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Statement of Originality

This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both.

Table of Contents

Glossary

This vocabulary captures important acronyms and defines important concepts used throughout the Net2DG project. Some of the technical definitions are taken from EN 50160 to ensure generality.

AMI	Advanced Metering Infrastructure
Aggregator	An entity that have an agreement with a prosumer regarding access to control consumption and/or production flexibility in the electricity market. An aggregator pools flexibility from a number of prosumers and converts this into services into the electricity market to be used by TSO, DSOs or the balance responsible.
CHP	Combined Heat and Power plant
CIS	Customer Information System
Consumer	The customer of the DSO and the final consumer of energy delivered via the distribution grid. A consumer can be a normal household, an SME or a large industry. A consumer can offer an ability to control consumption (loads and/or energy or electricity storage facilities), see also prosumer. A consumer will always be behind a meter.
Control bandwidth	The possible number of control actions that can be send to an actuator and executed within a given timeframe.
DER	Distributed/Dispersed Energy Resources. [EPRI]: Distributed energy resources (DER) are smaller power sources that can be aggregated to provide power necessary to meet regular demand. As the electricity grid continues to modernize, DER such as storage and advanced renewable technologies can help facilitate the transition to a smarter grid.
DG/RES-E	Distributed Generation / Renewable Energy Source - Electricity
DSO	Distribution System Operator
Fault	Adjudged or hypothesized cause of the deviation of the behaviour of a system from its intended behaviour. Put into the context of electricity grids, examples of grid faults include leakage due to aging cables, short circuits, bad connections etc. In the context of ICT systems, example faults include disruptions of the communication cable/fiber, high noise levels causing message modifications/bit flips, interference or congestion causing communication delays. Example of Usage:
GOD	Grid outage diagnostics
GIS	Geographic Information System

Grid	Hardware infrastructure related to power system. It contains all the related components from generation to end user i.e. cables, overhead lines, transformers, etc. Example of Usage: power grid, electricity, transmission grid, distribution grid, smart grid, etc.
HES	Head End System
Leakage current	Undesired current phase-to-ground, phase-to-neutral, or phase-to-phase. In most cases the last case will lead to the (in the LV grid mostly passive) protection system tripping. . Alternative Definition: Leakage current is the current that flows through the protective ground conductor to ground. In the absence of a grounding connection, the current could flow from any conductive part or the surface of non-conductive parts to ground if a conductive path was available (such as a human body). There are two types of leakage current: ac leakage and dc leakage. DC leakage current usually applies only to end-product equipment, not to power supplies. AC leakage current is caused by a parallel combination of capacitance and dc resistance between a voltage source (ac line) and the grounded conductive parts of the equipment.
Measurement Logging period	In case of local processing at the sensor, e.g. averaging, the time interval covered by this local processing. For instance, in smart meter data, the Measurement time granularity/logging period for data communicated to the head end is in the Danish case 15min. Within a logging period, values for current and voltages are automatically averaged. Energy is logged as unit growth.
Measurement sampling Time	The time interval between two readings at the local sensor
Measurement access delay	The duration of the period from when a measurement is available at a local sensor (e.g. Smart Meter) until this measurement is available for processing at an application running at the DSO site. Several applications are running at TME and they may have different data access delay. For instance, the current IT architecture of the current Smart Meter deployment in Denmark leads to a Measurement Access Delay of up to 24 hours as the time series from the Head End system is exported every 24 hours to the TME billing system.
Measurement accuracy	The deviation of a measurand from the true physical value. Measurement errors can be caused by noise, bias in the measurement procedure. The maximum error of a measurement device is usually specified in classes which are defined in standards as percentage from the measured value.

Measurement timing Uncertainty	The delay of accessing measurement values in case of real-time applications (i.e. when the true physical value has evolved since the measurement has been taken). Timing uncertainty can also originate from uncertainty in the timestamp precision or differences in timing across nodes.
OLTC	An Onload Tap Changer makes it possible to control the voltages on the LV side of the substation transformer within certain bounds. The voltage is changed by selecting different taps on the HV side of the transformer
NAN	Neighborhood Area Network
Net2DG	Leveraging Networked Data for the Digital Electricity Grid
Network	Hardware infrastructure related to data communication. It contains various network nodes and communication media to interconnect between two communicating entities. Example of Usage: an AMI system based on RF MESH communication on the NAN level, combined with 3GPP based WAN connection
Outage	[IEEE 1366]: The loss of ability of a component to deliver power. Net2DG interpretation of the standard term: An outage is the loss ability to deliver demanded electrical power to a point or position in the electricity grid.
PQ	Power Quality
Prosumer	A consumer that has the ability to deliver power to the grid. See also consumer.
PV	Photovoltaic
RES	Renewable Energy Sources
RMS Voltage	Root Mean Square voltage: The RMS value is the square root of the mean (average) value of the squared function of the instantaneous voltage values. The mean is taken over an integer number of cycles of 20ms.
SCADA	Supervisory Control And Data Acquisition
Short circuit	[IEC 60909]: the accidental or intentional conductive connection through a relatively low resistance or impedance between two or more points of a circuit which are normally at different potentials
Supply interruption	[EN 50160]: A condition in which the voltage at the supply terminals is lower than 1% of the declared voltage. A supply interruption can be classified as: Long interruption (longer than 3 min) caused by a permanent fault Short interruption (up to 3 min) caused by a transient fault
Transient overvoltage	Definition from EN50160: Transient over voltages are usually caused by lightning, switching or operation of fuses. The rise time of a transient overvoltage can vary from less than a microsecond up to a few milliseconds. For physical reasons, transients of longer durations usually have much lower amplitudes. Therefore, the coincidence of high amplitudes and a long rise time is extremely unlikely.
THD	Total Harmonic Distortion
TSO	Transmission System Operator

Voltage dip (or sag)	Definition from EN50160: a sudden reduction of the supply voltage to a value between 90% and 1% of the declared voltage followed by a voltage recovery after a short period. Conventionally the duration of a voltage dip is between 10 ms and 1 min. The depth of a voltage dip is defined as the difference between the minimum RMS voltage during the voltage dip and the declared voltage. Voltage changes which do not reduce the supply voltage to less than 90% of the declared voltage are not considered to be dips. Remarks: Typically, a dip is associated with the occurrence and termination of a short circuit or with other extreme current variations on the system or an installation connected to it.
Voltage swell	EN50160: RMS Voltage above 110% of reference voltage for time periods from 10ms to 60 seconds. Remark: Typically, a swell is associated with low load situation combined with high production (PV/WTG).
Voltage unbalance	EN50160: a condition in which the RMS value of the phase voltages or the phase angles between consecutive phases is not equal.
Use-Case (UC)	A use case typical express how the system interacts with users and in between sub-systems to deliver the desired value. It captures design elements and functional allocation between parts. In Net2DG use cases will be used on two levels; A high level blackbox level to express interaction between the user, the grid and the system as a whole. In addition, on a more detailed whitebox level to express application layer requirements as a complement to the baseline architecture description. A Use Case is defined considering a given set of operating conditions of the power grid.
User Story	A high level expression of desired value creation, typical in the form of "As a < type of user >, I want < some goal > so that < some reason >". See **https://www.mountaingoatsoftware.com/agile/user-stories** for more details on creation of user stories. In Net2DG user stories will be used to capture the essence of the desired outcome seen from the DSO point of view.
WTG	Wind Turbine Generator

1 Executive Summary

The Net2DG solution correlates data from smart meters and smart inverters with information from existing DSO subsystems, in order to enable and develop novel LV grid observability applications for voltage quality, grid operation efficiency, and LV grid outage diagnosis. The achieved observability is subsequently used by specifically developed novel control coordination approaches, which utilize the existing smart meter and smart inverter actuation capabilities in conjunction with selected existing DSO actuation for voltage quality enhancement and loss minimization in the LV grid.

This deliverable presents the use-cases for Net2DG and derives requirements from these use-cases on Net2DG applications and on the Net2DG Data Gateway. The definition of the use-cases starts from an analysis of the current DSO scenarios and DSO needs of the two DSOs in the Net2DG consortium and with input from the reference group of DSOs. This pre-analysis also includes the inspection of first data traces in several cases. In a next step, the deliverable describes the current situation with respect to energy markets and business relations of the DSOs in the consortium, and derives a market related future scenario from these. This pre-analysis is subsequently used to define a set of Net2DG user-stories and derive use-cases from these. These use-cases will be prioritized by the Net2DG consortium. In a final step, requirements on the Net2DG applications and on the Net2DG Data Gateway are derived from these use-cases.

The prioritized set of use-cases will be subject for implementation in Net2DG, the resulting and detailed architecture of the Net2DG system will be presented together with lower level requirements in the D1.2 deliverable of WP1.

2 Introduction

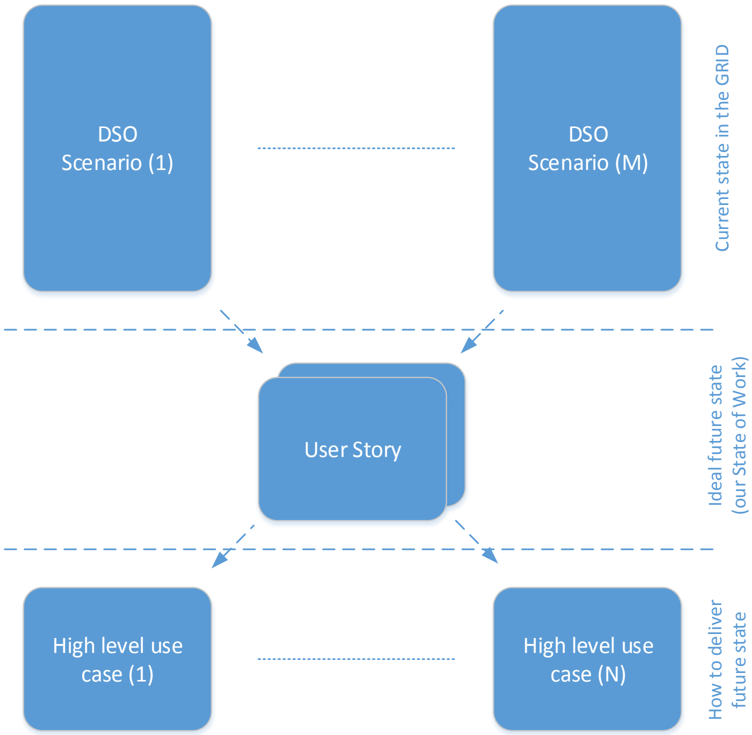
The Net2DG project will develop a proof-of-concept solution based on off-the-shelf computing hardware that uses available communication technologies to leverage measurement data from smart meters and smart inverters in LV grids. The Net2DG solution correlates these data with information from existing DSO subsystems, in order to enable and develop novel LV grid observability applications for voltage quality, grid operation efficiency, and LV grid outage diagnosis. The achieved observability is subsequently used by specifically developed novel control coordination approaches, which utilize the existing smart meter and smart inverter actuation capabilities in conjunction with selected existing DSO actuation for voltage quality enhancement and loss minimization in the LV grid.

The purpose of this document is to document the process from the original Net2DG hypotheses and goals as outlined in the project application into first set of application requirement to be used in the subsequent work packages.
The process includes structure process of documenting the AS-IS situation, below named DSO scenario. Aspects on market structure and regulatory framework are treated separately and will also form input for the Net2DG definition work.
Based on these, the document describes a number of user-stories, which attempt to extract a new value proposition to target identified challenges in the DSO scenarios. Finally, these user-stories are coupled to use-case to express, how the value is delivered to the user and finally application requirements that allocates functionality to components/(sub)-systems identified in the Net2DG system architecture.
Details on this methodology can be found below.

2.1 Methodology

WP 1 will address the challenges by analyzing the low voltage grid operation from three different angles:
Understanding what create outages in the low voltage grid
Understanding of barriers for achieving operational efficiency in the low voltage grid operation
Understanding what conditions create problems in delivering optimal voltage quality to end-consumers
The achieved knowledge will be used to identify potential cases for improvements in the form of value-based user stories and subsequently high-level use case for draft details on how this value can be delivered to the DSOs. The high-level use cases will then form the basis for identification of specific application requirements linked to the proposed Net2DG application architecture.

This can be illustrated as:



The DSO scenario descriptions will focus on providing details on grid conditions, problem characteristics and possible derived indicators. The scenarios will primarily be based on specific analyses of grid conditions in the Net2DG DSO partner's distribution networks. It will however also be broadened/generalized based on inputs from the Net2DG reference group.
User stories will be described in the form of:

As a < type of user >, I want < some goal > so that < some reason >

- *Constraint 1: Could be regulatory constraint (security, businessmodel etc.)*
- *Constraint N..*
- *Pass criteria 1: KPI/Measurable gain…*
- *Pass criteria N…*

The main purpose is to capture the intended value creation based on the DSO scenarios and the end result is set of specific (narrow) and prioritized user stories, which will be the basis for the research and development work within the Net2DG project.

Based on the user stories and the DSO scenarios, a set of high-level use cases will be made in order to create a first draft set of requirements on how the value should be delivered to the DSOs.

A use case will take the form of the following:

ID and name:	UC<*ID*>: *Short name*
Parent user story	*<reference to user story>*

Overview and goal	*Short description of the specific scenario this usecase is targeting*
System applicability	*Applicable system context*
Business rationale	*Why are we doing this specific use case? What are the success criteria?*
Precondition	*What state do we assume the system is in before the use case is executed?*
Actors:	*List of involved actors*
External stimulus	*What external stimuli (if any) trigger this use case.*
Main flow	1. *Actor x do* 2. *Actor y do* 3. *Etc.*
Alternate flow	*Any nonstandard behavior that needs to be considered?*
Characteristics	*What non-functional requirements should be considered (scalability, latency etc.)?*
Security impact	*Specific security related issues (not security should be considered in a Confidentiality-Integrity-Availability (CIA) context*

In the context of the WP1.1 the primary actors are the DSO (operator), the system (as a black box) and the grid upon which the system operates. Any details on how the system interacts internally are handled by WP 1.2.

3 DSO Scenarios

3.1 The environment of Thy/Mors Energy

This section will described the middle and low voltage grid of Thy/Mors Energy, it will not be a complete description of the full network, but highlight major structural element characteristic for the TME grid.

3.1.1 The MV and LV distribution Network of TME

3.1.1.1 General Grid Scenario

Thy-Mors Energi (TME) is a Danish DSO located at the North-Western part of Jutland. Thy-Mors Energi distributes electricity to approximately 44.000 delivery points. The geographical area is 1.600 km^2. Primarily this area is characterized by being one of the rural areas in Denmark with quite a lot of typically smaller town spread around.

3.1.1.2 MV Grid

The MV grid is a combination of a radial and mesh topology. Some typical examples for the MV topology is shown below (extract from the Scada system).

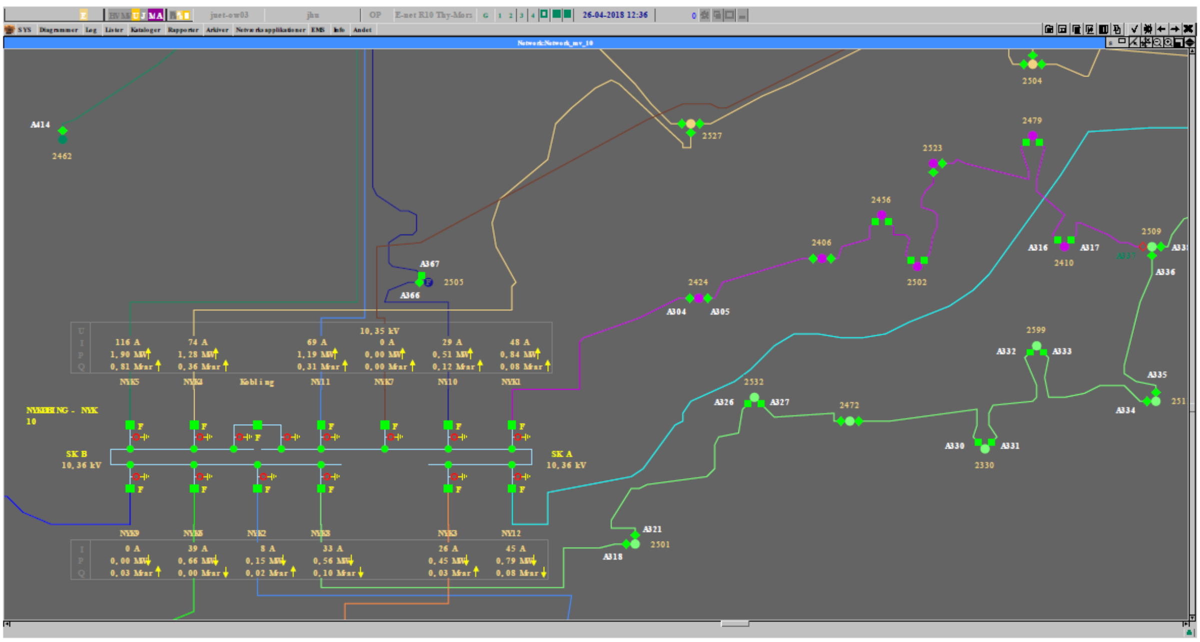


Figure 1 A section of the 10KV network in the TME Grid

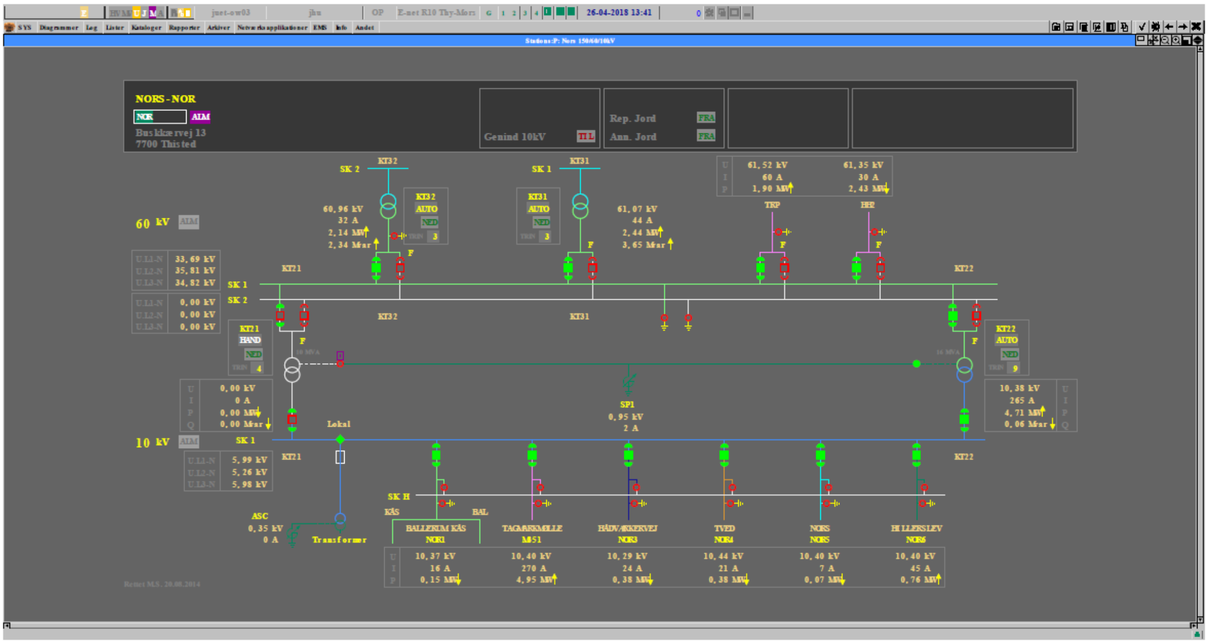


Figure 2 A detailed viea of a 60KV/10kV transformerstastion

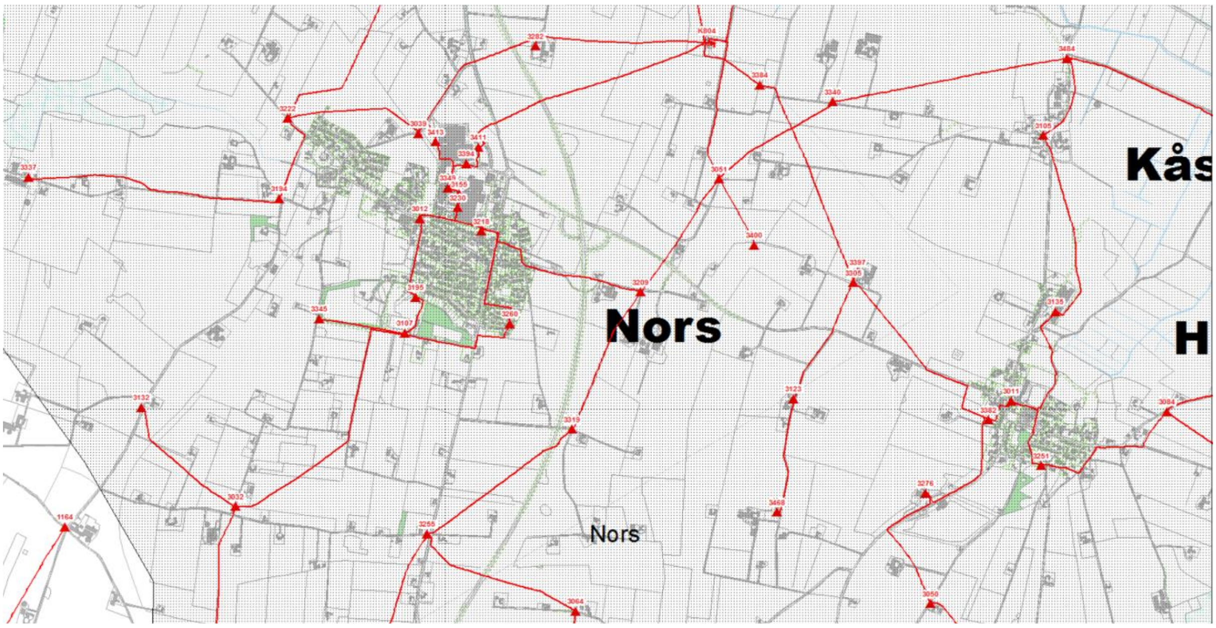


Figure 3 GIS view of MV grid in the intended Net2DG field test area

3.1.1.3 LV Grid

The area is well known to be windy and thus wind generation at household levels is not uncommon here, in addition to residential PV systems. Overall there are approximately 2.800 PV's and 786 wind turbines in the TME distribution grid.

Kamstrup smart meters are installed at household and commercial level. Consumer/commercial installed smart meters provide 15 min. intervals of updated information of voltages, power and events in the grid. Furthermore, TME is in the process of deploying the same smart meters in all 1.800

10/0,4kV substations. These meters provide measurements of energy and voltage with 15 minutes intervals on 3 phases.

Due to the highly distributed nature at TME nature, the LV grids are typically radial topologies and therefore very limited redundancies exist in the LV grid.

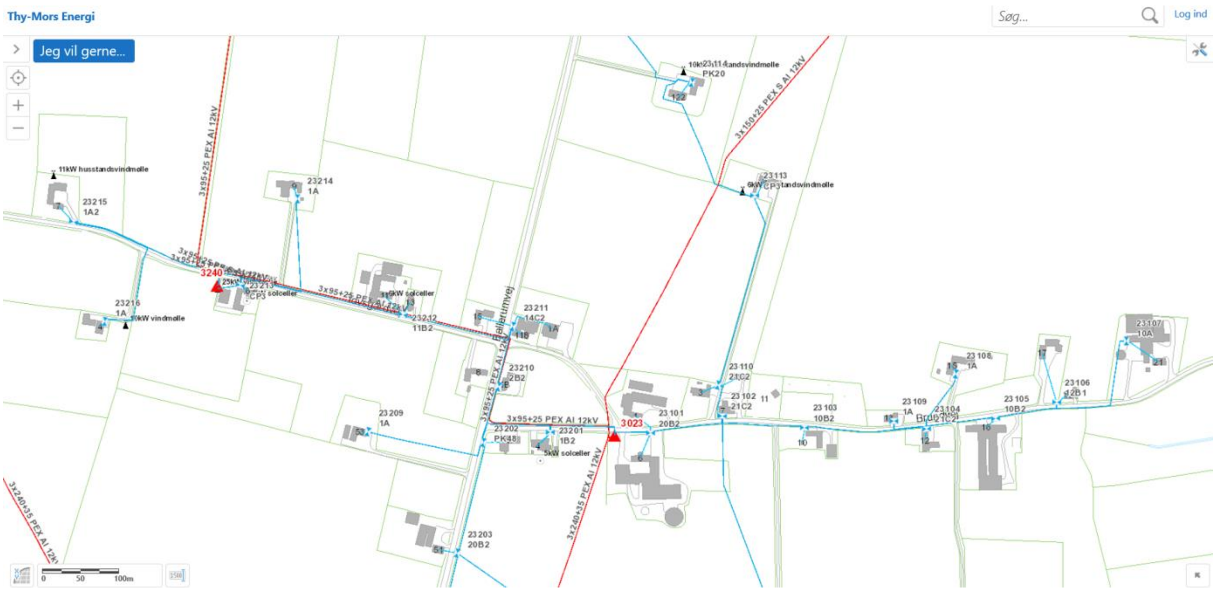


Figure 4 GIS view of a portion of the LV grid in the intended Net2DG field test area

An abstracted view of the LV grid is shown in Figure 5, a radial consist of cables and connectionboxes. The responsibility of TME typically ends at the connectionbox, the cable between this box and the house is the responsibility of the consumer.

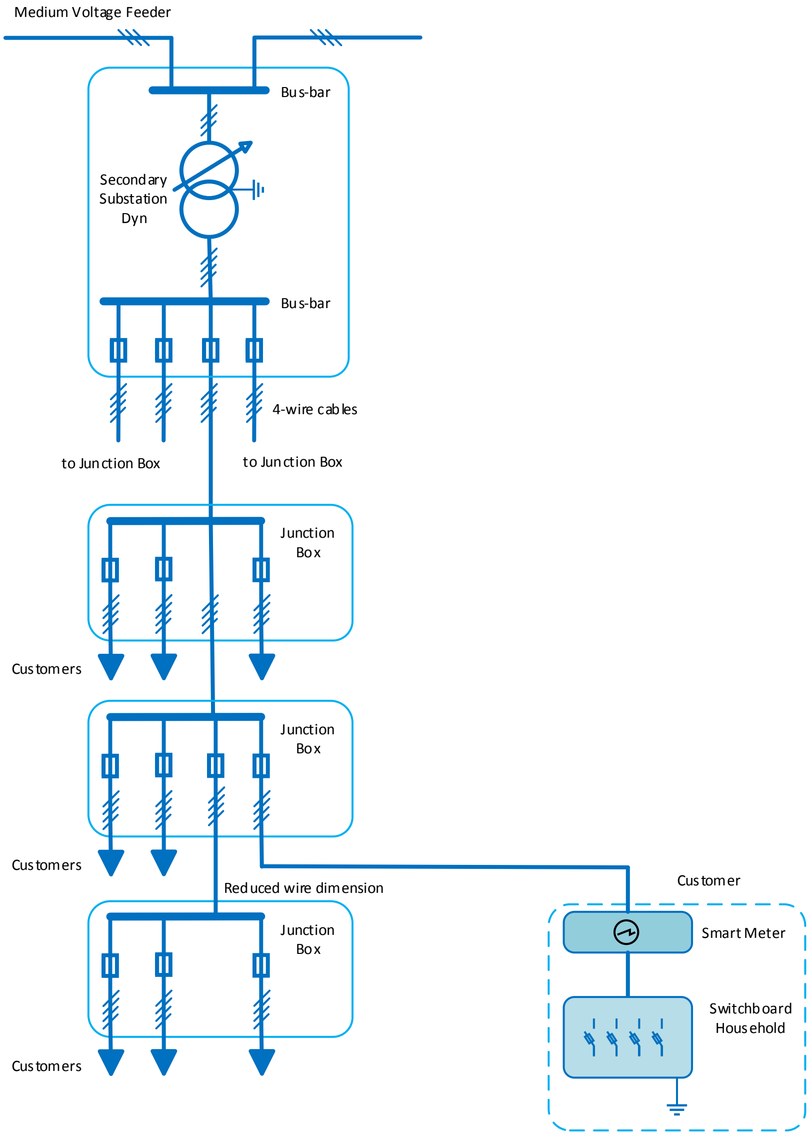


Figure 5 Abstracted view of the LV grid

3.1.2 The Enterprise IT Architecture of TME

The overall enterprise architecture of TME consists of a number of major applications like, Scada, AMI and CIS (Customer Information Management). For some of these, the daily operation has been outsourced to 3rd parties; this includes the Scada management system and the AMI system. The interconnect between the external scada system and the TME network is shown Figure 6.

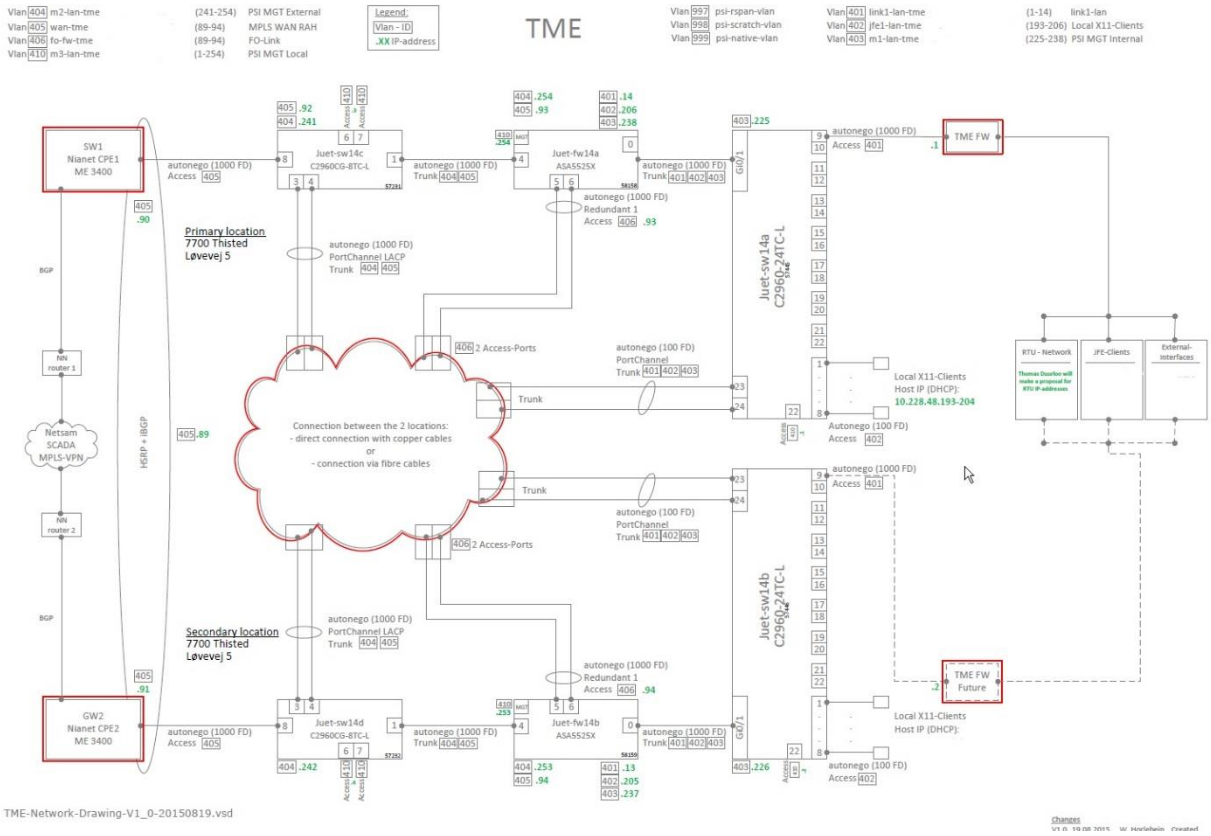


Figure 6 Network architecture for the TME Scada network

Data from the AMI system is exchanged via datafiles and secure file transfer (using the sftp protocol), while grid operators can log in to the AMI system and access data and meters on-demand. There is no API based integration for this part today.

3.1.3 Data sources from the TME setup

The potential data sources in the TME setup consists of household and substation smart meters (Kamstrup OMNIPOWER DC/CT meters) and PV inverters from Fronius. The inverters currently deployed in the TME grid are without remote communication and will require an update to include remote readout capabilities to be used by the Net2DG project.

3.1.3.1 Data from Kamstrup meters

The data from the smart meters can divided into billing data, data from the analysis logger and data from the voltage quality and occurrence logger. Below is described the most important data types from the meters. All values are calculated based on a 512 kHz inputs signal which after ADC and digital filtering is down sampled to 4 kHz. Voltages and currents are down sampled to 1 s RMS values and consumption data are down sampled to 1 s averages.

Billing data: Consumption data (both active and reactive) are divided into registers for the positive and the negative value. The registers are updated every second and data are stored every 15th minutes.

Analysis logger: The analysis logger can be setup to store several different parameters with a logging period down to 15 min. The most important values that can be logged are:

Average, minimum and maximum voltages on each terminal.
Average, minimum and maximum currents on each terminal.
Active and reactive consumptions and productions on each terminal.
Average current and voltage THD on each terminal
Average frequency.
Remark that up to 24 different registers can be stored in the analysis logger at the same time.
Voltage quality and occurrence logger: These loggers contain information about specific events with detailed information about the time of the event and parameters about the event. The most important types are described below:
Long-term voltage deviations: An averaging period is set from 10 seconds to 30 min. An event is created if the mean value of the voltage in this time interval is outside the predefined limits. The event contains information about the minimum, maximum and mean voltage and the actual power for the time interval and the start time of the interval.
Short-term voltage deviations: A voltage outside the limits for one or more seconds is registered. The first, last and min/max value are returned with timestamps together with the actual power.
Voltage outages: Voltage outages are detected and categorized into long (>3 min) and short (<= 3 min).
Voltage sags and swells: Sags and swells defined as +- 20% of nominal voltage with duration from 100 ms to 1 s are detected and counted.
Rapid voltage change: Defined as an 11.5 V change between two sampled are counted.
THD: An occurrence is detected if the 10 min mean THD exceeds 8% (according to EN50160) and is counted.
Neutral fault: Neutral faults are detected and logged with a timestamp.

3.1.3.2 Data from large scale production Meters

For large WTG (500kw and above) operating on industrial voltage levels (690V), production is measured by meter from EMH. They deliver hourly values for production.

3.1.3.3 Data from smart inverters

Smart inverters and co-located measurement devices such as the Fronius Smart Meter (used for local energy management) at customer sites in the LV grid of TME are a supplementary data source to smart meters. A detailed description of data, which can be delivered by Fronius systems, can be found in chapter 3.2.3.3.

3.1.4 Actuation possibilities

This chapter describes the actuation possibilities for grid control, which are possible without any infrastructural changes.

3.1.4.1 Actuation possibilities with Fronius inverters

In general, inverters integrating decentralized generation (and/or storage) electrically behave according to the requirements of the applicable grid code and the particular DSO requirements. Fronius smart inverters include a broad range of grid support features, which are either being activated and set up at the local user interface (i.e. inverter display), or which can be controlled via communication interfaces. Typically, a country-specific setup integrates the grid code and DSO requirements. This country setup is loaded at the time of commissioning, and can be modified according to individual (DSO) needs.

Regarding Net2DG, existing PV (and storage) plants featuring Fronius inverter equipment can be harnessed for actuation in several ways (with increasing level of effort). In the simplest case, the electrical behaviour can be adapted by a modification of the local settings (e.g. reactive power provision). If needed, up-to-date features (e.g. Volt/VAr control) can be integrated by updating the inverter software. Then, communication interfaces can be activated (or retrofitted if not available) and connected to the actuation system (e.g. via Modbus TCP SunSpec). Moreover, in case the existing hardware does not allow for the desired actuation mode, even the inverter itself could be replaced (or a battery could be retrofitted). Summing up, the actuation possibilities can and will be flexibly adjusted according to the needs of the DSO scenarios within Net2DG

3.1.5 TME Scenarios

The main relevant Net2DG scenarios identified in the grid of Thy/Mors Energy are described below.

3.1.5.1 Grid outage diagnostics

An outage in the grid is characterized as an energy supply interruption to the consumer. The interruption can be on a single phase, multiple phases or all phases.

The grid outage diagnostics scenarios focuses on the various main outage cases and the ability of the DSO operation to detect and correct the outage.

Grid outage process steps	
Initiator	A consumer complains about missing power The diagnostics process can also starts by a meter alarm (not used currently) or by an analysis of missing meter readings.

Process steps	1. The consumer calls the DSO customer service and complains about missing power (single/multiple/all phases).
	2. The operator asks the consumer to check relays and fuses
	  a. Blown fuse: This solves 75% percent of the problems.
	  b. No blown fuse: Continue troubleshooting
	3. If no problem, the operator asks the consumer to check power on all terminals by inspecting the smart meter (can be seen on the meter display)
	  a. If there is no power to the smart meter, the operator also checks the neighbouring meters.
	    i. If there are no problems at other customers -> it is the customers own problem most likely -> END Usecase

	ii. If other meters have problems -> a technician is send and a manual search is started. Meters are checked to see if one can locate the problem –> END Usecase b. Meter have power -> problem inhouse, the consumer have to call an electrician -> END Usecase
Applies to	**Immediate faults:** E.g., an entrepreneur reports the damage he made. Secondarily a customer complains about power issues. The fault types can be all phases, phase-phase, phase-neutral where fuses blow in substation or connection boxes. **Slowly developing faults:** E.g. an entrepreneur scrapes off the surface of a wire and does not report the damage. Fault type: Single phase-ground fault. If there is a bad ground connection, no fuse will blow and one does not affected the customers. This is a slowly developing fault. Troubleshooting is initiated when full outage occurs. **Temporary and slowly developing fault:** Loose connections in e.g. connection box that leads to a fault. Not necessarily a permanent fault but also short term outage.
Comments	Generally, it seems like only phase-ground faults are slowly developing and might be possible to detect on consumption data from the substation or voltage measurements from the substation or meters. Furthermore, it might be possible to detect a seasonal variation and a variation related to the weather that is related to phase-ground leakages. Actual immediate faults (phase-phase, phase-neutral, all phases) can be visualized with alarms from meters. This is a help for the operator to identify where the fault is.

Data traces

A data example from a cable fault in the Thy-Mors grid is shown below.

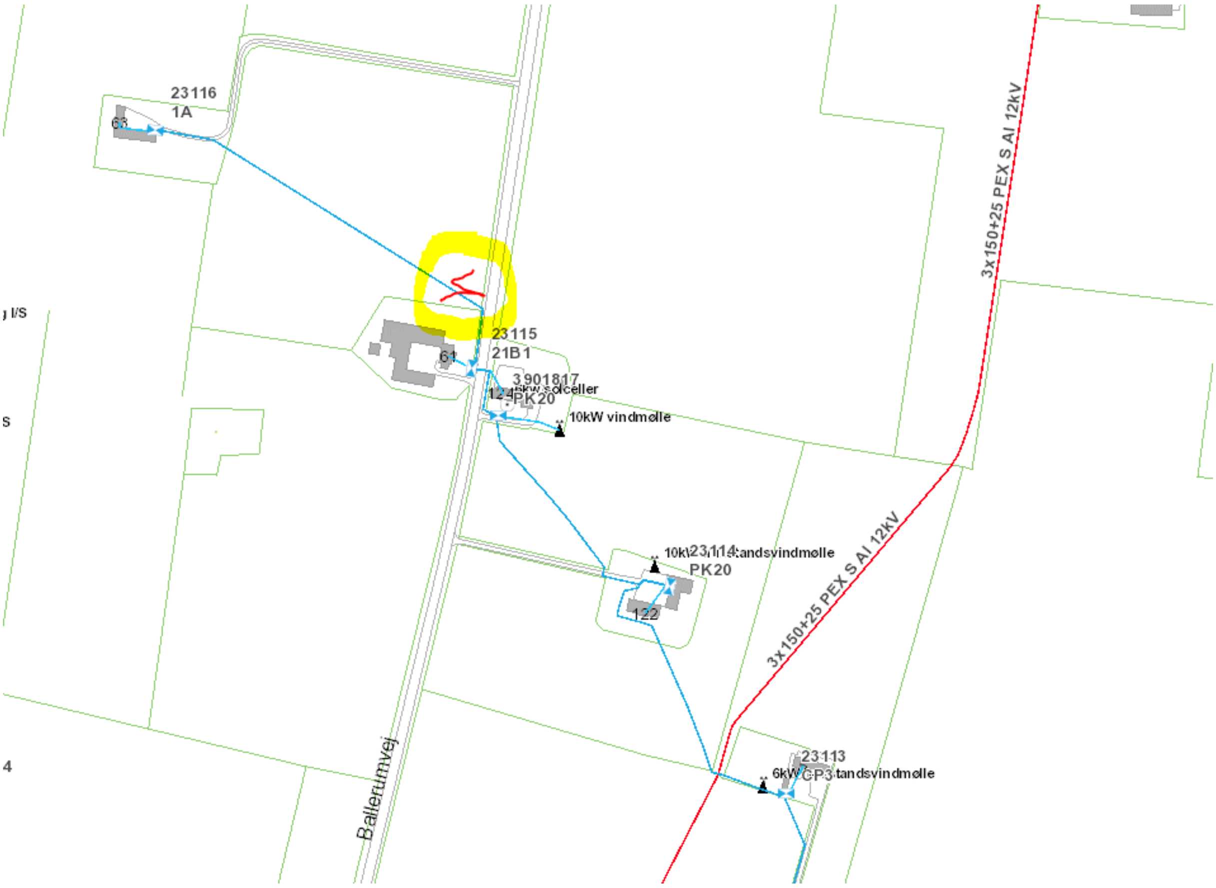


Figure 7 Affected grid

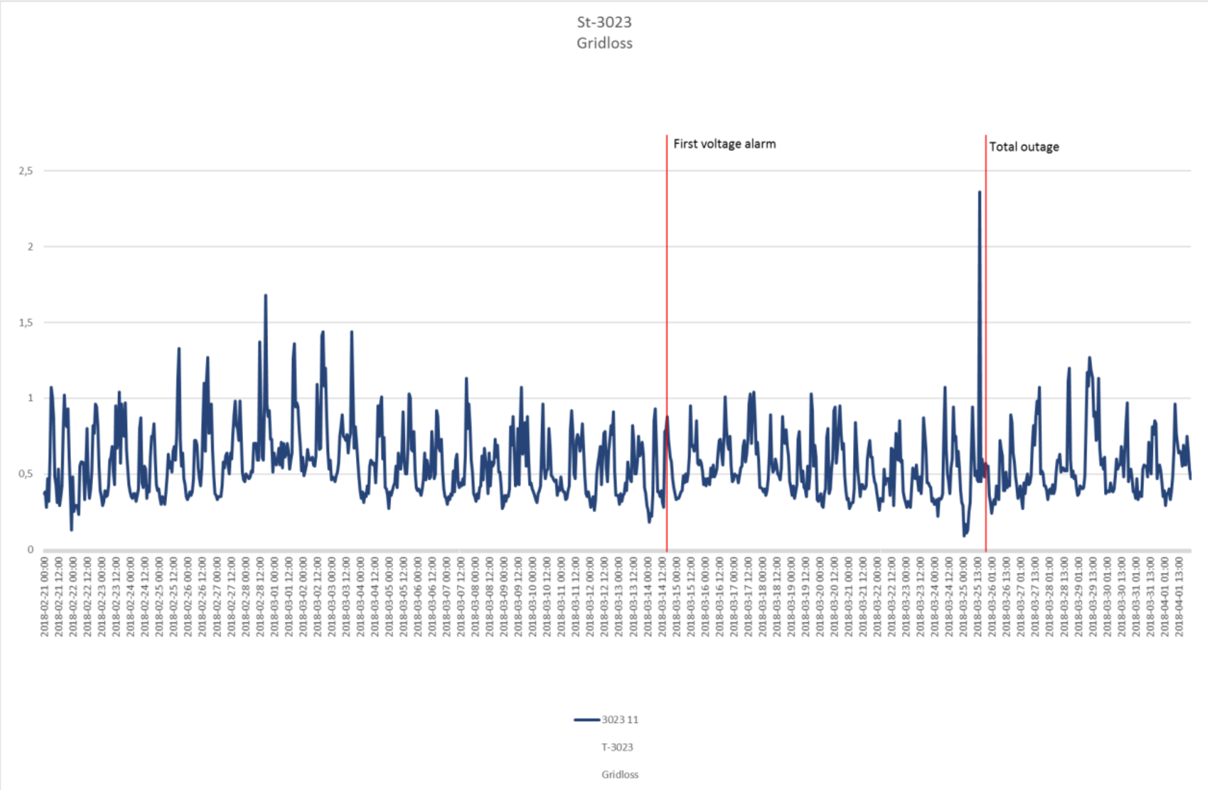


Figure 8 Calculated grid loss up to and around the cable fault

Figure 9 Measured minimum voltages up to and around the cable fault

3.1.5.2 Input to future improvements to Outage detection and diagnostics

An electric outage, which can be caused by several different occurrences, is an event that all DSOs want to minimize. However, it is unavoidable that, eventually, it may occur due to external phenomenon such as weather, earthquakes, lighting strikes or also due to the wear and tear of the assets. Since the grid cannot be 100% immune to outages, DSOs look for strategies to minimize the consequences. Here in the Net2DG project, the ambition is to be able to detect pre-conditions that may lead to an outage; if an outage occurs, to be able to detect it; and using diagnostic methodologies, to be able to predict where the root cause can be located.

By leveraging available data, the pre-outage detection functionality will process available operational data, such as the voltage and current profiles, and be able to assess if the RMS values are close to a previously set limit. In case this threshold is reached, the controller should identify the actions (manage any flexible assets such as storage, EV, DG or loads) in order to ensure the regulatory limit (from EN50160) is not overpassed. This will translate in less DG to be curtailed and a maximization of its value, while avoiding any potential outage. Also, by analyzing historic data (voltages, currents, temperatures, etc.), the Net2DG system will determine if there are any assets that require maintenance. Any deviations from normal operational conditions are recorded for asset management purposes. A report is then generated, including a description of the asset needing maintenance, the position, the problem and what caused the detection.

In case of an outage, the system will process all available data, including alarms, events and measurements from the available devices. The non-availability of data sources correlated with time (historical information) will warn the operator about an outage and the affected clients. If possible, the system will continue to track down the location of the outage by mapping the affected nodes in LV grid model and to suggest the possible cause(s) of the outage source.

3.1.5.3 Grid voltage quality

Voltage Quality issue process steps	
Initiator	A consumer have issue with the voltage quality
Process steps	1. The consumer calls with a complaint about alarms from technical equipment, equipment will not start or stops, blinking lights 2. Initially the operator investigates the data from the meter by reading analysis loggers and checking voltage quality loggers a. Voltage swells/dips problem -> one might change the tap changer in the substation. Consider changing the cables. 80% of the complaints are related to over/under voltage. b. Capacity problem in the transformer -> one normally chooses to monitor the state of the transformer in the future. Consider changing the transformer. Maximum load on the substation can be check by aggregating consumption from all meters underneath the substation. c. Undefined voltage quality problem -> a technician installs a class A analyzer and checks the voltage at the delivery point according to EN50160.

	3. If the voltage quality does not fulfil EN 50160: a. Field technician inspects the short circuit current. If it is low (minimum I_k for phase to neutral or phase to earth) this indicates a weak grid, and this could be the cause of many voltage problems and the transformer and/or cable should be reinforced. The minimum I_k should be at least 5 times higher than the fuse size at the consumer or minimum 500A at a new installation. b. The Field technician checks if it is possible to correlate the voltage problems to the current. If there is a low correlation, then the consumer is not the cause and the originator has to be found somewhere else in the distribution grid. c. The field technician looks for large “natural” consumptions -> customer problem. Short start currents are okay. d. The field technician looks for voltage THD issues (only around 20% of the complaints): Inspect the current THD. i. If the current THD at the consumer is high -> customers own problem. ii. If the current THD at the consumer is low -> grid problem.
Applies to	All issues related to voltage quality complaints from consumers/prosumers.
Comments	The complaint is normally related to problems with light adjusters. Normal causes for harmonics are: 3rd: Single phase motors 5th and 7th: 3 phase motors Frequency controlled devices Switch-mode power supplies A high THD might also lead to a high technical loss in the distribution grid. To be investigated.

Data traces

An example shows how over-voltages where registered at a user several times before a problem arised. The log data are shown below. Within a 4-hour interval, there are eight incidents with voltages above 258 V.

Type	RTC	Log ID	Meter no.	Mean Voltage	Max Voltage	Min Voltage
Phase 1 (overvoltage)	30-06-2016 11:09	59	19567926	254	258	250
Phase 2 (overvoltage)	30-06-2016 11:09	60	19567926	254	258	250
Phase 1 (overvoltage)	30-06-2016 11:19	62	19567926	254	257	249
Phase 2 (overvoltage)	30-06-2016 11:19	63	19567926	255	260	250

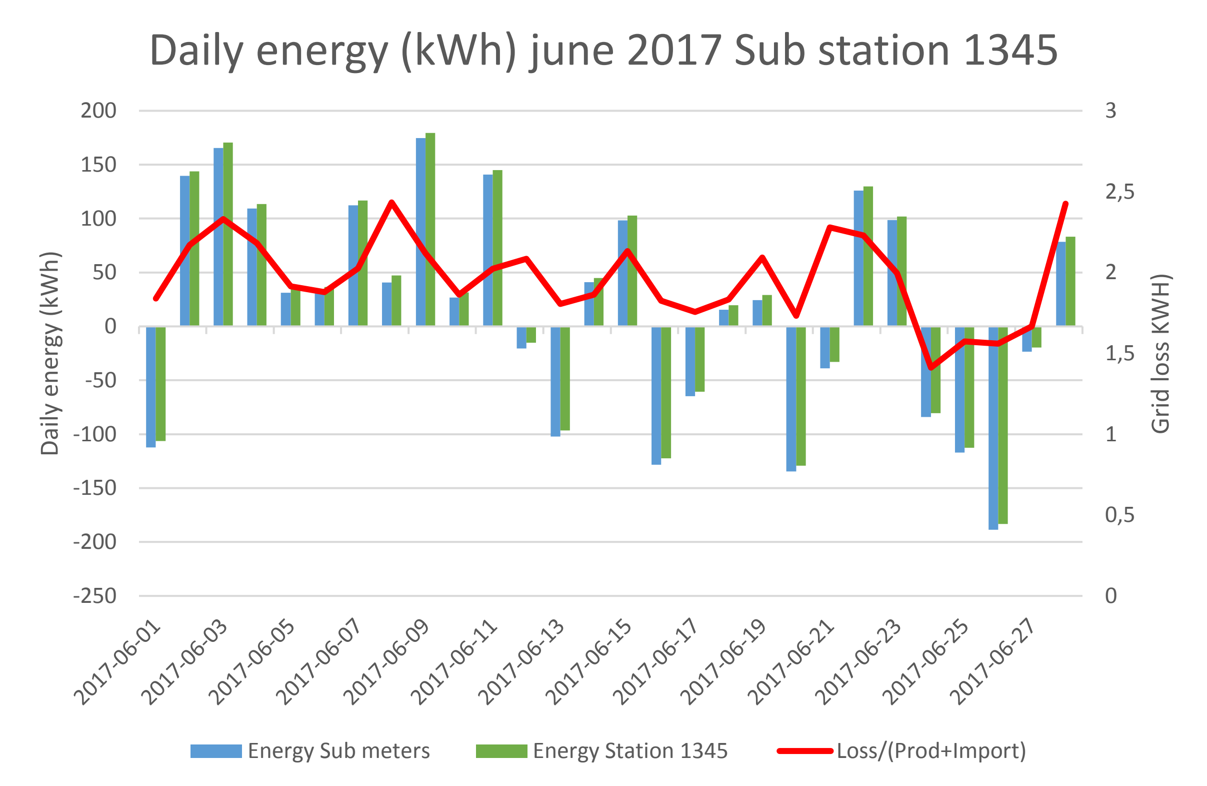
Phase 2 (overvoltage)	30-06-2016 11:29	64	19567926	254	259	249
Phase 2 (overvoltage)	30-06-2016 14:59	65	19567926	254	258	249
Phase 2 (overvoltage)	30-06-2016 15:09	66	19567926	255	259	249
Phase 3 (overvoltage)	30-06-2016 15:09	67	19567926	253	258	247

3.1.5.4 Grid operation efficiency

Efficient Grid Operation process steps	
Initiator	The DSO will be benchmarked at least yearly, which triggers the DSO to minimize net losses. Note that currently only the total grid loss is calculated.
Process steps	1. The grid operator wants to analyze the low voltage grid for grid losses 2. The grid operator focus on two scenarios: A. Fixed losses related to the grid and the installation : a. Capacitive losses in the 10 and 0.4 kV grid b. Oversized 10/0.4 V transformers. c. Capacitive losses in blind ends in the 10 kV grid B. Variable losses related to the consumption and production in the grid (these changes continuously): a. Theft (non-technical) b. Unnecessary high consumption c. Large reactive consumptions. Power factor. The importance of this effect should be investigated. d. Unbalanced consumption. e. THD related losses in substation. f. Non-measured consumption (in substations etc.) (non-technical)
Applies to	
Comments	○ The solution should handle fixed losses as part of normal grid capacity planning. ○ The solution should deal with dynamic losses automatically and adjust consumptions in the grid accordingly. ○ There are consumptions that are not measured but just estimated (could be streetlights without meters).

Data Traces

The grid efficiency is related to all the losses in the grid. Here is shown an example of the grid loss on a substation across different days. It is clear that the grid loss varies significantly and a robust calculation should be performed which includes the correct uncertainties before one can determine of the losses are acceptable or not.



3.1.5.5 Reactive power reduction for increased grid utilization

For the time being, there are no directly attached cost related to the amount of reactive power (inductive/capacitive) exchanged with the TSO, this could change in the future, as is the case in Germany and other places. The current situation (on a typical day) is shown in Figure 10 and Figure 11.

Data traces

A typical example on the changes in level of MW and MVAr exchange on three 60/10 kv transformer stations from the TME Grid are show below. A negative MVAr value indicates a capacitive load.

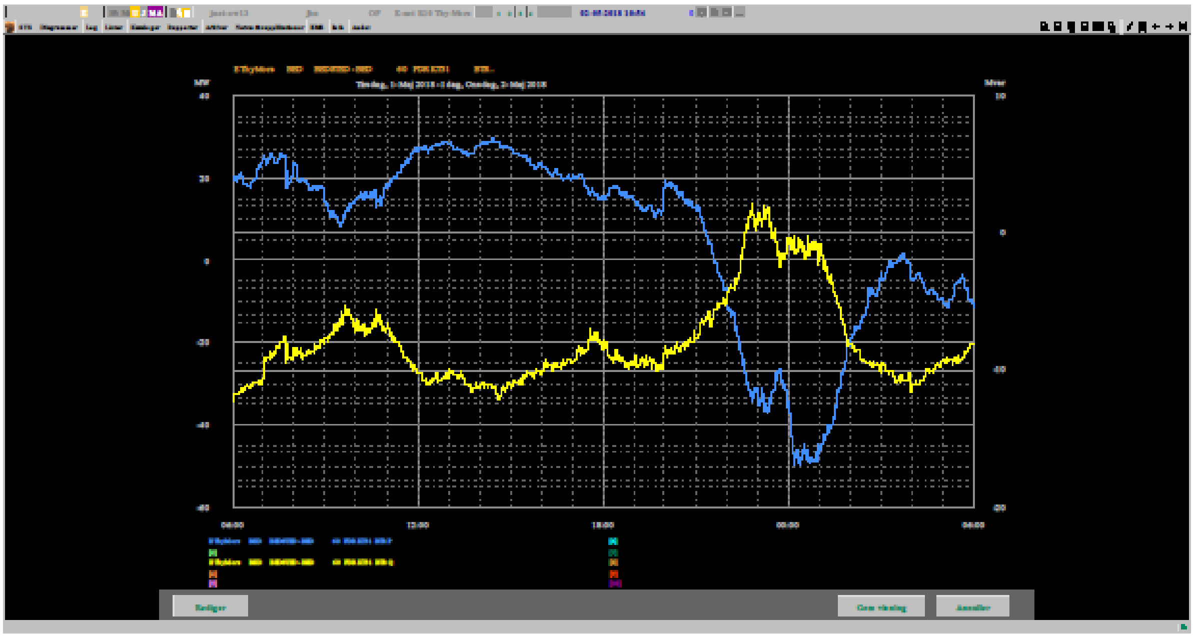


Figure 10 24h reading of MW and MVAr from the Bedsted 60/10 kv substation

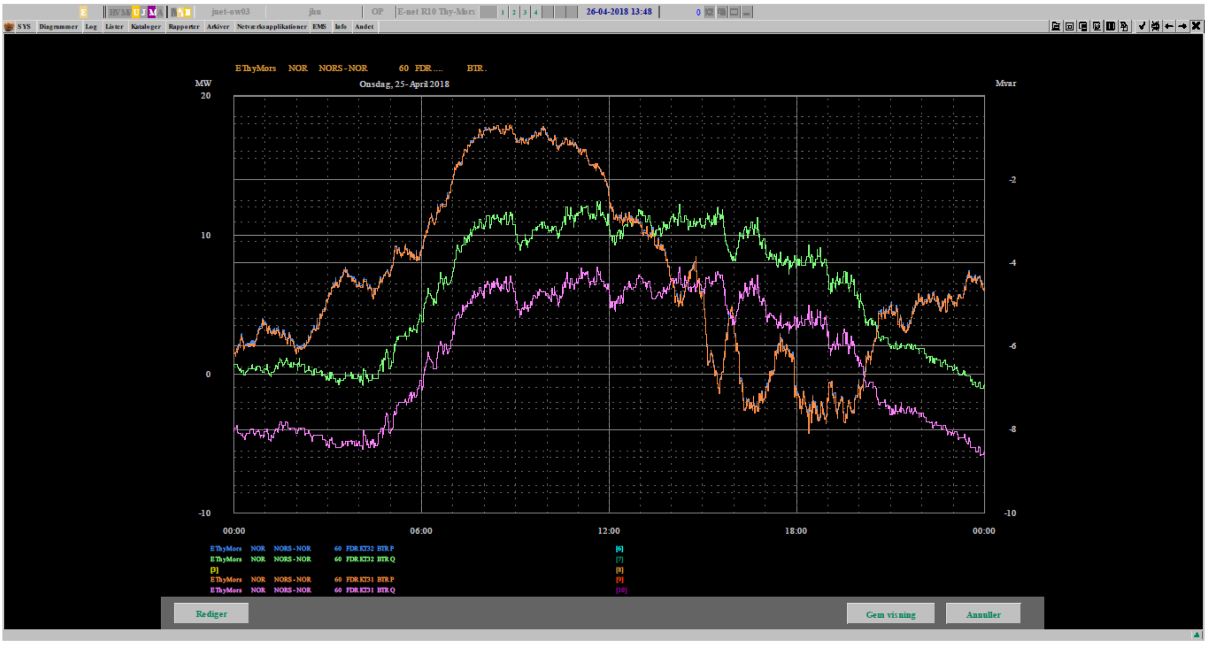


Figure 11 24h reading of MW and MVAr from the Nors 60/10kv substation

3.2 The environment of Stadtwerke Landau

The German Stadtwerke Landau a.d.Isar is operating the different communal infrastructures in the surrounding East-Bavarian region, among them the electricity distribution grid. The latter will be used as scenario for the development and evaluation of use-cases in Net2DG.

3.2.1 The MV and LV distribution Network of Stadtwerke Landau

General Grid Scenario: The distribution grid of Stadtwerke Landau a.d.Isar consists of a 20kV medium voltage grid with 101km cables and 33k overhead lines, which is connected by one primary substations to the HV grid operated by a different company, see Figure 12. The low-voltage grid is served by 180 secondary substations with a total installed power of 60MVA; this grid part is realized by 327km cable and serves 4200 residential households (among a total of 8300 metering points in the distribution grid). The distribution grid covers both the town of Landau and the neighboring rural areas. The region contains a high penetration of PV, with in total 1235 PV generators and an installed power of 26MVA.

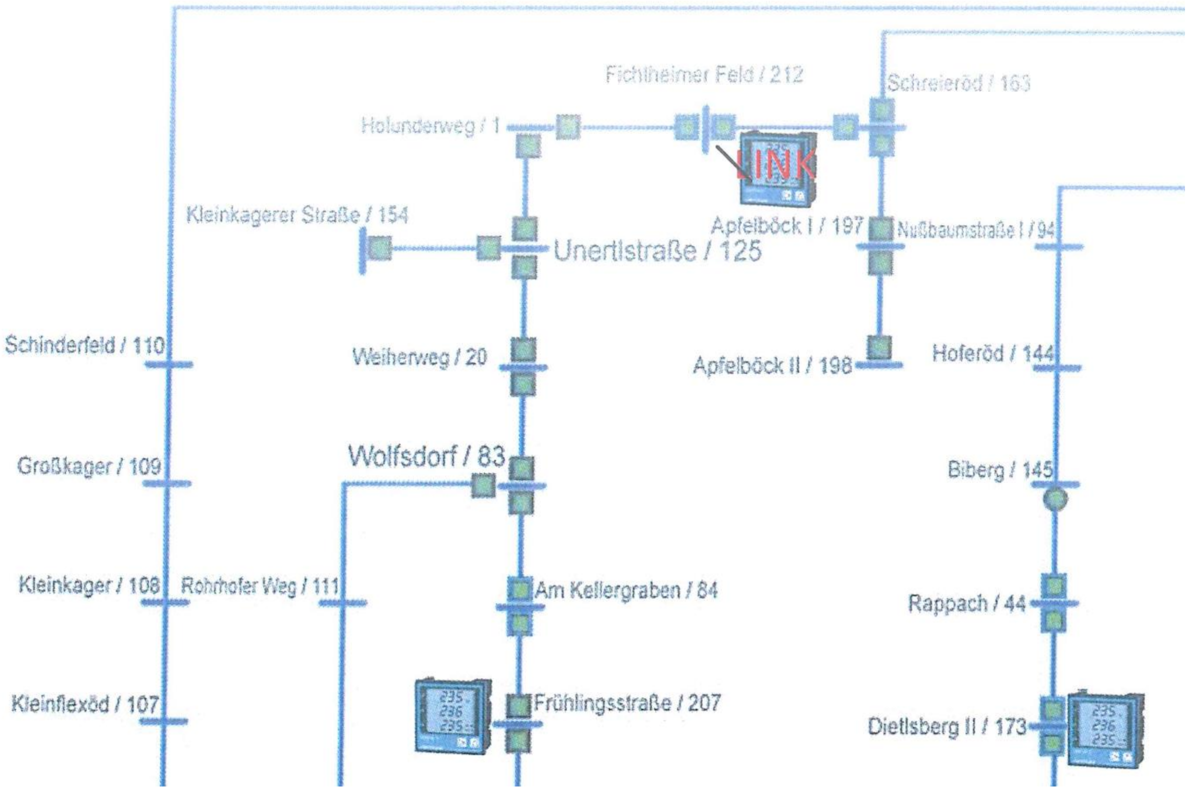


Figure 12 Part of the MV grid topology for Stadtwerke Landau, visualizing in addition the existing placement of different PQ measurement units at secondary substations.

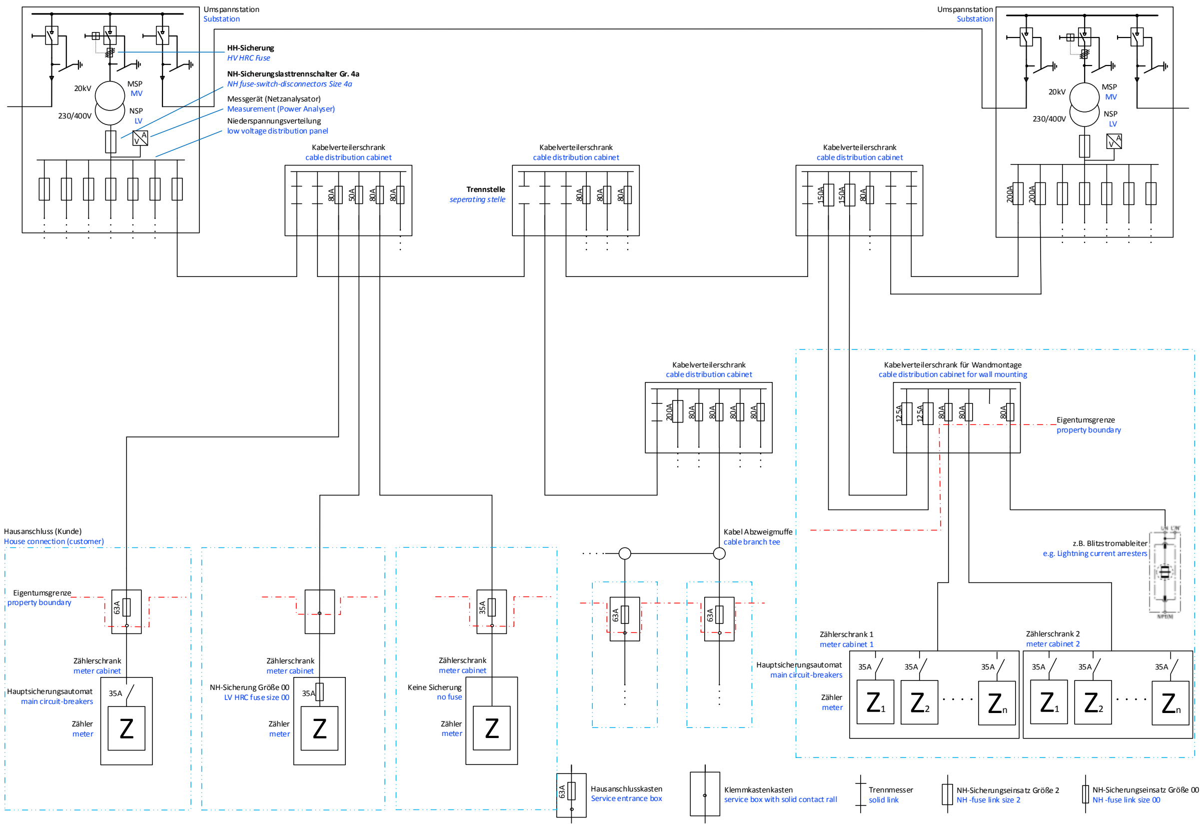


Figure 13 LV grid structure

The general setup of the Low Voltage grid is shown in the Figure 13. The following characteristics of the LV grid influence the relevance of and later also the realization of Net2DG use-cases:

- All LV Power lines are underground cables of short length (max 500m).
- The deployed LV cables are relatively new cables, as replacements have been taking place over the last 20 years.
- The LV grid is served by 180 secondary substations with 2...15 feeders per substation and contains about 2000 junction boxes with 2...8 outgoing feeders per junction box.
- There is a possibility for manual switching of the LV grid topology through insertion/separation of connections in some junction boxes. The LV grid is always operated in a radial structure, despite these breakers would allow meshed configuration.
- Due to the dimensioning and frequent placement of fuses (Figure 13), an outage at the customer connection may only occur in case of blown fuses, all other cases are expected to only lead to flicker or similar voltage problems.

3.2.2 The Enterprise IT Architecture of Stadtwerke Landau

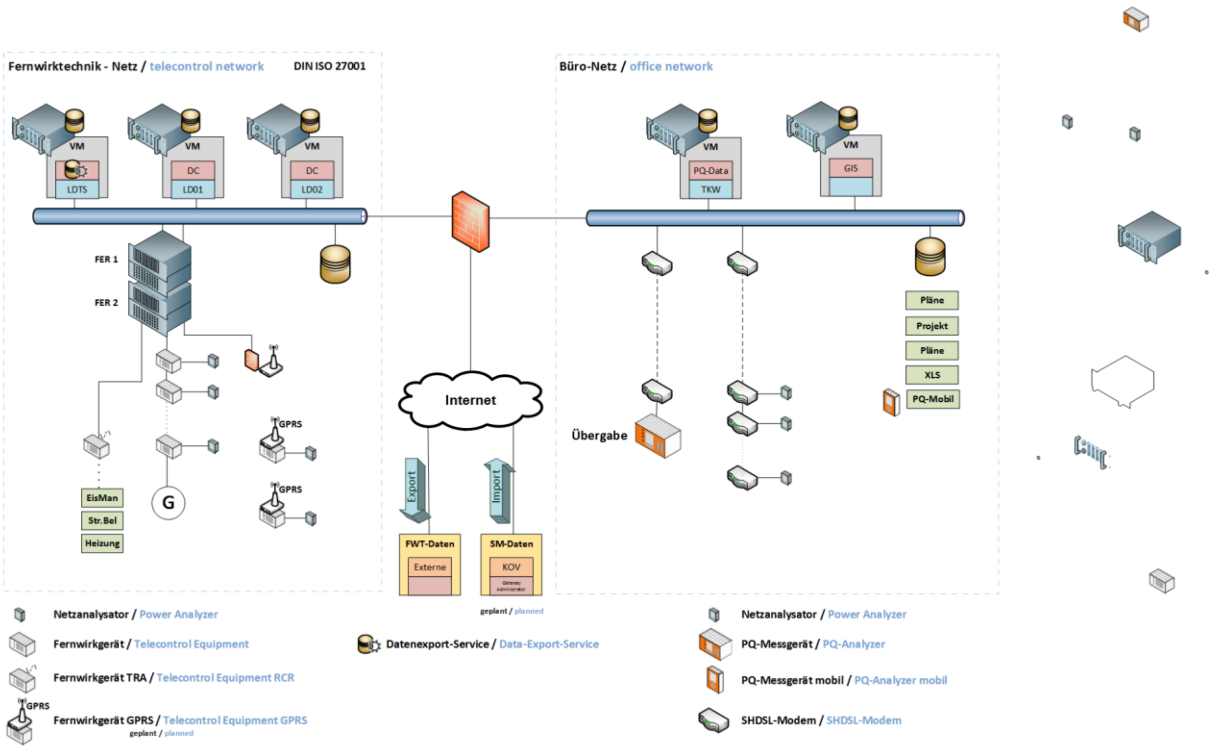


Figure 14 Schematic overview of the IT architecture of Stadtwerke Landau

Figure 14 shows the abstracted IT architecture of the Stadtwerke Landau scenario. It consists of three domains:

1. The Telecontrol network, in which the SCADA system is embedded:
   - The SCADA system, IDS Highleit, is running on two VMs on servers in the telecontrol network; see upper left in the figure. The current SW realization allows only to store measurements at time granularity of 3min or longer.
   - The measurements at the primary substation are connected to the SCADA system
2. The office network, in which among others the GIS data and the mobile PQ data is stored
3. The Smart Meter data will be provided by a third party. These data will be provided by a secured Internet connection.

Whenever data from one domain is required in one of the other domains, special data export services had been developed in-house in the past.

3.2.3 Data sources from the Stadtwerke Landau setup

The in principle available data sources are shortly characterized in the following. Note that not all data are ready to be used but remote access and data interfacing needs to be added in most cases. This aspect is not discussed here, as the main purpose is to show the data that can in principle be available.

3.2.3.1 Existing DSO based data sources

The following data sources are in principle available for Stadtwerke Landau:

- The GIS system (ESRI ArcMap) contains details about the length, diameter, material of cables and position of nodes both for the LV and MV grid.
    - A separate xls list with the street address and installed power of the distributed generation (incl. PVs) is available; the GIS system can map the street address to a geo-location.
- Meters at secondary substations: the location and type of the devices are shown in Figure 13. The devices provide 10min averages/min/max of voltages, current, and power at the bus-bar at the LV side of the substation. Only a subset of these units can be remotely read out from the current deployment.
- The SCADA system (IDS HighLeit) contains the measurements of voltage, currents, and power at the MV bus-bar of the primary substation busbar at the primary substation Zanklau (upper one in Figure 13). These are normally 15min averages.
- A Power Quality measurement device is placed at the MV side of the primary substation, which normally takes 10min average values, while in certain situation (e.g. triggered by protection system events), the measurement device can for a limited time take measurements with 100mus or below resolution.
- Different type of switches are deployed: Some can be switched remotely, others only notify their status via a remote connection to the SCADA system, and the remaining ones can only be manually switched and require inspection at the site in order to detect their status.
- Mobile PQ Measurement systems: can be connected to secondary substation, cable distribution cabinets, at customer connection; 10min time granularity for long-term measurements, for short ones or triggered by certain events, also 100mus and below for short time periods (up to 3-5s).
- Only few large customers are currently measured by remotely accessible meters (Zählerfernauslesung) at 15min time granularity or longer.

3.2.3.2 Smart Meters at End-Customer Connections

Smart Meter (dt. Intelligentes Messsystem) deployment is planned starting from 2019 and it is expected that within 3 years, about 500 Smart Meters will have been deployed. The process of certification of the gateway administrators is currently ongoing – details about HW and measurement capabilities depend on the Gateway administrators.

3.2.3.3 Inverters and co-located measurement devices

Smart DER inverters and co-located measurement devices can be harnessed as non-DSO data sources. These data sources are designed to fulfil requirements from two domains – first, the protection of the electrical interface (e.g. trip limits), and second, the plant operator's domain. Regarding the latter, monitoring and energy management are the primary features of interest. Particularly for energy management purposes (e.g. optimization of self-consumption, or dynamic feed-in control), the billing meter is a highly relevant point of measurement. However, as billing meters usually lack harmonized communication interfaces for customer-side energy management, many DER systems have a separate meter deployed next to the billing meter.

DER systems with Fronius equipment usually contain the "Fronius Smart Meter". This is a bidirectional meter with communication connection the PV inverter. The inverter contains the "Fronius Datamanager" being the local (field-level) Fronius data hub. The Datamanager provides local communication interfaces (read/write), and it is connected to "Fronius Solar.web" being the server-level Fronius data platform.

Available Data

Data, which can be obtained via Fronius devices, include general system information such as inverter type, nominal power of the inverter, SW/HW versions, battery type and capacity. Furthermore, the inverter saves operating data such as state codes, measured values and error codes, as seen in the following exemplary list:

- Inverter status
  - Inverter is working normally, standby, off, automatically shutting down, power reduction is active.
- Measured values
  - AC voltages and currents, AC power, AC frequency value, DC voltages and power.
- Error codes
  - AC voltage too high/too low, AC frequency too high/too low, no AC grid detected (islanding).

Measuring accuracy

Fronius PV inverters (Fronius Symo series) must prove to feature the following maximum measuring errors to pass the final inspection:

AC voltage: ±1 %
AC current: ±3 %
AC frequency: ±0.1 %
Active power: ±3.4 %

The typical measuring errors are significantly smaller. Exemplary data from the final inspection of Fronius Symo 5.0-3-M inverters tested in March 2018 show that the majority of the measured values are within the following ranges (mean value ± 3σ):

AC voltage: -0.44/+0.06 %
AC current: +0.54/+1.84 %
AC frequency: +0.02/+0.05 %
Active power: not available

The Fronius Smart Meter (63 A) fulfils the following requirements:

Active power: Class B according to EN 50470
Reactive power: Class 2 according to EN/IEC 62053-23

Time resolution

The time for the timestamp is synchronized daily. The time resolution and actuality of data is depending on the interface used to request it. The resolution varies between 1 and 5 seconds via the local interface (Modbus TCP Sunspec) and 5 to 30 minutes on server level (Fronius Solar.web).

Available interfaces

The following figure illustrates the communication architecture Fronius equipment provides for the scope of Net2DG.

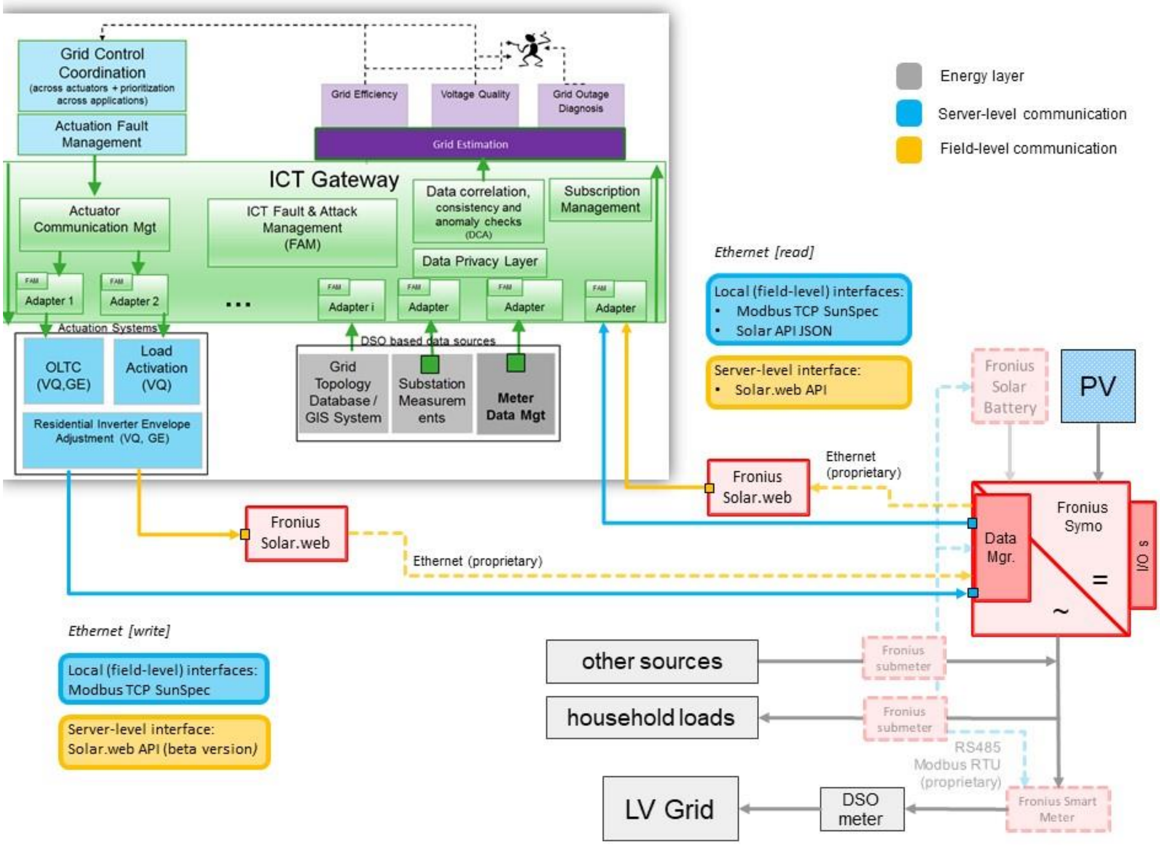


Figure 15 architecture inverter/battery deployment at the customer side and the possible interfaces

3.2.4 Actuation Options in Stw Lan Scenario

The following actuation options are in principle possible in the Stadtwerke Landau distribution grid. Similarly to the data sources, a remote activation of these may require further interfaces and also further steps in communication to impacted prosumers.

- PV curtailment in 4 levels (100%, 60%, 30%, 0) for all PV > 30kW, frequently also in the range of 10kW...30kW
- PV Inverters: Reduction of active power, reduction or increase of reactive power; locally autonomous control, or remotely controlled (more detailed information is given in chapter 3.2.3.3)
  - Inverters with storage: show even more control options in the control of active power
- Switches in the MV (partially remote) and LV (all manual) grid
- Shut down of feeders in the primary substation (to cut off loads and generators)
- Load activation (Street lights, Storage heating)
- Activation of emergency generation units

3.2.5 Stadtwerk Landau Scenarios

In the following subsections, the different scenarios of interest for Stadtwerke Landau are described. Each description first contains the current scenario in table form (in consistent style to Section 3.1.5), followed by a first wish list of how a more efficient scenario can look like in the future.

3.2.5.1 Loss Measurement and Minimization

This scenario is considered to be priority one by Stadtwerk Landau.

Loss Measurement and Minimization process steps	
Initiator	Yearly accounting of costs of energy losses in the grid (required by regulator)
Process steps	1. Measurement of yearly energy flows (aggregation of 15min measurements of exporting and importing energy at the primary substation) 2. Coordinated manual reading of electricity meters at consumers and at small generators; extrapolation of missing readings based on consumption history and values from similar prosumers. 3. Calculation of energy (kWh) lost in the distribution grids during the year based on the above two measurements/readings. 4. Multiplication of the lost energy with the average energy price for the year to obtain the cost of lost energy. 5. Reporting of values in internal financial accounting, reporting to regulator, publication on web site.
Applies to	Any causes of energy loss, no distinction of the different causes is made. The causes include • Technical loss: variable and fixed losses at transformers, variable losses on cables and lines, ... • non-technical losses: energy theft, non-metered consumption for DSO equipment (lights, maintenance machinery, etc.) in substations, etc.
Comments	Constant value for lost energy is used for network tariff calculation – may be adjusted eventually, but has not been adjusted by the German regulator for many years. Currently about 60kEUR actual costs of lost energy per year. No detailed knowledge about when and where in the grid losses occur are available.

3.2.5.2 Input for Future Solution for Loss Measurement and Minimization

Target in the future: Reduce the cost of lost energy – providing a benefit for the DSO and for the total economy

Step 1: Identifications of inefficient LV grids

- Expectation: losses over different periods of time and different LV grids vary strongly

- Due to load and generation changes
- Worst case in Stadtwerke Landau grid may be, no loads, all generation at peak, however this worst case would need to be confirmed.

Step 2: LV Loss reduction

- Target: obtain measurement-based loss estimate and compare with simulation based estimate to identify abnormal/unusual situations and support diagnosis of causes, including
  - Leakage (see earlier)
  - Lights in stations and cabinets left on
  - Unbalanced phases
  - Unnecessary high voltage
  - Reactive power

Optimize by

- switch positions in LV grid (Stadtwerke Landau has open ring structure and possibilities to switch 0-10 switches in each LV ring, see Sect. 3.2.1)
- Replace transformer by smaller one
- Switch transformers (3 positions possible) to optimize voltage within bounds
- Replace trafo by OLTC
- Reduce phase unbalancing (via load management, change of phase connections etc.)

3.2.5.3 Voltage variations measurement and minimization

This scenario is considered to be priority two by Stadtwerk Landau.

process steps	
Initiator	(a) Customer complaints about damaged equipment or (b) customer requests for connection of prosumers to the distribution grid
Process steps	(a1) Customer calls and complains about damaged grid-connected equipment. (a2) Mobile PQ measurement device is deployed in the junction box. (a3) After a period of few days up to 2 weeks, the mobile PQ measurement device is removed and the data extracted. (a4) Manual analysis of the PQ measurement data is performed by DSO staff to find anomalies and to diagnose potential causes; manual comparison to substation measurements may be done for the latter step. (b1) Customer request for new grid connection arrives at Stadtwerke Landau. (b2) For new generators: A calculation of a simple grid model is performed for the worst case of all generators producing at peak power and no consumer being active in the corresponding feeder of the LV grid. (b3) In case that the voltages in the feeder are all within +-3% of nominal voltage, the new grid connection is admitted without grid reinforcement. Otherwise grid

	reinforcements are designed. Current way of handling it at Stadtwerke Landau: LV grid planned for voltage levels +-3%, however using simplified assumptions (generators in the grid produce at peak power). Actual voltage levels at customer unknown, only partial measurements and manual readings (daytime only) in substations
Applies to	Voltage quality degradations caused by any reason. In case (a) focus on harmonics and voltage variations. In case (b) focus on average voltages only. For Net2DG, focus on one metric: 10min average value of voltage according to EN50160 and longer-duration (ca 10+sec) voltage dips or swells.
Comments	No continuous measurement of voltage levels at customers, only partial measurements and selected manual readings (daytime only) in substations. Actual voltage levels during incidents at customer unknown.

Data Traces

The following figures show an example data trace of measured voltages by a mobile PQ measurement system on the three phases at the Stadtwerke Landau office building connection. The measurement data has a logging period of 1 second (shown in the left), and the sliding window time average over a period of 10minutes is shown in the right hand graph. The variations in this scenario are small, 1second values show variability between 226V and 232V and the 10min averages show one Volt less variability in each direction. However, the duration of the measurement is just slightly below 3 hours, so this measurement example should here mainly show what type of traces can be obtained from the mobile PQ measurement device.

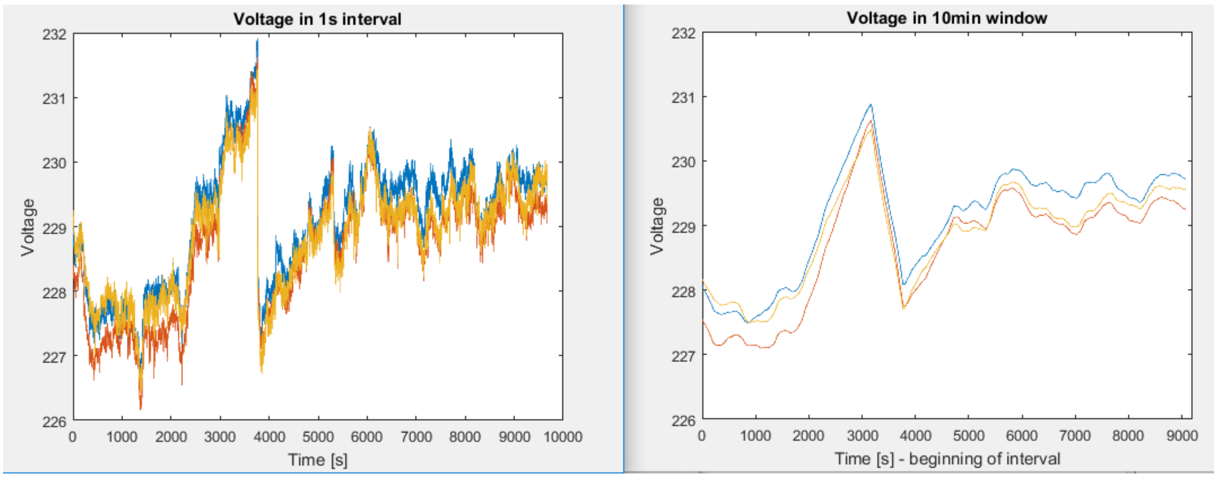


Figure 16 Voltage measurement in 1 second and 10min interval at the connection point of the building of Stadtwerke Landau

3.2.5.4 Input for Future Solution for Voltage variations measurement and minimization

Target of a possible Net2DG data processing applications can be:

- Investment deferral – by planning the grid based on actual measured voltage data and not based on worst-case assumptions
- Increased hosting capacity for renewables
- Reduce/proof/counterproof damages of customer equipment via continuous measurements of voltage quality indicators

As a first step, the use of actual voltage measurements in the grid planning can achieve the above. As a second step, automatic mitigation or avoidance of voltage variations and of voltage dips and swells of longer duration would be desired, e.g. via the following means

- generation control, load activation
- Future energy tariffs that gives incentives to customers to adapt consumption, see also Section 5.1.5.

3.2.5.5 Reactive power reduction for increased grid utilization

This scenario is considered to be priority three by Stadtwerk Landau.

process steps	
Initiator	Constraints on (capacitive) reactive power at transition point (primary substation) provided by higher layer grid operator
Process steps	1. higher layer grid operator defines constraint and provides measurements that may show violation of these constraints 2. DSO analyzes his own grid based on manual processing of measurements to identify causes of reactive power and to evaluate counter-measures, e.g. investments in capacitor banks, compensation in secondary substations, etc. 3. DSO adds compensation to its grid or buys into solutions provided by higher-layer grid operator
Applies to	Reactive power at transition to higher-layer grid operator, irrespective of the origin.
Comments	DSO’s own measurements at primary substation currently do not allow distinguishing reactive and capacitive reactive power. Also, no understanding of causes of reactive power at the transition points and of impact of reactive power on components of the distribution grid is available.

Data traces

Each point in the following figure shows active and reactive power measurements in every 15min interval at the transition point to the higher-layer grid operator (here Bayernwerke) during a whole year. The capacitive reactive power is required to be completely eliminated.

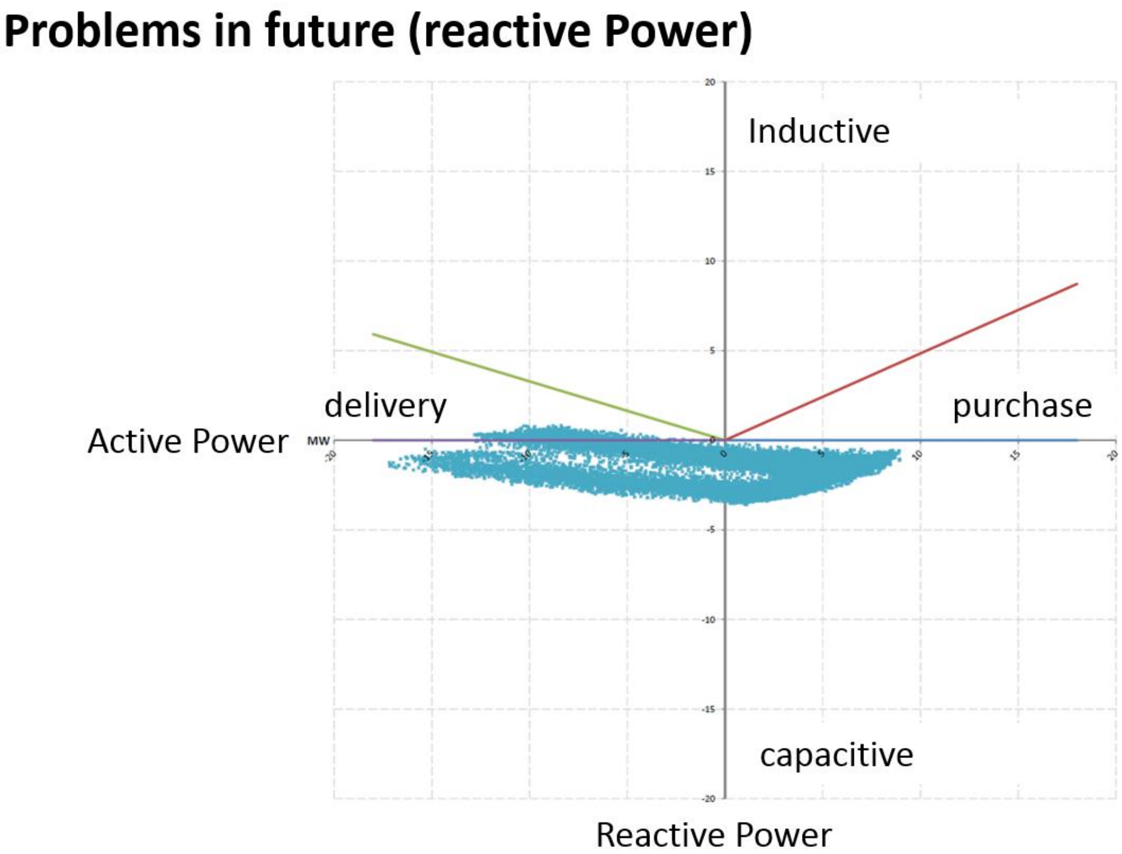


Figure 17 15min measurement results of active (x-axis) and reactive (y-axis) power at the primary substation of Stadtwerke Landau over a 1-year period.

3.2.5.6 Input for Future Solution for Reactive power reduction for increased grid utilization

Target of future Net2DG applications: (1) reduce grid investments by improved knowledge of reactive power included in planning; (2) Avoid stress/lifetime reduction on MV grid caused by reactive power; (3) reduce future expected costs connected to reactive power charged by the higher layer grid operator; (4) fulfill expected future regulatory requirements.

Two scenarios

(a) Increased utilization of the distribution grid
(b) Compliance towards constraints set by the higher-layer grid: To avoid reactive power injection to next voltage levels

First step: continuous measurements of reactive power in substations and other measurement points in order to characterize the reactive power and diagnose its causes.

Second step: Actively control substations or inverters envelopes in order to optimize reactive power, including also coordinated control across different LV grids.

Note: the target of this scenario may be in contradiction to the previous two scenarios.

3.2.5.7 Pre-outage fault detection

This scenario is considered to be priority four by Stadtwerk Landau.

process steps	
Initiator	Customer reports anomaly, e.g. flicker or short-term transient outage, or DSO staff inspects LV grid components as part of periodic maintenance
Process steps	1. Customer or maintenance staff reports anomalous behavior 2. Inspection by infrared camera to identify high-temperature connectors in the affected LV grid 2b. Alternatively: detection of voltage drops in junction boxes based on measurements with mobile PQ measurement devices 3. replaces/repair of identified connectors
Applies to	Any type of slowly degrading grid fault (which has not yet led to an outage). Specifically interesting case: detection and localization of loose cable connectors.
Comments	Occurrence likelihood: Currently rarely (once every few years)

3.2.5.8 Input for Future Solution for Pre-outage fault detection

Target: reduce outage occurrence frequency and duration by systematic pre-outage detection

Improvement potential in case of pre-outage detection

- Planning of repair (increases customer satisfaction) – no weekend/night additional payments to staff
- Perform switching to take cable out (no customer impact)
- Avoid escalating faults and outages

Description: loose cable connector leads to changes of resistance of the LV grid radial (but without leakage) and eventually later to an outage due to overheating; not necessarily will this cause a fuse to blow

- Potential solutions
  - Detection based on harmonics
  - Detection based on temporary outages
  - Detection based on voltage variations

Desired Benefits:

- avoid Large staff effort for detection in the field in particular for transient outages (multiple trips to customer without success)

- Increased customer satisfaction (avoiding unsuccessful diagnosis and repeated outages)

3.2.5.9 Outage detection and cable identification (post-outage)

This scenario is considered to be priority five by Stadtwerke Landau.

process steps	
Initiator	Outage at one or more phases at one or more prosumer connections
Process steps	1. Customer calls to report outage 2. DSO makes remote diagnosis by asking questions to the customer and by correlating this information with calls from grid neighbors 3. maintenance staff drives to the affected customer to make local measurements and diagnosis and localize outage by a sequence of local measurements and visual inspection of grid equipment (e.g. fuses)
Applies to	For all outages (single phase, multi-phase, etc.) irrespective of cause: • Main difference to multi-/all phases: customer calls may be delayed; currently may lead to wrong diagnosis of location of fault based on customer calls • 3-phase outage is more rare in Stadtwerke Landau grid (mostly 1 or 2 phases) Possible causes in Stadtwerke Landau scenario: • Faulty cable (aging or mechanical impact; mechanical impact is second most likely in Stadtwerke Landau scenario) LV or MV • Defect of sleeve (LV or MV) or cable branch tee (LV) • Loose cable connector (see next section) (in street cabinet LV or MV) • Short circuit e.g. due to animals (Stadtwerke Landau, about 4 times per year, spring and fall mainly) LV or MV • Blown fuse - LV or MV (just before trafo in secondary substation)
Comments	Occurrence frequency at Stadtwerke Landau: only few faults and staff knows grid rather well, new LV grid, built during last 25 years (change from overhead lines to cables) • However recent new situation: takeover of part of a distribution grid, less expert knowledge at staff for new grid parts; • Possibly more occurrence in 20-30 years with aging LV grid

3.2.5.10 Input for future solutions for Outage detection and cable identification (post-outage)

Target: (1) reduce duration of outages; later also (2) Proactively and automatically inform affected customers to avoid having to handle many incoming calls.

Step 1: Automatic detection of outage, alarming and visualization of affected customer connections to DSO

Step 2: Diagnosis and localization (cable identification) of possible causes; visualization to the DSO

Parameters to measure success of Net2DG solution:

- time from occurrence of fault until certain percentage (e.g. 95%) of customers has power established again, resulting costs:
  - Future potential impact on grid tariffs, see Section 6.2
  - Working hours of technicians in the field and of engineers in office to handle faults,
  - Customer satisfaction (to be further discussed how to measure)

3.2.5.11 Loss of Neutral detection and localization

This scenario is considered to be priority six by Stadtwerke Landau.

process steps	
Initiator	The neutral at a subset of LV customers is persistently not available
Process steps	1) Customer calls and reports equipment not working 2) DSO staff performs local measurement with mobile PQ measurement device and detects abnormal voltage behavior in the different phases 3) Measurements in Junction boxes are made by DSO staff to identify location of fault.
Applies to	Loss of neutral in conductors or transformers. Any cause of loss of neutral, including copper theft (rare in Germany) and accidental causes: • cable faults (slowly degrading or abrupt) • poor/degrading cable contacts (sleeves) • Harmonics (mainly 3rd) that stress/overload the neutral
Comments	The neutral is connected in rings with multiple secondary substations, so loss of neutral from one substation will in these cases lead to the neutral from another substation being used. However, this may still impact voltages (though the neutral is not completely lost) Occurrence likelihood at Stadtwerke Landau: • only very few sleeves in LV grid, hence occurrence only about once every 10 years, may happen more often in future scenarios of increased renewable generation In general, neutral integrity problems are more common in developing countries due a combination of aggressive environmental conditions, vandalism and in some cases, questionable workmanship. The consequence of a lost neutral conductor will vary,

depending mainly on the load balance conditions in a three phase system, but also on the type of earthing system used and the position of the break in the neutral relative to the load. Worst case scenarios could include both damage to connected loads due to overvoltages on single phase circuits or the creation of hazardous touch voltages on exposed conductive parts. Potential impact on single phase loads are voltages and currents changes, which potential cause damage or shut-off of loads.

3.2.5.12 Input for Future Solution for Loss of Neutral detection and localization

Target: reduce damage of customer equipment due to voltage changes (overlap to voltage variation use-case);

Expected procedure - Vision with Net2DG:

- Upon loss of neutral, the part of the grid which is suspected to have no/wrong neutral is marked in yellow and specific marker appears on the GIS map on likely locations (transformer/cables/sleeves), which may contain the cause of the loss of neutral

Related KPIs and estimated (qualitative) improvement potential:

- customer satisfaction increases
    1. Avoid damage to customer equipment from high/low voltages
    2. Avoid switch off of customer equipment due voltage changes
- For predictive detection: Reduce unscheduled maintenance and replace by scheduled maintenance
- Reduction of DSO staff hours spend on repair and detection
- Avoid preemptive replacement of cables and save of costs of cables

Solution approaches & Challenges

- Based on voltage deviations of different phases
    1. Also predictive case: Slowly decaying degradation, detects before complete loss
- Maybe based on harmonics
- Possibly via SM events

4 Control Related Scenarios

4.1 Current status

On the LV grid, there are currently only few active control measures in place today (considering the average automation level of DSOs in Europe and worldwide). Typically, Control capabilities are concentrated around remote-controlled MV (30-10kV) breakers in their MV/LV distribution substations, along with On-Load Tap Changers in their primary HV/MV transformers, which operate based on voltage measurements on the secondary side of the transformer (as an average of all 3 phases). Currently, regulation leave DSOs very little control over user loads etc., so direct load control will have to be on a voluntary basis, probably assisted by some form of economic compensation.

New grid codes may allow the DSO (or other control-responsible entity) to request PV/inverters to adjust active/reactive power output to the grid, which will be assumed available in the following.

4.2 Benefits of active control

Active control can assist the DSO in avoiding voltage swells or dips resulting in extended over/under-voltage situations that might stress the cables and junction boxes or even reduce lifetime of household appliances. This is currently very difficult, since no real-time voltage measurements from the LV grid are available, so it is not known when and where such situations occur. However, with smart meters installed at end-consumers, the situation may be significantly improved with respect to measurement feedback. Based on local measurements, it suddenly becomes feasible for the DSO to analyze the load situation in the grid and spot risk zones, as well as determine how to adjust the power flows to mitigate the situation with out-of-bound voltages etc. From an economic point of view, it is assumed that better control over the power flow in the grid should also be beneficial in terms of minimizing losses and reducing overall OPEX.

Active control can also assist in ensuring correct active/reactive power ratio in the grid. This is primarily beneficial for loss reduction purposes. By balancing active and reactive power locally, for instance by letting PV inverters produce or consume reactive power, the reactive power does not require transport over long distances and hence does not cause unnecessary losses. Also, actively controlling active and reactive power can reduce DG curtailment since the power interchange with the grid can be controller in order to avoid reaching the technical limits.

Finally, it is a declared goal for the DSO partners in the Net2DG consortium and assumed for DSO in general to reduce the amount of power interchange with the HV transmission system. This goal is based on the philosophy that in many cases it is preferable to make use of local production – especially from renewable sources – than buying it from sources elsewhere in the NordPool system. There is probably also cases, where this local energy consumption is less favorable seen from an economic point-of-view. Measurement feedback from consumers will, in principle at least, allow the DSO to estimate the consumption in real-time and activate local production to match the consumption and thereby decrease the need to import power from the HV grid. Matching production and consumption locally has the added advantage of keeping transportation losses down as well, as explained above.

A high-level control algorithm here envisioned within the NET2DG should:
1) estimate states and dynamics of assets (feeder-wide scope)
2) detect voltage swells and dips as well as active/reactive power mismatch in the grid (wherever such measurements are available)
3) generate setpoints for available actuators such as:
- On-Load Tap Changer (only for voltage control – see below)
- Residential Inverter Envelope Adjustment (for example for reactive power injection)
- Load Activation/Reduction
The controller may be centralized or semi-distributed with different sub-controllers being responsible for different geographical areas.

A potential architecture for such a control system can be envisioned as Figure 18.

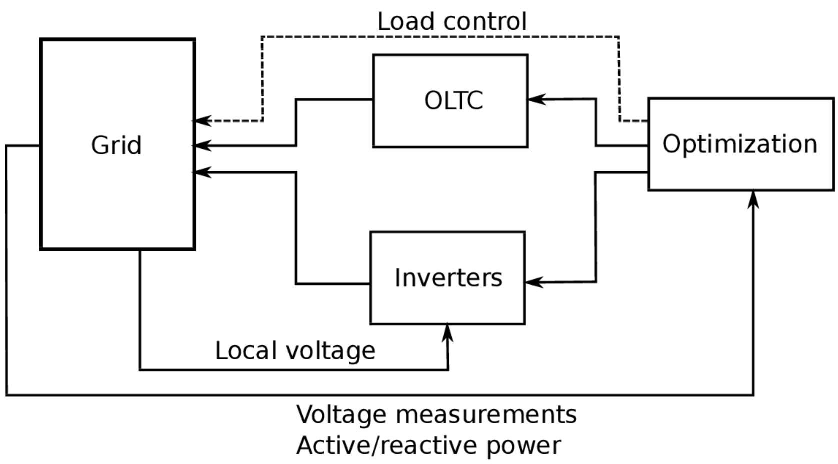


Figure 18 Potential control architecture. Note that direct load control is not feasible today and is thus included as a future possibility. However, direct control from the DSO's side via communication to tap changers (OLTC) and local inverters are in principle feasible

4.3 Grid control related scenarios

4.3.1 Scenario: Reactive power measurement and minimization (Grid Voltage Quality)

A radial in the LV grid with known configuration of loads is considered. Due to unforeseen circumstances (could be a faulty inverter), reactive power consumption suddenly drops at one point in the grid far downstream from the feeder. This status is detected via local sensor measurements, either directly in the grid or by local inverters, and the voltage quality status is communicated together with geographical information back to the controller (presumably located at the DSO).

When the controller receives information about the increased ratio of reactive power on the radial, it should determine the most effective way to counteract the mismatch. This would typically be done by solving an optimization problem that minimizes a cost function over a set of permissible candidate control actions. Complementing this objective function, potential control restrictions could include distance to lower/upper voltage bounds, active/reactive power ratio, and fairness (equal reactive power output among all assets over a given period of time).

As soon as an optimal or, if computation load and real-time demands do not permit an exhaustive search, a sub-optimal solution is found, the controller issues commands to selected actuators. This could for instance be in the form of set-points to inverters requesting that they output reactive or active (establishing an order of merit) power to the grid to re-establish the desired voltage quality.

4.3.2 Scenario: Voltage rise mitigation (voltage quality management)

A radial in the LV grid with known configuration of loads is considered. Because of overproduction from DG elements, the voltage rises at the downstream end of the radial, threatening power flow inversion from the LV grid to the MV grid. This status is detected via local sensor measurements, either directly in the grid or by local smart meters or inverters, which communicate the current status together with geographical information back to the controller.
The controller (similar to the one discussed above) recognizes the voltage rise and must then determine the optimal way of dealing with the situation.

Potential control objective functions for this scenario could include restrictions such as the number (rate) of tap changes, distance to lower/upper voltage bounds, and activation of consumption. Whenever the OLTC is required to change taps, they get worn; thus it would make sense to try to limit the number of tap changes. On the other hand, the activated loads should be deactivated again to balance out the extra consumption from an economical point of view, which would likely entail some sort of weighting between the potential control actions.

When the best possible mitigation strategy has been decided, the controller issues commands to selected actuators, for instance to activates extra loads in the vicinity to bring the voltage back down to safe levels.

4.3.3 Scenario: Multi-objective control (optimize Voltage Quality and Grid Efficiency simultaneously)

By exploiting redundancy in the different types of actuation systems, the controller should pursue ongoing optimization of voltage quality and grid efficiency at the same time. The means of actuation are as above, but the operation is “normal”, i.e., the system is not dealing with intermittent abnormal operating conditions in this case.

Potential control objective functions for this scenario might include difference between current voltage and lower/upper voltage bounds, active/reactive power ratio, fairness (equal reactive power output among all assets over a given period of time), and grid efficiency, for instance. Another important performance metric here could be the amount of power exchanged with the

MV/transmission grid; the more demand that can be covered by local production within the LV grid, the better.

In this scenario, the controller does not have to act as fast as in the two previous scenarios and can therefore use more processing power on optimization, as well as accept lower incoming data rates. On the other hand, since the controller is attempting to correct a non-alert situation, focus must be kept on maintaining the balance between production and demand, such that producers and consumers are not treated unfairly by e.g., being requested to consume more energy than necessary. This scenario is thus linked to the energy market, as discussed in the following chapter.

5 Energy Market Related Scenarios

5.1 Values chains and the role of the DSO and customers

5.1.1 The Value of Distribution in Liberalized Electricity Markets

In liberalized electricity markets, previously vertically integrated electricity supply systems are split into clearly defined and separately accounted entities such as electricity generation, high-voltage transmission, low-voltage distribution and customer supply. Moreover, besides the separation of the different elements of the physical infrastructure of the electricity supply chain also commodity markets have been implemented for wholesale electricity trade and retail electricity supply, representing further essential ingredients of competitive electricity markets, see Figure 19.

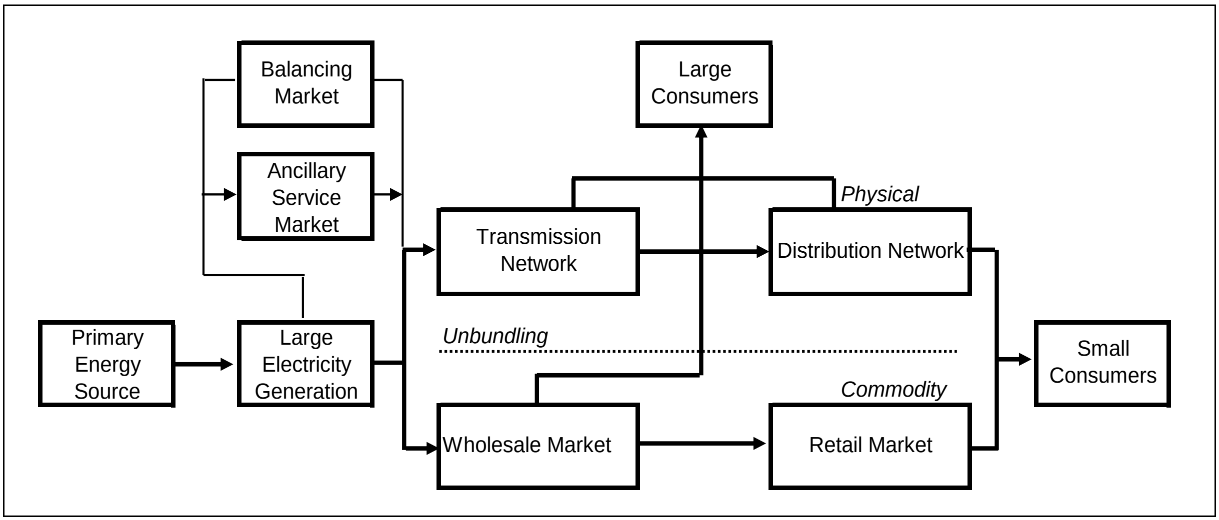


Figure 19 Conventional centralized electricity supply systems in a liberalized market

Whereas Figure 19 presents the major elements of a conventional centralized electricity supply system in a liberalized electricity market Figure 20 includes the most important additional components, connections, relationships, and interdependences in case of significant penetration of dispersed DG/RES-E electricity generation.

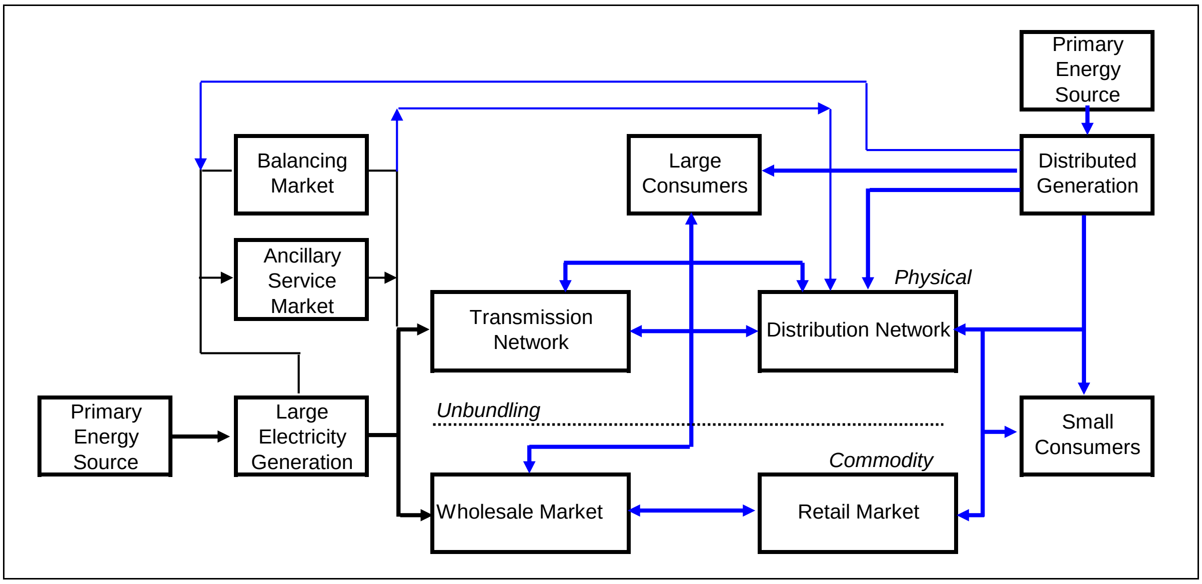


Figure 20 Electricity supply system in liberalized markets with high penetration of DG/RES generation in a liberalized market. The blue lines indicate the recent changes due to DG/RES generation.

Figure 20 demonstrates that DG/RES-E generation can complement the existing centralized electricity supply infrastructure, overcome network congestion, provide ancillary services and improve overall system reliability. Furthermore, the overall modularity of DG/RES-E generation offers enhanced flexibility in electricity system planning through the possibility to defer investments in centralized electricity generation facilities, as well as transmission grid reinforcements and extensions. On the other hand, the integration of DG/RES-E generation units with intermittent generation characteristics (e.g., wind, photovoltaics and in some cases also combined heat and power generation (CHP)) pose additional challenges to system balancing. Additionally, an increased level of DG/RES-E penetration requires a transition from centralized control and system balancing by few market actors to a control system that allows and coordinates decentralized decision making by many actors.

An important distinction has to be made between distribution networks and the transmission network. In general, DG/RES-E generators can offer local ancillary services to the distribution grid operators. Moreover, there often exist local needs for ancillary services (e.g. voltage support by active or reactive power changes) that only can be fulfilled locally unless reinforcements or extensions of the local distribution network infrastructure enable “imports” of ancillary services from the transmission grid operators. [1]

[1] Therefore, deploying DG/RES-E generation facilities on fitting sites can be an alternative for investments into grid reinforcements or extensions. Thus some ancillary services can be offered by DG/RES-E generators directly to the distribution system operator, whereas other ancillary services like frequency control (needed for the operation of the transmission systems) only can be offered by large centralised conventional power plants. However, at present very few implemented DG/RES-E generation units are equipped with the infrastructure necessary to provide ancillary services. This is supposed to change in the future with increasing shares of DG/RES-E generation in electricity supply systems.

5.1.2 Value Creation of the DSO

The DSO is responsible for the distribution system, including switching and securing the load limits as well as ensuring the network quality (voltage, frequency, active power and reactive power) within specified tolerance ranges. The frequency management is primarily the responsibility of the TSO. In the context of network management, the TSO requests intervention by the DSO, which can shut down installations of the network users via corresponding field communication networks to contribute to the stabilization of frequencies, if that is not triggered already automatically. Another value proposition in the context of network management is the testing of facilities for the control of (distributed) generation facilities as well as the testing and ensuring the network protection.

Additionally, the legal requirements for the control of feed-into the distribution system operator are defined by the DSO. Also, the contracts for feed-in management are between the DSO and the plant operators.

5.1.3 Costs and Revenues of the DSO

The main costs are depreciation costs for the investments in the grid, grid automation equipment, and grid control systems as well as the ongoing grid management costs. The grid management costs also include all pro rata costs for personnel, buildings, vehicle fleet, etc. The DSO does not receive any independent revenues from the grid consumers for the grid management value. Those are part of the grid charges that grid consumers pay for the value propositions of the DSO. However, according to the current rules in Central Europe, only the consumers of energy pay distribution charges, while generation is not charged. Generation facilities pay only (one-time) fees for the grid connection, but not any grid charges for grid operation and management.

The transformation of the energy system significantly increases both capital/depreciation costs and operating costs. The cost of the grid automation equipment and the communication link must be borne by the DSO, as this should be accessible for system security reasons alone. The network users must bear the costs for the system automation means. On the other hand, the costs of communication (communication infrastructure or use of public communication networks) may be shared between the DSO and the grid user, as the grid user can also use the energy management communication infrastructure for market purposes.[2]

5.1.4 Valorization of the DSO

The market participant introduced in Figure 20 are valorized either in a competitive (non-regulated) or regulated way. Figure 21 shows the end users’ tariff on the bottom and how the composition looks. While the retailers are competitive actors in the electricity market, the DSO and TSO are both regulated by a regulatory authority. Section 5.1.5.2 will give an introduction to current and future regulation approaches.

[2] Schäffler, H.; Jagstaidt, U. and Kossahl, J., „*Smart-Grid-Geschäftsmodelle für Verteilnetzbetreiber*“, VDE Kongress, 2012.

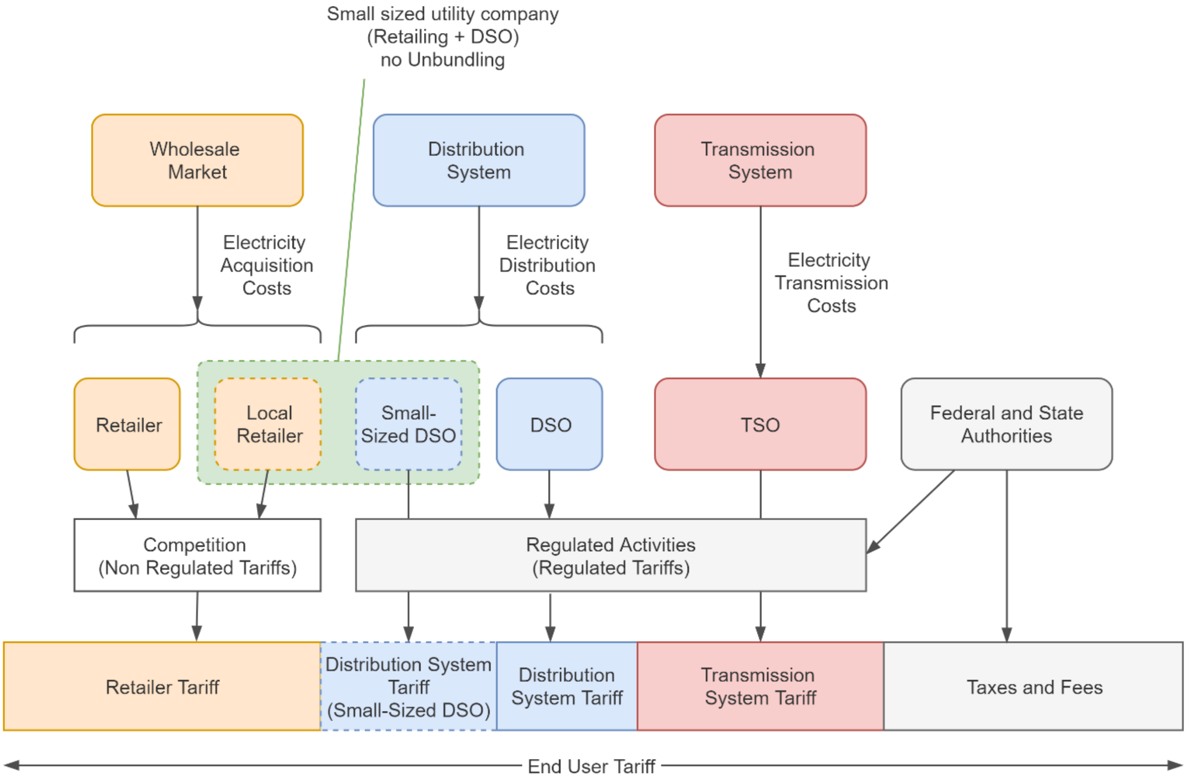


Figure 21: Composition of the end user tariff, consisting of retailer, distribution and transmission system tariff.

Figure 21 also shows the case of small-sized utility companies (e.g., in Austria: <100,00 consumers or <50 GWh). As the legislation[3] is aware of high administration costs by unbundling those small-sized utility companies, they may stay bundled as long as they do not exceed the limits. In the case of small-sized DSO, usually, another mid or large sized DSO is the link between the distribution system and the transmission system.

5.1.5 Business Models in General and for the DSO in particular

5.1.5.1 Business Models

The definition of a business model (BM) according to Osterwalder et al. (2010)[4] can be defined as follows:

[3] E.g. for Austria: *Bundesgesetz mit dem die Organisation auf dem Gebiet der Elektrizitätswirtschaft neu geregelt wird / Federal Act restoring the organization in the field of electricity* (Elektrizitätswirtschafts- und –organisationsgesetz 2010 – ElWOG 2010)

[4] Osterwalder, A., Pigneur, Y., Clark, T., 2010. Business model generation. A handbook for visionaries, game changers, and challengers. Wiley, Hoboken, NJ.

A business model describes the rationale of how an organization creates, delivers, and captures value

By Osterwalder et al. (2010) a BM Canvas is a very established strategic management and an entrepreneurial tool that is used to analyze business models for various businesses, see Figure 22. It defines the following nine BM building blocks to describe a company's activities:
Customer Segments: An organization serves one or several Customer Segments.
Value Propositions: It seeks to solve customer problems and satisfy customer needs with value propositions.
Channels: Value propositions are delivered to customers through communication, distribution, and sales Channels.
Customer Relationships: Customer relationships are established and maintained with each Customer Segment.
Revenue Streams: Revenue streams result from value propositions successfully offered to customers.
Key Resources: Key resources are the assets required to offer and deliver the previously described elements …
Key Activities: … by performing a number of Key Activities.
Key Partnerships: Some activities are outsourced and some resources are acquired outside the enterprise.
Cost Structure: The BM elements result in the cost structure.

The blocks can be combined into a BM Canvas, a visual chart with elements describing a firm's or product's value proposition, infrastructure, customers, and finances.

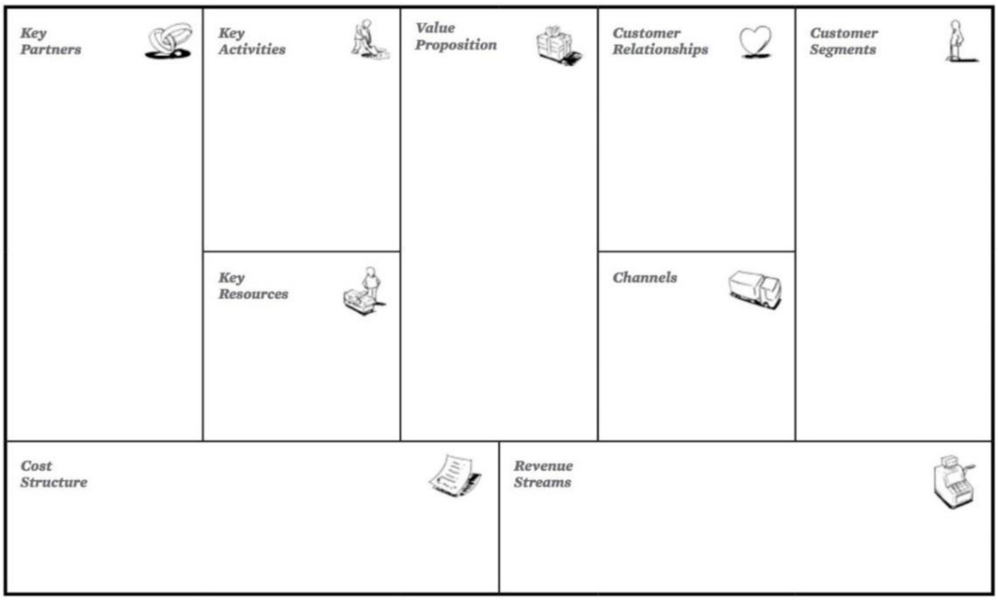


Figure 22 The Canvas Business Model

5.1.5.2 DSO Regulation

Grid operators, in particular, play a key role in the success of decentralized systems. Because they provide the networks to which the systems are connected, and they are usually the ones who (have to) take the power of decentralized systems[5]. Additionally, to investments in environmentally friendly generation plants, there has are also those for the provision or adaptation of the corresponding grid infrastructure. E.g., information technology may provide the possibility of a more flexible, 'intelligent' grid operation. These investments and adaptation services may be offset by long-term benefits for the overall system, which, however, are not always reflected in corresponding and secured revenues for the relevant actors, especially in the usual payback periods.

Due to the monopoly characteristics of DSOs, a regulatory authority has been established. The regulation in some countries relied on price incentives to drive efficiency, maintenance, and asset renewal. The “RPI-X” formula was the mechanism used under the distribution price control reviews to set allowable revenues for the DSOs. “RPI-X” caps price increases to the system charge, the predominant revenue stream of DSO′s levied on consumer bills. The charge cap is based on the rate of inflation defined by the Retail Prices Index minus a factor “X” (hence, “RPI –X”). “X” is a function of the capital and operational expenditure (CAPEX and OPEX respectively) of the DSO. For the OPEX element, DSO′s are incentivized by benchmarking against the best practice DSO in the sector. For CAPEX, the assessed value of the asset base, plus investment, minus depreciation equals the asset value. DSO’s earn an allowed rate of return on these assets based a weighted average cost of capital (WACC). Together with separately calculated service incentives, this represents the revenue structure of the UK′s regulated distribution business model. [6]

New approaches, shown in the UK, places new duties placed from the regulator to take account of factors other than cost, such as climate change targets, fuel poverty and security of supply, the RPI-X mechanism has been described as unfit for purpose[7]. This is based on the grounds, that it incentivizes incremental efficiency gains over system innovation, and so fails to deliver environmental and social benefits[8]. To incentivize a “timely delivery of a sustainable energy sector”[9], RPI-X has been replaced by the RIIO (Revenue=Incentives+Innovation+Output) framework for the price control review currently being negotiated. The RIIO framework is a significant shift towards a legal revenues structure that better incentivizes smart grid solutions. An important question for the future is the fact, if the reaction of the DSOs to RIIO, is expected to incentivize enough investment in smart grids to accommodate the

[5] P. Späth et al., „Integration durch Kooperation: Das Zusammenspiel von Anlagen- und Netzbetreiber als Erfolgsfaktor für die Integration dezentraler Stromerzeugung“, in behalf of the Austrian Ministry of Transport, 2006.

[6] Stephen Hall, Timothy J. Foxon, “*Values in the Smart Grid: The co-evolving political economy of smart distribution*”, Energy Policy, Volume 74, 2014, Pages 600-609, ISSN 0301-4215,https://doi.org/10.1016/j.enpol.2014.08.018.

[7] Xenias, D., Axon, C., et al., “*Scenarios for the development of smart grids in the UK: literature review”,* UKERC Working Paper, REF UKERC/WP/ES/2014/001, 2014.

[8] Müller, C., “*Advancing regulation with respect to smart grids: pioneering examples from the United Kingdom and Italy*”. In: Proceedings of the Fourth Annual Conference on Competition and Regulation in Network Industries, Brussels, 2011.

[9] Ofgem “*RIIO – a new way to regulate energy networks. Office of Gas and Electricity Markets*”, London, 2010.

volume of renewables necessary to meet decarburization goals. In an interview of Hall and Foxon (2014) a DSO stated:

> *"The key game changer with RIIO is actually we get told we have to fix our problems, so we have problem areas where we can fix them traditionally but we could also fix them with innovation [smart grid technologies]. So it [RIIO] doesn't specify that you have to install so many cables, so many overhead lines so many transformers. It just tells you, you have to fix the problem. That really opens up the opportunity for us to use innovation in that way"*

The new regulation allows smart grid technologies to be assessed alongside conventional reinforcement solutions, which is more in line with a commercial logic of technology deployment on a cost basis as opposed to constraining activities. Across the DSO sample in Hall and Foxon (2014), there was broad uncertainty as to the ability of the new framework to incentivize sufficient innovation to manage the volume of renewable generation compatible with the emissions reductions targets.

5.1.5.3 Business models for and with the DSO

Innovations in grid integration and operation approaches show that there are alternatives to conventional methods by implementing active network management concepts based on new communication technologies. These alternatives - mostly called "Smart Grid solutions" - enable a more dynamic distribution grid design and have to result in alternative business strategies or models. In general, such business models incorporate the interactions, strategy and value exchanges of different actor segments in a distributed electricity supply system. As written previously, the example of Denmark, where the process of restructuring the energy system from a strictly central hierarchy to a highly decentralized system design has been in place for decades, shows that decentralized energy systems also function well and quickly in the market if the necessary framework conditions are created. For example, the issue of network cost allocation for reconnecting plant operators was solved quite differently than in many European countries (the network costs are not attributed to the plant operator, but socialized via the network tariffs).[10]

A new way of thinking and adapted regulation processes brings smart grid investment decisions closer to what Jackson (2011)[11] describes as the "smart grid investment problem" as shown in Figure 23. The aggregated benefits of smart grid technology deployment define the likelihood of smart investments. Jackson (2011) includes remote meter reading and demand-side management; these are un-captured values for DSOs due to the structure of the current market conditions. The "risk" element of Figure 23.

[10] Prüggler W. et al. „ KONDEA - Konzeption innovativer Geschäftsmodelle zur aktiven Netzintegration dezentraler Verbraucher- und Erzeugeranlagen ", 2010.

[11] J. Jackson, "*Evaluating Smart Grid investments at cooperative and municipal utilities in US*", Metering Int., 1, pp. 76-78, 2011.

is notionally complicated by the strength of the regulatory incentive. If further values exist and can be leveraged, the volume of the risk range will be reduced.

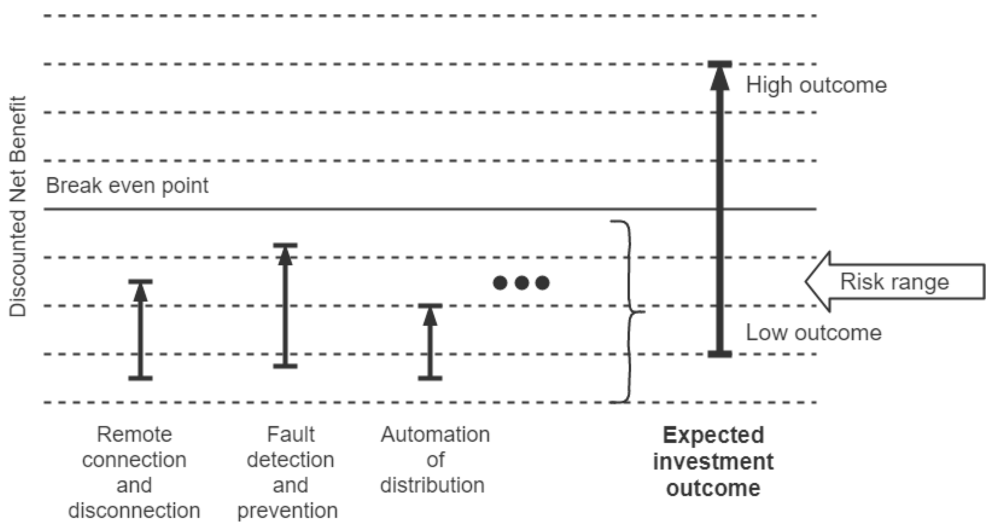


Figure 23 The smart grid investment problem*. Source: Adapted from Jackson (2011) p.77 and Hall and Foxon (2014). *The values are illustrative only and define the problem, they do not relate to the relative value of each benefit.

According to Bialek and Tylor (2010)[12] there is a "broken value chain" in the smart grid, by values in the smart grid transitions that are not captured by the investing utilities. Xenias et al. (2014) describe the "value chain" in the smart grid to comprise familiar market participants who may be further enabled by smart technology deployment.

Agrell et al. (2013)[13] characterized some of the effects of new asset investments policy on the network tasks, assets and costs and contrasted this with the assumptions of the current economic network regulation. At this moment the authors investigated three common scenarios as illustrated in Figure 24. The first scenario corresponds to a situation where the traditional unbundling requirement on the DSO is relaxed and where the DSO is allowed to make direct investments in DER activities. The second scenario shows the decentralized DSO case where the regulator contracts with the DSO and delegates the coordination of smart services to the DSO. The third scenario is again a decentralized scenario, only now the regulator coordinates the DER investments directly via centralized incentives.

The investment opportunities could involve investments in technologies, measurement equipment or protective devices and investments can be done by both the DSO and the smart service provider. This

[12] Bialek, J., Taylor. P., "*Smart grids: the broken value chain: Durham Energy Institute*". DECC Workshop Summary Notes, 3 November 2010.

[13] P.J. Agrell, P. Bogetoft, M. Mikkers, "*Smart-grid investments, regulation and organization*", Energy Policy, 52, pp. 656-666, 2013.

means that the social gains from investments are attained if and only if both DSO and smart service provider invest.

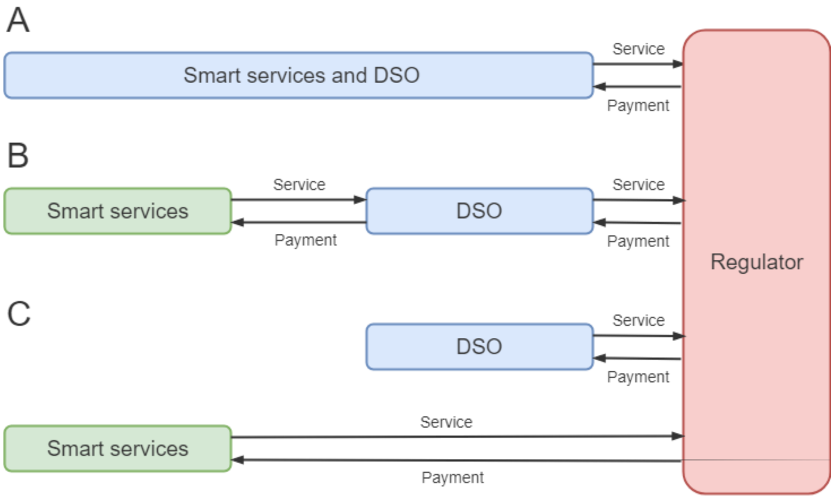


Figure 24 DER investor, DSO and regulatory organization and delegation. (A) The integrated case, (B) Separate and decentralized incentives and (C) Separate and centralized incentives. Adapted from Agrell et al. (2013)

5.1.6 Current business model canvas for Thy-Mors Energi

This section describes the As-Is business model canvas for TME Elnet.

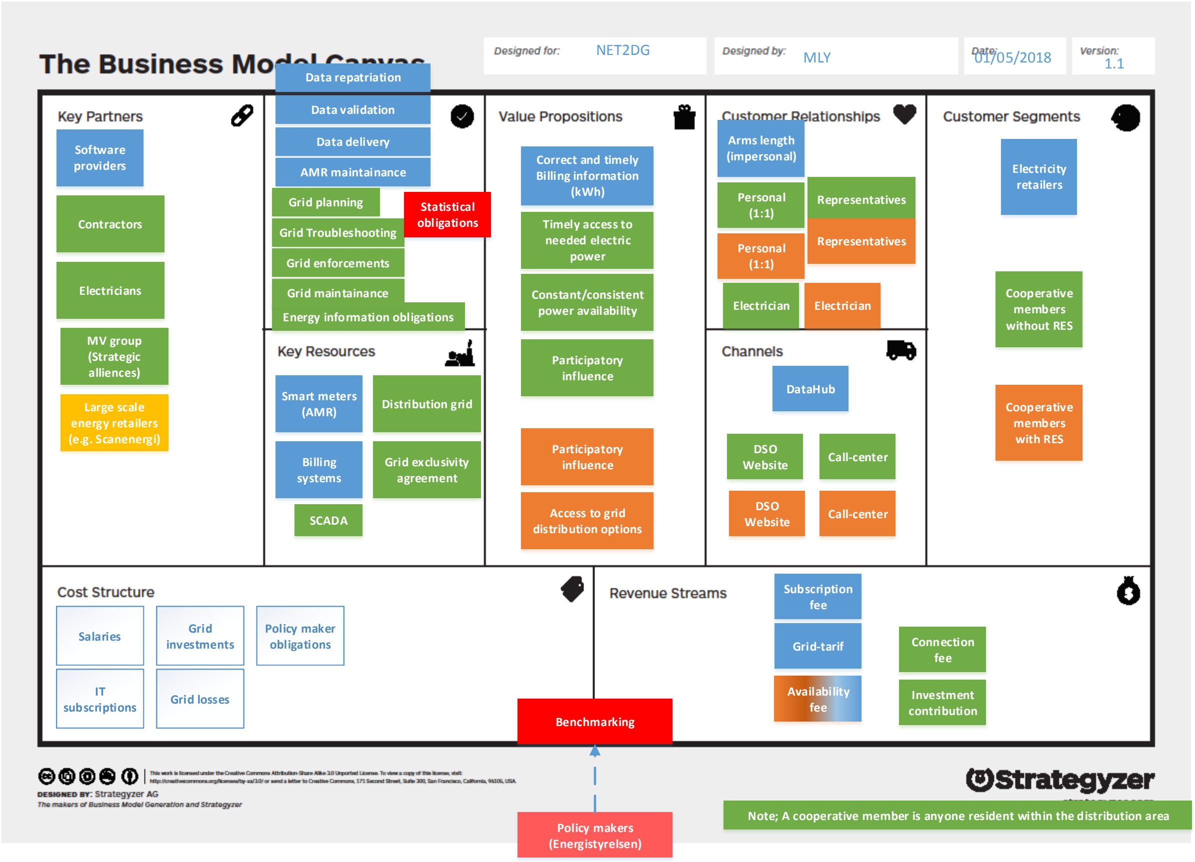


Figure 25 Business Canvas for Thy-Mors Energi

The DSO function at Thy-Mors Energi, Thy-Mors Energi Elnet, mainly has two customer segments; Electricity retailers and Cooperative members. The cooperative members are residents or as minimum owning an energy delivery point within the TME distribution area. The energy retailers on the other hand is not restricted in geography, only in operational activity. By operational activity we mean; Each electricity retailer, themselves, decides where and how to operate.

Electricity retailers:

The value TME Elnet is offering its customers on the retailer side is; Correct and timely energy billing information. TME Elnet provide this value by having an arms-length to all electricity retailers active on the Danish market due to the market regulation and structure. The communication between DSOs and retailers happens through the DataHub, a platform owned by Energinet, the danish TSO. The revenue streams generated is; a subscription fee, for being connected to the grid, and a grid-tarif. The grid-tarif covers the energy transportation costs within the DSO operated grid. Furthermore, the electricity retailers charge the end-user for any fee related to DSO services provided to any end-user. E.g. a "service" could be; Closure of metering point, if payment obligations from the end-user is not respected.

TME elnet can provide the value by repatriating, validating and sending metering values from smart meters directly to the DataHub. Key resources therefore include optimized AMR (Automatic Meter

Reding) system and an effective billing system and processes. To ensure this we form strategic alliances with AMI system providers.

Cooperative member

The cooperative member customer segment can be divided into two categories; Members with RES and Members without RES. The only significant difference between these customer segments is additional revenue streams from members with RES installed.

Regarding, the cooperative customer segment the value propositions are as follows; Timely access to sufficient power. Consistent power availability and participatory influence, and access to distribution grid capacity. The customer relationship with these customers is personal 1:1 short term interactions, based on a long-term commitment from being a resident or delivery point owner. The long-term commitment of owning a delivery point allows for the cooperative member to engage with the company through their chosen representatives at a yearly meeting.

The revenue streams from these customers are, connection fee and investment contribution, which both are one-time payments. Secondly cooperative members owning a RES pay an availability fee which is charged through their electricity retailer.

In order to ensure timely access to electric power, consistent power availability and quality, TME Elnet enforce a long-term planning policy and investment strategy to ensure low need for troubleshooting and force-majeure maintenance. The primary resources are the distribution grid itself, the SCADA and monitoring systems, while operating under a distribution exclusivity agreement which is limited in time. TME Elnet partner up with local contractors and electricians to ensure installation and construction work done to the grid. Furthermore, TME Elnet creates strategic alliances to ensure a strong bargaining power towards our internal influencing factors, and to create economy of scale. Finally TME Elnet have to cover the energy that is lost in our distribution grid by acquire lost energy from large scale retailers.

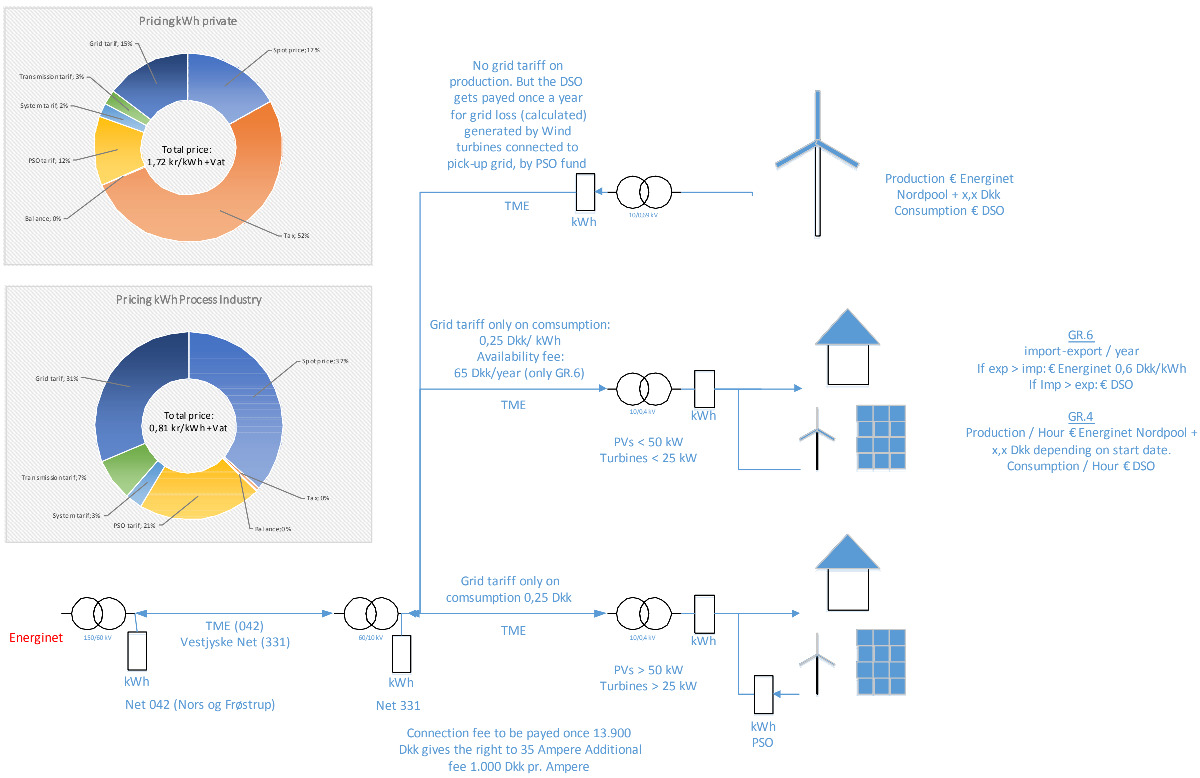
The cost structure to all customer segments is a shared flat calculation with respect to the cooperative nature of TME Elnet, and is made up of: personnel salaries, location rentals, software subscriptions to AMI system providers, grid investments and maintenance, grid losses.

Other factors

The TME Elnet business model is affected by external factors such as national policymakers that enforce policies and requirements to the monopoly alike nature of the grid exclusivity agreement. An example of this is the requirement for DSO to provide statistical data for benchmarking purposes. The result of the benchmarking will both affect the revenue streams and the cost structure, while it is a key activity that TME Elnet is obligated to do.

The external influences is not a normal part of the Business model canvas, however in order to understand the models in a holistic perspective it is important to be aware of these implications.

5.1.7 TME Payment flows



- TME does not receive any money for transported produced energy
- Only for consumed kWh 0.25 DKK /kWh
- In addition payment of ca 500 DKK/year for metering rental and service related to that
  - higher SM costs (at 60/10kV transition) as higher-voltage meter is more expensive
- Onetime payment at installation of 13000DKK for 35 Amps connection
  - Additional 1000DKK for each additional Amp
- Windturbines: full costs of installation as one-time payment
  - Metering costs vary depending on type of meter
- No payment of TME as DSO to ENerginet.dk (instead from customer money)
- Payment of transport and loss costs to Vestjyske Net
  - Total loss costs, based on rough calculation using average loads, shared equally by several DSOs using Vestjyske; lumpsum payment, not transparent
  - Real loss costs due to TME expected to be lower, as relatively constant production from Wind

5.1.8 Stadtwerke Landau Payment Flows

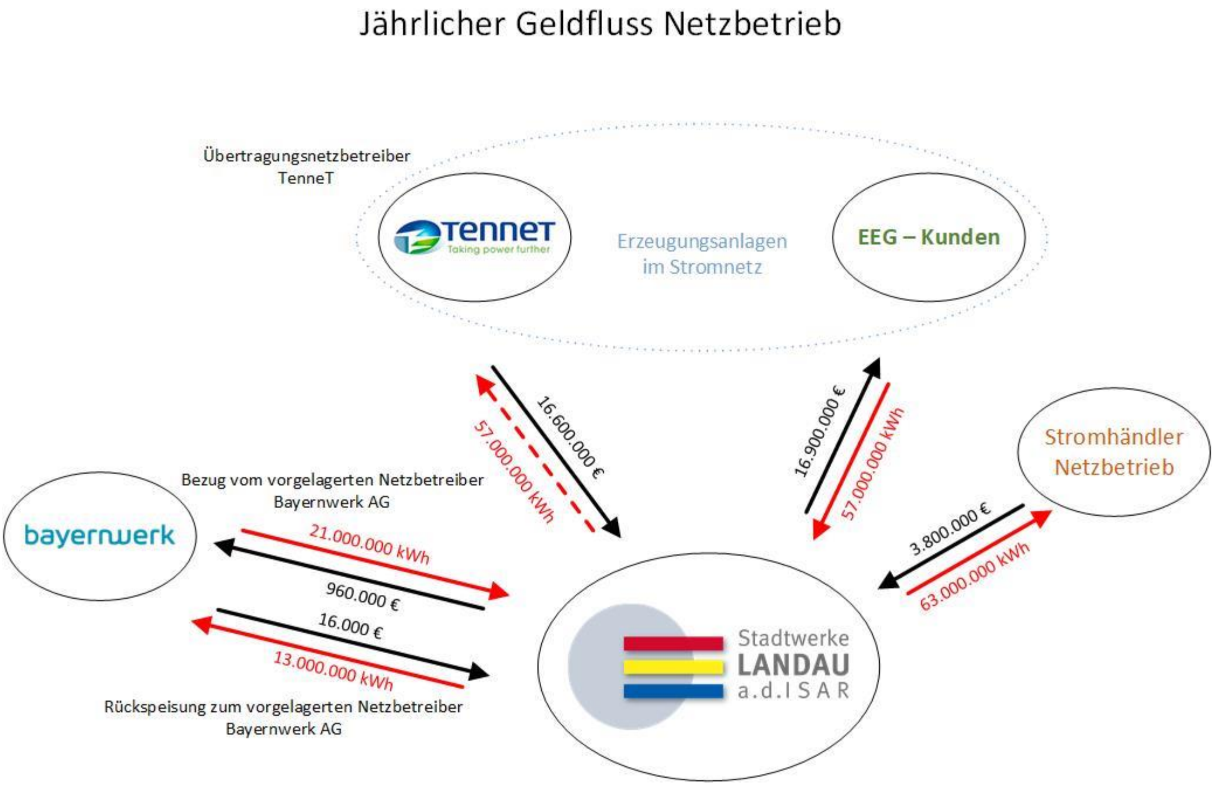


Figure 26 Revenue streams for Stadtwerke Landau

The figure above shows the money flows (black) and the related energy flows from the perspective of Stadtwerke Landau as DSO. Some remarks:

- The payment to the higher-layer grid operator as well as the grid tariffs payed by the customers via the retailers are calculated by the maximum power in a quarter of an hour during the year and by the a payment per kWh.
- The grid tariffs are calculated by the regulator and cover the following cost categories: (1) interest of own capital; (2) staff cost for network operation; (3) equipment and third party services; (4) depreciation of investments; (5) costs of energy losses; (6) payments to higher layer grid operator for imported energy.

Conclusion:

- Short term financial benefit for DSO from reducing losses/investments, however compensated by reduced grid tariffs subsequently; for losses even over many years, losses are not early recalculated by the regulator, amount of losses stayed the same for many years)
- Customer perception strongly shaped by outages, losses also matter but less extent
- Outages currently not in the grid tariff calculation, but expected to be part of it in the future

5.2 Scenario: DSO support of Regional Energy Product

Regional products have become fashionable, in particular regarding food products, as the customer connects several advantages to them and therefor is willing to pay a higher price. In particular, such products are perceived by customers as: (1) Environmentally friendly due to low transport effort; (2) Supporting regional producers (farmers or similar), which keep value generation in the region; (3) High quality.

Regarding electricity, several German energy retailers are in the process of offering so-called regional energy. When a customer subscribes to this (typically slightly more expensive) regional energy product, the utility has to assure that it buys sufficient energy amounts from generation units that are placed within a certain geographic region (some 100km, German regulation defines this more precisely). This is currently implemented by the retailer buying so called 'Herkunftsnachweise' from the generation company. The selling point to the customer is that these regional energy products support the regional value generation.

process steps	
Initiator	Consumer subscribes to ‘Regional’ Energy Product at Energy Retailer
Process steps	1. Retailer buys certificates for regionality (German: Herkunftsnachweise) at producers within geographic vicinity of the Consumer. 2. At the end of the year, the retailer proves that that total energy consumption of all consumers subscribed to the Regional Energy Product within one region is covered by appropriate certificates.
Applies to	Geographic regions that contain generation and consumption
Comments	While the current regional energy products typically achieve the advantage that they support generation within the region financially, very frequently the actual revenue is not staying in the region as generation units are operated by remote companies (more frequently than for farmers – to draw the comparison). Therefore, the regional value generation argument may be rather weak in this case for electricity. The other advantages typically connected to regional products, i.e. environmentally friendly due to low transport costs and high quality do not apply to such regional energy products. The aspect of efficiency with respect to transport and distribution costs could however be achieved, but this will require a turning away from the paradigm that regionality certificates are based on yearly energy amounts. The current regional energy products are purely involving consumer, retailer, and generation companies; the DSO has no stake and no role in them. No current incentives for energy generation in moments of high local needs. Current pricing scheme is flat.

5.2.1 Data Traces

The subsequent preliminary analysis looks at measurements from a single LV grid of TME and investigates two types of metrics:

(1) **Total amount of energy flowing through a substation:**

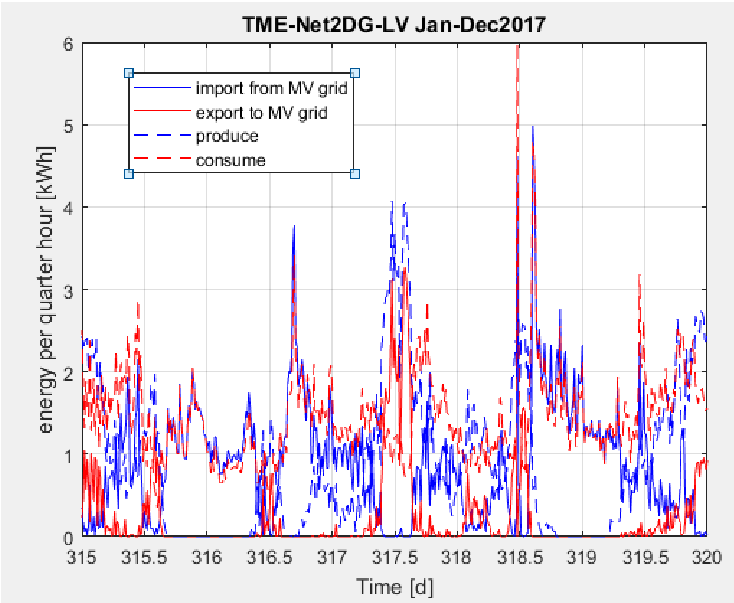


Figure 27 Energy exchange on a substation level

The solid lines in the figure above show the energy flow in each direction over an example secondary substation based on measurements with time granularity of 15minutes. Note that there are many 15min intervals, in which both exporting and importing takes place; as these directions are measured separately, there is no need to move to a finer time granularity for the calculation of the total energy flow.

The reduction of the total energy flow through the substation can be achieved by: (a) shifting demands or generation; (b) including storage in the grid domain; (c) connecting new/other consumers or generators to this grid domain or moving some 'out-of-sync' consumers/generators to other grid domains. An example of the impact of storage given the scenario from above is shown in the following figure:

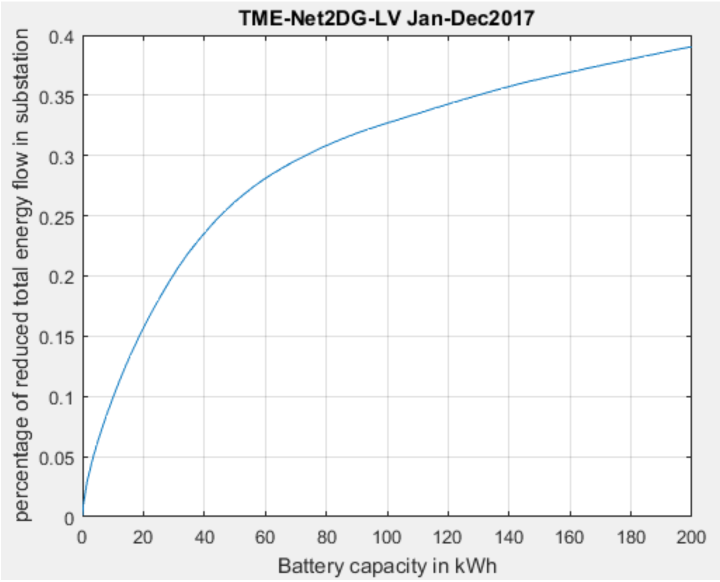
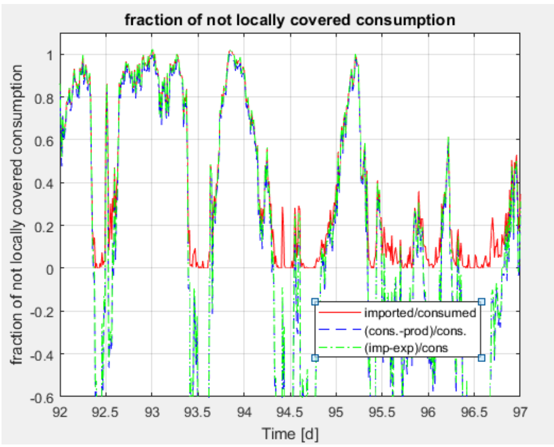
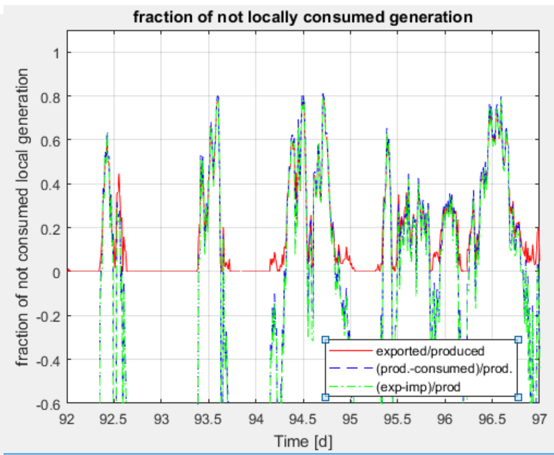


Figure 28 Impact on energy exchange on substation level by introducing storage capacity

(2) **Fraction of consumption or generation that is covered by resources in the same LV grid**: these metrics can be calculated using the aggregated Smart Meters Measurements of all customers in the LV grid.





The figures above show examples of the behavior of the inverse metric calculated for all end-customers in the considered grid domain. The blue dashed line shows the metric calculated based on the end-customer measurements, while equivalent calculations (only deviating by losses) can be done using substation measurements in addition to consumption and generation measurements, see the red and green curves in the figure.

In summary, the already available measurements at TME can in principle be the basis for the calculation of regionality metrics. However, the realization in practice requires to overcome some challenges as described in the following. The prediction of the future behavior and also the optimization of these metrics will require additional data sources which need to be determined in a more detailed analysis.

5.2.2 Input for future solutions

Goals of future 'truly regional' energy products can be:

1. To assure that regionally produced energy is also used effectively (instead of being exported at partially negative prices); this in particular for time-varying renewable generation
2. To support an economically feasible energy infrastructure transition to renewable generation, which implies
    a. to reduce the need for electricity transmission grid build up
    b. to give incentives to extend the 'better suitable' type of (renewable) generation
3. To increase distribution grid efficiency by reducing energy losses
4. Increase willingness to pay of consumers based on clear and measurable advantages (see Item 1-3) for the region or for society as a whole

Realization of such concepts will require cooperation of utility, consumer, generation companies, **and of the DSO.** The DSO may also benefit economically from providing 'services' that enable such future 'truly regional' energy products.

Vision of Regional Energy Product

- Retailer offers regional energy product to customers
    - At slightly higher price
    - But therefore guarantees certain minimum percentage of actual regional production
        - Retailer proofs the achievement of it backwards based on DSO data!
- DSO provides the relevant data to retailer
- DSO uses its actuation capabilities to increase this fraction (and gets payment by retailer for that)
- DSO provides data/set points to aggregators, retailers, and directly to certain flexible demands to support their control with increased regionality as target

The following regionality metrics are possible:

(1) Total amount of energy flowing through a substation (target is to keep this metric below a certain bound or minimize)
(2) For subset of regional energy product customers: fraction of consumption/generation of the set of these customers that is provided/consumed by resources in the same grid domain (target is to keep this metric above a certain bound or to maximize)

Note that the minimization or maximization of these metrics can have a positive impact on grid losses and also on grid investment deferral (due to reduced capacity needs for the substation and selected cables). These are however side-effects here, while the driver for the use-case is the regional energy product provided by utilities within this grid domain.

Target of the use-case can be to (1) process measurement data to provide evidence of the value of different regionality indices for the historic grid behavior; (2) give recommendations about measures to improve such regionality indices; (3) predict future behavior of regionality indices; (4) process grid measurements to provide triggers and input to real-time flexibility management functions such as EV charging, control of flexible loads, etc.. These four cases can be considered sub-usecases to the regional energy use-case.

The following challenges need to be addressed by Net2DG functionality if this use-case is implemented (to be decided):

(1) Sub-usecase Regionality Measurement: While the required data is in principle available, the data is currently stored in different systems and can only be manually correlated at this time. Net2DG shall therefore connect the data from the different systems and allow to calculate these metrics automatically. As a second challenges, the data is only available with access delay of up to 24 hours in the TME system (due to the configuration of the Smart Meter Data access). Therefore real-time calculations of this metric are currently not possible and shall be investigated for other use-cases

(2) Sub-use-case Recommendations for Regionality Improvement: the 'handles' for improvement via grid topology configuration and by grid planning need to be investigated and a cost-benefit analysis will be important to decide on the usefulness of such improvements. As an example, switching the LV grid topology, as possible in the Stw Landau case, may improve the regionality metrics but it can have other drawbacks on grid efficiency, grid reliability, or voltage quality.

(3) Prediction of the future behavior on long-term time-scales of weeks and months is an interesting sub-usecase but out of scope for Net2DG.

(4) Sub-use-case Regionality Imrovement by Flexibility Management: The actual Demand Management systems are out of scope for Net2DG; instead the processing of DSO data in order to derive input information that is passed on interfaces to these Flexibility Management System is the focus of Net2DG.

6 EU and National Regulations

The regulatory frameworks on EU and national level will affect the possible outcome from the Net2DG project. This section will highlight the most important regulatory frameworks, which has been identified.

6.1 European Regulations and the Role of 'Smart Grids Task Force (SGTF)'

The Smart Grids Task Force (SGTF) plays a key role in advising the European Commission on policy and regulatory frameworks at European level to co-ordinate the first steps towards the implementation of Smart Grids, under the provision of the Third Energy Package, and to assist the Commission in identifying projects of common interest in the field of Smart Grids under the context of regulations on guidelines for Trans-European Infrastructure (COM (2011)658 and 657). The SGTF will take stock of all the actions proposed in the Commission Communication on Smart Grids COM(2011)202 and initial results of SGTF's Expert Groups, as well as lessons learned and developments performed by other stakeholder groups in this area, such as the European Electricity Grids Initiative (EEGI), related standardization groups, etc., and should be in close contact with their further developments. The Third Energy Package provides the appropriate collaborative environment for the implementation of Smart Grids and roll out of smart metering systems across Europe. The SGTF is designed to provide a joint regulatory and commercial vision on Smart Grids taking into account accumulated experiences worldwide and the technological challenges to be faced mainly during next decade/s, so as to co-ordinate the first steps towards the implementation of Smart Grids under the provision of the Third Energy Package.

The Smart Grids Task Force was set up by the European Commission in 2009 to advice on issues related to smart grid deployment and development and consists of five Expert Groups, which focus on specific areas. Their work helps shape EU smart grid policies:

- **Expert Group 1 – Smart grid standards:** Expert Group 1 was set up in 2009 to explore smart grid services and operation, and how best to deliver smart grids for the benefit of the energy system and its users. Successful smart grid deployment depends on the technical standards and provisions designed to allow the interoperability of systems and technologies within a smart grid environment, which is the focus of attention for this expert group. The group provides guidance on how to ensure interoperability, connectivity and ultimately functionality of components and processes for the provision of smart energy grid services.
- **Expert Group 2 – Regulatory recommendations for privacy, data protection and cyber-security in the smart grid environment.** In 2014 the SGTF launched an initiative aiming to mitigate the risks on personal data and security of smart metering systems. Under this initiative, an Expert Group was launched in 2017 with the task to investigate energy-specific cybersecurity issues (see more comprehensive description below).
- **Expert Group 3 – Regulatory recommendations for smart grid deployment:** Under this initiative, an Expert Group was launched in 2016 with the task of collecting information and

investigating the necessary further steps for facilitating energy storage (incl. sector coupling), demand side flexibility, self-consumption and smart home automation in the EU.

- **Expert Group 4 – Smart grid infrastructure deployment:** This Expert Group covers both energy and telecom infrastructure issues. In terms of energy infrastructure – among others – issues in the context of smart grid projects that aimed to be included in the EU's projects of common interest (PCI) under the draft regulation on guidelines for trans-European energy infrastructure (COM(2011) 658) are investigated.[14] Expert Group 4 also was called for ideas for projects of common interest under the Regulation on guidelines for trans-European Telecommunications networks (COM(2011)657). The work of the group was to support and motivate the potential beneficiaries in building cooperation between both sectors – energy and telecommunication.
- **Expert Group 5 – Implementation of smart grid industrial policy:** This Expert Group deals with the analyses and insights from the most novel smart grid projects across the European Union (EU) Member States and conducts a screening across Europe (incl. maintenance and extension of comprehensive database).

6.1.1 Regulatory Recommendations for Privacy, Data Protection and Cyber-Security in the Smart Grid Environment

To protect consumers' personal data when it comes to smart meters and smart grids, the European Commission recommends various data protection and privacy provisions. Consumer personal data is protected by EU rules[15] on the processing of data and on the free movement of this data. This Regulation sets rules on who can access personal data and under what circumstances. The Commission has also produced guidance on data protection and privacy for data controllers and investors[16] in smart grids (Data Protection Impact Assessment Template supported by Commission Recommendation 2014/724/EU). The Commission is also working on new rules[17] on the exchange of data to allow market players to access vital market information while guaranteeing a high level of data protection, privacy and security. The European Network and Information Security Agency (ENISA), in cooperation with ENER and CNECT, has drawn-up security measures to help smart grid providers improve the infrastructures' cyber resilience. The proposal for a list of security measures for smart grids contains 45 security measures and the mapping of the identified security measures to potential threats. The Commission, alongside the Energy Expert Cyber Security Platform (EECSP)[18], is preparing a strategy on cybersecurity for the energy sector under the Directive on security of network and information

[14] Smart Grids Task Force Expert Group 4 - Infrastructure Development - DEFINITION OF AN ASSESSMENT FRAMEWORK FOR PROJECTS OF COMMON INTEREST IN THE FIELD OF SMART GRIDS under the EC 'Proposal for a regulation of the European Parliament and of the Council on guidelines for trans-European energy infrastructure and repealing Decision No 1364/2006/EC (COM(2011) 658), Brussels, July 2012, http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0658:FIN:EN:PDF).

[15] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2016.119.01.0001.01.ENG&toc=OJ:L:2016:119:TOC

[16] https://ec.europa.eu/energy/en/information-investors-and-data-controllers

[17] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1516725378661&uri=CELEX:52016PC0864R(01)

[18] http://ec.europa.eu/transparency/regexpert/index.cfm?do=groupDetail.groupDetail&groupID=3341

systems[19]. The Commission has also suggested developing a Network Code on Cyber Security to complement existing national rules and to tackle cross-border issues.

In addition, the Commission, in collaboration with industry and other stakeholders, conducted a two-year assessment process and delivered a full package of recommendations at the end of November 2016 to ensure privacy and cyber-security in smart-metering systems per the 10 minimum functional requirements set out in the Commission Recommendation[20] and in line with the General Data Protection Regulation (GDPR).[21] The outcome of this assessment is compressed in the official document of the European Commission: RECOMMENDATIONS - COMMISSION RECOMMENDATION of 9 March 2012 on preparations for the roll-out of smart metering systems (2012/148/EU).

6.2 GDPR

The General Data Protection Regulation (GDPR), Regulation (EU) 2016/679, is a regulation in EU law on data protection and privacy for all individuals within the European Union. It also addresses the export of personal data outside the EU. The GDPR aims primarily to give control to citizens and residents over their personal data and to simplify the regulatory environment for international business by unifying the regulation within the EU.

It was adopted on 14 April 2016,[22] and after a two-year transition period, becomes enforceable on 25 May 2018. The GDPR replaces the 1995 Data Protection Directive.[23] Because the GDPR is a regulation, not a directive, it does not require national governments to pass any enabling legislation and is directly binding and applicable.

The GDPR extends the scope of EU data protection law to all foreign companies processing data of EU residents. It provides for a harmonization of the data-protection regulations throughout the EU, thereby making it easier for non-European companies to comply with these regulations; however, this comes at the cost of a strict data-protection compliance regime with severe penalties of up to 4% of worldwide turnover or €20 million, whichever is higher.[24]

The GDPR also brings a new set of 'digital rights' for EU citizens in an age of an increase of the economic value of personal data in the 'digital economy'.

An identification of potential personal data in the context of Net2DG and an analysis of the consequences for the project is performed in the Data Management Plan.

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[19] https://ec.europa.eu/digital-single-market/en/network-and-information-security-nis-directive

[20] https://publications.europa.eu/en/publication-detail/-/publication/a5daa8c6-8f11-4e5e-9634-3f224af571a6/language-en

[21] The General Data Protection Regulation (GDPR) governs the following issues: Regulation (EU) 2016/679[1], the European Union's ('EU') new General Data Protection Regulation ('GDPR'), regulates the processing by an individual, a company or an organisation of personal data relating to individuals in the EU. It doesn't apply to the processing of personal data of deceased persons or of legal entities. The rules don't apply to data processed by an individual for purely personal reasons or for activities carried out in one's home, provided there is no connection to a professional or commercial activity. When an individual uses personal data outside the personal sphere, for socio-cultural or financial activities, for example, then the data protection law has to be respected.

[22] https://www.eugdpr.org/

[23] *eur-lex.europa.eu: EUR-Lex - 31995L0046 - EN - EUR-Lex*

[24] https://www.gdpreu.org/compliance/fines-and-penalties/

6.3 NIST

In response to a mandate given by the U.S. Congress and the U.S. Administration, NIST (National Institute for Standards and Technology), through its Engineering Laboratory-led Smart Grid program and public-private Smart Grid Interoperability Panel (SGIP), is leading the coordination and acceleration of smart grid interoperability and security standards. This is done in collaboration with the private sector and NIST has published the Framework and Roadmap for Smart Grid Interoperability, which provides the foundation for future work (see https://www.nist.gov). By utilizing expertise in NIST's Engineering, Physical Measurement, Information Technology, and Communication Technology Laboratories, this program will advance the measurement science that will increase asset utilization and efficiency, improve grid reliability, and enable greater use of renewable energy sources in the grid through research, standardization, testing and implementation of the NIST Framework.

The 'Smart Grid National Coordination Project' leads, coordinates and manages the national public-private stakeholder partnership effort to accelerate development of interoperability standards for the smart grid, fulfilling NIST's statutory responsibility under the Energy Independence and Security Act of 2007 (EISA).[25] NIST's highly visible leadership of smart grid standardization efforts helps to ensure that the estimated $400 billion of industry smart grid investment over the next 20 years in the U.S. will be interoperable and secure, and promotes international harmonization and alignment to maximize the ability of U.S. manufacturers to compete in a global smart grid market. The project also provides programmatic leadership of NIST-wide smart-grid measurement science research. This also includes associated aspects of cyber security.[26]

6.4 National Regulations in Selected European Countries

This section gives some background on national regulations in Germany and Denmark (the two countries in which the DSOs from the consortium operate); additional information on other countries is given in the Appendix.

6.4.1 Germany

The new Digitisation of the Energy Turnaround Act (Gesetz zur Digitalisierung der Energiewende) entered into force on 2 September 2016. The cornerstones can be summarized as follows (Source: Federal Law Gazette (Bundesgesetzblatt), https://www.bgbl.de):

- <u>*Background:*</u> On 8 July 2016, the new 'Digitisation of the Energy Turnaround Act' had cleared the final legislative hurdle in the German Federal Council (Bundesrat). The new law shall finally get the long-awaited smart meter roll-out going and connected infrastructure in Germany, defining

[25] https://www.epa.gov/laws-regulations/summary-energy-independence-and-security-act

[26] NIST's cybersecurity program supports its overall mission to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and related technology through research and development in ways that enhance economic security and improve the quality of life. The need for cybersecurity standards and best practices that address interoperability, usability and privacy is denoted to be critical for the U.S. economy.

future roles and tasks for all market participants. Despite its ambitious name, the new law mainly covers smart metering, not everything connected with digitisation in the energy sector. The new Act is originally based on the Third Internal Market Package, introduced by the EU as far back as 2009. The Directives of this Package require all EU member states to equip at least 80% of consumers with intelligent metering systems by 2020, subject to a positive national commercial assessment of the roll-out. Contrary to other areas of energy policy (particularly for renewable energy), the German government has been wary of the costs associated with this task. It took a long time until a first legislative proposal was on the table, and an even longer time to agree on the new – but still limited – German smart metering regime.

- *Key Objective:* The key objective of the new law is to facilitate the implementation of smart meters and so-called 'Smart Meter Gateways'. In that respect, Germany will finally implement EU Directives 2009/72/EG and 2009/73/EG. The new law also introduces specific and detailed requirements, both for the design of the smart meter devices and for the transmission of data. The overall goal is to open up the German energy market to digitisation, while ensuring a high standard regarding data protection and ICT security.
- *New Roles, New Regulations:* The central part of the reform is the newly-implemented Smart Meters Operation Act (Messstellenbetriebsgesetz). In 77 sections, the new Act sets out new rules on the marketing and use of 'Smart Meters' and 'Smart Meter Gateways'. In that respect, the Smart Meters Operation Act introduces new regulated market roles, particularly the role of the 'Meter Operator', who is in charge of – and responsible for – the implementation, operation and maintenance of smart meters, and who has specific legal obligations in that role. According to the new law, the responsibility connected with the roll out of the 'Meter Operator' initially rests on the energy supply grid operator (Energieversorgungsnetzbetreiber). Using a special public procurement procedure, they can however transfer this position to a third party service provider. The Smart Meters Operation Act defines extensive technical requirements for the technologies involved, particularly regarding the reliability and security of energy measurement and the transmission of data. Compliance with the new rules is controlled and supervised by both the Federal Office for Information Security (Bundesamt für Sicherheit in der Informationstechnik) and the Federal Network Agency (Bundesnetzagentur).
- *Next Steps:* Entry into force on 2 September 2016 did not mean that smart meters will arrive overnight. The new Act contains a staggered roll-out plan for the installation of smart meters. The roll-out began in 2017, and shall continue until 2032. The process comprises different roll-out periods for different types of end consumers and plant operators, depending on the amount of energy consumption that they use, or feed in. For some types of consumers and operators, the roll-out will have to be finished before the end of 2024. The Smart Meters Operation Act in principle requires operators to equip consumers above 6,000 kWh yearly consumption, and plant operators with an installed capacity of more than 7 kW, with smart meters. Below, this is optional.

The introduction of smart meters is tied to compliance with a staggered price cap for annual costs. In any event, the roll-out will not begin before the manufacturers of the necessary devices can provide them. This requires a certification by the Federal Office for Information Security.

- *Responsibilities:* Meter operators, suppliers and service providers need to refine their business models to make the most of the new legal regime. The government did not see itself in a position to say how often meter operators will use the option to equip consumers up to 6,000 kW/h with new meters, in light of the new price caps. Since the entire field is strongly regulated, ensuring compliance with the legal regime is key for all market participants.

  a) Grid Operators: The operators of energy grids have to make an important decision early, probably at a very early stage of the implementation process: they must decide if, and to what extent, they want to use third party suppliers as part of their own smart metering infrastructure. The new law allows such an outsourcing of responsibilities and defines corresponding market roles, e.g. the role of the smart meter gateway administrator' or of the smart meter operator. If the grid operator decides to install a third party as operator for the smart meters, this will be subject to public procurement rules.

  b) Service Providers and Manufacturers: Enterprises that want to offer supporting services have a rather short period left to implement the new legal requirements. This applies particularly to enterprises designing, manufacturing and marketing the hardware devices which shall be used as smart meters or smart meter gateways.

  c) Telecommunications Service Providers: For telecommunications service providers planning to offer connectivity services for smart meters and smart grids, the key point is that the new law is technologically neutral. This means that, in principle, all types of communication technologies can be used to provide connectivity for the new smart meter infrastructure. However, connectivity services still have to comply with rather strict legal conditions, e.g. regarding their reliability and performance and transmission security. The Federal Office for Information Security provides an overview of its current technical requirements on its website.

6.4.2 Denmark[27]

As a consequence of the energy agreement, half of electricity consumption in 2020 will be met by electricity from wind turbines, and at the same time new electricity consumption is expected. An energy system with a smart grid design requires greater exploitation of the energy from wind as soon as it is produced, for example by heats pump and electric cars. This will allow for greater exploitation of cheap wind turbine electricity, and it will mean less need to expand the electricity infrastructure to meet new electricity consumption.

[27] 'Smart Grid Strategy – The Intelligent Energy System of the Future', Danish Ministry of Climate, Energy Buildings, May 2013 (https://www.metering.com/wp-content/uploads/2013/11/Denmark_Smart_Grid_Strategy.pdf)

The Danish Smart Grid Strategy sets the course for development of a smart grid, which can make this green transition cheaper, provide savings on electricity bills and help promote new services and products to the benefit of consumers. The Smart Grid Strategy describes a number of specific initiatives, to be performed by the central government as well as by the energy sector. The energy sector has an important role, since among other things development of a smart grid must be encouraged by market forces through development of consumer electricity products, which make it attractive for households and businesses to make their flexible electricity consumption available to the electricity system.

The development of a smart grid depends primarily on whether consumers see a value in making their flexible consumption available. There are several ways to encourage consumers to do so. Firstly, consumers want a financial incentive, however flexible electricity consumption also makes it possible for consumers to become involved actively in the green transition and it allows for the development of a host of new services for the more high-tech consumers. The most important condition for successfully activating consumers is to provide them with the option of settlement by the hour instead of the fixed-price settlement (known as template settlement) used today, according to which the consumer pays the same price for electricity, regardless of which time of the day they use the electricity. To enable hourly settlement, consumers need to have hourly meters installed that can be accessed remotely. The grid companies have already installed remotely-read hourly meters at 50% of consumers, who together account for 75% of electricity consumption. However, it is expected that hourly settlement will not have been fully rolled out until all consumers have had remotely-read hourly meters installed. In connection with its 2013 Growth Plan DK, the government has therefore taken steps to ensure roll-out of the remaining remotely-read hourly meters.

In order to include a future coherent and smart energy system in the smart grid agenda, the Danish Ministry of Climate, Energy and Building is establishing a partnership with broad participation from the energy sector. In collaboration with other sector players, this partnership will help Denmark to exploit the considerable export potential for the smart grid and smart energy solutions. Denmark has more smart-grid projects than any other country in the EU, and it is crucial that this competitive advantage is translated into growth and employment in the future.

7 Derived User Stories and Use-cases

This chapter contains a consolidation of scenarios from the previous sections, and will identify the generic high-level stories/usecase, which are the basis for Net2DG development.

7.1 Generic description of the Low Voltage Distribution Grid

As an outset, the following model of a low voltage distribution grid will be use as the context for subsequent userstories/usecases and finally application requirements.

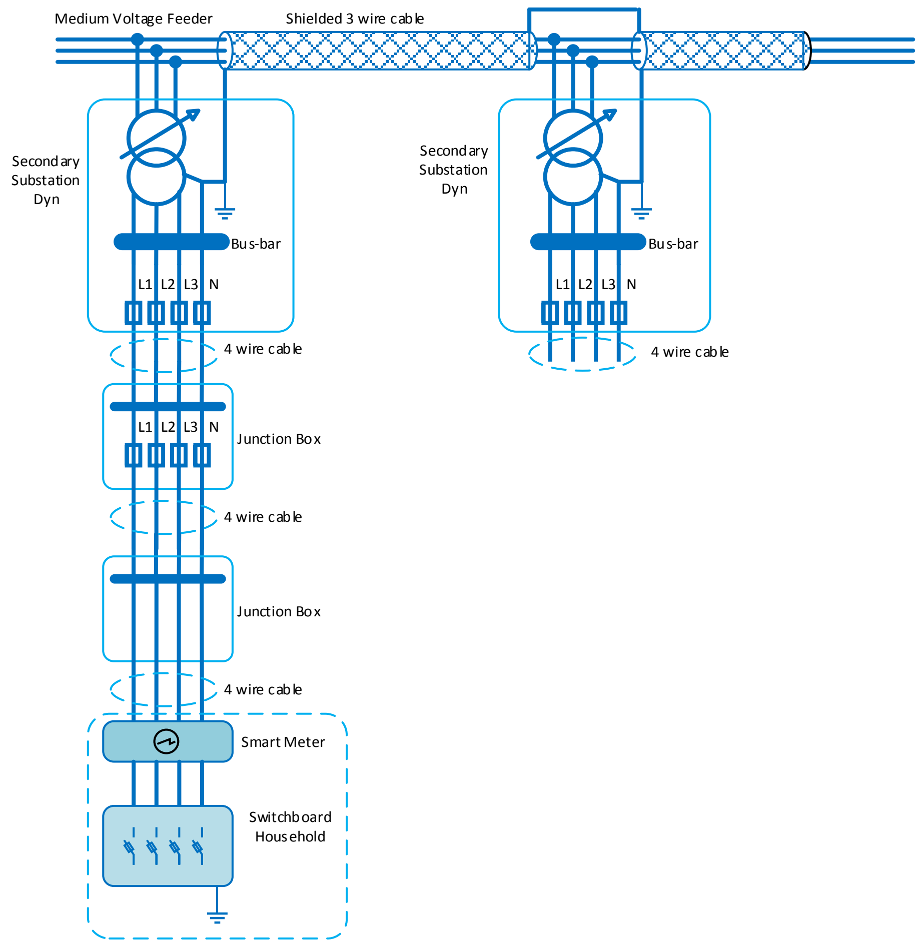


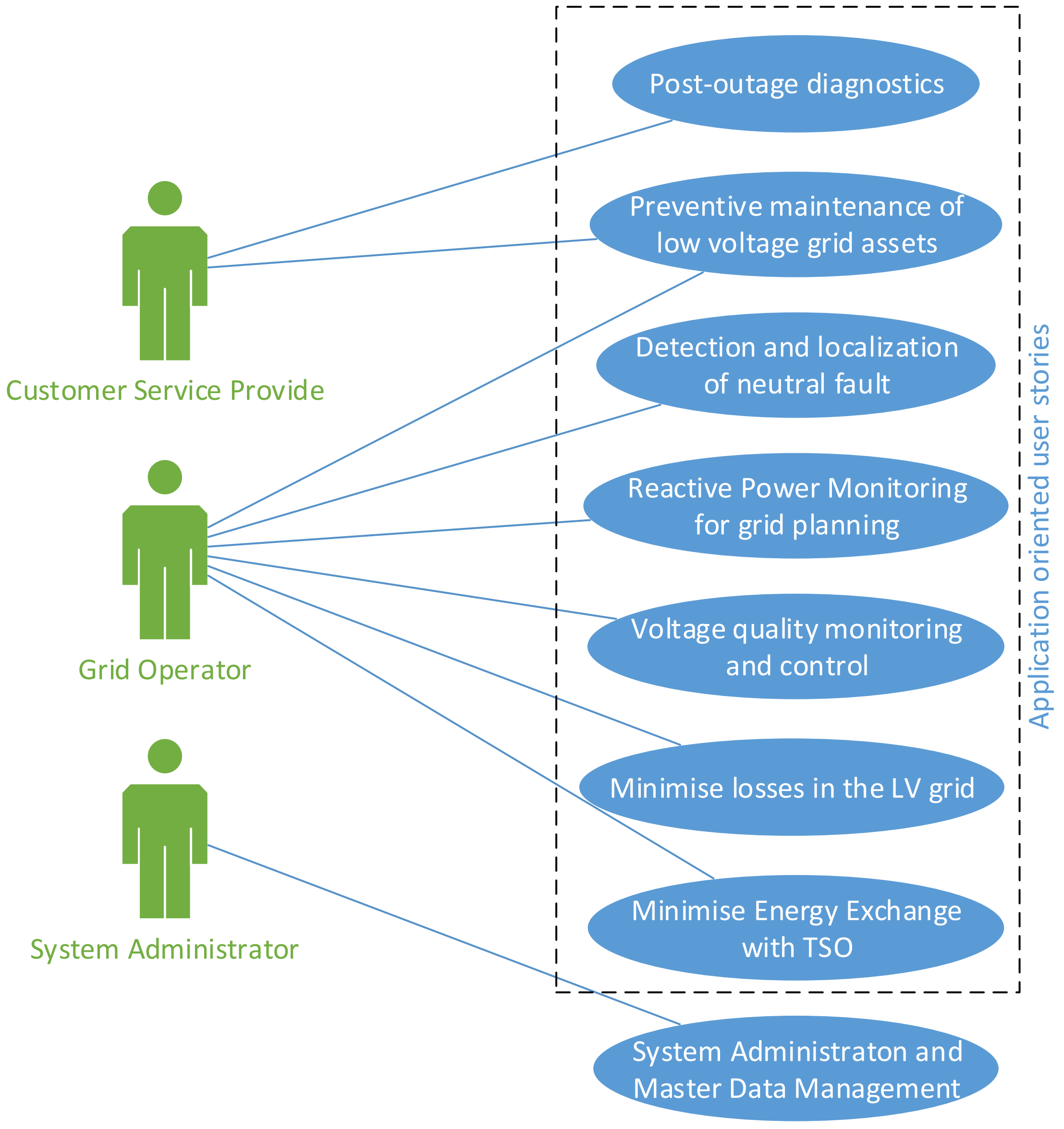
Figure 29 Conceptual model for LV Grid

7.2 Identified Areas and Structure

Based on the DSO scenarios, the market descriptions and regulatory input, a set of functional areas have been identified. Each of them are described as a high-level user story capturing the value, main goals and intends and a breakdown into the envisioned use-cases that would describe how the value is created.

7.2.1 Identification of User stories

Based on input from DSO grid scenarios, control aspects and market overviews, the following user stories have been identified:



7.2.2 Application oriented user stories

User story – 1: Post-outage Diagnostics

As a Customer Service Operator, I want to identify root causes for outage so that my consumers can have their power distribution restored as fast as possible

- The solution must be able to detect and localize all/single/multiple phases outages.

- It should be able to detect and localize blown fuses, cable faults, bad connections in junctions' boxes and transformers, short circuits (as e.g. caused by animals).
- The solution should aim at near-realtime characteristics for improved decision-making in fault situations (re-coupling etc.).
- Pass criteria 1: The solution automatically detects outages in the LV grid within some 10 minutes after their start
- Pass criteria 2: The solution can identify likely root causes and their locations (which cable) in order to dispatch field technicians as fast as possible.
- Pass criteria 3: the solution should minimize manual work involved.
- Pass criteria 4: the solution should minimize false alarms and faulty localization and diagnosis outcomes
- Pass criteria 5 (optional): the solution should be able to notify affected customers via interfacing to existing customer information channels.

User story – 2: Preventive maintenance of Low voltage grid assets

As a Customer Service provider, I want to reduce the occurrence rate of future outages so that my connected consumers and prosumers experience fewer outages

AND

As a Grid Operator, I want to be able to plan equipment maintenance based on actual needs from the grid so that replacement costs are reduced and my maintenance staff will get work plans with less number of ad-hoc actions.

- The solution should be able to detect short-term transient outages or anomalies in the voltages or energy losses that are caused by loose cable connectors, aging cables, and cable damages such as scrapped off insulation.
- The solution should be able to localize the cable that is faulty within a time horizon of few days.
- Pass criteria 1: The solution can identify and localize damages to grid assets that might evolve into grid outages.
- Pass criteria 2: the solution should minimize manual work involved.
- Pass criteria 3: the solution should minimize false detections and faulty localization and diagnosis outcomes.

User story – 3: Detection and localization of neutral fault

As a Grid Operator, I want to identify and localize a neutral fault, so that I can reduce the duration of the fault and my prosumers are exposed to potential hazardous situations for a minimal duration only. Also, I would also want to minimize the total cost of the outage, including ENS, field crew service and root cause detection.

- The solution must be able to detect the lack of a neutral, or when the neutral is provided by a different secondary substation as opposed to the phases.
- It should be able to identify the cable or connection that is faulty.
- Pass criteria 1: The solution automatically detects lack of neutral in the LV grid within one hour after occurrence of the fault.

- Pass criteria 2: The solution can identify when a neutral is provided by a different substation as opposed to the phases.
- Pass criteria 3: The solution can localize the cable or connection that causes the lack of or wrong neutral.
- Pass criteria 4: the solution should minimize manual work involved.
- Pass criteria 5: the solution should minimize false alarms and faulty localizations outcomes

User story – 4: Reactive Power Monitoring for grid planning

As a Grid Operator, I want to understand the extent and the causes of reactive power in my distribution grid so that I can reduce the additional stress on grid components and can reduce the amount of over-dimensioning in my grid planning

- The solution should be able to visualize continuous historic measurements of reactive power at different grid points.
- The solution should be able to diagnose the main sources of reactive power in individual Low voltage grids and in the MV grid
- Pass criteria 1: The solution should enable a grid planning that minimizes over-dimensioning cause by worst case reactive power assumptions
- Pass criteria 2: The solution should enable a grid planning that can meet requirements from the regulator and from higher-layer grid operators regarding reactive power

User story – 5: Voltage quality monitoring and control

As a Grid Operator, I want to reduce overvoltages, undervoltages and voltage dips and swells, so that my connected prosumers operate under an adequate voltage profile at their connection points.

- The solution should achieve the relevant bounds from EN50160 for voltage variations, and for longer (few seconds+) voltage dips and swells.
- The solution should be able to visualize quality issues in the LW grid and diagnose causes of the voltage problems.
- The system should monitor voltage profiles from smart meters, inverter and sensor data
- The solution must be able to detect values which are outside a window of values previously defined and which can be customized.
- The solution should create warnings for the operator and indicate visually where the problem(s) was detected
- The solution should calculate the set-points/envelopes to send to prosumers to correct the situation that generated the alarm
- The operator must be able to use the solution to assess if the problem was corrected and remain resolved.
- The solution should be able to identify whether inverters operate in a configuration that is compatible to the connection requirements reflect by the individual contract between DSO and plant operator
- The solution should be able to decrease the impact (disconnected prosumers) of voltage rise/sags
- Pass criteria 1: The solution should reduce the number of voltage quality complaints from customers.

- Pass criteria 2: The solution should notify the Grid Operator when the voltage quality does not fulfil EN50160 in certain points of the grid.
- Pass criteria 3: The solution should make recommendations for actions which could solve the voltage quality problem.

User story – 6: Minimize losses in the LV grid

As a Grid Operator, I want minimize grid losses so that I can reduce my OPEX and my connected prosumers and the regulator perceive me as a green and efficient operator

- The solution should be able to calculate and record losses in different LV sub-grids (connected to different secondary substations) on a time resolution of 15minutes.
- The solution should be able to take into account the quality of the input data used for the loss calculation and should derive confidence intervals on the calculated loss values.
- The solution should be able to generate statistics used for benchmarking the LV grid in comparison to other DSOs.
- The solution should be able to identify anomalies in the loss behavior of individual low voltage grids.
- The solutions should be able to compare different LV (sub-)grids and identify inefficient LV grids.
- The solutions should make recommendations for actions that can reduce losses.
- Pass criteria 1: The solution generates grid loss time series and corresponding confidence intervals that are confirmed to be statistically correct (e.g. confirmation by high precision measurements or high precision models).
- Pass Criteria 2: The solution automatically detects and diagnosis anomalies in the loss behavior of multiple LV grids.
- Pass criteria 3: The solution can make recommendations for actions that can be shown in lab experiments or simulations to reduce the grid losses
- Pass criteria 4: The solution minimizes the manual work involved.

User story – 7: Minimise energy exchange with Transmission System

As a Grid Operator, I want to support regional energy products that are offered by retailers, so that my payments to Transmission System operators are reduced.

- The solution should be able to measure different regionality indicators.
- The solution should be able to interface with demand and generation management systems in order to increase regionality indices.
- The solutions should make recommendations for grid planning that can increase regionality indices.
- The solution should be able to identify whether inverters operate in a configuration that is compatible to the connection requirements reflected by the individual contract between DSO and plant operator.

- Pass criteria 1: The solution should give trustworthy statistics that can be used by retailers to market regional energy products
- Pass criteria 2: the solution should minimize manual work involved.

7.2.3 System Administration and Master Data Management

In addition to the previous user-stories that address specific outcomes that the DSO wants to obtain from the Net2DG system, there is also a user-story on how the DSO will interact with the Net2DG system. The user story for this is provided below; as the detailed use-cases are of different nature, those are developed in the architecture deliverable D1.2.

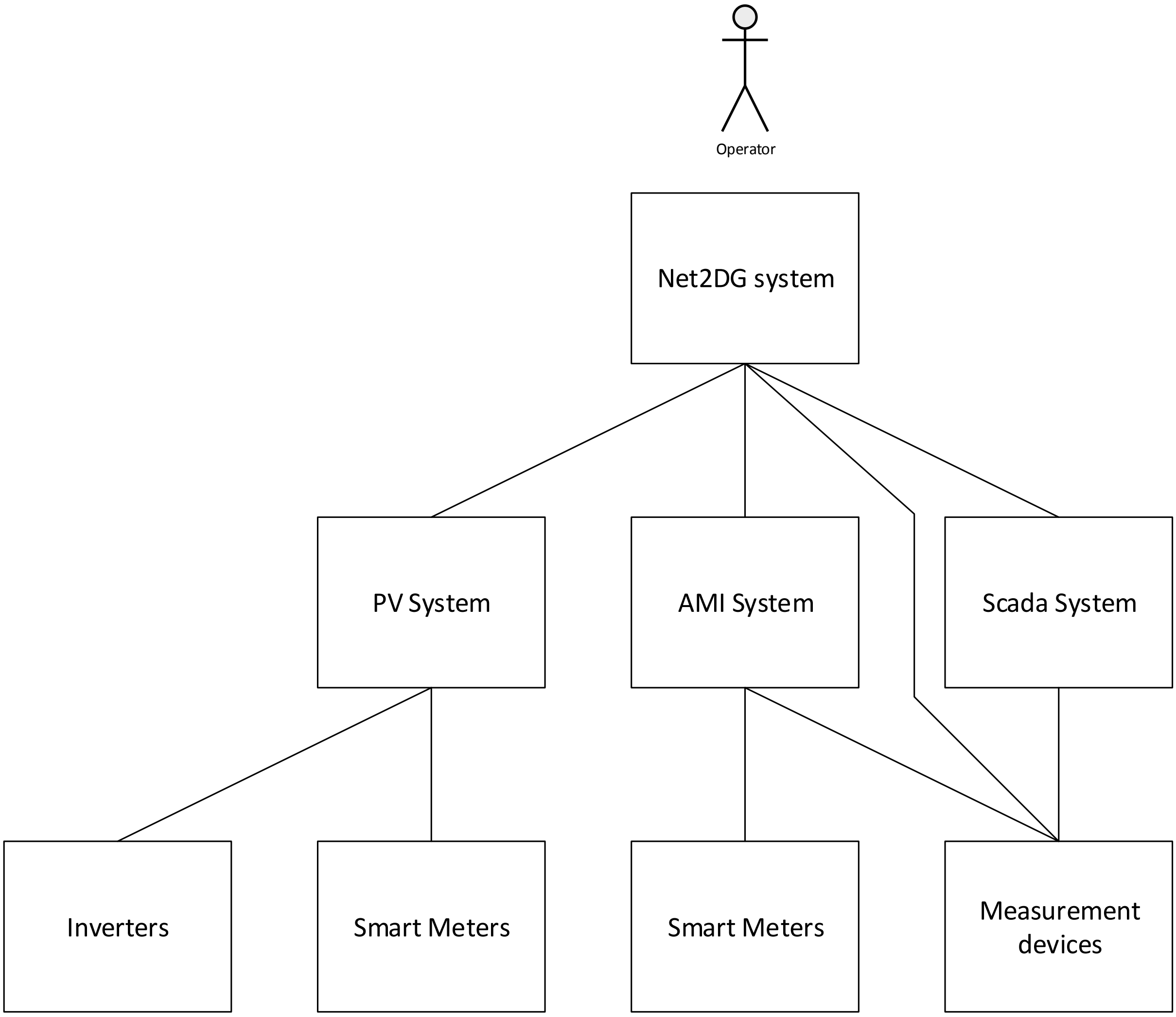
User story – 8: System Administration and Master Data Management
As a System Administrator, I want to be able to manage the system easily and simple without too much manual configuration and hassle.
The solution must be able to:

- *Automatically discover new data sources and actuation units and its characteristics (e.g. control bandwidth, data resolution, data accuracy, etc.) and related software components at Net2DG system start.*
- *Add or remove data sources or actuation units and related software components during operation.*
- *Add/Remove applications during operation. Ensure changes in the grid topology or grid configuration is seamlessly updated in running Net2DG system also during operation.*
- *Ensure changes or upgrades to the network connection does not lead to interruptions in using the system.*
- *Gracefully shutdown of the Net2DG system enabling later resume/restart without loss of data or work processes.*
- *Pass criteria 1: The solution should minimize manual work involved.*
- *Pass criteria 2: The solution should automatically detect, update and remove data sources and actuation units.*
- *Pass criteria 3: The solution should minimize the unavailability of Net2DG.*

7.3 Usecases

7.3.1 Use case actors

The use cases operate on an abstracted level of the complete Net2DG system context. The identified actors are shown in the figure below.



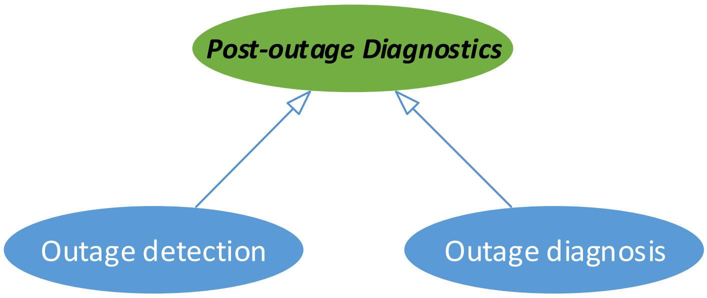
7.3.2 Application Use-cases

The following subsections present the use-cases that are derived from the user stories. One user-story may thereby lead to multiple use-cases, as the use-cases are seen as the atomic units in Net2DG for implementation. Each subsection starts with a diagram showing the user-story (top) and the derived use-cases (bottom).

The use-case acronyms are divided into four groups:

- Fault Management (FM): this group broadens the original 'Outage Detection' scenario from the Net2DG proposal as it includes other faults and also the preventive case.
- Voltage Quality (VQ): according to the original scenario from the Net2DG proposal
- Loss Minimization (LM): which narrows down the grid operation efficiency scenario from the Net2DG proposal
- Regional Energy (RE): as a new use-case group derived from user story 7, which has the potential to bridge to the energy retailers and other market players as described in Sect. 5.2.

7.3.2.1 Grid Outage Detection

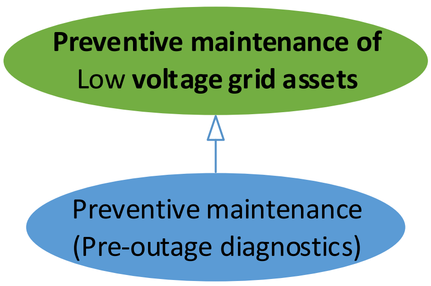


ID and name:	UC FM-1: Outage Detection
Parent user story	*Post Outage diagnostics*
Overview and goal	*The detection of the outage in user story 1.*
System applicability	*LV grids that contain several remotely accessible measurement devices*
Business rationale	*Reduce duration of outages, increase customer satisfaction, reduce working hours of DSO staff related to detection and diagnosis of outages and related to customer interaction in outage situations*
Precondition	*Normal operation of a LV grid*
Actors:	*Smart Meters, Inverters, Measurement devices at substations and junction boxes* *Net2DG System*
External stimulus	*(Persistent) Outage occurs*
Main flow	1. Net2DG system *receives measurements and alarms from the Smart Meters, Inverters and measurement devices* 2. *Net2DG system places these events and measurements in the context of the LV grid topology data model.* 3. *Based on processed alarms and/or detected unreachability/lack of measurements of some measurement devices, the Net2DG system detects an outage and visualizes the outage in the LV grid.*
Alternate flow	-
Characteristics	*Latency: detection within few minutes.*
Security impact	-

ID and name:	UC FM-2: Outage Diagnosis
Parent user story	*Post Outage diagnostics*

Overview and goal	*The detailed diagnosis (root cause analysis and localization) which is the second step in user story 1*
System applicability	*LV grids that contain several remotely accessible measurement devices*
Business rationale	*Reduce duration of outages, increase customer satisfaction, reduce working hours of DSO staff related to detection and diagnosis of outages and related to customer interaction in outage situations*
Precondition	*Outage detection according to Use-Case before has occurred*
Actors:	*Smart Meters, Inverters, Measurement devices at substations and junction boxes* *Net2DG: Data Gateway, Grid Outage Diagnosis application (GOD)*
External stimulus	*(Persistent) Outage occurs*
Main flow	1. *The Net2DG system may request actively more measurements and information from the affected area of the LV grid based on an intelligent selection of measurement sources.* 2. *The Net2DG system will process the available information in order to diagnose the cause and location of the outage within the LV grid* 3. *The Net2DG system will visualize likely causes and their location on an abstracted grid topology to the DSO. In case of multiple locations and causes, different likelihood categories (very likely, possible, etc.) will be visualized.*
Alternate flow	*The diagnosis may also be triggered by the grid operator who has information from customer calls about a potential outage (optional flow).*
Characteristics	*Latency: Diagnosis within some 10 minutes*
Security impact	-

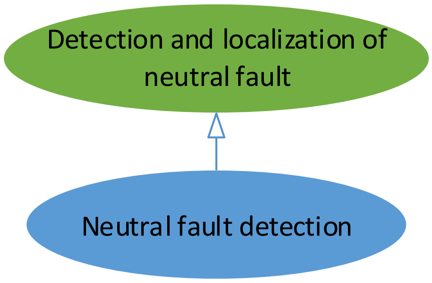
7.3.2.2 Preventive maintenance of Low voltage grid assets



ID and name:	UC FM-3: Preventive maintenance (asset management)

Parent user story	Preventive maintenance of Low voltage grid assets
Overview and goal	See user story 2
System applicability	LV grids that contain several remotely accessible measurement devices
Business rationale	Reduce maintenance costs by only replacing the necessary equipment, reduce working hours of DSO staff by better planned maintenance work and by avoiding faults
Precondition	Normal operation of a LV grid
Actors:	Smart Meters, Inverters, Measurement devices at substations and junction boxes if installed Net2DG System
External stimulus	Monitoring of different data sources in the LV grid which could indicate a potential out-of-bound condition (e.g. to high Voltage, current, oil temperature of transformers, humidity, ambient temperature etc.)
Main flow	1. The Net2DG system receives measurements from smart meters, inverters, measurement devices and preferably substations. 2. The Net2DG system places measurements in the context of the LV grid topology data model and estimate the grid states 3. The Net2DG system determines if there are any assets that require maintenance based on the historic data (voltages, currents, THD levels, temperatures, etc.) and the estimated state. Any deviations from normal operational conditions are recorded for asset management purposes. 4. The Net2DG system generates a report including a description of the asset needing maintenance, the position, the problem and what cause the detection. 5. A notification is automatically send to the operator and displayed on the LV grid.
Alternate flow	None
Characteristics	The asset management app continuously monitors the grid state and generates reports on a daily or more frequent basis.
Security impact	-

7.3.2.3 Detection and localization of neutral fault

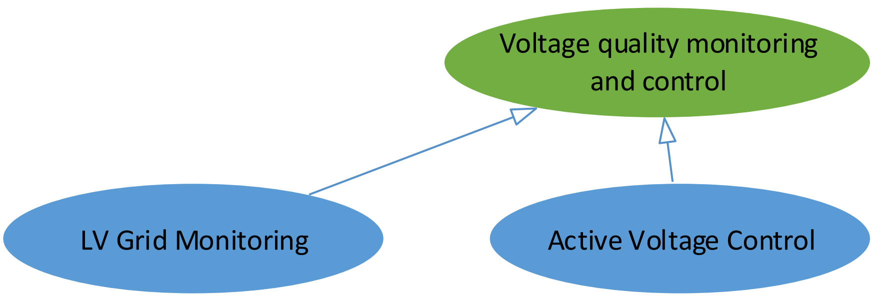


ID and name:	UC FM-4: Neutral fault detection
Parent user story	*Detection of neutral fault*
Overview and goal	*See user story 3*
System applicability	*LV grids that contain several remotely accessible measurement devices*
Business rationale	*Detect loss of neutral in the LV grid which can lead to over- and under-voltages at the prosumers, with potential harmful effect.*
Precondition	*Normal operation of a LV grid*
Actors:	*Smart Meters, Inverters, Measurement devices at substations and junction boxes* *Net2DG System*
External stimulus	*Monitoring of different voltages from data sources*
Main flow	1. Net2DG system receives measurements from smart meters, inverters, measurement devices and preferably substations. 2. Net2DG system *places measurements in the context of the LV grid topology data model.* 3. *The Net2DG system determines if there are any neutral faults in the LV grid based on voltage profiles, historical information and other data (for ex. Smart meter logs, zero sequence measurements, etc.) from the grid.* 4. *The operator is notified if a fault is detected.*
Alternate flow	*None*
Characteristics	*The Net2DG system continuously monitors the state of the grid and generates reports as faults are detected.*
Security impact	*No specific security threats anticipated from this usecase*

ID and name:	UC FM-5: Neutral fault diagnostic and location
Parent user story	*Localization of neutral fault*
Overview and goal	*See user story 3*
System applicability	*LV grids that contain several remotely accessible measurement devices*

Business rationale	*Detect and locate predictable position causing the loss of neutral in the LV grid.*
Precondition	*Normal operation of a LV grid*
Actors:	*Smart Meters, Inverters, Measurement devices at substations and junction boxes* *Net2DG System*
External stimulus	*Detection event from UC-FM-4*
Main flow	*1. The Net2DG system may request actively more measurements (like logged data) and information from the affected area of the LV grid based on an intelligent selection of measurement sources.* 2. The Net2DG system will process the available information in order to diagnose the cause and location of the neutral fault within the LV grid using the *trend of the voltage profile within the signaled faulty feeder* 3. *The operator is notified and the location of the fault in the LV grid is visualized.*
Alternate flow	*None*
Characteristics	*The neutral fault app continuously monitors the state of the grid and generates reports and signals with events to operators as faults are detected.*

7.3.2.4 Reactive Power and Voltage quality monitoring and control



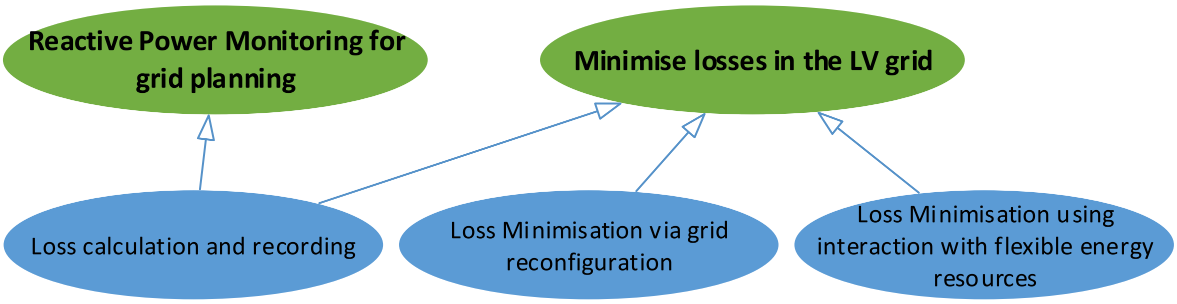
ID and name:	UC VQ-1: *LV Grid Monitoring*
Parent user story	*Userstory 4 and 5*
Overview and goal	*Low Voltage Grid Monitoring for voltage quality supervision (EN50160)*
System applicability	*LV grids that contain several remotely accessible measurement devices*
Business rationale	*Increase the added value of sources of information to monitor and detect (potential) problems with EN50160 compliance.*
Precondition	*Normal operation of an LV grid where there are several information sources which are not processed or correlated to generate valuable information to the operator and grid planner*

Actors:	*Smart Meters, Inverters, Measurement devices at substations and junction boxes* *Net2DG System*
External stimulus	*Any event or detection of data outside the defined limits.*
Main flow	1. *The Net2DG System receives measurements, events and alarms from the Smart Meters, Inverters and sensors* 2. *The Net2DG System converts and maps these events and measurements according to the LV Grid model.* 3. *Based on the LV Grid model, processed events and measurements are analyzed against defined profiles for voltages (EN50160). The selected parameters will be decided in WP2.* 4. *The Net2DG System signals visually the nodes and feeder branches where alarms may have occurred and also measurements which are out of bounds.* 5. The Net2DG system may increase the monitoring granularity in space and time for parts of the LV grid that operate close to or outside the desired boundaries (scoping function). 6. The Net2DG system will diagnose whether alarms are caused by operational conditions (high loads) or by faults. 7. The Net2DG system derive a EN50160 compliancy report and recommends a set of corrective measures
Alternate flow	*N/A*
Characteristics	*This functionality should be running periodically, in short cycles or even in (near) real-time.*
Security impact	-

ID and name:	VQ-2: Automatic Voltage Regulation
Parent user story	*Userstory 5*
Overview and goal	Active mitigation of a subset of EN50160: voltage dips/swells and out-of-limit voltages
System applicability	*LV grids that contain several remotely accessible measurement devices, and in addition remotely controllable inverters and/or remotely controllable OLTC*
Business rationale	*Success criteria are related with the minimization of customer complaints (customer satisfaction) and reducing compensations to customers originating from damaged equipment and reducing (current or future) regulatory fines due to EN50160 violations.*
Precondition	*Normal operation of an LV grid and with operational ICT/IT system;*
Actors:	*Smart Meters, Inverters, Measurement devices at substations and junction boxes, OLTC (if present)* *Net2DG System*
External stimulus	*previous use-case (*UC<*LV-MON1*>*: LV Grid Monitoring) has detected an event*

Main flow	1. *Net2DG system will identify available controllable assets.* 2. *Net2DG system will take decisions on which assets to utilize for the mitigation action.* 3. *Net2DG will calculate setpoints to each of the identified controllable assets.* 4. *Net2DG system will send setpoints to the appropriate actors.* 5. *Net2DG system will obtain additional measurements to monitor the impact of the control actions.* 6. *Net2DG system will store a log of the action.*
Alternate flow	*N/A*
Characteristics	*This functionality is triggered by the previous use-case and should act within time-scales of few minutes up to hourly range (depending on information sources and actuator control bandwidth).*
Security impact	*There is a security impact related to active control of assets in the field. CIA aspects must be applied in the design.*

7.3.2.5 Minimise losses in the LV grid



ID and name:	LM-1: Loss calculation and recording
Parent user story	*Userstory Loss Minimization*
Overview and goal	*Calculate and record losses for the total LV grid and for individual subgrids connected to a secondary substation; generate statistics for benchmarking*
System applicability	*LV grids that contain several remotely accessible measurement devices, specifically smart meters at customers and at distribution transformer connection point*
Business rationale	*Increase the added value of smart meter data by using it to get accurate grid loss time series and statistics.*
Precondition	*Normal operation of an LV grid where there are several information sources which are not processed or correlated to generate valuable information to the operator and grid planner*

Actors:	*Smart Meters (essential), Measurement devices at substations (essential), Inverters and junction boxes* *Net2DG System*
External stimulus	*Executed periodically.*
Main flow	1. *Net2DG system receives measurements from all smart meters and other data sensors that measure energy* 2. *Net2DG system converts and maps these events and measurements according to the LV Grid model.* 3. *Based on the LV Grid model, and estimation of missing measurement locations, time series of losses (absolute and relative) together with confidence values are calculated on the highest possible time resolution that the input data allows.* 4. The calculated losses (including reactive power) including confidence intervals will be archived for later trends analysis. 5. At the end of a pre-defined time period, e.g. quarter of a year, statistics about losses will be calculated and archived that will enable the benchmarking of the LV grid.
Alternate flow	*N/A*
Characteristics	*This functionality should be running periodically, daily, weekly or monthly. No need for real-time behavior.*
Security impact	*Privacy aspects of recording and persisting consumption data must be considered.*

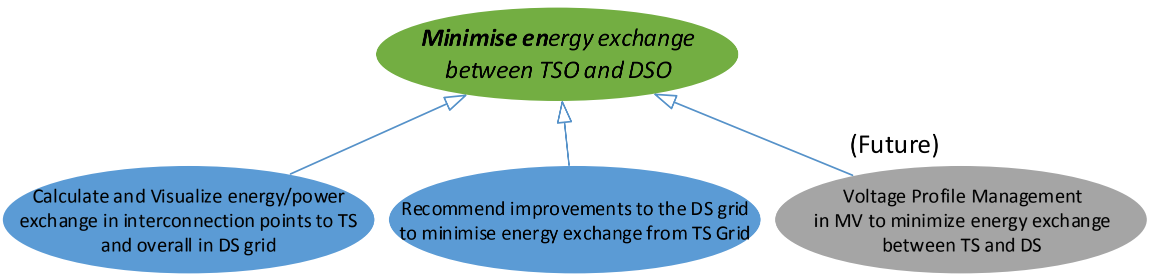
ID and name:	LM-2: Loss Minimisation via grid reconfigurations
Parent user story	Userstory Loss Minimization
Overview and goal	Minimizing grid losses, both technical Joule losses and also commercial losses within a certain LV grid. Success criteria is to increase grid operation efficiency and also OPEX
System applicability	LV grids that contain several remotely accessible measurement devices, specifically smart meters at customers and at distribution transformer connection point
Business rationale	Increase the added value of smart meter data by using it to decrease OPEX and increase grid efficiency.
Precondition	Normal operation of an LV grid where there are several information sources which are not processed or correlated to generate valuable information to the operator and grid planner
Actors:	Smart Meters (essential), Measurement devices at substations (essential), Inverters and junction boxes, remotely controlled switches Net2DG System
External stimulus	New results from Use-Case LM-1 available

Main flow	1. Net2DG system obtains the loss time series calculated by UC LM-1 and the LV grid topology. 2. Based on the topology and the loss results, The Net2DG system identifies a set of loss minimization methods to be used in grid planning, including switching of the LV topology, upgrading of grid components. 3. The Net2DG system calculates the expected benefit of the different loss minimization methods for the LV grid. 4. The minimization methods and their benefits are visualized to the grid operator, who can select certain methods for data export. 5. A specification of the grid enhancement method is exported by the Net2DG system in a data format that can be processed by the used network planning tools.
Alternate flow	N/A
Characteristics	This functionality should be running periodically, e.g. monthly, or based on availability of a substantial amount of new loss values from Use-Case UC-1
Security impact	-

ID and name:	LM-3: Loss Minimization using interaction with flexible energy resources
Parent user story	User story Loss Minimization
Overview and goal	Minimizing grid losses, both technical joule losses and also commercial losses within a certain LV grid. Success criteria is to increase grid operation efficiency and also OPEX. Primary focus is to adjust reactive power flow in the grid to minimize associated loss.
System applicability	LV grids that contain several remotely accessible measurement devices, specifically smart meters at customers and at distribution transformer connection point and controllable assets (actuators) that allows direct control of reactive power generation.
Business rationale	Increase the added value of smart meter data by using it to decrease OPEX and increase grid efficiency.
Precondition	Normal operation of an LV grid where there are several information sources which are not processed or correlated to generate valuable information to the operator and grid planner
Actors:	Smart Meters (essential), Measurement devices at substations (essential), Inverters and junction boxes Net2DG System
External stimulus	New results from Use-Case LM-1 available in short time-intervals (every few hours)

Main flow	1. Net2DG system obtains the loss time series calculated by UC LM-1 and the LV grid topology. 2. The Net2DG system may request actively more measurements (like logged P and Q data) and information from the affected area of the LV grid based on a selection of measurement sources. 3. The Net2DG system will process the available information in order to diagnose the cause and location for the measured loss within the LV grid. 4. The Net2DG system determines if the loss is related to reactive power and if so A. The Net2DG system obtains other relevant data from actuators in terms of set points. B. The Net2DG system calculates new set points to control actuators in a way that minimizes losses caused by reactive power flow. C. The Net2DG system sends the control actions to the actuators. D. The Net2DG system monitors the command execution and compensate from errors in the communication or execution. 5. The Net2DG initiate monitoring of the new situation in the particular section of the LV Grid that has been affected and visualize this to the operator.
Alternate flow	Optional: control of active power production/consumption to minimize loss related to active power levels.
Characteristics	This functionality should be running periodically on short time periods, e.g. every hour.
Security impact	The authentication and authorization of setpoints must be considered to avoid injection of false configurations.

7.3.2.6 *Minimise energy exchange between TSO and DSO*



The “Voltage Profile Management in MV to minimize energy exchange between TS and DS” usecase is for further study and not included in the primary Net2DG scope. A draft usecase formulation can be found in appendix D.

ID and name:	UC RE-1: Calculate and Visualize energy/power exchange in interconnection points to TS and overall in DS grid
Parent user story	User story – 7
Overview and goal	See user story-7
System applicability	The Distribution grid and its exchange points with Transmission grid *(e.g.Hv/MV substations).*
Business rationale	Create an awareness of the energy exchange between TSO and DSO. *Success criteria are related to minimization of payment to higher-layer grid operators.*
Precondition	Normal operation
Actors:	Net2DG system, AMI system, RES (PV, WTG..) system, SCADA system, DSO
External stimulus	None
Main flow	1. The Net2DG system collects consumption and production data from the AMI and RES systems and calculates an energy flow overview for the entire /important nodes in the distribution grid. In particular power exchange with TS in primary substations (HV/MV) is of main interest 2. The Net2DG present this in a GIS overview to the DSO .
Alternate flow	*N/A*
Characteristics	*This use case is executed regularly, but at low priority.*
Security impact	*Load profiles and production plans are confidential and should be treated accordingly.*

ID and name:	UC RE-2: Recommend improvements to the DS grid to minimise energy exchange with TS Grid
Parent user story	User story – 8
Overview and goal	See user story-8
System applicability	The DS grid and its exchange points with TS grids.
Business rationale	Improve the usages of locally produced energy within the DS grid and reduce exchange with TS grid. The economic benefit is reduction on net tariffes payed to the TS for exporting and importing energy.
Precondition	Normal operation, UC RE-1
Actors:	Net2DG system, AMI system, RES (PV, WTG..) system, DSO operator
External stimulus	None

Main flow	1. The Net2DG system identifies potential reconfiguration to DS grid, which can minimize the overall energy exchange with TS grid. 2. The Net2DG present this as a list of improvements including expected effect and with a possibility to show in a GIS view towards the DSO.
Alternate flow	*N/A*
Characteristics	*Executed upon request from DSO operator*
Security impact	-

7.3.3 Connecting Usecases to the High Level Grid Operation Usecase

Inspired by classical operational stages in transmissions systems the Net2DG view on operational state of Distribution grids is shown in Figure 30.

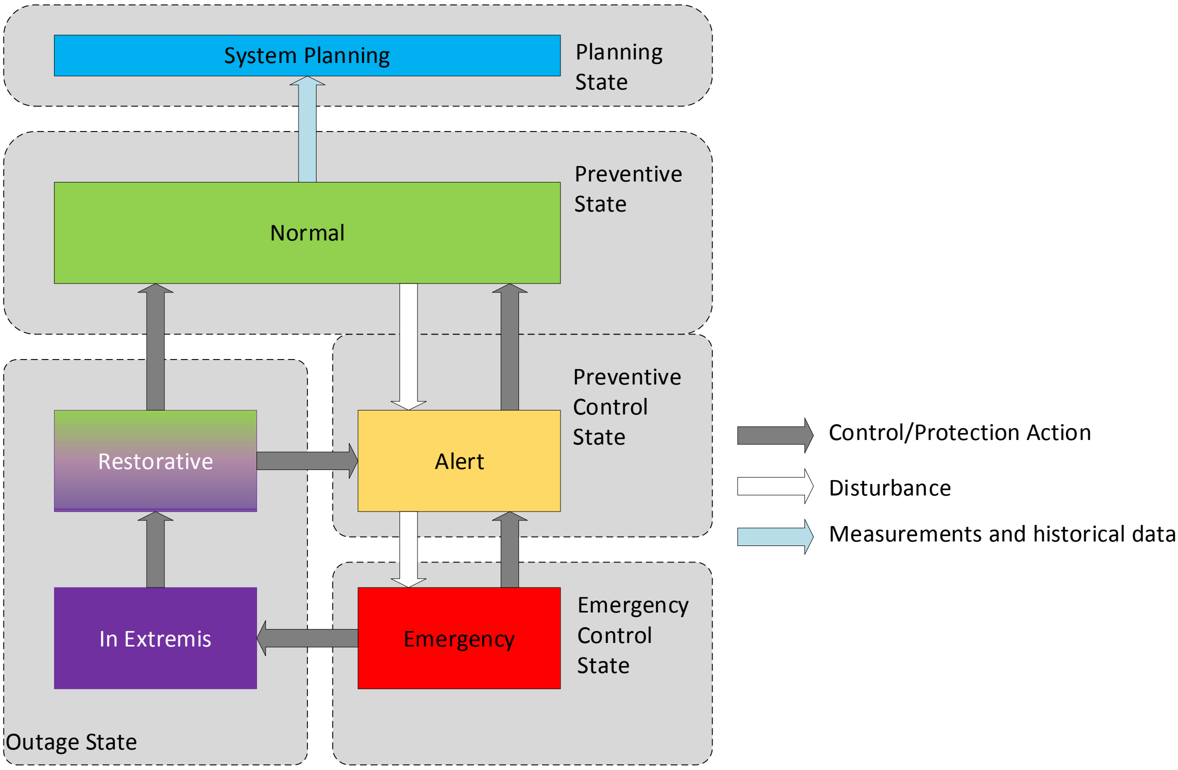


Figure 30 Operational States in Distribution Grids

The planning state comprises of activities related to maintenance of assets but also future grid expansions. The preventive state is the daily operation of the DS within the normal parameters and technical conditions. A preventive control state may be entered when operational parameters are close to their limits but not exceeding them. This is the case for example with voltages in given nodes close to 1.1 or 0.9 pu limits. Control actions may be taken to bring the specified parameters on a safer range. Emergency control state is entered when a given operational parameter is outside its limits e.g. overvoltages, undervoltages, overloading of cables, transformers in substations. The outage state is reached when parts of the electrical grids including consumers are lost due to faults.

Each of the usecases defined in 7.3.2 has a primary relation to one of the operational states, this relationship is shown in the table below:

Use case ID	Operational state
UC FM-1: Outage Detection	Outage State
UC FM-2: Outage Diagnosis	Outage State
UC FM-3: Preventive maintenance (asset management)	Planning State
UC FM-4: Neutral fault detection	Outage State
UC FM-5: Neutral fault diagnostic and location	Outage State
UC VQ-1: *LV Grid Monitoring*	Preventive State Preventive Control State
VQ-2: Automatic Voltage Regulation	Preventive State Preventive Control State Emergency Control State
LM-1: Loss calculation and recording	Planning State Preventive State
LM-2: Loss Minimisation via grid reconfigurations	Preventive State Preventive Control State
LM-3: Loss Minimisation using interaction with flexible energy resources	Preventive State Preventive Control State
UC RE-1: Calculate and Visualize energy/power exchange in interconnection points to TS and overall in DS grid	Planning State Preventive State
UC RE-2: Recommend improvements to the DS grid to minimise energy exchange from TS Grid	Planning State Preventive State

7.3.4 Use case Prioritisation

Within the Net2DG project the set of usecases are prioritized based on a partner score of each usecase. The individual scoring can be found in Appendix C: Scoring of Use cases.

The overall usecase prioritisation is shown below:

Use case ID	Priority
UC FM-1: Outage Detection	1
UC LM-1: Loss calculation and recording	2
UC FM-3: Preventive maintenance (asset management)	3
UC FM-2: Outage Diagnosis	4
UC VQ-1: *LV Grid Monitoring*	5
UC FM-5: Neutral fault diagnostic and location	6
UC VQ-2: Automatic Voltage Regulation	7
UC RE-1: Calculate and Visualize energy/power exchange in interconnection points to TS and overall in DS grid	8

UC FM-4: Neutral fault detection	9
LM-2: Loss Minimisation via grid reconfigurations	10
UC RE-2: Recommend improvements to the DS grid to minimise energy exchange from TS Grid	11
LM-3: Loss Minimisation using interaction with flexible energy resources	12

8 Requirements

The use-cases from Section 7.3 are now used to derive application requirements for Net2DG. These requirements are targeted towards components likely to be part of the Net2DG solution architecture, i.e. the requirements use a simplified Net2DG architecture as shown in the following figure:

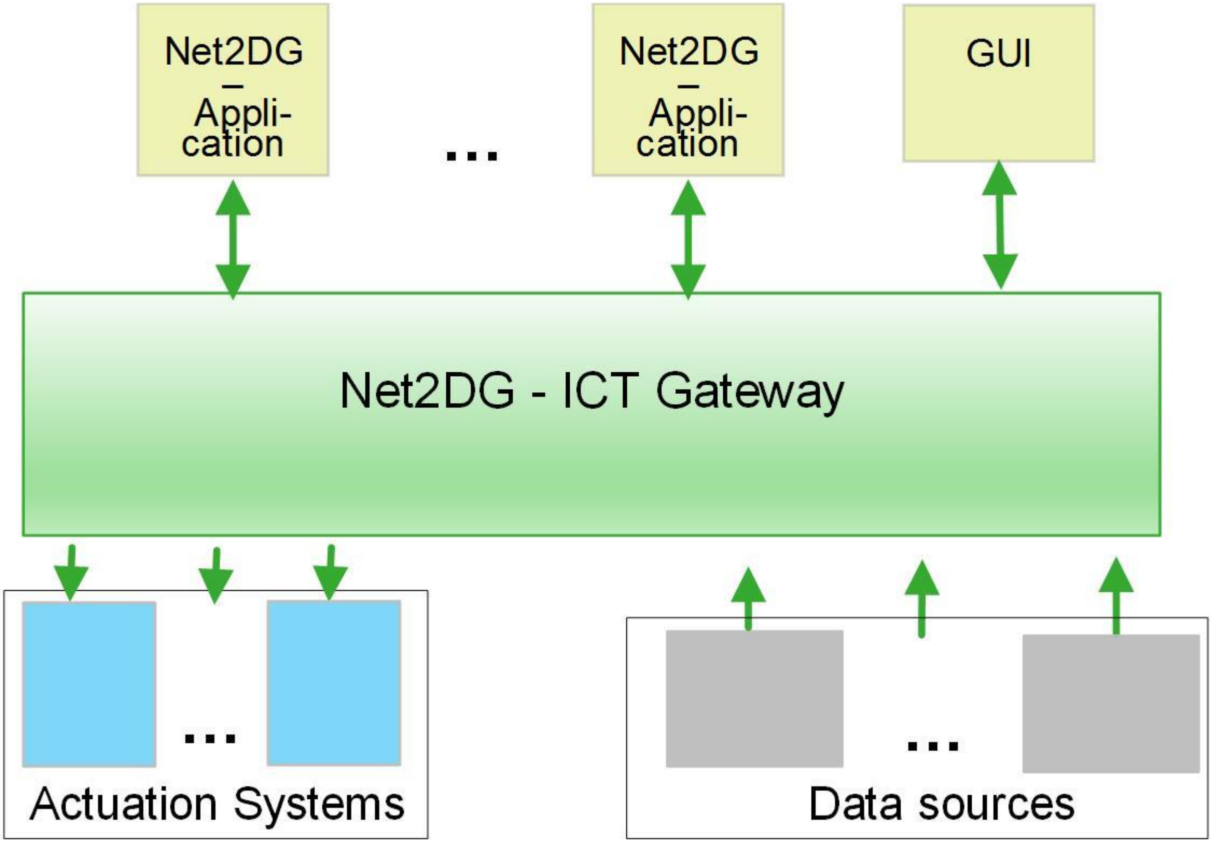


Figure 31 Simplified Net2DG Architecture

Basic principle of the architecture is that the applications only interact with other components via the ICT Gateway. For each use-case, there will be one application and the use-case may use a common visualization application. Note that the above architecture will be more detailed in D1.2.

Also, further requirements on the ICT Gateway will result from the system administration and management and general requirements to deployment, technology choices etc. and be documented on deliverable D1.2. While this deliverable focuses on the requirements that are directly related to the use-cases. Focus are on the new components and not the existing systems they will interface with (such as the PV or AMI systems).

Note that the set of requirements described below states the ambitions of the use-cases and the Net2DG project; the progress of the research in WP2-WP5 may show that some of the requirements may not be feasible or may need to be adjusted to be technically doable.

Requirements are expressed using terms from the well-known RFC2119 vocabulary

Must = mandatory
Should = recommended

8.1 Requirements for Outage Detection UC

- Outage Detection (ODet) application:
  - ODet appl. must be able to subscribe to events (such as relevant alarms from AMI or PV systems) coming from the ICT Gateway
  - ODet appl. must be able to request the LV and MV grid topology from the ICT Gateway
  - ODet appl. must correlate the received events and use the communication device and measurement device status to distinguish between
    - ICT fault
    - Grid outage of single customer
    - Grid outage of multiple customers
  - The ODet application should be able to take decisions on additionally needed information and request this information from the data Gateway
  - The ODet application must be able to communicate its result to the ICT Gateway
  - By processing the grid topology and measurements, the ODet application should calculate # of affected clients and energy not supplied (ENS) and store this in the ICT Gateway.
- Graphical User Interface (GUI)
  - The GUI application must be able to subscribe to events (visualization requests from e.g. other applications) from the ICT Gateway
  - The GUI application must be able to visualize ICT outages in the LV grid topology
  - The GUI application must be able to visualize grid outages in the LV grid topology
- ICT Gateway
  - ICT Gateway (IG) must maintain a representation of the LV and MV grid topology and be able to expose it to the application
  - IG must be able to receive events and alarms from Smart Meters, Inverters, and/or measurement devices in substations and junction boxes and identify, their location in the grid topology representation
  - IG must be able to receive subscriptions from applications on different event types, identify these events and forward it to the application
  - IG must be able to receive application output and provide it to other applications that have subscribed to it or that request it
  - IG should have a continuous connectivity monitoring function, which can make active request for data from selected measurement devices and use results for verification of connectivity.
- Response time requirement: The time between occurrence of the first relevant alarm until the visualization of detection result should stay below 10min

8.2 Requirements for Outage Diagnosis UC

- Outage Diagnosis (Odiag) application:
    - ODiag appl. must be able to be triggered by the ICT Gateway based on detection events from the Outage Detection application
    - ODiag application must be able to obtain the result from the Outage Detection application via the ICT Gateway
    - ODiag application must be able to request the detailed grid topology and additional measurement data from the affected LV and/or MV grid region from the ICT Gateway
    - ODiag appl must process the received data and reachability information in order to calculate the likelihood of the following causes of the outage
        - Blown fuse
        - Cable Fault
        - Bad connection in junction box
        - Short circuit
        - Outage of phase on MV level of secondary substation
        - Others (unknown)
    - The ODiag application must be able to communicate its result to the ICT Gateway
    - ODiag appl. must be able to subscribe to events from the GUI (events being input provided by the user) coming from the ICT Gateway
    - The ODIAG should be able to be triggered by a GUI event.

- Graphical User Interface (GUI)
    - The GUI must be able to visualize different causes of outages and their probabilities in the LV grid topology
    - The GUI must be able to visualize the likelihood of different locations of grid outage causes in the LV grid topology
    - The GUI should be able to receive input from a user concerning an outage and store this information to the ICT Gateway as a GUI event

- ICT Gateway (IG):
    - ICT Gateway (IG) must maintain a representation of the LV and MV grid topology and be able to expose it to the application
    - IG should be able to actively call an application based on trigger events derived from other application output
    - IG should be able to serve requests from applications for measurement data and ICT reachability information within a LV grid region specified by the application
    - The IG must support receiving input commands from the GUI and make them available to applications via a subscription mechanism.

Response time requirement (considering interaction of applications and IG): The time between triggering of the ODiag application by a detection result until it provides its diagnosis result back to the IG should stay below 10min

8.3 Requirements for Preventive Maintenance UC

Preventive Maintenance (PM) application:

- PM appl. must be able to subscribe to specific categories of measurement data.
- PM appl. must be able to receive measured voltage and currents from smart meters, inverters, measurement devices and substations via the ICT Gateway.
- PM appl. Must be able to request the LV and MV grid topology from the ICT Gateway
- PM application must be able to calculate the missing parameters for the grid model nodes that do not have information accessible
- PM application must store all calculated values in the ICT Gateway marked as estimated.
- PM application must be able to detect and identify any asset within the LV grid that requires maintenance based on the historic data (voltages, THD level, currents, temperatures, etc.) and the estimated state.
- PM application must be able to persist any deviations from normal operational conditions asset management purposes in the ICT Gateway.
- PM application must generate a report including a description of the asset needing maintenance, the position, the problem and what caused the detection.

Graphical User Interface (GUI)

- The GUI must be able to present visually the grid model with all the information mapped
- GUI must be able to signal assets that are classified as requiring a maintenance action
- GUI must be able to issue automatically notifications to the operator and display them on the LV grid model.

ICT Gateway (IG):

- IG must maintain a representation of the MV and LV grid topology and be able to expose it to the application that have subscribed to them
- IG must be able to receive measurement data from Smart Meters, Inverters, and/or measurement devices in substations and store for application access.
- IG must be able to establish a correspondence between the device ID serving as information source and the grid model

- IG must support application requesting new data from specific devices and create corresponding jobs towards relevant systems.
- IG must support application requests for existing data by relevant queries data (devices, type, time etc.).

- IG must be able receive application and GUI output and provide it to other applications that have subscribed to it or that request it

Response time requirement: (non-critical functionality) 1 hour

8.4 Requirements for Neutral Fault Detection UC

Neutral Fault Detection (NDet) application:

- NDet appl. must be able to receive measured voltage and currents from smart meters, inverters, measurement devices and substations via the ICT Gateway.
- NDet application must be able to analyse voltage profile, historical information and trends and events or alarms to detect if there are neutral faults on a certain LV Grid
- NDet application must store information about the fault to the ICT Gateway.

Graphical User Interface (GUI)

- GUI must be able to present the fault to the operator in context of the LV grid.

ICT Gateway (IG):

- IG must maintain a representation of the MV and LV grid topology and be able to expose it to the application that have subscribed to them
- IG must be able to receive measurement data from Smart Meters, Inverters, and/or measurement devices in substations and store for application access.
- IG must support application requests on existing data by relevant query data (devices, type, time etc.).
- IG must be able receive application and GUI output and provide it to other applications that have subscribed to it or that request it

Response time requirement: Depending on the pooling cycle for updated information, the NDet should run immediately after any new information received.

8.5 Requirements for Neutral Fault Diagnostic and Location UC

Neutral Fault Diagnostic and Location (NDiag) application:

- NDiag appl. must be able to be triggered on a neutral fault event generated by the NDet application.
- NDiag appl. must be able to analyse voltage profiles, historical information and trends and events or alarms to detect if there are neutral faults on a certain LV Grid and correlate this information both geographically and also on the grid model
- NDiag application must be able to request additional measurements from smart meters, inverters and/or measurement devices in substations.
- NDiag application must generate a possible position (feeder indication) of the problem.

Graphical User Interface (GUI)

- GUI must be able to visually identify the feeder where the neutral fault has occurred. If there are more than 1 possibility, both should be signaled

ICT Gateway (IG):

- IG must maintain a representation of the MV and LV grid topology and be able to expose it to the application that have subscribed to them
- IG must be able to receive measurement data from Smart Meters, Inverters, and/or measurement devices in substations and store for application access.
- IG must support application requesting new data from specific devices and create corresponding jobs towards relevant systems.
- IG must support application requests on existing data by relevant query data (devices, type, time etc.).
- IG must be able receive application and GUI output and provide it to other applications that have subscribed to it or that request it

Response time requirement: Depending on the pooling cycle for updated information, the NDiag should run immediately after any new information received.

8.6 Requirements for LV Grid Monitoring UC

LV Grid Monitoring (GMon) application:

- GMon appl. must be able to subscribe to specific categories of measurement data and events
- GMon appl. must be able to receive measured voltages, events, etc. from smart meters, inverters, measurement devices and substations via the ICT Gateway.
- GMon appl. must be able to request the LV and MV grid topology from the ICT Gateway
- GMon application must be able to calculate the missing parameters for the grid model nodes that do not have information accessible
- GMon application must store all calculated values in the ICT Gateway marked as estimated.
- GMon application must be able to detect and identify any deviation from the defined profiles for Voltages in EN50160 within the LV grid.
- GMon application must be able to persist any deviations from EN50160 in the ICT Gateway.
- GMon application must generate an EN50160 compliancy report and recommend a set of corrective measures. The report must be stored in the ICT Gateway.
- The GMon application should be able to request a higher monitoring granularity in space and time from measurement sources in parts of the LV grid that operate close to or outside of boundaries (scoping function).

- The GMon application should be able to verify if inverter functions such as Q(U) and P(U) are activated and operate according to the expected characteristic curves.
- The GMon application should be able to diagnose whether out-of-bound voltage parameters are caused by operational conditions such as high loads or by faults.

Graphical User Interface (GUI)

- The GUI must be able to present visually the grid model with all the information mapped
- GUI must be able to signal deviations to EN50160 within the grid

ICT Gateway (IG):

- IG must maintain a representation of the MV and LV grid topology and be able to expose it to the application that have subscribed to them
- IG must be able to receive measurement data and events from Smart Meters, Inverters, and/or measurement devices in substations and store for application access.
- IG must support application requesting new data from specific devices and create corresponding jobs towards relevant systems.
- IG must support application requests from existing data by relevant queries data (devices, type, time etc.).
- IG must be able receive application and GUI output and provide it to other applications that have subscribed to it or that request it

8.7 Requirements on Automatic Voltage Regulation UC

Requirements on Automatic Voltage Regulation (AVR) application

- The AVR app must be able to receive a trigger from the IG, which was issued by the voltage monitoring application
- The AVR app must be able to request the detailed grid topology and additional measurement data from the affected LV grid region from the ICT Gateway
- The AVR app must be able to obtain an up to date status of the reachability of measurement data sources in the affected LV grid region.
- The AVR app must be able to identify available controllable assets in the affected LV grid region
- If the AVR application is not able to get access to relevant measurement points in the grid (needed for generation of setpoints), it should be able to make a state estimation to get values for this point.
- The AVR app must be able to receive tuning (performance and constraint) parameters from the GUI via the ICT GW
- The AVR app should be able to be triggered by a GUI event.
- The AVR app must be able to receive user input to override actions from GUI
- The AVR must be able to predict dynamic behavior of a subset of the grid over a specified time horizon

- The AVR app must be able to send setpoints (voltage, active power, and/or reactive power) to available assets via the ICT Gateway

Graphical User Interface (GUI)

- GUI must be able to receive tuning parameters and constraints as user input and store in ICT gateway
- GUI must be able to receive manual override input as user input and store in ICT gateway.
- GUI must be able to show time series of triggers, states and commands issued (or predicted)

ICT Gateway (IG):

- The IG should be able to prioritize setpoint communication to assets based on information from the application
- IG must maintain a representation of the MV and LV grid topology and be able to expose it to the application that have subscribed to them
- IG must be able to receive measurement data and events from Smart Meters, Inverters, and/or measurement devices in substations and store for application access.
- IG must support application requesting new data from specific devices and create corresponding jobs towards relevant systems.
- IG must support application requests from existing data by relevant queries data (devices, type, time etc.).
- IG must be able receive application and GUI output and provide it to other applications that have subscribed to it or that request it
- The IG must be able to identify controllable assets and their control possibilities to an application.
- The IG must be able to communicate set-points to controllable assets and detect the status of the asset (whether set point received and executed).

Response time requirement: The AVR app must be able to compute a response within one minute of receiving a trigger event

8.8 Requirements on Loss Calculation and Recording UC

Loss calculation (LC) application

- The LC application must be executed periodically with configurable period
- The LC application must be able to obtain the grid topology and its evolution over a specified time interval in the past from the IG
- The LC application must be able to obtain all available energy (active and reactive) measurements, the corresponding time intervals, and the accuracy of the measurements and time intervals from the IG
- The LC application must be able to obtain other measurements such as voltages from the IG, in order to use them for extrapolation of missing energy measurements

- The LC application must be able to extrapolate missing energy measurement points from a grid model.
- The LC application must be able to correlate the energy (active and reactive) measurements and measurement time intervals in order to obtain a series of values over time intervals of
  - Absolute loss of energy (in kWh) in LV grid parts below a substation or junction box and accuracy of this loss calculation
  - Relative loss of energy and accuracy of this relative loss: relative to total energy flow through the junction box/substation and relative to sum of generation and intake.
- The LC application must be able to write back the calculated sequence of loss values and time intervals to the IG.

Graphical User Interface (GUI)

- The GUI application must be able to plot the behavior of the absolute and relative losses over the corresponding time intervals for a user-specified time period and for substations or junction boxes specified by the user

ICT Gateway (IG)

- The IG must be able to execute the LC application periodically with configurable time period
- IG must maintain a representation of the MV and LV grid topology and be able to expose it to the application that have subscribed to them
- IG must be able to receive measurement data and events from Smart Meters, Inverters, and/or measurement devices in substations and store for application access.
- IG must support application requesting new data from specific devices and create corresponding jobs towards relevant systems.
- IG must support application requests from existing data by relevant queries data (devices, type, time etc.).
- IG must be able receive application and GUI output and provide it to other applications that have subscribed to it or that request it

8.9 Requirements for Loss Minimization via Grid Reconfigurations UC

LM Reconfiguration (LMRec) application:

- LMRec appl. must be able to obtain results from the LC application and the current grid configuration from the ICT Gateway
- LMRec appl. must be able to identify a set of grid reconfigurations based on the loss information calculated by the LC application and the grid topology

- LMRec appl. must be able to calculate the impact of different grid reconfigurations on losses in the LV grid
- LMRec appl. must be able to store its results in the ICT Gateway
- LMRec appl. must be able to export grid planning data in a format that can be processed by network planning tools.

Graphical User Interface (GUI

- GUI should be able to visualize the different grid reconfigurations and their benefits in terms of losses to the grid operator

ICT Gateway (IG):

- IG must be able to periodically execute the LMRec application (periodic mode)
- The DSO should be able to request a start of the LMRec application via the IG (user triggered mode)
- IG must maintain a representation of the MV and LV grid topology and be able to expose it to the application that have subscribed to them
- IG must be able to receive measurement data and events from Smart Meters, Inverters, and/or measurement devices in substations and store for application access.
- IG must support application requesting new data from specific devices and create corresponding jobs towards relevant systems.
- IG must support application requests from existing data by relevant queries data (devices, type, time etc.).
- IG must be able receive application and GUI output and provide it to other applications that have subscribed to it or that request it

Response time requirement: The calculation of improvements and their impact can take several hours up to few days.

8.10 Requirements for Loss Minimization using interaction with flexible energy resources

LM Active Management (LMAct) application:

- LMAct appl. must be able to obtain the loss timer series data from the LC application and the current grid configuration from the ICT Gateway
- LMAct application must be able to request additional measurements from smart meters, inverters and/or measurement devices in substations.
- LMAct appl. must be able to process these data and if the loss is caused by reactive power flow it will initiate:
    - LMAct appl. must be able to obtain information about available flexible assets and their capabilities from the IG

        - LMAct appl. must be able to calculate optimized set points for flexible assets and send them to the IG
    - LMAct appl. must be able to subscribe to events from the GUI (events being input provided by the user) coming from the ICT Gateway

Graphical User Interface:

- GUI must be able to visualize modified/new setpoints for flexible assets
- The GUI should be able to receive input from a user concerning loss minimization and store this information to the ICT Gateway as a GUI event

ICT Gateway (IG):

- ICT Gateway (IG) must maintain a representation of the LV and MV grid topology and be able to expose it to the application
- IG must be able to actively call an application based on trigger events derived from other application output
- IG must be able to serve requests from applications for measurement data and ICT reachability information within a LV grid region specified by the application
- IG should be able to obtain information from connected smart inverters
- IG must be able to trigger GUI based on outcome from the LMAct application
- IG must be able to communicate modified setpoints to interfaces to management systems for flexible assets as above
- The IG must support receiving input commands from the GUI and make them available to applications via an subscription mechanism

Response time requirement: From triggering the LMAct application until communication of new setpoints to the management systems – less than 10min.

8.11 Requirement for Calculation of Energy Exchange UC

Calculation of Energy Exchange (CalcExch) application:

- CalcExch appl. must be able to request measured production and consumption data from smart meters, inverters, measurement devices and substations via the ICT Gateway.
- CalcExch appl. Must be able to request the LV and MV grid topology from the ICT Gateway
- CalcExch application must be able to establish a correspondence between the measured data and the grid model and calculate the powerflow in the DS Grid.
- CalcExch application must be able to store the powerflow information to the ICT Gateway.

- CalcExch appl. must be able to subscribe to events from the GUI (events being input provided by the user) coming from the ICT Gateway
- The CalcExch should be able to be triggered by a GUI event.

Graphical User Interface (GUI)

- The GUI must be able to present visually the energy flow in a GIS view of the DS grid and the exchange points towards TS.
- The GUI should be able to receive input from a user concerning an outage and store this information to the ICT Gateway as a GUI event

ICT Gateway (IG):

- IG must maintain a representation of the MV and LV grid topology and be able to expose it to the application that have subscribed to them.
- IG must be able to receive measurement data and events from Smart Meters, Inverters, and/or measurement devices in substations and store for application access.
- IG must support application requesting new data from specific devices and create corresponding jobs towards relevant systems.
- IG must support application requests from existing data by relevant queries data (devices, type, time etc.).
- IG must be able receive application and GUI output and provide it to other applications that have subscribed to it or that request it.
- IG must be able receive application and GUI output and provide it to other applications that have subscribed to it or that request it.

8.12 Requirement for Recommend improvements to DS grid to minimise energy exchange from TS grid and in DS grid

Minimize Energy Exchange Recommendation application (MinExchRec):

- MinExchRec appl. must be able to request the calculated DS gridpowerflow from the ICT Gateway.
- MinExchRec appl. Must be able to request the LV and MV grid topology from the ICT Gateway
- MinExchRec application must be able to identify possible reconfiguration of the DS grid, which minimise the overall energy exchange.
- MinExchRec application must be able to store the potential reconfigurations for visualisation purposes

Graphical User Interface (GUI)

- The GUI must be able to present visually the energy flow in a GIS view of the DS grid and the exchange points towards TS.
- The GUI must be able to present the potential reconfiguration and their expected improvement in a GIS view to the operator.

ICT Gateway (IG):

- IG must maintain a representation of the MV and LV grid topology and be able to expose it to the application that have subscribed to them
- IG must be able to receive measurement data and events from Smart Meters, Inverters, and/or measurement devices in substations and store for application access.
- IG must support application requesting new data from specific devices and create corresponding jobs towards relevant systems.
- IG must support application requests from existing data by relevant queries data (devices, type, time etc.).
- IG must be able receive application and GUI output and provide it to other applications that have subscribed to it or that request it
- IG must be able receive application and GUI output and provide it to other applications that have subscribed to it or that request it

9 Summary and Next Steps

The Net2DG solution correlates data from smart meters and smart inverters with information from existing DSO subsystems, in order to enable and develop novel LV grid observability applications for voltage quality, grid operation efficiency, and LV grid outage diagnosis. The achieved observability is subsequently used by specifically developed novel control coordination approaches, which utilize the existing smart meter and smart inverter actuation capabilities in conjunction with selected existing DSO actuation for voltage quality enhancement and loss minimization in the LV grid.

This deliverable presents the use-cases for Net2DG and derives requirements from these use-cases on Net2DG applications and on the Net2DG Data Gateway. The definition of the use-cases starts from an analysis of the current DSO scenarios and DSO needs of the two DSOs in the Net2DG consortium. This pre-analysis also includes the inspection of first data traces in several cases. In a next step, the deliverable describes the current situation with respect to energy markets and business relations of the DSOs in the consortium, and derives a market related future scenario from these. This pre-analysis is subsequently used to define as set of Net2DG user-stories and derive use-cases from these. In a final step, requirements on the Net2DG applications and on the Net2DG Data Gateway are derived from these use-cases.

The detailed architecture of the Net2DG system together with lower level requirements will be presented in the next deliverable of WP1.

10 Annex A: Use-case Details

10.1 Loss of Neutral - Additional info

Almost by definition, the systems and installations that are most adversely affected by the abnormal condition of a lost or broken neutral conductor are single phase systems and single phase circuits that are derived from three phase star connected supplies. Three phase systems that include single phase loads may experience voltage shifts between the star point and the three phases, depending on the balance of single phase loads across the three phases.

By convention, a solidly earthed neutral conductor is at zero potential to earth. The potential on a correctly installed neutral conductor may rise slightly above this theoretical zero value, depending upon the load current that is carried by the neutral and the consequential voltage drop resulting from the neutral current. In a single phase system that is derived from a single phase source, a break in the neutral conductor will simply result in a loss of the energy supply. However, in a three phase system having a distributed neutral, a break in the neutral conductor may result in undesirable variations of the three (phase to neutral) voltages.

Provided the neutral conductor remains continuous, the voltages between each phase and the neutral is largely unaffected, excepting for voltage drops in the circuit, which are load dependent. For the (unusual) case of equal load distribution across the three phases, even in the event of a loss of the neutral conductor, the individual voltages from each of the three phases to the star point will remain at approximately the nominal level of 230V. A break in the neutral conductor can however result in wide excursions of the voltages between each phase and the star point if the three single phase load currents deviate from the ideal balanced condition. Depending on the degree of unbalance between the single phase loads, in the extreme, the three single phase voltages (phase to neutral) could vary from as low as zero volts, to any voltage up to the phase to phase voltage. Irrespective of load balance, the voltages between phases are not affected by a break in the neutral conductor.

Loss of neutral at the transformer:

- Single Phase Transformer - For installations supplied from a single phase transformer, the impact of broken neutral is not very severe. Customers connected to that particular transformer will not have supply as the return path will have been broken; temporary loss of neutral can however also lead to voltage variations (e.g. caused by inductances) that may cause damage. Hazardous touch voltages might also be experienced on exposed conductive parts.
- Dual Phase Transformer - A loss of neutral on a dual phase transformer will cause the voltage to float up to the line voltages depending on the load balancing on the system. This type of fault condition may damage the customers equipment connected to the supply.
- Three Phase Transformer - A broken neutral on a three phase transformer will cause the voltage to float up to the line voltages depending on the load balancing on the system. This type of fault condition may damage the customers equipment connected to the supply.

Loss of neutral at the Conductors:

- LV Conductors – ABC or Bare LV Conductors - The impact of broken neutral at the low voltage conductors will be similar to when the conductor is broken at the transformer. For single phase Aerial bundled conductors (ABC), a broken neutral will just result in loss of power to the customers. No damage will occur to the connected loads. For dual phase and three phase low voltage conductor will result in supply voltage floating up to line voltages instead of phase voltage. This type of fault condition may damage the customers equipment connected to the supply.

10.2 Energy Infrastructure interfaces for industry 4.0 (other use-case candidates not followed-up)

➔ After discussion with Stadtwerke Landau and TME – not to be considered in Net2DG as industrial consumer should then work closely with Net2DG

Industrial energy consumers are in the transition to industry 4.0, in which different ICT systems at the industrial branch are inter-connected to achieve the next level of data exploitation and automisation. A connection of ICT systems of the industrial customer to energy data and related services provided a natural ingredient of a holistic industry 4.0 concept. Expected benefits obtained by the industrial DSO customer from such data exchange and service provisioning, in particular for energy-intensive industrial branches, are:

1. Reduction of time to detect and diagnose faults at the industrial plant based on measurement and diagnostics data from the DSO
2. Reduction of the costs of energy and of the costs of the grid connection by
    1. Reactivity to variable energy prices
    2. Support of regional energy products (see previous use-case)
    3. Reduction of energy losses at the customer’s site
3. Optimization of internal processes, e.g. maintenance, taking into account impact on energy costs

Stadtwerke Landau: potential industrial customer with remote control of production abroad is in their grid; high requirements to coordinate planned downtimes.

11 Appendix B – Further Information on Markets and Valorisation

11.1 The Vision of Smart Grids

11.1.1 Active Distribution Grids

The evolutionary changes of the distribution grids regarding system design, development and network operation philosophy are expected to be gradual and uneven. But it is supposed to be clear that the distribution networks evolve towards transmission-like architectures. This transition process may require several intermediate steps:

In a first step, the implementation of new and advanced information, communication, control and data management systems are supposed to be a precondition to move from the traditional approach of DG/RES-E connection (`fit and forget'; see Figure 32.a below) to more "active" distribution network operation (Figure 32.b) supporting also the implementation of future advanced concepts like micro-grids (Figure 32.c) and/or virtual power plants (Figure 32.d). Both of these latter concepts may need the utilization of advanced solutions such as information and communication technologies (ICT) and flexible controlling devices (FACTS).[28] Moreover, further steps of complexity describe the implementation of corresponding devices enabling the management of bidirectional load flows also on distribution grid level, accompanied by additional upgrades of protection devices and the implementation of new software and hardware (i.e., power electronics-based) technologies for more flexible system control. In the following Figure 32.a-d the gradual evolution of future distribution network architectures is presented in detail.

[28] FACTS…Flexible Alternating Current Transmission Systems

Figure 7.7a. Tr (a) Traditional Distribution Grid Schemes

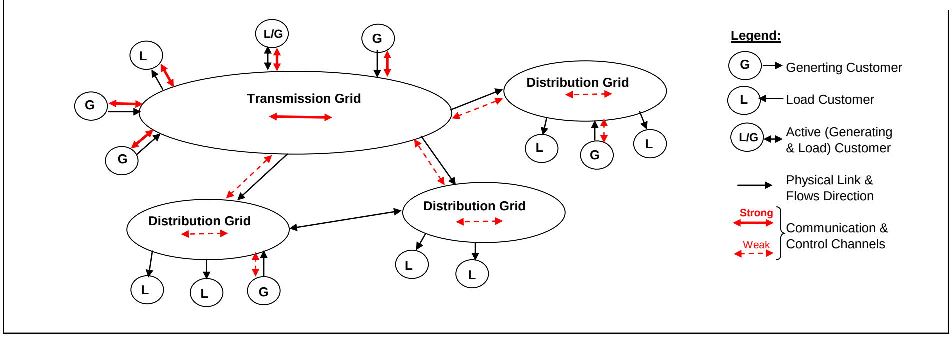


Figure 7.7b. Active Distribution Grids Scheme

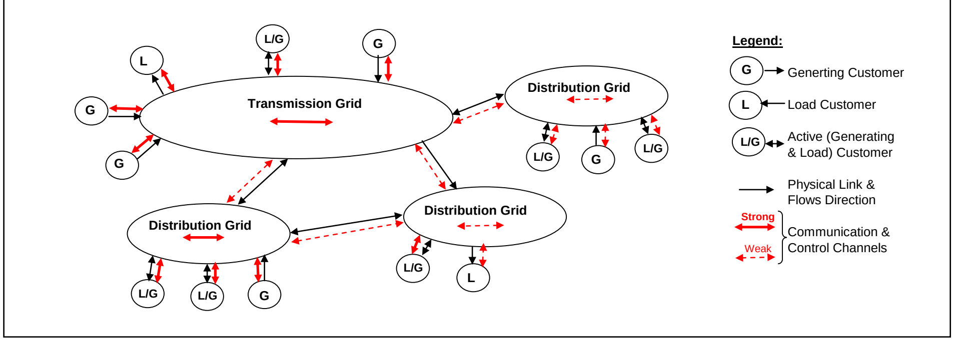


Figure 7.7b. Ac (b) Active Distribution Grids Schemes

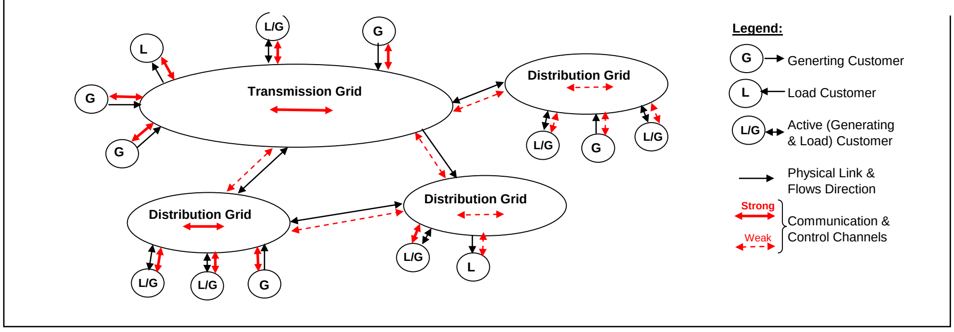
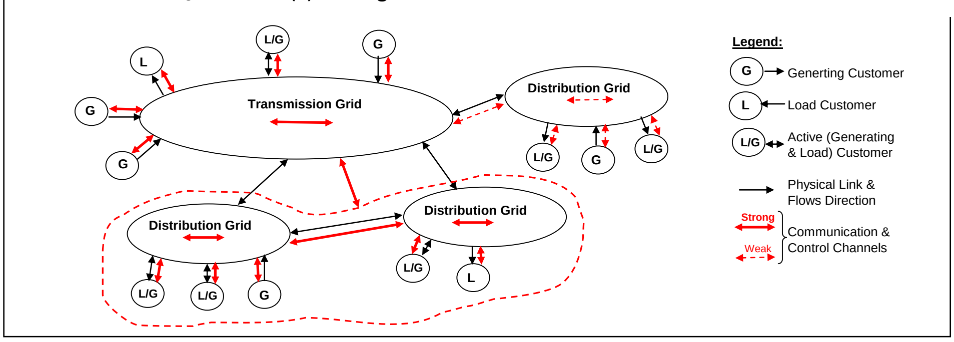


Figure 7.7c. Mi (c) Microgrids Scheme



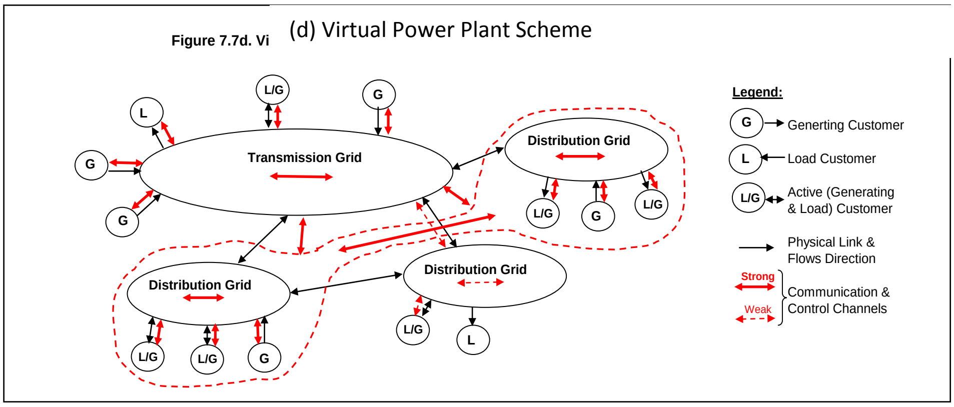


Figure 32 Different configurations of future distribution grid architectures:
(a): Traditional distribution grids; (b): Active distribution grids; (c): Micro-grids[29]; (d): Virtual Power Plants[30].

Future concepts going beyond those configurations presented in Figure 32.a-d may rely on fully active, smart and intelligent operation of distribution grids. This means that fully autonomous “cells” have to be implemented on distribution grid level. More precisely, the distribution system may be subdivided in more subsystems by islanding procedures. Each subsystem has to be eventually able to balance supply and demand effectively (i.e. be self-sufficient) for a twofold reason: (i) to be able to disconnect from the interconnected system and continue running in case of large and widespread disruptions and (ii) to reduce the burden (in terms of control actions and losses) on the upstream transmission systems. In a fully autonomous cell concept on distribution grid level also comprehensive “communication” between the transmission and distribution grid is essential for requesting the cell to provide black-start capability support and restore the service after a fault. In practise, Denmark has been the first country implementing a “cell concept” like that. Corresponding experience so far is briefly summarized below.

[29] In general, a micro-grid is a part of a distribution network containing DG/RES-E sources, together with local storage devices and controllable loads. It can be regarded as a controlled entity which can be operated as a single aggregated load or generator, eventually providing network support and services. Micro-grids generally have a total installed capacity between few hundred kW and a few hundred MW. The unique feature of micro-grids is that, although they operate mostly connected to the distribution network, they can be automatically disconnected by intentional islanding in case of faults affecting the upstream network. Then, micro-grids having sufficient generation and storage resources can ensure power supply to local customers. After a fault has been cleared and the upstream network operation restored, micro-grids can be resynchronised to the rest of the system. Additionally, the islanding procedure could also allow a micro-grid to support ‘black start’ in case of a widespread system outage.

[30] The Virtual Power Plant concept (VPP) is a decentralised energy management system tasked to aggregate different small generators for the purpose of energy trading and/or providing system support services. The VPP concept is not itself a new technology, but a scheme to combine DG/RES-E and storage and exploit the technical and economic synergies between the systems’ components. This aggregation is not necessarily pursued by physically connecting the different power plants but by interlinking them via information and communication technologies. For this reason the result is a virtual power plant, which may then be a multi-fuel, multi-location and multi-owned power station. A VPP balances required and available power in identified areas, based on offline schedules for DG/RES-E generation, storage, demand-side management capabilities and contractual power exchanges. For a grid operator or energy trader, buying energy or ancillary services from a VPP is equivalent to purchasing from a conventional power plant.

11.1.2 The Danish Cell-Architecture Concept

Denmark currently has the highest share of dispersed DG/RES-E generation (30% of installed power generation) all over Europe. DG/RES-E generation in the Danish power system mostly comprises small and medium combined heat and power (CHP) and wind power plants. This is particularly a feature of the system in Western Denmark, where DG/RES-E generation capacity amounts more than 50% of total, being installed throughout the distribution systems at voltage levels of 60kV and below.

As a consequence of this large dispersed DG/RES-E penetration, problems may arise when predicting and controlling the total power generation, as CHP units mostly operate by heat demand, while wind plants produce according to wind availability. When DG/RES-E generation exceeds local consumption the transmission lines to the interconnected neighboring countries are used to sell surplus production. However, also different problems in terms of security of supply and reliability have to be tackled by the system operators with increasing DG/RES-E penetration.

To face all these issues with large-scale dispersed DG/RES-E generation, the Danish TSO has been developing an advanced “cell architecture”. The aim of this new system architecture is to streamline and centralize the control of a large number of DG/RES-E units widespread throughout the distribution systems, while also exploiting benefits of dispersed DG/RES-E generation and counterbalancing the corresponding impact on grid operation.

A cell can be characterised as a portion of the Western Denmark distribution system down to a 150/60 kV substation, containing DG/RES-E capacity and local loads typically up to 100 MW aggregated. A cell is structurally like a micro-grid. The Danish TSO, in particular, expects to comprehensively interact with the distribution grid operator (DSO) whose distribution network contains the cells. Moreover, the TSO is able to control the cells centrally as conventional power plants in terms of power output, ancillary services and network support request, disconnection from the transmission network in case of upstream emergencies, and also in terms of black-start capability request for a post-fault restoration operation.

In normal situations, a cell relies on the upstream transmission system, exporting the excess production from dispersed DG/RES-E generation or importing the needed power in case of shortages of dispersed generation. When implementing intentional islanding, communication assumes a crucial role. In a situation like that, a command from the transmission control centre (operated by the TSO) communicates to the cell controller (operated by the DSO) that local generation and demand must be balanced immediately. Also in the islanding mode, voltage and frequency control must then be carried out at cell level by using the DG/RES-E resources. Other key issues to be addressed concern the dynamic transition of protection, control, and other network schemes from grid-connected mode to islanding and vice versa (incl. black-start capability support and restoration of system services after a fault).

Finally, it is important to note that by this new distribution system architecture – being already partly implemented in Western Denmark – it is possible for the DSO to actively control real and reactive power exchanges between the cell and the upstream transmission network as well as to monitor DG/RES-E generation units and load flows within the cell.

Smart grid technologies facilitate new ways of thinking about the values of urban infrastructure; driving a search for new business models.

11.2 Regulatory aspects in UK

The Smart Grid implementation process in the UK is split into two main phases: (i) Smart Meter Rollout and (ii) Establishment of a Smart Grid Regulatory Landscape rewarding Innovation:

- *Phase 1: UK Smart Meter Rollout:* The nationwide rollout of Smart Meters takes place from 2015 to 2020 (i.e. 53 million meters, approximately 26 million homes). The total costs are estimated £11 billion, expected to deliver a net benefit to the UK of £6.7bn. The 'big six' energy suppliers are leading the rollout, coordinated by government with industry support. Consumers will pay for the rollout. The creation of a centralised Data and Communications Company (DCC) underpins the process by Communications Services and Data Services. More in detail, the responsibilities are as follows: the roll-out of smart meters in the UK is being coordinated by the Department of Energy and Climate Change (DECC). It will be governed by industry regulator Ofgem once the meters are in place. The ICT community provides the 'smart' to a traditional industry via:
  -> Communications Services: Transferring huge new volumes of energy data to the DCC
  -> Data Services: Controlling, securing and using that data to improve the energy system
  -> In Home Displays: Engaging customers in their energy usage
  -> Consumer Access Devices: Building on this to develop an integrated 'smart home'
- *Phase 2: Realising a UK Smart Grid Regulator Landscape rewarding Innovation:* Low Carbon Networks Fund (LCNF) – a £500m fund over the five year price control period until 2015 – was the single largest pot of money that any one country is allocating to understanding smart grid and triggered innovative projects together with third parties. In addition, the Network Innovation Competitions (NIC) motivated the network companies to compete for funding for research, development and trialling for new technology, operating and commercial arrangements since 2013. Funding has been provided for the best innovation projects which help all network operators understand what they need to do to provide environmental benefits and security of supply at value for money as the UK moves to a low carbon economy. A new performance based regulation model to set price controls to ensure that consumers pay a fair price for investment has been established (RIIO: Revenue = Incentives + Innovation + Outputs).

11.3 Regulatory aspects in Italy[31]

The Italian regulator's approach in terms of Smart Grids is mainly based on implementing innovative pilot projects which have to fulfil certain criteria as there are:

- Demonstration pilots need to be real operations in the real grid, not lab-based simulations
- Regulatory attention is put to both, effectiveness (performance) and efficiency (cost): pilots are paid by all customers
- Transparency of the rules is important: procedures, evaluation methods and criteria, etc. need to be known by several parties involved ex-ante
- Knowledge development is expected to be conducted together with the involvement and the support of the best expertise (e.g. RSE and Universities like Politecnico Milano, etc.)
- Continuous monitoring in the medium and long-term is expected: cost-benefit analyses for the whole life-time of the new components
- Replicability and dissemination of the best-practices is expected
- Output disclosure is expected, because demonstration pilots are paid by all customers (i.e. results must be public, no patents)

In addition, the following requirements for Smart Grid demonstration pilots need to be met to be supported and awarded in Italy:

- Focus is on MV networks. 75% of distributed generation rated power is connected there
- Active grids are favoured only: at least reserve power-flow for 1% of time from MV to HV
- Real time control system at MV level is expected: the selected MV network has to be controlled (voltage limits / anti-islanding)
- Open grid: non-proprietary communication protocols only, in order to minimize interface costs for network users
- Pilot selection process with both measures, quantitative benefit/cost ratio and qualitative score (sophisticated KPI approach is implemented)
- Pilots are awarded with extra-WACC (+2%) for 12 years ('input-based')
- Dissemination is obligatory, i.e. report to the Regulatory Authority every six months for selected projects, published on Regulator's website

[31] Regulatory incentives for smart grids demonstration and deployment in Italy, within the European framework, Autorita per l'energia elettrica il gas e il Sistema idrico, Luca Lo Schiavo, Infrastructure Division, Regulatory Department, Deputy Director, IRED 2014, Kyoto, 20 Nov. 2014

12 Appendix C: Scoring of Use cases

The usecases are scored on three parameters using a (1-5) score (5 = best):

Value seen from the partners point of view. 5 = high value, 1 = low value.
Project feasibility, this covers an evaluation of the implementation feasibility (technological risk, complexity, competence match etc.). 5 = good fit to the project, 1 = bad fit.
Cost in terms of anticipated effort (man-power) to realise this usecase. 5 = low effort, 1 = high effort.

Besides the scoring from the partner group, then the feedback from the reference group on usecase value will also be taken into account.

Tabel 1 Feedback from Austrian Reference Group

Use case ID	**Value (1-5)**
UC FM-1: Outage Detection	5
UC FM-2: Outage Diagnosis	4
UC FM-3: Preventive maintenance (asset management)	4
UC FM-4: Neutral fault detection	3
UC FM-5: Neutral fault diagnostic and location	3
UC VQ-1: *LV Grid Monitoring* *Remark:* given it includes 'DSO friendly DER configuration' verification	4
VQ-2: Automatic Voltage Regulation	2
LM-1: Loss calculation and recording	4
LM-2: Loss Minimisation via grid reconfigurations	3
LM-3: Loss Minimisation using interaction with flexible energy resources	1
UC RE-1: Calculate and Visualize energy/power exchange in interconnection points to TS and overall in DS grid *Remark:* based on only DSO feedback (no joint DSO-Retailer integration!)	1
UC RE-2: Recommend improvements to the DS grid to minimise energy exchange from TS Grid	1
RE 3: Voltage Profile Management in MV to minimize energy exchange between TS and DS	1

Usecase ID	Partner	Value	Feasibility	Cost	Total Score
UC FM-1: Outage Detection	TME	5	5	5	15
	Std.Wrk.Lan	3	4	3	10
	GD	5	4	4	13
	Fronius	5	3	2	10
	RT	5	4	4	13

	AAU-WCN	4	4	3	11
	AAU-AT	3	3	3	9
	AAU-ET	5	4	3	12
	KAM	5	4	4	13
	TUW	4	5	2	11
Total Overall Score					117

Usecase ID	Partner	Value	Feasibility	Cost	Total Score
UC FM-2: Outage Diagnosis	TME	5	4	3	12
	Std.Wrk.Lan	3	4	3	10
	GD	4	3	3	10
	Fronius	5	3	2	10
	RT	4	4	4	12
	AAU-WCN	4	4	3	11
	AAU-AT	3	3	3	9
	AAU-ET	4	3	2	9
	KAM	5	4	3	12
	TUW	5	3	4	12
Total Overall Score					107

Usecase ID	Partner	Value	Feasibility	Cost	Total Score
UC FM-3: Preventive maintenance (asset management)	TME	5	4	4	13
	Std.Wrk.Lan	4	4	3	11
	GD	4-basic 5-advanced	5- basic 3- advanced	5 – basic 3-advanced	11-14
	Fronius	5	3	2	10
	RT	4	4	3	11
	AAU-WCN	4	4	3	11
	AAU-AT	2	3	2	7
	AAU-ET	4	3	2	9
	KAM	5	4	2	11
	TUW	5	5	3	13
Total Overall Score					107-110

Usecase ID	Partner	Value	Feasibility	Cost	Total Score
UC FM-4: Neutral fault detection	TME	2	3	3	8
	Std.Wrk.Lan	3	4	3	10
	GD	2	3	3	8
	Fronius	5	3	2	10
	RT	3	4	3	10
	AAU-WCN	4	4	3	11
	AAU-AT	4	3	3	10
	AAU-ET	4	3	4	11
	KAM	3	4	3	10
	TUW	2	4	3	9
Total Overall Score					97

Usecase ID	Partner	Value	Feasibility	Cost	Total Score
UC FM-5: Neutral fault diagnostic and location	TME	4	3	2	9
	Std.Wrk.Lan	4	4	3	11
	GD	2	2	1	5
	Fronius	5	3	2	10
	RT	3	4	4	11
	AAU-WCN	3	3	4	10
	AAU-AT	4	3	3	10
	AAU-ET	4	3	2	9
	KAM	4	3	3	10
	TUW	5	3	4	12
Total Overall Score					97

Usecase ID	Partner	Value	Feasibility	Cost	Total Score
UC VQ-1: *LV Grid Monitoring*	TME	3	4	3	10
	Std.Wrk.Lan	2	3	2	7
	GD	5	5	4	14
	Fronius	5	3	2	10
	RT	5	4	4	13
	AAU-WCN	4	4	3	11
	AAU-AT	5	4	4	13
	AAU-ET	5	4	4	13

	KAM	5	4	3	12
	TUW	1	3	4	8
Total Overall Score					111

Usecase ID	Partner	Value	Feasibility	Cost	Total Score
VQ-2: Automatic Voltage Regulation	TME	3	1	1	5
	Std.Wrk.Lan	5	4	4	13
	GD	4 (from ca 5 years in future)	2 (lack of regulatory feasibility)	3	9
	Fronius	5	3	2	10
	RT	5	4	4	13
	AAU-WCN	4	4	2	10
	AAU-AT	5	5	5	15
	AAU-ET	2	3	2	7
	KAM	4	3	2	9
	TUW	1	3	4	8
Total Overall Score					99

Usecase ID	Partner	Value	Feasibility	Cost	Total Score
LM-1: Loss calculation and recording	TME	3	4	4	11
	Std.Wrk.Lan	4	4	3	11
	GD	4	5	4	13
	Fronius	5	3	2	10
	RT	3	4	4	11
	AAU-WCN	4	4	2	10
	AAU-AT	5	4	4	13
	AAU-ET	5	4	3	12
	KAM	4	4	4	12
	TUW	5	5	4	15
Total overall score					118

Usecase ID	Partner	Value	Feasibility	Cost	Total Score
	TME	3	1	1	5

LM-2: Loss Minimisation via grid reconfigurations	Std.Wrk.Lan	4	3	3	10
	GD	4 (high value in case of success)	2 (risk of too little possibilities to reduce losses)	3	9
	Fronius	5	3	2	10
	RT	2	2	4	8
	AAU-WCN	2	3	4	9
	AAU-AT	3	2	2	7
	AAU-ET	3	2	2	7
	KAM	4	3	3	10
	TUW	3	3	3	9
Total overall score					84

Usecase ID	Partner	Value	Feasibility	Cost	Total Score
LM-3: Loss Minimisation using interaction with flexible energy resources	TME	2	1	1	4
	Std.Wrk.Lan	4	2	3	9
	GD	3	3	3	9
	Fronius	5	3	2	10
	RT	2	2	4	8
	AAU-WCN	4	3	2	9
	AAU-AT	4	3	3	10
	AAU-ET	3	1	2	6
	KAM	2	1	1	4
	TUW	5	5	4	14
Total overall score					83

Usecase ID	Partner	Value	Feasibility	Cost	Total score
UC RE-1: Calculate and Visualize energy/power exchange in interconnection points to TS and	TME	3	5	5	13
	Std.Wrk.Lan	2	3	3	8
	GD	4	5	5	14
	Fronius	5	3	2	10
	RT	4	4	4	12
	AAU-WCN	2	3	4	9
	AAU-AT	3	3	3	9
	AAU-ET	5	4	4	13

overall in DS grid	KAM	3	4	4	11
	TUW	5	5	2	12
Total overall score					111

Usecase ID	Partner	Value	Feasibility	Cost	Total score
UC RE-2: Recommend improvements to the DS grid to minimise energy exchange from TS Grid	TME	5	3	2	10
	Std.Wrk.Lan	2	3	3	8
	GD	3	2	3	8
	Fronius	5	3	2	10
	RT	3	4	4	11
	AAU-WCN	2	3	4	9
	AAU-AT	2	2	2	6
	AAU-ET	4	3	3	10
	KAM	3	2	4	9
	TUW	5	3	3	11
Total overall score					92

Use case ID	**Ref.group input**	**Std. Lan Value**	**TME Value**	**DSO Value Prio**	**Consortium total score**	**Cons. Prio**	**Final Priority**
UC FM-1: Outage Detection	5	3	5	1	117	2	1
UC FM-2: Outage Diagnosis	4	3	5	3	107	6	4
UC FM-3: Preventive maintenance (asset management)	4	4	5	1	110	5	3
UC FM-4: Neutral fault detection	3	3	2	9	97	8	9
UC FM-5: Neutral fault diagnostic and location	3	4	4	4	97	8	6
UC VQ-1: *LV Grid Monitoring*	4	2	3	7	111	3	5
VQ-2: Automatic Voltage Regulation	2	5	3	6	99	7	7

LM-1: Loss calculation and recording	4	4	3	4	118	1	2
LM-2: Loss Minimisation via grid reconfigurations	3	4	2	7	84	11	10
LM-3: Loss Minimisation using interaction with flexible energy resources	1	4	2	11	83	11	12
UC RE-1: Calculate and Visualize energy/power exchange in interconnection points to TS and overall in DS grid	1	2	3	12	111	3	8
UC RE-2: Recommend improvements to the DS grid to minimise energy exchange from TS Grid	1	2	5	9	92	10	11

13 Appendix D: Voltage Profile Management

13.1 Use-Case: Voltage Profile Management in MV

ID and name:	RE 3: Voltage Profile Management in MV to minimize energy exchange between TS and DS
Parent user story	User story – 8
Overview and goal	See user story-8
System applicability	The DS grid and its exchange points with TS grids.
Business rationale	Use of active control of dispersed RES and DR sources can reduce exchange between TS and DS by means of voltage control.
Precondition	Normal operation, UC RE-1
Actors:	Net2DG system, AMI system, RES (PV, WTG..) system, DR systems, DSO operator

External stimulus	None
Main flow	1. *The state of production and demand in the DS grid is estimated based on monitoring data acquired from sensors in the DS grid* 2. The Net2DG system identifies potential control actions to RES/DR sources and OLTC enabled substations on the MV distribution grid, which can minimize the energy exchange with TS grid by means of new set points and settings for the local control of RES/DR and/or OLTC settings. 3. The Net2DG system sends the updated set points and settings to individual RES/DR sources and/or substations. 4. The Net2DG system monitors the effect of the control commands with respect to minimise the energy exchange with TS.
Alternate flow	2a) The Net2DG system compensates for RES/DG sources which do not responds or rejects the control message by calculating a new steady state scenario. 2b) The Net2DG system sends a new set of control commands. Optional : Demand/response for load curtailment
Characteristics	The Net2DG system must be resilient and robust towards failing devices or lack of communication and must never bring the MV/LV grid in an unbalanced situation.

13.2 Requirement for Voltage Profile Management in MV to minimize energy exchange between TS and DS

- Improve DS grid import / exchange application:
  - MinExchAct application must be able to request measured data and calculated DS grid powerflow from the ICT Gateway.
  - MinExchAct application must be able to identify possible voltage control actions to RES/DR and OLTC enabled assets in the DS grid, which minimize the overall energy exchange.
  - MinExchAct application must be able to store the device reconfiguration and request the ICT Gateway to send them to relevant devices.

- Graphical User Interface (GUI)
  - The GUI must be able to present visually the energy flow in a GIS view of the DS grid and the exchange points towards TS.
  - The GUI must be able to present the new setpoints and their expected improvement in a GIS view to the operator.

- ICT Gateway (IG):

- IG must maintain a representation of the MV and LV grid topology and be able to expose it to the application that have subscribed to them
- IG must maintain a list of controllable assets and their connectivity state.
- IG must be able to communicate modified setpoints to interfaces to management systems for controllable assets