THE DREAM INNOVATIVE SOFTWARE ARCHITECTURE FOR HIGH DG-RES DISTRIBUTION GRIDS

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ABSTRACT

The DREAM [1] software architecture model describes a reference class model and sequence diagrams, derived from use cases, that aid in integrating the different components for active distribution grids to applications. DREAM can be used in the commercial and grid operation application domains. It is designed to support the simulation (proof-of-concept) to the implementation stage (proof-of feasibility) of systems. The framework facilitates interoperability on the software and hardware level as well as from the communication technology level.

The framework was designed from a use cases perspective. The major functionality implemented relates to flexible, heterarchic aggregation and coordination of devices involved in demand and supply of electricity. In the grid context, aim is to achieve a common objective, prioritize actions and operate on various timescales of grid operational and market functions. To that end, in the framework, monitoring data are handled and stored in a distributed fashion in order to directly steer or coordinate the operation of devices. These persistent data also allow handling forecasts and 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. A first implementation is now being built.

INTRODUCTION

Embedding an ever increasing proportion of renewable energy resources poses a considerable challenge to electricity grid operators in normal, critical and emergency operational circumstances of electricity grids. Combining cost-effective commercial operation of customer demand and supply and operation within increasing distribution constraints poses challenges. Software agent based solutions to tackle these problems are appearing [2,3] during the last decade, implementing use cases ranging from imbalance and ancillary services market operation in the commercial segment and to self-healing applications in the distribution grid operating domain. Besides common hierarchical concepts to operate MV and LV grids, in the DREAM control and coordination architecture, software agent based architectures also allow operation in a heterarchical[1] setting, offering the possibility to determine the most appropriate leading agent, depending on the particular operational circumstances of the grid.

In the DREAM architecture [1], the software components facilitating these novel control and coordination concepts are grouped according to functionality into packages in a layered structure as shown in Figure 1. On the basis of the LV and MV power distribution network and ICT communication networks topology, a number of software packages with basic functions are defined. Apart from implementation of control in high penetration DG-RES networks, the bottom layer allows emulation and simulation studies prior to real-time operation in electricity distribution networks. The middleware layer comprises monitoring and control, persistence, coordination topology and set-up. On top of these, forecasting, flexibility utilization and coordination are defined to allow VPP operation to optimize power distribution and commercial electricity market operation. The packages have been designed using UML (Unified Markup Language [4]) with an integrated round-trip engineering code generation tool. The individual packages are discussed in the following sections.

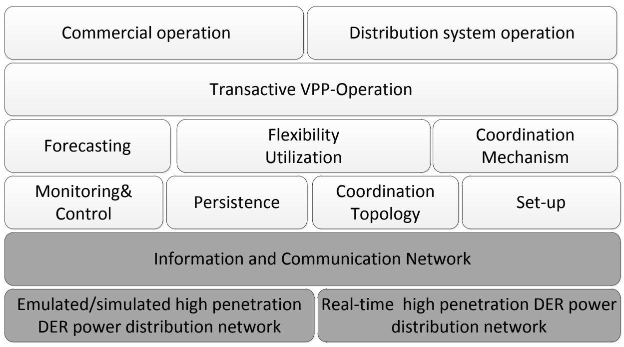

Figure 1 DREAM package structure

1 A system of organization where the elements of the organization are unranked (non-hierarchical) or where they possess the potential to be ranked a number of different ways

MONITORING AND CONTROL

The monitoring & control package focuses on being used in a distributed computing setting and is designed with interfaces to existing standards in the electricity domain like IEC-61850 and CIM but also more general purpose M2M protocols in the IoT (Internet of Things) to allow a higher granularity. The DREAM monitoring and control package contains functionality to retrieve or push measurements and to control devices remotely, such as switches or flexible devices. All measurable devices implement a monitor interface and a Monitor object may keep a list of these measurable devices and either periodically request new measurements via polling or receive new measurements whenever a significant change occurs in an event based way.

PERSISTENCE

The persistence package features the design of a distributed data architecture for storage of data with flexible requirements on storage duration, security and resilience using a distributed database approach with noSQL (**n**ot **o**nly SQL). 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.

COORDINATION TOPOLOGY

Different topologies for agent based coordination algorithms may be predefined for operation in normal, critical and emergency operational strategies. Switching between coordination topologies encompasses 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 electrical system topology may be actively altered by switching actions during operation of the power network with a concomitant change in the software agent coordination topology by the DREAM framework.

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 and supply. 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. E.g., 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..

SET-UP

The set-up 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. In this way each of them is unambiguously pinpointed individually also in a distributed computing setting. How grid points are connected to one another 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 set-up information to algorithms that aim to measure or control parts of the grid. The set-up package allows to define the static connectivity information between grid components. The package represents the static configuration part of the DREAM framework. The package can grossly be subdivided into two parts. One part is connected to the tree structured LV part of electricity grids; the other part to the meshed MV-parts of the grids. In non-meshed MV-grids parts of the DREAM-functionality cannot be realized.

FORECASTING

The forecasting package, allows consumption and production forecasts based on persistent data collected. These may include previous realizations and also external information like meteorological forecasts and prices. 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 forecasted 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 near-real-time (now-casting) to respond to balancing needs. Thus this presents the requirement for different timeframe capabilities namely, daily, hourly or now-casting. The Forecaster object 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 set-up information (e.g. storage capacity). This defines a strong connection to the set-up, persistence and monitoring packages.

FLEXIBILITY UTILIZATION

The flexibility utilization package, contains tools for optimizing energy and power profiles of production or consumption devices via LP (Linear Programming) and combinatorial approaches. 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 a certain stepwise increasing 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 realize flexibility functionality. In Figure 2, a collection of PowerMatcher agents' [2] aggregated bid curves for a typical MV cluster setting with some storage, EV charging units, heat pumps and micro CHPs during a number of consecutive days is shown. Price steps are on the X-axis (0-100), the day number at the Y-axis and the colour codes and the Z-coordinate denote the total power (-1800 kW- 3500 kW). The equilibrium price, the light-green contour level, can be seen to shift over each day, dependent upon the total composition of power demand and supply. The steepness and thus the flexibility in the cluster also varies considerably as is the expected flexibility and value.

In DREAM the flexibility is discriminated in an energy flexibility in kWh over a certain period and a momentary power flexibility. There are four potential users of flexibility: aggregators, distribution and transport system operators, suppliers/retailers 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.

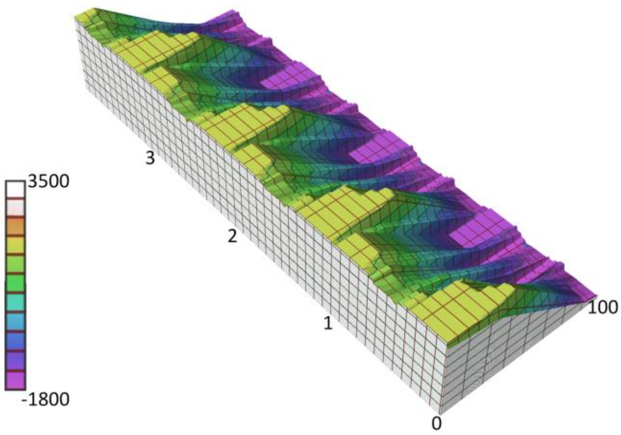

Figure 2 Aggregated bidcurves as a function of time

COORDINATION PROTOCOLS

This packages entails the agent protocol implementation. It allows implementing different types of agent-based coordination in a multiprocessing, distributed computing environment. A market based agent in a VPP uses a coordination protocol. Examples of these protocols are PowerMatcher [2], PeerMart [5] and Intelligator [6]. Taking PowerMatcher as an example. The auctioneer agent in a market context receives bids and an objective agent pushes the aggregated agents to reach a certain goal. The scope of the coordination mechanism is the possibly real-time changing topology of a certain MV-grid as depicted in the common dictionary.

Coordination protocols also may be sequences of interactions as described in the individual DREAM application functions. In the latter sense, a script of actions to be executed in certain sequence between agents may be defined, that is executed either during normal, critical and emergency operations. In order for the agents to fulfil their task they need to have available the persistent information of the agents in order to be able to construct the bids.

One of the DREAM use cases tests device

responsiveness in a small set-up with a few flexible devices. Here a heat pump and a CHP are coordinated 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.

CONCLUSION

The DREAM framework allows building electricity grid applications ranging from commercial optimization using VPPs[2] via congestion management at the MV/LV level to self-healing applications with grid elementary cells coordinating with one another on a peer-to-peer or ad-hoc federation basis. The architecture has been defined using UML [3] from a large collection of use cases specifications, class diagrams and sequence diagrams. A first version of the software architecture is available. Currently, industrial validation of the architecture, extension and implementation in Java to achieve interoperability between industrial platforms are underway. Several different real life and living lab field tests are planned together with consortium partners from industry to validate the framework.

Acknowledgments

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2 Virtual Power Plant
3 Unified Modeling Language