other Generation Following function)
- ESS Schedule (data used by Generation Following function)
- Power Resource Manager (DPMC). This Power Resource Manager operates as a "black box" application that combines requests from different operational functions to determine net result to send to DER. An example of how it might work is shown in Section 6.
- Electrical points of connection of the PV (PV PoC), the ESS (ESS PoC), and the Plant (PCC)

2.3. Operational Function Actors

The operational functions in this Use Case are:

- Charge/Discharge (DWGC) is used to set active power (generation, consumption) of the ESS
- Generation Following Mode (DWFL) is used by the ESS to follow the PV generation and compensate (add generation or consumption) in order to meet the requested active power at the PCC
- Coordinated Charge/Discharge Mode (DTCD) is used to ensure the ESS state of charge reaches its target by the end of the day (thus being ready for the next day)

2.4. Information Exchanged

The information exchanged in this Use Case includes:

- LMP information (not in MESA)
- PV active power output forecast data (not in MESA)
- Charge/Discharge parameters (see Table 1)
- Generation Following parameters (see Table 2)
- Coordinated Charge/Discharge parameters (See Table 3)

- Plant Schedule of target plant active power output at the PCC for every pricing time period (e.g. every 5 minutes, every 15-minutes, every hour) over 24-hours, determined from the calculated optimal energy output. For this use case, the pricing time period is every 15 minutes.
- ESS Schedule of Generation Following parameters for every 15-minutes period over 24 hours
- Real-time PV active power generation
- Real-time ESS active power generation or consumption
- Real-time ESS state of charge data

3. Steps of data to be exchanged between actors

Step No	*Name of process/activity*	*Description of process/activity*	*Information producer*	*Information receiver*	*Information exchanged*
Day-Ahead					
A-1	Receive Day-Ahead 15-minute prices for energy	Based on Locational Marginal Pricing (LMP) information, capture 15-minute prices for the following day	LMP information source	DERMS	15-minute prices for energy
A-2	Determine PV active power output forecast	Determine PV active power output forecast for next day	Weather and forecasting systems	DERMS	Weather and PV forecasts
A-3	Identify any ESS constraints	Identify any ESS constraints for the next day, such as maintenance impacts, starting state of charge, special uses	DERMS	DERMS	Internal calculation
A-4	Determine ESS state of charge target for the end of the next day	Determine what the SoC should be for the ESS by the end of the following day	DERMS HMI (or internally)	DERMS	Manual input
A-5	Develop Plant Schedule for the next day	Develop the optimal Plant Schedule for target active power at the PCC for each 15-minute period for the next day, based on LMP information, PV forecast, load forecast, and any ESS constraints	DERMS	Plant Schedule	Time period: every 15-minutes Target: Active Power
A-6	Develop ESS Generation Following Schedule	Develop ESS Schedule for Generation Following parameters, including target active power from the Plant Schedule, priority, ratio, for each 15-minute period of the following day	DERMS	ESS Schedule	Time period: every 15-minutes Priority: DGFL.ModPrio PCC: DGFL.EcpRef Target: DGFL.FolWTgt Ratio: DGFL.FolWPct Ramp up: DGFL.RpuRte Ramp down: DGFL.RpdRte
Midnight					
B-1	Activate new ESS Schedule (at midnight)	Activate ESS Schedule for Generation Following and update any parameters that may have changed	DERMS	ESS Schedule	Activation: FSCH.Mod

Step No	Name of process/activity	Description of process/activity	Information producer	Information receiver	Information exchanged
B-2	Enable DFLF Generation Following function	Enable DFLF Generation Following function	DERMS	DFLF Function	Enable: GFLF.FctEna
B-3	Enable DTCD and provide the target State of Charge for the ESS for the next midnight	Provide the target State of Charge for the ESS for the next midnight	DERMS	DTCD Function	DTCD.FctEna DTCD.SocUseTgtPct
As needed during Current Day					
C-1	Update Day-Ahead 15-minute prices for energy	Based on Locational Marginal Pricing (LMP) information, capture updated 15-minute prices	LMP information source	DERMS	15-minute prices for energy
C-2	Update PV active power output forecast	Determine PV active power output forecast for next day	Weather and forecasting systems	DERMS	Weather forecasts
C-3	Update Plant Schedule	Update the optimal Plant Schedule for target active power at the PCC for each 15-minute period for the next day, based on LMP information, PV forecast, load forecast, and any ESS constraints	DERMS	Plant Schedule	Target: Active Power
C-4	Update ESS Schedule	Provide updates to the ESS Schedule, reflecting new or removed constraints	DERMS	ESS Schedule	Time period: every 15-minutes Priority: DGFL.ModPrio PCC: DGFL.EcpRef Target: DGFL.FolWTgt Ratio: DGFL.FolWPct Ramp up: DGFL.RpuRte Ramp down: DGFL.RpdRte
C-5	Update the target State of Charge for the ESS	Provide updates to the target State of Charge for the ESS for the next midnight	DERMS	DTCD Function	DTCD.SocUseTgtPct
Every 15-Minutes during Current Day					
D-1	Every 15-minutes, access target active power from Plant Schedule	Access the target active power from the Plant Schedule for the current 15-minute time period and use it to set Generation Following target	Plant Schedule	DWFL Function	DGFL.FolWTgt
D-2	Every 15-minutes, use ESS Schedule to update any DGFL parameters	Use ESS Schedule to update any DGFL parameters for the current 15-minute time period	ESS Schedule	DWFL Function	Priority: DGFL.ModPrio PCC: DGFL.EcpRef Ratio: DGFL.FolWPct Ramp up: DGFL.RpuRte Ramp down: DGFL.RpdRte
Repeated Real-Time Interactions during Current Day					
E-1	Receive real-time PV generation measurement	Receive real-time filtered PV generation measurement every second	PV PoC	DWFL Function	PV Active power: DGFL.EcpRef@MMXU.TotW
E-2	Receive real-time active power measurement at the PCC	Receive real-time filtered active power measurement at PCC every second	Plant PCC	DWFL Function	PCC Active power: MMXU.TotW

Step No	Name of process/activity	Description of process/activity	Information producer	Information receiver	Information exchanged
E-3	DGFL: Calculate delta error from expected active power at PCC	Calculate delta "error" active power by subtracting the PV active power output from target active power at PCC	DGFL Function	DWFL Function	Internal calculation
E-4	DGFL: Calculate Ideal, Max, Min, & Priority	Calculate the Ideal, Max, Min, & Priority active power for the ESS by subtracting the PV forecast active power from the PCC target, while including the delta error and the ratio.	DGFL Function	DWFL Function	Internal calculation
E-5	DGFL: Request Ideal, Max, Min, & Priority ESS active power	Request Ideal, Max, Min, & Priority active power for the ESS from the target active power output at the PCC and by applying the ratio.	DGFL function	Power Resource Manager (DPMC)	Ideal DGFL.ReqWSet Max DGFL.ReqWSet Min DGFL.ReqWSet Priority: DGFL.ModPrio
E-6	DTCD: Calculate Ideal, Max, Min, & Priority to achieve target State of Charge	Calculate Ideal, Max, Min, & Priority for DTCD, based on time left to achieve target State of Charge and on available active power from PV	DTCD Function	DTCD Function	DTCD.DateTgtTms PV Forecast Internal calculation
E-7	DTCD: Request Ideal, Max, Min, &Priority ESS active power	Request Ideal, Max, Min, & Priority generation and consumption of active power for the ESS	DTCD Function	Power Resource Manager (DPMC)	Ideal DTCD.ReqWSet Max DTCD.ReqWSet Min DTCD.ReqWSet Priority: DTCD.ModPrio
E-8	Receive real-time ESS active power measurement	Receive real-time ESS active power measurement	ESS PoC	Power Resource Manager (DPMC)	DSTO.Ecp@MMXU.TotW
E-9	Combine DGFL and DTCD requests	The Power Resource Manager uses an algorithm to determine the net result of active power requirement for the ESS (see examples in Section 6) and then	Power Resource Manager (DPMC)	Power Resource Manager (DPMC)	Internal optimization algorithm
E-10	Issue command for ESS active power	Issue command for ESS active power as a percent of WMax	Power Resource Manager (DPMC)	Storage (ESS)	DWGC.GnWPctSpt

4. Diagrams

4.1. Locational Marginal Pricing (LMP)

Locational Marginal Pricing (LMP) can be available day-ahead, hour-ahead, within 15-minutes intervals, and in real-time, as illustrated for California in Figure 2. These prices can then be used to determine how best to achieve the optimal financial goals while still meeting all DER obligations.

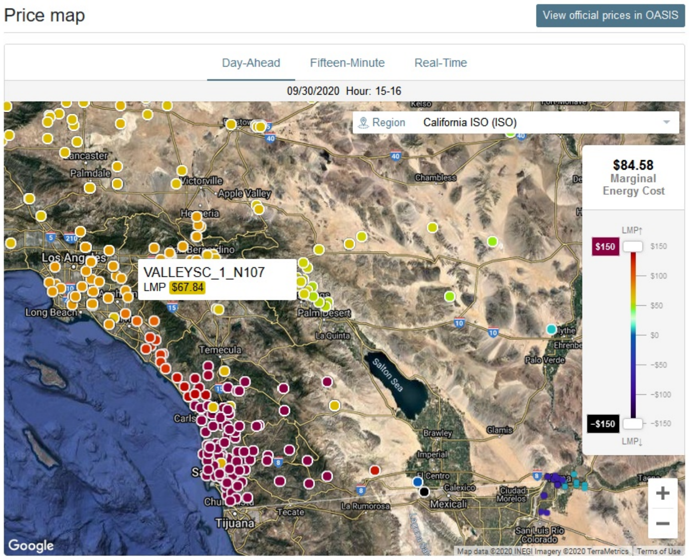

Figure 2: Locational Marginal Pricing (LMP) for Southern California

4.2. Sequence Diagrams for Energy Arbitrage

4.2.1. Day Ahead Planning and Current Day Updates

Sequence diagram of the steps shown in Section 3.

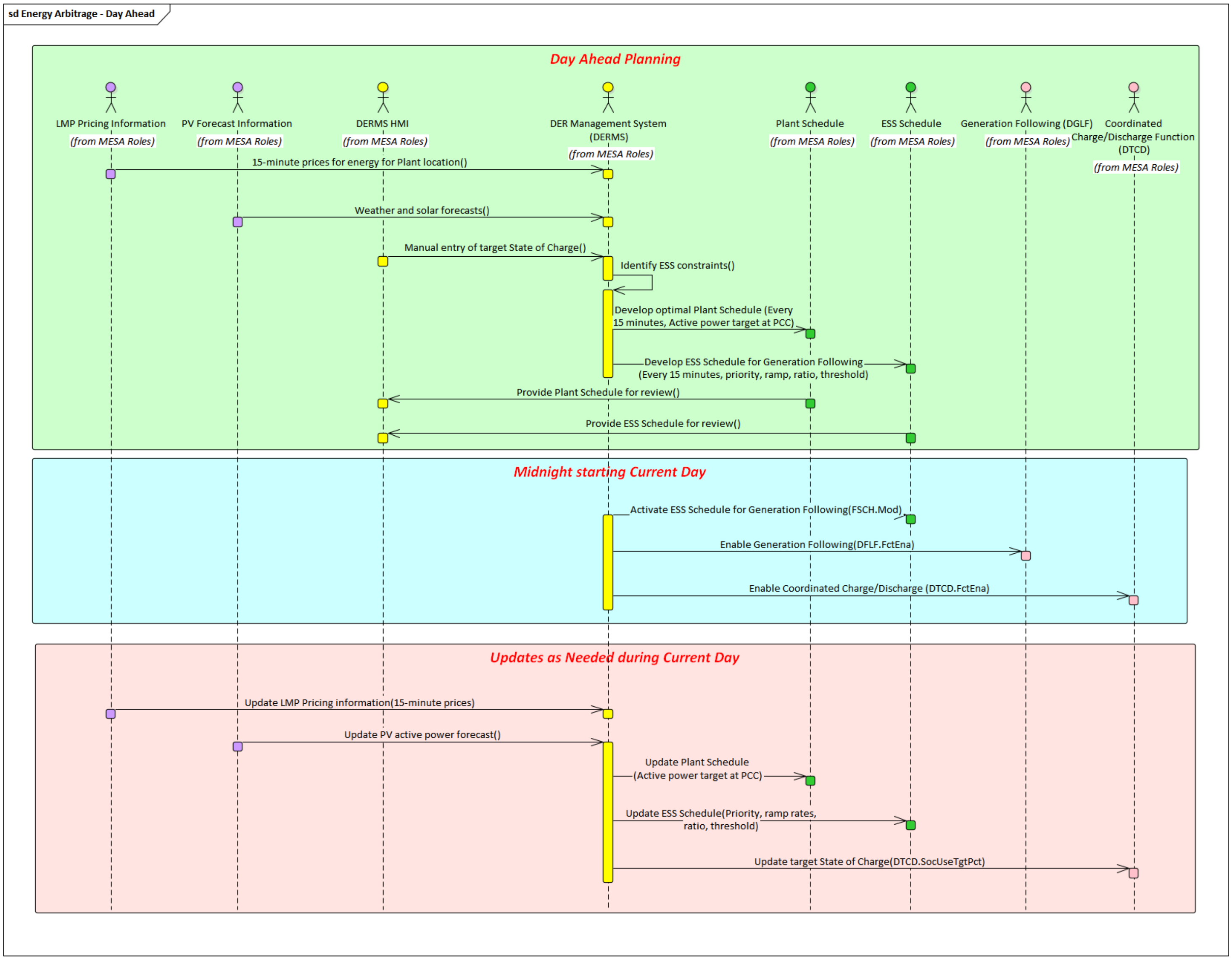

Figure 3: Day Ahead Planning and Current Day Updates

4.2.2. Operations During the Current Day

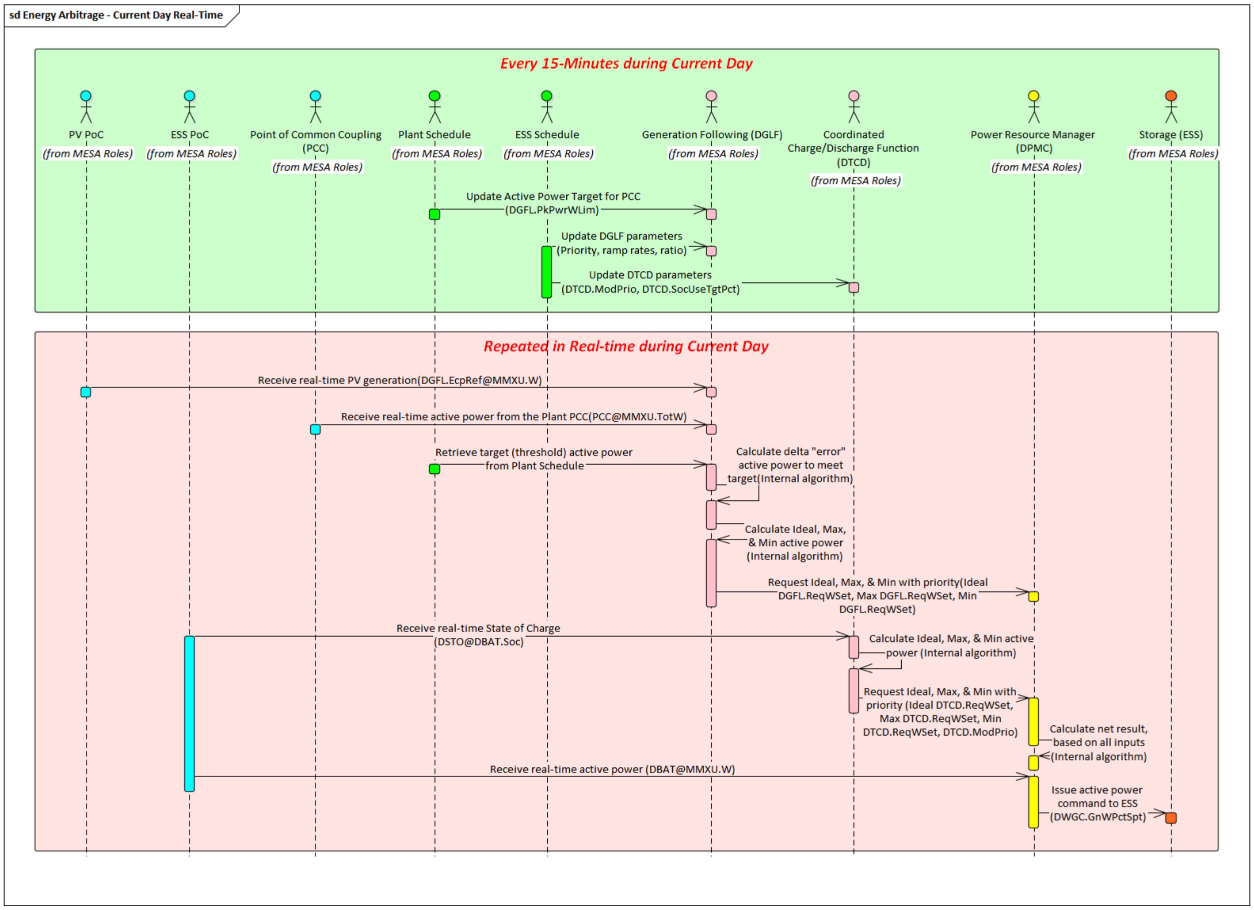

Figure 4: Interactions during the current day

5. MESA Data Objects

5.1. Charge/Discharge Commands

Table 1: Charge/Discharge

Analog Input DNP3 Point Index	Name / Description	Units	IEC 61850 Logical Node	IEC 61850 Data Object	CDC
AI150	**Charge/Discharge Mode Priority**	n/a	DWGC	ModPrio	ING
AI151	**Charge/Discharge Enabling Time Window**	Seconds	DWGC	WinTms	ING
AI152	**Charge/Discharge Enabling Ramp Time.** Ramp time, in seconds, for moving from current operational mode settings to new operational mode settings	Seconds	DWGC	RmpTms	ING
AI153	**Charge/Discharge Reversion Timeout Period**	Seconds	DWGC	RvrtTms	ING
AI154	**Charge/Discharge Active Power Target.** Percentage of maximum active power.	Percent	DWGC	GnWPctSpt	ASG
AI155	**Charge/Discharge Ramp Up Time Constant.** Ramp time, in seconds, for moving from the current active power target to a higher active power target.	Seconds	DWGC	OpnLoopMax	ING
AI156	**Charge/Discharge Ramp Down Time Constant.** Ramp time, in seconds, for moving from the current active power target to a lower active power target.	Seconds	DWGC	OpnLoopMax	ING
AI157	**Charge/Discharge Discharge Ramp Up Rate**	Percent per Second	DWGC	RpuRte	ASG
AI158	**Charge/Discharge Discharge Ramp Down Rate**	Percent per Second	DWGC	RpdRteMax	ASG
AI159	**Charge/Discharge Charge Ramp Up Rate**	Percent per Second	DWGC	RpuChaRte	ASG
AI160	**Charge/Discharge Charge Ramp Down Rate**	Percent per Second	DWGC	RpdChaRteMax	ASG
AI161	**Charge/Discharge Minimum Reserve for Storage.** The reserve level below which the storage system may be only be discharged in emergency situations, expressed as a percentage of the usable capacity.	Percent	DWGC	SocUseMinPct	ASG
AI162	**Charge/Discharge Maximum Reserve for Storage.** The reserve level above which the storage system may be only be charged in emergency situations, expressed as a percentage of the usable capacity.	Percent	DWGC	SocUseMaxPct	ASG

5.2. Generation Following Mode

Table 2: Generation Following Mode

Analog Input DNP3 Point Index	Name / Description	Units	IEC 61850 Logical Node	IEC 61850 Data Object	CDC
AI187	**Active Power Response Mode #2 Priority**	n/a	DWFL	ModPrio	ING
AI188	**Active Power Response Mode #2 Enabling Time Window**	Seconds	DWFL	WinTms	ING
AI189	**Active Power Response Mode #2 Enabling Ramp Time**	Seconds	DWFL	RmpTms	ING
AI190	**Active Power Response Mode #2 Reversion Timeout Period**	Seconds	DWFL	RvrtTms	ING
AI191	**Active Power Response Mode #2 Signal Meter ID**	n/a	DWFL	EcpRef	ORG
AI192	**Active Power Response Mode #2 Reference Power Measured**	Watts	MMXU	TotW	MV
AI193	**Active Power Response Mode #2 Power Threshold**	Watts	DWFL	FolWThr	ASG
AI194	**Active Power Response Mode #2 Ratio**	Percent	DWFL	FolWPct	ING
AI195	**Active Power Response Mode #2 Ramp Up Rate.** Maximum ramp up rate.	Percent per Second	DWFL	RpuRte	ASG
AI196	**Active Power Response Mode #2 Ramp Down Rate.** Maximum ramp down rate.	Percent per Second	DWFL	RpdRte	ASG
AI197	**Active Power Response Mode #2 Attempted Output.** Watt output that the mode is attempting to achieve based on the Watts input and other parameters.	Watts	DWFL	ReqWSet	MV
AI???	**Active Power Response Mode #2 Power Target**	Watts	DWFL	FolWTgt	ASG

5.3. Coordinated Charge/Discharge Mode

Table 3: Coordinated Charge/Discharge Mode

Analog Input DNP3 Point Index	Name / Description	Units	IEC 61850 Logical Node	IEC 61850 Data Object	CDC
AI163	**Coordinated Charge/Discharge Mode Priority**	n/a	DTCD	ModPrio	ING
AI164	**Coordinated Charge/Discharge Enabling Time Window**	Seconds	DTCD	WinTms	ING
AI165	**Coordinated Charge/Discharge Enabling Ramp Time.** Ramp time, in seconds, for moving from current	Seconds	DTCD	RmpTms	ING

Analog Input DNP3 Point Index	Name / Description	Units	IEC 61850 Logical Node	IEC 61850 Data Object	CDC
	operational mode settings to new operational mode settings				
AI166	**Coordinated Charge/Discharge Reversion Timeout Period**	Seconds	DTCD	RvrtTms	ING
AI167	**Coordinated Charge/Discharge Target State of Charge.** Charge that the system is expected to achieve, as a percentage of the usable capacity.	Percent	DTCD	SocUseTgtPct	ASG
AI168	**Coordinated Charge/Discharge Target Date.** Date by which the storage system must reach the target SOC. Days since January 1, 1970, UTC.	Days	DTCD	DateTgt	ING
AI169	**Coordinated Charge/Discharge Target Time.** Time by when the storage system must reach the target SOC. Expressed as the number of seconds since the start of Target Date.	Milliseconds	DTCD	DateTgtTms	ING
AI170	**Coordinated Charge/Discharge Energy Request.** Amount of energy that must be transferred from the grid to the charger to move the SOC from the value at the specific time of reference to the target SOC.	Watt-hours	DTCD	SocWReq	ING
AI171	**Coordinated Charge/Discharge Minimum Charging Duration.** Minimum duration to move from the SOC at the time of reference to the target SOC.	Seconds	DTCD	ChaDurTms	ING
AI172	**Coordinated Charge/Discharge Date of Reference.** Date that the SOC is measured or computed by the storage system and is the basis for the Energy Request, Minimum Charging Duration, and other parameters	Days	DTCD	DateTgt	ING
AI173	**Coordinated Charge/Discharge Time of Reference.** Time that the SOC is measured or computed by the storage system and is the basis for the Energy Request, Minimum Charging Duration, and other parameters	Milliseconds	DTCD	SocDateTms	ING
AI174	**Coordinated Charge/Discharge Duration at Maximum Charge Rate.** Duration that energy can be stored at the Maximum Charge Rate.	Seconds	DTCD	ChaDurMax	ING
AI175	**Coordinated Charge/Discharge Duration Maximum Discharge Rate.** Duration that energy can be delivered at the Maximum Discharge Rate.	Seconds	DTCD	DschDurMax	ING

5.4. Binary Enable/Disable

Binary Inputs DNP3 Point Index	Name / Description	IEC 61850 Logical Node	IEC 61850 Data Object	CDC
BI70	**Operating Mode - Charge/Discharge Enabled**	DWGC	ModEna	SPC
BI71	**Operating Mode - Coordinated Charge / Discharge Management Enabled**	DTCD	ModEna	SPC
BI73	**Operating Mode - Active Power Response Mode #2 Enabled**	DWFL	ModEna	SPC

Additional Active Power Functions and Scheduling for Storage

6. Set active power for generating or consuming operational function

The set active power defines the operational function in which the DER's active power (generating or consuming) at the Referenced ECP is set to the target value or to a percentage of WMax.

Although similar to AGC in that the DER ramps to the active power target, this function includes default values and may be enabled with the target active power value set by any authorized entity without any contractual characteristics or limitations imposed by AGC.

6.1. Active power following operational function

6.1.1. General

The active power following function requests one DER to “follow” the active power level generation or consumption of a second DER and to compensate for any delta between a requested net active power level (FolWTgt) and the applicable active power of the second DER (FolWRef). A threshold (FolWThr) can be used to indicate a specific active power level to start the following action. The percentage (FolWPct) is applied to this delta active power to determine what percentage of compensation is required. The result is then added to the current active power of the second DER, and sent to the DER.

6.1.2. Load following and peak power limiting

Active power following of load is illustrated in Figure 1. In this example, load following is illustrated with storage (or other type of controllable load) compensating 100% (FolWPct = 100) for load greater than the target (FolWTgt) after the load reaches the threshold (FolWThr). The blue star shows desired threshold (FolWThr) and the green line shows desired follow value (FolWTgt). The purple fill shows net load. In this example, FolWThr = FolWTgt. This operational function could be used for Peak Power Limiting if specific resources were identified to compensate for excess load, otherwise the Active Power Limiting of load (minimum limit) could be used.

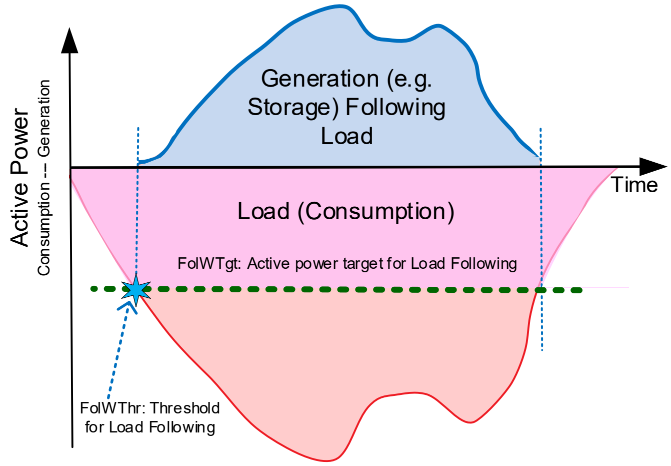

Figure 5 – Active power load following

6.1.3. Generation following

Active power following of generation is illustrated in Figure 2. In this example, generation following with storage (or any controllable load) is compensating for PV greater than the threshold: (FolWPct = 100). The blue star shows desired threshold (FolWThr) and green line shows desired follow value (FolWTgt). The green fill shows net generation. In this example, FolWThr = FolWTgt.

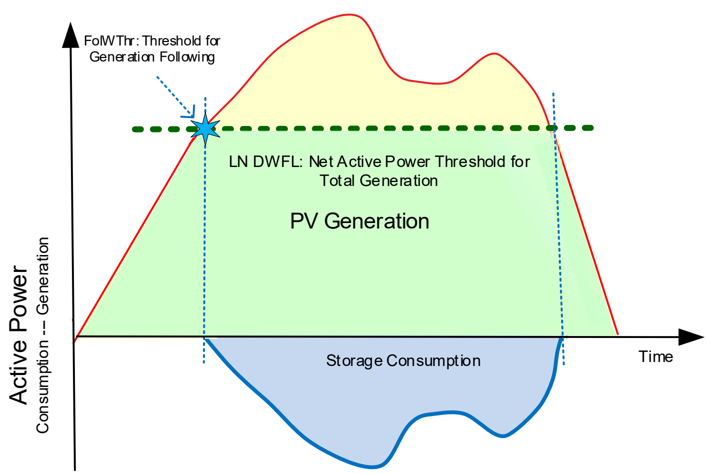

Figure 6 – Active power following of generation

If no active power threshold is set (FolWThr = 0), then the target is followed even if the followed DER is not providing any active power, as illustrated in Figure 3. The green line shows desired follow value (FolWTgt), while the green fill shows net generation.

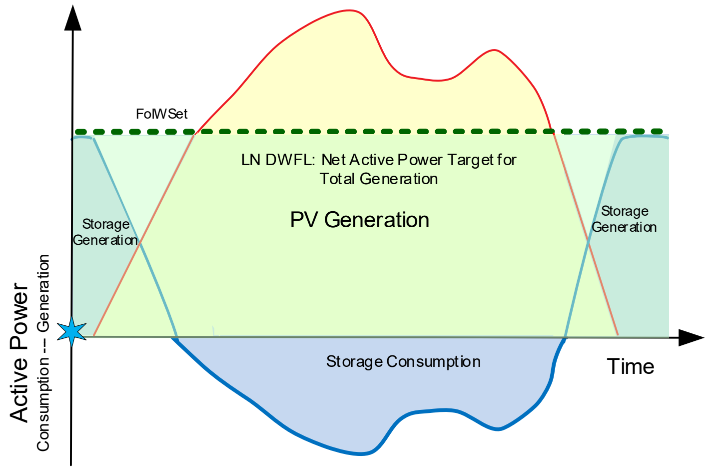

Figure 7 – Active power following of generation without a threshold

If the amount of compensation for active power is less than 100%, then not all generation is compensated for, as illustrated in Figure 4. In this example, generation following with storage compensating for PV is set to meet 50% of the target active power (FolWPct = 50) without a threshold (FolWThr = 0). The green dotted line shows desired follow value (FolWTgt), while the purple dotted line shows the actual following, with the green fill showing net generation.

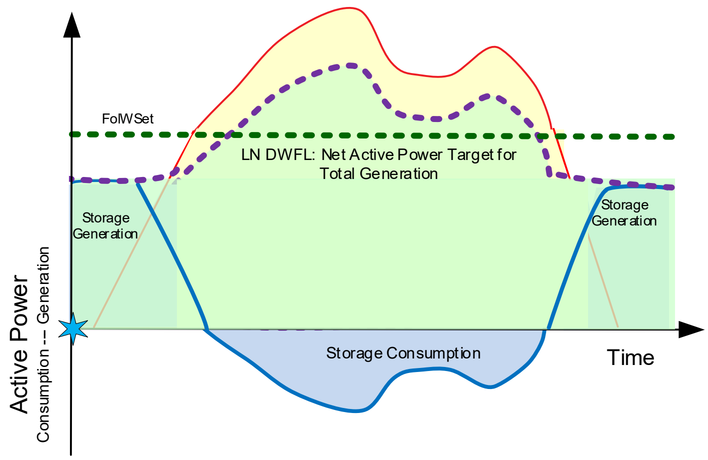

Figure 8 – Active power following of generation with percent compensation less than 100%

6.2. LN DAGC: Automatic generation control operational function

The Automatic Generation Control operational function is used by a Balancing Authority to increase/ decrease DER active power with the purpose of managing frequency, typically through direct commands every 4 or 10 seconds.

Because it generally considered a contractual function, it is expected that additional information will be needed to ensure compliance and to manage these external commands. This additional information could include the minimum and maximum available active power assigned to the AGC function (WMinAvl and WMaxAvl). It may also use the expected state of charge (SocExpc) and/or the expected state of energy (SoeExpc) at a specified time from now (SocExpcTms), assuming persistence of the current command.

6.3. LN DTCD: Coordinated Charge/Discharge operational function

The Coordinated Charge/Discharge operational function manages the charging and discharging of storage over time with the goal of achieving a specified State of Charge (SocUseTgt) at a specific time (DateTgt). Additional parameters include the duration that energy can be stored at the maximum charge rate (ChaDurMax) and the duration that energy can be exported at the maximum discharge rate (DschDurMax). Some calculated values include the minimum duration to move from the SOC at the time of reference to the target SOC, whether by charging or discharging (DurMin), the amount of energy that must be transferred (charge or discharge) to move the SOC from its current value to the target SOC (WhReq), and the date and time that the SOC was last measured or computed (SocDate), to be used by other parameters to improve their accuracy. See Figure 5.

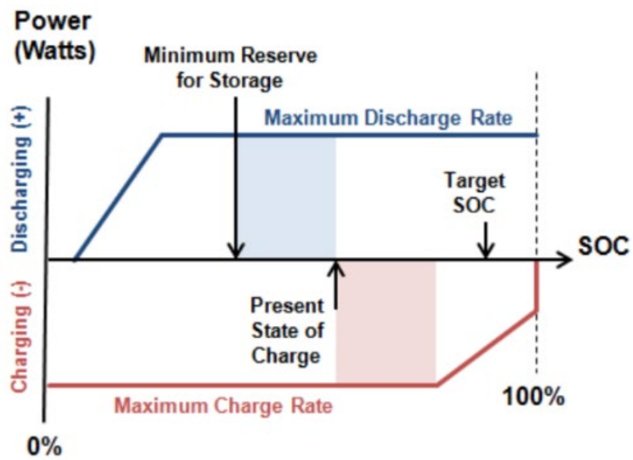

Figure 9 – Coordinated charge/discharge

7. Combining Active Power Requests from Different Functions: Ideal, Max, Min, Priority

7.1. Concepts of Ideal, Max, Min, and Priority

Operational functions often are enabled at the same time. If they request to set the same item, such as active power or reactive power, then there needs to be a mechanism for the operational functions to indicate how important their request is at any point in time or situation. For example, if an operational function is a mandatory grid code, it should have precedence over any market function. Therefore, the priority of the operational function (ModPrio) should be set to reflect that precedence.

However, particularly for market-based functions, there may be “grayer” levels of importance that may not be clearly handled by priority. For instance, an operational function may “prefer” a particular value for active power, but can “live with” a somewhat higher or lower value. In this case they could indicate an “ideal” value, a “maximum” value, and a “minimum” value. Which of these values would be selected as the “net result” would then be based on the combination of these ideal, maximum, minimum, and priority settings of the operational function.

Although alternate methods for defining these multiple values could be designed in the future as part a single instantiation of an LN, the simplest method for now is to use 3 instantiations of the same operational function LN (or two if only a maximum and ideal were needed). The algorithm used by the DPMC would calculate the net result “Ideal” value as follows:

Given a higher priority mode’s Min, Max, Ideal setpoints (e.g. Coordinated Charge/Discharge) and a lower priority mode’s Min, Max, Ideal setpoints (e.g. Active Power Following), the “amalgamation” of the setpoints is performed using the following logic:

```
new_setpoints['max'] = min (max (higher_priority['min'], lower_priority['max']), higher_priority['max'])
new_setpoints['min'] = max (min (higher_priority['max'], lower_priority['min']), higher_priority['min'])
new_setpoints['ideal'] = max (min (higher_priority['ideal'], new_setpoints['max']), new_setpoints['min'])
```

If a third operational function is added to the stack, then the higher priority setpoints are set to be the result of the previous amalgamation operation (new_setpoints). Then the net resulting “Ideal” value would be sent by the DPMC to the appropriate resources.

As an example, a PV plus Storage plant wishes to optimize its revenue by using storage (ESS) to compensate for PV during the times of the day when the price of energy is the highest, while still resulting in a specified ESS state of charge by the end of the day in order to be prepared for the following day. The plant energy management system activates two operational functions, Coordinated Charge/Discharge (DTCD) and Active Power (Generation) Following (DWFL), but changes the Ideal, Max, Min, and Priority of these functions over the day in order to meet the desired goal of optimal revenue as well as meeting other constraints (e.g. resource nameplate and operational limits, charging the ESS from the PV rather than from the grid, avoiding curtailment of generation, etc.).

7.2. Example of Ideal, Max, Min, and Priority for Energy Arbitrage

The following Table 4 shows the changing Ideal, Max, and Min values, as well as Priority for each of the two operational functions for each of the different times during the day. At 6:00, the focus is on ramping up total generation by discharging ESS to add to the PV active power generation. At 10:00, the focus is on ensuring the ESS starting to be charged in order to meet the target state of charge by the end of the day. Around 13:00, the focus is on maximizing generation since this is the time period of maximum locational marginal prices. At 16:00, the focus shifts again on ensuring the ESS has achieved its target state of charge from the PV generation before PV generation stops. At 20:00, the focus is on maintaining the ESS state of charge to be ready for the following day.

Table 4 – Ideal, Max, Min, & Priority of DTCD and DWFL over a day

6:00 AM Focus on ramping up total generation by adding ESS to PV				
Priority	99	20	5	
Operational Function	Nameplate and Operational Settings	Coordinated Charge/ Discharge (DTCD)	Active Power (Generation) Following (DWFL)	Net Result at PCC
50 MW				
40 MW	Max	Max	Max	
30 MW		Ideal	Ideal	"Ideal" Net Result
20 MW				
10 MW				
0 MW				
-10 MW				
-20 MW				
-30 MW				
-40 MW	Min	Min	Min	
-50 MW				

10:00 AM Focus on charging ESS to meet target SoC				
Priority	99	20	5	
Operational Function	Nameplate and Operational Settings	Coordinated Charge/ Discharge (DTCD)	Generation Following (DGFL)	Net Result at PCC
50 MW				
40 MW	Max			
30 MW				
20 MW				
10 MW			Max	
0 MW			Ideal	
-10 MW				
-20 MW		Max		"Ideal" Net Result
-30 MW		Ideal		
-40 MW	Min	Min	Min	
-50 MW				

13:00 Focus on meeting maximum generation				
Priority	**99**	**5**	**20**	
Operational Function	**Nameplate and Operational Settings**	**Coordinated Charge/ Discharge (DTCD)**	**Generation Following (DGFL)**	**Net Result at PCC**
50 MW				
40 MW	Max	Max	Max, Ideal	"Ideal" Net Result
30 MW				
20 MW		Ideal		
10 MW		Min		
0 MW				
-10 MW				
-20 MW				
-30 MW				
-40 MW	Min		Min	
-50 MW				

16:00 Focus on achieving target state of charge before PV stops generating				
Priority	**99**	**20**	**5**	
Operational Function	**Nameplate and Operational Settings**	**Coordinated Charge/ Discharge (DTCD)**	**Generation Following (DGFL)**	**Net Result at PCC**
50 MW				
40 MW	Max		Max, Ideal	
30 MW		Max		"Ideal" Net Result
20 MW		Ideal		
10 MW				
0 MW		Min		
-10 MW				
-20 MW				
-30 MW				
-40 MW	Min		Min	
-50 MW				

20:00 Focus on maintaining SoC				
Priority	**99**	**20**	**5**	
Operational Function	**Nameplate and Operational Settings**	**Coordinated Charge/ Discharge (DTCD)**	**Generation Following (DGFL)**	**Net Result at PCC**
50 MW				
40 MW	Max		Max	

30 MW				
20 MW				
10 MW				
0 MW		Max, Ideal, Min		"Ideal" Net Result
-10 MW				
-20 MW				
-30 MW				
-40 MW	Min		Min	
-50 MW				

8. Scheduling

8.1. Basic Scheduling Capability

The scheduling capability are capable of receiving, storing, executing, and cancelling schedules that provide autonomous local control of the DER and support multiple types of scheduled timeframes such as daily, multiple days, weekly, monthly, and annually. Each schedule can be activated and deactivated, and includes:

- A beginning time (e.g. Day = midnight, Week = Sunday, Month = first of the month, Year = January 1)
- A schedule duration (e.g. 24 hours, 7 days, 31 days, 366 days)
- One or more scheduled entries
- A repetition indication (yes/no)
- If repetition is enabled, the schedule repeats at a multiple (x) of its beginning time (i.e. every x days, every x weeks, every x months, every x years) until cancelled (e.g. a daily schedule repeats every 7 days on a Sunday, a multiple day schedule repeats every 7 days for 4 days starting every Tuesday, a monthly schedule repeats starting on the first of every month)

Each scheduled entry within a schedule includes:

- A start time which is the time since the beginning time of the schedule
- The duration time, implied by the start time of the next scheduled entry or by the end of the schedule
- Priority with the higher number with a higher priority
- Scheduled value (e.g. a specific numeric value associated with a function, the enabling/disabling of a function)

The scheduling capability supports multiple schedules being active at the same time, with their priority determining which scheduled value takes precedence if there is a conflict between them.

8.2. Use of Scheduling with Ideal, Max, Min

The use of scheduling with the Ideal, Max, Min, Priority capabilities could use six "instantiations" each of the two functions, namely the Generation Following function and the Coordinated Charge/Discharge function, and 6 Schedules. These instantiations would be:

#1 DWFL Ideal	#2 DWFL Max	#3 DWFL Min	#4 DWFL Ideal	#5 DWFL Max	#6 DWFL Min
Ideal Priority Ideal FolWTgt Ideal FolWThr Ideal FolWPct	Max Priority Max FolWTgt Max FolWThr Max FolWPct	Min Priority Min FolWTgt Min FolWThr Min FolWPct	Ideal Priority Ideal FolWTgt Ideal FolWThr Ideal FolWPct	Max Priority Max FolWTgt Max FolWThr Max FolWPct	Min Priority Min FolWTgt Min FolWThr Min FolWPct

#1 DTCD Ideal	#2 DTCD Max	#3 DTCD Min	#4 DTCD Ideal	#5 DTCD Max	#6 DTCD Min
Ideal Priority Ideal SocUseTgtPct	Max Priority Max SocUseTgtPct	Min Priority Min SocUseTgtPct	Ideal Priority Ideal SocUseTgtPct	Max Priority Max SocUseTgtPct	Min Priority Min SocUseTgtPct

Time Period	Schedule A	Schedule B	Schedule C	Schedule D	Schedule E	Schedule F
0:00	Enable #1 DWFL	Enable #2 DWFL	Enable #3 DWFL	Enable #1 DTCD	Enable #2 DTCD	Enable #3 DTCD
0:15	Enable #4 DWFL	Enable #5 DWFL	Enable #6 DWFL	Enable #4 DTCD	Enable #5 DTCD	Enable #6 DTCD
0:30	Enable #1 DWFL	Enable #2 DWFL	Enable #3 DWFL	Enable #1 DTCD	Enable #2 DTCD	Enable #3 DTCD
0:45	Enable #4 DWFL	Enable #5 DWFL	Enable #6 DWFL	Enable #4 DTCD	Enable #5 DTCD	Enable #6 DTCD
1:00	Enable #1 DWFL	Enable #2 DWFL	Enable #3 DWFL	Enable #1 DTCD	Enable #2 DTCD	Enable #3 DTCD
1:15	Enable #4 DWFL	Enable #5 DWFL	Enable #6 DWFL	Enable #4 DTCD	Enable #5 DTCD	Enable #6 DTCD
…..						
23:45	Enable #4 DWFL	Enable #5 DWFL	Enable #6 DWFL	Enable #4 DTCD	Enable #5 DTCD	Enable #6 DTCD

In this concept of multiple schedules with multiple instantiations of the functions, the following set of actions would take place:

- Before each time period, the system would update the parameters for the disabled instantiations (e.g. #4, #5, and #6 during the first and third 15 minutes of each hour), based on PV forecast, the LMP prices, the time remaining in the day for achieving the ESS SOC, and any other constraints that may have occurred.

- At the start of each time period, the 6 schedules would enable the next instantiations (e.g. #4, #5, and #6 at the start of the second and fourth 15 minutes of each hour)
- When enabled, the 6 instantiations would calculate their desired active power values for the ESS (labeled WSpt in 61850-7-420) and would send these values to the "Power Resource Manager" which would (as a black box function) combine the prioritized requested values to determine an "Ideal Net Result" for active power of the ESS.
- This "Ideal Net Result" could be sent directly to the ESS or may be further refined if other functions might also request changes.

An alternative could be just to use three Ideal, Max, Min instantiations, and update these "on the fly" at the beginning of each time period. The only concern with this scheme could be the need to make sure all parameters are updated "simultaneously" so that there would not have unexpected results.

9. Example of Net Results over the Day

From 8minute solar energy: Until I or Bora can draw a similar diagram showing only Generation Following and Coordinated Charge/Discharge.