RESEARCH REPORT

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D5.1.46: Requirement documentation on selected promising use-cases

for Smart Grid communication simulator environment

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Summary

This objective of the work is to provide requirement documentation on some promising use-cases selected for a Smart Grid simulator environment, which combines the energy and telecom parts of such a Smart Grid system.
In this deliverable the Micro Grid has been selected as representative Smart Grid structure for low voltage distribution networks, covering as example following topics in its use-cases: Local (micro) distribution grid control including islanding mode, Fault location, isolation and service restoration (FLIR or FLISR), and Smart meters and advanced meter reading/infrastructure (AMR, AMI) for covering demand side management and network end point topics. To study these topics, integration of a proper network simulation and a communication emulator network with multiple heterogeneous connections are needed. The simulators need to act in real time, when the time constraints can be very limited and the reaction times are fast.

This study presents use-cases for the Micro Grid control, including supply and demand side, black start in islanding mode, protection and restoration, and presents requirements on control communication.

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1 Introduction

The strategy of VTT Research and Development has included Smart Grids as one of the focus points of the existing and future work. VTT is participating in significant national (e.g. SGEM/Cleen) and international (e.g. FINSENY/EU-FI-PPP, Artemis IoE, EIT-ICT labs, ADDRESS/FP7) projects and research clusters in this field. The drivers are related to the visions of VTT, namely *Clean Globe, Low Carbon Energy, and Digital World.*

The competences required in this work come from both the energy and ICT fields of VTT R&D. This objective of the work is to provide requirement documentation on some promising use-cases selected for a Smart Grid simulator environment, which combines the energy and telecom parts of such a Smart Grid system.

In this deliverable the Micro Grid has been selected as representative Smart Grid structure, covering as example following topics in its use-cases:

Local (micro) distribution grid control including islanding mode, which is an Important case when considering the future distributed energy resources management, especially in countries with weak distribution grids or very high penetration of DER.

Fault location, isolation and service restoration (FLIR or FLISR). This topic requires functionality of several Smart Grid devices and reliable communication between them, and requires control actions on several grid hierarchy levels. FLIR/FLISR is also recognised important from the business point of view, since the faults cause lots of disturbances for the customers and additional work for the Distribution Network Operators, and is a significant case when considering the utilisation of *IEC 61850 protocol*. To cover this topic, it is essential to be able to study different communication infrastructures on especially the distribution hierarchy levels, which can be demonstrated efficiently by Micro Grid use-cases.

Smart meters and advanced meter reading/infrastructure (AMR, AMI) can be efficient additional tools for distribution network management, and Microgrid use-cases can be very representative for this demand-side topic. When considering this infrastructure, topics that should be considered are large amounts of data gathering points, aggregation of the data, security and privacy, and data management.

To study these topics, integration of a proper network simulation and a communication emulator network with multiple heterogeneous connections are needed.

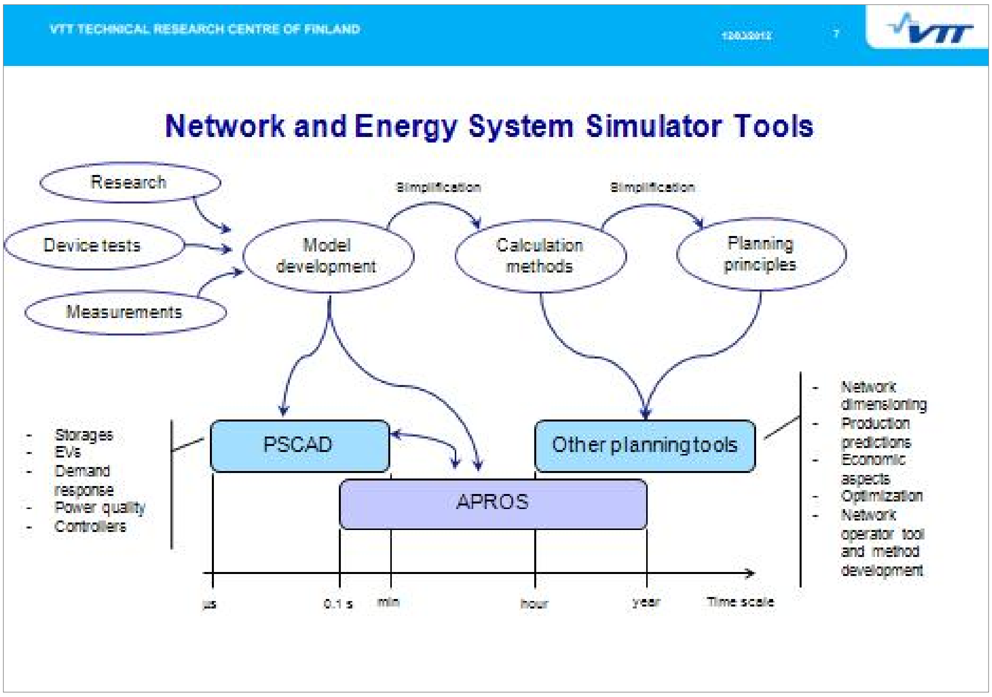
With the simulators we aim to implement the energy network devices as applicable and reactive systems that can both indicate their internal status and receive controlling commands from outside. The simulators need to act in real time, when the time constraints can be very limited and the reaction times are fast. The telecommunications network emulator system here means that we design and implement firstly the components that can form a generic communication network with its components. The components being mainly gateways, routers, access points, adapters, and the actual communication media. In addition, for the selected use case and scenario, we configure the emulated network using these components and integrate it with the simulators of the energy network.

This study presents use-cases for the Micro Grid control, including supply and demand side, black start in islanding mode, protection and restoration, and presents requirements on control communication.

2 Electricity Distribution automation and control communication simulation

2.1 Electricity Distribution automation simulators: purpose for automation and control studies

For Electricity Distribution automation simulation, there are different tools for different time horizons, time steps and fidelities:



Simulation interests for APROS or equivalent software are e.g.

- Timesteps in the scale of 0.1 seconds to minutes
- Grid integration of of PV and storages
- Independent micrograds, islanded operation
- Control of PV/storage for network management
- Coordinated / local control techniques
- Impacts on other energy systems or controlled energy consumption
- Communication, agent techniques…

Generally VTT and other SGEM partners use electromagnetic transient simulators like PSCAD for dynamic simulation of accurate device or network electromagnetic transient studies:

- Timesteps in the scale of microseconds
- Controllers, inverters, electrical protection etc. can be simulated
- DC-modelling for solar cells, converters, etc.
- Extensive model libraries, including SGEM libraries
- ”PSCAD Extends Apros studies where more details are needed”

Time step level and fidelity requirements, and other simulator feature requirements, are different for different issues to be studied. For the most relevant research topics, following simulation recommendations can be given:

Topics to be studied	Time step level and fidelity requirements	General comments and recommendations for simulation studies.
Power quality and fast protection issues	Requires electromagnetic simulation on milliseconds or less. Electromagnetic simulation (e.g. PSCAD) as stand-alone simulation are enough, and do not require an integrated two-way telecommunication part.	In SGEM, PSCAD can achieve this detail level, and a comprehensive model library is available for SGEM partners. However, PSCAD does not allow direct real-time connection to other simulators or emulators, but merely provides static I/O through textfile read/write. Another way to connect to PSCAD would be via a Matlab-bridge, but this will make in itself a too slow connection with too much latency for real two-way communication analysis. This makes PSCAD less suitable for a two-way communication test structure. Also, power quality level and other fast protections typically are triggered directly on local level, and do not need nor allow communication for that task. Thus, such tasks can be simulated by PSCAD as stand-alone simulations and do not require an integrated two-way telecommunication part for such analysis.
Grid restoration issues	Measurement and control actions for efficient restoration require direct real-time two-way connection between network simulator and telecommunication emulator. Required time step level within range of communication message round-trip i.e. 100 ms or below, depending on the application. Requirements on electricity network simulator: active and reactive power, frequency, cos fi, creation of measurement signals and send& receive events.	Restoration of the network (i.e. self-healing functionality) would benefit very much from coordination. Such coordination requires two-way communication to the required network components for proper measurement data and coordinated restoration commands. Required time step level is not as strict as for the power quality case, since the communication message round-trip is in range 100 ms. However, requirement for a direct real-time two-way connection between network simulator and telecommunication emulator is strict. The network simulator should at least be able to simulate active and reactive power, frequency Also, the simulator should be able to create measurement signals and send& receive events. An advantage would be also to be able to simulate possible consequences, but this is second priority. Larger analysis for the entire energy system (including other could energy production or use) would need also consequence mechanisms included in the simulator.
General coordination issues	Same as above + Inclusions of energy system consequence mechanisms.	General coordination issues, e.g. comparing synchronous vs asynchronous control (like direct controlled centralized systems vs agent based decentralized systems): Generally same requirements apply as for “Restoring issues” above, but since this often will be a larger analysis for an entire energy system (including energy production and use) the network simulator would need also consequence mechanisms included in the simulator.

2.2 Communication network emulator

2.2.1 Purpose of network emulation

The main objectives of the Smart Grid telecom network emulator are to offer a flexible system for interconnecting the Electric Grid systems simulators and to be able to study the impact of telecommunication in the Smart Grid control loop. Such environment includes smart meters, smart buildings, field devices, operations servers, etc. Also real equipment can be attached to the network emulator.

The emulator is designed and implemented in a modular way to ensure its applicability for different SG infrastructures. Support for interconnected virtual SG laboratories is taken into account, and therefore the target platform selection can vary from single servers to multiple network processor environments.

One objective is also to follow the on-going efforts of different national and European projects that focus on developing piloting systems for Future Internet and Smart Grid technologies.

2.2.2 Technologies available

The most suitable technologies found were based on combination of virtual machines and virtual connections. A virtual machine is an instance of an operating system running as an individual process on top of another operating system. The number of levels in this hierarchy can be more than just two. Virtual connections can be established between these virtual machines, and they can resemble physical communication interfaces regarding all their attributes.

The virtual machines on telecom emulator system present instances of networked nodes, such as access points, gateways, routers or bridges. The virtual connections represent usually physical connections between the networked nodes. With configuring different kind of parameters for these connections one can change e.g. bandwidth, delay, jitter, error rate, etc. of each of the virtual connection. This enables of emulation of different networking technologies, them being wired or wireless, and their circumstances.

The energy network devices can be either actual devices or software simulators (or even combinations of these two). For connections both physical and virtual interfaces can be used. Furthermore, a whole smart grid simulation and emulation system can run on a single computer system when using the virtual machines also for the simulator applications. The virtual machines also support running simultaneously several different operating system entities.

Examples of virtual machine supporting environments are VMware, KVM, and Virtualbox. For virtual connections Virtual Distributed Ethernet can be considered to be used.

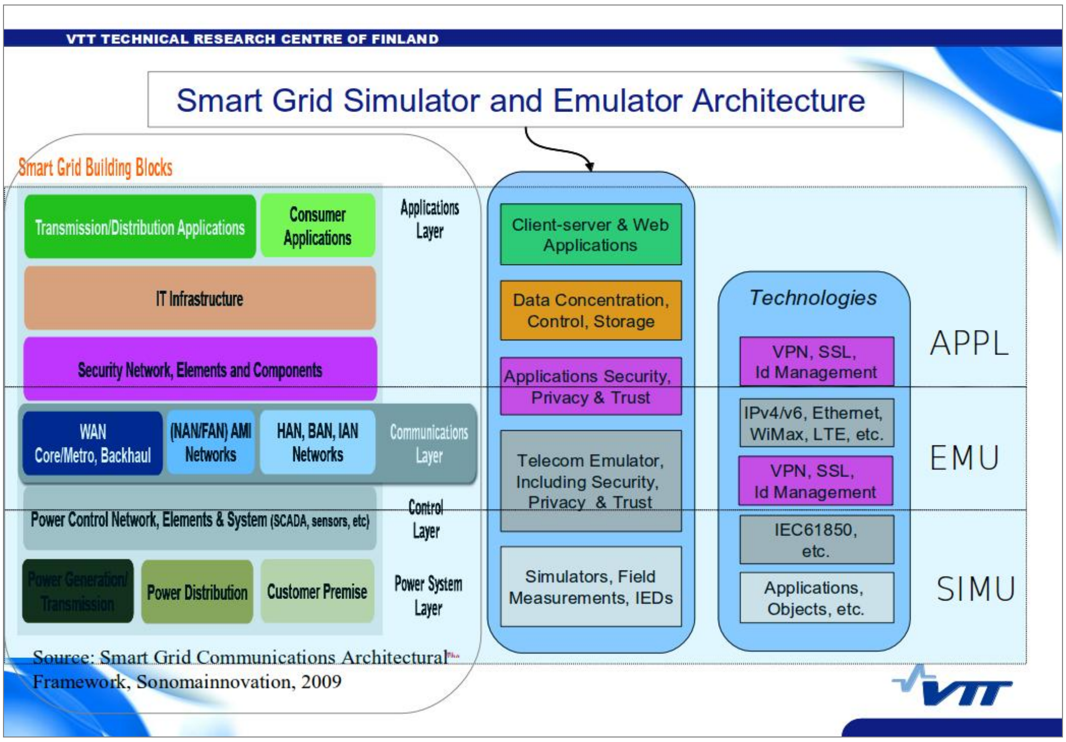
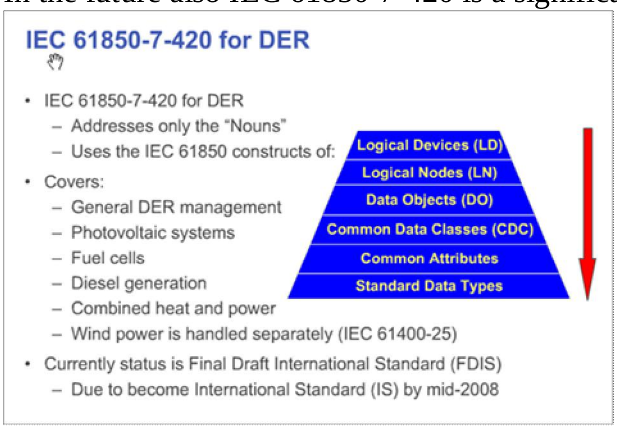


Figure: An example of a Smart Grid simulator/emulator implementation architecture.

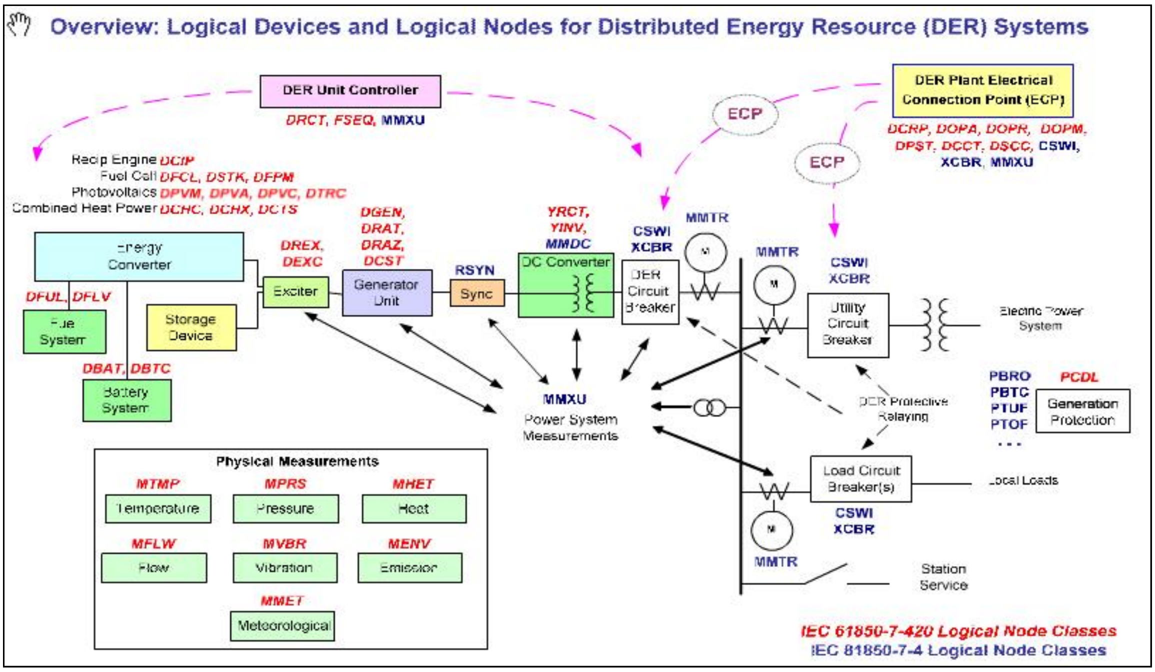
2.3 Considered use-case areas

As starting point, following use-case areas have been briefly evaluated and are listed here in the significance order of which they bring to our goals for the simulator and emulator development.

1) Micro grid control including islanding mode. (Scope: micro grids and distribution network).
   - An important case when considering the future distributed energy resources management, especially in countries with weak distribution grids or very high penetration of DER. Requires integration of network simulation and communication emulator network with multiple heterogeneous connections.
   - In the future also IEC 61850-7-420 is a significant case.



   - See the examples of IEC 61850 for microgrids below.



2) Fault location, isolation and service restoration (FLIR or FLISR). (Scope: distribution network).
   - Requires functionality of several Smart Grid devices and reliable communication between them. This is also recognised important from the business point of view, since the faults cause lots of disturbances for the customers and additional work for the Distribution Network Operators.
   - Requires control actions on several grid hierarchy levels. For this, it is essential to be able to study different communication infrastructures on these levels.
   - Is significant case when considering the utilisation of IEC 61850 protocol.

3) Advanced meter reading/infrastructure (AMR, AMI) (scope: LV/MV network)
   - Should be considered when requiring millions of data gathering points, aggregation of the data, security and privacy, and data management.
   - Can also be relevant for micro-grids.

The above use-case areas can be well combined and covered for very significant parts by studying the needs and detailed use-cases of a Micro Grid. The use-cases of a Micro Grid are presented more in detail in chapter 3.3.

3 Microgrid definition and position in balancing & control

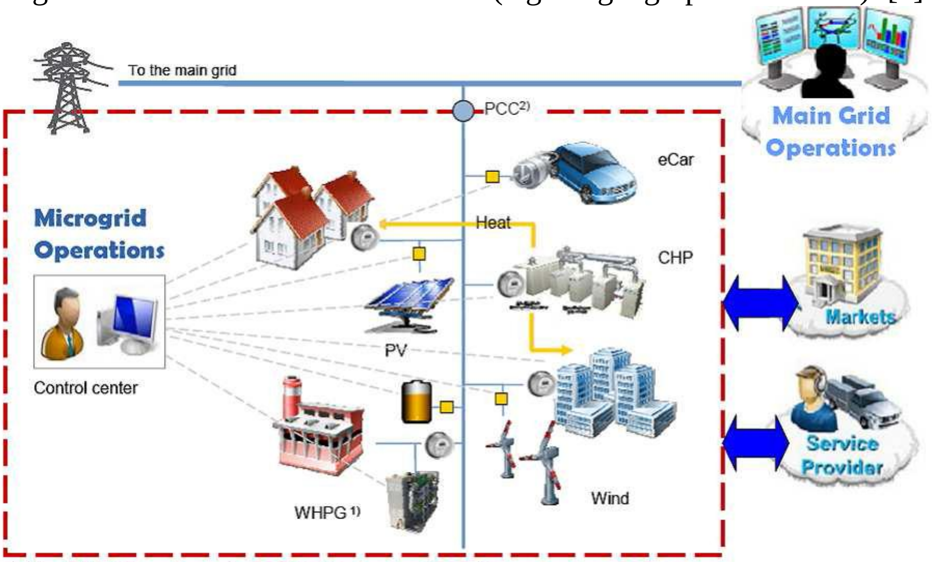
This chapter is added for the reader to clarify the Microgrid definition and its position for the balancing market and ancillary services. The chapter is based on definitions and descriptions from use-case study for Microgrids published by the FINSENY project [1].

3.1 Microgrid definition

A Microgrid comprises of local low-voltage (LV) and even medium-voltage (MV) distribution systems with distributed energy resources (DERs, e.g. micro turbines, fuel cells, photovoltaic) and storage devices (e.g. flywheels, energy capacitors and batteries) in order to satisfy the demands of energy. Larger Microgrids allow also for aggregation of consumers as well as DERs, analogous to a Virtual Power Plant (VPP). The size of a Microgrid can vary and range from residential to campus or community wide systems.

The difference between a Microgrid and a passive grid penetrated by micro-sources lies mainly in the way of management and coordination of available resources. In contrast to VPPs a Microgrid is generally intended to balance supply and demand. It always contains a distribution network which has to be managed. Furthermore, an important difference is the ability of the Microgrid to run autonomously in islanding mode.

Microgrids can be operated in a semiautonomous way, if interconnected to the grid, or in an autonomous way (islanding mode), if disconnected from the main grid. From the Microgrid controller (or operator) point of view, the overlaying power grid appears as just one generator/load, depending on the actual electricity flow. Analogously, to the overlaying grid operator, the Microgrid appears as just one generator/load. Microgrids can be disconnected from the overlaying grid in the presence of disturbances over the latter one, thereby providing enhanced reliability and high power quality to its users. Furthermore, at remote locations which are not integrated into a power system off-grid Microgrids can be used for electrification (e.g. on geographical islands). [1]



1) Waste Heat Power Generation 2) Public Common Connection
Source: Siemens AG

3.2 Balancing Markets and Regulation

An elegant and efficient way of balancing and regulating the electricity system is the establishment of a separate and additional balancing market. In many European control areas the ongoing liberalisation of the energy market has led to the establishment and today's availability of these separate markets in parallel to the general wholesale market. The market rewards the cooperation for the stabilization of the electric power network. Balance is reached when the supply (production and import) is equal to the demand (consumption and export).

The controller of the balancing market is the TSO who also is the single buyer on this market. Access to the supply side of the balancing market is mainly limited to the large power producers, but DG operators and energy suppliers also have access.

As soon as a situation of power shortage arises, the TSO corrects this by buying the lowest priced offer in the balancing market. Most offers come from the large power producers. The TSO may charge the energy supplier(s) that caused the imbalance on basis of the (relatively high) price that it has paid on the balancing market.

Vice versa, in case of a surplus of produced electricity the TSO accepts and receives the highest bid in the balancing market for adjusting generation devices downwards. Also in this case the energy supplier(s) pay the TSO so-called "imbalance charges". Handling these imbalance charges is arranged in the energy contracts between all market players.

In case a large power producer does not comply with its contracts, e.g. there is a malfunctioning of a generating facility, it has to pay for the balancing costs itself, as large power producers are responsible for their own energy program. *To stimulate market players to make their forecasts of electricity production and demand as accurate as possible and to act in accordance with these energy programs, the price for balancing power (imbalance charges) must be above the market price for electricity.* Because balancing power is typically provided by units with high marginal costs, this is in practice always automatically the case. For participation in the regulation and balancing, different requirements have to be fulfilled.

The table below shows a typical classification for providing stabilization and balance in a national electrical network. In these markets, incomes are higher than in the general wholesale market for the same energy amount traded. [1]

Service	Definition	Nature	Providers
Primary Regulation	Generators adapt performance automatically in case of frequency changes (e.g. <30sec)	Often Unpaid & mandatory (depends on market)	All or most important Generators (depends on market)
Secondary Regulation	Regulated performance to avoid changes in frequency (e.g. <=100 sec)	Paid & Facultative	Generation groups enabled by network operator and integrated in regulation areas.
Tertiary Regulation	Power variation with respect to plan. Response in no longer than e.g. 15 minutes, duration of at least e.g. 2 hours (<15min)	Paid & Facultative (Mandatory offer)	Generators and pumping units authorized by the OS

3.3 Ancillary Services

In addition to regulation, ancillary services are all services necessary for the operation of a transmission or distribution system. It comprises compensation for energy losses, frequency control (automated, local fast control and coordinated slow control), voltage and flow control (reactive power, active power, and regulation devices), and restoration of supply (black start, temporary island operation). These services are provided by generators and system operators and are required to provide system reliability and power quality.

There is not yet a separate market for all ancillary services today- it may be an additional market that comes up in the near future. The value of the most feasible ancillary services may be relatively low, but such services will represent incremental revenue opportunities for DGs, usually in circumstances where constraints restrict network development, e.g. environmental, planning, and terrain related constraints. [1]

Possible suppliers of ancillary services on distribution level:

Ancillary service	**Large power producers**	**DG operators**
Compensation for power losses	+	+
Frequency control	+	–
Voltage support (active power)	–	+
Reactive power	–	+
Black start	+	+
Reserve	+	+
Local power quality management	-	+

4 Microgrid usecases

4.1 High level use-cases

The high level use-cases listed below are mainly based on a use-case study for microgrids published by the FINSENY project [1]. The use-cases have been evaluated, commented and ranked from the viewpoint of simulation&emulation value:

High level Use-case [1]	**High level Use-case Description** [1]	**Energy network simulator with telecom emulator can provide substantial value**	**Rank**
Control & Management Use Cases			
Balancing supply and demand on different time-scales	Reliable and efficient performance of a Microgrid is based on the central tasks of load balancing and power stabilization. Besides a permanent balance between power generation and consumption electrical stability is mainly handled through voltage and frequency control. Control methods can vary from direct control to agent-based approaches.	Yes. Especially test & development of control methods and algorithms.	1
Demand-side Management	Demand-side management includes the planning, implementation, and monitoring of utility activities designed to encourage consumers to modify patterns of electricity usage. This includes also automated processes for load management.	Yes Test & development of automated processes for load management.	1
Supply-side Management	Supply-side management includes the planning, implementation, and monitoring of utility activities designed to monitor and control Distributed Energy Resources (DERs).	Yes Monitoring and controlling, and effects of e.g. malfunctions.	1
Storage Management	Storage devices are very important in the Microgrid scenario to ensure the balancing of (volatile) supply and demand. It includes a broad field of different kinds of solutions from pumped-storage to electric vehicles.	Yes Monitoring and controlling, and effects of e.g. malfunctions and storage levels.	1
Black Start in Islanding Mode	Black start in islanding mode describes the restoration procedure of the Microgrid after a general system black out using predefined rules and exploiting autonomous agent concepts.	Yes. Especially test & development of predefined rules and autonomous concepts.	1
Protection & Restoration	Improvement in the utility reliability and power quality can be done by minimizing the effect of faults and interruption for the supply of the customers. <u>One of the ways is to enhance the</u>	Yes. Especially coordination	1

	coordination between the protection systems and the switches. The general practice for alleviating outages or faults in power systems is the isolation of the faulted part of the power system. In the process of isolation, some un-faulted areas loose power. Restoring power, as soon as possible, to these out-of-service areas is essential. That process is called restoration. It entails a fast and efficient switch operation scheme that isolates the faulted area and restores the remaining parts of the system. Fault indicators (FI) and over-current protective relays are the main devices used for fault detection and isolation in distribution networks. When a permanent fault occurs, the operator knows its occurrence from the information delivered by FIs. Then, orders to the breakers and switches will be sent for localizing, isolating the faulty section and re-energizing the same sections of the network. The fault treatment processes need protection systems which are coordinated by ICT infrastructure.	between protection systems during restoration..	
Smart Metering	The Microgrid control can rely on the availability of an Advanced Metering Infrastructure for Smart Metering. Without it the functions or services on supply-side and demand-side cannot be metered and accounted. Furthermore, Smart Metering is often seen as a prerequisite of Smart Grids and provides the first step for encouraging the customer to participate more actively in energy management.	Partly. Effect of malfunctioning smart meters and their communication could be tested for most use-cases above.	2
Auto-configuration	When new devices (e.g. DERs or intelligent appliances) or sub-systems (e.g. Home/Building Energy Management Systems) are installed in the Microgrid they automatically configure itself. All monitoring and control functions of the devices can be used after auto-configuration in a secure and trusted manner by the Microgrid control center.	Marginally. Effect of new additional devices can be tested for various control concepts	3
Planning	For the design and update of the Microgrid infrastructure planning tools and simulations are used which take different possible changes into account (e.g. w.r.t. DERs, grid topology, population, regulation, etc.).	Partly. Mainly through simulation of first six use-cases above.	2
Business Use Cases			
Microgrid Operator sells/buys energy on external market	The Microgrid operator acts as an aggregator for all his contracted prosumers inside the Microgrid and represents them towards an external market (e.g. wholesale market).	partly Mainly through simulation of first four control use-cases above for test bench purposes.	3
Microgrid Operator sells balancing and ancillary services	The Microgrid operator sells balancing or ancillary services for the stabilization of the electric power network or the consumption of CO2 or other climate related budgets	Yes Mainly through simulation of first four control use-cases above.	2
Microgrid provides Islanding Mode	The Microgrid operator provides the service to go in islanding mode to the overlay grid operator.	Yes Mainly through	2

		simulation of first four control use-cases above.	
Microgrid provides an open trading and communication platform for all internal and external trading	This use case comprises supply-side players such as micro-sources and central generators as well as demand-side players such as storage devices and normal end consumers, both inside and outside of the Microgrid. Selling and buying of energy on the internal and external markets under various optimization strategies is the main purpose of this use case. In contrast to the use case “Microgrid Operator sells/buys energy on external market“, this use case takes into account all different markets inside and outside the Microgrid. The Microgrid operator is no longer an aggregator for all prosumers in the Microgrid, but provides an open trading platform for all internal and external trading of the prosumers in the Microgrid. The openness of this market platform ensures the competition between all market participants inside and outside of the Microgrid.	Partly Mainly through simulation of first four control use-cases above for test bench purposes.	3

4.2 Balancing supply and demand on different time-scales

Rank: High

Relevance of Simulation with Communication Emulation: High

This usecase is mainly based on the FINSENY use case ID FINSENY/WP3/CUC-1 and sub-usecases CUC-1.1 to CUC-1.6 [1]

Reliable & efficient performance of a Microgrid is based on the central tasks of load balancing and power stabilization. DERs or small power plants could be aggregated (e.g. VPP) as well as the demand (consumers) to ease the burden of load balancing. Besides a permanent balance between power generation and consumption electrical stability is mainly handled through voltage and frequency control.

The Microgrid Operator (MO) has to achieve the overall load balance and system stability. Solutions to stability problems of one category should not be at the expense of another. The control services rely on different methods (from direct control to agent-based approaches) and data models are different for DERs (e.g. PV, CHP), storage and consumption.
For a Microgrid two main modi operandi have to be considered:

- Connected (to the Overlay grid)
- Islanding (autonomous Microgrid)

For the operational task to balance, stabilize and optimize the Microgrid the MO uses forecasting information and the status reports from the demand-side, supply-side and storage management systems. In addition he uses all available information on the power grid.
For this main control task it will be necessary to receive real-time measurements of all energy generators, consumers and storage devices. The control services act on different time-scales and will detect all electrical imbalances, and if the difference between energy consumed and produced exceed a predetermined threshold. In case of an electrical instability the MO uses a bunch of automated and semiautomated ancillary services. In case of a load imbalance the MO will change generation and storage capacity as well as consumption dependent on the actual situation.

Relevant Sub Use-cases:

Sub Use-Case [1]	**Description of Sub Use-Case [1]**	**Energy network simulator with telecom emulator can provide substantial value**
CUC-1.1 Forecasting energy production and consumption on different time-scales	The Microgrid operator may have to forecast generation and consumption in order to plan for possible imbalance situations in advance. This requires that he has detailed information about short and long-term generation and consumption profiles, e.g. Numerical Weather Predictions (NWP) and expected consumer consumption during absence periods. The Microgrid operator uses a variety of strategies and methods to accomplish the output generation forecasting and the load forecasting.	Partly. The consequences of forecasting errors or missing forecasts can be analysed.

CUC-1.2 Monitoring	Monitoring has to collect measured data on different time-scales from DERs, Home/Building Energy Management Systems, inverters, switches, substations, and also forecasting and regulation data. Data, to be collected, are e.g. voltage, current, frequency, phase angle, active and reactive power, and state of the control elements. These data need different monitoring approaches depending on their time horizons. A measurement of these quantities could be time-critical and partially need high sample rates. Further measurements are sent only when they exceed thresholds or every time a state change occurs. The task is to optimize the data collection to find a compromise between getting precise enough system states and not overloading the monitoring network. The monitoring protocols have to support all time scales with high reliability. All information collected will be stored in a high-performance database for further processing.	Yes The functionaltiy, its malfunctioning and consequences can be analysed.
CUC-1.4.1 State analysis and sub-sequent actions for providing ancillary services	Based on the collected and processed data to determine the Microgrid's state the Microgrid Operator will have to manage DERs and consumers in order to guarantee the network stability. The stability of the Microgrid - in connected as well as in islanding mode - is affected by voltage and frequency fluctuations, which must stay within predefined acceptable limits. In order to ensure stability in any event the Microgrid Operator will have to monitor all network elements and act accordingly when a deviation exceeds preset thresholds. For this task the MO can rely on a set of Ancillary Services provided on Demand- and Supply-side, e.g. Active Power Voltage Control, Primary, Secondary and Tertiary Reserve, Load Shedding or Shifting.	Yes. The functionaltiy, its malfunctioning and consequences can be analysed. Improved reliability concepts of the microgrid can be tested.
CUC-1.4.2 State analysis and sub-sequent actions for dispatching a contracted energy profile	Microgrid Operator has a contract about import and export of energy profile with the Overlay Grid operator. Contract can be static (e.g. 96 values of kWh per day for every 15 minutes, or 24 values for 24 hours) or dynamic according to an optimization objective (e.g. minimize import / export). The contract is the result of negotiations and market interaction as described in high level use case "Microgrid Operator sells and buys energy on external markets". In order to dispatch the energy profile, Microgrid Operator combines an efficient mixture of the functions described in high level use cases "Demand side management" and "Supply-side management". Such a mixture can comprise functions like "Automated Load Shifting", "Price-based Load Shifting", "Secondary reserve" and "Tertiary reserve". In order to effectively utilize the above functions and coordinate each one ahead of time, Microgrid Operator should implement a coordination function (Energy Profile Coordination). The above functions are effective in different time-scales; therefore the coordinator should take this into account and use these functions accordingly. Moreover, the coordinator assesses data that are produced by Forecasting and Monitoring functions.	Partly. See use cases "Demand side management" and "Supply-side management"
CUC-1.4.3 State analysis and sub-sequent actions for providing operation in islanding mode.	If the Microgrid has no connection to any other electrical network, or the Microgrid Operator has to switch to the islanding mode because a critical imbalance occurs he immediately has to take the necessary actions to balance the internal demand and supply. These actions could include load and generation shedding.	Yes. See use cases "Demand side management" and "Supply-side management"
CUC-1.5 Optimal power flow (intelligent loss minimization)	This use case describes how power flow optimization (intelligent loss minimization) can be achieved. A variety of different techniques can be utilized in order to achieve an optimized power flow. This section only describes those that are controlled directly by the MG operator.	Yes. Testbench for optimization algorithm.

	In order to achieve an intelligent loss minimization the following aspects can be utilized by the Microgrid operator. - Controlling the voltage of the network within the given limits. If the voltage is always kept to the maximum, currents of constant power consumers will decrease and therefore also the losses. - Another method that can achieve multi objective optimization for operation of microgrid including losses reduction is microgrid econfiguration. This can be achieved by balancing loads (exchange between feeders). Microgrid reconfiguration is a process that consists in changing the status of the network switches in order to re-supply the non-energized areas after a fault occurrence, or to optimize given criteria (such as grid losses) in normal operation. - Without changing the network configuration it is possible to influence load flows by controlling active and reactive power injections and consumptions at dedicated points in the network. This may be done within a Microgrid by utilizing the flexibility in active and reactive power supply / demand of DER units and controllable loads. The Microgrid operator needs to calculate the optimal load flow and request actions from DER units and controllable loads.	
CUC-1.6 Switching to and from Islanding Operation	This use case comprises two alternatives: a) the Microgrid is in connected mode and switches to islanding mode b) the Microgrid is in islanding mode and switches to connected mode. The reason for the switching is of no importance for this use case. The use case only deals with the switching operation itself. Switching from connected mode to islanding mode may cause problems in the Microgrid, when the balance between supply-side and demand-side cannot be achieved in case the internal power generation inside the Microgrid is not sufficient. If so, the Microgrid Operator has to initiate suitable countermeasures to avoid longer-term problems inside the energy provision to his Microgrid customers. The different actions possible here are presented in the use case “State Analysis and sub-sequent actions for providing operation in Islanding mode” (5.1.4.3). This use case includes voltage control within the microgrid. When the overlaying grid is disconnected the short circuit is reduced which results in a more weak voltage profile. In case of switching from islanding to connection mode, a new adaptation to frequency and voltage level in the Overlay Grid must be initiated.	Yes. The functionaltiy, its malfunctioning and consequences can be analysed. Improved reliability concepts of the microgrid can be tested.

Actor roles in Use-case:

Actor Name [1]	**Actor Type (person, organization, device, system)** [1]	**Actor Description** [1]	**Needed in Energy network simulator & telecom emulator**
Microgrid Control Center	System	The control system comprehending different subsystems of the Microgrid operator to ensure the control & management tasks of the Microgrid and the aggregation of supply and demand.	Yes
other actors See detailed usecases Demand and Supply side managament			

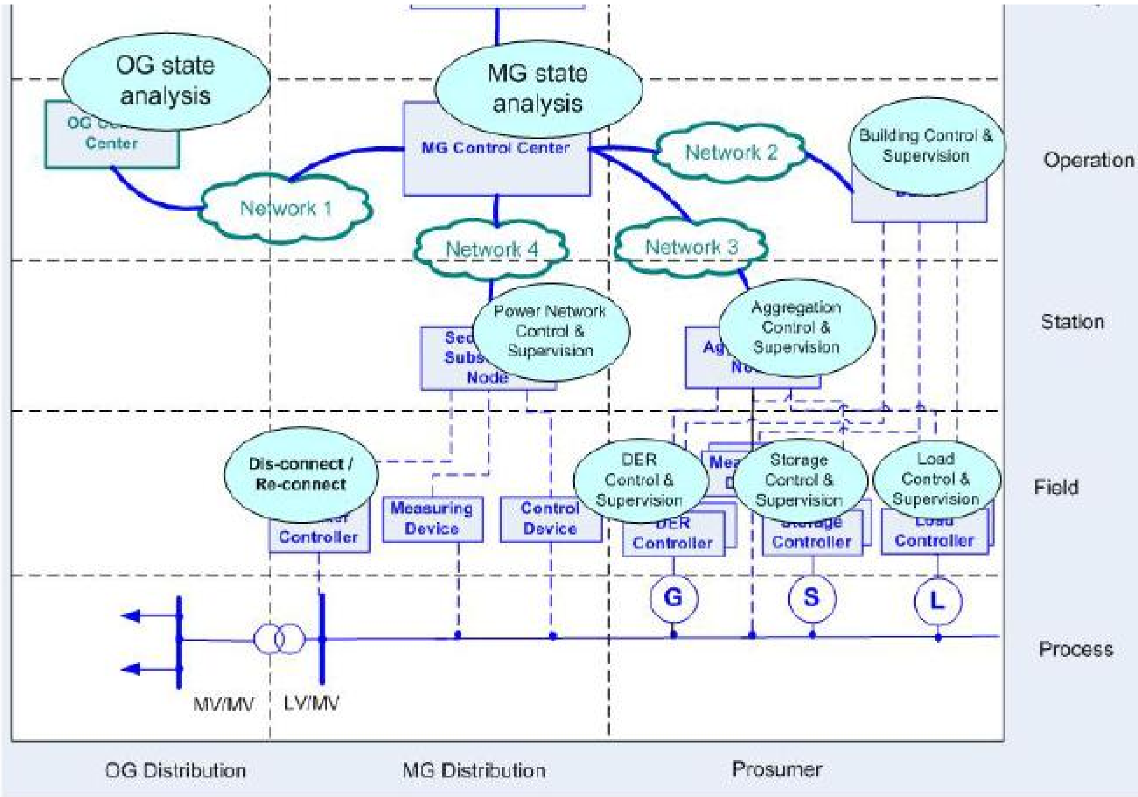


Figure 1: Functional layer for the UC "Switching to-from islanding Mode". [1]

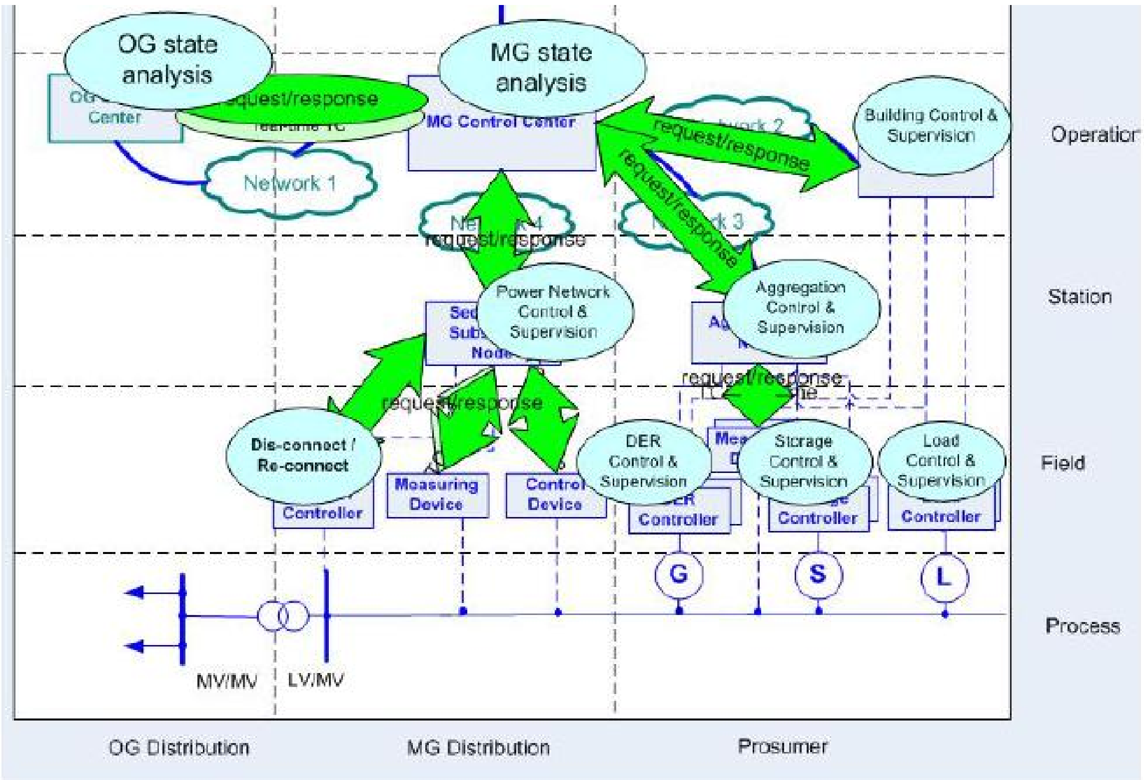


Figure 2: Communication layer for the UC "Switching to-from islanding Mode". [1]

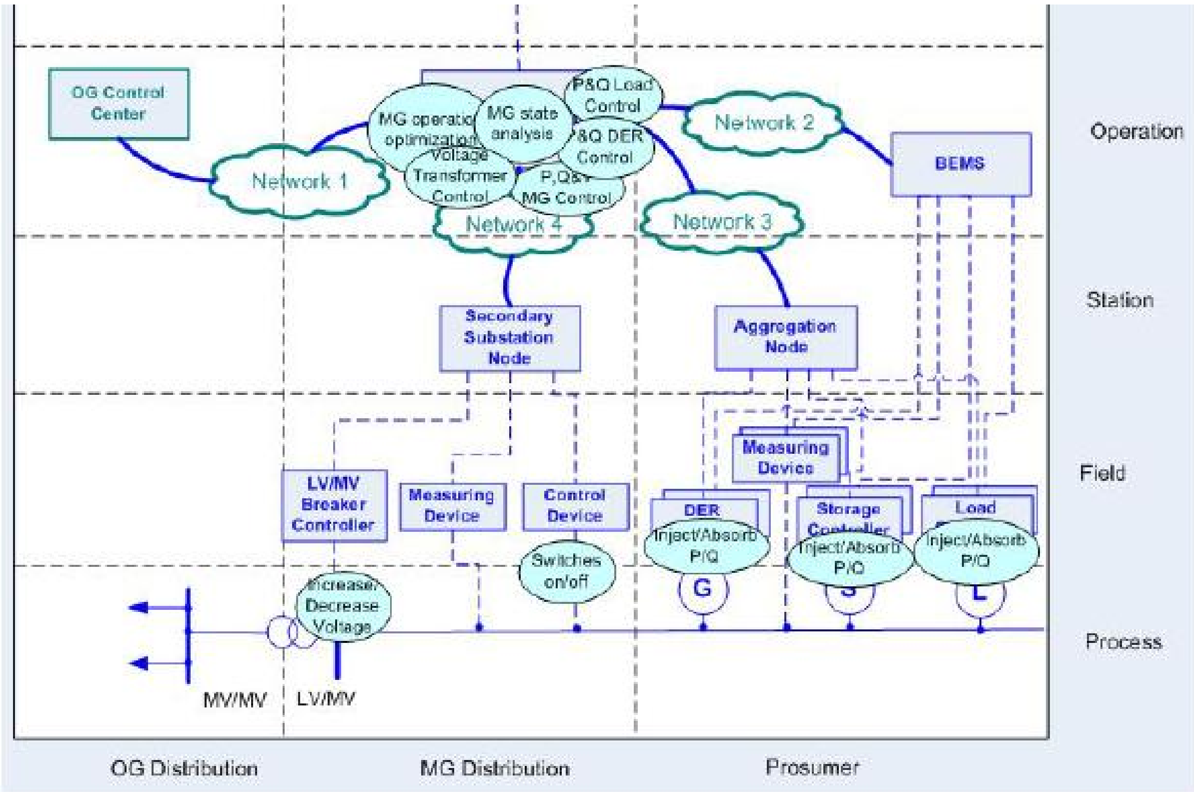


Figure 3: Control UC Optimal power flow [1]

4.2.1 Demand side management (DSM)

Rank: High

Relevance of Simulation with Communication Emulation: High

This usecase is mainly based on the FINSENY use case ID FINSENY/WP3/CUC-2, and sub-usecases CUC-2.1, CUC-2.2.1, CUC-2.2.2 [1]

Demand side management (DSM) is the process of managing the consumption of energy with to goal to increase the grid reliability and stability. Various controlling scenarios and functions take place in order to achieve energy consumption management. Intelligent Load Shedding, Automated Load Shifting and Price-based Shifting are alternative ways to control energy consumption on different timesscales.

Relevant Sub Use-cases:

Sub Use-Case [1]	**Description of Sub Use-Case [1]**	**Energy network simulator with telecom emulator can provide substantial value**
CUC-2.1 Continuous determination of available control power on different time-scales	The Microgrid operator has to monitor its own imbalance position and available options to balance it. For this purpose he needs to have a defined amount of control power (depending on the extension of the microgrid) which is either committed by flexible consumers making their loads controllable or power suppliers committing a certain capacity of their DER for control power. If the control power is provided by flexible consumers making their devices available for load shifting or load shedding an energy management system has to aggregate the availability of the several devices and send the data to the monitoring database which checks the deviations from what is committed. It calculates scenarios on different time scales (e.g. 15 min-4 hours) to provide available options for the Microgrid Operator.	Yes. The monitoring, its malfunctioning and consequences can be analysed. Improved reliability concepts of the microgrid can be tested.
CUC-2.2.1 Intelligent load shedding in critical operations	When Microgrid energy production and consumption comes to imbalance because of either unexpected demand increase or sudden generation drop, then immediate action must take place. Load shedding is a real-time control means to abruptly decrease demand by shutting down loads. In order to minimize the severity of the problems that abrupt load shedding causes, Microgrid Operator prior to load shedding elaborates plans that prioritize loads according to their significance and their characteristics (e.g. time dependence, locality dependence). At the time the Microgrid reaches an instability situation, the problem has to be assessed and a predefined load shedding plan must be selected and executed in real-time. Under this scenario, a careful and intelligent load selection for shutting down loads takes place after automatic assessment of the problem situation. After the assessment and identification of the proper load shedding plan, controllable loads are being shutting down according to the plan, via the exchange of control signals. Moreover use case comprises the following functions: · *Load Shedding Plan Selection.* Within the boundaries of this function Microgrid Operator selects the most appropriate load shedding plan to execute according to given time, severity and	Yes. The load shedding real time triggering and signals, their malfunctioning and consequences can be analysed. Improved reliability concepts of the microgrid can be tested.

	locality data of the critical situation. · *Load Shedding Execution.* This function carries out the transmission of the proper control signals to consumers that executes in real-time the load shedding procedures.	
CUC-2.2.2 Automated Load Shifting / Load Shaping	In this use case we assume an infrastructure at the consumers' premises where there exists an Home/Building Energy Management System that interacts with selected loads which can be controlled and scheduled remotely. Microgrid Control Center directly signals the Energy Management System in order to modify either with increase or reduction the energy consumption at the consumers' premises. This control function has the objective to shift loads in order properly balance and stabilize the grid. Control actions are initiated by Microgrid Operator and directly affect load scheduling in time dimension, if not overridden by the consumer itself. Consumers voluntarily and partially assign control of their loads to Microgrid Operator on the specific extent they wish. Financial incentives can be the main motivation of consumers but also environmental awareness and others. The use case contains a function that control signals originated by Microgrid Control Centre to Home/Building Energy Management System conveying commands for scheduling controllable load operation.	Yes. The load shifting real time triggering and their signals, overriding or malfunctioning and consequences can be analysed.. Improved reliability concepts of the microgrid can be tested.
CUC-2.2.3 Price-based Load Shifting	Microgrid operator manages consumers' available flexibility for increasing or decreasing consumption by providing price incentives. Prices are transmitted to the Home/Building Energy Management System and consumers modify their load profile and schedule in response to the price incentive. The use case contains a function that transmits signals originated by Microgrid Control Center to Home/Building Energy Management System which convey price information.	Yes. The price-based load shifting real time signals, their acceptance or malfunctioning and consequences can be analysed..

Actor roles in Use-cases:

Actor Name [1]	**Actor Type** [1]	**Actor Description** [1]	**Needed in Energy network simulator & telecom emulator**
Microgrid Control Center	System	The control system comprehending different subsystems of the Microgrid operator to ensure the control & management tasks of the Microgrid and the aggregation of supply and demand.	Yes
Home/Building Energy Management System	System	System acting at the interface between Smart Home/Building and the Microgrid. It communicates inhouse with Smart Appliances and to the outside with the Microgrid Control Center. It aggregates the services of the Smart Appliances in the household and provides them to the Microgrid. Furthermore, it can implement some level of intelligence to fulfill the services.	Yes

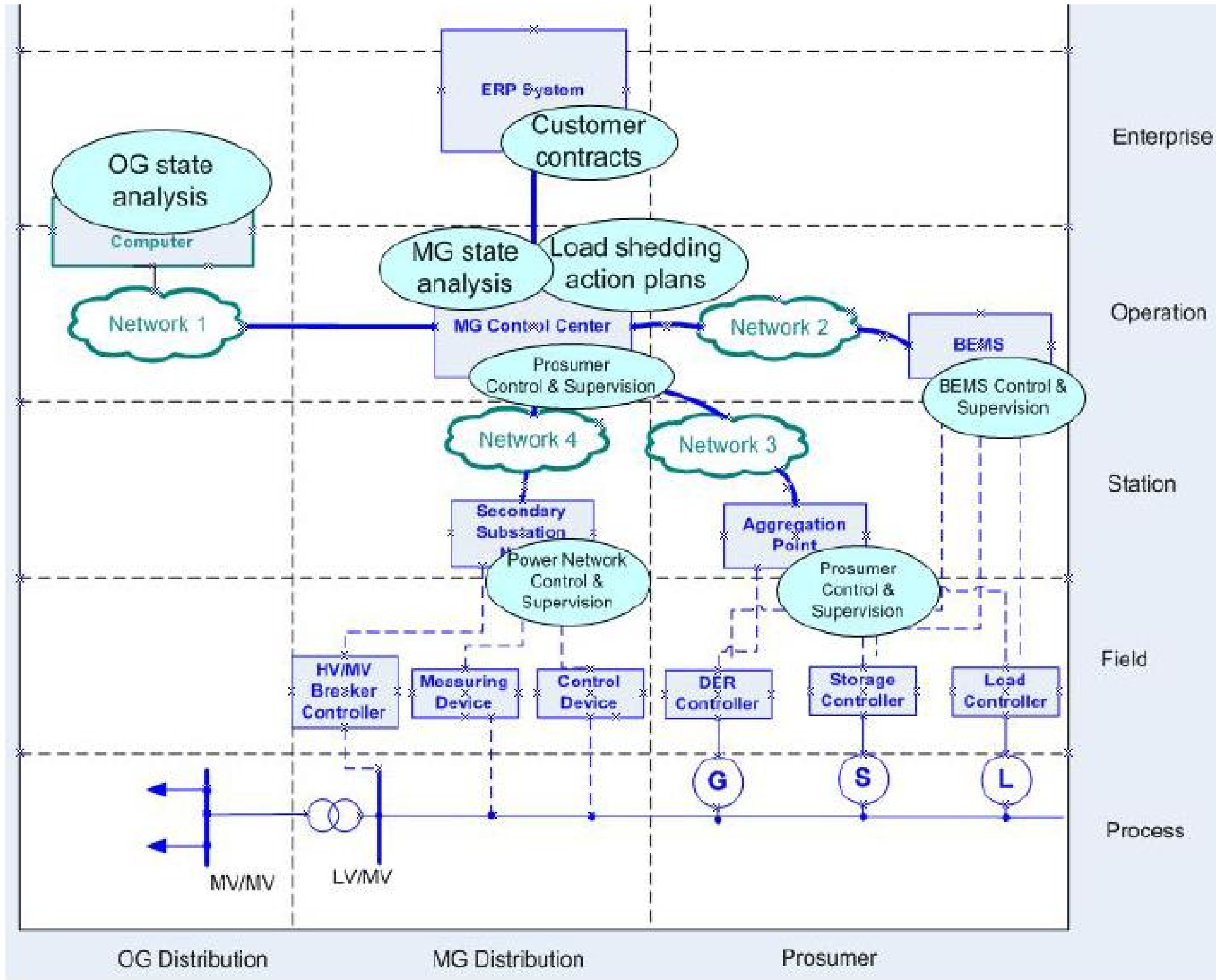


Figure 4: Control UC Intelligent load shedding [1]

4.2.2 Supply-side management

Rank: High

Relevance of Simulation with Communication Emulation: High

This usecase is mainly based on the FINSENY use case ID FINSENY/WP3/CUC-3, and sub-usecases CUC-3.1, CUC-3.2.1 - CUC-3.2.8 [1]

This section about supply-side management gathers all aspects related to monitoring and control of decentralized supply. Therefore, supply-side management describes the most relevant use cases which are somehow related to DER units. This contains use cases about monitoring the state of DER units as well as use cases about controlling the active and reactive power generation. Goals of these use case reach from secure operation of the microgrid via optimized power quality within the MG until ancillary services offered to the overlay grid operator by control of DER units. Some of these use cases may be based on similar technical principles, but are pursuing different goals.

<u>Relevant Sub Use-cases:</u>

Sub Use-Case [1]	Description of Sub Use-Case [1]	Energy network simulator with telecom emulator can provide substantial value
CUC-3.1 Continuous determination of available control power on different time-scales	The Microgrid operator has to monitor its own imbalance position and available options to balance it. For this purpose he needs to have a defined amount of control power (depending on the extension of the microgrid) which is either committed by flexible consumers making their loads controllable or power suppliers committing a certain capacity of their DER for control power. If the control power is provided by power suppliers committing a certain capacity of their DER in a certain time for control power, the Microgrid Control Center has to aggregate the availability of the several DERs and check the deviations from what is committed. It calculates scenarios on different time scales (e.g. 15 min-4 hours) to provide available options for the Microgrid Operator.	Yes. The functionalities, their malfunctioning and consequences can be analysed. Improved reliability concepts of the microgrid can be tested.
CUC-3.2.1 Active Power Voltage Control	In order to keep the voltage along the lines within the Microgrid as constant as possible, the Microgrid Control Center controls all DER units and flexible demand. In this use case only the active power is controlled. This works best in networks with mostly ohmic characteristic of lines (X/R << 1, typically MV to LV level).	Yes. see above.
CUC-3.2.2 Reactive Power Voltage Control	This is only used internally by the Microgrid Operator to stabilize the voltage in the Microgrid. In order to keep the voltage along the lines within the Microgrid as constant as possible, the Microgrid Control Center controls all DER units and flexible demand. In this use case only the reactive power is controlled. This works best in networks with mostly reactive characteristic of lines (X/R >> 1, typically HV to MV level). The benefit of using ICT in this use case is an optimal utilization of different DER units that are able to provide this service.	Yes. see above.
CUC-3.2.3 Reactive Power Compensation	This is a service provided at the interface to the overlay grid, but the optimization is carried out within the Microgrid and may be of special importance in disconnected (islanding) mode. The Microgrid has a contracted maximum and minimum power	Yes. see above.

	factor. He uses the flexibility of DER units to keep the power factor within the given limits and therefore reduces the requirement to install other kinds of compensation systems. Hence, it does not completely replace an adequate planning of reactive power needs of the network but it introduces flexibility and therefore reduces the need for installations. ICT is needed to coordinate the capabilities of all DER units in an optimal way (not every unit can deliver this service at the same time or at the same price).	
CUC-3.2.4 Voltage Var Control	The last reactive power related UC is a service offered to the overlay grid operator and can therefore only be offered in connected mode. The microgrid provides reactive power (both capacitive and inductive) to the overlay grid in order to increase voltage stability and optimize load flows as requested by the Overlay Grid Control Center.	Yes. see above.
CUC-3.2.5 Enhance Local Power Quality	Disturbances of power quality in a network regarding harmonics caused by DER units or other electrical devices can be minimized by optimizing the power electronics of the DER units or filters. In order to enhance the local power quality regarding harmonics, the Microgrid Control Center controls all DER units. In case of insufficient power quality the devices enhance the local power quality with regard to harmonics. This may be done by preliminarily switching to a different operating point, increasing or reducing power, changing control algorithm of devices etc..	Partly. Impacts of Setpoint communication could be analysed. Harmonics must be simulated with own dedicated tools for electromagnetic transient simulations, e.g. PS-CAD.
CUC-3.2.6 Primary Reserve	The Microgrid provides primary reserve power to the system. Therefore, Microgrid Control Center and DER units need to form a pool that can be offered at the reserve power markets. Currently this is not allowed but in the future it is quite likely to be required (as less conventional plants will be available for this). Offers in reserve power markets are likely to take place on a regular basis (tertiary requirements), but within the Microgrid pooling may be a very dynamic process (primary requirements). Activation of this service is likely to remain an automatic process as it is today.	Yes. The functionality and malfunctioning consequences can be analysed. Improved reliability concepts can be tested.
CUC-3.2.7 Secondary Reserve	The Microgrid provides secondary / tertiary reserve power to the system. To the external system the Microgrid acts as one entity (represented by its Microgrid Control Center) and internally it optimizes the use of DER units and flexible demand for this purpose.	Yes. see above.
CUC-3.2.8 Tertiary Reserve		Yes. see above.

Actor roles in Use-case and Sub Use-cases:

Actor Name [1]	**Actor Type** [1]	**Actor Description** [1]	**Needed in Energy network simulator & telecom emulator**
Microgrid Control Center	System	The control system comprehending different subsystems of the Microgrid operator to ensure the control & management tasks of the Microgrid and the aggregation of supply and demand.	Yes
Overlay Grid Operator	Organization	The Overlay Grid Operator is the operator of the grid to which the Microgrid has a connection point. The Overlay Grid Operator is a Grid Operator. The term „Grid Operators“, refers to the undertakings of operating, building,	Boundary Condition or input scenario

		maintaining and planning of the electric power transmission and distribution networks.	
DER Unit	Device	Distributed Energy Resource including Distributed Generation (small PV, wind, etc.) which is connected to the Microgrid. The device provides some degree of intelligence to be monitored and controlled.	Yes

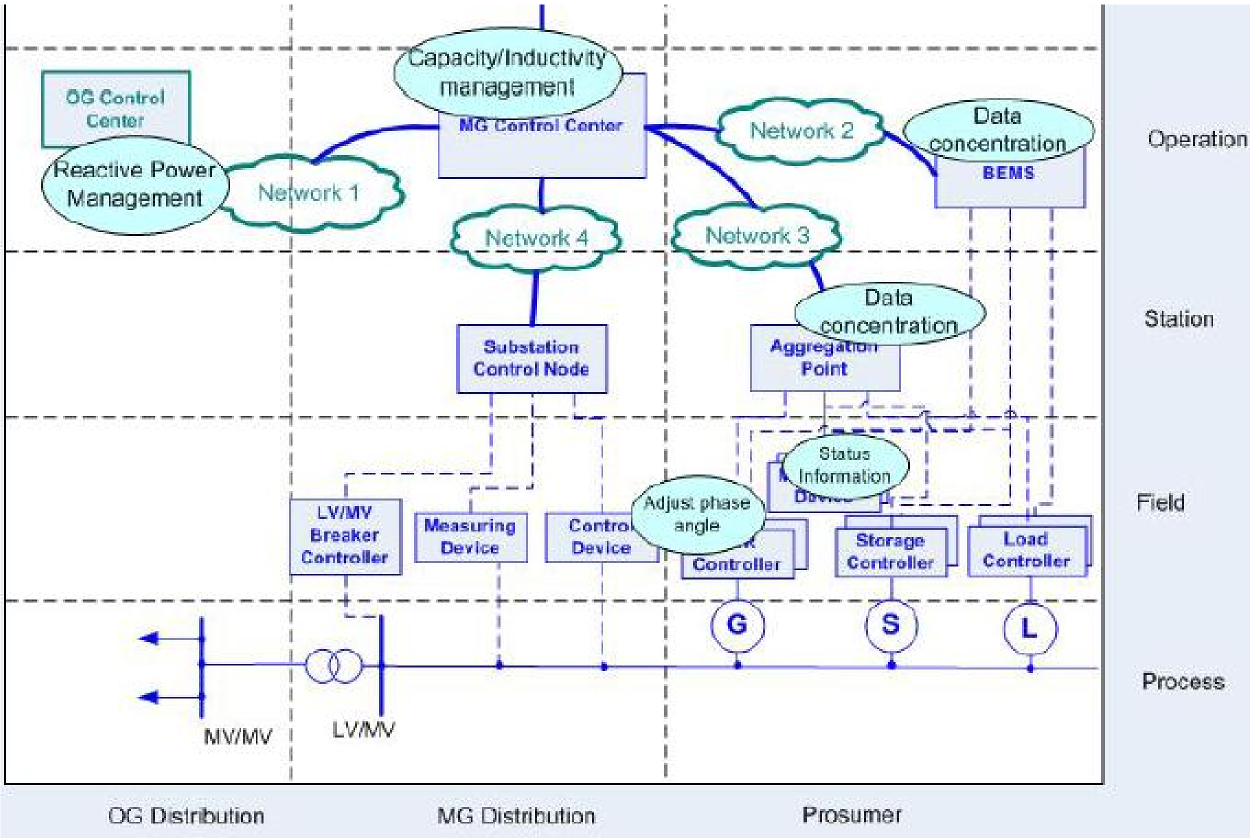


Figure 5: Control UC Voltage VAr control [1]

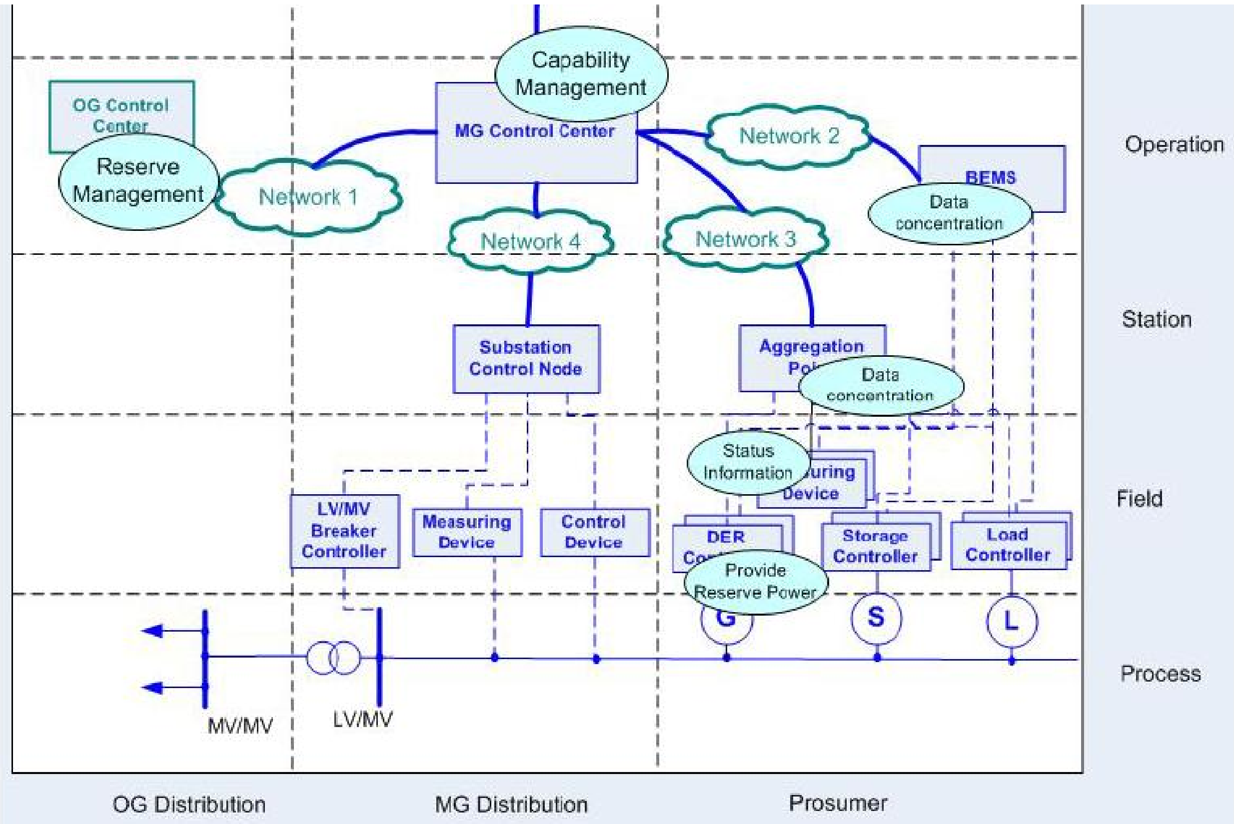


Figure 6: Control UC Primary reserve [1]

4.3 Microgrid Black Start, Protection & Restoration

Rank: High

Relevance of Simulation with Communication Emulation: High.
Black start and Restoration MCC functions could be developed and evaluated from the dynamic operation point of view through studies to be performed in a combination of energy network simulation model and communication emulation

This usecase is mainly based on the FINSENY use case ID FINSENY/WP3/CUC-4 [1]

If a system disturbance provokes a general black out such that the Microgrid (MG) was not able to separate and continue in islanding mode, and if the system is unable to restore operation in a specified time, a first step in system recovery will be a local Black Start.
Two types of Black Start (BS) functions are needed:

- Local Black Start of the Microgrid after a general system black out;
- Grid reconnection during Black Start.

The strategy to be followed is a matter for investigation and involves the cooperation of the various system controllers both central and local, using predefined rules and exploiting autonomous agent concepts. The restoration process for any power system is a very complicated process. The related restoration tasks are usually carried out manually, according to predefined guidelines. They have to be completed fast in a real time basis under extreme stressed conditions. In a Microgrid, the whole procedure is much more simple because there are not many loads, switches and large, difficult to control, generation units. In addition, the power electronic interfaces of the distributed resources and loads offer considerable flexibility. Thus, the idea of creating a totally automatic system for restoration seems quite realistic.
A special feature of the Microgrid central controller concerns re-connection during Black Start, helping in this way the upstream DMS system that is managing the distribution network. During faults on the main grid the Microgrid may be disconnected from the main utility and will continue to operate with as much connected DG, as possible. During reconnection the issue of out-of phases reclosing needs to be carefully considered. The development of local controllers in close co-ordination with the Microgrid Central Controller functions need to be developed and evaluated from the dynamic operation point of view through studies to be performed in the simulation platform. These Black Start functions contribute to assure an important advantage for power system operation in terms of reliability as a result from the presence of a very large amount of dispersed generation.
The restoration procedure in a MG has some similarities with the approach adopted on a medium sized power system, namely: the need for several sources with Blackstart capabilities and standby power supply and a monitoring and control scheme embedded in the Microgrid Control Center (MGCC). Blackstart functionalities can be based on a set of rules identified in advance and embedded in the Central Controller.

Actor roles in Use-case:

Actor Name [1]	**Actor Type** [1]	**Actor Description** [1]	**Needed in Energy network simulator & telecom emulator**
Microgrid Control Center	System	The control system comprehending different subsystems of the Microgrid operator to ensure	Yes

		the control & management tasks of the Microgrid and the aggregation of supply and demand.	
Overlay Grid Operator	Organization	The Overlay Grid Operator is the operator of the grid to which the Microgrid has a connection point. The Overlay Grid Operator is a Grid Operator. The term „Grid Operators“, refers to the undertakings of operating, building, maintaining and planning of the electric power transmission and distribution networks.	Input scenario
Consumer	Person/ Organization	A consumer of electricity which is a private, business building, large industrial / manufacturing industry or transportation system. The consumer acts as a customer. The consumer may operate Smart Appliances (an electrical load with some intelligence to control it) which are flexible in demand.	Behaviour of various consumers should be modelled.
Overlay Grid Control Center	System	Control center from which the overlay grid is operated. All required supervision and control functions are carried out here.	As scenario and communication counterpart.
DER Unit	Device	Distributed Energy Resource including Distributed Generation (small PV, wind, etc.) which is connected to the Microgrid. The device provides some degree of intelligence to be monitored and controlled.	Yes
Network Smart Device	Device	An intelligent electrical device in the Microgrid that can be supervised and controlled (e.g. sensors, circuit-breakers or switches)	Yes

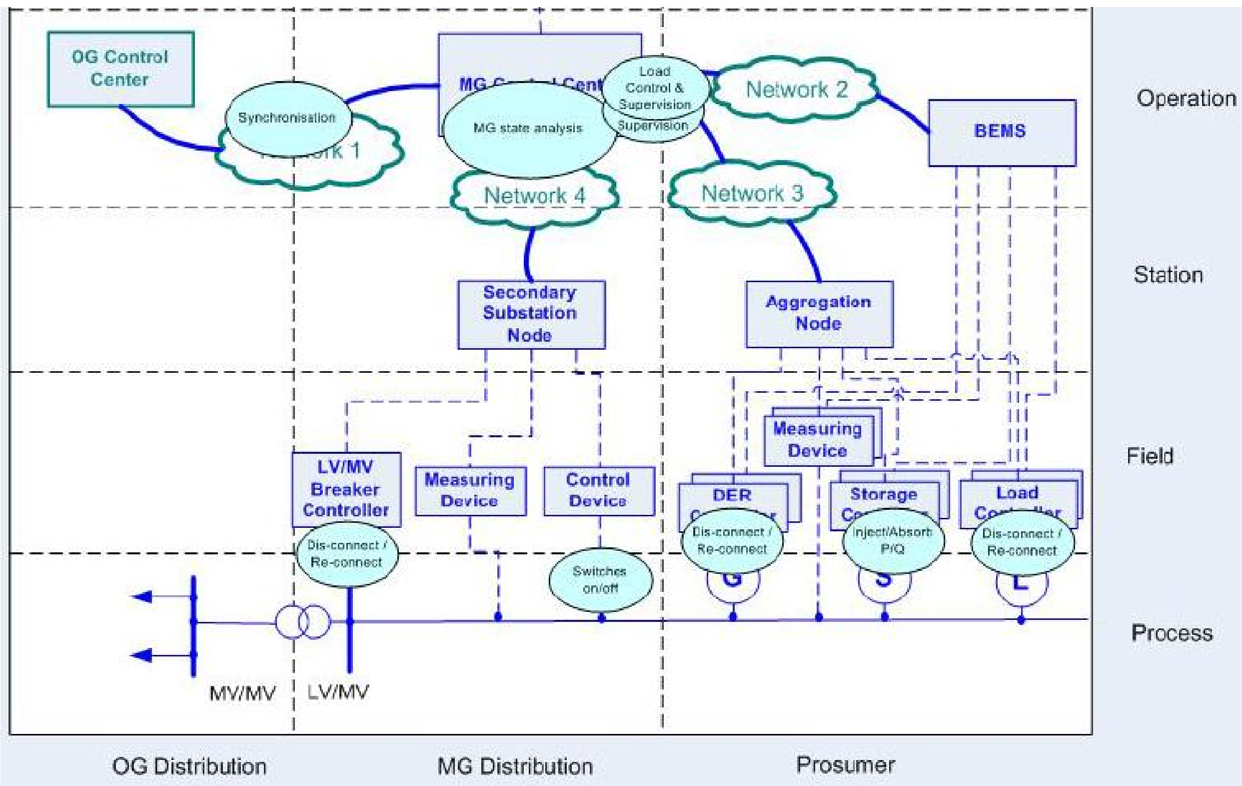


Figure 7: Control UC Black start in Islanding mode [1]

4.4 Communication requirements of the Control Use Cases

Use Case ID	Use Case Name	Use Case Activity	Communication Requirement (e.g. QoS, bandwidth, latency, reliability, determinism, grade of distribution) [1] + *{Data processing requirement} [1]*
CUC-1.1	Forecasting energy production and consumption on different time-scales	Planning Data collection	Medium BW for collecting forecast & planning data, non real-time
CUC-1.2	Monitoring	Supply Side Monitoring Demand Side Monitoring Power Grid Monitoring	Partially strict real-time, high volume; Protocol Types: Transaction-based, Request/Response, publish/Subscribe; Traffic Management
CUC-1.4.1	State analysis and sub-sequent actions for providing ancillary services	State analysis and sub-sequent actions for providing ancillary services	*{High processing power for state calculation}*
CUC-1.4.2	State analysis and sub-sequent actions for dispatching a contracted energy profile	Dispatching a contracted Energy Profile	*{Medium processing demand for computing resources for calculation and simulation models}*
CUC-1.4.3	State analysis and sub-sequent actions for providing operation in islanding mode.	State analysis and sub-sequent actions for providing operation in Islanding mode	*{High processing power for state calculation}*
CUC-1.5 CUC-1.6	Optimal power flow (intelligent loss minimization) Switching to and from Islanding Operation	Microgrid Operator invokes Islanding mode	Transmission and Evaluation of disconnection from overlay grid may be handled in real-time: - Transmission for messages for state analysis in the microgrid in the order of "ms" - medium to high bandwidth required, depending on the devices in the microgrid *{High demand for computing resources for calculation and simulation models in Microgrid Control Centre}*
		Microgrid switching from connected mode to islanding mode	Transmission of new schedules and strategies inside isolated microgrid must be handled in real-time to avoid short outage of energy supply inside microgrid systems - Transmission for message "Switch_islanding_control" in the order of "ms" - eventually medium bandwidth sufficient (< 1 Mbit/s) Transmission of required data and actions less critical (some seconds), medium bandwidth probably sufficient (< 1 Mbit/s) *{High demand for computing resources for calculation and simulation models in Microgrid Control Centre}*
		Switching to Connected Mode	*{Medium processing demand for adaptation to electrical parameters in Overlay Grid}*
CUC-2.1	Continuous	Monitoring available control power on different	High demand for collecting data about

	determination of available control power on different time-scales	time-scales	availability, real-time, update from all devices each 15 minute needed *{High demand for computing resources for calculation and simulation models}*
CUC-2.2.1	Intelligent load shedding in critical operations	Load Shedding Execution,	Reliable communication with very low latency among control entities
		Load Shedding Plan Selection	*{High demand for computing resources for calculation and simulation models}*
CUC-2.2.2	Automated Load Shifting / Load Shaping	Automated Load Shifting	Reliable communication with transactional nature. Time-scale is secondary control. *{High demand for computing resources for calculation and simulation models}*
CUC-2.2.3	Price-based Load Shifting	Price-based Load Shifting	Reliable communication with transactional nature. Time-scale is tertiary control. *{High demand for computing resources for calculation and simulation models}*
CUC-3.1	Continuous determination of available control power on different time-scales	Continuous determination of available control power on different time-scales	Low demand for collecting data about availability (e.g. once per hour) needed as safety check. *{High demand for computing resources for calculation and simulation models}*
CUC-3.2.1	Active Power Voltage Control	Active Power Voltage Control	Grid data is static, not transmitted Capabilities should be described with data < 10 kB *{High demand for computing resources for calculation and simulation models}*
CUC-3.2.2	Reactive Power Voltage Control	Reactive Power Voltage Control	
CUC-3.2.3	Reactive Power Compensation	Reactive Power Compensation	
CUC-3.2.5	Enhance Local Power Quality	Enhance Local Power Quality	
CUC-3.2.4	Voltage Var Control	Voltage Var Control	Status of DER units in the order of < 10 kB *{Medium demand for computing resources, no network simulation required}*
CUC-3.2.6	Primary Reserve	Primary Reserve	
CUC-3.2.7	Secondary Reserve	Secondary Reserve	
CUC-3.2.8	Tertiary Reserve	Tertiary Reserve	
CUC-4	Black Start in Islanding mode	Cutting of the microgrid Building of the microgrid Connection of all the MS to the MG Synchronisation of the small islanded microgrid LCs connect controllable loads to the MG Synchronization of the MG with the overlay network	Communication between the MGCC and active Network Devices Communication between the MGCC and all the MSs. Bidirectional communication between all the MCs and with the MGCC Bidirectional communication between LCs, MCs, and the MGCC. Bidirectional communication between MGCC and the Control Centre Overlay Grid *{Remote control from the MGCC to inverters associated with the storage devices.}*

5 Microgrid Control Center and Field Level Functions

From the use-cases presented in chapter 3.3, following microgrid control center and field level functions can be identified [1]:

	Layer	Function	Relevance of simulator&emulator for e.g. testing
Microgrid Control Center functions	Application layer	MG long term schedule	Moderate, only simulation tests.
		Demand-Side Management	High
		Supply-Side Management	High
		Storage Management	High
		Balancing Demand & Supply	High
		MG offline simulation	Moderate
	Control layer	Capability Management	High
		Generation Control & Supervision	High
		Load Control & Supervision	High
		Capacity/Inductivity management	High
		OG State analysis	Minor
		MG State analysis	High
		MG generation & load scheduler	High
		MG power computation	High
		MG operation optimization	High
	Sub-Control layer	P&Q Load control	High
		P&Q DER control	High
		P&Q MG control	High
		Voltage Transformer Control	High
	Access layer	Registration handler	High
		Resource & service discovery	High
		Access control	High
Field Level functions	ML Control Functions (field level part)	DER Control & Supervision	High
		Load Control & Supervision	High
		Storage Control & Supervision	High
	LL Control Functions	DER Output control	Simulation
		Load Control	Simulation
		Increase/Decrease Active/Reactive Power output	Simulation
		Provide Reserve Power	Simulation
		Transfer excess/draw deficit	Simulation
		Dis-connect/Re-connect	Simulation
	LL Monitoring Functions	Power network Monitoring	Simulation
		DER Monitoring	Simulation
		Power Quality Measuring	only PSCAD simulation
		Power Factor Measuring	Simulation
		Voltage Measuring	Simulation
		Output Measuring	Simulation
	Middleware Fct	Bootstrapping with registration	
	Sub Field Level Fct	Switches on/off	Simulation
		Inject/Absorb P/Q	Simulation
		Adjust phase angle	Simulation

6 Future work

VTT is participating in several national and international Smart Grid related projects. The planned work related continuing efforts for Smart Grid simulator implementation are carried mainly within the following projects:

- FINSENY: architecture design and trial system implementation for distribution network (2012-2015).
- SGEM IV: Smart Grid simulator system implementation (2012-2014).
- TSES 11814 (EIT ICT funding): Smart Grid virtual laboratory trial (2013).

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[2] K. Eger, J. Götz, R. Sauerwein, R. Frank, D. Boëda, I. M. D. De Cerio, R. Artych, E. Leukokilos, N. Nikolaou and L. Besson, “FI.ICT-2011-285135 FINSENY D.3.3 v1.0 Microgrid Functional Architecture Description,” (FP7) Siemens AG, Grenoble INP, Iberdrola S.A., Orange Labs, Synelixis, Thales, 03 31 2013. [Online]. Available: http://www.fi-ppp-finseny.eu/wp-content/uploads/2013/04/FINSENY_D3-3_Microgrid_Functional_Architecture_v1_0_March_2013.pdf. [Accessed 29 08 2013].