D 5.2

DREAM Framework for active distribution grids:
Common capabilities

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ABSTRACT:

In working packages 2 to 4 of the DREAM project, use cases have been defined for operation of power grids in novel commercial configurations and new grid environments and required scientific advances have been inventoried. In the project, from these use cases in WP-5, the DREAM information architecture framework has been derived consisting of a number of loosely coupled coherent packages, each covering a part of the desired functionality.

In this document, the common capabilities of the DREAM framework are discussed. The design and the design considerations are discussed guided by the UML class diagram models. Subsequently, an in-depth analysis of a number of applications of the DREAM information architecture components is presented, illustrated by UML sequence diagrams detailing processing and message exchange between objects and agents in partly heterarchic settings. Then, attributes of the DREAM framework to aid in interoperability in simulation and field test environments as well as in heterogeneous programming environments are discussed. Finally, the further software development and engineering process in realizing the framework for test and deployment concludes.

¹ PU = Public
² R = Report; R+O = Report plus Other. Note: all “O” deliverables must be accompanied by a deliverable report.
³ Filename must follow the semantic defined in the Handbook (eg DX.Y_name_v0x). v1 corresponds to the final release number.
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<sup>4</sup> Refer to the DREAM Management Handbook for more details on the IR Process and roles of contributors.

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<sup>7</sup> Typically person(s) with appropriate expertise to assess the deliverable quality.

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<td>CA</td>
<td>Commercial Aggregator</td>
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<tr>
<td>CASE</td>
<td>Computer Aided Software Engineering</td>
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<tr>
<td>CEMS</td>
<td>Customer Energy Management System</td>
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<tr>
<td>CEN</td>
<td>European Committee for Standardization</td>
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<tr>
<td>CENELEC</td>
<td>European Committee for Electrotechnical Standardization</td>
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<td>CIM</td>
<td>Common Information Model</td>
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<tr>
<td>CHP</td>
<td>Combined Heat and Power</td>
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<td>DER</td>
<td>Distributed/dispersed Energy Resources</td>
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<tr>
<td>DG</td>
<td>Distributed Generation</td>
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<tr>
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<td>Digital Subscriber Line</td>
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<td>DSO</td>
<td>Distribution System Operator</td>
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<tr>
<td>EV</td>
<td>Electric Vehicle</td>
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<td>FACTS</td>
<td>Flexible AC Transmission Systems</td>
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<tr>
<td>FPAI</td>
<td>Flexible Power Application Interface</td>
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<tr>
<td>GOOSE</td>
<td>Generic Object Oriented Substation Events</td>
</tr>
<tr>
<td>HP</td>
<td>Heat Pump</td>
</tr>
<tr>
<td>HVAC</td>
<td>Heating Ventilation and Air Conditioning</td>
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<tr>
<td>IP</td>
<td>Internet Protocol</td>
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<tr>
<td>IEC</td>
<td>International Electric Committee</td>
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<tr>
<td>IoT</td>
<td>Internet of Things</td>
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<tr>
<td>KPI</td>
<td>Key Performance Indicator</td>
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<tr>
<td>LV</td>
<td>Low Voltage</td>
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<tr>
<td>MPEC</td>
<td>Mathematical Programming with Equilibrium Constraints</td>
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<td>noSQL</td>
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<td>On load tap changer</td>
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<td>Open service gateway initiative</td>
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<td>Transmission system operator</td>
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<td>USEF</td>
<td>Universal Smart Energy Framework</td>
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<td>Unified Modeling Language</td>
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1. Introduction

1.1 Overview of the DREAM framework requirements

The DREAM framework architecture was designed to integrate the different types of use case applications from the research field, the simulations and the test cases of the upstream DREAM working packages together. Target of the framework is facilitating the implementation of the preferentially agent-based coordination mechanism, defining the distributed processing resources and storage resources and partitioning the intelligence to aid in increasing the operational value of high percentage DER distribution grids and decreasing their adverse effects on grid operation and in the market. Figure 1-1 shows the central role of working package 5 in the framework.

![Diagram of DREAM framework](image)

The use cases from working packages 2-4 have delivered the contours of the framework, which was subsequently refined, detailed and integrated. Working package 2 use cases cover day ahead and intra-day energy management, energy balancing and scheduling in commercial electricity markets. Working package 3 use cases handle energy management and planning of electrical power possibly under grid constraints also in local DSO mediated power balance and ancillary services markets. Short-time balancing in close interaction between grid operation and commercial operation exists and
real-time control from a grid optimization perspective. Working package 4 finally defines a number of real-time load control use cases within commercial constraints, but also operation in critical and emergency circumstances. In working packages 7-9 field applications of the framework are tested and in WP6 the use cases are evaluated and analyzed.

A reference class model has been established, that aids in integrating the different components in the DREAM solution for active distribution grids. The application domains, where the framework will be used are quite different as are the technology readiness levels of the individual components ranging from simulation (proof-of-concept) to implementation (proof-of feasibility). The framework has to facilitate interoperability on the software and hardware level as well as from the communication technology level. Looking from the use cases perspective, the major functionalities to be implemented relate to the following:

- Flexible, heterarchic aggregation of devices involved in demand and supply and in the grid context to achieve a common objective. In the individual use cases, aggregation takes place on the LV-level, the MV-level and the commercial level as well as a part of a portfolio of a balance responsible party.

- Prioritization and operation on various timescales of grid operational and market functions. The process of guaranteeing the equilibrium between demand and supply at any moment in time is a result of steering and coordination actions of a number of actors with different interests. These actions may conflict in certain physical parts of the grid. In order to guarantee sustained operation and minimizing congestion and losses; therefore, prioritization has to take place regarding the current objective and the optimization rationale of (parts of) the grid.

- Handling and storing monitoring data. In current electricity grid operations, monitoring data are only collected from the substation level upwards by SCADA-systems and underlying databases. Real-time monitoring of consumption and production data at discrete time-intervals only takes place for large installations above a certain limit for commercial and grid operation purposes. The data are stored centrally using mostly large relational database systems like Oracle or SQLServer. Real time telemetry and interval metering of consumers and producers on 15 minute or hourly basis only takes place if an installation produces or consumes more than a certain limit (typically a connection capacity of 1 MW) or has a smart meter. These measurements also allow state estimation calculations on the low-voltage level for other measuring points in the grid extending the scope of models in DREAM to lower Voltage levels.

- Directly steer or coordinate the operation of devices and aggregated clusters of devices. In electricity grids, apart from remotely controllable OLTC’s and STATCOMs for Voltage control, switching actions only take place at the medium-voltage level and then only if the grids have a looped or meshed topology. However Power Electronics devices are also extending their scope to lower Voltage segments, actively steering power flows. To optimize from the commercial perspective currently only loads and generators above several MWs are actively controlled. In current smart grid living labs the scope of this control is extended, when local dispersed generation systems or demand response are invoked by actually coordinating and
influencing set-points. These aggregates are ‘hot-pluggable’ and use bids and allocations from market algorithms to coordinate large amounts of devices connected in the grid in a loosely coupled way.

- Handling forecasts and persistence. In active distribution grids, individual LV-cells and MV-cells of the grid may be configured quite differently from one another and also may represent local ‘hot spots’ with a local concentration of dispersed generation or demand. Forecasts for end-users and grid segments therefore no longer can be based on lump-sum aggregations and statistics, but will have to be calculated for individual grid segments and be available on various levels for different types of aggregations and on different time scales. In the TSO and national market context, contingency calculations are made for power flows given the reached day-ahead portfolios of market responsible parties. This will also have to be extended further to lower grid levels to prevent and handle contingencies and power quality problems. More frequent collection of data in the lower distribution levels also aids in improving asset management. This also means, that realization data of lower nodes in the network, necessary to make more fine-grained forecasts on several time-scales, have to be processed and stored. This puts additional requirements to defining and partitioning the distributed storage mechanisms.

- Create interaction possibilities with actors or communities of actors on global and local markets and with operations in active distribution grids and customer energy management. Externally, these possibilities also could attribute to giving better incentives and provide feedback on energy efficient behavior of electricity consumers and producers. Internally, ICT based interaction and aggregation structures currently available in social networks could also be used in coordination of supply and demand of energy carriers like electricity.

- Build in precautions on security and flexible ownership of data in such a way, that exposure of information is within the predefined scope (security-by-design principle) and does not unnecessarily affect privacy or makes abuse of information possible. In these security-by-design principles, using a dispersed and distributed context not only as a basis for coordination but also as a basis for collecting and aggregating metering and monitoring data reduces the risks.

### 1.2 Methodology

The main stream ICT architecture development method UML was used in the development of the framework. After descriptions of use cases, in this method, first step was developing class diagrams. In these diagrams, the associations, generalizations/compositions and inheritance aspects in problem space are modeled. This step allows optimal partitioning of functionality with maximum reuse possibilities. In this document, apart from the abstract model, some implementation aspects are also considered to illustrate mapping to the real-world of power engineering standards. After inception, to assure a seamless extension and integration in a multi-project software engineering and integrated development environment, the architecture was brought into a computerized architecture tool (Visual
Paradigm) to guide the process and to assure consistency of the model throughout during alternating coding and design cycles.
2. DREAM packages

2.1 Overall package structure

In modern software engineering architecture design, complex systems are split-up into coherent separately testable building blocks, called packages, which together can be assembled to applications. Packages not only aid in software partitioning, but also in hardware partitioning; individual package implementations may reside on different hardware paving the way to agent solutions, which operate in a distributed computing environment. A first design of the DREAM framework has been given in an internal deliverable as a starting point for first development. In this chapter the structure and design considerations as elaborated in a number of joint sessions are clarified. The first level decomposition is given by Figure 2-1. The DREAM-framework has a layered structure with 4 basic packages built on the information and communication network. The information and communication network on its turn can be built partly on an emulated/simulated bottom layer or a real-time bottom-layer connected to the high penetration DER power distribution network. In order to give an impression of the DREAM framework, first the individual packages are to be considered.

There is a layered package structure. The high penetration DER network is made active from a control and coordination perspective by a heterogeneous information and communication network. From the top functionality is derived from commercial operation and distribution system operation functionality. Central concept is the market-based operation of a VPP to achieve a commercial or
distribution objective using a coordination mechanism using state-of-the-art agent technology. This market based-operation may expose electricity producers or consumers directly to the national scale or novel distribution markets as well in using agents to use market algorithms in applications like PowerMatcher [Powermatcher,2011]. VPP-Operation is supported by three packages:

- The agent-based protocols, which are used in the coordination mechanism. The package provides functionality to specify the message exchange mechanism and the message types that are exchanged. In an agent based approach, the responsibilities are implemented based on the local primary processes and data of the agents are limited and available locally in the context of the agent.
- Flexibility utilization. The package provides a manner to provide input patterns and algorithms and get output patterns to maximally utilize the demand and supply flexibility in terms of momentary kW as a function of time or overall kWh during a certain timespan.
- Forecasting. The modules in this package allow the generation of forecasts for grid relevant parameters within various timeframes using statistical models on user behavior, recent realizations and external information obtained via WEB-portals.

Hierarchically below this layer of three packages four packages are positioned:

- The (micro-) data acquisition and control package. The package provides a generalized, uniform way to handle data either from test sets in simulations or real measured for active control. The package is complementary to current common SCADA-systems used for operating power systems. The functionality in this part of the DREAM packages is targeted to serve the lower distribution levels and the additional functions in future grids and in the DREAM framework like local and near real-time forecasting and coordination.
- The coordination topology package. In the package, coordination topology changes as a result of the real-time situation in the grid as well as emergent aggregation mechanisms can be implemented. The package is strongly linked to the setup package, through which information on the physical network is defined. Topologies for coordination and message interchange include hierarchic, peer-to-peer and twitter like broadcasting data/requests/bids via tweets/retweets between the relevant devices in the network dependent on the grid operational state (cf. trending topic). Flexible switching from one topology to another allows dynamic switching from one coordination mechanism to another.
- Persistence. In this package interfaces to existing database systems and standards are contained as well as to new innovative, possibly distributed data storage methods handling the large amounts of data from the lower Voltage distribution grids.
- The setup package. In the set-up package static and dynamic information is contained. An important class in this package is a repository of so called grid points.

The DREAM framework builds on top of the communication and the high DG-RES power distribution network, connected in real-time and/or in an emulated way for simulation. It uses these
networks without requiring immediate changes to them. On the long term renewals or extensions of the existing networks may be performed in such a way that the DREAM framework functionality is optimally supported. The DREAM framework makes use of the widely adopted and deployed standards for communication networks where available and suitable. With reference to the ISO/OSI model that describes conceptually the protocol stack for a communication network the following assumptions are made. Technologies on the physical and datalink layer may comprise powerline communication, residential wired and wireless internet access and home networks (e.g. 3G, DSL, WiFi, in-house powerline), and others. Ethernet is the most commonly used datalink layer. In the power sector, apart from non-deterministic IP-protocol, other protocols are used in order to satisfy functional requirements for short response times for applications with a fast, deterministic response time via Ethernet. An example is the GOOSE message exchange protocol as defined in IEC-61850. It is probable that most agent-to-agent communication will be carried out over IP networks, but for parts of application functionality other protocols thus will be necessary. So a synergy between fast deterministic protocols for real-time control and the Internet for more loosely coupled, service oriented applications has to be realized in the DREAM framework. IP technology, including the so-called Internet of Things (IoT), and all web technologies rely on the IP network layer and those technologies are widely adopted in many industries and enterprises, with the availability of many state-of-art standards and products. The DREAM framework specifies how existing standards from the internet, web and energy and specifically the electricity domains can be reused and extended on the application level to realize the DREAM goals. Satisfying energy efficiency targets has led to vast rollouts of smart meters at customer premises. The increase of the local generation like PV with inverters interfaced to customers’ information networks through WiFi and the Internet has also led to systems that allow transmission and aggregation of production data at low levels in the grid. Energy companies are also offering gadgets for energy awareness and Customer Energy Management systems. In social media contexts, also energy communities are emerging, that try to balance their produced or consumed electricity in virtual power plant contexts.

In the following subchapters, each of these packages in the framework is further clarified using UML class diagrams, a further functional description and some extra information how to embed packages in existing ICT-standards in the power industry, but also from the perspective of ICT-development as the future Internet and the IoT (Internet of Things). In order to give an impression of the DREAM framework, first the individual packages will be considered.

2.2 dream.setup

In Figure 2-5 a class diagram overview is given of the setup package in the DREAM framework. The package represents the static configuration part of the DREAM framework. The package can be subdivided into grossly two parts. The left part is connected to the tree structured LV part of electricity grids; the right part to the meshed MV-parts of the grids. In non-meshed MV-grids parts of the DREAM-functionality cannot be realized. In the following subsections both parts are detailed further.
Grid Points and the Grid Point Repository

The setup package defines the building blocks of the electrical grid: the devices, the household connections, the transformers and several types of partitions of the distribution grid (tree segments, elementary cells, composite cells). These classes are all considered grid points with their own unique identifier, so that we have a way to unambiguously pinpoint each of them individually also in a distributed computing setting. How grid points are connected to each other is laid out in the grid point repository (cables are not yet modelled in the DREAM-repository). The repository contains e.g. the information about which devices are connected to which elementary cell and which transformer is connected to this elementary cell. The repository is a class that may serve the setup information to algorithms that aim to measure or control parts of the grid.

Elementary Cells

In DREAM use cases the elementary cell concept is important. Figure 2-2 shows a physical part of the grid. In terms of the dream framework this is one composite cell. Three substations feed into this composite cell. The composite cell has a meshed set-up and remotely controlled switches are placed throughout it. The notion of elementary cells is now defined as the area between several or sometimes one remotely controlled switches. Some of these areas have been marked purple in the picture. The elementary cells in turn are consisting of downstream LV cells (TreeSegments in terms of the DREAM framework). In the next paragraphs, the topologically different connectivity for treesegments and meshed segments is further explained in more detail.
In the tree segmented left part of Figure 2-5, displayed in Figure 2-3, the links between the classes at the lower Voltage levels is modelled to be static. Classes and the physical grid here are structured in a tree-like way with hierarchical connections. User connections cluster devices; TreeSegments cluster UserConnections. On their part, TreeSegments are part of Elementary cells. Devices include FlexibleDevices that have an active and reactive power setpoint to influence the momentaneous flow of electricity. A user connection connects a number of devices ‘behind the meter’ either on a residential LV-level or a MV-level. User connections are connected to the CEMS (the Customer Energy Management System). So, a user connection belongs to a tree structure segment, representing the aggregation using a transformer and thus to an elementary cell. The first option gives the LV prosumer-connectivity in a tree network; the second one the MV prosumer connectivity in a looped/meshed network.

With respect to the evolving Internet of Things a distinction needs to be made between the more industrial MV prosumer and the domestic LV prosumer because of the interfaces, protocols, and communication networks involved. While for MV-level connections grid elements are likely to support the protocols and interfaces that are typically used in the energy domain, the LV-level connections are impacted by the rapidly evolving Internet of Things.

Several new consortia were formed recently (in 2014, see [AppleHomekit], [AllSeenAlliance], [OpenInterconnectConsortium], [ThreadGroup]) that address the remote control and delivery of value added services to devices in private homes. Those domotica oriented initiatives aim at largely the same devices in the same prosumer households that are to be controlled within the DREAM framework, and they are likely to develop each their own and at least partially competing standards.
Within the DREAM framework, the agents that act on behalf of energy suppliers (e.g. aggregator agent) or distributors (e.g. elementary cell) do not communicate with prosumer device agents directly but via the CEM. This allows for increased privacy and security for individuals households and hides the complexity of household devices from the energy domain. The CEM performs the collection of configuration information from its connected prosumer devices, performs the flexibility related functions (Section 2.6) and provides the corresponding energy forecast (Section 0). With the CEM being a class in the DREAM framework it provides by definition all the necessary interfaces towards the other classes in the framework. However, depending on where it is implemented with respect to the IoT services, it may or may not be able to implement the corresponding methods to control and collect information from the connected prosumer devices.

In order to avoid conflicting interests a common understanding needs to be achieved between the manufacturers of household appliances, providers of web based services (see consortia mentioned above), and energy suppliers and distributors. From the perspective of DREAM it is necessary to include those functions in the appliances or cloud based APIs that are necessary for a market based operation in a normal, critical, or emergency situation.

For the positioning of the CEM with respect to non-DREAM IoT services there are basically two possibilities that can be used simultaneously. One is that the CEM connects directly to prosumer devices and exposes their capabilities and data to the DREAM framework as well as to IoT service providers. The other possibility is that the CEM interfaces to APIs provided by IoT service providers that act as gateway to prosumer devices. The two possibilities can coexist simultaneously, even for the same household. For example, a CEM could communicate with all Vendor_1 devices through an assumed Vendor_1 Homekit webservice API while it could communicate with Vendor_2 devices directly through the protocol of one of the other consortia mentioned above.

With respect to the dream.setup package a considerable benefit of domestic IoT can be the self-discovery of appliances and their capabilities by the CEM. This can lead to a dynamic decentralized composition of the configuration that occurs automatically and is always up to date. Appliances can report themselves to the next higher agent in the hierarchy, i.e. the CEM, or the CEM could discover appliances in its domain automatically and periodically. The CEM can then report the aggregated local configuration, aggregated flexibility and aggregated forecast (see later Section 0) to two other agents: the agent that represents the energy supplier (e.g. aggregator), and the agent that represents the DSO (i.e. elementary cell). Accordingly, those agents can report and update their aggregated data to higher level agents (their “parents”). This way, complete information about the grid propagates through the corresponding agents of the framework. Data explosion is mitigated by aggregating at each step and only passing on what is relevant for the next hierarchical level. The bottom-up aggregation process also relieves a number of personal data protection concerns by having the granularity and traceability in the real-world mapped on the data level. Finally, persistence data can be compressed to behavioral models by aggregation.
Only minimal manual configuration is then needed in the CEM to include the relevant identifiers for the grid point in the distribution network, and energy supplier, respectively. To some extent those might even be derived from e.g. geographical location or other databases.

**Meshed MV part**

The structure of the higher Voltage level MV-grids (see Figure 2-4) is different from the LV-part by the meshed topology of these types of infrastructures. Tree segments are connected to a meshed segment. In the model the transformer parts with an incoming and outgoing flow have been modelled using a tap changer, that can be manually and on-line operated. OLTCs are used more and more by DSOs. The BoundaryDefiner class contains switches and circuit breakers, which in near real-time can split up the MV-grid in different cells. This splitting can be achieved by by service personnel and online via DSO-operator control room actions. The BoundaryDefiners implement the IMonitor interface. The OnlineDefiners also implement the IControl interface. In this way, DREAM framework applications can have the most recent information on the current configuration of the grid via the monitoring and control interface (see 2.7). Furthermore, VarCompensators are modelled, for controlling the injection of reactive power. Switches are modelled to change the topology of power flow and the way elementary cells are concatenated by switching, which is not possible in the tree segmented LV-part. Provisions are made in DREAM to make the switching and control elements mappable to existing standards like IEC-61850 and CIM by defining the appropriate interface classes. The picture also discriminates elementary cells and composite cells, which are treated further in the section on coordination topologies. The evolving IoT is not likely to have immediate impact on this part of the grid because...
those more industrial prosumers are unlikely to subscribe to domestic web services or use household type of appliances.
Figure 2-5 Setup package class diagram
2.3 dream.coordinationtopology

Coordination topologies encompass one of the basic concepts of heterarchy of the Virtual Power Plant concept in DREAM. Coordination topologies include critical, emergency and normal topologies for message interchange in coordination algorithms, but also may reflect ways of communication paths formed after emergent aggregation. Coordination topologies consist of sets of composite cells that in their turn consist of static elementary cells; the topology may be actively altered by switching actions during operation of the power network. Changing topologies are the building blocks of DREAM coordination. Elementary cells are operated according to a cell coordination algorithm implemented in the software agents, which manage the customer energy management systems and influences demand. A cell operator operates a coordination algorithm in a coordination topology in the role of a leader, a follower or to achieve a common goal for a collection of (composite) cells. The coordination topology concept will be used in some use cases. Eg., whenever a problem arises, one of the elementary cell’s cell operator gets the leader role and the other elementary cells will receive the follower role. So the coordination topology assigns a role to each elementary cell. Each elementary cell is in exactly one composite cell as is reflected in the diagram.
2.4 dream.coordinationmechanism

In Figure 2-7 the agent based coordination classes in DREAM, as operated by a cell operator, are depicted. A market based agent in a VPP uses a coordination protocol. The auctioneer agent in a market context receives bids and an objective agent pushes the aggregated agents to reach a certain goal. Examples of these protocols are PowerMatcher [Powermatcher,2011], PeerMart [Peermart,2006] and Intelligator [Intelligator,2014]. The scope of the coordination mechanism is the possibly real-time changing topology of a certain MV-grid as depicted in the common dictionary [D5.1,2014]. Coordination protocols also may be sequences of interactions as described in the individual DREAM functions, described later. In the latter sense a script of actions to be executed in certain sequence between agents may be defined, that is executed during normal, critical and emergency operations [IR4.1,2014]. In order for the agents to fulfill their task, storage of persistent information of the agents plays an important role. One of the DREAM use cases tests device responsiveness in a small setup with a few flexible devices. Here a heat pump and a CHP are represented by device agents. The objective agent will force the desired behaviour in the devices, so that the responsiveness of the devices can be tested. Another use case features a LV tree segment concentrator agent that concentrates the flexibility bids of all the flexible devices in that specific LV tree segment. Different LV concentrators aggregate to a MV concentrator so that the entire MV segment’s flexibility can be computed, handled and stored.
2.5 dream.persistence

In Figure 2-7 the persistence package is outlined. The package contains primitives to store, aggregate and compress large amounts of data elements from GridPoints in a flexible way. A data element consists of a timestamp, a key and a value. The timestamp denotes at what time the measurement took place. The timestamp is a long value that represents the number of milliseconds since January 1st 1970 ("epoch"). The key identifies the GridPoint plus the property under measurement, e.g. the real power of home energy box 235473478. The value is the actually measured value, e.g. 312 Watt. The combination of these two values uniquely identifies the measurement.

A data store contains a collection of data elements. It has methods to add data elements to it, and retrieve data elements from it. A data store also has a persistence level that defines how secure the data should be stored before the data store acknowledges to its clients that it has stored the data. This persistence level may range from "one in memory" (very fast, but fragile) to "all on disk" (very secure, but slow). It depends on the application at hand which persistence level is required. Another property of a data store is its retention time. This setting determines how long the data elements should be stored before they may be deleted from the system. This setting may range from just minutes to several years, depending on the use case. We expect that there is not a single database available that is able to fulfill the requirements of all use cases, and we may need two or three databases to cover them all. Using high-level abstractions for the data store (such as a List in the Java collection framework), allows the DREAM application builder to plug in different implementations of the data store without changing the client code. It is then possible to use e.g. simple flat files, traditional SQL databases, or modern NoSQL databases to actually implement the data store for the use case at hand. Using a distributed database is likely a good fit for applications where data is created in different parts of the grid. If the amount of data is large, or the latency must be very low, then it is impractical to send and receive the data from a centralized place in the network. A distributed database, with a presence close to every cell in the grid, can be used to mitigate these problems. In other domains, such as social media, distributed databases are used to store huge amounts of user data around the globe. Facebook
pictures and Twitter messages, for example, are stored close to the users that access them most frequently. Also in the electricity domain, distributed databases will be a necessity for part of the information infrastructure that drives the grid operation.
2.6 dream.flexibility

A device has flexibility if it is capable of shifting its production or consumption of energy in time or the total amount of energy in a certain period within the boundaries of end-user comfort requirements and without changing its total energy production or consumption. Flexibility of a coordinated cluster of devices or (virtual) power plant is a statistical interpretation of the shift-ability of the group of devices in the cluster. It is measured as the amount of power increase or decrease, with respect to its current power consumption or production, which can be sustained for a given period of time. Flexibility can be expressed via a FlexibilityBid that states a vector for the amount of flexibility for what price. The steepness, or price elasticity, of such a flexibility graph indicates the availability of flexibility at a certain moment in time. Historic patterns and forecasts of this steepness indicate the ability of a device to contribute to flexibility functionality. In DREAM the flexibility has to be discriminated in an energy flexibility in kWh over a certain period and a momentary power flexibility.

There are four main users of flexibility: Aggregators, Distribution and Transport System Operators, Suppliers and end customers. The Aggregator is solely delivering a technical service to an Energy Supplier and/or a DSO. Thus its interest in flexibility is finding the most economically optimal solution while maintaining the requirements of the DSO and/or Supplier. A DSO will use the customer’s flexibility to: (i) reduce imports/exports from the overlaying network, (ii) minimize energy losses and/or (iii) optimize the grid usage (e.g., minimizing the need for infrastructure upgrades for solving contingencies). For a supplier customer flexibility is also valuable in maintaining the demand and supply balance in the electricity system as a whole. In today’s liberalized market, this type of balancing takes place in the wholesale markets for electricity (especially the Day-ahead, Intra-day and Balancing Markets). Currently this would make the energy supply company—being the intermediary between the end-customer and these markets — interested in paying for the customer flexibility.
Finally, the residential or industrial customer is becoming more interested in utilizing its own generation, shifting to lower tariff times or adhering to capacity limitations.

It is clear that there are conflicting interests in exploiting flexibility. In order to utilize flexibility optimally, characteristics and key performance indicators (KPIs) must be defined. The following have been identified for the Dream project:

**Type**: active or reactive power

**Ramp Power**: Function of upper and lower boundaries, with steps, for ramping power in watts.

**Current Allocation**: Current power allocation of the device or cluster of devices in watts

**Response Time**: Time at which the flexibility can react (seconds)

**Longevity**: Length of time ramp can be held. Function with ramp power as variable.

**Cost**: €cents per kWh or kW of flexibility

**Location**: Elementary cell position in grid (see deam.setup section 2.2)

**Risk**: Certainty that provision will be able to be maintained and met. (percentage)

**PriceVector**: The amount of power flexibility for what price

In addition to these characteristics it is important to distinguish between different grid operation modes (normal, critical and emergency) and levels of flexibility during these times. During normal operation, flexibility offered should not negatively impact quality of power nor infringe on the comfort or power requirements of the end customer. Flexibility offered during normal operation would be defined as “declared flexibility”. In critical or emergency operation, comfort and power requirements of customers should be met as much as possible however priority is to the power quality and physical network. This flexibility is what is defined in the framework mapping as “undeclared flexibility”. Even in these situations declared flexibility might be used if it is offered cheaper by service providers. In some countries, in critical operation, comfort and power requirement of prosumers is only affected according to contracts; in emergency operation, the DSO can violate them without contract.

These characteristics and KPIs bring forth the need for standardization of flexibility as well as a platform to easily utilize and evaluate large scale demand response for multiple stakeholders. A number of initiatives are emerging which focus on standardizing flexibility. FPAI, within TNO, focuses on generating a platform for end users to offer flexibility while systems such as USEF, from the USEF.org foundation, are creating a marketplace platform to offer aggregated flexibility to energy market as well as evaluating the response of flexibility. This package largely envisions flexibility for the near real time or instantaneous availability however to adequately utilize flexibility knowledge of behaviour as well as effect on daily consumption patterns should be considered. One of the main reluctances of stakeholders utilizing flexibility in their portfolios is the lack of insight to risk which comes with demand response. Existing works with/without concern for potential risk. For example, ensuring flexibility offered is realized or larger imbalances are not created due to using all flexibility at once. To enable stakeholders to incorporate demand response in business safety boundaries should be applied.
to reserve flexibility. This shows a clear connection to the forecasting package of which not only the boundaries of flexibility be forecasted, but also the effect to utilizing it on the daily consumption pattern.

A recently completed SmartGrid LivingLab project in Hoogkerk, near to Groningen, the Netherlands, nicely illustrates implementation of the Flexibility and Forecasting concepts used in DREAM. To calculate the day-ahead flexibility, the B-Box central control algorithm is used [BBox, 2007]. It essentially takes a heat demand forecasted profile, electricity spot price profile (APX) and electricity device (EV, CHP, HP) to create an optimized electricity profile to use. This is done not at a device level but of an entire cluster. The profile created is using a one hour time step and is refreshed every day. This concept was reworked and validated in the follow-up field test PowerMatching city II which features approximately 40 real households. The concerted action of the forecasting system with PowerMatcher is illustrated in Figure 2-10.

Figure 2-10 PowerMatching City VPP Optimization

It could be shown that a VPP with residential devices such as, heat pumps, micro-CHPs, EVs, and white goods could be operated within the portfolio of a commercial aggregator (CA), in this case a utility company acting as a balancing responsible partner [TDOA, 2013]. In addition to optimizing the energy profile of the cluster, the CA offered regulatory power to the national system operator for balancing purposes. A decentralized demand response coordination mechanism was used to ensure that the cluster followed the optimised energy profile and at the same time made realtime adjustments in the cluster allocation to provide regulatory power requested by the system operator.

In addition to market based optimizations, flexibility use via demand response has been shown to be capable of aiding TSOs for ancillary services such as secondary frequency control. This application was tested in a laboratory environment with power hardware in the loop. Under the European DERri project and using the University of Strathclyde’s Distribution Network and Protection
laboratory (D-NAP), an experiment investigated the impact of the agent-based demand supply matching in more critical scenarios. This work was based upon a real-world event which saw successive generator tripping and sympathetic loss of distributed generation in response to the subsequent large frequency drop. It was shown the demand response was able to avoid the sympathetic tripping of generators and contribute to the rapid restoration of the frequency.

Flexibility is one of the key concepts within the DREAM framework. The first type is the flexibility that consumers willingly put at the disposal. This type of flexibility offers both ramp up and ramp down power for a certain period of time. Utilizing data from the IoT in the prosumer’s domain and related services it can take into account richer information for smarter choices and more convenience. For example, charging a prosumer household’s electric car would easily be delayed if on the next day no road trip would be in the users’ agenda, but enforced if there was a long trip planned that required a full charge. This scenario would require monitoring the car’s battery as well as the adult family members’ calendars, something that is quite straightforward in IoT and web services, but not yet commodity in the energy domain. Customer segmentation show, that some categories would be very willing to buy products implementing this approach, while other segments are very reluctant.

The second type of flexibility represents the DSO’s power to curtail devices at the customers’ premises. Usually DSOs only call on this power in case of congestion in critical circumstances. By maximizing the declared flexibility, the need for undeclared flexibility decreases. This increases customer satisfaction. Also in this case, making use of the IoT could make the use of undeclared flexibility more fair and less inconvenient. It could differentiate between what part of momentary power consumption is essential and what could easily be missed for a while. There could be intermediate levels between on or off, not regulated by price but by purpose of usage in a critical / emergency situation. For example, the prosumer’s CEM could have (machine) learned that keeping the lights on at night in certain areas of the house is very important, but switching off the terrace heater at the current temperature is no big issue.

The third type of flexibility entails flexibility options or flexibility capability. Marketwise, in most cases, most profit is made via these flexibility capabilities. In the current framework, modelling this type of capability will be emphasized.

A number of use cases propose algorithms to implement a flexibility optimizing component for a cluster of flexible devices or a certain grid segment. These components are called flexibility optimizers. These flexibility optimizers utilize forecasted profiles as produced by the forecasting component. Consider the following example of the interplay of forecasting and flexibility optimization. The heat demand of a cluster of heat pumps is predicted using forecasts of the next day temperature by the forecasting component. Given this heat demand the expected electricity consumption pattern can be calculated. This consumption pattern typically will not be optimal given the goals of the optimization. The heat storage capacity of buildings provides the possibility to uncouple the electricity
consumption from the immediate heat demand. The flexibility optimizer uses its algorithm to find the optimal electricity demand pattern over the day. This optimal profile is the main result of this component.
2.7 dream.monitoringcontrol

The DREAM monitoring and control package represents the functionality to retrieve or push measurements and to control remotely controllable devices, such as remotely controllable switches or flexible devices. All measurable devices implement the IMonitor interface and a Monitor object may keep a list of these measurable devices and either periodically request new measurements (Polling) or receive new measurements whenever a significant event occurs (Event based). Monitor objects may be instantiated in an application. The most appropriate option (Polling or EventBased) may vary per use case and per device. The measurement class represents a measurement a device might make. It may be the current at a certain point in the grid or the output voltage of a transformer. Some of the DREAM use cases use the concept of pseudo measurement to indicate a measurement that is derived instead of directly measured. This is why we distinguish real measurements from pseudo measurements. An example of this is when an algorithm needs information from a place in the grid where no sensor is installed. The algorithm will calculate the best simulated value. The main way of controlling devices in the grid is through setpoints. Flexible devices may be open to receiving a power set point. Switches may be set to open or close. This is represented in the setpoints class. Setpoints have a starting time that lies in the future, or that represents the current time to indicate a request that should take place instantaneously. Construction as an interface construction is used so that Monitors have a single, unified way to retrieve measurements and to send control signals devices. An example usage of a monitor is in the detection of a critical situation in a part of the grid. An elementary cell is watched by a monitor that receives measurements from key grid points in that elementary cell by polling them every minute. When an overload occurs, the monitor detects this through interpretation of the measurements e.g. leading to a state estimation. The monitor is then able to take appropriate action. This follow-up action might happen through the bidding of an agent in a market or by the cell
operator that alters the role of the critical cell to solve the problem. A Controller is set-up in a comparable way and aggregates control actions for a number control objects. Monitors and controllers are used by process visualisation objects, that fulfill the role of user interface for the different types of users. These may be defined or plugged in into SCADA packages or may be part of research applications in simulations. SCADA packages are modeled under the visualisation class. The mapping of real-time measurement and control signals is defined in the setup-package via the IMappable interface.
2.8 dream.forecasting

The forecasting package is envisioned to be used in multiple time-layers of the dream framework to coordinate control of agents on several time frames. A number of different types of variables or profiles will exploit the forecasting package. Profiles such as base (non-flexible) electric load, meteorological data (wind, ambient temp, solar irradiation), base load (non-flexible electricity), flexibility can be forecasting on a number of different timeframes. When considering the day ahead markets, hourly day ahead forecasts are required. For reserve power requirements, electricity profiles need to consider hourly and new real time (now-casting) to respond to balancing needs. Thus this presents the requirement for different timeframe capabilities namely, daily, hourly or now-casting.

From this it is possible to define a number of emerging characteristics to define a profile:

- **startTime** – (datetime) at which the profile begins
- **interval** – (seconds) between values
- **ProfileElement** – Values of which are forecasted.
- **SimpleProfileElement** – (List<double>). Single Value being forecasted. E.g. Solar Irradiation
- **CompositeProfileElement** – (List<double, double>). E.g. a range being forecasted. E.g. Maximum and minimum ramp power.
- **Name** – Name of value being forecasted. E.g. base load
- **Unit** – Unit of value being forecasted. E.g. Watt

The Forecaster generates a forecasted profile which is either a single list of values, for example wind power generated for a day, or an array of maximum and minimum values, for example the upper and lower ramp power capabilities hourly for a day. The forecaster utilizes other profiles, external data (e.g. weather data) or historic profiles (e.g. hourly consumer electric power) along with cluster or device setup information (e.g. storage capacity). This defines a strong connection to the setup and monitoring packages.
As was stated previously, the forecasting package can be used a number of different levels of a smart grid. At the highest level, in the role of the aggregator, the forecaster uses a price profile of the day-ahead spot market to optimize the energy profile of the cluster. Additionally, the aggregator offers regulatory power to the national system operator for balancing purposes in real time. To accomplish this, the optimizer utilizes measurement, historic and forecasted data at both the day ahead time frame and near real time.

An application used in the Integral project [PowerMatchingCity, 2014], is depicted in Figure 2-12. Using forecasting weather data and historic cluster behaviour, the total decentralized generated power (wind, solar etc.), consumed electricity and flexibility profiles are forecasted. A solver then optimizes cluster profile to minimize cost based on the day ahead spot market price. Now-casting, forecasting for timespans very close to real-time, is utilized to update forecasts and determine optimal profiles to allow regulatory power to be offered.

![Figure 2-12 Aggregator optimization view](image)

Furthermore at the end consumer level flexibility offered utilizes forecasted prices to optimally use generated community and local photovoltaic power. In the previously mentioned field test, end users were assigned to be either cost saving or sustainably focused as illustrated in Figure 2-13. In the cost saving case the users would shift their flexibility bid to consumer more if the forecasted price was high and vice versa for a lower forecasted price. In a similar fashion the sustainably focused end users would shift flexibility offered to consume less if the forecasted photovoltaic power was high or more if the forecasted photovoltaic power was minimal. Given that the forecasting package is utilized by multiple stakeholders a strong correlation to the coordination mechanism, agent protocol and flexibility packages is required.
The IoT offers the possibility for more localized data specific to individual user connections. The task of making the detailed localized forecast could be with the CEM as announced in Section 2.2. It could use information about a user’s context (e.g. calendar, location) in addition to data from their devices (e.g. car battery level). Historical data could be stored and analysed and interpreted locally, e.g. using machine learning. Just like for composing all information about configuration, the framework could start from using local data (within a prosumer’s domain) and let them “bubble up” for aggregated data on cell / DSO and aggregator / energy supplier levels, anytime new or updated information becomes available, e.g. when using flexibility.

### 2.9 Partitioning

The packages described above can be compiled together in one monolithic program. This might happen in case of a modelling situation. The complete system executes in the context of one program and message exchange takes place via method calls between objects, that each have been allotted a piece of memory for storing and retrieving their data. The package structure of DREAM, due to its internal interdependency structure and is well suited for dividing the functionality across several processes, possibly operating on several processors to create massively distributed systems. The prime abstraction enabling this is the agent abstraction. Further, helping the use of an agent approach, the GridPointRepository aids in providing a database to store grid connectivity related information and a distributed database for persistent data is part of the framework. Via a distributed GridPointRepository and a distributed database for persistent information, complexities in implementing and testing a distributed approach can be circumvented. Most objects can be created stateless, which allows implementation via Webservices. Finally, the UserConnection and CustomerEnergyManagement system have been modeled explicitly, allowing precise deployment in home energy management systems.
3. Basic functionality as derived from the use cases

3.1 Introduction

In the following four chapters a number of applications of the framework from separate domains are given of the mapping of the use cases to the semantics of the framework. The mapping was derived from the sequence diagrams of the initial use cases as stated in IR2.1, IR3.1 and IR4.1. The use cases treated here concern setting up and reconfiguring clusters. The sequence diagrams are collected in a separate section at the end of this chapter.

3.2 Initializing and connecting objects in a cluster of grid points

In order for devices and services, e.g. agents, to exchange information with one another, they need to know their existence, relation, and how to address each other. In the normal topology situation that can best be achieved by a registry where all that information is contained and can be retrieved by any service. A registry (or network of federated registries) provides details about all devices and services for the full topology. However, in a critical or emergency situation, the registry might be disconnected from parts of the network and the services contained in that isolated part then need other means to find and contact each other for an autonomous collaborative operation. There is a connection between electricity, system, communication and application context topologies. In such a case ad-hoc discovery becomes required functionality and the DREAM framework thus must support it. However, a technical solution might take into account that an emergency character typically occurs only after a normal topology situation and that information about previously available peer devices and services might be cached in each device. This would simplify the discovery of peer devices. Whether this is a feasible solution needs further investigation. Thus, before operations in a use case can start, objects and agent processes have to be created and objects have to be facilitated to communicate. The sequence diagram in Figure 3-1 gives the start-up message interchange of a typical application. The key role in this process is played by the GridPointRepository, which contains the connection information of the GridPoints in a particular application. A GridPointRepository can be maintained as a large fixed data structure being built in an application, but also be constructed using emergent discovery techniques. The repository also can be centralized or distributed across several file systems and data bases. In the use case below, an existing repository is assumed. Initially, a central database will underlie the repository; a distributed repository, aligned to the physical infrastructure is also an implementation option. Links can be laid in a bottom-up way and are maintained during further operation. Five objects are linked together in the sequence of events in Figure 3-1. The sequence starts with getting a user connection from the GridPointRepository by a FlexibleDevice. Subsequently the further connectivity information can be uncovered and the different hierarchical levels can be linked. Note, discovery takes place from the bottom up; from FlexibleDevice to ElementaryCell. The repository contains connectivity information from all the grid points in the particular application. After traversing the sequence of steps connectivity information is available for all object instances in the application. Via the GridPointRepository the information can also be made available for objects in a
distributed setting being present in different threads of a program, different executables, also residing on different processors.

### 3.3 Change the coordination topology dynamically

Coordination of demand and supply in an agent based manner can be achieved via various agent-based mechanisms. PowerMatcher [Powermatcher,2011] is a market-based algorithm for coordinating the demand and supply of electricity based on a hierarchical approach with distributed agents and a central auctioneer. PowerMatcher uses a VPP setting consisting of agents exchanging bids and allocations. PowerMatcher is scalable by the fact, that concentrator agents aggregate bids on several hierarchical levels. Another coordination method using agents, the PeerMart [Peermart,2006] algorithm, uses a peer-to-peer market approach also in a massively distributed setting. The PowerMatcher method has been shown to give good results in normal grid operations with no strict requirements on response times. The Peermart-algorithm uses more local peer-to-peer approach. Therefore it can be applied if there is a tense requirement on response times for message exchange between the agents. In constraint network situations, it may be necessary to coordinate with faster response times in a part of the physical network. A possible way of handling local congestion is the event of congestion due to a local abundance of HVAC devices in the grid. In the same use case application, the coordination topology is changed dynamically from a PowerMatcher based multi-segment coordination, a normal operation topology, to a peer-to-peer coordination mechanism, which is acting locally, in a critical topology, to solve congestion by matching PV generation with heat pump consumption. In the initial part of the sequence diagram in Figure 3-2, the DeviceAgents, of HP and PV type, are added to the LVTree object, which, besides having implemented the Imonitor interface, also acts as a concentrator to steer the agent interactions. Having the HP and PV agent setup information available also allows setting up peer-to-peer connection settings for message exchange to coordinate via a PeerMart approach. The LVTree object has implemented the IMonitor interface, which allows starting up an LVMonitor. Once the coordination topologies are built, the LVTree object subscribes to this LVMonitor process to be notified once a certain maximum power value kWMax has been superseded. The VPP then initializes a new coordination protocol and the coordination protocol retrieves the agents previously added to the NormalTopology in order to be started as PowerMatcher agents. If the Monitoring process signals an alert, agents in the affected TreeSegment are removed from the NormalTopology, which is the scope of the PowerMatcher algorithm. The remainder of the VPP remains under the PowerMatcher regime. For the congested segment, the PeerMart algorithm is initialized, and the previously defined peer to peer topology is retrieved and put into operation. Finally if the alert ends and operation using the Peermart coordination algorithm can be stopped, the agents are added again to the scope of the PowerMatcher algorithm. So, instead of having a fixed number of agents involved in one coordination strategy, this mechanism allows to vary the number of agents and the coordination mechanism dependent on the current situation in the grid.
3.4 Sequence diagrams

Figure 3-1 Initializing a number of GridPoints
Figure 3-2 Changing the coordination strategy for a section of the network
4. **Day ahead, intra-day and balancing market operation functionality**

4.1 **Introduction**

In this chapter a number of applications of the DREAM framework are described that are active on the various commercial markets for electricity. These include the existing markets, operated on a national scale by TSOs, but also variants, in which the DSO mobilizes and pays for resources to aid in grid operation. In the following two sample applications are treated in detail.

4.2 **Ramping power to TSO or DSO imbalance markets**

In the diagram in Figure 4-1 the use case of providing ramp-up and ramp-down power to deliver imbalance power on two types of market is depicted, the DSO imbalance and the TSO imbalance market; the markets are modelled using the DREAM markets package as ReservesMarket. The DSO is modelled as a cell operator monitoring and controlling the power network. The commercial aggregator as a ConcentratorAgent interacts with MV or LV Prosumer DeviceAgents. In the sequence of events, the fully commercial operation is checked with the currently time-dependent maximally allowable power limitations as imposed by the DSO for the particular LV or MV segment (getPowerLimits). The limits are applied to the current aggregated bid curve to deliver an equilibrium price, which, on allocation, does not lead to superseding the limits (function applyLimits). Then, the imbalance on the local DSO Imbalance market and the current TSO imbalance market are read and, depending on the current portfolio position, appropriate power bids are sent to either the DSO, regional, or the TSO, national, imbalance market. The resulting allocations are spread to the individual prosumers by emitting power Setpoints.

4.3 **MV energy management**

The MV energy management use case is depicted in Figure 4-2. LV- and MVProsumers are modelled as DeviceAgents. There are two Commercial Aggregator agents at the LV and the MV level each concentrating loads and generation at the corresponding Voltage level. The use case starts with the collection of energy contractual propositions with LV and MV prosumers. In these, the LVProsumer and MVProsumer options for later optimization are quantified. A PowerHistory DataStore from the persistence package contains the necessary retrievable database for historical power realisation and price information. Local resources may comprise various generation and demand entities. These entities may exhibit different behavioral characteristics (operational, technical, economical), which have to be to the aggregator’s knowledge (derived from observation of historical data, contractual statements or consumers/producers declarations). The following types of demand entities are considered:
a. Curtail-able loads, i.e. consumers that accept demand shedding, which is reimbursed at a specific bid price.
b. Flexible loads, i.e. consumers that adjust their daily profile following hourly price signals, while respecting an energy target and other technical constraints (e.g. hourly ramping).
c. Bid loads from price elastic consumers, i.e. consumers that adjust their hourly demand depending on the retail price.
d. Switching customers, i.e. consumers that are medium-term price elastic, that would select the aggregator to serve their entire mid-term (e.g. one month) demand profile, if the retail price wouldn’t exceed an offer price threshold.

Generation and electrical storage entities include dispatchable and non-dispatchable sources, with energy limits, and specific bid prices to sell their energy. The operational frequency is the same of the PTU frequency in which the market operates (typically 5-15 minutes). The MV aggregator mediates on the external market on behalf of the MV and LV prosumers. Then, the MV aggregator observes the development of the consumed or produced power in the portfolio and optimizes in view of historic developments in the total power balance, the situation on the energy spot market and the contracts with the individual customers. Each entity optimizes on terms of its own objective function based on the utility of the primary process of production or consumption. The MV aggregator acts as the leader by setting a price at the MV and distribution LV level. The price is determined using a mathematical programming with equilibrium constraints (MPEC) approach.
4.4 Sequence diagrams

Figure 4-1 Ramp-up/ramp-down provision using a market based algorithm
Figure 4-2 MV_Level energy management
5. Combination of distribution grid and commercial operation functionality

5.1 Introduction

In this chapter a number of interactions in the DREAM framework between grid and market operation is described. The interplay of planned, provided but not used and actual delivered flexibility and at what level are the important aspects are dealt with here.

5.2 Provision of LV flexibilities in a short term time scale

A first application (Figure 5-1) describes a mechanism of short-term time scale local (LV) flexibilities provision in order to assess possible supplementary local reserves enabling to solve short-term and real-time network constraints (congestions, voltage deviations). The objects in this use case are the Prosumer DeviceAgent, with a concentrator at the home, modeled via a CEM, a customer energy management system and a commercial aggregator LV-level. The DSO LV level monitoring and control is modeled as a CellOperator object. At the beginning of this use case, the day-ahead and intraday processes are assumed to be completed, resulting in an optimal plan of energy balance and knowledge of available flexibilities, taking into account network constraints. The aim of this use case is to establish a local market for flexibility bids (with new short-term flexibility bids which are declared too late to be transmitted up till the TSO), feasible only within a distributed control environment, as defined in the DREAM framework. The DeviceAgents issue Measurements to the LV Homebox, that allows computation of a FlexibilityBid. FlexibilityBids are discussed in 2.6. The FlexibilityBids are aggregated for the subset of commercial aggregator clients in the LV cell managed by the CellOperator. Various Commercial Aggregator agents in the DSO segment send their FlexibilityBids in this way. The aggregated FlexibilityBids are used by the LV DSO to plan the use of flexibility via function planLVFlexibility, leading to sending a aggregated FlexibilityAllocation to the individual commercial aggregators for their prosumers. These, on their turn, calculate the usage of their LV flexibility for the individual HomeBoxes. This Flexibility is translated to Setpoints to be issued by the DeviceAgent on the device level.

5.3 Provision of MV Flexibilities in a short term time scale

A similar mechanism as in the previous paragraph can be devised including an extra aggregation level at the MV cell operational level commercially and physically and also including MV Prosumers. This scheme is depicted in Figure 5-3. In this use case a local flexibility market (with new short-term flexibility bids, which are declared too late to be transmitted to the TSO to be included in the existing commercial markets. Apart from the LV Homebox Customer Energy Management system, Commercial Aggregators at the LV level and MV Level and LV Level DSO CellOperator agents, MV Prosumers, MV CA and MV DSO Concentrator Agents are part of the agents that communicate. Again,
the use case operates typically at 15 minute time intervals. Dependent on real-time collected Measurements the Customer Energy Management system determines the flexibility in power production or consumption having detailed knowledge of the current en future value of the primary processes of the user. One might think of the customer energy management system, knowing user comfort preferences, being connected to a heat pump. The DSO cell operator plans the additional LVFlexibility and optimizes all bids from all aggregators in the segment to an individual aggregated allocation per aggregator. In this process, the LV commercial aggregator and the LV CellOperator also may send Bids for delivering parts of their flexibility to the MV level. This process is planned and mediated by the MV CA ConcentratorAgent and MV DSO Cell Operator in view of the current status of the portfolio and the physical grid respectively. In this way, at the DSO LV level, part of the available Flexibility can be exposed to the higher distribution level.

5.4 Short-term scheduling LV or MV

This functionality applies to the situation that the DSO is forced to reduce or increase the active power in its network in order to maintain the balance between short-term forecasted demand and initially scheduled one. This decision could be based on realizing, that there is a significant deviation from the predicted load/renewable energy generation or other reasons causing under- or over-realization imbalance. In the sequence diagram two different commercial aggregators are modelled in the same MV/LV elementary cell interacting with a LV_MV_DSO CellOperator. The DSO informs a number of LV and/or MV aggregators to proceed to a reduction/increase of power in the next time-frame, calling on their current Flexibility. The time-frame in this use case is supposed to be in the order of one hour. The aggregators, then, negotiate in order to arrive to an agreement regarding the amount of power that each one will have along with the price that he will be paid and the value of power consumption or production in their primary processes. The negotiation could take the form of an auction, where each partner sends price vector bids with the power that he is willing to reduce/increase. Each aggregator decides upon the variables under control in order to optimize the value of a specific objective function representing either cost or profit. This goal is dependent on the variables under its own control, influenced by the choices made by the prosumers included in its portfolio. The decisions of aggregators are indirectly influenced by the decisions of other aggregators by participating in the negotiation. At the end of the negotiation and after a final agreement has been reached the DSO gets informed about the result. The precise mechanism has been described in [IR2.1,2014].
5.5 Sequence diagrams

![Sequence Diagram]

Figure 5-1 LV cell provision of flexibility
This document has been produced and funded under the EC FP7 Grant Agreement 609359.
Figure 5-3 MVCell provisioning of flexibility
6. Distribution grid operation functionality

6.1 Introduction

A number of distribution system use cases are discriminated to use the flexibility of loads and DG-RES in real-time to handle events regarding momentary power and not energy [IR4.1, 2014]. In all these use cases the question how flexibility is best competitively divided in parts of the grid taking into account the present operation mode, being normal, critical or emergency. In this chapter also the interaction of the DSO-operator with the DREAM framework is contained.

6.2 Real-time flexibility release

Real-time flexibility release for the LV Cell

As shown in the section on ‘Real-time flexibility provision’ functionality (5.2), Measurements and Setpoints, FlexibilityBids and Flexibility Allocations are interchanged between LVProsumer, commercial LV- and MV-Aggregators and LV and MV DSO CellOperators. The more direct way of releasing the flexibility, triggered by the fact, that the grid is in critical or emergency situation, is depicted for the LV DSO grid management level in Figure 6-1 by-passing the LV-aggregator level. In the last loop, below in the figure, the undeclared flexibility at the end-consumer premises is uncovered via a cyclic process. In the diagram the objects are a DeviceAgent, a ConcentratorAgent and CellOperators at the DSO and the ElementaryCell level. Dependent on the congestion status of a part of the LV grid, the managing commercial Aggregator agents and the DSO agents interact according to specific message protocols. In all modes, DeviceAgents send an object-array Measurements. Using load flow calculations, the grid is checked for contingencies. If a critical mode is detected, load-shedding takes place coordinated and optimized by the commercial aggregator based on the setpoint issued by the LVCell DSO CellOperator. Based upon the measurements, the DSO LV Aggregator advises SetPoints, also most probably for the momentary power, to the connected device agents via the LV Commercial Aggregator. If the congestion worsens and the system comes into emergency mode, the DSO directly controls the load and merely informs the commercial aggregator to reconcile the lost revenues. To obtain an impression of undeclared flexibility, as depicted in the bottom part of Figure 6-1, the MV ElementaryCell operator tries to obtain an impression of the flexibility of the Devices at the aggregated LV level using a tâtonnement procedure with iteratively varying prices. Such a mechanism could also be implemented using a PowerMatcher mechanism in which power delivery or power consumption capability is traded without actual production or consumption as described in [RegelDuurzaam, 2010].

Real-time flexibility release for the MV elementary Cell
The scope of the use case can be extended to the MV segment using the same principle as shown in Figure 6-2. Tatonnement of the different segments of the grid also can be done using an iterative approach. If the MV elementary Cell DSO agent detects a problem, he can use the available real-time flexibilities to solve the problem. They are provided to him through the use case “Real-time flexibility provision” of chapter 5.3. This will mostly include an optimization, but dependent on the actual problem there will be differences (see the following use cases). New set points will result for the MV Prosumers and the LV Cells from the optimization. If the situation is critical but without immediate danger for the grid stability, these set points will be send to the MV Aggregators and he will transfer them directly to “his” MV Prosumers and their particular LV aggregators which on their part will transfer the set points to their LV Prosumers. In the case of an emergency the adjusted set points are directly transferred to the MV Prosumers, and over the LV DSO agent to the LV Prosumers. The reasons for that are described in the above LV use case. To avoid deadlock situations when the MV Prosumer receives a set point both from his Aggregator and from the DSO agent, the DSO signal has always higher priority.

As shown in the lower part of Figure 6-6 Local MV control to solve a contingency in an emergency situation, if there is an extreme problem in the grid that does not even leave the time for an optimization, the MV elementary Cell DSO agent has the possibility to send an “emergency signal” and the MV Prosumers and the LV DSO agents to force them to adjust their set points according to predefined rules. Apart from the use of pre-declared flexibilities the MV elementary Cell DSO agent can also use possible non-declared real-time flexibilities of the MV Prosumers. This is especially true for contingencies that require just a certain amount of flexibilities to be used within a certain area without regard to the precise position or kind of flexibility. To use these, the DSO defines a maximal price he would be willing to pay for the use of flexibilities. This information is given to the MV aggregators together with the required amount of flexibility. The MV aggregator will negotiate with their MV Prosumers (and through their subordinated LV aggregators with the LV Prosumers) proposing to them in the beginning a pre-defined smallest price and then successively increasing it. At each price the MV Prosumers can decide if they want (or can) provide flexibility or not at that price. This is repeated until the demanded flexibility is released or the maximal price is reached. After the new set points are communicated, the higher grid level DSO (here the substation DSO agent) is informed about the use of flexibility, from there the information is passed to the MV DSO agent. This is important as the flexibilities could also be used in higher grid levels.

6.3 Contingency management

Local control in normal operation

Local control is implemented in a bottom-up fashion. Local control requires that agents can control LV-components to deliver restoration services. Local control also means that if the Prosumer inverter/converter connected to the home gateway detects a contingency (e.g. an over-voltage or under-voltage situation) at the point of common coupling also an appropriate response is generated. In
normal operation circumstances the system will adjust the local setpoint for reactive power in order to compensate according to a predefined characteristic value given by the DSO. The sequence of events is depicted in Figure 6-3. This scheme is also applicable for the MV Prosumer as depicted in Figure 6-4. In both cases, the DSO CellOperator has to be informed of the overall power delivered in order to integrate it in the overall operation.

Local control in emergency situation

In the normal operation use case, local control only involves setting the reactive power. Emergencies arise if the DSO concentrator agent notifies or if communication is disrupted. In this case also the active power set points are set locally. This mechanism pertains at the LV as well as the MV level. In Figure 6-5 the sequence for an LV control action is depicted. In case of a communication problem to the DSO concentrator agent or an emergency notification by the DSO concentrator, the setpoint for real power between the flexible devices is controlled together with the set point for reactive power. The same mechanism also can be used at the MV elementary cell level as illustrated in Figure 6-6. At the end of the emergency, the FlexibleDevice set point control is released.

Decentralised control for contingency management with optimisation by a cell leader

The flexibility available in an elementary cell consisting of a number of LV and MV parts may be utilized concertedly in order to solve a contingency if local solving of the contingency as discussed previously appears to be impossible. The sequence of events to solve the contingency at the MV and LV aggregation level is depicted in Figure 6-7 and Figure 6-8. The context of the solution is in the grid segments managed by the LV DSO concentrator. In the scheme now also DateValueStores registering events in the grid and online tap changers and reactive power sources are present to aid in solving a contingency. Also forecasts of the expected behaviour of the part of the grid are available. Using power flow calculations, state estimations are made continuously to check for contingencies. In the scheme, the necessary compensation is obtained from the neighbouring MV cell to avoid energy imbalances. A next higher level to use a MV cell concentrator leader role is depicted in Figure 6-9. Again the sequence of events is analogous to the optimization at the lower level. A scheme for contingency management is with a DSO agent interacting with a number of MV Commercial aggregator agents. The DSO aggregator agent now also uses substation OLTC and FACTS devices in order to extend the control possibilities. The last way of decentralized contingency management is via peer-to-peer optimisation (see Figure 6-10). This scheme contains a number of pre-emptive steps to determine the control flexibility according to model calculations. In Figure 6-11 a last scenario using grid configuration in a meshed network is depicted. This mechanism is only possible in meshed networks. In case of a reconfiguration event, consisting of an intra-substation re-switching, the Flexibility in DSO_substation_i is managed and optimized to adapt to the new power flows. In Figure 6-11 also communication
between agents is depicted for an inter-substation event where a switching event is also delegated to DSO Substation j.

6.4 Frequency support

The message exchange functionality and the mechanism for contributing to frequency support is depicted in Figure 6-12. On the MV and LV aggregator level Concentrator agents construct a ControlDroop to be mobilized in case of a potential frequency deviation. The combined FlexibilityBid, finally is sent to the TSO, that monitors the primary frequency. Once a significant deviation in the frequency is found, shedding for the load or generator with the locally computed frequency thresholds are affected. After the frequency event, reconciliations might place to compensate the contributors. In this way an automated, intelligent load shedding mechanism is implemented. Extension to Frequency Curtailment Reserve can be implemented as well in a Virtual Power Plant point of view. As there already exists a number of mechanisms having such features for centralized generation, promoting this product by a new player in competition for a limited volume and high availability product is difficult in current balancing marking mechanisms/markets but with delegation of these services to lower grid levels niches might appear.

6.5 Self-restoration after fault

In Emergency Topologies collections of pairs of MV cells may be defined, that can interact firstly in a peer-to-peer fashion. The time variable topology is the basis for coordination via the message exchange protocol in the agent framework and determines which agents interact with one another. As an example, consider the scenario where a falling tree disrupts a transport line of the MV network. The self-healing cell should isolate the disrupted segment and route the power via an alternative route. To avoid complexity in calculating a system response in the emergency state and also to minimize communication overhead, in such a case there is no possibility for a hierarchical coordinated connection restoration. Therefore the nodes in the cell have to solve the problem locally by redirecting the power flows. Topologies may be created statically and dynamically and in the form of federations on-the-fly as a reaction to events on the grid.

The static example is shown in Figure 6-13. After a circuit breaker opens, the fault location is computed using the History and the pre-Fault Measurements. The section is isolated by setting switches by the DSO substation ConcentratorAgent. The DSO cell operator only logs the event. The self-healing ConcentratorAgent takes over the task of the DSO substation ConcentratorAgent. The latter checks the reconfiguration possibilities, calculates Load Flows and does a contingency congestion check. The calculated SwitchSettings are issued to neighbouring MV Elementary cells. Effects of these altered settings in terms of contingency and congestions are automatically mitigated by starting the ManageFlexibility application between MV cells discussed earlier. The dynamic variant of this DREAM application is depicted in Figure 6-14. Here the self-healing ConcentratorAgent issues the switch requests to the neighbouring MV-cells. Finally in the substation to substation federation, the self-healing concentrator agent performs the reconfiguration and switching calculations and the issuing
of switch settings. Again, concerted exchange of Flexibility mediates possible adverse effects of the switching operations in terms of power flow.

6.6 DSO-Operator interaction with the DREAM-framework

The DREAM concepts are experimental. Therefore an operator view is contained in the model. DSO operators have the overruling possibility to set the coordination and operation modes at any time. In Figure 6-16 a use case for the operator interaction in the grid is illustrated for visualizing, controlling and setting the allowed DREAM control modes for parts of the grid. Initially by the Visualisation component, from the GridpointRepository a selectionList is retrieved for the specific Location, where control is desired. The operator can select a Gridpoint to focus on. As specified in the setup class structure (section 2.2) different levels of aggregation are accessible and can be prepared for further functions in this way. Once such a selection has been made the following sub-functions become available:

- Visualisation. The IMonitoring interface, implemented by GridPoints, is key in the sequence diagram. Available Measurement types can be retrieved and selected by an operator for display. The sub-function can be used from the CompositeCell level via the ElementaryCell to the UserConnection level. Explicitly, the following aggregations are accessible:
  - Whole Network
  - Primary substation with all related MV feeders
  - One/or more individual MV feeders
  - One/or more individual secondary substations including all there LV feeders
  - Individual feeders in a specific substation (if possible / if it has sense) with all their energy boxes
  - Individual Energy boxes

- In the MonitoringControl package, IEC61850 and CIM interfaces can be defined for IMonitor allowing access to these widely used standards, but also legacy or proprietary implementations of IMonitor can be implemented.

- Control. The IControl interface, also implemented for GridPoints, has to be used here. The same access methods as for Measurement retrieval are defined here, but now for read-out and definition of setPoints.

- ModeSelection. In this subfunction, the link to the current allowed operation modes is set. In this case a link to the CellOperator (a software process performing the agent-based coordination) is established and visualized. The mapping of the CellOperator to the physical grid is defined in the implementation view; the physical level therefore depends on the technical design of a particular use case application. ModesAllowed can be set by a DSO-operator and the CellOperator has to explicitly acknowledge. The modes are:
- Fully automatic: DREAM agents receive information, do model calculations, coordinate and finally act directly on the equipment.
- Semi automatic: DREAM agents receive information, calculate and propose actions to the DSO operator.
6.7 Sequence diagrams

Figure 6-1 Real time flexibility release in the LV cell.
Figure 6-2 Real-time flexibility release in the MV-cell
Figure 6-3 LV local control during normal operation
Figure 6-4 MV elementary Cell local control during normal operation
Figure 6-5 Local LV control to solve a contingency in an emergency situation
Figure 6-6 Local MV control to solve a contingency in an emergency situation
Figure 6-7 Distribution network optimization by cell leader
Figure 6-8 Decentralized LV cluster control with optimization by cell leader
Figure 6-9 MV cell optimization by cell leader
Figure 6-10 Decentralized control via P2P
Figure 6-11 Grid reconfiguration
Figure 6-12 Frequency control
Figure 6-13 Self-healing after fault (static)
Figure 6-14 Self-healing after fault (dynamic)
Figure 6-15 Substation to substation federation
Figure 6-16 Operator interaction
7. Distribution grid control and monitoring interfaces

An IMappable interface is defined to achieve a logical connection to IEC 61850. Connected to TCP/IP, IEC 61850 may also include Webserver functionality, which allows Webservice calls. The current trend in substation automation standards is IEC 61850. This standard suite defines abstract data models and their mapping to a protocol set as described in the Figure 7-1.

IEC 61850 has been extended to meet the requirements for almost the whole electrical energy supply chain [IEC 61850, Schwarz]. illustrates the possible mapping mechanism for IEC 61850 [IEC 61850] electricity domain object models. Core ACSI Services use a standardized layered data communication structure with MMS and TCP/IP mappings for the lower OSI-model layers.
Figure 7-2 shows the mapping on grid components and Figure 7-3 show the connection possibilities to DREAM. Access can be achieved via an IAccessMappable interface implementation by an IEC61850 wrapper component.
A CIM storage mapping can be achieved using a common XML-schema approach using WEB-service technologies like SOAP or the light-weight RESTful interfaces. In the DREAM setup package the connection to CIM [CIM, 2013] the connection may be achieved in a similar way to allow exchange connection to grid operational database models in the electricity industry.
8. End-user and supply/demand device interaction

8.1 End user interaction

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<th>Price Reaction</th>
<th>Market Integration</th>
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<td>+ Full Use of Response Potential</td>
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<tr>
<td>- Uncertain System Reaction</td>
<td>+ Certain System Reaction</td>
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<td>- Market Inefficiency</td>
<td>+ Efficient Market</td>
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<td>+ No Privacy Issues</td>
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<th>Decisions on local issues made centrally</th>
<th>Top-down Switching</th>
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<td>- Low Scalability</td>
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One-way Communications | Two-way Communications

Figure 8-1 Communications vs decision level matrix

In interacting with end electricity customers a number of interaction types exist [Greunsven, 2012, Kok, 2013]. These depend on the directionality of communication and the level at which decisions are made. The decision matrix is shown in Figure 8-1. With top-down switching via one-way communications, the system reaction is uncertain and problems with customers may occur regarding privacy and autonomy; the demand response will only be used partially. In case of centralised optimisation with two-way communication, the system reaction can be verified and the degree to which the demand response potential can be used increases. In communicating prices one-way the system reaction again is not verifiable beforehand and sending the right price in view of the current value of electricity in the primary device and user process is hardly achievable. Therefore bidirectional and local decision making is needed to make full use of the demand response potential. In the latter scheme, devices can be couple to markets more directly.

In the DREAM architecture, this approach is supported by the fact, that a platform is provided in the dream.coordinationmechanism platform for flexible deployment of VPPs. Also the agent based approach allows deployment of parts of the agent implementations on customer gateways close to the smart meters or the intelligent devices themselves. So, to integrate the processes of the user devices, in normal circumstances, the DREAM-framework will have to be positioned on the upper right corner, where decisions are made locally via two-way communication. Only in critical and emergency situations, centralized coordination driven by grid restoration and optimization principles will have a higher chance of being used. But also in this case, the leveled utilization of flexibility provision and then possibly of real use will preempt the system to trip to a critical or emergency state.
8.2 Customer device interfaces

A user connection (or home concentrator box) aggregates a number of devices at the user's premises at a physical location. The class makes the rest of the physical grid accessible to the user devices by providing the LV segment connectivity information. Furthermore they might act as information concentrators also having access to a smart meter. For the UserConnection there is a CEM-mapping, delivering the access to a communications port of a smart meter data from the customer energy management system and to the values to be read or written for the devices. For connectivity to CEM (Customer Energy Management) devices, CEN-CENELEC [CENELEC,2013] currently is developing models for devices accessible in home gateways. A possible interfacing to the smart meter is shown in Figure 8-2. Possibilities exist also to connect to a smart meter. Currently within OSG-I [OSGI] specifications for a set of modular Java components have been defined and certified implementations exist for facilitating home gateway data connectivity. FPAI [FPAI_2014], a platform for demand response currently by industry and TNO, also is based on OSG-i.

Figure 8-2 CEN/CENELEC model of home gateway customer energy management

Figure 8-3 SGAM mapping of grid and customer connectivity and database standards
The CEM-mapping in DREAM is in accordance to the green zone in the customer domain of SGAM (see Figure 8-3). In this way the whole customer process zone is covered.

8.3 Service interaction modes

In the current power system, demand side management and demand response is limited to certain larger business consumers and it is triggered by incentives like time of use (TOU) prices. However, the large potential of flexibility in households and smaller businesses is hardly used as a resource from the grid management or the commercial perspective. In this way, grid operation currently is a process of reacting to what happens, rather than being able to proactively exert control. The DREAM framework does offer this control by incorporating the aggregation and deployment of flexibility at all levels and for all parties in the grid. To that end the concept of a flexibility profile object will be defined. Flexible devices report their flexibility profile in a standardized way. Aggregators, operating service applications in a Web-context, may aggregate the flexibility profiles of groups of flexible devices and offer the aggregated flexibility to interested parties.
9. Development, deployment and generic simulation capabilities

9.1 DREAM life cycle model

Currently, DREAM is an UML model contained in the Visual Paradigm software architecture development environment. This environment has a plugin in the Java eclipse development environment. Primarily, further model development and development of components will be done using these two tools and in Java. However, the CASE-tool also has code generation facilities for C and C++, which are used extensively in real-time systems. In this way, cross-platform development of agents is possible enabling agents to be developed in C++ to obey real-time constraints, that are not reachable by Java programming. Components will undergo unit tests with simulation tools like Matlab and R. Common code development and version management of code and components is necessary. A tool like Subversion or Codeforge are likely candidates to support this. The current version of DREAM has a flawless daily build of the most recent version of a number of applications.

9.2 Interprocess communication between agents

The DREAM framework is set up in such a way that multi-threading and multi-processing of the agents is possible. The architecture of the current interoperability library of PowerMatcher [Powermatcher,2011] for agent communication supporting RPC, Linux remote procedure calls, Windows WFC, Soap and Restfull based Web service communication will be reused. Interfaces to Matlab simulation environments or dedicated simulation environments (e.g. PowerMatcher) have to be supported.
10. Conclusion

The capabilities of the innovative DREAM framework for control and monitoring in heterarchic electricity networks have been described. Class diagrams of a number of packages are presented and explained allowing the building of heterarchic agent applications in a distributed computing environment. Capabilities of a large set of heterarchical applications serving pure commercial energy applications as well as common DSO operation, grid related power related applications are discussed. Subject for further study are extending the flexibility class concept in DREAM, getting experience with persistence data in a real-time distributed agent setting and using emergent technologies to feed the complex repository of points in the grid exchanging information.

The current version of the framework now has to be extended with the functions defined in the class and sequence diagrams to deliver version 1 for usage of the framework to be used in the field tests.
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<th>PowerMatchingCity, 2014</th>
<th>A detailed account for phase 2 of this living lab is given in <a href="http://www.powermatchingcity.nl/site/pagina.php?id=41">http://www.powermatchingcity.nl/site/pagina.php?id=41</a></th>
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<td>OASIS</td>
<td>See <a href="http://docs.oasis-open.org/ws-dd/ns/dpws/2009/01">http://docs.oasis-open.org/ws-dd/ns/dpws/2009/01</a></td>
</tr>
<tr>
<td>ThreadGroup</td>
<td>Google / Nest, Samsung, ARM. See <a href="http://threadgroup.org/">http://threadgroup.org/</a></td>
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