Functional Specification For Community Energy Storage (CES) Control Hub

Revision 2.1

AEP AMERICAN ELECTRIC POWER

CES Control Hub

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Specification Revisions
Rev 1.0 – 05/18/09
Rev 1.1 – 06/18/09
Rev 2.0 –08/31/09
Rev 2.1 – 12/09/09

i. Acknowledgements

This Functional Specification for Community Energy Storage (CES) has been developed by American Electric Power (AEP) with input by others. It is our full intention to make it freely available to and for the use of all utilities, vendors and other interested parties. In that spirit we draw attention to the license attached as appendix A which is considered a part of this document.

We have received comments and contributions from other utilities and interested companies. The companies whose logos appear below have provided helpful feedback leading to some modification of this functional Specification. AEP is willing to continue coordinating this as a collaborative effort and will make updates available on our web site. For a copy of the latest version, please visit **www.aeptechcenter.com/CES**. Ideas to improve or correct this functional specification are welcome and may be directed to Tom Walker (tjwalker@aep.com).

Contributors to CES Functional Specifications

Altairnano

EPRI - Facilitator of Specification Development

ii. Specification Content

The Community Energy Storage (CES) system consists of storage units and a central control hub. These are described in two compatible documents:

1) Functional Specification for CES Unit
2) Functional Specification for CES Control Hub

The overall control scheme is described in the CES Control Hub functional specification and the storage units are described in the CES Unit functional specification. It is necessary to consider the two documents together.

iii. List of Acronyms

AEP – American Electric Power
CES – Community Energy Storage
CT – Current Transformer
DDC – Distribution Dispatch Center
DER – Distributed Energy Resources
DESS – Distributed Energy Storage System
DR – Demand Reduction
HAN – Home Area Network
HMI – Human-Machine Interface
MAIFI – Momentary Average Interruption Frequency Index
OMS – Outage Management System
PCS – Power Conversion System
PHEV – Plug-in Hybrid Electric Vehicle
PLC – Power Line Carrier
SAIDI – System Average Interruption Duration Index
SAIFI - System Average Interruption Frequency Index
SCADA – Supervisory Control and Data Acquisition
URD – Underground Residential Distribution

iv. Specification Development

It is intended that further development of this specification move ahead quickly through the collaborative arrangement described above. Specific areas noted for additional work include:

Standard Acceptance Test plans (electrical, physical, environmental, interfaces)
Alarm, operating status, settings tables
Operating mode definitions, list of commands
Overhead (pole mounted) version of storage unit
Specification of DC/DC interface module
DDC Interface standardization
HAN requirements and standards
Communication and Security requirements
Historical basis to automate determination of trigger levels
PQ – flicker mitigation, harmonic filtering
Controlling voltage profile with multiple groups
Optimizing power factor correction with multiple groups
Charge / discharge scheduling for renewable generation firming

Contributors are welcome to bring particular focus on these areas or other areas of specific interest. Please bring your additions to the attention of AEP or EPRI using the information given in the acknowledgement section above.

1. Introduction - CES

Community Energy Storage (CES) consists of multiple small battery-based energy storage units connected to the utility transformers' 240/120 V secondary and controlled from a common remote control. The individual CES Units will be pad-mounted and typically be deployed in Underground Residential Distribution (URD) settings adjacent to a single phase pad mount transformer. A large number of these small storage units will be aggregated regionally and controlled as a fleet (see Figure 1).

The individual CES Units will have controls to manage their individual charge and discharge activity in response to regional needs at the feeder, station, or system level. The regional needs will be managed by a CES Control Hub or by integration into another control platform, herein referred to as an Integration Platform. If used, the CES Hub will be deployed as hardware and software typically installed at the station for the feeder(s) on which its fleet of CES Units are installed. A utility may elect to implement the same control functionality in an Integration Platform which has broader application, possibly including other distributed resources. The Integration Platform would not require the hardware on which the CES Hub will implement this regional control functionality.

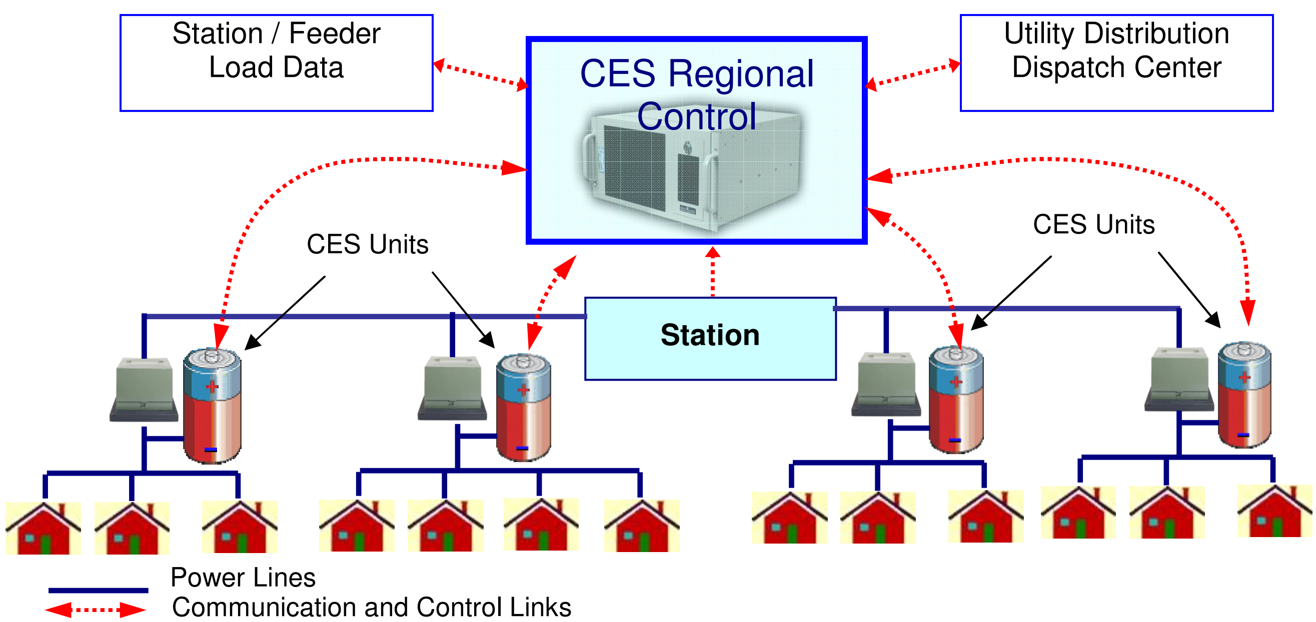


Figure 1 Communication & Control Layout for CES

CES will provide capacity, efficiency, and reliability benefits through the following key functions:

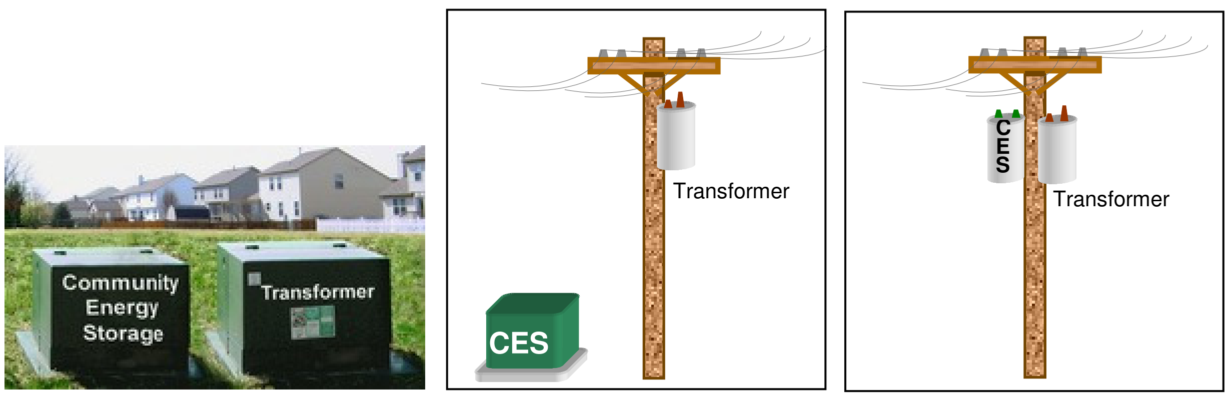
Grid functions:

1) Serve as a load leveling, peak shaving device at the station level
2) Serve as a power factor correction device at the station level (VAR support)
3) Be available for ancillary services through further aggregation at the grid level

Local functions:

4) Serve as backup power for the houses connected locally
5) Serve as local voltage control
6) Provide efficient, convenient integration with renewable resources

Initially the individual CES Units will be pad-mounted and typically be deployed in Underground Residential Distribution (URD) settings adjacent to a single phase pad mount transformer. Alternatively, the CES Unit may be installed at the base of a secondary riser pole for use on overhead facilities. A future specification may require a pole mounted version. Figure 2 shows the installation configurations that are envisioned.



a) Padmount CES with padmount transformer

b) Padmount CES with pole-top transformer

c) Pole-top CES with pole-top transformer

Figure 2 - Possible combinations of Community Energy Storage (CES) with residential transformers

2. Scope – CES Control Hub

This document defines the requirements for a CES Control Hub that is able to exercise aggregated control of several hundred CES units that are electrically connected to the same feeder(s) supplied from a common station. The CES Hub consists of hardware and software suitable to perform this aggregate control. Figure 3 illustrates the Communication and Control Structure.

As mentioned above, the CES Hub functionality may be implemented on a separate Integration Platform which is outside the scope of this specification. The capability to be interfaced to an Integration Platform is a requirement, but the interface is not within scope. For this reason, the CES Hub software shall be documented and maintained in a format that facilitates porting to other platforms. Discussion in this document that pertains to CES Hub functionality implies implementation of that same functionality on the Integration Platform as an option at the purchaser's discretion. Discussion pertaining to the physical CES Hub is not relevant to implementation on a separate Integration Platform.

This document does **NOT** include the Functional Specification of the Community Energy Storage (CES) Units covered in the accompanying document **"Functional Specification for Community Energy Storage (CES) Unit"**. Compatibility with that specification is required, and is intended through the requirements contained herein.

The CES Hub may be flexibly configured to control groups of CES Units on one or more feeders in an area. The CES Hub may be located at the associated station, or at any other location that is appropriate depending on the available communications infrastructure. A scheme to accomplish this flexible configuration is within scope.

The CES Hub shall be interfaced with the Distribution Dispatch Center (DDC). This interface is to permit settings changes and manual commands to be sent to the CES Hub. The DDC interface shall provide CES status, resource availability and operating parameters to the DDC. The DDC interface is within scope.

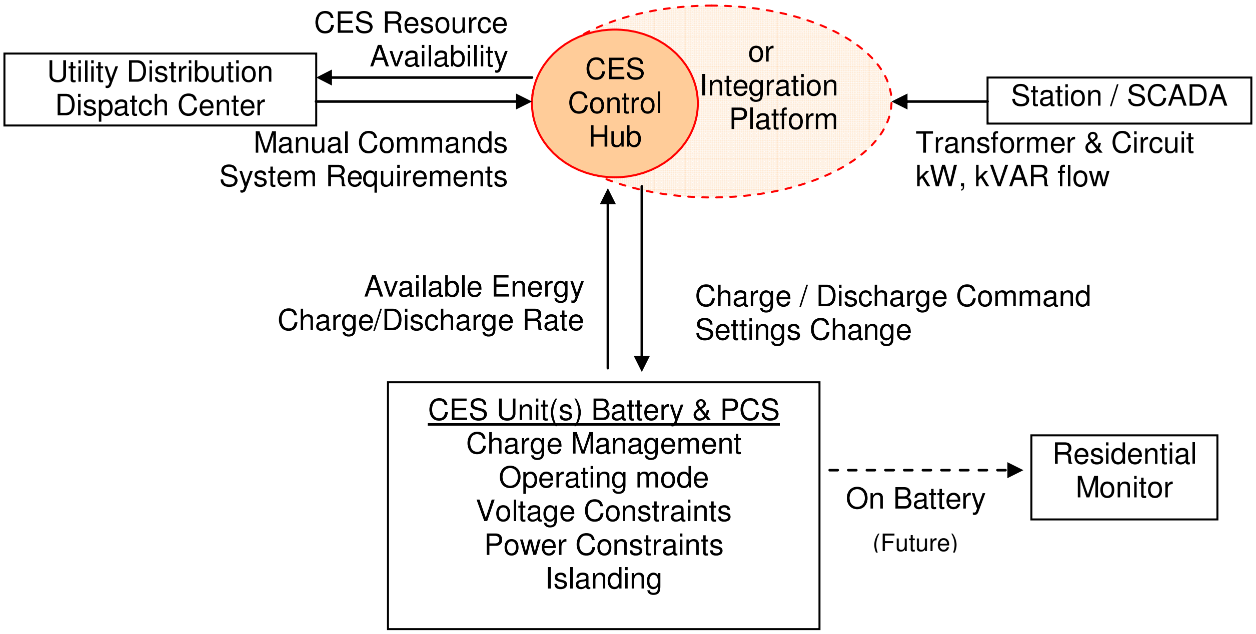


Figure 3 Communication & Control Structure

The CES Hub shall communicate with its CES Unit fleet. The CES Unit interface is within scope.

The CES Hub shall be interfaced to station devices to obtain feeder and station level power flow. This may be via SCADA or local area network. This station interface is within scope.

This specification of CES Control Hub Functions contains some details such as variables and mathematical relationships which are included solely for illustrative purposes. Examples are given in the sections discussing charge and discharge management. Those supportive details are not requirements.

The CES Hub shall be a self-contained control in an enclosure suitable for indoor installation or outdoor installation in a control cabinet. In addition to the fundamental hardware and software components, it includes a communications module, antenna, and Ethernet interface to other devices on a LAN. Provision of the hardware and enclosure is within scope.

3. CES Control Functions

This discussion of the CES control scheme includes requirements for the CES Unit as well as the CES Hub. Figure 4 shows the information flow between the CES Hub and its fleet of CES Units.

3.1. CES fleet Group definitions

3.1.1. Each CES Hub is in control of a fleet of CES Units electrically connected to the distribution feeders on a station. The fleet consists of one or more Groups of CES Units to be operated as an aggregated resource. A Group may be defined for an individual feeder, but will typically be defined as a subset of units on a feeder. Each of three phases could be set up separately, for example, to utilize the CES fleet to improve feeder balance. CES Units on the same phase but distant from each other along the feeder may be defined in different Groups in order to manage power factor correction, voltage profile, and losses optimally. A single CES Hub is expected to handle hundreds of CES Units. The CES Hub shall facilitate flexible assignment of CES Units and communication with them as Groups.

3.1.2. The CES Control Hub and deployment scheme shall accommodate hub failure through some form of redundancy. This might be accomplished by having a standby hub or by using some form of multiple settings groups. In designing a redundant scheme, care must be taken to avoid having an individual CES Unit being controlled by multiple hubs or having hubs left without an associated controlling hub.

3.1.3. The CES Hub shall maintain an inventory of CES Units in its fleet, including Group assignments and all necessary addressing information for communications. When required by the specific deployment, the CES Hub shall reassign Groups dynamically to accommodate changes in network topology.

In order to call upon each CES Unit for charging or discharging, the CES Hub needs to maintain static and dynamic parameters from each CES unit under its control:

CES Hub Fleet inventory

Static parameters:

1. Group membership (feeder and feeder partition)
2. Unit Demand Capability in kW; continuous rating of CES Unit
3. Unit Energy Capacity in kWHr
4. Unit Reserve Capacity in % of Energy Capacity

Dynamic parameters:

1. Unit status (disabled, tripped, charge, discharge, standby)
2. Unit charge / discharge rates, kW and kVAR
3. Unit Energy Availability in kWh
4. Proportional adjusted power availability in kW

3.1.4. As a future option, the CES Hub may maintain an inventory of other controllable resources such as electric vehicle batteries. PHEV's could be managed as a part of the CES fleet to make optimal use of charging opportunities. This may require communication through the CES Unit to a Home Area Network.

3.2. The CES Hub shall initiate and perform two way communications with all CES Units in its fleet at a regular time interval, the Command Interval. The Command Interval shall be a CES Hub setting with a default value of 5 minutes. Security requirements, to the extent they are defined in emerging industry standards, shall be considered foundational and must be satisfied by the communications procedures adopted.

3.2.1. Minimal communications shall proceed even if no charge or discharge cycle is in progress. This will assure that communications are functioning and will keep the CES Hub up to date regarding CES Unit availability.

3.2.2. A single broadcast command may result in many CES Unit responses, so the CES Hub shall have a means to track individual unit responses and identify failures to respond. States that have not changed shall not be repeated in every response in order to reduce the communications burden.

3.2.3. The CES Hub management of the communications cycle shall accommodate communications cycle lengthening if necessary to accommodate the number of messages and system latency.

3.3. The CES Hub shall be interfaced to the DDC SCADA system or a similar DDC tool to present system status and operating parameters.

3.3.1. The DDC interface shall permit remote access to all CES Hub and CES Unit status and operating parameters and will allow modification of all system settings.

3.3.2. The DDC interface shall provide commands to manually override CES Hub charge / discharge commands.

3.3.3. The data viewable by SCADA shall be refreshed at the same rate as the communications Command Interval mentioned below.

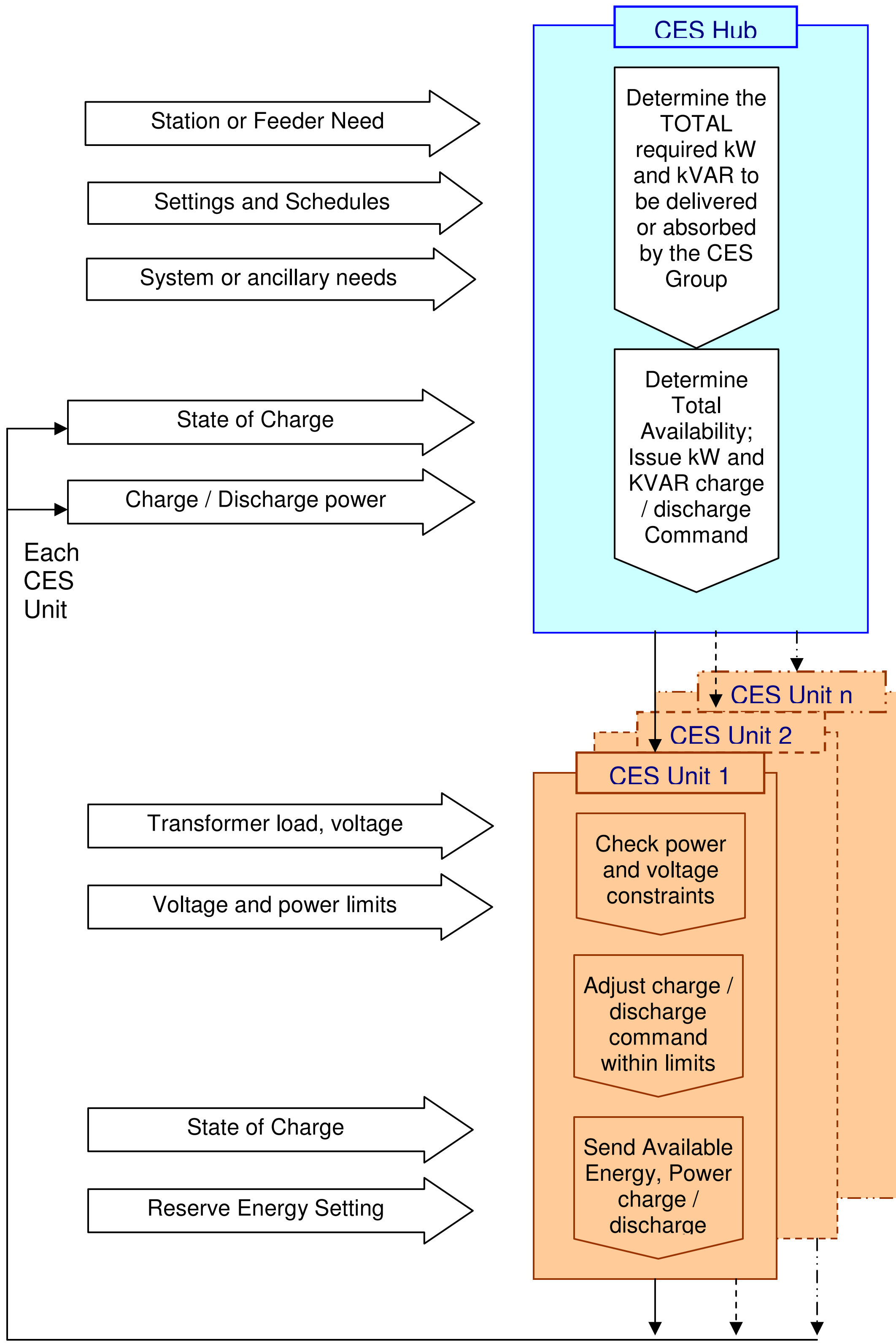


Figure 4 – Information Flow of CES Charge / Discharge Cycle

3.4. The CES Hub shall be able to receive direct measurements of feeder level and station transformer level power flow per phase at the station. From power flow, CES Hub settings, and status of Group CES Units the CES Hub shall determine the charge or discharge requirements for the Group. Data required at the feeder level for each Group include:

Static parameters:

1. Group (feeder) level discharge triggers (kW & kVar)
2. Group (feeder) level charge trigger (kVA)
3. Group Demand Capability in kVA; total of CES Units in Group
4. Command Interval (time between charge / discharge commands)

Dynamic parameters:

1. Group status (tripped, charge, discharge, standby totals)
2. Group charge / discharge rates, kW and kVAR (total of group)
3. Group Energy Availability in kWh (total of available group)
4. Feeder kW and kVAR power flow

Data for feeder and transformer loads shall be refreshed each Command Interval of the charge / discharge cycle.

The CES Hub shall first satisfy individual feeder level peak load shaving requirements, and then use remaining available discharge capacity within its fleet for transformer peak load shaving if required. Similarly, the total charging of Groups should not raise the total demand above the transformer charge trigger.

Note that different triggers may be established for each phase, and that the Fleet/Group management will be per phase to correct feeder imbalance.

3.5. The CES Control Hub shall provide or assure time synchronization of the fleet to within one second. As an example, the CES Control Hub could maintain time based on a GPS signal. It would synchronize all CES Hubs in its fleet as a part of daily log maintenance. An attempt would be made to correct for communications latency between the Hub and CES Units.

3.6. The CES Units in the fleet shall have a compatible set of functions (see the CES Unit Functional Specification). Those functions include islanding, compliance with local power constraints, compliance with local voltage constraints, response to the real and reactive power dispatch commands of the CES Hub, and response to DDC or system override commands. Each CES Unit shall maintain a set of static and dynamic parameters:

Static parameters:

1. Unit Demand Capability in kW (continuous rating of CES Unit)
2. Transformer capability in kVA (or secondary system limiting factor)
3. Reserve capacity (% of total storage energy; site specific setting)
4. Maximum & Minimum Voltage Limits (site specific settings)

Dynamic parameters:

1. Unit status (disabled, tripped, charge, discharge, standby)
2. Unit charge / discharge rates, kW and kVAR
3. State of Charge (remaining kWHr)
4. Unit Energy Availability in kWh (State of Charge minus reserve)
5. Transformer power flow, kW and kVAR
6. CES Unit power flow, kW and kVAR
7. Unit voltage; each leg and total

3.7. Logs shall be kept at the CES Units and the CES Hub. Settings records shall contain all static data. Operating logs shall capture all dynamic data. Performance summary logs shall capture totaled or averaged data. Memory shall be provided to retain all logs for a minimum of 3 days at the CES Unit and CES Hub levels.

3.8. CES Management Application

3.8.1. A CES Management Application (also discussed in the CES Unit Functional Specification) shall be included to perform management of the CES Hub and CES Units as well as for archiving and analyzing setting, operating, and performance summary logs. The CES Management Application is software that may be run on a PC such as a laptop carried into the field. It will provide necessary functions to support the controls, such as firmware updates and system configuration. It will also provide functions to perform analysis at the feeder and CES Unit levels. The time period for feeder performance analysis shall be configurable, defaulted to a calendar day.

The analysis functions shall exclude data points which are outside expected values. For example, zero power flow at the station or a CES Unit failing to report should not be included in average values. The method of excluding data point outliers shall be configurable.

3.8.2. The CES Management Application shall provide analysis of log data to measure the impact of CES on feeder performance, including:

Feeder Level (daily) -
Total kWHr charge / discharge
Charge / discharge durations
Fleet round trip efficiency
Peak demand with and without fleet
Charge cycle demand with and without fleet
kVAR Hr provided / consumed by fleet
Peak kVAR provided / consumed by fleet
Feeder pf with / without fleet
Average charge / discharge per CES, kWHr, kVAR Hr, kW and kVAR
Load factor with / without fleet
Total charge / discharge exceptions due to power / voltage limits
Communications failures (number and duration)
Islanding customer minutes
Islanding customer events (number of customer interruptions avoided)
Islanding events (number of interruptions avoided)
Islanding duration
Number and duration of CES Unit outages (fully discharged)
Minimum and maximum available energy of the fleet

3.8.3. The CES Management Application shall provide analysis of log data to measure the performance of each CES Unit, including:

CES Unit (daily) -
Minimum and maximum available energy
Total kWHr charge / discharge
Charge / discharge durations
Unit round trip efficiency
Peak charge / discharge power, kW
kVAR Hr provided / consumed
peak kVAR provided / consumed
Feeder pf with / without fleet
Charge / discharge exceptions due to power / voltage limits
Islanding customer minutes
Islanding customer events (number of customer interruptions avoided)
Islanding events (number of interruptions avoided)
Islanding duration
Number and duration of CES Unit outages (fully discharged)

4. Dispatch of Discharge Command to CES Units

The CES Control Scheme can accomplish feeder level load leveling and power factor correction through triggered charge and discharge commands issued to the CES fleet by the control hub. Control commands will be issued to each Group defined within the fleet. Groups may be flexibly defined as needed by feeder, phase, branch, and so on.

4.1. Peak Load Shaving Alternatives

The following alternatives shall be available for initiation and control of real power discharge for peak load shaving:

1) Scheduled discharge – discharge cycle set to initiate at a specific time, ramp to a predetermined discharge rate for a predetermined duration, then ramp down to zero. This will be the discharge portion a set 7-day charge / discharge schedule that is determined and set manually.
2) Time triggered load following – discharge cycle initiates at a set time and performs load following to maintain the demand at that time. Duration is not fixed. Discharge continues until feeder demand (excluding discharge power) drops below the initial level or until available charge is depleted.
3) Demand triggered load following – discharge cycle initiates when feeder demand reaches a set level and performs load following to maintain the set demand. Duration is not fixed. Discharge continues until feeder demand (excluding discharge power) drops below the initial level or until available charge is depleted.
4) Adaptive peak load shaving – Historic demand profile is used to automatically select the trigger time and/or demand trigger. Once triggered, load following will be performed. At intervals the current demand (excluding discharge) and estimated duration will be compared to the remaining available energy. The load following trigger level will be adjusted accordingly to reduce the probability that the fleet will become depleted prior to the estimated discharge cycle end. The algorithm to determine the trigger level and to make adjustments will be customized by the CES operator.
5) Discharge override – Discharge initiation, continuance, or termination may be accomplished through manual override commands or through an override invoked by another system. This information will be received through the DDC interface. The command will be similar to the scheduled discharge, with fixed discharge rate and duration.

4.2. Power Factor Correction

Reactive power will be provided to or consumed by the CES fleet in response to the CES Control Hub independently of the peak load shaving. The following alternatives shall be available to determine the power factor correction:

1) Scheduled Power Factor Correction – Reactive power output / consumption begins at a set time for a set duration with a predetermined profile (adjustments to magnitude at set intervals). This will be a set 7-day output / consumption schedule that is determined and set manually.

2) Feeder Level Power Factor Triggers – Reactive power output / consumption is adjusted to satisfy, to the extent possible, feeder level needs to stay within set bounds; minimum and maximum feeder power factor. If enabled, this trigger is always active.

3) Station Level Power Factor Triggers - Reactive power output / consumption is adjusted to satisfy, to the extent possible, station level needs to stay within set bounds; minimum and maximum feeder power factor. If enabled, this trigger is always active. If station and feeder level power factor triggers are both enabled, station level has the higher priority.

4) Override Power Factor Correction – Reactive power output / consumption may be accomplished through manual override commands or through an override invoked by another system. This information will be received through the DDC interface. The command will have variable parameters to initiate a fixed output / consumption for a fixed duration.

4.3. Peak Load Shaving Fleet Control

The CES Control Hub will determine the discharge requirement and dispatch the command to the CES fleet. The format of communications to the CES Units will be the same regardless of the peak load shaving alternative being used. Figure 5 shows charging and discharging of the entire CES fleet for a feeder in a load following mode.

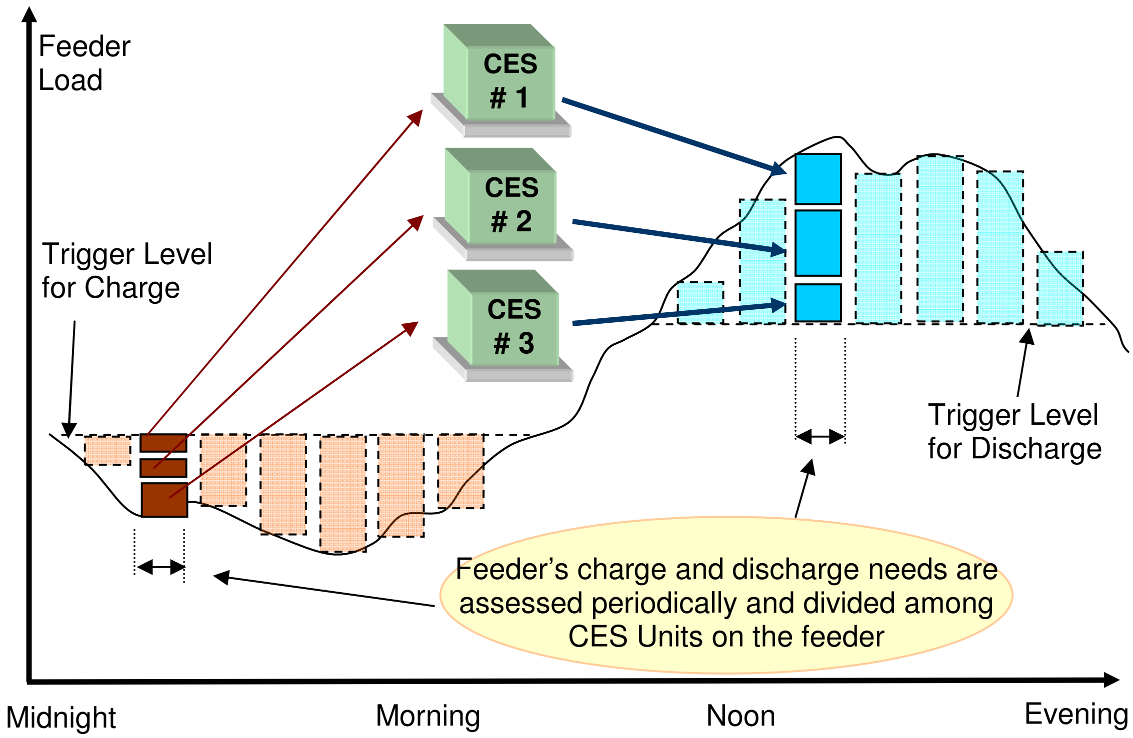


Figure 5 – Feeder level demand profile showing CES Unit charge and discharge

The CES Hub will dispatch CES Units based on available energy, but the system will not exceed the available output limits for any given Unit. As described in the CES Control Scheme, the combined CES Hub and Unit controls result in the following set of priorities for dispatching CES Units' discharge:

CONSTRAINTS

1. Individual CES Unit and site (transformer) power limitations
2. Individual site voltage limitations (avoid overvoltage or under voltage)
3. Preservation of individual CES Unit reserve charge

REAL POWER

4. Real power peak shaving by manual command
5. Real power peak shaving by schedule
6. Real power peak shaving for station requirements
7. Real power peak shaving for feeder requirements

REACTIVE POWER

8. Reactive power correction by manual command
9. Reactive power correction by schedule
10. Reactive power correction for station requirements
11. Reactive power correction for feeder requirements

An option shall be provided to adjust the reserve charge settings for the entire fleet or group. This will permit the system to give preference to load leveling over reliability concerns. It shall be implemented by a multiplier varying from zero to one that adjusts all individual CES Unit reserve charge settings. The default value is one.

Units in a Group will participate in discharging in proportion to their energy availability, but limited by individual unit power and voltage constraints. Units with the highest energy availability will contribute the most real power. Units with the lowest energy availability (excluding those at or below their energy reserve level) will contribute the most reactive power. This will minimize the tendency to become voltage or power limited.

The CES Hub will reassess the discharge requirement periodically (established by the Command Interval setting). The discharge command will be increased or decreased as needed to bring the demand back to its trigger level. Note that a single value derived from total fleet/group energy availability and expressed as a percent is sufficient to provide the command to all CES Units in the Group. Since the CES Units may be limited by local constraints, each will limit itself accordingly.

Figure 6 shows an example of the participation of individual units for discharge.

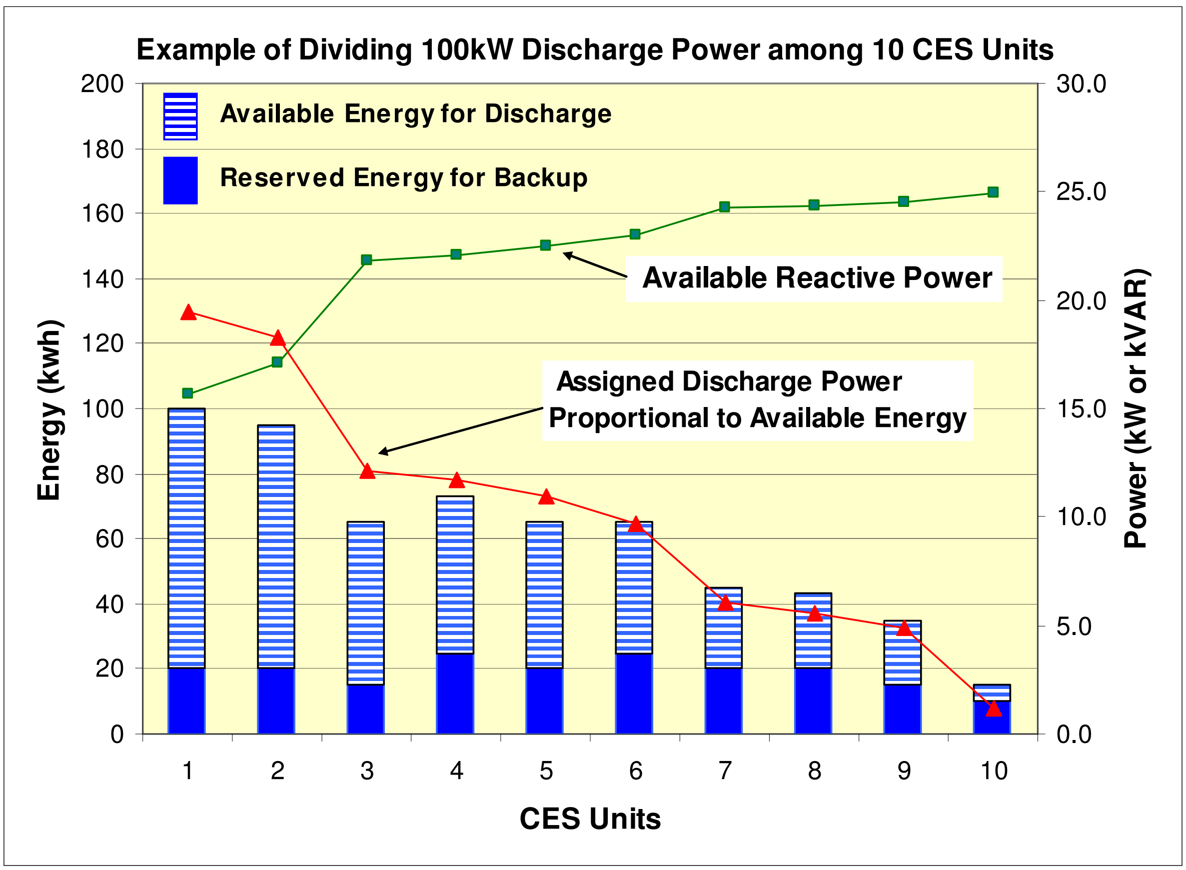


Figure 6 – Participation of CES Units in Discharging

In this illustration, the Group for this feeder consists of 10 CES Units. Unit reserve energy settings are shown in solid blue. The available energy (state of charge minus reserve) is shown in blue hash. The CES Hub has determined that the current peak shaving requirement is100 kW. Each unit is requested to contribute real power in proportion to its available energy. This results in real power contributions ranging from 1.5 kW to 19 kW as shown by red markers.

The reactive power requirement for the entire Group is determined by the CES Hub from feeder conditions, station conditions, schedule, or override request. The units are commanded to provide reactive power in inverse proportion to their available energy. Each CES Unit is then responsible to stay within power and voltage limits, and will provide the requested VAR correction to the degree possible given the changing local conditions. In the example, the outputs of the 10 units range from 16 kVAR to 25 kVAR as indicated by the green markers. A total of 143 kVAR reactive power compensation is available.

Local CES Unit power or voltage limits may prevent a given unit from participating fully as requested. It will participate to the maximum possible while remaining within limits. It will report its real and reactive power output to the CES Hub for computation of the next discharge command.

4.4. CES Fleet Control Example

Following is an example of a control exchange between the CES Hub and a Group of Units which satisfies the discharge control objectives described above. Satisfaction of the objectives is a requirement of this specification. The details of this example are not requirements of this specification.

The method of control described in this example is intended to minimize the amount of information communicated and provide assurance that sufficient information is resident locally to meet requirements for temporary loss of communications, for having units missing from the Group, having varying reserve requirements, and having varying states of charge. It is necessary to accommodate those considerations, but not explicitly as described here.

Figure 7 illustrates the control conversation between the CES Control Hub and a Group of 10 CES Units, each rated 25 kW and 50 kWh. For simplicity assume this is a single phase example. The trigger level, 5000 kW may be set by any of the peak load shaving alternatives (scheduled, load triggered, etc.).

At the beginning of a command interval, the CES Control Hub receives status information from each CES Unit in the Group, including energy availability. Units may report less than full energy availability depending on their individual State of Charge (SOC) and the individual reserve requirement. The reserve requirement may have been modified by a previously issued Control Hub Command, a multiplier (0 to 1) that adjusts the Group uniformly to balance reliability vs. peak load shaving. Units that do not report are excluded from the availability total. Units that report a disabled status are excluded from the availability total.

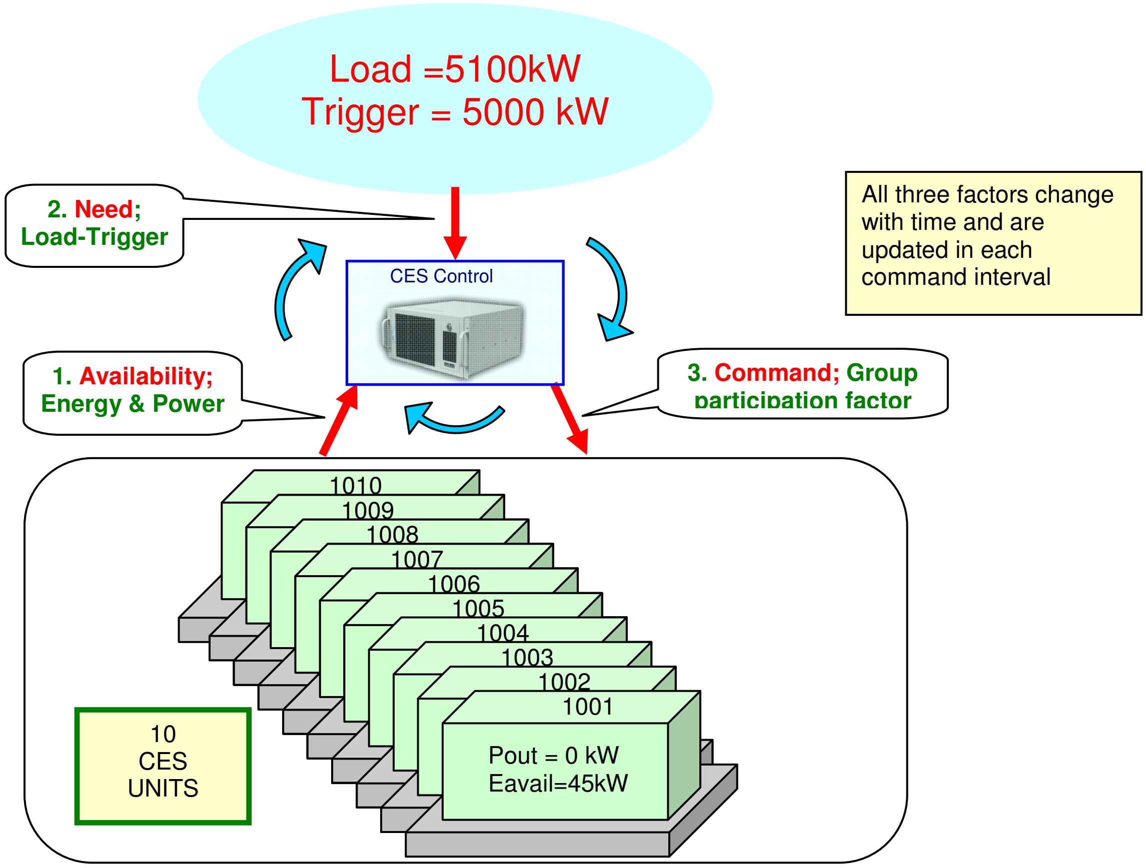


Figure 7 - CES Fleet Control Discharge Control Conversation

The CES Control Hub determines the need for discharge by comparing the Station and Feeder demands to the trigger level. If discharge is needed, then the total CES Unit availability is used to calculate the required participation factor for the Group. The participation factor is the broadcast to the Group, and the individual CES Units make adjustments to their output.

1. Fundamental parameters passed from CES Units to CES Hub:
   - Available Energy, (kWh)
   - Actual Power Contribution (kW, kVAR)
   - Voltage
2. Fundamental parameters for calculation of discharge need:
   - Trigger Levels (Station and Feeder, kW, kVAR)
   - Load Levels (Station and Feeder, kW, kVAR)
   - Fleet / Group Contribution (kW, kVAR)
3. Fundamental parameters passed from CES Hub to CES Units
   - Normalized Request (kW, kVAR contribution in % of rated kW)

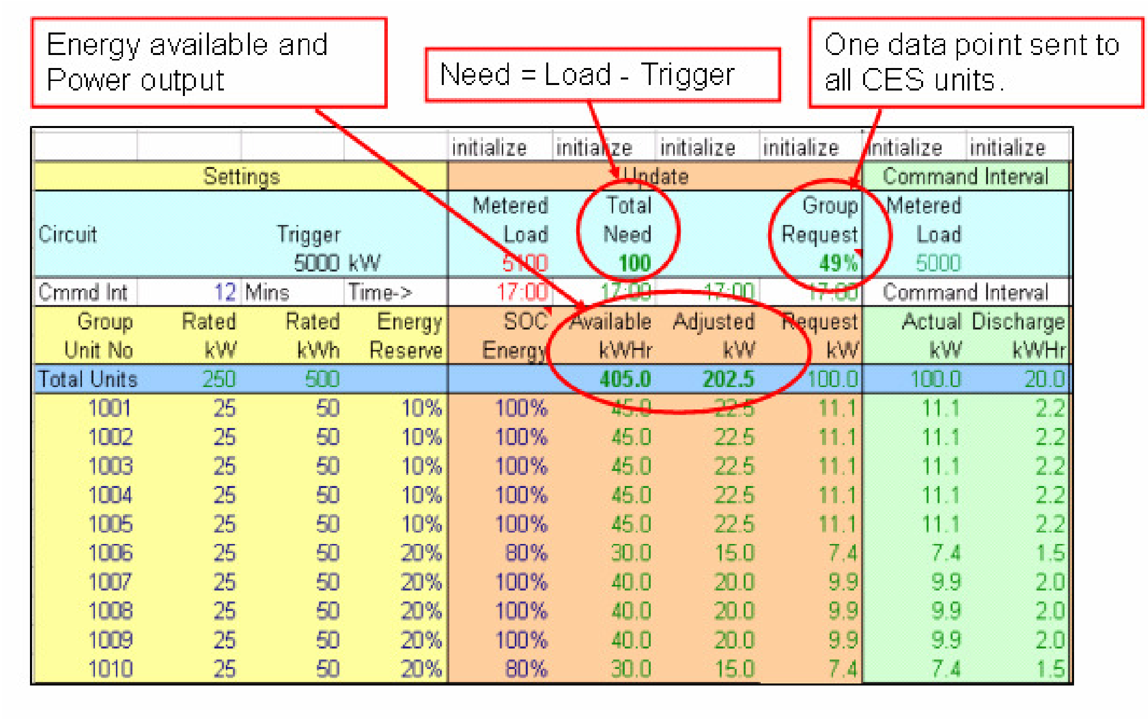
Figure 8 provides sample data for a single command interval with the following parameters:

UNIT PARAMETERS:

- State of Charge = Unit stored energy; % of Energy rating
- Depleted Charge Reserve = Minimum state of charge for self protection and extended outage recovery, including adjustment for charge estimate accuracy; % of Energy rating
- Backup Reserve Setting = Unit charge reserve for providing backup, % of Energy rating
- Backup Adjustment Factor = Fleet / Group factor to scale Backup Reserve (range of 0 to 1)
- Energy Reserve = Depleted Charge Reserve + (Backup Reserve Setting x Backup Adjustment Factor); % of Energy rating
- Available Energy = (State of Charge – Energy Reserve) x Energy Rating; kWh
- Adjusted Power = Power Rating adjusted in proportion to available energy; kW
- Actual Unit Power = current discharge rates; kW and kVAR
- Actual Transformer Power = total demand on transformer, kW and kVAR
- Actual Voltage = 240/120 V measurement at AC interface

GROUP PARAMETERS

- Backup Adjustment Factor = Group multiplier, 0 to 1; setting issued to Fleet / Group
- Triggers = Station / Feeder targets for power flow; kW, kVAR
- Station / Feeder Demand = current power flow at station/ feeder level; kW, kVAR
- Total Available Energy = sum of unit available energies; kWh
- Total Available Power = sum of unit adjusted powers; kW, kVAR
- Total Actual Power = sum of current unit discharge; kW, kVAR
- Total Need = Station / Feeder Demand + Total Actual Power – Trigger (real and reactive components)
- Participation Factor = calculated power output requirement for Group; % of total available power (real and reactive components)



				initialize	initialize	initialize	initialize	initialize	initialize
	Settings			Update				Command Interval	
Circuit		Trigger 5000 kW		Metered Load 5100	Total Need 100		Group Request 49%	Metered Load 5000	
Cmmd Int	12 Mins	Time->		17:00	17:00	17:00	17:00	Command Interval	
Group Unit No	Rated kW	Rated kWh	Energy Reserve	SOC Energy	Available kWHr	Adjusted kW	Request kW	Actual kW	Discharge kWHr
Total Units	250	500			405.0	202.5	100.0	100.0	20.0
1001	25	50	10%	100%	45.0	22.5	11.1	11.1	2.2
1002	25	50	10%	100%	45.0	22.5	11.1	11.1	2.2
1003	25	50	10%	100%	45.0	22.5	11.1	11.1	2.2
1004	25	50	10%	100%	45.0	22.5	11.1	11.1	2.2
1005	25	50	10%	100%	45.0	22.5	11.1	11.1	2.2
1006	25	50	20%	80%	30.0	15.0	7.4	7.4	1.5
1007	25	50	20%	100%	40.0	20.0	9.9	9.9	2.0
1008	25	50	20%	100%	40.0	20.0	9.9	9.9	2.0
1009	25	50	20%	100%	40.0	20.0	9.9	9.9	2.0
1010	25	50	20%	80%	30.0	15.0	7.4	7.4	1.5

Figure 8 – CES Fleet Discharge Example Data

Figure 8 shows the individual CES Unit status for 10 available units which each report their Actual Power and Adjusted Power. This step of the example presumes no previous output and shows 10 units reporting a Total Available Power of 202.5 kW. The Feeder Demand is 5100 kW which is above the Trigger of 5000 kW, so there is a Total Need of 100 kW. The participation factor is calculated as 100 / 202.5 = 0.49. The CES Hub issues a command to output at a rate of 49%, and the CES Units respond accordingly. Unit 1002, for example adjusts to an output of 11.1 kW. Unit 1010, with a lower state of charge and a higher energy reserve adjusts to an output of 7.4 kW.

5. Dispatch of Charge Command to CES Units

5.1. Charge Trigger Alternatives

Charge trigger alternatives, compatible with discharge alternatives, shall be as follows:

1) Scheduled charge – charge cycle set to initiate at a specific time, ramp to a predetermined charge rate for a predetermined duration, then ramp down to zero. This will be the charge portion of a set 7-day charge / discharge schedule that is determined and set manually.
2) Time triggered charging – charge cycle initiates at a set time and limits total fleet charging to maintain the feeder demand at that time. Duration is not fixed. Charge continues until feeder demand (excluding charge power) exceeds the initial level or until all units are fully charged.
3) Demand triggered charging – charge cycle initiates when feeder demand drops to a set level and limits total fleet charging to maintain the feeder demand at that time. Duration is not fixed. Charge continues until feeder demand (excluding charge power) exceeds the initial level or until all units are fully charged.
4) Adaptive charging – Historic demand profile is used to automatically select the trigger time and/or demand trigger. Once triggered, demand limited charging will be performed. At intervals the current demand (excluding fleet charge) and estimated duration will be compared to the remaining energy deficiency. The trigger level will be adjusted accordingly to reduce the probability that the fleet will not be fully charged prior to the estimated charge cycle end. The algorithm to determine the trigger level and to make adjustments will be customized by the CES operator.
5) Charge override – Charge initiation, continuance, or termination may be accomplished through manual override commands or through an override invoked by another system. This information will be received through the DDC interface. The command will be similar to the scheduled charge, with fixed charge rate and duration.
6) Depleted Unit Charge Request – As a means to maintain individual Unit health, a CES Unit may solicit permission to charge if it reaches a minimal state of charge (variable setting). The CES Unit will send an alarm to the DDC via the CES Hub and await permission to charge. A trickle charge feature may be engaged to minimize impact n the power system during such charge cycles.

5.2. Charge Fleet Control

A charge cycle may be initiated based on a defined trigger (station and feeder combined), a schedule, or an override command. Figure 9 shows an example of the participation of individual units in charging.

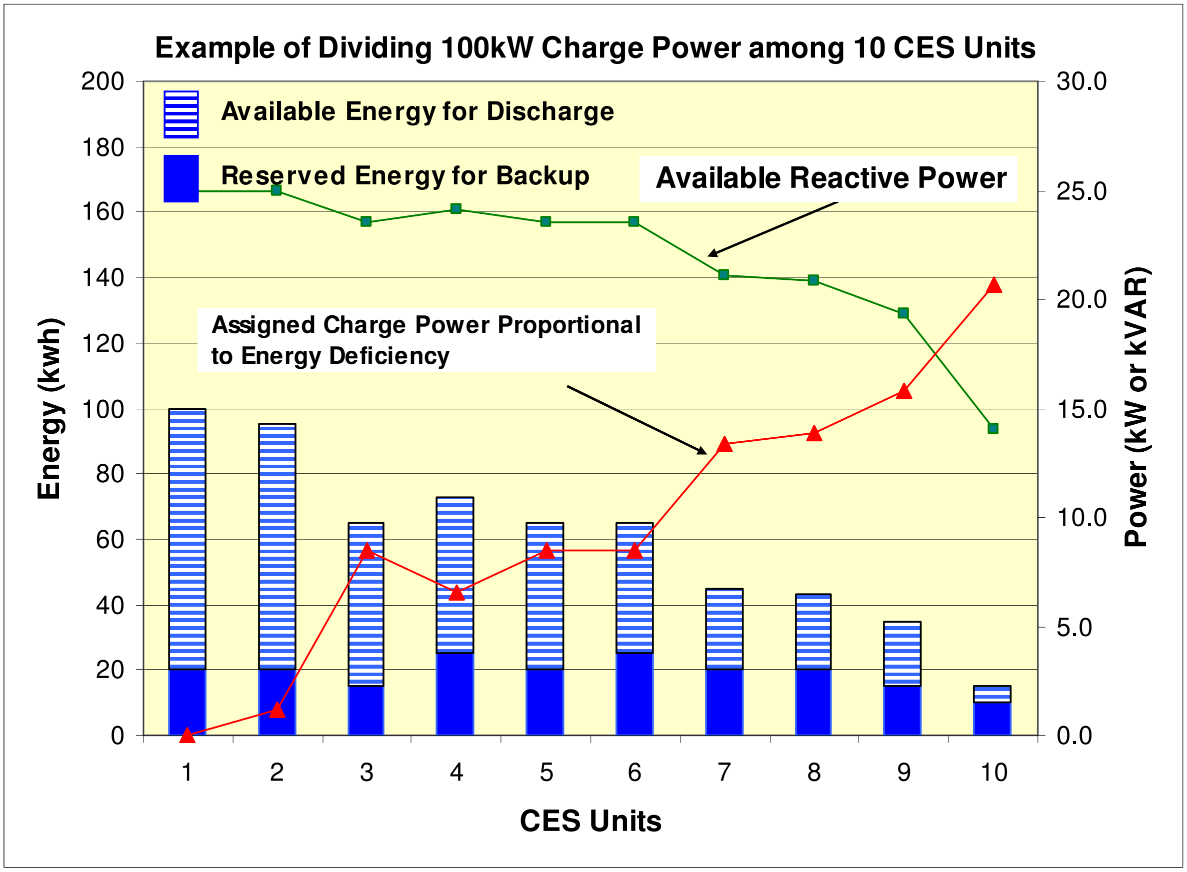


Figure 9 – Participation of CES Units in Charging

The total Group charge deficiency is known by the CES Hub from the total Group energy capacity minus the total Group State of Charge. Charging opportunity is defined by an adjustable trigger point as illustrated in Figure 5 above. The charging trigger requires that station and feeder demands are both below set levels. Individual CES Units in a Group will participate in charging proportional to their respective energy deficiencies. The CES Unit deficiency is the difference between CES Unit full charge and current state of charge. In the example given in Figure 9 the 10 units charge at rates ranging from zero to 25 kW as indicated by the red markers.

The reactive power dispatch is handled during charging in a fashion similar to the discharge cycle. The Units are requested to provide VAR correction inversely proportional to their charge rates. The individual CES Units are responsible to remain within power and voltage limits. The example illustrated in Figure 9 shows a total of 220 kVAR available.

6. CES Hub Construct Features

6.1. The CES Hub may be installed in the station from which the associated feeders are derived or at some other location that offers good communications facilities and an appropriate physical environment. The CES Hub shall be suitable for mounting in typical telecommunications racks and / or server racks. The CES shall be in an enclosure that is suitable for outdoor installations in a control cabinet.

6.2. The CES Hub shall have capability to handle up to 1,000 CES Units. This requirement includes processor capability, communications rate, and storage for logs for 30 days of operation.

6.3. **As an option,** the CES Unit Control shall include Human-Machine Interface (HMI) that includes a display and manual controls. All settings must be viewable and settable, statuses viewable, operating parameters viewable, and logs configurable and viewable.

6.4. The CES Hub shall provide two power supply options; 120 V AC 60 Hz, or 125/250 V DC.

6.5. Settings, dynamic data, and logs shall be stored in non-volatile memory. In the event of a power supply interruption, the CES Hub shall not loose information necessary to restart.

6.6. Environmental – The CES Hub shall be designed to perform all its functions in the following outdoor environment:

Operating Ambient Temperature:	-30°C to +50°C
Humidity:	10% to 95% non-condensation

6.7. Harmonics, Noise and EMI emissions

CES Hub is essentially a computer-based controller that will be installed in the control room of a station or a similar environment. In general, CES Hub shall not interfere with nor be susceptible to interference from power line carrier (PLC), radio, television, or microwave equipment. Specifically, CES Hub shall comply with 47 CFR FCC, Part 15, Subpart B for a class A device.

7. Factory Acceptance Testing

The system supplier shall conduct system operation tests according to applicable standards and procedures. Representatives from the purchaser and the supplier shall be allowed to participate in factory acceptance tests covering the functionality of all system components.

8. CES Hub Alarms and Status

The CES Hub will provide status and alarm information to the DDC. It shall provide aggregate CES fleet data in addition to individual CES Unit data.

8.1. Individual CES Hub Alarms are tabulated here. All alarms shall be GPS time stamped.

Alarm	Action	Reset
Comm Failure	Warning	Auto
Power Deficit	Warning	Manual
Energy Deficit	Warning	Manual

8.2. CES Hub status to the DDC display will be provided in the form of operating parameters tabulated here.

Station load		kW, kVAR	
Feeder load		kW, kVAR	
Station voltage		PU	
Group Active	Unit reports	status	ID
Active Power	Unit reports	total power in/out	kW
Active VAR	Unit reports	Total VAR in/out	kVAR
Available Energy	Unit reports	Total available energy	kWh
group exceptions	Unit reports	Units unavailable	cause
Weak Units	Unit reports	Outliers; variation from average	
Island event	Unit reports		

9. CES Hub Settings and Operating Parameters

9.1. Following are CES Hub settings. All settings shall be accessible locally through a connected PC or remotely.

Setting	Instance	Measurement	Units	Default
DDC Comm Retry	on loss of communications	Time	minutes	5
Command Interval		Time	minutes	5
Fleet Members		ID	address	
Fleet Groups		ID	address	
Group power rating	group rating total	power	kW	
Group energy rating	group rating total	energy	kWh	
Group reserve capacity	Group total		percent	
Trigger Mode	set manually	Schedule / triggered		Trigger
VAR Mode	set manually	Schedule / triggered		Schedule
Station Load Trigger		Station load	kW	
Station VAR Trigger		Station load	kVAR	
Station Charge Trigger		Station load	kVA	
Feeder Load Trigger		Feeder load	kW	
Feeder VAR Trigger		Feeder load	kVAR	
Feeder Charge Trigger		Feeder load	kVA	

9.2. Following are CES Hub Inputs in addition to individual CES Unit inputs (tabulated in the CES Unit Functional Specification).

Station load		kW, kVAR	
Feeder load		kW, kVAR	
Station voltage		PU	
Group Active	Unit reports	status	ID
Active Power	Unit reports	total power in/out	kW
Active VAR	Unit reports	Total VAR in/out	kVAR
Available Energy	Unit reports	Total available energy	kWh
group exceptions	Unit reports	Units unavailable	cause
Island event	Unit reports		

9.3. Following are CES Hub Outputs to the CES Units (also tabulated in the CES Unit Functional Specification).

Reactive Power	In / Out	Percent
Real Power	In / Out	Percent

10. Standards & Code Compliance

The CES and subsystems shall be designed, manufactured, and tested according to the latest standards including but not limited to IEEE, ANSI, NEC, and NEMA. Equipment furnished shall meet the guidelines defined in the applicable standards listed in Table II below.

Table II - APPLICABLE STANDARDS & CODES

1	ANSI/IEEE C2-2007	National Electrical Safety Code.
2	ANSI Z535 – 2002	Product Safety Signs and Labels.
3	FCC Sections15.109 & 15.209	FCC Code of Federal Regulations Radiated Emission Limits; General Requirements.
4	IEEE 519-1992	IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems.
5	IEEE C37.90.2-2004 TM	IEEE Standard Withstand Capability of Relay Systems to Radiated Electromagnetic Interference from Transceivers.
6	IEEE Std. C37.90.1-2002 TM	IEEE Standard for Surge Withstand Capability (SWC) Tests for Protective Relays and Relay Systems (ANSI).
7	IEEE P2030	Draft Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), and End-Use Applications and Loads
8	Smart Energy Profile (SEP)	Standard system for communication with demand side management equipment
9	IEC 61968	Application integration at electric utilities – System interfaces for distribution management
10	UL 1741	UL Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources
11	UL 1778	Underwriters Laboratory’s Standard for UNINTERRUPTIBLE POWER SYSTEMS (UPS) for up to 600V A.C.
12	UL 1778	Underwriters Laboratory’s Standard for Distributed Generation.

APPENDIX A – CES CONTROL HUB FUNCTIONAL SPECIFICATION LICENSE

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