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Reference Model for Energy Management
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Abstract

Managing energy consumption of devices is different from several well understood network management functions because of the special nature of energy supply and use. This document explains issues of energy management arising from its special nature and proposes a layered reference model for energy management addressing these issues.

Status of this Memo

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1. Introduction

Managing energy consumption of devices is different from several well understood network management functions because of the special nature of energy supply and use. This memo explains issues of energy management arising from its special nature and proposes a reference model for energy management addressing these issues.

Defining a suitable reference model for energy management has proven to be explorative work that cannot be done in a single step because the area is rather new to people at the IETF. Ideas for a reference model have been elaborated in [I-D.ietf-eman-framework] and previous versions of this draft.

This revision is an attempt to combine the relationship model proposed in the last version (-02) of [I-D.ietf-eman-framework] with the concept of power interfaces proposed in the previous version (-02) of this draft. The result is a four layer model of energy management.

This draft starts with identifying and describing in Section 2 the special issues of energy management that require the development of a new reference model. The issues concern power supply, power and energy metering, and the reporting of low-power states.

Section 3 addresses these issues and proposed a new four layer model for energy management, see Figure 1.

```
+-----------------------------------------------+
|        energy management system (EnMS)        |
+-----------------------------------------------+
          |||                     |||
+---------------------+           |||
|  energy management  |           |||
|   mediation (EMM)   |           |||
+---------------------+           |||
           ||                     |||
+-----------------------------------------------+
|   local energy management interface (LMI)     |
+-----------------------------------------------+
                       |
+-----------------------------------------------+
|          power supply and use (PSU)           |
+-----------------------------------------------+
```

*Power supply and use (PSU) layer
At the lowest layer electrical objects are physically connected by power supply lines, and these connections constitute an electric supply topology.

*Local energy management interface (LMI) layer
This layer provides access to local information and to local control functions at managed electrical devices.

*Energy management mediation (EMM) layer
At this layer management functions use topology information from the PSU layer to infer information on remote devices and to realize control functions for remote devices.

*Energy management system layer
This layer contains a centralized or distributed energy management system that manages powered devices.

All communication with the energy management system (drawn with three parallel lines) in Figure 1 is subject of standardization in the EMAN working group. Communication between the EMM layer and the LMI layer (drawn with two parallel lines) is an application area of standards developed in the EMAN WG, but here also proprietary protocols may be used. Communication between the LMI layer and the PSU layer (drawn with a single line) is not subject of standardization by EMAN.
At the core of this framework are just a few key concepts. Energy is used by Powered Devices, some of which supply power to other devices and so are a subset called a Power Supply. Devices have power interfaces, which are like network interfaces, through which power is transferred into (an "inlet") or out of (an "outlet") a device. Measurement occurs at interfaces so that the total or net consumption of a device can be determined.

2. Energy Management Issues

This section explains special issues of energy management particularly concerning power supply, power and energy metering, and the reporting of low-power states.
To illustrate the issues we start with a simple and basic scenario with a single powered device that consumes energy and that reports energy-related information about itself to an energy management system, see Figure 2.

```
+---------------------------+
| energy management system |
+---------------------------+
            ^  ^
 monitoring |  | control
            v  v
     +------------------+
     | powered device  |
     +------------------+
```

The device may have local energy control mechanisms, for example putting itself into a sleep mode when appropriate, and it may receive energy control commands for similar purposes from a management system. Information reported from a powered device to the energy management system includes at least the power state of the device (on, sleep, off, etc.).
This and similar cases are well understood and likely to become very common for energy management. They can be handled with well established and standardized management procedures. The only missing components today are standardized information and data models for reporting and configuration, such as, for example, energy-specific MIB modules [RFC2578] and YANG modules [RFC6020].

However, the nature of energy supply and use introduces some issues that are special to energy management. The following subsections address these issues and illustrate them by extending the basic scenario in Figure 2.

2.1. Power Supply

A powered device may supply itself with power. Sensors, for example, commonly have batteries or harvest energy. However, most powered devices that are managed by an energy management system receive external power.
While a huge number of devices receive power from unmanaged supply systems, the number of manageable power supply devices is increasing. In datacenters, many Power Distribution Units (PDUs) allow the network management system to switch power individually for each socket and also to measure the provided power. Here there is a big difference to many other network management tasks: In such and similar cases, switching power supply for a powered device or monitoring its power is not done by communicating with the actual powered device, but with an external power supply device (which may be an external power meter).
Consequently, a standard for energy management must not just cover the powered devices that provide services for users, but also the power supply devices (which are powered devices as well) that monitor or control the power supply for other powered devices.
A very simple device such as a plain light bulb can be switched on or off only by switching its power supply. More complex devices may have the ability to switch off themselves or to bring themselves to states in which they consume very little power. For these devices as well it is desirable to monitor and control their power supply.
This extends our basic scenario from Figure 2 by a power supply device, see Figure 3.

```
            +------------------------------------------+
            |         energy management system         |
            +------------------------------------------+
                  ^  ^                       ^  ^
       monitoring |  | control    monitoring |  | control
                  v  v                       v  v
            +---------------+        +-------------------+
            | power supply |########| powered device  |
            +---------------+        +-------------------+

                    ######## power supply line
```

The power supply device can be as simple as a plain power switch. It may offer interfaces to the energy management system to monitor and to control the status of its power outlets, as with PDUs and Power over Ethernet (PoE) *[IEEE-802.3at]* switches.

The relationship between supply devices and the powered devices they serve creates several problems for managing power supply:

* Identification of corresponding devices

  - A given powered device may be need to identify the supplying power supply device.

  - A given power supply device may need to identify the corresponding supplied powered device(s).

* Aggregation of monitoring and control for multiple powered devices

  - A power supply device may supply multiple powered devices with a single power supply line.

* Coordination of power control for devices with multiple power inlets

  - A powered device may receive power via multiple power lines controlled by the same or different power supply devices.

2.1.1. Identification of Power Supply and Powered Devices

When a power supply device controls or monitors power supply at one of its power outlets, the effect on other devices is not always clear without knowledge about wiring of power lines. The same holds for monitoring. The power supplying device can report that a particular socket is powered, and it may even be able to measure power and conclude that there is a consumer drawing power at that socket, but it may not know which powered device receives the provided power.

In many cases it is obvious which other device is supplied by a certain outlet, but this always requires additional (reliable) information about power line wiring. Without knowing which device(s) are powered via a certain outlet, monitoring data are of limited value and switching on the consequences of switching power on or off may be hard to predict.

Even in well organized operations, powered devices' power lines get plugged into the wrong socket, or wiring plans are changed without updating the energy management system accordingly.

For reliable monitoring and control of power supply devices, additional information is needed to identify the device(s) that receive power provided at a particular monitored and controlled socket.

This problem also occurs in the opposite direction. If power supply control or monitoring for a certain device is needed, then the supplying power supply device has to be identified.

To conduct energy management tasks for both power supply devices and other powered devices, sufficiently unique identities are needed, and knowledge of their power supply relationship is required.

2.1.2. Multiple Devices Supplied by a Single Power Line

The second fundamental problem is the aggregation of monitoring and control that occurs when multiple powered devices are supplied by a single power supply line. It is often required that the energy management system has the full list of powered devices connected to a single outlet as in Figure 4.

```
              +----------------------------------------+
              |       energy management system         |
              +----------------------------------------+
                 ^  ^                       ^  ^
      monitoring |  | control    monitoring |  | control
                 v  v                       v  v
              +---------+        +-------------------+
              | power   |########| powered device 1 |
              | supply  |   #    +-------------------+-+
              +---------+   #######| powered device 2 |
                              #    +-------------------+-+
                              #######| powered device 3 |
                                     +-------------------+
```

With this list, the single status value has clear meaning and is the sum of all powered devices. Control functions are limited by the fact that supply for the concerned devices can only be switched on or off for all of them at once. Individual control at the supply is not possible.
If the full list of powered devices powered by a single supply line is not known for the controlling power supply device, then control of power supply is problematic, because the consequences of control actions can only be partially known.

2.1.3. Multiple Power Supply for a Single Powered Device

The third problem arises from the fact that there are devices with multiple power supplies. Some have this for redundancy of power supply, some for just making internal power converters (for example, from AC mains power to DC internal power) redundant, and some because the capacity of a single supply line is insufficient.

```
+-----------------------------------------------+
|            energy management system            |
+-----------------------------------------------+
    ^  ^               ^  ^               ^  ^
mon. |  | ctrl.   mon. |  | ctrl.   mon. |  | ctrl.
    v  v               v  v               v  v
+-----------+      +-----------+      +-----------+
| power     |######| powered   |######| power     |
| supply 1  |######| device    |      | supply 2  |
+-----------+      +-----------+      +-----------+
```

The example in Figure 5 does not necessarily show a real world scenario, but it shows the two cases to consider:

- *multiple power supply lines between a single power supply device and a powered device

- *different power supply devices supplying a single powered device

In any such case there may be a need to identify the supplying power supply device individually for each power inlet of a powered device. Without this information, monitoring and control of power supply for the powered device may be limited.

2.1.4. Relevance of Power Supply Issues

In some scenarios, the problems with power supply do not exist or can be sufficiently solved. With Power over Ethernet (PoE) *[IEEE-802.3at]* there is always a one-to-one relationship between a Power Sourcing Equipment (PSE) and a Powered Device (PD). Also, the Ethernet link on the line used for powering can be used to identify the two connected devices.
For supply of AC mains power, the three problems described above cannot be solved in general. There is no commonly available protocol or automatic mechanism for identifying endpoints of a power line. And, AC power lines support supplying multiple powered devices with a single line and commonly do.

2.1.5. Remote Power Supply Control

There are three ways for an energy management system to change the power state of a managed entity. First is for a management system to provide policy or other useful information (like the electricity price) to the powered device for it to use in determining its power state. The second is sending the entity a command to switch to another state. The third is to utilize an upstream device (to the powered device) that has capabilities to switch on and off power at its outlet.
Some entities do not have capabilities for receiving commands or changing their power states by themselves. Such devices may be

controlled by switching on and off the power supply for them and so have particular need for the third method.
In Figure 3 the power supply can switch on and off power at its power outlet and thereby switch on and off power supply for the connected powered device.

2.2. Power and Energy Measurement

Some devices include hardware to directly measure their power and energy consumption. However, most common networked devices do not provide an interface that gives access to energy and power measurements for the device. Hardware instrumentation for this kind of measurements is typically not in place and adding it incurs an additional cost.
With the increasing cost of energy and the growing importance of energy monitoring, it is expected that in future more devices will include instrumentation for power and energy measurements, but this may take quite some time.

2.2.1. Local Estimates

One solution to this problem is for the device to estimate its own power and consumed energy. For many energy management tasks, getting an estimate is much better than not getting any information at all.
Estimates can be based on actual measured activity level of a device or it can just depend on the power state (on, sleep, off, etc.).
The advantage of estimates is that they can be realized locally and with much lower cost than hardware instrumentation. Local estimates can be dealt with in traditional ways. They don't need an extension of the basic example above. However, the powered device needs an energy model of itself to make estimates.

2.2.2. Management System Estimates

Another approach to the lack of instrumentation is estimation by the energy management system. The management system can estimate power based on basic information on the powered device, such as the type of device, or also its brand/model and functional characteristics. Energy estimates can combine the typical power level by power state with reported data about the power state.
If the energy management system has a detailed energy model of the device, it can produce better estimates including the actual power state and actual activity level of the device. Such information can be obtained by monitoring the device with conventional means of performance monitoring.

2.3. Reporting Sleep and Off States

Low power modes pose special challenges for energy reporting because they may preclude a device from listening to and responding to network requests. Devices may still be able to reliably track energy use in

these modes, as power levels are usually static and internal clocks can track elapsed time in these modes.
Some devices do have out-of-band or proxy abilities to respond to network requests in low-power modes. Others could use proxy abilities in an energy management protocol to improve this reporting, particularly if the device sends out notifications of power state changes.

2.4. Entities

The primary focus of energy management is entire devices, but in some applications it is necessary or desirable to also have visibility into energy use of internal components such as line cards, fans, disks, etc. Components lack some of the features of devices, such as having power interfaces; instead, they simply have a net total consumption from the pool of power available within a device. Note that a device need not have an AC power cord. For example, a DC-powered blade server in a chassis has its own identity on the network and reports for itself, and so is a separate device, not a component of the chassis.

3. Energy Management Reference Model

This section specifies a reference model for energy monitoring and explains how it solves the problems outlined above. It is structured into four layers:

```
+-----------------------------------------------+
|        energy management system (EnMS)        |
+-----------------------------------------------+
          |||                    |||
+---------------------+          |||
|  energy management  |          |||
|   mediation (EMM)   |          |||
+---------------------+          |||
           ||                    |||
+-----------------------------------------------+
|   local energy management interface (LMI)    |
+-----------------------------------------------+
                       |
+-----------------------------------------------+
|          power supply and use (PSU)           |
+-----------------------------------------------+
```

At the power supply and use (PSU) layer electrical objects (powered entities) are physically connected by power supply lines. Their connections constitute an electric supply and metering topology.
The local energy management interface (LMI) layer provides a set of functions for monitoring and controlling individual powered entities.

These functions are local to the entity and restricted to only report properties and states of the entity, as with most common network management functions on managed entities today.
The energy management mediation (EMM) layer provides 'convenience' functions to the energy management system. It performs functions specific to energy management by utilizing information from the PSU layer to infer information on Electrical Objects (EOs) and to bundle control functions concerning the same EO. It also offers some more general functions such as proxying and aggregation on monitored information.
The energy management system (EnMS) layer contains a centralized or distributed energy management system that manages a set of powered devices.

3.1. Power Supply and Use (PSU) Layer

This layer models the electrical connections between electrical objects. "Electrical object" (EO) is used as general term for three kinds of objects. An EO is a powered entity (PE). Connections between them are made with power supply lines.
According to the general issues identified in Section 2.1 the following specific issues are addressed at this layer:

- *Identification of electrical connection endpoints
- *Supply relationships between connected EOs
- *Aggregation of power supply for multiple PEs
- *Metering at connection endpoints
- *Metering relationships between connected EOs
- *Aggregation of metering for multiple PEs

For the general problem of identifying EOs, there are many methods already in use by network management systems. Such methods include identification by IP addresses, by MAC addresses, by serial numbers, by assigned UUIDs, etc. Those can be re-used for identifying EOs.
There does not yet exist a commonly used way to address different power interfaces of the same device. There are power distribution units that enumerate their power outlets and Power over Ethernet switches that enumerate their ports and port groups.
The reference model for the PSU layer uses the concept of a power interface to address the identification of individual connection endpoints of power supply lines at EOs.
This term is not new. It is already used similarly by the IEEE standard for Power over Ethernet (PoE) *[IEEE-802.3af]* and [IEEE-802.3at] where a power interface denotes the interface between a device and the Ethernet

transmission medium. The following terms for components of the PSU layer are derived from PoE terminology.

3.1.1. Components of the PSU Layer

*Power Interface (PI)
A power interface is the interface between an EO and a power transmission medium. There are some similarities between power interfaces and network interfaces. A network interface can be used in different modes, such as sending or receiving on an attached line. A power interface (PI) has an attribute indicating its mode that can be one of the following:

-inlet: receiving power

-outlet: providing power

Most power interfaces never change their mode, but as the mode is simply a recognition of the current direction of electricity flow, there is no barrier to a mode change.

A power interface can have capabilities for metering power and other electric quantities at the shared power transmission medium. This capability it modeled by an association to a power meter.

In analogy to MAC addresses of network interfaces, a globally unique identifier is assigned to each power interface.

Physically, a power interface can be located at an AC power socket, an AC power cord attached to a device, an 8P8C (RJ45) PoE socket, etc.

*Powered Entity (PE)
An entity which consumes or supplies power with one or more PIs in mode "inlet" is called a powered entity (PE). This extends the term powered device (PD) used in [IEEE-802.3af] and [IEEE-802.3at] to cover not only entities that are individual devices, but also entities that are just components of devices.

*Power Source (PS)
An entity with one or more PIs in mode "outlet" is called a power source (PS). This extends the term Power Source Equipment (PSE) used in the IEEE PoE standards [IEEE-802.3af] and [IEEE-802.3at] where at a single PI the PSE provides power to a single PD only. Here a PS may supply an arbitrary number of PEs at a single PI. Most PSs have also PIs in mode "inlet" and all are also a PE.

*Power Meter (PM)
A metering function attached to a power interface of an entity is called a power meter (PM). Power meters are contained within an entity and attached to one or more of the entity's power interfaces. A single PM can only provide a single meter reading at a time. Most PIs will be connected to a single other PI only, but those attached to multiple power interfaces only measure the aggregate use over all of the other interfaces. Components that lack interfaces have a meter for their total net consumption.

3.1.2. Power Supply Topology

Similar to network interfaces, power interfaces can be connected to each other via a shared (power) transmission medium. The most simple connection is a single outlet connected to a single inlet as shown in Figure 7.

```
+----------------+    +----------------+
| power source   |    | powered entity |
|   +----------+ |    | +----------+   |
|   | PI, ID 1 ########## PI, ID 2 |   |
|   | (outlet) | |    | | (inlet,  |   |
|   |          | |    | |  meter)  |   |
|   +----------+ |    | +----------+   |
+----------------+    +----------------+
```

This figure extends the PSU layer of Figure 3 by power interfaces. The power source has a single power interface in outlet mode connected to a power supply lime that connects it to the power interface of the powered entity in inlet mode. The corresponding PSU layer model of the topology in Figure 7 is shown by Figure 8.

```
PS ----- PI ID 1 ----- PI ID 2 ----- PE
         outlet        inlet
                         |
                         |
                       PM
```

This model shows four relationships,

*a containment relationship modeling the power source PS containing the power interface PI with ID 1,

*a containment relationship modeling the powered entity PE containing the power interface PI with ID 2,

*a metering relationship between PI ID 2 and a power meter PM.

*a connection relation between PI ID 1 and PI ID 2.

Implicit in this model is a containment relationship between the PE and the PM. It is implicit, because the PI ID 2 is contained in the PE and the PI ID 2 has a metering relationship with the PM.
The model also shows that PIs have an attribute indicating the mode. In Figure 8 PI ID 1 is in mode "outlet" and PI ID 2 is in mode "inlet".
Figure 9 extends the PSU layer of the example from Figure 4 by power interfaces. A power source with a single outlet supplies three powered entities.

```
+-----------------+        +-------------------+
| power source    |        | powered entity I |
|   +----------+ |        | +----------+      |
|   | PI, ID 3 ############## PI, ID 4 |      |
|   | (outlet) | |   #    | | (inlet)  |      |
|   +----------+ |   #    | +----------+      |----+
+-----------------+   #    +-------------------+ II |
                      #      | +----------+        |
                      ########## PI, ID 5 |        |
                        #    | | (inlet)  |        |
                        #    | +----------+        |-----+
                        #    +---------------------+ III |
                        #      | +----------+            |
                        ########## PI, ID 6 |            |
                               | | (inlet)  |            |
                               | +----------+            |
                               +-------------------------+
```

The corresponding PSU layer data model is shown by Figure 10.

```
PS ----- PI ID 3 --+-- PI ID 4 ----- PE I
         outlet    |   inlet
                   |
                   +-- PI ID 5 ----- PE II
                   |   inlet
                   |
                   +-- PI ID 6 ----- PE III
                       inlet
```

Figure 11 shows the PSU layer model of the example from Figure 4. A PE with three inlets is supplied by two power sources PS I and PS II.
There are two power supply connections between PS I and the PE.

```
          PS I  --+-- PI ID 7  ----- PI ID 8  --+-- PE
                  |   outlet         inlet      |
                  |                             |
                  +-- PI ID 9  ----- PI ID 10 --+
                      outlet         inlet      |
                                                |
          PS II ----- PI ID 11 ----- PI ID 12 --+
                      outlet         inlet
```

[3.1.3.](#) [Power Sources](#)

In the PSU layer, a EO that is a power supply can be seen as having two roles in that it is also a PE. A good example is a PoE switch that is a PE supplied with AC power and a PS supplying other PEs with DC power. Examples which are pure AC devices include a UPS or a PDU.

```
     +----------------------------------------------------------+
     | powered entity / power source                            |
     |  +----------+    +----------+  +----------+  +----------+  |
   ###### PI ID 13|    | PI ID 14|  | PI ID 15|  | PI ID 16|  |
     |  | (inlet) |    | (outlet)|  | (outlet)|  | (outlet)|  |
     |  +----------+    +----#-----+  +----#-----+  +----#-----+  |
     +----------------------#------------#------------#--------+
                            #            #            #
```

[Figure 12](#) shows the example a power source with three power outlets and a power inlet and [Figure 13](#) shows its PSU layer information model.

```
     EO -------+------------+------------+------------+
     PE        |            |            |            |
     PS     PI ID 13     PI ID 14     PI ID 15     PI ID 16
            inlet        outlet       outlet       outlet
```

[3.1.4.](#) [Power Meters](#)

On the PSU layer each power and energy meter is integrated with one or more power interfaces, though usually just with one, or with a component. A common case is shown by Figures and where the PE has metering capability at its power inlet. Power outlets can have metering capabilities as well.
When power meters are attached to more than one power interface within a single powered entity, the PM cannot report per power interface individually, but just the summed of multiple interfaces. A common example is a PoE switch that measures power per group of eight ports. Another example is a powered entity with two power inlets that only measures the total power input to the entity as illustrated by [Figure 14](#) and modeled by [Figure 15](#).

```
+--------------+                                          +--------------+
| power        |    +--------------------------+    | power        |
| source 1     |    | powered entity           |    | source 2     |
|  +---------+ |    | +---------+  +---------+ |    | +---------+  |
|  | PI ID 17########## PI ID 18|  | PI ID 19########## PI ID 20|  |
|  | (outlet)| |    | | (inlet) |  | (inlet) | |    | | (outlet)|  |
|  +---------+ |    | +----#----+  +----#----+ |    | +---------+  |
+--------------+    |      #            #      |    +--------------+
                    | +----#------------#----+ |
                    | |     power meter      | |
                    | +----------------------+ |
                    +--------------------------+


            PS I  ----- PI ID 17 ----- PI ID 18 --+-- PE
                        outlet          inlet     |
                                          |       |
                                          |       |
                                         PM       |
                                          |       |
                                          |       |
            PS II ----- PI ID 19 ----- PI ID 20 --+
```

A power meter can cover any mixture of inlets and outlets and simply reports the sum. As an example, see the model of a the dual role PE and PS from Figure 13 extended by a power meter attached to all PIs in Figure 16.

```
     EO -------+------------+------------+------------+
     PE        |            |            |            |
     PS     PI ID 13     PI ID 14     PI ID 15     PI ID 16
            inlet        outlet       outlet       outlet
               |            |            |            |
               +------------+------------+------------+----- PM
```

3.1.5. External Power Meters

A device which is only a power meter is modeled exactly as any other PS. It is modeled as a device that has an inlet power interface receiving power from a PS and one or more outlet power interfaces providing power to PEs, see, for example, Figure 17. The fact that a device may consume none of the energy that passes through it is not relevant to EMAN.

```
          +-------------------------------+
          | external power meter          |
          |  +----------+    +----------+  |
from PS ###### PI ID 21|    | PI ID 22###### to PE(s)
          |  | (inlet) |    | (outlet,|  |
          |  |         |    |  meter) |  |
          |  +----------+    +----------+  |
          +-------------------------------+
```

3.1.6. PSU Layer Relationships

The PSU topology is usually asymmetric. PS devices supply other PEs with power and meters may measure power that is consumed or provided by other entities than the one at which the measurement was conducted. This way we define two kinds of relationships between EOs in the PSU layer: power source relationships and power meter relationships

3.1.6.1. Power Source Relationship

A power source relationship exists between an outlet PI of a PS and an inlet PI of a PE. It is an asymmetric relationship. The role of the outlet is providing energy and the role of the inlet is receiving energy.

An outlet can be directly connected to multiple inlets and thus can have multiple power source relationships. An inlet is typically connected to a single outlets only and thus has only one power source relationship to a directly connected outlet. While not common, an inlet can be connected to multiple outlets.

The relationship is transitive. If an outlet PI acts as power source for an inlet PI of an entity that itself acts as PS for further PEs, then the outlet may have also power source relationships to inlets of entities supplied by the entity in the middle.

Figure 18 shows a simple example. PI ID 23 has a power source relationship with PI Id 24. But since the entity in the middle is a dual role device that also acts as PS, PI ID 23 has also a power source relationship with PI ID 26.

```
            PS 1              PE 1 / PS 2               PE 2
             |                     |                      |
             |               +------+------+              |
             |               |             |              |
          PI ID 23 ----- PI ID 24     PI ID 25 ----- PI ID 26
          outlet         inlet        outlet         inlet
             |                                            |
            PM                                           PM
```

3.1.6.2. Power Meter Relationship

The power meter relationship is very similar to the power source relationship. It is asymmetric as well and it has two roles: the metering PI and the metered PI. Different from the power source relationship, the role of a PI does not depend on its mode. The metering PI can be an outlet PI or an inlet PI. The same holds for the metering PI. Thus this relationship works not just downstream but also upstream.
In Figure 18 PI ID 23 has a metering relationship as metering PI with PI ID 24 in the downstream direction. In the same way, PI ID 26 is the metering PI in a metering relationship with PI ID 25. Assuming that PE 1 / PS 2 is just a switch with no energy consumption, PI ID 23 and PI ID 26 have two metering relationship with each other with different directions. In one PI IS 23 measures power remotely for PI ID 26 and in the other one measured value at PI ID 26 can be used to report the power at PI ID 23.

3.1.7. PSU Layer Information Model

Figure 19 illustrates the information model of the PSU layer. Electrical objects (EOs) are a synony for powered entity.

```
      +---------------------+ 1       +------------+ 1..N   +--------+
   +->| electrical          |---------| power      |--------| power |
   |  | object              |    0..N | interface  |   0..N | meter |
   |  +---------------------+         +------------+        +--------+
   |                                  | ID         |
   |  +---------------------+         | mode       |
   +--| powered entity      |         +------------+
      +---------------------+       0..N |    | 0..N
                                         +----+
```

Each EO contains a number of PIs. PIs have two attributes, their ID and their mode. Each PI may be attached to one or more PMs. A PM may be attached to one or more PIs. Finally, a PI may be connected to one or more PIs of other EOs.

3.2. Local Energy Management Interface (LMI) Layer

The local energy management interface (LMI) layer provides a set of interfaces for monitoring and controlling power and use of energy at EOs. These interfaces are offered by an EO and restricted to only report and control properties and states that are local to the EO, as do most of the common network management interfaces at managed entities today.
Interfaces at this layer deal components of the PSU layer at the local EO. They are structured into five specific interfaces:

```
        ^            ^            ^            ^           ^
        |            |            |            |           |
+--------------------------------------------------------------------+
| EO    |            |            |            |           |         |
|       v            v            v            v           v         |
| +----------+ +----------+ +----------+ +----------+ +----------+ |
| |    PI    | |    PI    | |  meter   | |  power   | |  power   | |
| |monitoring| | control  | | reading  | |  state   | |  state   | |
| |          | |          | |          | |monitoring| | control  | |
| +----------+ +----------+ +----------+ +----------+ +----------+ |
+--------------------------------------------------------------------+
```

*PI monitoring
This interfaces provide methods for retrieving information on PIs contained in the EO. Particularly included is information on the mode of the PI (inlet or outlet) and its operational state (on, off, ready, etc.) and known power source relationships and power meter relationships.

*PI control
PI control is limited to switching PIs on and off.

*Meter reading
This interfaces includes methods for reporting quantities that are measured by power meters and that are related to power and to energy consumption.

*Power state monitoring
Methods of this interface provide information on power states of PEs. These methods are only available at PEs. But since all EOs can be considered to be PEs they can in general be made available at any EO.

*Power state control
The number of control methods at this interface may be very small. At least included is a method for setting the power state of a PE.

3.3. Energy Management Mediation (EMM) Layer

Information and control means provided by the LMI layer is local to the reporting EO. However, with information from the PSU layer, there are some obvious steps of processing this information to make it more useful or easier to digest by an energy management system. In general, all functions in this layer are 'convenience' functions and an energy management system can execute all of them directly.
This layer may contain various kinds of functions. The ones that are already known can be structured into 7 groups:

*remote PE information

*remote PE control

*all available information on a PE

*all available control affecting a PE

*aggregated information from multiple PEs

*aggregated control of multiple PEs

*proxying for an EO

This list may not be complete, so that new 'convenience' functions may be added. Some of them may not match any of the groups listed above. Figure 21 shows (except for the proxying functions) how the groups are structured in the EMM layer and interact with the LMI layer.

```
+---------------------------------------------------------------+
|                   energy management system                    |
+---------------------------------------------------------------+
          ^           ^    ^    ^    ^    ^           ^
          |           |    |    |    |    |           |
          v           |    |    |    |    |           v
+------------------+  |    |    |    |    |  +------------------+
|    aggregated    |  |    |    |    |    |  |    aggregated    |
|     info on      |  |    |    |    |    |  |    control of    |
|   multiple PEs   |  |    |    |    |    |  |   multiple PEs   |
+------------------+  |    |    |    |    |  +------------------+
  |    |         |    |    |    |    |    |    |         |    |
  |    |         v    v    |    |    |    v    v         |    |
  |    |  +-------------+  |    |    |  +-------------+  |    |
  |    |  |  all info   |  |    |    |  | all control |  |    |
  |    |  |  on a PE    |  |    |    |  |   of a PE   |  |    |
  |    |  +-------------+  |    |    |  +-------------+  |    |
  |    |    |         |    |    |    |    |         |    |    |
  |    +---------+    |    |    |    |    |    +---------+    |
  |         |    v    v    v    |    v    v    v    |         |
  |         |  +-------------+  |  +-------------+  |         |
  |         |  |  remote PE  |  |  |  remote PE  |  |         |
  |         |  | information |  |  |   control   |  |         |
  |         |  +-------------+  |  +-------------+  |         |
  |         |         |         |         |         |         |
  v         v         v         v         v         v         v
+----------------------------------------------------------------+
|                           LMI layer                            |
+----------------------------------------------------------------+
```

In this layer, EOs offer functions to the EnMS that concern other PEs. By doing so, they establish a relationship to the respective PEs. Relationships on this layer include

* Reporting relationship
  This relationship is between a reporting EO and a PE on which it reports. It is an asymmetric relationship and the PE on which is reported may not even have any knowledge on the existence of the relationship. Subject of reporting can be the power supply status for PE, metered values for a PE, a power state information on a PE, and other information on the PE that is relevant for the energy management system.

* Control relationship
  Analogous to the reporting relationship, the control relationship is between a controlling EO and a controlled PE. Again, the PE does not necessary know of this relationship, for example, in case the controlling EO controls the power supply of a PE by communicating with the PS supplying the PE. This can be done in a way that is completely hidden from the PE. Subject of control can be the power supply of the PE, its power state, and other states relevant for the energy management system.

* Proxy relationship
  This is a relationship between a proxying EO and a proxied PE. The concept of a proxy relationship overlaps with the reporting relationship and the control relationship. A proxy relationship always includes one of the two or both. Characteristic for a proxy relationship is that it includes reporting or control function that the proxying EO cannot conduct without remotely retrieving data or remotely controlling other EOs.

The groups of the EMM layer are described individually in the following subsections.

3.3.1. Remote PE Information

This group contains functions that allow an EO to provide information about another PE. These functions are useful in scenarios like the ones described in Section 2.1 where an EO switches or measures power at an outlet PI. If the EO has information on the PSU layer topology, particularly about which PEs are connected to the outlet, then it can combine this information and report on the power supply for the connected PEs.
This way an EO uses local information and deduces information on other, remote PEs from it. Such information may not be as reliable as a direct report from the concerned PEs, but it is often valuable information for energy management. Such reporting must be cognizant of possibilities like devices with multiple power supplies.

The functions in this group can also be implemented by EOs that are neither one of the concerned PEs nor the EO at which the observation or measurement was conducted. In such a case the executing EOs of these functions act as a kind of mid-level manager between management system and managed devices and could, for example, be components of an conventional element management system.
Obviously, the EO that reports on a certain other PE has a reporting relationship to the PE. However, if the PE is aware of the relationship, the PE may have means to report which EO has which kind of relationship to it.
Like some other functions on the EMM layer, the remote PE functions are 'convenience' functions. Inferring available information from different EOs can also be done by the energy management system.

3.3.2. **Remote PE Control**

This group has some similarities to the previous one. Again, operations at an EO are combined with knowledge of the PSU layer topology in order to realize operations on a remote PE. In the example scenario from figures and , power for the PE can be switching by switching the outlet PI ID 1 of the PS. On the LMI layer the offered function would be "switch of PI ID 1 at PS". This function can be offered by the PS at the EMM layer as "switch power for the PE". Both function would have the same technical effect, but they are semantically on different layers.
Here, the EO that controls an PE has a control relationship to the PE. If the PE is aware of the relationship, the PE may have means to report which EO has which kind of relationship to it.
Again, like in the previous group, these functions are convenience functions and they can be executed by the PS, by the PE or by any other EO.

3.3.3. **Parent function: All Available Information on a PE**

This group provides just a single logical function that we call the parent function for reporting: A parent EO makes all information on a PE, that is available somewhere in the network, but that might be distributed among several EOs, available at a single point of contact, the parent.
Realizing such a function would be expected to require to instantiate several of the functions in the "Remote PE Information" group described above.
The parent EO that provides all available information on a certain other PE has definitely a reporting relationship to it. In addition it may have a proxying relationship, for example if it reports the PE's power state.
This function is again a 'convenience' function for an energy management system that in some cases may be much easier done locally at involved EOs than within the energy management system.

3.3.4. All Available Control Affecting a PE

This group also provides just a single logical function: The parent control function: It makes all control functions affecting a PE, that are available somewhere in the network, but that might be distributed among several EOs, available at a single point of contact, the parent. Realizing such a function would be expected to require to instantiate several of the functions in the "Remote PE Control" group described above.
Again, the parent EO that controls a certain other PE has a control relationship to it. If controls the power state, it may also be a proxy relationship.
This function is again a 'convenience' function for an energy management system that in some cases may be much easier done locally at involved EOs than within the energy management system.

3.3.5. Aggregated Information from Multiple PEs

Functions in this group aggregate monitoring information from multiple PEs into more compact representations with potential loss of information.
For example, power measurements from a set of PEs may be summed up into a single value that is provided to an energy management system that does not need more detailed information. aggregating such information in the EMM layer is not just a convenience functions but may also increase scalability of the energy management system.
Aggregation is not necessarily limited to just summing up values. Also included, for example, are aggregation functions that give information on how many PEs of a group are in a certain power state. The range of potential functions in this group appears to be huge. However, it will probably sufficient to standardize the most commonly used ones only.

3.3.6. Aggregated Control of Multiple PEs

Like monitoring and reporting functions covered in the previous group, also control functions can be aggregated. Examples include switching power supply for all PEs in a given group or setting all of them to the same power state with a single command.
Again, this can be considered a convenience function, but at the same time increase scalability of the energy management system. And again it will probably be sufficient to standardize just a few of the wide range of possible functions in this group.

3.3.7. Proxying for an EO

This section still needs to be written. Summary: An EO can act as a proxy for an EO that cannot directly communicate with the energy management system.

3.4. Energy Management System Interface (EnMS) Layer

The EMS receives EMAN data directly from devices, or via the mediation layer. Similarly, it can exercise control directly or via the mediation layer. In many cases, the same action can be accomplished through either means, though some are only available via mediation.

4. Security Considerations

This memo currently does not impose any security considerations.

5. IANA Considerations

This memo has no actions for IANA.

6. Acknowledgements

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7. Open Issues

7.1. Devices or entities?

Entities expands on the category of devices by adding components. Do components have all the features of devices (including having power interfaces) or do they only have metering of their energy/power use? The relationships among powered devices, powered entities, components, and electrical objects needs to be clarified.

7.2. Add PM monitoring and control interfaces to LMI layer?

In earlier versions of this draft, monitoring and configuring the power meter have also been considered. Shall we list them as further local interfaces on the LMI layer?

7.3. Topology changes

Ideally topology would never change so the EMS need only query it once. A date/time stamp for time of last topology change would enable the EMS to know when it needs to rescan the topology.

7.4. Topology reporting

For each interface, there is a list of [device,interface] tuples that is connected to the interface. If one of these is listed as "unknown", then any number of unknown devices may be connected (that is, the device need not specify the number, since likely it will usually not know). Topology information need not be symmetric. A device providing power to the second may know the ID of the second while the second device may lack knowledge of the ID of the supplying device. The mediation layer brings together such information to form a more complete picture.

7.5. Proxying

Does all proxying occur at the mediation layer?

7.6. PSU Info Model

The PSU layer information model needs to be further elaborated.

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