Watt?? Another Energy Object??
Introduction to the Energy Management Object

Richard Blair
System Architect
Schneider Electric

Rich Morgan
Product Application Engineer
Rockwell Automation

Abstract:

Industrial energy management has long been expensive, application-specific and difficult to cost justify. Believing that a standardized approach would render this technology more readily accessible, the Energy Initiative Special Interest Group (SIG) is currently working on completing the definition of a CIP Energy™ Management Object. This object defines multiple Curtailment Levels that allow devices to reduce energy consumption, while continuing operation at altered production rates. Each Curtailment Level comprises a set of attributes describing the energy savings and instructions to the device on how to go to that level.

This paper introduces the current vision of the definition of the CIP Energy Management Object. After terms and definitions are introduced, the state model is presented. Each attribute and object specific service are explored. Next, interactions between an Energy Management Client and a device containing the Energy Management Object are identified. Also included is a discussion exploring how the Energy Management Object complements other, previously defined energy objects. Devices that lend themselves to implementing the Energy Management Object are considered. The paper closes with a summary of the anticipated benefits of the Energy Management Object to vendors, users and system designers.

Definition of Terms

Managed Entity – A device that supports the Energy Management object.

Energy Management Client ("Client") – A managing application that controls Managed Entities by interacting with instances of their energy management objects.

Managed Instance – An instance of an Energy Management object that may be owned by a Client. A managed entity can have multiple Managed Instances.

Energy Management State ("State") – A set of conditions that defines the behavior of a Managed Instance.

Curtailment Level ("Level") – Collection of data representing a power level to which a Managed Instance can be commanded.

Pass Code – A client-created 32-bit unsigned integer that must be present in all Energy Management Object specific service requests. The Pass Code is an integrity mechanism used to establish an exclusive relationship between a server and an authorized client or set of clients for energy management.

Data Object – Generic term used to describe an object capable of storing data (e.g. the File Object).

Keywords

Energy Management, Curtailment level, Energy, Power

Introduction

The need exists in industrial applications for a standardized method of communicating with control devices to support the automated management of energy consumption and power levels. The Energy Management Object specifies a standardized device-level interface, based upon CIP™ that is designed to meet this need.

In today's industrial environment, an application may utilize a number of methods to control the operation of devices, including direct analog and digital control, scheduled and unscheduled communications, etc. The Energy Management Object interface provides an alternate, standardized method that supplements customary control methods, for the purpose of controlling the energy usage and power level of industrial devices and systems. The interface is comprised of a discrete collection of power curtailment levels that can be selected by an energy management application.

The Energy Management Object can act as a proxy to provide the Energy Management Object interface for one or more simple devices that do not possess the capabilities to implement power curtailment levels.

A device that supports the Energy Management Object may also support other energy-related CIP objects.

An Energy Management Client can reduce power consumption by commanding one or more instances of the energy management object to a curtailment level. Several options are available for providing versatility, and for managing the content of an energy management object instance's curtailment levels.

A Managed Instance can transition between various States and Levels. The collection of object-specific services is used to control:

- Entry into and exit from Energy Management States
- Within the State, transition between Curtailment Levels

A Managed Instance may have multiple defined Levels. Every Managed Instance must contain at least one Curtailment Level that represents full power operation. The Client can respond to conditions, energy saving requests, etc., by selecting Levels that exist in each member of its collection of Managed Instances, and by commanding each Managed Instance to transition to the selected Level.

A Client can be used to:

- Command a Managed Instance to transition to Energy Management States and Curtailment Levels
- Select an appropriate energy management action for a given set of conditions
- Configure Curtailment Levels in a Managed Instance.

Within the Managed state, a Managed Instance's operational capabilities and power levels may remain in transition for a time until a commanded Curtailment Level is attained.
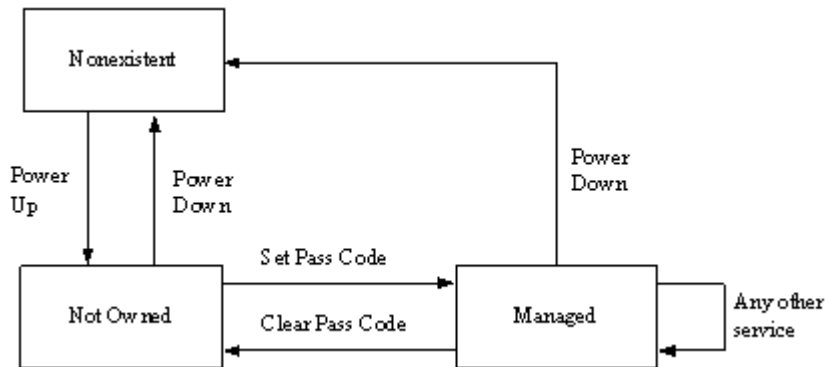
Energy Management States

A managed entity supporting the Energy Management Object can transition between various States and energy-saving Curtailment Levels. The object specific Energy_Management service is used to change at what Level a Managed Instance is operating.

There are three Energy Management States for Managed Instances:

1. Nonexistent – The device is powered down; or the Managed Instance has not yet been created.
2. Not Owned – The Managed Instance is operational but no Client has established an ownership relationship.
3. Managed – The Managed Instance is operational and a Client has established an ownership relationship.

The following state transition diagram offers an illustration of the energy management behavior of a Managed Instance.

Figure 1 – Energy Management Object Instance State Diagram

Energy-saving Curtailment Level Assignment

The Energy Management Object embodies the general approach that energy management is performed by a Client. The Client selects pre-defined, discrete energy-saving Curtailment Levels in a collection of Managed Instances in order to attain system-wide energy management objectives. There are numerous options available to device vendors, machine OEMs, and system designers to assign energy-saving Levels to suit a particular application. Examples include:

- Curtailment Levels and their IDs may be pre-assigned by device vendors and documented in product literature
- Curtailment Levels and their IDs may be assigned by a machine builder during control system design
- Curtailment Levels and their IDs may be set during system commissioning (by use of Energy Management object specific services)
- Curtailment levels may be set dynamically by a Client that is attempting to optimize energy usage during machine or process operating conditions

The list above is not exhaustive. There is no intent to limit how a particular Client performs energy management utilizing the Energy Management Object, or how a Managed Entity implements the Energy Management Object.

Ownership Relationship between Client and Managed Instance

On power up, a Managed Instance enters the Not Owned state. A Client desiring to establish an ownership relationship with the Managed Instance can issue an object specific Establish_Ownership service request. This will establish an owner relationship between the Client and the Managed Instance, and the Managed Instance will transition to the Managed state. With this relationship established, the Client can now perform energy management activities with the Managed Instance. The Client may also share the Pass Code, allowing other Clients to interact with the Managed Instance as an owner.

An ownership relationship between the Client and Managed Instance will exist until an authorized Client releases ownership or power is cycled to the Managed Instance.

Energy Management Object Instance Attributes

Like all CIP objects, the Energy Management Object contains a set of instance attributes. The following sections describe the 9 instance attributes that comprise the Energy Management Object.

Curtailment Levels

Curtailment Levels are used by a Client to control the amount of power that a Managed Instance consumes during operation. Because Curtailment Levels may be customized to reflect different production behaviors, it is possible that some Curtailment Levels contain the same Percent Power data. Mechanisms are provided to allow filtering the availability of Curtailment Levels based upon desired production behaviors.

The Curtailment Levels attribute contains an array of structures describing the set of Curtailment Levels supported by the Managed Instance. The Curtailment Levels array consists of one member corresponding to each supported Curtailment Level. A Managed Instance contains at least one Level (with ID = 0) for uncurtailed operation.

A Curtailment Level may be specified in the Energy_Management Service by reference to its ID or its Percent Power. In cases where the Power values are the same in multiple Levels, a Client would need to use the ID in order to select one of those Levels. The Curtailment Levels attribute members may be read by the common Member services or object specific services.

The Curtailment Levels of a device may be read for:

- Display or informational purposes.

- Coordination of Curtailment Levels in multiple Managed Instances to control energy consumption.

- Backing up Levels to facilitate device replacement.

The Curtailment Level structure consists of seven members that are described in the following paragraphs:

ID

The ID member of a Curtailment Level contains a value that is unique for each Curtailment Level in the Curtailment Levels array of a Managed Instance. Because each ID is unique, a Client can use this to identify each Curtailment Level within a Managed Instance.

Data Object Path

To enable a Managed Instance to transition to a particular Curtailment Level, it needs a set of instructions, set-points, data values, etc. For static Curtailment Levels (i.e. those defined and configured from the factory within a Managed Instance) a device can implement vendor specific (e.g. hard-coded) links between Curtailment Levels and these instructions. A preferred approach is to store these instructions in a Data Object (e.g. the File Object) instance. The Data Object Path member is then used to point to a Data Object instance containing the instructions. The value of the member can be hidden using the Hide Data Object Association field in the Capabilities member.

The Data Object Path member value is set using the Associate_File object specific service request. The contents and format of a Data Object instance is vendor specific.

Data Object Validity Check

The Data Object Validity Check can be used by a Managed Instance to verify that a data object was not modified outside of the Energy Management Object environment. The content of this member is vendor specific.

Capabilities

The Capabilities member indicates permissions granted to a Client for actions on this Curtailment Level. The default value of zero (0) gives a Client full editing access to the Level. There are four capabilities defined:

- to prevent modification to the Level

- to prevent deletion of the Level

- to hide the identity of the associated data used by the Managed Instance to transition to the Level

- To indicate if a Data Object is needed

Status

The Status member provides a mechanism for the Managed Instance to inform a Client about the status of this Curtailment Level. Two fields are available:

- The Level Unavailable field can be used by a device to indicate that the Level is not available at this time. One reason could be that the Level is currently being modified (due to an object specific service request) or that the current state of the device prohibits transition to this Level.

- The Data Status field describes the state of the associated Data Object.

Percent Power

The Percent Power member value indicates the percentage of Uncurtailed Power that will be consumed when operating at this Level. It has a permissible range of 1 to 10,000, reflecting 0.01 to 100.00 per cent of Uncurtailed Power.

Description

The Description member may be used to provide a descriptor for the Curtailment Level. The data type is STRINGI, so multiple languages can be used to describe the Level.

Number of Curtailment Levels

This attribute contains the number of members in the Curtailment Levels array of a Managed Instance. The Managed Instance is responsible for updating this attribute as Levels are added and removed from the Curtailment Levels Array.

Instance Capabilities

The Instance Capabilities attribute provides a mechanism for the Managed Instance to inform an Energy Management Client about what capabilities it currently supports. At this time, only one capability is provided, which can be used to protect the array of Curtailment Levels from modification.

Instance Status

The Instance Status attribute provides a mechanism for the Managed Instance to inform a Client about its current operating characteristics. There are seven fields in this attribute.

If the Managed Instance is currently in transition to a new Curtailment Level, the Matching ID field identifies the ID of the target Level.

The Capture in Progress field identifies whether the Managed Instance is currently in the process of saving a Curtailment Level, due to either a Capture_Level or Modify_Level object specific service request.

The Level Mismatch field indicates whether the current data set matches the present Curtailment Level. In order to create new Levels using the Capture_Level object specific service, a device must allow modification of the data set to reflect operation at the desired Level. This would constitute a mismatch, and this field would indicate that situation. After the new operating Level is captured, the mismatch is no longer present.

The Curtailment Levels Array Full field indicates to a Client if there is no more room in the Managed Instance to store additional Curtailment Levels. While the specification allows for up to 10001 Levels, a device may implement a lower number due to memory constraints, etc.

The Management Unavailable field can be used by a Managed Instance to indicate to a Client that it is currently not accepting Energy_Management service requests. This allows a Managed Instance to easily turn off energy management during critical operations, critical production schedule periods, etc.

The In Transition field is used to indicate if the Managed Instance is currently transitioning to a Curtailment Level but not yet complete.

The Present State field value indicates the current state of the Managed Instance.

Present Curtailment Level ID

The Present Curtailment Level ID attribute contains the ID of the Curtailment Level at which the Managed Instance is currently operating or, if in transition to a new Level, the Curtailment Level at which it was operating before beginning the transition.

When the value of this attribute is zero (0), the Managed Instance is operating without curtailment (at full load).

Present Expected Power

The Present Expected Power attribute contains a calculated value to indicate the Managed Instance's present expected power consumption in kW. It is the product of the current Percent Power member and the Uncurtailed Power divided by 10000:

$$\frac{(Percent\ Power)\ x\ (Uncurtailed\ Power)}{10000}$$

When operating with no curtailment, this attribute is equal to the Uncurtailed Power attribute.

Owner Path

The Owner Path attribute contains the path to the current Energy Management Client that owns the Managed Instance. The object specific services Establish_Ownership or Change_Ownership set the value of this attribute when a Client establishes or modifies an ownership relationship with a Managed Instance. The Owner Path may be used by other Clients to identify the Client that established ownership of the Managed Instance. If no Client currently owns the Managed Instance, the path is empty.

Uncurtailed Power

The Uncurtailed Power attribute indicates the nominal, average real power consumed by or under control of the Managed Instance (in kW) when it is running at full operation. The Client can use this value to determine, in combination with Percent Power members, possible energy savings when considering energy actions.

Options

The Options attribute provides selection of operational behaviors of Managed Instances. This attribute is optional. At this time, there is only one option available, the Power up Curtailment Level selector.

The Power up Curtailment Level field controls what a Managed Instance does upon power on. If the Managed Instance was at a particular Level when power was removed, this field lets the user choose whether the Managed Instance should remain at that Level upon power up or if it should return to the full power Curtailment Level.

Object Specific Services

This section describes the twelve object specific services associated with the Energy Management Object. With the exception of the Establish_Ownership service, all other object specific services are Pass Code protected. The Pass Code is a mechanism used to establish an exclusive relationship between a Managed Instance and an authorized Client or set of Clients for energy management. In order to use these services, the Client needs to provide and maintain a Pass Code for each Managed Instance.

Establish_Ownership Service

The Establish_Ownership service sets a Pass Code and Owner Path to establish an ownership relationship between a Client and an Energy Management Object instance. The Client provides a Pass Code and an EPATH to itself in the request. Upon successful completion of this service, the Energy Management Object instance enters the Managed state. The Client needs to include this agreed upon Pass Code in all other object specific service requests.

The Owner Path attribute can only be set during the Establish_Ownership or Change_Ownership service requests. The Owner Path may be used to help diagnose conflicts between energy management Clients. If more than one Client is required to have access for energy management, it is up to the owning Client to share the Pass Code among them. The Pass Code is not exposed in the class or instance attributes.

Release_Ownership Service

The Release_Ownership service terminates the Managed Instance's ownership relationship with its Client. A Client can only execute this service if the Managed Instance is operating at the uncurtailed power level. Upon successful completion of this service, the Energy Management Object instance enters the Not Owned state and clears its Owner Path attribute and Pass Code.

Change_Ownership Service

The Change_Ownership service changes a Managed Instance's Owner Path attribute and Pass Code. As an example of the use of this service, consider an owner Client that has shared an instance's Pass Code with other Clients, but requires exclusive access for a time. The Client can issue a Change_Ownership request with a different Pass Code to lock out other Clients. When its need for exclusive access ends, it may change the Pass Code back, restoring access to the other Clients.

Energy_Management Service

The Energy_Management service can be used by a Client to command a Managed Instance to a Curtailment Level. This service provides a mechanism to carry out energy management activities through explicit request/response messages. The service request data is made up of a Pass Code, a Command, and a Curtailment Level.

Three commands are provided. The Client can command a Managed Instance to a Curtailment Level by specifying the ID of the Level in the request. Alternatively, the Client can command a Managed Instance to go to a Curtailment Level whose Percent Power member is less than or equal to the Percent Power level specified in the request. As a final alternative, the Client can command the Managed Instance to a Curtailment Level whose Percent Power member is greater than or equal to the Percent Power value in the service request. These three commands give a Client extreme flexibility when controlling Managed Instances.

Energy_Management_Query Service

The Energy_Management_Query service can be used by a Client to preview a managed instance's response to an Energy_Management service request parameter set. The available Energy_Management command parameters allow the Managed Instance to choose a Curtailment Level above or below a requested Percent Power, so the Client may use the Energy_Management_Query service to identify the resulting Level for a given set of Energy_Management command parameters. The Client can then use this information to estimate anticipated energy usage upon execution of an Energy_Management command using those parameters.

The Energy_Management_Query service request data is identical to the content of an Energy_Management service request. The service response data contains a Status and a target Curtailment Level ID. In addition, a field in the Command parameter can be set to allow a Client to simply verify ownership.

Unlike the Energy_Management service, the Energy_Management_Query service does not return an exception response for an invalid energy management Command, but instead returns detailed Status information.

Capture_Level Service

In all but extremely simple devices (where a vendor pre-programs Curtailment Levels) there is a need to allow customers (e.g. end users, OEMs, etc.) to create Curtailment Levels. In this scenario, the device would be configured, its operation verified and its power consumption measured outside of the Energy Management Object instance. After intended operation is validated, the Energy Management Client, using the Capture_Level service, can take a snapshot of this operating mode so that the Managed Instance can return to this configuration at a later time.

The Capture_Level service is used to add a new Curtailment Level to a Managed Instance based on the current operating characteristics of a Managed Entity. The Client provides all Curtailment Level attributes except the Curtailment Level Data, which is provided by the managed entity in the form of a Data Object instance and the unique ID. Once a Level is captured, the device can be reconfigured to capture additional levels, if desired.

Remove_Level Service

The Remove_Level service is used to delete a Curtailment Level from the stored list of Curtailment Levels Array in a Managed Instance. Curtailment Levels that are read-only cannot be deleted.

Revise_Level Service

The Revise_Level service allows a Client to revise the attributes associated with an existing Curtailment Level. The service request data is similar to the Capture_Level service, allowing modification of all Curtailment Level members except for ID and Capabilities. This service does not allow a Client to provide data for the Curtailment Level Data Object attribute, but it can request that this attribute is updated with the current operating state of the Managed Instance (i.e. captured).

Read_Level Service

The Read_Level service is used to upload a single Curtailment Level structure from the stored list of Curtailment Levels to a Client. The Data Object associated with the Curtailment Level is not read using this service, but a path pointing to the instance is read (provided it is not marked as hidden). The path may then be used by the Client to read the data object using Data Object services.

Write_Level Service

The Write_Level service allows a Client to download a single Curtailment Level to a Managed Instance. This service does not transfer any necessary data object that should be associated with the Curtailment Level. The Write_Level service cannot be used to overwrite a Curtailment Level in a Managed Instance with the same ID. If the operation is successful, the Curtailment Level is added to the array of Curtailment Levels and the Number of Curtailment Levels is updated.

Associate_Level Service

The Associate_Level service is used to associate a Data Object instance with a Curtailment Level.

Disassociate_Level Service

The Disassociate_Level service is used to remove a Data Object Instance association from a Curtailment Level. Only the association is removed, the data object is not removed from the managed entity.

Energy Management Messaging Sequences

The following sections illustrate several examples of how a Client may use common and object specific services of the Energy Management Object to manage energy usage within a device. The examples are based on some common use cases, and use messaging sequences between a Client and a Managed Instance for demonstration purposes. These diagrams are illustrative and do not necessarily imply required Client behavior.

Establish Ownership

Figure 2 demonstrates successful ownership of a Managed Instance by a Client. An optional step (Verify Ownership) demonstrates a method that can be used by a Client to verify that it is the current owner of that Managed Instance.

Figure 2 – Client Establishes Ownership of a Managed Instance


```
        Client                                                    Managed Instance
          │                                                              │
          │──Establish_Ownership(PassCode, Proposed Owner Path)─────────▶│
          │                                                              │  Change State
          │                                                              │  to Managed
          │◀─────────────────Success response────────────────────────────│
          │                                                              │
          │                                                              │
          │   Verify Ownership: Get_Attribute_Single(Owner Path Attrib. #5)│
          │ ─ ─              (optional, repeat periodically)           ─ │
  Compare response Owner Path │                                          │
  with Proposed Owner Path in │◀ ─ ─ ─ ─ ─ ─ ─Response(Owner Path)─ ─ ─ ─│
  Establish_Ownership service │                                          │
          │                                                              │
```
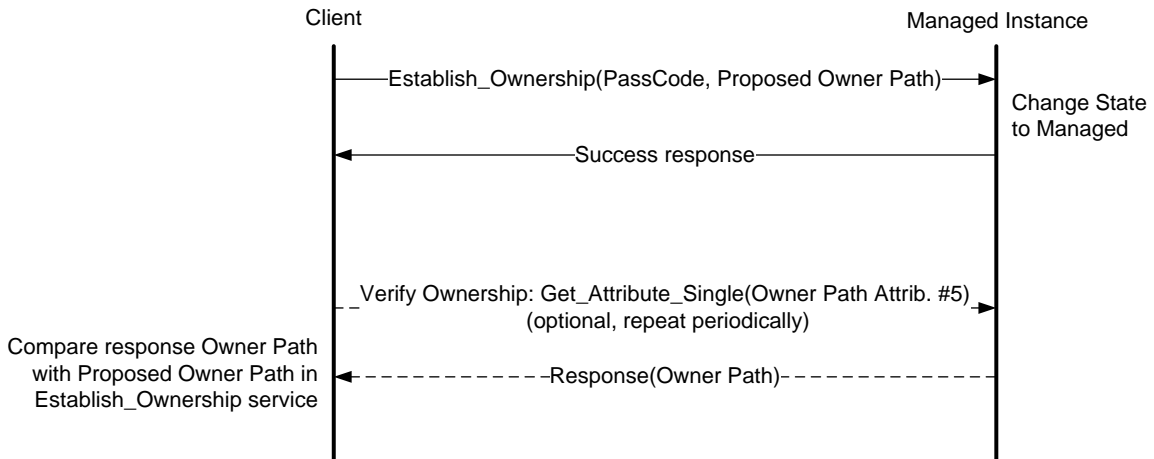
Reestablish Ownership

Following a loss of power, a Managed Instance initializes into the Not Owned state. In this state, any object specific service request (other than Establish_Ownership) will fail. Furthermore, if a Client shares a Pass Code and another Client uses this shared Pass Code to either relinquish ownership or to change the Pass Code, any object specific service requests by the first Client will also fail.

Figure 3 demonstrates how a Client can use the Energy_Management_Query service (with the Check Ownership bit set in the Command parameter) to determine if it is still the owner of the Managed Instance. Depending upon the response, the Client could use the Establish_Ownership service to re-establish ownership.

Figure 3 – **Example: Client Re-establishes Ownership After Power Loss**


```
        Client                                                    Managed Instance
          │                                                              │
          │────Energy_Management_Query( PassCode,──────────────────────▶│
          │       CMD:Check Ownership = 1, C.L.)                         │
          │◀───────Response (Status, Target Level ID)─────────────────────│
          │                                                              │  PassCode has
          │                        . . .                                 │  been cleared:
          │                                                              │  e.g. power cycle
          │────Energy_Management_Query( PassCode,──────────────────────▶│
          │       CMD:Check Ownership = 1, C.L.)                         │
          │◀──────Error Response (Object State Conflict)──────────────────│
          │                                                              │
  Resend Pass Code │                                                     │
  and EPATH │────Establish_Ownership(PassCode, EPATH)────────────────────▶│  Set Passcode and EPATH
          │                                                              │  Transition to Managed state
          │◀─────────────────Success response────────────────────────────│
          │                                                              │
```

Perform Energy Management Command Query

A Client can use the Energy_Management_Query service request to preview the response to an Energy_Management service request. The status returned may indicate the Curtailment Level ID that corresponds to the requested Level, or a conflict or error that would not permit the execution of an Energy_Management command. Figure 4 shows a Client executing an Energy_Management_Query command and its associated response.

Figure 4 – Client Queries a Managed Instance
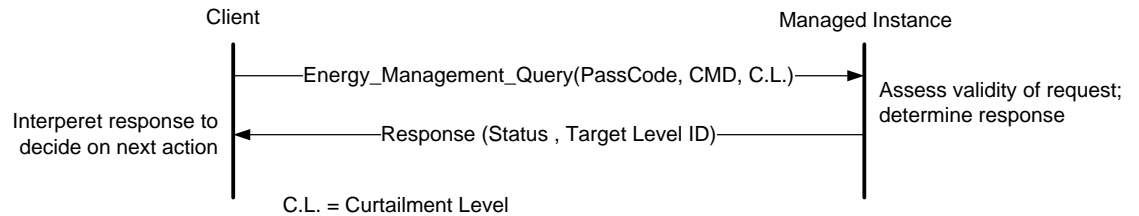
Command to Curtailment Level

After a Client decides it wants to command a Managed Instance to a new Curtailment Level, it needs to send an Energy_Management service request with the appropriate parameters. The previous example demonstrated a method for a Client to audit the contents of an Energy_Management command parameter set. Upon receipt of a valid Energy_Management command, a Managed Instance will begin the transition to the new Level and return a successful response to the request. Typically, the transition will take some time to complete. The Client can periodically poll the Managed Instance, using the Get_Attribute_Single service request of the Instance Status attribute, to verify when the transition into the commanded Level is complete. Figure 5 demonstrates this scenario.

Figure 5 – Client Commands a Managed Instance to a Curtailment Level
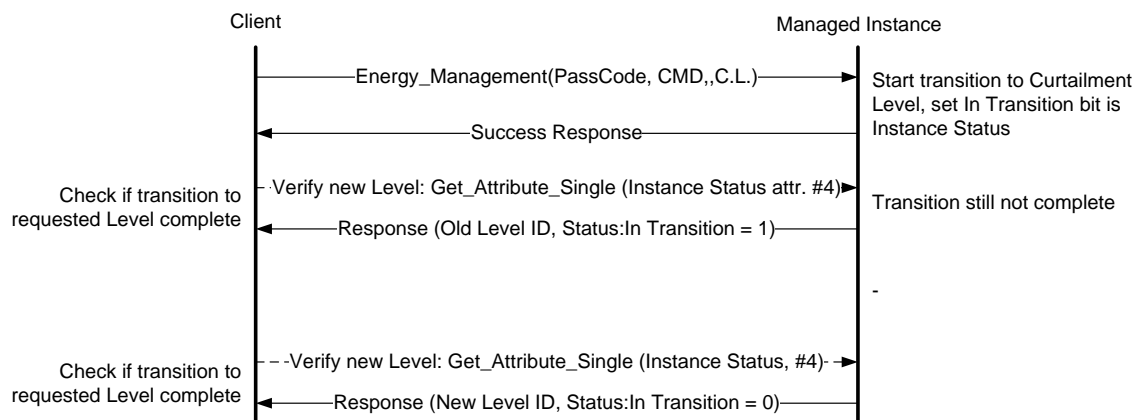
Obtain Exclusive Access to a Managed Instance

An owner that has shared its Pass Code with other Clients may determine that modifying the instance may require exclusive ownership of the instance for a time. The Change_Ownership command provides this ability. After the maintenance of the Managed Instance is complete, the owner may change the Pass Code and Owner Path back to their previous values and inform the other Clients.

Figure 6 – Client Establishes Exclusive Access for a Period of Time

```
                              Client                                    Managed Instance
Exclusive ownership    │────Change_Ownership(OldPassCode, NewPassCode,───→│  Remain in Managed
required, issue Change │              NewOwnerPath)                        │  state with new Pass
Ownership request      │←─────────────Success Response───────────────────│  Code and Owner Path
                       │                                                  │
                       │                    . . .                         │
                       │                                                  │
Perform tasks          │─────────────Service Requests────────────────────→│
requiring              │←────────────Success Responses────────────────────│
exclusive access       │                                                  │
                       │                    . . .                         │
Restore shared         │────Change_Ownership(NewPassCode, OldPassCode,────→│  Remain in Managed
ownership, tell        │              OldOwnerPath)                        │  state with former Pass
other owners           │←─────────────Success response───────────────────│  Code and Owner Path
                       │                                                  │
```
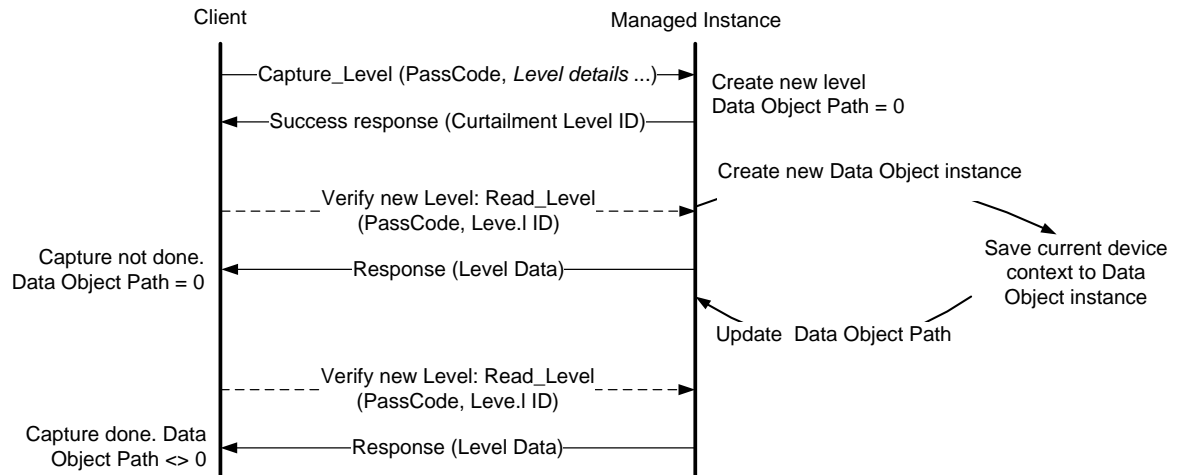
Capture a New Curtailment Level

One method to create Curtailment Levels within a Managed Instance is to place a device in the desired operating condition and then use the Capture_Level service to save this condition into a Curtailment Level. Adjustment of the operating condition of a device containing a Managed Instance is done by other means than the Energy Management Object.

Figure 7 – Create New Curtailment Level in a Managed Instance

```
                    Client                            Managed Instance
                      │──Capture_Level (PassCode, Level details ...)→│  Create new level
                      │                                              │  Data Object Path = 0
                      │←──Success response (Curtailment Level ID)────│
                      │                                              │      Create new Data Object instance
                      │                                              │
                      │────Verify new Level: Read_Level──────────────→│
                      │        (PassCode, Leve.l ID)                 │          Save current device
Capture not done.     │←──────Response (Level Data)──────────────────│          context to Data
Data Object Path = 0  │                                              │          Object instance
                      │                                              │      Update Data Object Path
                      │────Verify new Level: Read_Level──────────────→│
                      │        (PassCode, Leve.l ID)                 │
Capture done. Data    │←──────Response (Level Data)──────────────────│
Object Path <> 0      │                                              │
```

Backup Curtailment Levels

Curtailment Levels not inherent to a Managed Instance will need to be restored in the unlikely event the device needs to be replaced. Figure 8 shows a method that can be used to backup Curtailment Levels within a Managed Instance. A Client need not be the owner of the Managed Instance to perform this operation. Common services can be used to read the size of the Curtailment Levels array and to get the contents of each member of the array. If the Data Object Path size member of a Curtailment Level is non-zero, object, common or vendor specific services can be used to retrieve the associated Data Object contents. The Client may also want to check the Status member to make sure that the Level being backed up is complete and not in the process of being revised or missing its associated Data Object instance (if required).
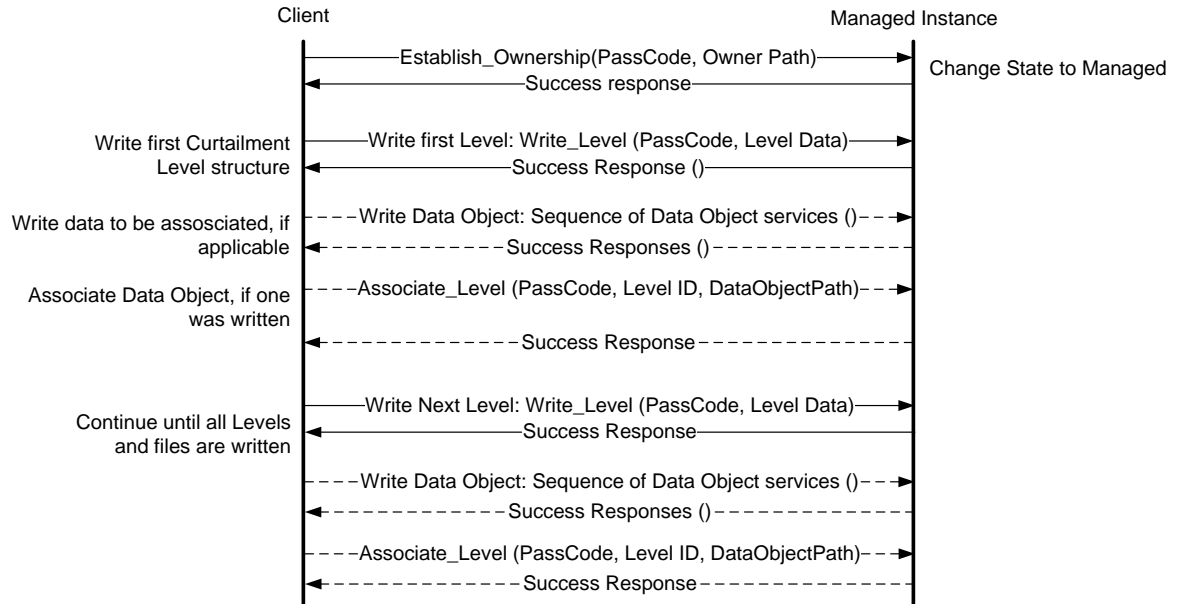
Figure 8 – Back Up Curtailment Levels from a Managed Instance
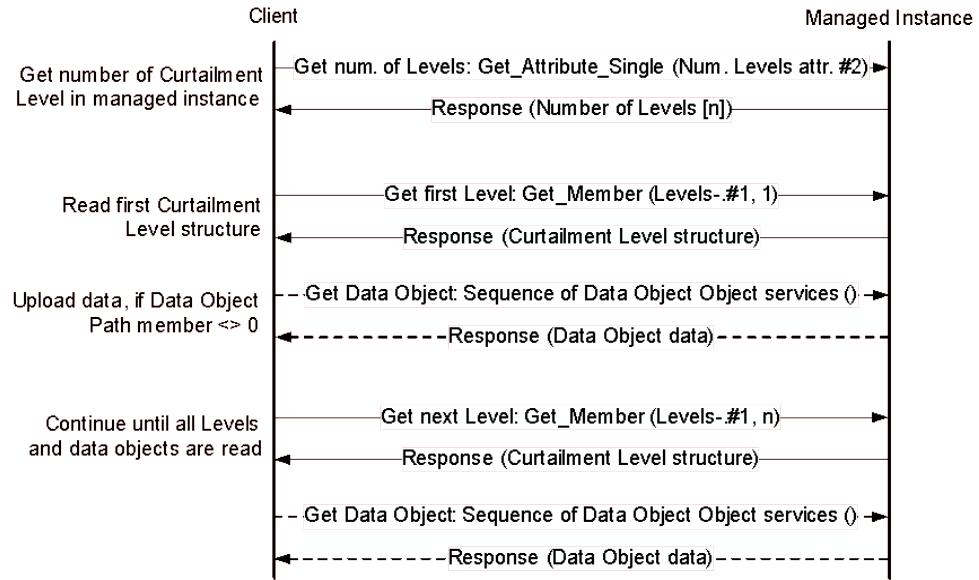
Restore Curtailment Levels

There may come a time when a Client will need to restore Curtailment Levels that were present in a Managed Instance (e.g. device replacement). Figure 9 demonstrates one method that could be used to accomplish this task. Note that a Client must own the Managed Instance to perform this activity. The Curtailment Level with ID = 0 cannot be restored using the Write_Level service, because it is always present in a Managed Instance. Instead, the Revise_Level service should be used for this special Level.

Figure 9 – Restore Curtailment Levels in a Managed Instance

```
                    Client                                            Managed Instance
                      |————Establish_Ownership(PassCode, Owner Path)————|  Change State to Managed
                      |←————————————Success response———————————————————|
                      |                                                  |
Write first Curtailment|———Write first Level: Write_Level (PassCode, Level Data)——→|
       Level structure |←——————————————Success Response ()——————————————|
                      |                                                  |
Write data to be assosciated, if|——Write Data Object: Sequence of Data Object services ()——→|
            applicable |←———————————————Success Responses ()————————————|
                      |                                                  |
Associate Data Object, if one|——Associate_Level (PassCode, Level ID, DataObjectPath)——→|
         was written  |                                                  |
                      |←——————————————Success Response—————————————————|
                      |                                                  |
Continue until all Levels|————Write Next Level: Write_Level (PassCode, Level Data)————→|
     and files are written|←——————————————Success Response————————————————|
                      |                                                  |
                      |——Write Data Object: Sequence of Data Object services ()——→|
                      |←———————————————Success Responses ()————————————|
                      |                                                  |
                      |——Associate_Level (PassCode, Level ID, DataObjectPath)——→|
                      |←——————————————Success Response—————————————————|
```

Device Considerations

This section will describe potential device types that could be likely candidates for the inclusion of an Energy Management Object.

Simple Device

A simple device (e.g. a fan controller with multiple speed settings) could have a predefined instance of an Energy Management Object with fixed Curtailment Levels (one for each speed setting). Configuration of the device would allow for setting the Percent Power member for each Curtailment Level corresponding to the fan load being controlled, as well as the uncurtailed power attribute.

Highly Configurable Device

A highly-configurable device (e.g. a Programmable Logic Controller) could contain capabilities to programmatically create instances of the Energy Management Object. The various attributes and Curtailment Levels could be configured using CIP or the device programming tools. The contents of the Energy Management Object's attributes would be customized to match the program(s) within the device.

Energy Management Client

An energy management Client needs to be an integral part of the control system. It cannot arbitrarily instruct a device to conserve energy without understanding its full effect on the whole control operation. When an energy management Client is informed that energy needs to be reduced (e.g. due to a demand request), it will need to decide which Managed Instances under its control should be curtailed to not only reduce energy consumption, but to continue to produce product (albeit at a altered production level).

Energy Management Object and Other Energy Objects

The Energy Management Object can coexist with the Energy Awareness Objects and / or the Power Management Object. These objects, although related, are independent. The implementation of a Base Energy Object alongside the Energy Management Object provides an effective way for a device to report the actual energy savings resulting from moving to a Curtailment Level. If implemented in the same device, a Power Management Object instance and an Energy Management Object instance may have the same or different clients. In either case, it is important for the client or clients to maintain big-picture awareness of the operating environment as it manages power and energy in its collection of devices.

Conclusions

The Energy Management Object completes the CIP Energy triangle. The Energy Awareness (Base, Electrical and Non-Electrical) objects provide a way for CIP devices to measure energy generation and consumption. The Power Management Object adds the capability to manage energy usage during idle periods. With the addition of the Energy Management Object, devices can now be managed to conserve energy consumption during production.