



BSI Standards Publication

General requirements for Home and Building Electronic Systems (HBES) and Building Automation and Control Systems (BACS)

Part 12-2: Smart grid — Application specification — Interface and framework for customer — Interface between the Home / Building CEM and Resource manager(s) — Data model and messaging

National foreword

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General requirements for Home and Building Electronic Systems (HBES) and Building Automation and Control Systems (BACS) -
Part 12-2: Smart grid - Application specification - Interface and
framework for customer - Interface between the Home / Building
CEM and Resource manager(s) - Data model and messaging

Exigences générales relatives aux systèmes électroniques pour les foyers domestiques et les bâtiments (HBES) et aux systèmes de gestion technique du bâtiment (SGTB) - Partie 12-2: Réseau intelligent - Spécification d'application - Interface et cadre pour le client - Interface entre le gestionnaire d'énergie pour le client (CEM, Customer Energy Manager) et le gestionnaire de ressources pour foyers domestiques/bâtiments - Modèle de données et échange de messages

Allgemeine Anforderungen an die Elektrische Systemtechnik für Heim und Gebäude (ESHG) und an Systeme der Gebäudeautomation (GA) - Teil 12-2: Smart grid - Anwendungsspezifikation - Schnittstelle und Modell für Anwender - Schnittstelle zwischen dem Heim-/Gebäude CEM und den Ressourcenmanagern - Datenmodell und Informationsaustausch

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1	Contents	Page
2	European foreword.....	6
3	Introduction.....	7
4	1 Scope.....	8
5	2 Normative references.....	8
6	3 Terms, definitions and abbreviations.....	8
7	3.1 Terms and definitions.....	8
8	3.2 Abbreviations.....	10
9	4 Energy management.....	11
10	4.1 Architectural overview.....	11
11	4.2 Definition.....	12
12	4.3 Energy Management roles.....	13
13	4.3.1 General.....	13
14	4.3.2 Energy producer role.....	13
15	4.3.3 Energy consumer role.....	14
16	4.3.4 Energy storage role.....	15
17	5 Resource Manager.....	15
18	6 Customer Energy Manager (CEM).....	17
19	6.1 General.....	17
20	6.2 Local optimization.....	17
21	6.3 Implicit control.....	17
22	6.4 Explicit control.....	18
23	6.5 Summary.....	18
24	7 Energy Management Concepts.....	19
25	7.1 General.....	19
26	7.2 Design philosophy.....	19
27	7.3 Abnormal condition.....	19
28	7.4 Power measurements.....	20
29	7.5 Power forecasts.....	20
30	7.6 Control types.....	20
31	7.6.1 General.....	20
32	7.6.2 Power Envelope Based Control.....	20
33	7.6.3 Power Profile Based Control.....	23
34	7.6.4 Operation Mode Based Control.....	25
35	7.6.5 Fill Rate Based Control.....	27
36	7.6.6 Demand Driven Based Control.....	30
37	8 Energy Management Data Models.....	31
38	8.1 Basic Data Types.....	31
39	8.1.1 General.....	31
40	8.1.2 Common concepts related to Time.....	32
41	8.1.3 Common concepts related to Identifiers.....	32
42	8.1.4 Common concepts related to Strings.....	32

43	8.1.5	Meaning of optionality	32
44	8.2	Resource Manager	33
45	8.2.1	ResourceManagerDetails	33
46	8.2.2	PowerValue	34
47	8.2.3	PowerForecastValue	34
48	8.2.4	PowerRange	35
49	8.2.5	NumberRange	35
50	8.2.6	PowerMeasurement	35
51	8.2.7	Role	36
52	8.2.8	ReceptionStatus	36
53	8.2.9	Transition	36
54	8.2.10	Timer	37
55	8.2.11	InstructionStatusUpdate	37
56	8.3	Power Forecast	38
57	8.3.1	Description	38
58	8.3.2	PowerForecast	38
59	8.3.3	PowerForecastElement	39
60	8.4	Control Types	40
61	8.4.1	Power Envelope Based Control	40
62	8.4.2	Power Profile Based Control	43
63	8.4.3	Operation Mode Based Control	48
64	8.4.4	Fill Rate Based Control	50
65	8.4.5	Demand Driven Based Control	57
66	8.5	Enumerations	61
67	8.5.1	RoleType	61
68	8.5.2	Commodity	61
69	8.5.3	CommodityQuantity	61
70	8.5.4	Currency	62
71	8.5.5	InstructionStatus	62
72	8.5.6	ControlType	64
73	8.5.7	PEBC.PowerEnvelopeLimitType	65
74	8.5.8	PEBC.PowerEnvelopeConsequenceType	65
75	8.5.9	ReceptionStatusValues	65
76	8.5.10	PPBC.PowerSequenceStatus	66
77	9	Communication	66
78	9.1	Introduction	66
79	9.2	Generic tasks	67
80	9.2.1	Update Resource Manager Details	67
81	9.2.2	Activate Control Type	67
82	9.2.3	Update Active Control Type	68
83	9.2.4	Communicate Power Measurement	68
84	9.2.5	Update Power Forecast	69
85	9.2.6	Revoke Power Forecast	69
86	9.3	Power Envelope Based Control Tasks	70
87	9.3.1	Update Power Constraints	70
88	9.3.2	Revoke Power Constraints	70
89	9.3.3	Update Energy Constraints	71

90	9.3.4	Revoke Energy Constraints	72
91	9.3.5	Process Instruction	72
92	9.3.6	Revoke Instruction	73
93	9.4	Power Profile Based Control Tasks	73
94	9.4.1	Update Power Profile Definition	73
95	9.4.2	Revoke Power Profile Definition	74
96	9.4.3	Process Schedule Instruction	74
97	9.4.4	Revoke Schedule Instruction	75
98	9.4.5	Process Start Interruption Instruction	76
99	9.4.6	Revoke Start Interruption Instruction	76
100	9.4.7	Process End Interruption Instruction	77
101	9.4.8	Revoke End Interruption Instruction	78
102	9.5	Operation Mode Based Control Tasks	78
103	9.5.1	Update System Description	78
104	9.5.2	Revoke System Description	79
105	9.5.3	Process Instruction	79
106	9.5.4	Revoke Instruction	80
107	9.6	Fill Rate Based Control Tasks	81
108	9.6.1	Update System Description	81
109	9.6.2	Revoke System Description	81
110	9.6.3	Update Leakage Behaviour	82
111	9.6.4	Revoke Leakage Behaviour	82
112	9.6.5	Update Usage Forecast	83
113	9.6.6	Revoke Usage Forecast	83
114	9.6.7	Update Fill Level Target Profile	84
115	9.6.8	Revoke Fill Level Target Profile	84
116	9.6.9	Process Instruction	85
117	9.6.10	Revoke Instruction	85
118	9.7	Demand Driven Based Control Tasks	86
119	9.7.1	Update System Description	86
120	9.7.2	Revoke System Description	87
121	9.7.3	Update Average Demand Rate Forecast	87
122	9.7.4	Revoke Average Demand Rate Forecast	88
123	9.7.5	Process Instruction	88
124	9.7.6	Revoke Instruction	89
125	Annex A (informative)	Use Cases	90
126	A.1	Overview	90
127	A.2	Organizing	91
128	A.2.1	UC_EM_O100: Configuring CEM in network	91
129	A.2.2	UC_EM_O101: Configuring master CEM with Smart Grid Operator Credentials	91
130	A.3	Scheduling	92
131	A.3.1	UC_EM_S200: CEM collects Energy Profiles, Tariff Profiles and Storage Details	92
132			
133	A.4	Management	93
134	A.4.1	UC_EM_M300: CEM selects alternative Energy Sequences by energy costs	93
135	A.4.2	UC_EM_M301 CEM modifies start time of Energy Sequence	93

136	A.4.3	UC_EM_M302: CEM changes an Energy Profile to make temporary use of stored energy	94
137			
138	A.4.4	UC_EM_M303: Demanded power cannot be delivered by domestic grid	94
139	A.4.5	UC_EM_M304: Two electric vehicles conflicting in their power load.....	94
140	A.4.6	UC_EM_M305: EMG requests temporarily energy saving	95
141	A.4.7	UC_EM_M306: Energy Storage requests high priority	96
142	A.5	Case studies	97
143	A.5.1	UC_EM_M307 Charging an EV in the context of JWG4 ("Power Limitation PV") with the dynamic control mode of ISO/DIS 15118-20	97
144			
145	A.5.2	UC_EM_M308: Charging an EV in the context of JWG4 ("Power Limitation PV") with the scheduled control mode of ISO 15118 series and monetary incentives	98
146			
147	Bibliography		100
148			

European foreword

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This document is part of the EN 50491 series of European Standards — General requirements for Home and Building Electronic Systems (HBES) and Building Automation and Control Systems (BACS), which will comprise the following parts:

- Part 1: General requirements;
- Part 2: Environmental Conditions;
- Part 3: Electric Safety Requirements;
- Part 4-1: General functional safety requirements for products intended to be integrated in Building Electronic Systems (HBES) and Building Automation and Control Systems (BACS);
- Part 5-1: EMC requirements, conditions and test set-up;
- Part 5-2: EMC requirements for HBES/BACS used in residential, commercial and light industry environment;
- Part 5-3: EMC requirements for HBES/BACS used in industry environment;
- Part 6-1: HBES installations — Installation and planning;
- Part 6-3: HBES installations — Assessment and definition of levels;
- Part 11: Smart Metering — Application Specification — Simple External Consumer Display;
- Part 12: Smart grid — Application specification — Interface and framework for customer;
- Part 12-1: Interface between the CEM and Home/Building Resource manager— General Requirements and Architecture;
- Part 12-2: Interface between the Home/Building CEM and Resource manager(s)— Data model and messaging;
- Future Part 12-3: Home/Building Customer Energy Manager (CEM);
- Future Part 12-4: Resource Manager.

179 Introduction

180 Over recent decades, energy production and its consumption patterns have changed dramatically. Although
181 central energy production is still dominant, the trend for distributed production is distinctive following an
182 increasing number of renewables. Alternative energy sources are highly fluctuating in their production
183 capabilities, which may result in the grid operators having difficulty to keep a balance between energy
184 production and consumption. The complexity of keeping the grid reliable is further increased by the change in
185 the electric energy consumption and production of the customer itself, e.g. the use of electric vehicles and
186 personal generation facilities.

187 A Smart Grid that allows the grid operator to be flexible and reactive is needed. Such reactivity requires a
188 communication flow between energy consuming and producing entities, from single family houses to large
189 factories.

190 The EN 50491-12 series describes aspects of the smart grid that relate specifically to the premises
191 (home/building) part of the smart grid and describes the common interface between equipment in the
192 premises and the smart grid. This part 2 of the series defines the fundamental aspects of semantic
193 interoperability for the S2 interface and the related data exchange between a CEM and the Resource
194 Managers within the premises.

195 Different use cases are explained in Annex A, which should help to understand the philosophy of this
196 document.

1 Scope

This document specifies the fundamental aspects of semantic interoperability for the S2 interface and the related data exchange between a CEM and the Resource Managers within the premises. It provides a technology independent set of data models and interaction patterns in order to enable applications for Energy Management within the premises. This document does not include:

- mappings to concrete data representations (XML, JSON and similar);
- mappings to application protocols for the message passing;
- security related aspects.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/DIS 15118-20, *Road vehicles — Vehicle to grid communication interface*

ISO 4217, *Codes for the representation of currencies*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1.1

Power Envelope Based Control

coordination of the CEM based on limitations to the device

Note 1 to entry: The CEM can set minimum and maximum values for the power that shall not be exceeded by the device.

3.1.2

Power Profile Based Control

control type where coordination from the CEM is based on profile modification, including concepts of sequence shifting, sequence selection

3.1.3

Operation Mode Based Control

control type where the resource manager offers the CEM multiple operation modes that the CEM could choose from

Note 1 to entry: The behaviour of the device will be modified by selecting operation modes.

3.1.4

Fill Rate Based Control

control type based on measurements indicating the fill level and the fill rate

234 **3.1.5**235 **Demand Driven Based Control**

236 control type where the CEM can decide how a given demand should be fulfilled

237 **3.1.6**238 **resource manager**

239 software component that exclusively represents a logical group of devices or a single smart device, and is
 240 responsible for sending unambiguous instructions to the logical group of devices or to a single device,
 241 typically using a device-specific protocol

242 Note 1 to entry: In the context of this document the Resource Manager manages the energy flexibility of a logical group of
 243 devices or a single smart device.

244 Note 2 to entry: The Resource Manager may be implemented in a special device, in the smart device itself or outside of
 245 the device.

246 Note 3 to entry: The Resource Manager typically consist of a communication handler (information layer, strictly related to
 247 data format and protocol handling) and an application handler (application layer, related to functional extensions of the
 248 CEM).

249 **3.1.7**250 **role**

251 categorization of the behaviour of a participant by its capabilities related to energy management, each
 252 participant at least supporting one

253 **3.1.8**254 **S1 communication**

255 interface between CEM and energy management gateway

256 **3.1.9**257 **S2 communication**

258 interface between CEM and resource manager

259 **3.1.10**260 **smart grid**

261 electric grid including a variety of operational and energy measures as well as control of the production and
 262 distribution of electricity

263 **3.1.11**264 **smart grid operator**

265 instance requesting energy profiles from the CEM in order to keep the grid stable and reliable

266 **3.1.12**267 **tariff based energy management**

268 optimization strategy for energy management based on variable tariffs according to user's requirements

269 **3.1.13**270 **time slot**

271 fixed period of time with a specific duration

272 **3.1.14**273 **use case**

274 describes interactions between an actor and another actor or a system to achieve a specific goal, either very
 275 abstract or very detailed; can be nested

276 **3.1.15**277 **user**

278 either a person (e.g. installer or resident) or surrogate service

279 **3.1.16**280 **prosumer**

281 household or device that produces and consumes energy of the same commodity

282 **3.1.17**283 **single application smart system**

284 group of devices having a communication interface for a single application such as heating or lighting, that
 285 consume, produce or store energy (or a combination thereof) and that can be controlled by a resource
 286 manager for the purpose of energy management

287 **3.1.18**288 **home and building electronic system**289 **building automation control system**

290 logical group of devices which uses a multi-application communication system where the functions are
 291 distributed and linked through a common communication process

292 Note 1 to entry: HBES/BACS is used in homes and buildings plus their surroundings. Functions of the system are e.g.:
 293 switching, open loop controlling, closed loop controlling, monitoring and supervising.

294 Note 2 to entry: In literature, HBES/BACS could also be referred to as "home control system/network", "home electronic
 295 system" "building automation system", etc.

296 Note 3 to entry: Examples of HBES/BACS applications are the management of lighting, heating, energy, water, fire
 297 alarms, blinds, different forms of security, etc. See introduction in EN 50491-4-1.

298 **3.1.19**299 **abnormal condition**

300 situation in which a Resource Manager shall sacrifice user comfort when requested by the CEM

301 **3.2 Abbreviations**

Abbreviation	Description
API	Application Programmable Interface
BACS	Building Automation Control Systems
CEM	Customer Energy Management
CHP	Combined Heat and Power
DDBC	Demand Driven Based Control
EM	Energy Management
EMG	Energy Management Gateway
EV	Electric Vehicle
FRBC	Fill Rate Based Control
HBES	Home and Building Electronic Systems
HMI	Human-Machine Interface

Abbreviation	Description
I/F	Interface
M/O	Mandatory / Optional
M	Mandatory
O	Optional
OMBC	Operation Mode Based Control
PEBC	Power Envelope Based Control
PPBC	Power Profile Based Control
PV	Photovoltaics
RM	Resource Manager
RTP	Real Time Pricing
SASS	Single Application Smart System
SG	Smart Grid
TBEM	Tariff Based Energy Management
TOU	Time Of Use
95PPR	95 Percent Probability Range
68PPR	68 Percent Probability Range

4 Energy management

4.1 Architectural overview

In EN 50491-12-1, the system architecture of the Smart Grid premises side is described. It includes the common interface between the equipment in the home/building, referred to as the Customer Energy Manager (CEM), and the Smart Grid (SG), referred to as the Energy Management Gateway (EMG). The communication between the EMG and the CEM is referred to as the S1 communication whereas the communication between the CEM and the Resource Manager on the premises side is referred to as the S2 communication.

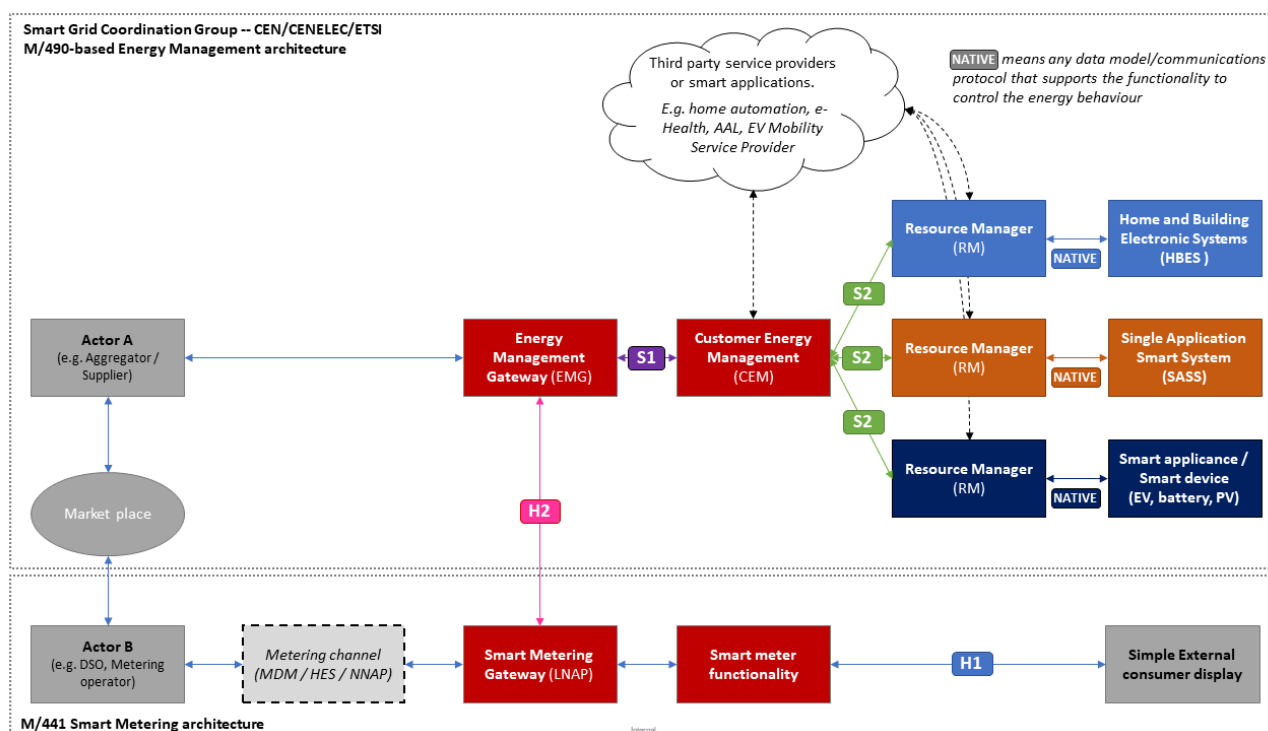


Figure 1 — Architectural overview of Premises smart grid system

Although the solution specified in this document mainly refers to S2 Communication, data that will be transmitted via S1 needs to be considered as well. However, this document does not specify S1 Communication.

4.2 Definition

A HBES/BACS/SASS or (Smart) device is usually purchased to fulfil a goal of the end user of the device or devices. For example, the goal of the end user of an electric boiler is to have hot tap water, and the goal of the end user of a heat pump is to have a comfortable room temperature. Meeting these goals is what is defined as user comfort.

Although these goals shape the behaviour of a Smart Device, they do not completely define it. There might be multiple ways in which the goal of the end user can be achieved. For example, when there is still enough hot water in the electric boiler, the heating of the water could be postponed. In other words, there is some flexibility in achieving the goal of the end user. This is illustrated by Figure 2.

A battery or electric vehicle has a particular target state of charge at a particular moment in time. There are multiple ways to achieve this target, each with their own associated power profile. While all power profiles achieve the target state, these profiles can have a big impact on the power grid. Influencing how a device achieves its targets is what is defined as Energy Management. However, not all HBES / BACS /SASS or (Smart) devices have an explicit goal. For example, the sole purpose of a stationary battery might be to perform Energy Management; there is no other goal from the end user.

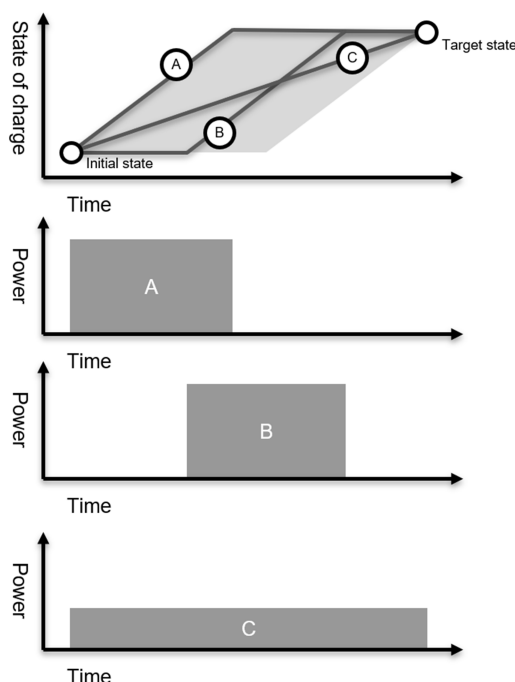


Figure 2 — Example of how different power profiles can achieve the same target state

Energy Management always involves one or multiple types of energy which are exchanged with the grid, such as electricity (exchanged with a power grid), natural gas (exchanged with a gas grid) or heat (exchanged with a heat grid). These types of energy might be interconnected in the behaviour of the device.

For example, a (micro) CHP typically consumes natural gas, but at the same time produces electricity. For Energy Management purposes, it is necessary to know the behaviour of HBES / BACS /SASS or (Smart) devices with respect to these types of energy. These different energy types that are exchanged with a grid are referred to as commodities.

4.3 Energy Management roles

4.3.1 General

In the S2 ecosystem, there are multiple entities fulfilling roles. This subclause gives an overview of these roles and gives concrete examples. Each role assumes a specific functionality and behaviour for a specific Commodity and is attributed to the entity by the entity itself. Entities referred to with roles are defined as EM (Energy Management) Participants. EM participants can fulfil one or multiple of these roles:

- energy management;
- energy producer;
- energy consumer;
- energy storage.

4.3.2 Energy producer role

4.3.2.1 Description

An Energy Producer is an EM participant that produces energy. It can operate under specific capabilities and constraints such as additional costs or the maximum amount of energy. As other EM participants, especially the CEM, need to know these capabilities and constraints, each Energy producer shall provide a control type that contains those capabilities and constraints.

In general, all Energy Producers are categorized by their flexibility of energy production. Controlled Producers are able to adapt their production whereas Uncontrolled Producers do not have that capability.

4.3.2.2 Controlled Producers

Controlled Producers can adjust the amount of energy they are producing according to their capabilities and constraints (e.g. max power). They need to communicate the flexibility of energy production behaviour to the CEM, which in turn will send instructions to trigger changes.

4.3.2.3 Uncontrolled Producers

Uncontrolled producers are those energy generating EM participants that do not offer a way to influence their mode of operation and thus cannot offer flexibility of power to the CEM.

Photovoltaics can be an example of an uncontrolled producer, if for example the inverter does not offer any curtailment functionality. In case such curtailment options are available, the device should expose the controlled producer role. This example shows that, ultimately, it is not the type of device but its feature set that determines which role (controlled or uncontrolled producer) applies.

Additionally, Uncontrolled Producers will typically be less predictable than controlled producers, because they offer much less control over when they are able to operate in a specific range of their operational parameters. In those cases, it is especially important for the CEM that Uncontrolled Producers can provide a power forecast of expected power levels and their probabilistic variations.

4.3.3 Energy consumer role

4.3.3.1 Description

All EM participants that consume energy and utilize the provided energy to conduct some form of work are grouped as Energy Consumers. The fed energy is thus transformed to work, heat, etc. and can generally not be regained from the EM participant. This role includes standard home EM participants that participate actively in the EM network. Examples include water heaters, air conditioner or electric vehicles.

Every Energy Consumer can support the CEM by providing measurements, forecasts and/or control options.

4.3.3.2 Water heater

A water heater is an EM participant that utilizes power to heat water. Flow heaters are heating water while it flows through and thus need to react on demand and are out of scope here. Water heaters with storage capability form the relevant use case from a demand side management perspective as they can operate in flexible boundaries to keep the stored water at a given level and temperature.

Water heaters are usually categorized by their maximum capacity in litres and the energy they need to heat water and to keep it at a given temperature. During operation time, the operational mode of the water heater is influenced by the water capacity and the minimum temperature required for the stored water.

Depending on the use of water heaters, the needed energy for heating water as well as the possibility to store hot water, water heaters are well suited to support efficient Energy Management.

4.3.3.3 Air Condition

Air conditions are EM participants that utilize energy to cool down the air in a building. In contrast to water heaters, they typically do not have any storage capabilities themselves, but the room may be used as a buffer if a certain bandwidth in temperature is allowed.

In this way, an air condition is also able to shift the power load in time in order to fulfil energy management requirements.

4.3.4 Energy storage role

4.3.4.1 Description

Furthermore, EM participants that can store energy play an important role in managing energetic environments as they are able to take energy in when it is abundant (or cheap) and release energy when it is scarce (or expensive). It has to be noted that this capability comes with consequences, e.g. storing energy requires more energy than what can be released at a later point. Every Energy storage shall be able to declare its storage capacity including any consequences.

4.3.4.2 Stationary battery

Batteries are the standard EM participants when it comes to storing electricity. They are available with various capacities and can greatly contribute to balancing loads for premises, on grid level or in other environments.

While a battery is mainly defined by its capacity, charging time, required current and efficiency (ratio of consumed energy to released energy), which also play an important role in utilizing this EM participant optimally.

4.3.4.3 Electric vehicle

In addition to fixed batteries installed at a fixed location, mobile batteries (usually stored in electric vehicles) shall be considered as well.

Mobile batteries share all properties and operational parameters of stationary batteries, however, they have the added property of mobility, which means a mobile battery can appear in or disappear from a system at any point in time. They are thus less reliable than stationary batteries.

Furthermore, to use mobile batteries to optimize the utilization of energy in a system, the mobility requirements shall be considered. I.e. an electric vehicle shall be charged at a given (scheduled) time and should sometimes not be drained below a certain level, which would render the vehicle immobile.

5 Resource Manager

The Resource Manager has a gateway function with embedded intelligence. It is a software component that represents a single energy flexibility. This specification does not define where the Resource Manager runs physically. This could for example be on the Smart Device itself, on a separate device or in the environment of the manufacturer (e.g. Cloud services).

The Resource Manager connects on one side with the CEM using S2, and on the other side with a HBES / BACS / SASS or (Smart) device. How the Resource Manager communicates with the HBES / BACS / SASS or (Smart) device is out of scope for this document.

For example, when a Resource Manager is implemented on the Smart Device itself, a local API can be used. It could also communicate through another device or a domain specific protocol.

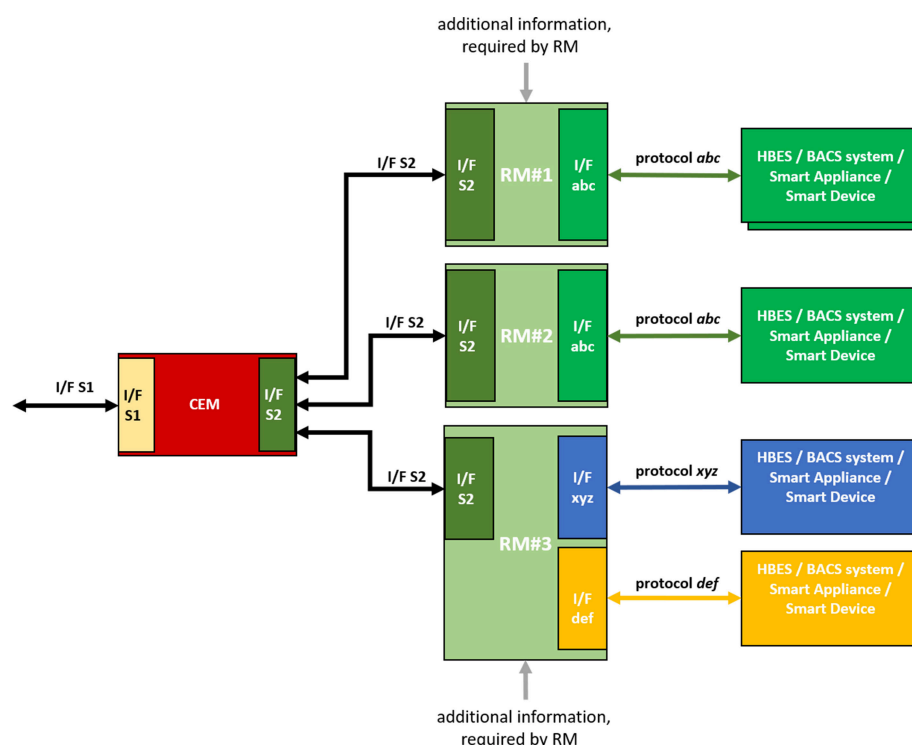


Figure 3 — Example Resource Manager and HBES/BACS/smart appliance/device combinations

Figure 3 shows a number of possible combinations which are typical in a real-world installation. Annex A provides detailed examples that help to better understand this conceptual architecture

Fundamentally, the RM exchanges information with the CEM to fulfil the needs of energy management. On its other side, the RM exchanges information with the device(s) to fulfil the needs of the user and the device/service. In order to take the right decisions, additional information might be required that is not supplied to it by the S2 or its native interface(s). This could be weather forecast information in order to improve the production forecast of a solar panel, the communication with third party services for user behaviour prediction, etc. From the CEM's perspective, the combination of Resource Manager and device(s) is responsible for maintaining user comfort and device integrity. This means that when a CEM fails to send proper instructions to a Resource Manager, and therefore the Resource Manager gets in conflict with the comfort requirements from the user, or in conflict with a safe operation of the device, the Resource Manager shall handle those instructions to the best of its ability and possibly reject them. However, if a CEM needs to act against device specific user comfort goals, the proper mechanism is to use the abnormal condition feature described in 7.3.

The Resource Manager acts as a barrier between the device specific side and the domain specific side. On the device-specific side, it communicates with the HBES/BACS/SASS or (Smart) device using a specific API or protocol, which is usually tailored towards the specific device or device category. On the domain specific side, the Resource Manager communicates with the CEM using S2. It could, however, also communicate with other software components for domains other than energy management, e.g. home automation, ambient assisted living, or remote maintenance. Functionality for these other domains is out of scope for this specification.

It is the task of the Resource Manager to inform the CEM about the capabilities and constraints of the HBES/BACS/SASS or (Smart) device in the context of energy management. In order to do that, a Resource Manager typically has to enrich information that it receives from a HBES/BACS/SASS or (Smart) device. For example, an electric boiler could inform the Resource Manager using a device specific protocol whether it can turn-on or off. For the CEM, the concept of *on* or *off* is insufficient. It needs to know what the energy consuming or producing behaviour is when the device is *on* or *off*. In this example, the Resource Manager needs to inform the CEM that when the device is *on*, it will consume 2 000 W, while when it is *off*, it only consumes 10 W. This means that the Resource Manager shall enrich the information it receives from the Smart Device. A Resource Manager could, for example, do that using a lookup table, by learning the

observed device's behaviour, or by consulting an external information source, which is represented as "additional Information" in Figure 3.

6 Customer Energy Manager (CEM)

6.1 General

The CEM is a software component that is responsible for energy management within the premises. This specification does not define where the CEM runs physically. This could, for example, be on a gateway device within the premises, on a Smart Device or in a manufacturer specific environment.

The CEM communicates with the Resource Managers using S2 to obtain the capabilities and constraints from devices and find the most optimal allocations for the devices. What is optimal depends highly on how the energy system of a country or region is organized and which (financial or other) incentives there are for energy consumers or producers to alter their energy behaviour. Since it is very likely that different optimization targets will co-exist, there will probably be many CEM implementations, each implementing their own optimization strategy.

Three categories of optimization targets for CEMs can be identified:

- local optimization (6.2);
- implicit control (6.3);
- explicit control (6.4).

In the case of Local optimization, S1 as defined in Figure 1 might for example be used to communicate smart meter data to the CEM, but not to send it control signals. With Implicit or Explicit control, S1 will also be used to deliver control signals to the CEM.

The following subclauses discuss examples of the optimization strategies.

6.2 Local optimization

With local optimization goals, no or only little information from outside the premises is necessary to optimize the energy behaviour.

One example is optimizing the energy consuming and producing behaviour towards the constraints of a grid connection. Usually, the price for a grid connection is significantly lower for connections with a lower maximum power capacity. For example, some locations (e.g. offices) require multiple charging points for electric vehicles. The combined charging power of all charging points would require a very expensive grid connection. A CEM could reduce charging power dynamically and optimize for a lower grid connection, saving the costs of a grid connection with more capacity. A sophisticated CEM could even prioritize cars that need to leave soon or could incorporate a stationary battery that charges while there are no cars charging, so cars can charge faster at other moments.

Another example is optimizing for deferring energy tariffs for production and consumption. In some countries, prosumers receive a lower price per kWh when they feed energy into the power grid, than when they consume energy from the grid. This incentivizes prosumers with local production (e.g. solar panels) to directly consume energy when it is available, or to store it locally as an alternative to feeding the power at one point in time and buying it back from the grid at another point in time. Given the different tariffs, a CEM could optimize the energy producing and consuming devices inside the premises, in order to minimize unnecessary export of energy. This can be done without the need of receiving external signals. It only needs to be informed about local energy production and consumption to find the optimal allocation.

6.3 Implicit control

With implicit control schemes, the CEM receives an incentive signal from a Smart Grid Operator through S1. It is up to the CEM to decide what its response to this signal is. There is no need for the CEM to inform the Smart Grid Operator on what its capabilities are or what actions it is going to take.

The Tariff Based Energy Management (TBEM) is an example of an optimization strategy based on predefined tariffs whereby the consumer adapts his energy consumption to decrease energy costs. TBEM can be defined as the changes in electric usage by prosumers from their normal consumption patterns in response to changes in the price of electricity over time.

TBEM can also be defined as the incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized. TBEM includes all intentional modifications to consumption patterns of electricity of end use customers that are “intended to alter the timing, level of instantaneous demand, or the total electricity consumption”. See also CEN CENELEC ETSI, Smart Grid Coordination Group — Sustainable Processes, 2012 for details.

For this, a Smart Grid Operator transmits a tariff to the customer inside the premises. The customer adapts their energy consumption or production to the tariff. In this context:

- **Time-of-use (TOU) tariffs** are usually static tariffs and provide different price levels for different Time Slots. The customers have advance knowledge of the tariffs, their time slots, as well as the associated price;

- **Real-time-pricing (RTP)** tariffs provide different price levels that can be changed in real time depending on occurring events in the Smart Grid. Consequently, RTP tariffs can depend on the renewable generation in a power grid and provide an appropriate incentive for customers to adapt their energy behaviour indirectly to this.

As a result, TBEM use cases lead to an increased consumption of renewable energies by end-use customers and thus by premises. In turn, the increased consumption of renewable energies helps to better cope with the volatility of renewable energies and helps solving challenges in power grids.

6.4 Explicit control

Explicit control, also referred to as Demand Side Management, is based on S1 communication with the aim to adjust the energy consumption or production directly and achieve the optimization targets. The CEM informs the Smart Grid Operator about its capabilities. Based on this, the Smart Grid Operator will send instructions towards the CEM. An Energy Management entity like the EMG communicates with the CEM which, in turn, communicates directly with energy producers, storages and consumers in the building via the S2 communication to adapt the energy behaviour. With explicit control, the Smart Grid Operator has detailed knowledge of what the result of sending control signals will be. Usually, explicit control is based on bilateral contracts between the owner of the CEM and a Smart Grid Operator.

Some versions of explicit control signals are very intrusive. For instance, German utilities can in some cases decrease the power feed-in of big photovoltaic systems and windfarms via a ripple control. It should be noted, however, that explicit control is not in contradiction to prosumer autonomy or even device autonomy. The CEM should only expose capabilities that the prosumer is willing to expose. For example, a prosumer may be willing to let the CEM influence the temperature of a heat buffer, but only if the building is sufficiently heated according to the setpoint of the prosumer. Also, the CEM should only expose capabilities that do not interfere with the operation of devices. When a device needs to turn off because it, for example, reached a critical temperature, the CEM should not expose any other option than turning off the device. Ultimately, CEMs can be programmed to only accept instructions which do not interfere with the comfort and safety of the prosumer.

A typical example of explicit control is where an Aggregator influences the energy behaviour of a household and the household is financially compensated for exposing these capabilities to this Aggregator. The Aggregator, in turn, can earn money by optimizing the energy purchase on energy wholesale markets. It could also make money by providing auxiliary services to system operators or by providing congestion management services towards DSOs, for which implicit control systems are typically not suitable.

6.5 Summary

There are many possible optimization targets that CEMs could implement. Which optimization target is relevant for the owner of the CEM depends on local rules and regulations, how the energy system is organized, market conditions, technological advances and the type of devices that are managed. Also, different optimization targets may be combined within one CEM (e.g. TOU tariffs, explicit curtailment for solar

panels). Whenever the optimization goal of the prosumer changes, the CEM implementation can (from a technical point of view) easily be exchanged for another implementation, without the need of changing devices or the firmware running on these devices.

Nevertheless, an approach is needed that allows the EMG to influence the energy behaviour of the premises without having knowledge of every element of the entire infrastructure. The decision on how to achieve flexibility of energy consumption and production units should either be made by the CEM or the devices directly.

7 Energy Management Concepts

7.1 General

This Clause explains the energy management concepts that are used by the S2 interface. It will provide the necessary context to aid the understanding of the actual specification itself.

7.2 Design philosophy

The design philosophy of the S2 interface is to divide the energy management responsibilities between the CEM and the resource manager. As explained in Clause 5 and in Clause 6, the Resource Manager describes the 'technical' flexibility capabilities and constraints, whereas the CEM focuses on how to utilize the value of that flexibility by considering incentive schemes for example.

It is not possible to create an exhaustive list of all possible smart devices and all possible CEM strategies for the expected lifetime of the S2 specification, let alone all possible combinations of devices and CEMs. For this reason, the S2 interface supports a clear separation of concerns between devices and CEMs by focusing on a generic description of energy flexibility. The flexibility capabilities that smart devices provide can be mapped onto this generic description of flexibility, while it also does not impose any limitations on CEM algorithms to exploit this flexibility in a specific way.

While cost may play a role in CEM algorithms for the overall optimization, the flexibility capabilities of individual resources are described from a technical perspective rather than from a commercial perspective. The only exception is when Resource Managers need to express specific running costs (e.g. due to wear and tear, like in 8.4.3.3) that the CEM might need to be aware of in order to pursue its algorithms objective. Resource Managers are intentionally not aware of the overall optimization strategy that the CEM will use.

The following paragraphs explain the energy management concepts that are communicated over S2 from the Resource Manager to the CEM. First, the measurements and power forecasts are described. They provide the CEM with useful information about the (future) behaviour of a device, but do not give the CEM the option to control energy flexibility. The ability to control a device is explained in detail in 7.6.

7.3 Abnormal condition

As explained in 4.2, the objective of the CEM is to utilize flexibility of smart devices, HBES, BACS or SASS, without compromising user comfort. However, in some extreme situations, it might be desirable to go against the wishes of the end user and sacrifice user comfort, for example to avoid a complete black-out. Sacrificing user comfort can have a severe impact on the end user, and could, for example, lead to buildings that are too hot or too cold, cold showers and insufficiently charged electric vehicles. A situation in which user comfort may be sacrificed is defined as an *abnormal condition*.

What exactly constitutes as an abnormal condition is up to the CEM implementation and might be subject to (local) laws and regulations. However, an abnormal condition should be avoided, and only be applied when it would otherwise result in an even greater discomfort or damage. For example, a CEM might receive an abnormal condition signal directly from the DSO, and a DSO could only be allowed to send that signal if it can prove that it has done everything else it could do to avoid a black-out.

Resource Managers can indicate which behaviour is available during abnormal conditions. A CEM can only use this behaviour when it indicates with an Instruction that there is an abnormal condition. Devices capable of dealing with abnormal conditions should always indicate these options to the CEM. Resource Managers or any of the underlying systems, should always guarantee safe operation and avoid extreme wear of devices, even during abnormal conditions.

7.4 Power measurements

If power measurements are available, they will be provided to the CEM by the Resource Manager. It is important to stress that this only concerns power measurements of one the supported commodities (e.g. electricity, gas or heat), and only power which is exchanged between the device and the (local) grid. Measurements of other quantities (e.g. rpm values of a washing machine) or power measurements of individual components of the device (e.g. power usage of the electric motor) are currently not foreseen through the S2 interface as it cannot be assumed that the CEM knows how to interpret and process such measurements.

7.5 Power forecasts

It can be very useful for a CEM to know in advance what the future energy usage of a device will be. This is true for both controllable and non-controllable devices. Such a forecast can be used by an energy management algorithm to establish the base load it will have to work with. If a device is capable of forecasting, its Resource Manager can use the power forecast to communicate the forecast to the CEM. An example of such a device would be a solar panel that uses the weather forecast to predict its power profile for the next two hours.

The power forecast is associated with one or multiple commodity-quantities and contains ordered elements which all contain a duration, an expected power value and optionally a description of the known statistical certainty of that expected value. A `CommodityQuantity` is a data structure that combines a commodity (e.g. natural gas) and the associated quantity for expressing power (e.g. litres per second), and in the case of electricity the power phase(s).

7.6 Control types

7.6.1 General

There are five control types that can be used by the Resource Manager to describe the energy flexibility that a device shall offer. These control types are chosen in such a way that they cover all the flexibility options that can be found in smart devices. A Resource Manager may support multiple control types. Charging of an EV for instance, may be controlled by Power Profile Based Control or Fill Rate Based Control.

The CEM decides which control type to use. There can be only one active control type at the same time, but different control types may be used sequentially. A Resource Manager will only be controlled by one CEM at a time.

The control types are explained in more detail in the following paragraphs.

7.6.2 Power Envelope Based Control

7.6.2.1 General

The Power Envelope Based Control is used for devices that can be influenced to use a minimum and/or maximum amount of power over time. So the CEM cannot control the amount of power produced or consumed by the device directly, but it can dictate power limits, which can change over time. The Resource Manager informs the CEM with which power limits it can work. Optionally, the Resource Manager can also instruct the CEM how much energy it needs to consume or produce in a certain timespan, which the CEM shall take into consideration while setting power limits.

A typical example is curtailing solar panels. The amount of power converted by the inverter of a solar panel cannot be controlled; this directly depends on the amount of solar irradiation. However, in some cases it might be desirable for the inverter to convert less electricity (e.g. due to congestion in the power grid). In this case the CEM can provide a `PowerEnvelope`, which for different time blocks provides a minimum and a maximum amount of power the inverter is allowed to convert.

Another example is charging an electric vehicle. Although the `ControlType Fill Rate Based Control` is much more desirable for charging electric vehicles (since it gives the CEM more information, so it can do better optimizations with more value to the power grid and the owner of the electric vehicle), in some cases there is not enough information available and the Power Envelope Based Control provides an alternative.

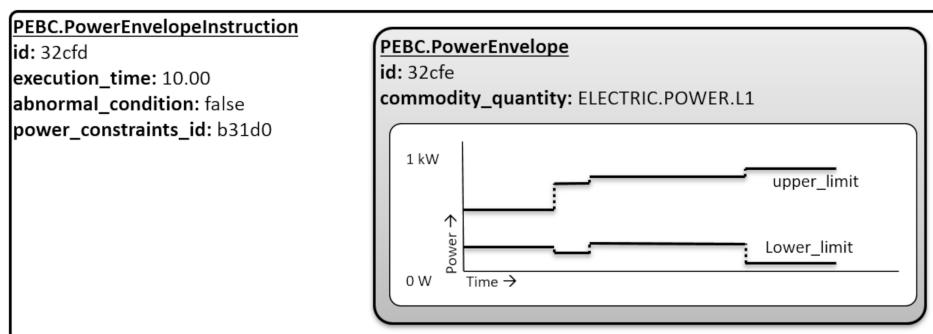


Figure 4 — Example of a PEBC.Instruction from the CEM containing a PowerEnvelope

A Resource Manager can inform the CEM of its planned behaviour through a PowerForecast. Figure 4 provides an example of what a PEBC.Instruction from the CEM containing a PowerEnvelope can look like. A PowerEnvelope is a profile that describes an upper and a lower power limit at different points of time. The profile starts at the 'execution_time' as described in the PEBC.Instruction. It is associated with one CommodityQuantity and contains ordered elements which all contain a duration, a lower limit and an upper limit. The CEM can send different PEBC.Instruction objects for different timespans. Positive numbers indicate load and negative numbers indicate generation, and the number for the lower limit shall always be equal or lower than the upper limit. This means that, for example, when curtailing PV production, it is actually the lower limit that indicates the maximum amount of electric power that can be produced by the installation.

If a Resource Manager provided a PowerForecast to the CEM, and it has processed a PowerEnvelope, it shall provide the CEM with an updated PowerForecast if the PEBC.Instruction caused the device to change its (future) power behaviour. Figure 5 illustrates how a PowerEnvelope can influence the PowerForecast provided by the ResourceManager.

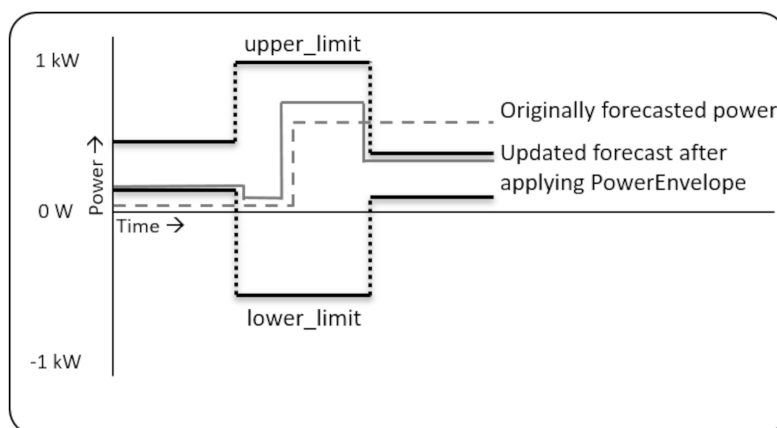


Figure 5 — Example of how a PowerEnvelope can influence the PowerForecast

It is important to emphasize that the CEM is not free to pick any PowerEnvelope; it shall be something the device could actually adhere to. So the Resource Manager first needs to describe what the PowerEnvelope can look like by communicating what its power and energy constraints are for a certain period of time.

7.6.2.2 Power Constraints

The power constraints are describing the power ranges in which either the upper limit or the lower limit can be placed by the CEM. Figure 6 shows a common example based on an EV charging station where only the upper limit is curtailable and the lower limit is a fixed at the zero power level. This is the most common description of a curtailable energy consumer.

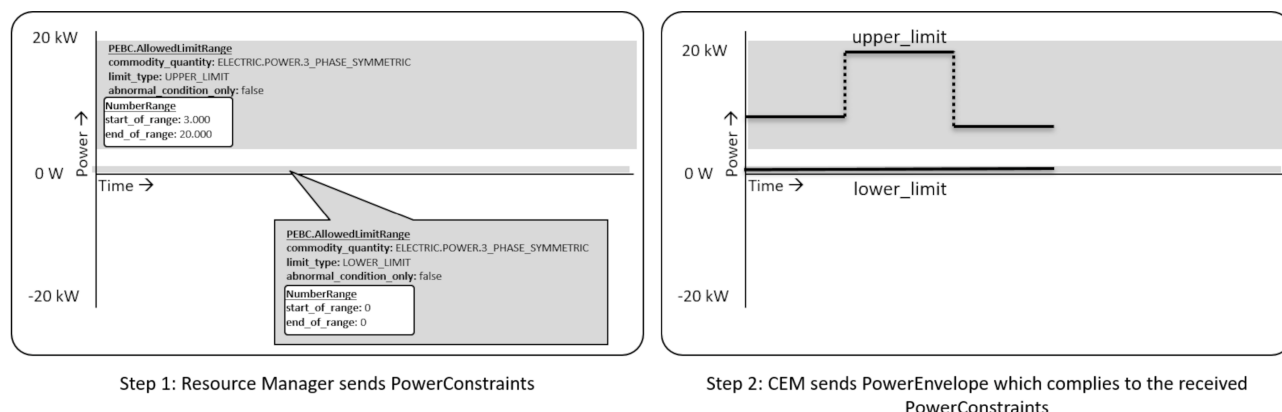


Figure 6 — Simple PowerEnvelope example based on EV charging

For the rare case that a device can only make discrete steps, it is possible to define multiple ranges for the same limit, and it is possible to define a single value instead of a range. Figure 7 provides an illustration of the full theoretical possibilities of power constraints even when a device combining all such characteristics may most likely not exist in the real world.

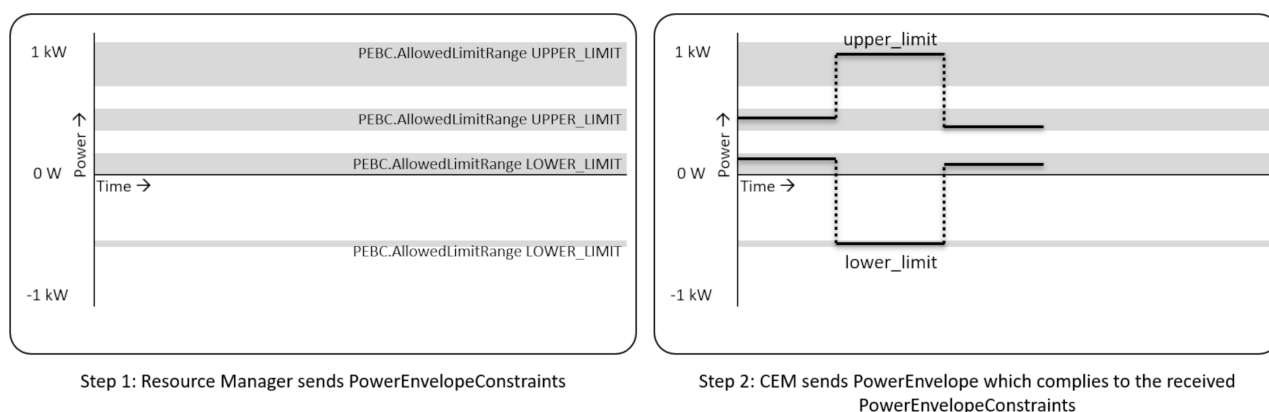


Figure 7 — Theoretical example of how a Resource Manager can constrain the upper_limit and lower_limit of the PowerEnvelope

The Resource Manager can define these constraints with the PowerConstraints element. This data structure describes what the allowed value ranges for the upper limit and the lower limit in the PowerEnvelope are. When necessary, the Resource manager can change its PowerConstraints over time.

It can also be important for a CEM to understand what the consequence is of applying a PowerEnvelope. There are two possibilities:

- **Vanish:** The load or generation that is limited will vanish. This is for example the case with curtailing production from solar panels; the potentially generated energy is lost and will never reappear.
- **Defer:** The load or generation that is limited is postponed to a later moment: This can for example be the case with charging an electric vehicle; when a PowerEnvelope is applied, the car will simply charge slower and will take longer to fully charge. The load is merely postponed.

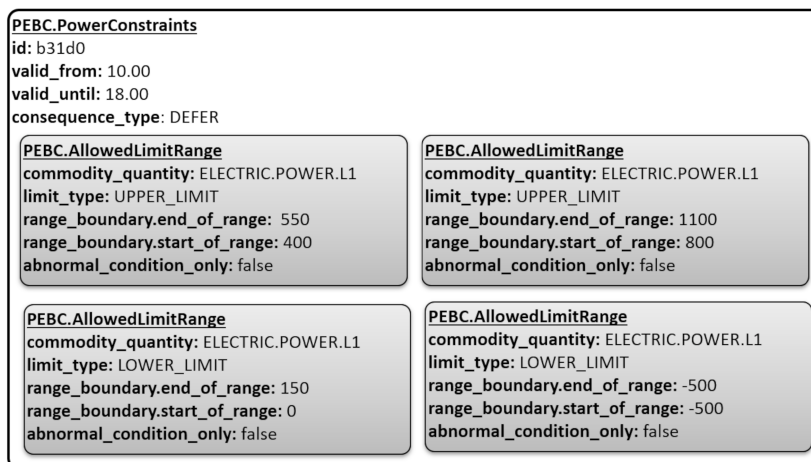


Figure 8 — Example of the PowerConstraints based on Figure 7

Based on the example PowerConstraints shown in Figure 7, the CEM shall respond with a PowerEnvelope with elements with a lower_limit with the value -500 or a value in the range between 0 and 150, and an upper_limit with values in the range between 400 and 550 or the range between 800 and 1100.

7.6.2.3 Energy Constraints

While there always need to be clearly defined power constraints the usage of the EnergyConstraints element is optional. That data structure allows the Resource Manager to describe for specific time periods what it considers as acceptable levels for the average power.

A very common example for EnergyConstraints is the charging of an electric vehicle. While the charging station technically has very high levels of freedom when it comes to its charging power, it also knows that it needs to transfer a certain amount of energy during a certain period of time to meet the vehicle's mobility needs. The Resource Manager of a charging station could theoretically achieve that goal by reacting to each PowerEnvelope curtailment with updated PowerConstraints which are defined in such a way that the mobility needs can be met. This approach, however, reduces the overall flexibility of the system and it might limit or even contradict the planning strategy of the CEM. So a more flexible approach would be for the Resource Manager to keep the PowerConstraints constant and communicate additional EnergyConstraints.

Since EnergyConstraints are locking the average power into a certain range, they enable the system to reach both goals. The CEM can still utilize the widest possible power curtailment choices, but at the same time the PowerEnvelope will need to ensure that the Resource Manager can transfer the necessary amount of energy, as defined in the energy constraints.

7.6.3 Power Profile Based Control

The Power Profile Based Control type is typical for devices that perform a task (with a clear start and end) with a corresponding power profile that is known or can be predicted. Their main flexibility comes from the ability to change the start time of that power profile. Flexibility can also come from pausing the power profile or providing a small number of alternative power profiles for the CEM to choose from.

White goods, such as a washing machine with a delayed start option, are good examples of this category. A consumer fills the washing machine with dirty clothes, selects a program and chooses the final time by which this program should be finished. The Resource Manager communicates the power profile associated with the program and the deadline to the CEM, and the CEM can then decide what the best possible start time is, giving its optimization objectives.

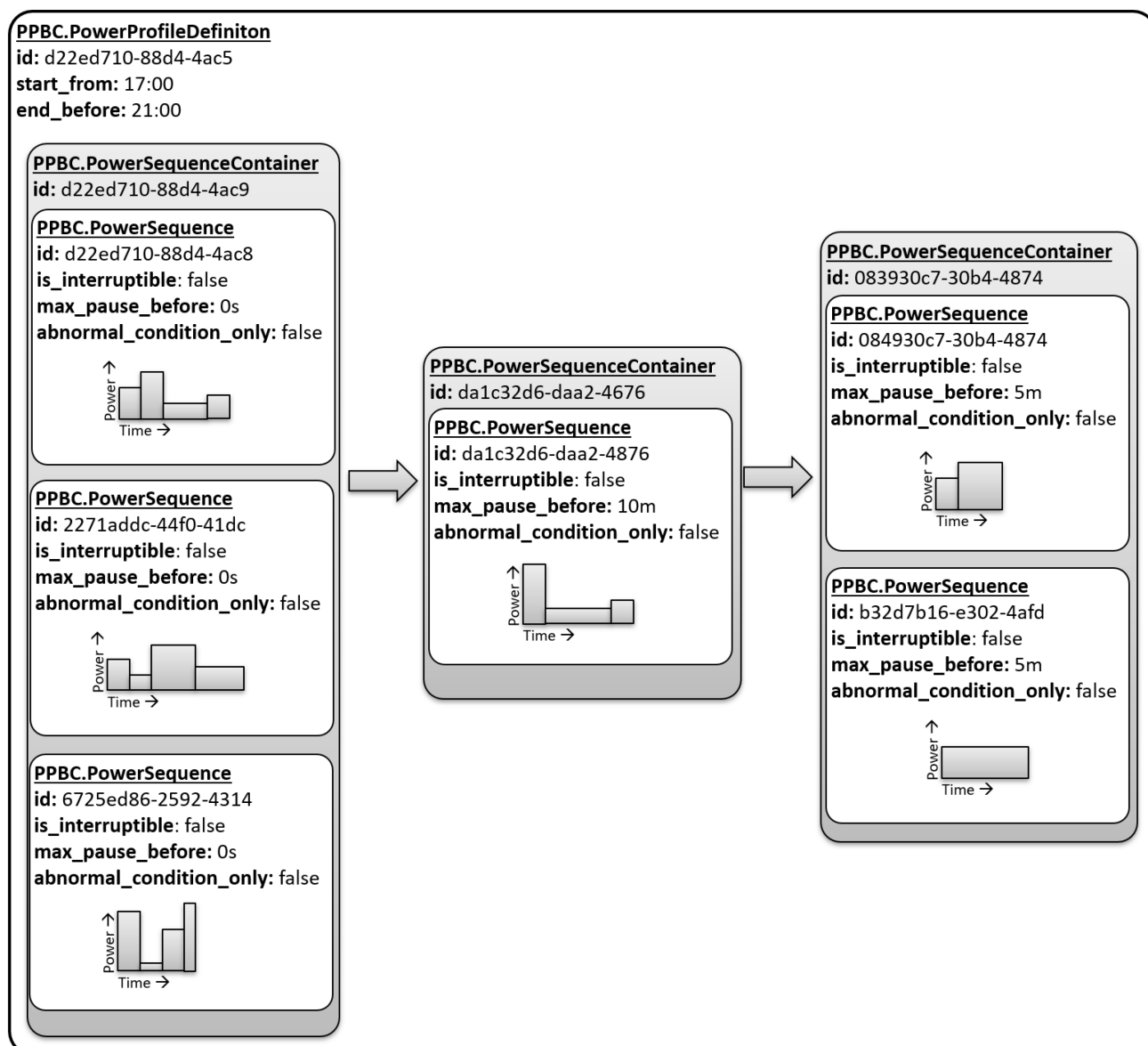


Figure 9 — Example of a power profile definition

The Resource Manager describes all possibilities to execute its task to the CEM using a PPBC.PowerProfileDefinition, as illustrated by Figure 9. There are multiple ways in which the Resource Manager can give the CEM options to choose from.

First of all, the PPBC.PowerProfileDefinition has a start_time and end_time. The start_time describes the earliest point in time the Resource Manager can start the task. The end_time describes the latest point in time in which the task should be finished. The timespan between these two points shall be longer than the time that is needed to complete the task, allowing the CEM to decide when the task starts within these constraints. For example, a washing machine might give a start_time of 12.00 and an end_time of 15.00 for a 2 h program, giving the CEM the possibility to start the program anywhere between 12.00 and 13.00.

Secondly, a task can be divided into subtasks that can be individually scheduled. The CEM is free to schedule these tasks as it pleases, as long as they remain in the same order. These subtasks are described in PPBC.PowerSequenceContainer objects. The Resource Manager can optionally give a constraint on the time between two specific subtasks using the max_pause_before property of the PPBC.PowerSequenceContainer. When a task cannot be divided into subtasks, the Resource Manager shall provide one PPBC.PowerSequenceContainer in the PPBC.PowerProfileDefinition. For example, a washing machine might provide the CEM the option to schedule the heating phase of the program independently from the tumble

phase of the program, as long as tumbling comes after heating and there is not a longer pause than 10 min in between.

Thirdly, the Resource Manager could give the CEM alternative power profiles for a subtask. In that case, a PowerSequenceContainer contains more than one PowerSequence. When multiple PowerSequence objects are provided, the CEM can decide which one it wants to use for the subtask. The PowerSequence objects themselves describe the power consumed or produced during the execution of the task. For example, a washing machine might give the CEM the option to do the heating phase quicker with more power, or slower with less power.

Finally, the Resource Manager can also indicate to the CEM that a PowerSequence is interruptible. That means that this subtask can be paused at any moment. When a PowerSequence is not interruptible, it can effectively only be paused before or after the PowerSequenceContainer, depending on other constraints. An interruptible PowerSequence can be interrupted multiple times and for as long the CEM decides is necessary, as long as the task finishes before or on the end_time. For example, a washing machine might give the option to the CEM to interrupt the tumbling phase of the wash at any moment.

The CEM communicates its decisions to the Resource Manager using the ScheduleInstruction for each PowerSequenceContainer. With this instruction the CEM indicates at which moment which PowerSequence needs to start. These instructions shall comply with the constraints provided by the Resource Manager using the PowerProfileDefinition. The CEM can send instructions for the different PowerSequenceContainers at different moments. For interrupting and resuming a PowerSequence the CEM can use the StartInterruptionInstruction and the EndInterruptionInstruction.

The Resource Manager informs the CEM about the status using the PowerProfileStatus data structure. This data structure expresses which PowerSequence is currently being executed and how far it has progressed.

7.6.4 Operation Mode Based Control

Devices that fall within this control type have the possibility to control the amount of power they produce or consume, without significant effects on their future flexibility options. These devices are modelled as a state machine, where each state (referred to as an operation mode) has an energy production or consumption associated with it. The Resource Manager informs the CEM about these states, their properties and the constraints associated with transitioning between states. The CEM then decides which state should be selected when.

Typical examples for this control type are diesel generators and variable electric resistors. Such devices are often useful for balancing microgrids.

The control type Operation Mode Based Control offers a lot of flexibility; it can assume a range of power levels at almost arbitrary moments in time. When this type of flexibility would be modelled with power profiles, as used for Power Profile Based Control, the number of possible permutations would rapidly grow beyond practical limits.

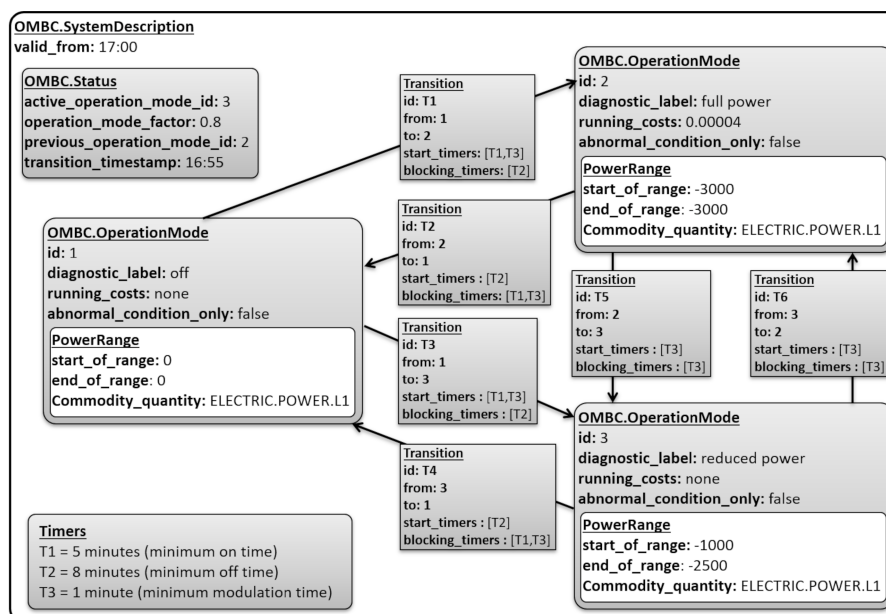


Figure 10 — Example system description for the Operation Mode Based Control type

To avoid such issues, the operation mode control type is modelled as a state machine. An example is shown in Figure 10. A resource manager can declare multiple operation modes for a device. An operation mode is a mode/state that a device can find itself in, that is associated with a specific power value. There can only be one active operation mode at a time. For example, a diesel generator can have three operation modes: one for being off, one for running at reduced power and one for running at full power. The *off* operation mode has a single power value of 0 W associated with it, the *reduced power* operation mode has a power value range of -1000 W to -2500 W (a negative value denotes production), and the *full power* operation mode has a single power value of -3000 W.

The Resource Manager shall inform the CEM when and how the device can transition from one operation mode to the other. In order to do that, the Resource Manager defines transition objects, which indicate from which operation mode the device can go to another. If there is no transition defined between operation mode A and B, the CEM cannot instruct the device to go to operation mode B directly if operation mode A is currently active. However, it might be possible to reach operation mode B by going through other operation modes. For example, if there is a transition from A to X and one from X to B, the device can reach operation mode B by going through X first.

Sometimes there are timing restrictions for transitioning between operation modes. For example, some heat pumps may have to run for at least 20 min before they can be switched off again. The Resource Manager can inform the CEM about timing constraints using timers. The CEM shall take these timers into consideration when instructing the Resource Manager to transition to another operation mode. The Resource Manager defines the timers. A timer has a fixed duration and can, at a certain point in time, be running or can be finished. Once a timer is activated, it will be running for the duration defined by the Resource Manager. Once the duration has passed, the timer will be finished, until it is activated again. When a timer is activated while running, it resets and it will take the whole duration again before being finished.

Transitions interact with timers. A transition can start a timer, but can also be blocked by a timer. The combination of operation modes, transitions and timers allow the CEM to know upfront what the timing constraints of the device are, allowing the CEM to take this into consideration for its plans. In the example of the heat pump the Resource Manager could define a timer named *minimum_on_timer* with a duration of 20 min. The transition from the operation mode *off* to the operation mode *on* starts the timer. That means that when the heat pump turns on (it transitions from *off* to *on*), *minimum_on_timer* will be activated and will be running for the next 20 min. The transition from *on* to *off* is blocked by *minimum_on_timer*. This means that the transition is unavailable for the CEM as long as *minimum_on_timer* is running. Once the timer is finished, the transition from *on* to *off* is available again for the CEM, meaning that the CEM then has the possibility to

turn the heat pump off. This effectively means that once the heat pump turns on, it cannot turn off for at least 20 min. A transition always starts zero or more timers and is blocked by zero or more timers.

An operation mode can either have a single power value associated with it, or it can have a range associated with it. This way, the number of states needed for devices offering stepless control can be reduced dramatically. Technically operation modes are always defining a range of power values. The operation mode can be configured by the CEM with a factor. The factor is any number between 0 and 1, indicating which value in the range should be picked. 0 is associated with the start of the range, 1 with the end of the range. The desired power value can be calculated with the following formula:

$$\text{power_value} = (\text{end_of_range} - \text{start_of_range}) * \text{factor} + \text{start_of_range}$$

When an operation mode only has a single possible power value, the start and end of the range shall be equal, effectively making the factor irrelevant.

Since the factor is a property of the active operation mode, the CEM can change the factor without the need of going through a transition and making sure there are no blocking timers.

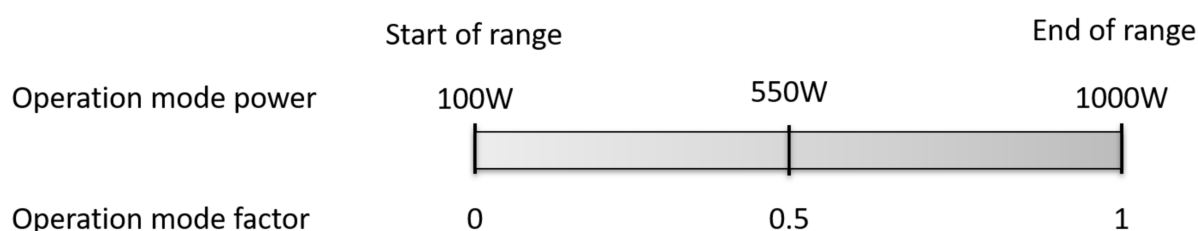


Figure 11 — Visual example of how the factor maps to power values

Operation modes can also declare power values for multiple Commodities. For example, a natural gas based generator consumes natural gas, but produces electricity. For both commodities a range of power values will be given, with the factor being applied to both ranges linearly.

With the information a CEM receives through the Operation Mode Based Control type, it is able to determine what it can expect from a device. This way, a CEM can know what its options are given the current situation, but it is also able to create a realistic plan for the future. Using the state machine and all associated constraints, all the possibilities of the device are known beforehand. A CEM can instruct an operation mode-controlled device by sending the desired target operation mode and the point in time when the transition should take place.

Implementors should be aware that the state machine which is communicated within the Operation Mode Based Control is not intended to be — and typically cannot be — a precise or complete representation of the real state machine of a real device; it is a rough approximation. In reality, many state transitions are possible (e.g. due to safety or error conditions) which are not expressed in the flexibility-oriented state machine as communicated by the Resource Manager. Real state transitions are always a result of the real device changing its internal state. Therefore, the CEM needs to closely monitor the status updates which are provided by the Resource Manager in order to correctly understand the present state of a device, its corresponding operation mode and the implications for flexibility.

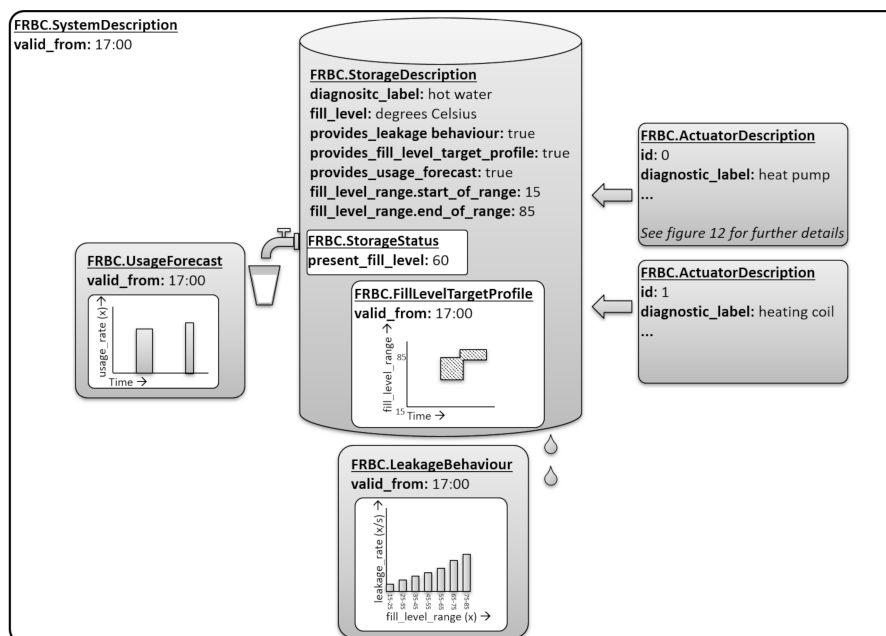
7.6.5 Fill Rate Based Control

The Fill Rate Based Control type can be used for devices that have the ability to store or buffer energy. How energy is stored or buffered does not matter, as long as there is a means to measure how full the storage or buffer is. The Resource Manager informs the CEM about the characteristics of the storage (allowed state of charge, optionally leakage and usage) and the actuators that can influence the storage and their characteristics and constraints. An actuator is modelled in a similar way as Operation Mode Based Control devices. The CEM indicates how it wants the actuators to behave.

There are many examples of devices that can store or buffer energy. Stationary batteries and electric vehicles are examples of devices that store energy in batteries. Heating devices such as CHPs, (hybrid) heat pumps or

boilers can buffer energy in a dedicated heat buffer (typically a thermally insulated water tank), but a room with an allowable bandwidth for the temperature can also be used as a buffer.

Finally, there are also devices that produce cold, like air conditioners, fridges and freezers. Just like heat, cold can be buffered. There are even more ways to buffer or store energy imaginable, such as storing energy in the form of hydrogen, air pressure, water pressure or angular momentum.



$$\text{net fill rate} = \text{fill_rate} \langle \text{actuator } 0 \rangle + \text{fill_rate} \langle \text{actuator } 1 \rangle - \text{leakage_rate} - \text{usage_rate}$$

Figure 12 — Example for Fill Rate Based Control

The main component of this control type is the storage itself (see Figure 12). A Resource Manager shall be able to inform the CEM about its fill level, a measure of how full the storage is, and the lower and upper boundaries that the fill level should remain within, either due to operational constraints or comfort requirements. Although the fill level typically has a physical unit associated with it, it is not relevant for energy management algorithms to know which unit is being used. For a thermal buffer that stores hot water for example, the fill level could be the temperature of the water expressed in degrees Celsius. The acceptable boundaries in that case could be a lower boundary of 15 °C and upper boundary of 85 °C.

There can be several processes that have an influence on the fill level; these processes can optionally be modelled in this control type. First of all, a storage can leak; a process that typically reduces the fill level independently from the use of the energy in the storage or the operation modes of the actuators. For a thermal buffer, dissipation of heat gradually reduces the temperature. Since the rate of leakage typically depends on the fill level (a thermal buffer might leak faster if the water has a temperature of 75 °C than when the water has a temperature of 45 °C), the rate of leakage can be expressed in the form of a function of the fill level using the FRBC.LeakageBehaviour data structure. There are also processes that could consume energy from the storage. For example, when hot tap water is consumed, the fill level in the storage will become lower. When a Resource Manager is capable of forecasting this, it is able to provide the CEM with a forecast of the usage of the storage using the FRBC.UsageForecast data structure.

Some storage devices might have a target for the fill level for a certain point in time. This can for example be the room temperature in the morning, or a target state of charge for a charging electric vehicle that should be reached just before the daily commute to work. By providing this target to the CEM, the CEM is able to figure out the most optimal path towards this target. The Resource Manager can indicate the target for the fill level using the FRBC.FillLevelTargetProfile data structure. Not meeting fill level targets is a possible outcome under the conditions described in Clause 5 and especially 7.3 (Abnormal condition). Resource Managers should deal with those situations as appropriate for the device.

Besides the storage itself, there are also actuators that influence the fill level of the storage. For example, an electric boiler has an actuator that consumes electricity, and increases the fill level of the storage. Storage devices can also have multiple actuators associated with them. For example, a hybrid heat pump typically has an actuator that consumes electricity to increase the fill level, but also an actuator which consumes natural gas to increase the fill level.

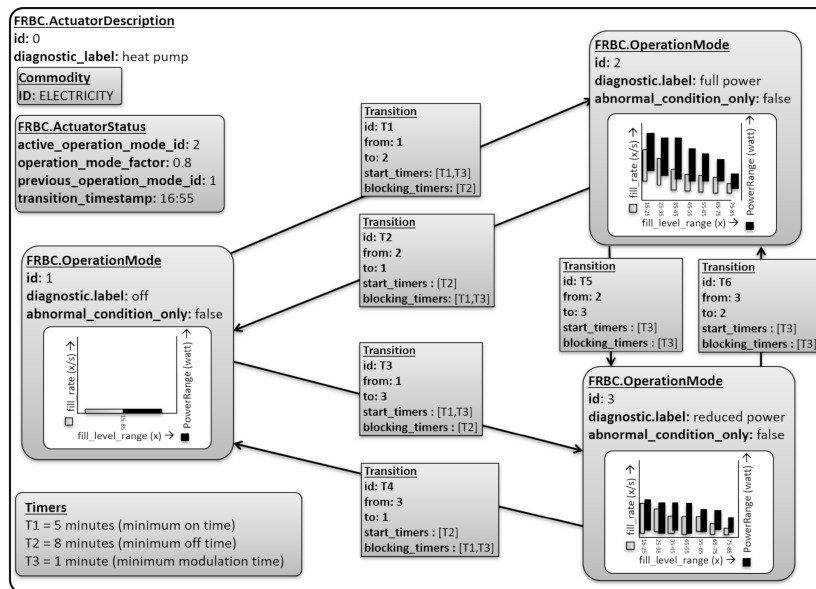


Figure 13 — Example of the actuator details of Fill Rate Based Control

Actuators are modelled using the same state machine concept as the Operation Mode Based Control type (described in 7.6.4): an actuator can define operation modes, transitions and timers (see Figure 13). In contrast to the operation mode from Operation Mode Based Control, FRBC.OperationMode also describes the actuator's effect on the fill level of the storage (see Figure 14). The change of fill level is referred to as the *fill rate* (change in fill level per second). Since for most devices, the fill rate and the energy produced or consumed depend on the fill level of the storage, it is possible to define these values as a function of the fill level of the storage.

fill_level range	start_of_range (factor = 0)		end_of_range (factor = 1)	
	fill_rate (x/s)	Power (watt)	fill_rate (x/s)	Power (watt)
15 - 35	0.01	40	0.55	2500
35 - 65	0.01	40	0.50	2250
65 - 85	0.01	40	0.35	1750

Example

With fill_level 40 and factor 0.25

$\text{fill_rate} = (0.50 - 0.01) * 0.25 + 0.01 = 0.1325 \text{ (x/s)}$

$\text{power} = (2250 - 40) * 0.25 + 40 = 592.5 \text{ watt}$

Figure 14 — Example of an operation mode for Fill Rate Based Control

Describing different values for different fill levels is very useful for devices where the fill level influences the actuator. For example, a CHP with a sterling engine produces electricity from the difference between temperatures. When the temperature in a thermal buffer increases, the difference in temperature between the buffer and the burner decreases, which decreases the electrical power produced. This can be modelled by providing different power values for different fill level ranges, with a technique that is commonly known as piecewise linear approximation, which allows to capture the nonlinear behaviour which is typical for these types of systems. Also, some operation modes might not be available for all fill levels. Batteries usually cannot

charge fast if the state of charge is very high. A Resource Manager could define a *fast charging* operation mode for a battery, which is only available up to 80 % state of charge, while the *slow* charging operation mode might cover the whole range until 100 % state of charge.

As with the fill level, the leakage behaviour is also modelled with piecewise linear approximation.

As becomes apparent from the description above, devices that fall within the Fill Rate Based Control type can be very versatile. They typically allow a fine-grained control, which can result in a lot of added value for the optimization goal of the CEM. In addition to that, some typical Fill Rate Based Control devices (e.g. charging electric vehicles or heating buildings with heat pumps) require significant amounts of power, which further increases the value of their flexibility. With the information the CEM receives about the device, it is able to determine the present and future possibilities. The CEM can send instructions to the device by sending the desired running mode for a certain actuator and the desired time of the transition.

7.6.6 Demand Driven Based Control

Demand Driven Based Control can be used for systems that are flexible in the type of energy carrier they use but are not capable of buffering or storing energy (in that case Fill Rate Based Control should be used) (see Figure 16). The Resource Manager informs the CEM of a certain demand and which actuators are available to fulfil this demand. The CEM then decides which actuators to use and how.

A typical example is a hybrid heat pump, that generates heat using either electricity (using a heat pump) or natural gas (using a gas boiler), but doesn't have a thermal buffer. The hybrid heat pump shall deliver a given amount of heat, but can still decide whether to generate this heat using electricity or natural gas. Typically, such systems favour the heat pump, but use the gas boiler in case the heat demand cannot be fulfilled by the heat pump alone or when there is a shortage of capacity in the electricity grid.

Similar to the Fill Rate Based Control (see 7.6.5), Demand Driven Based Control has the concept of multiple actuators that contain operation modes, transitions and timers (for a detailed explanation of operation modes, transitions and timers see 7.6.4). In addition, the Resource Manager informs the CEM of the present *demand rate*. The demand rate is number that indicates how much needs to be produced (in the previous example this was heat), but what exactly needs to be produced is not made explicit to the CEM. The demand rate can be expressed as a range (e.g. there needs to be a heat production between 5kW and 20kW), or as a single value (in that case the start of the range and the end of the range are equal). The demand rate can be regularly updated by the Resource Manager. When capable, the Resource Manager can also provide a forecast of the average demand rate in the near future by using the DDBC.DemandRateForecast data structure. The forecast of the demand rate is expressed as a profile of a single value and not as a range.

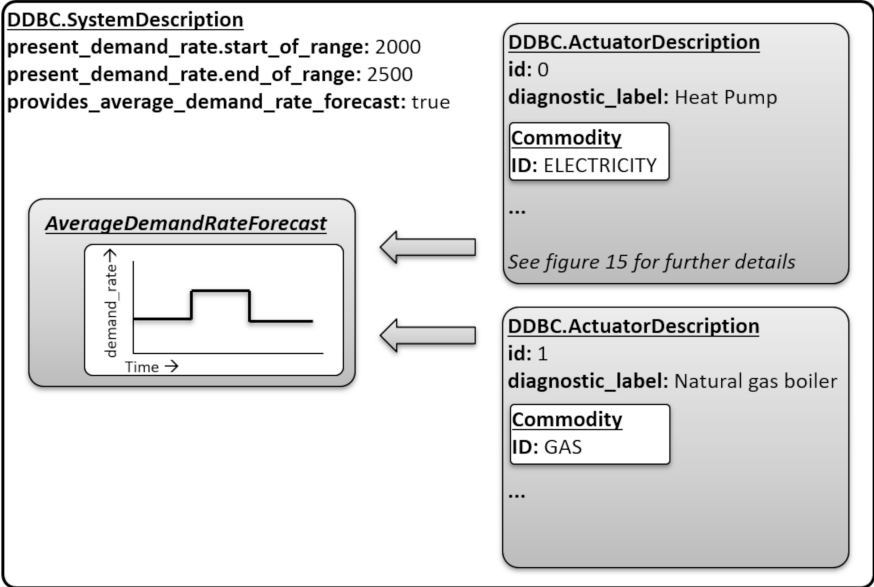


Figure 15 — Schematic overview of the data the Resource Manager send to the CEM