



Funded by the European Union

Project Number: 774145
 Project acronym: Net2DG
 Project title: Leveraging Networked Data for the Digital electricity Grid
 Contract type: H2020-LCE-2017-SGS

Deliverable number:	D5.1
Deliverable title:	First integrated deployment at Lab and Testbed
Work package:	WP5
Due date of deliverable:	M24
Actual submission date:	M24 - 27/12/2019
Start date of project:	01/01/2018
Duration:	42 months
Reviewer(s):	Jesper Hummel (TME), Hans Peter Schwefel (GD)
Author/editor:	Florin Iov, Catalin Ciontea
Contributing partners:	Aalborg University (AAU), GridData (GD), Fronius (Fronius), Resiltech (RT), Kamstrup (KAM), Thy-Mors Energi (TME), Stadtwerke Landau (StwLan)

Dissemination Level of this Deliverable:	PU
<i>Public</i>	<i>PU</i>
<i>Confidential, only for members of the consortium (including the Commission Services)</i>	<i>CO</i>

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 774145. Further information is available at www.net2dg.eu.

This document reflects only the author's view and that the Agency is not responsible for any use that may be made of the information it contains.

Document history

Version nr.	Date	Authors	Changed chapters
0.1	13/08/2019	Florin Iov	ToC and first chapters
0.2	05/11/2019	Catalin Ciontea	Editing chapters
0.3	27/11/2019	Catalin C	First Draft ready for reviewers
0.4	10/12/2019	Florin, Catalin	Review comments incorporated
1.0	20/12/2019	Florin Iov	Final version ready

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This deliverable contains original unpublished work except where clearly indicated otherwise.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.

Contributors

Part. Nr.	Part. short name	Name of the Contributor	E-mail
01	AAU	Florin Iov, Catalin Ciontea, Rasmus Løvenstein Olsen, Kamal Shahid	fi@et.aau.dk , cic@et.aau.dk , rlo@es.aau.dk , ksh@es.aau.dk
03	GD	Hans-Peter Schwefel, Nuno Silva, Ivan Mercep, Domagoj Drenjanac	schwefel@griddata.eu , nuno.silva@griddata.eu , mercep@griddata.eu , drenjanac@griddata.eu
04	RT	Nicola Nostro, Enrico Schiavone	nicola.nostro@resiltech.com , enrico.schiavone@resiltech.com
05	Fronius	Christoph Winter, Nicole Diewald	winter.christoph@fronius.com , diewald.nicole@fronius.com
06	KAM	Karsten Handrup	kaha@kamstrup.com
08	TME	Rolf Kirk	rok@thymors.dk
09	StwLan	Robert Damböck	robert.damboeck@swlandau.de



Table of Content

Table of Content.....	3
List of Figures.....	5
List of Tables.....	6
List of Acronyms	7
Executive Summary	9
1 Introduction.....	10
2 Deployment Architectures	10
2.1 Overall Net2DG architecture	11
2.2 Conceptual Deployment Architectures	14
2.2.1 Real-Time Hardware-in-the Loop Laboratory	14
2.2.2 TME field trial	16
2.2.3 StwLan field trial.....	18
2.3 Complementarity of Demonstrators	19
3 Release 1 Laboratory Deployment	21
3.1 Main Working Assumptions	21
3.2 Deployment Architecture.....	22
3.3 Component overview	23
3.3.1 RT-Grid Simulator	23
3.3.2 Generic VMS-EM	27
3.3.3 GTS.....	29
3.3.4 ICT-Gateway	29
3.3.5 Application Layer	29
3.4 Physical Realization	31
3.4.1 Laboratory Implementation	31
3.4.2 Data Exchange and Interfaces	31
3.5 Integration test cases and preliminary results.....	32
3.5.1 Voltage Measurements	34
3.5.2 Current Measurements	34
3.5.3 Events	35
3.6 Preliminary application results.....	36
3.6.1 ODet results.....	36
3.6.2 GMon Results	37
3.7 Candidate tasks and features for next release.....	39
4 Release 1 Thy-Mors Energy Field Trial	40
4.1 Grid scenario	40
4.2 Deployment architecture	41
4.3 Component overview and interfaces	41
4.4 Grid topology Head-End	42



4.5	SolarWeb adapter.....	43
4.6	AMI Adapter	43
4.7	Data Validation	44
4.7.1	Topology Data.....	46
4.7.2	Inverter Data	47
4.7.3	AMI Data.....	47
4.8	Candidate tasks and features for next release.....	47
5	Release 1 StwLan Field Trial	49
5.1	Grid Scenario	49
5.2	Deployment Architecture.....	50
5.3	Component overview and interfaces	51
5.4	EM Subsystem deployment.....	52
5.5	Data validation	54
5.5.1	Topology Data.....	55
5.5.2	RTU Data.....	55
5.5.3	Inverter data	57
5.5.4	GMon results	59
5.6	Candidate tasks and features for next release.....	59
6	Conclusions and Outlook.....	60
7	References.....	62



List of Figures

Figure 1. Final High- Level Architecture of the overall Net2DG system.	11
Figure 2. Proposed RT-HIL Deployment Architecture.	15
Figure 3: Deployment architecture of TME Field Trial.	17
Figure 4. Deployment architecture of StwLan Field Trial.	19
Figure 5. Laboratory Deployment Architecture considered for Release 1.	22
Figure 6: Block diagram of RT-HIL RGM	23
Figure 7: Single line diagram of Reference Grid Model (Feeder 5)	24
Figure 8: Block diagram of Solar PV system.	25
Figure 9: Residential load model	26
Figure 10: Non-residential load model	26
Figure 11. Definition of a PoM in Reference Grid Model.	27
Figure 12: Internal structure of the VMS.	28
Figure 13: Topology HES underlying functionalities	29
Figure 14. Overview of ICT-GW laboratory deployment in Release 1.	30
Figure 15. Overview of RT-HIL deployment in laboratory infrastructure.	31
Figure 16. Result of SQL command to query relevant voltage data.	34
Figure 17. Result of SQL command to query relevant Current data.	35
Figure 18 Results of SQL command to query relevant events data.	35
Figure 19. Example of on-demand data provided by VMS to ICT-Gateway - triggered by ODet receiving an event.	37
Figure 20: GMon results for consumer 11504.	38
Figure 21. TME field trial region for Release 1 is the LV grid area behind substation 3011.	40
Figure 22. Deployment architecture of TME Release 1 Field Trial.	41
Figure 23. Grid Topology Head-End design.	42
Figure 24. Test Smart Meter positioned at Kamstrup used for validation purposes in the TME field test.	44
Figure 25. Tables created by ICG in MySQL Database.	46
Figure 26. Results of SQL command to query TME grid topology elements.	46
Figure 27: StwLan field trial region for Release 1 is the LV grid area starting from the substation TS20 (green triangle in the center);	49
Figure 28: Deployment architecture of StwLan Release 1 Field Trial	50
Figure 29. RTU deployment architecture in junction box or substation	53
Figure 30. Deployment of one Janitza device (left) and RTU (right) at a junction box in the field trial region.	54
Figure 31. Results of SQL command to query grid topology elements.	55
Figure 32. Result of SQL command to query relevant voltage data.	56
Figure 33. Result of SQL command to query relevant current data, the values do not yet include the scaling (factor 120 in the substation measurement) by the current transformer.	57
Figure 34. Result of SQL command to query relevant voltage data.	58



Figure 35. Results of SQL command to query relevant active energy data. 58

List of Tables

Table 1. Complementarity and synergies of demonstrators.....	20
Table 2. Measurement Signals collected in each PoM.	26
Table 3 UDP Packet format per PoM/SM	31
Table 4. Example of UDP Port Assignment	32
Table 5. Laboratory Test cases in Release 1.....	33
Table 6. Test Cases for TME Field Trial in Release 1	45
Table 7. Test Cases for StwLan Field Trial in Release 1	54



List of Acronyms

Net2DG	Leveraging Networked Data for the Digital electricity Grid
AMI	Advanced Metering Systems
API	Application Programming Interface
AVR	Automatic Voltage Regulation (Net2DG application)
CIM	Common Information Model
CLN	Control and Logging Network
CSV	Comma Separated Values (file type)
DB	Data Base
DSO	Distribution System Operator
EM	Electrical Measurement
GIS	Geographic Information System
GMon	Grid Monitoring (Net2DG application)
GUI	Graphical User Interface
GTS	Grid Topology Subsystem
HE/HES	Head-End/Head-End Subsystem
HTTP	Hyper Text Transfer Protocol
ICT	Information and Communications Technology
ICT-GW	ICT Gateway
IP	Internet Protocol
INV	PV grid Inverter (subsystem)
LAN	Local Area Network
LC	Loss Calculation (Net2DG application)
LV	Low Voltage
MV	Medium Voltage
NTP	Network Time Protocol
ODet	Outage Detection (Net2DG application)
ODiag	Outage Diagnosis (Net2DG application)
OGM	Observability Grid Model
OLTC	On-load tap changer
PV	Photovoltaic
PM	Preventive Maintenance (Net2DG application)
PoM	Point of Measurement
RAM	Random Access Memory
REST	Representational State Transfer
RGM	Reference Grid Model
RTU	Remote Terminal Unit
RT-HIL	Real-Time Hardware-in-the-Loop
SCN	Subsystem Communication Network
SM(s)	Smart Meter(s)
SPVS	Solar PV System
SW	Switch (breaker)
TCP	Transmission Control Protocol



TSO	Transmission System Operator
UD	Utility Driver (KAM specific application protocol)
UDP	User Datagram Protocol
VM server	Virtual Meter Server
VMS	Virtual Measurement Subsystem
VMS-AMI	VMS for AMI
VMS-EM	VMS for EM
VMS-INV	VMS for PV grid Inverters
XML	Extensible Markup Language (file type)



Executive Summary

This document is the first deliverable from WP5 in Net2DG project, with the objective to document the architectures of the two field test deployment sites, the lab setup and provide the overall framework of WP5 for the remaining time of the project. It defines the conceptual deployment architectures for each demonstrator based on deliverable D1.3 to be reached at the end of Net2DG project. It is also explaining the complementarity and synergies of laboratory and field trails in demonstrating the Net2DG applications in scope.

The specific deployment architectures and selected applications to be demonstrated at M24 as part of the Release 1 in the project are also explained in detail. Integration of all involved subsystems and applications in laboratory framework as well as in the field trails is presented. Preliminary results from an extensive set of test cases proves a successful integration of these subsystems and applications. A list of specific targets for Release 2 in the project (M30) is given for all demonstrators.

1 Introduction

The purpose of deliverable D5.1 is to provide evidence of successful integration of different components that constitute the overall Net2DG solution with respect to first (Release 1) experimental evaluation out of three. To this aim the document provides a description of the first laboratory and field prototypes and reports on the preliminary results from these deployments.

In order to have a clear view, the deliverable first presents the overall Net2DG architecture and its main blocks, from the electrical grid up to the Application Layer through the ICT Gateway (Section 1). A high-level description of the functionalities of the blocks and the input received and output produces is also provided, thus giving an overview of the interfaces.

Prior to deploy and test the solution on the two reference DSOs, it is used a Real-Time Hardware-in-the-loop (RT HIL) approach in a laboratory environment, to ensure successful integration and assessment of the main functionalities of the developed solutions. Therefore, the conceptual deployment architecture for RT HIL Laboratory is presented in Section 2.2.1, with the description of the involved subsystems. This approach ensures scalability and applicability of the developed solutions in a wider context. Similarly, the deliverable describes the actual field trials, namely TME and StwLan (respectively in Section 2.2.2 and Section 2.2.3), using functionalities relevant for the given site test.

Field trials on one hand give to the project the evidence that the designed, developed and deployed solution is operating as expected in the real world, on the other hand give the confidence to the DSOs regarding the benefits of using this novel solution.

The workflow for WP5 demonstrations is planned in several releases in order to align with the other workpackages that are delivering gradually the developed solutions and applications. The first Release is focusing mainly in establishing the interfaces and subsystems for data collection mechanisms for all three demonstrators (Section 3, 4 and 5) as well as first implementations of selected applications i.e. Outage Detection (ODet) and Grid Monitoring (GMon). It is also developing a reduced low voltage distribution grid model to run in laboratory by using reference data provided by TME. This model is used to generate operational conditions and events for testing the above mentioned applications.

The subsequent releases in Workpackage 5 are related to:

- Implementation and testing of advanced functionalities for the applications in the first release
- first implementation and testing of remaining applications
- extended testing of all applications using a complete Real-Time distribution grid model behind a secondary substation.

The following of this deliverable describes for the three test trials the current assumptions and architecture simplifications adopted for Release 1

2 Deployment Architectures

This section is presenting the particular deployment architectures that are targeted at the end of Net2DG project for each Field Trial and the laboratory starting from the overall architecture defined in [1].

2.1 Overall Net2DG architecture

The overall high-level system architecture of the Net2DG solution is presented in Figure 1 based on [1]. This architecture shows four main blocks: the Application Layer, the ICT Gateway (along with a Data Base), the HeadEnd layer and the Electrical Grid.

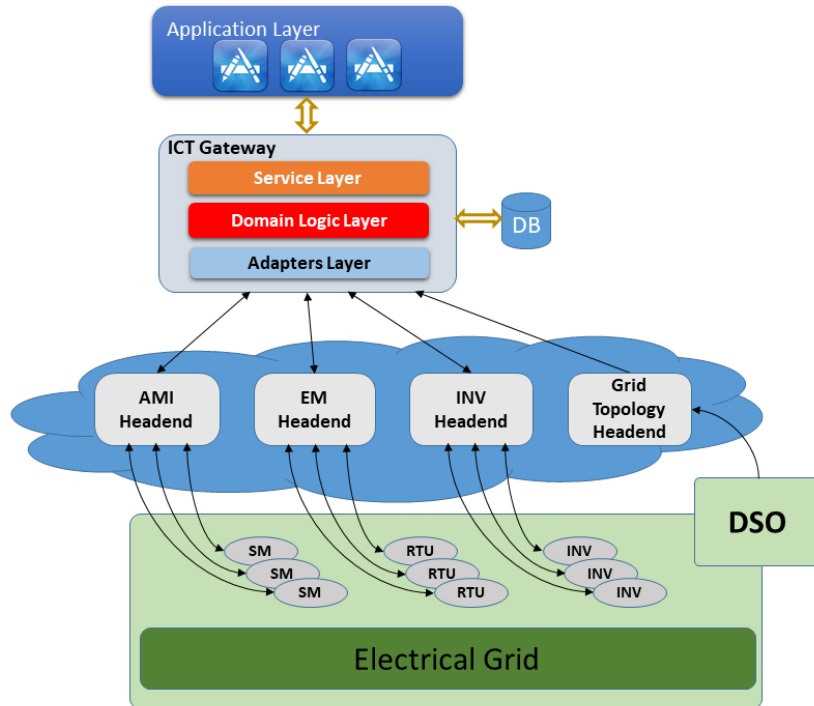


Figure 1. Final High- Level Architecture of the overall Net2DG system.

The **Application Layer** includes novel applications developed in the context of Net2DG project [2] aiming at supporting the DSO in three main areas: Operation Efficiency, Voltage Quality and Outage Diagnosis. Each of the application runs on top of the ICT Gateway (ICT GW) and retrieves the grid topology information, the measurements and the events through the ICT Gateway.

The **ICT GW** is in charge of establishing connections to the different data and actuation subsystems, in addition to the Grid Topology Subsystem, which is in charge to provide the topological information of the electrical grid under observation. Due to heterogeneity of subsystems deployed in the field, the **ICT GW** needs to adapt the collected data in a uniform format to be easily stored in the Data Base and provided to the applications that will request them.

The measurement and actuation subsystems used are the AMI subsystem, the Inverter subsystem and the EM subsystem (using Janitza measurement devices in Net2DG).

The **AMI subsystem** refers to the Advanced Metering Infrastructure (AMI) infrastructure aiming at collecting and making available to the ICT GW data from Smart Meters (SMs) deployed in the grid. In particular, the following measurands from SMs are collected:

- detailed values for the following measurands and corresponding OBIS codes:
 - Active power P+



- Active power P-
- Reactive power Q+
- Reactive power Q-
- Active energy A+
- Active energy A-
- Reactive energy R+
- Reactive energy R-
- UL1, average
- UL2, average
- UL3 average
- IL1, average
- IL2, average
- IL3 average
- Moreover, the AMI HE collects events that can be made available on request to the ICT GW; the current implementation does not collect such information, which is moved to next release.

The **INV subsystem** refers (in the current implementation and deployment) to the SolarWeb infrastructure aiming at collecting and making available to the ICT GW data from Photo Voltaic (PV) Systems deployed in the grid. In particular, the following measurands from PVs are collected:

- DevWork: AC output energy for each inverter
- UACMeanL1: AC mean voltage of phase 1 to neutral conductor for each inverter
- UACMeanL2: AC mean voltage of phase 2 to neutral conductor for each inverter
- UACMeanL3: AC mean voltage of phase 3 to neutral conductor for each inverter

In addition to measurands, the SolarWeb subsystem is able to provide service messages that represent alarms generated within the PV system. The current implementation gets the following service messages:

- AC voltage too low
- AC voltage too high

The INV system will also account for data exchange to PV inverters i.e. sending various references and settings as provided by e.g. AVR application.

The **EM subsystem** refers to the Remote Terminal Unit (RTU) aiming at collecting and making available to the ICT GW measurements and alarms from electrical measurement devices, here from the brand Janitza, deployed in the grid. In particular, the following measurands from EM are collected for the three phases:

- Active energy
- Reactive energy
- Voltage
- Current

In addition to measurands, the EM subsystem is able to provide messages that represent alarms generated within the EM system. The current implementation gets the following service messages:

- UnderVoltage
- OverVoltage

As mentioned, Application Layer includes applications aiming at supporting DSOs, a short description of the applications is given in the following:

- **Grid Monitoring (GMon)** - it allows the DSO to specify an area of the grid and a time interval in the past and then uses measured average voltage values over 15min intervals in order to provide the following output to the DSO through the GUI:
 - Time Series of 15min average voltages at all grid nodes in the selected LV grid area over the full-time interval
 - List of grid nodes, which have been exceeding configurable limits of 15min average voltages
 - frequency of over- and under-voltages at these nodes in the selected time period
 - 95% quantiles of 15min average values over a 1-week time-window and evolution of these quantiles over time. Release 1 uses a sliding window shifted by one day each time.
 - Number of 'strong' sags and swells for each 'measured' grid node for each day.
- **Outage Detection (ODet)** - it allows the DSO to specify an area of the grid in order to provide for each grid node in the LV grid area the following output to the DSO through the Graphical Unit Interface (GUI):
 - Probability the grid node has an ICT outage
 - Probability that the grid node has a power outage
 - Number of phases that are affected by the power outageFurthermore, the application may create an 'Outage detected' event as output.
- **Outage Diagnosis (ODiag)** - it allows to determine and localize the cause of an outage. This application, which is triggered by the detection event of the ODet Application, will request additional measurements (1second values of voltages, and in case of the substation also currents) from the ICT Gateway. The location and behaviour of the fault is assessed by processing data gathered from reachable measurement devices and deploying methods for short-circuit impedance calculation, in order to provide the following output to the DSO through the GUI:
 - A list of grid locations (substation, cables, junction boxes) and the likelihood that the cause of the outage is associated with this grid location
 - The timestamp at which the fault started to become active; Release 1 thereby focuses on symmetric short-circuit faults.
 - The location of the fuse that has been burnt (if any) as consequence of the short-circuit fault.
- **Loss calculation (LC)** - it allows the DSO to specify an area of the grid and a time interval in the past and then uses measured average active and reactive energy values in order to provide the following output to the DSO through the GUI:
 - Total energy values for the reference time interval
 - Total accumulated active energy loss in the LV grid part below the trafo LV busbar

- Total energy that has been flowing through the LV trafo in the time period
- For each 15min interval:
 - Average active power loss in the LV grid part below the trafo LV busbar
 - Average active power passing through the LV trafo in that period
 - Average reactive power loss in the LV grid part below the trafo LV busbar
 - Average reactive power passing through the LV trafo in that period.
- **Preventive Maintenance (PM)** - it runs periodically to assess the asset condition and health indices of particular grid components. The PM evaluates data (e.g., voltage, current, total harmonic distortion level, ambient temperature) based on a set of rules that accounts for configurable thresholds and time durations. According to the evaluations, PM either orders a maintenance visit or reschedules the existing maintenance plan, when this value is higher than a configurable target value. Main purpose of PM is to lessen the likelihood of failure of observed grid components while keeping maintenance effort and expenses low.
- **Automatic Voltage Regulation (AVR)** - it manages the control coordination of the grid for a:
 - Fair distribution of grid support to counteract over-voltage due to multiple generators along feeder, maximizing DER hosting capacity without grid reinforcement
 - Fair distribution of grid support to counteract over-voltage due to multiple generators along feeder, utilizing controllable storage
 - Reactive power balancing below (secondary) substation to prevent transformer overloading

2.2 Conceptual Deployment Architectures

2.2.1 Real-Time Hardware-in-the Loop Laboratory

In order to verify Net2DG applications prior to site testing a RT-HIL approach is used. The conceptual laboratory deployment of Net2DG solutions in the RT-HIL framework is shown in Figure 2.

The following subsystems are involved:

RT-Grid Simulator – is based on Opal-RT system and contains several modules as: Grid Topology and Parameters, Grid Model, Operational Scenarios, Load Profiles including generation, and triggering of grid events.

VMS-AMI – Virtual Measurement Sub-System for Advanced Metering Infrastructure. It contains several modules namely: Virtual Smart Meters (VSM), Virtual Data Collection (VDC) and Virtual Head-End (VHE) to emulate the entire AMI system.

VMS-EM – Virtual Measurement Unit Sub-System. This sub-system is emulating generic measurement devices such as Remote Terminal Units and PQ measurement units. It also contains dedicated modules as: Virtual Device Measurement (VDM), Virtual Remote Terminal Unit (VRTU) and a Virtual Head-End (VHE).

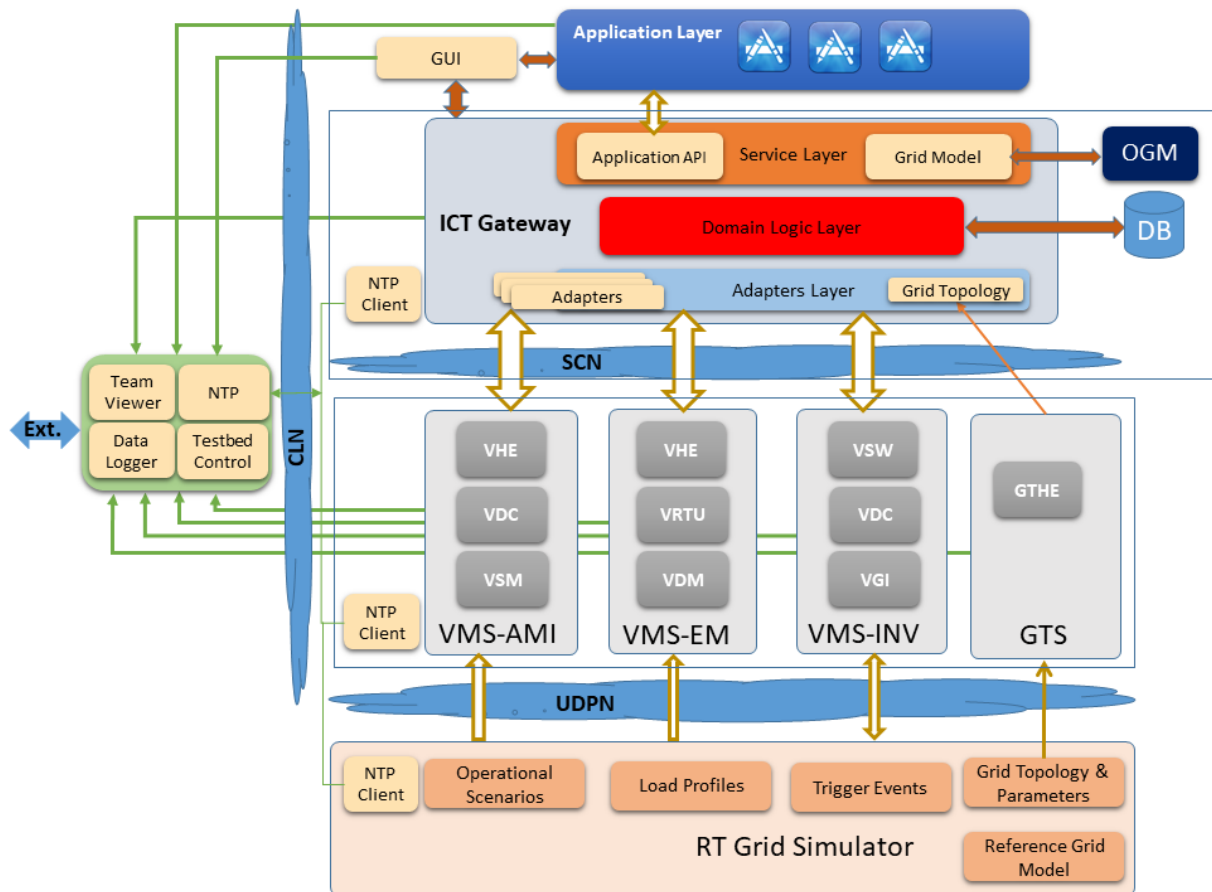


Figure 2. Proposed RT-HIL Deployment Architecture.

VMS-INV – Virtual Measurement Sub-System for Grid Inverter emulates the behaviour of the data collection mechanism for Grid inverters by using the following modules: Virtual Grid Inverter (VGI), Virtual Data Collection mechanism (VDC) and Virtual Solar Web (VSW).

GTS – The grid topology subsystem obtains the grid topology information from the corresponding files of the real-time simulator and makes it available to the ICT Gateway.

ICT Network – there are 3 different ICT networks one for testbed management, one for ICT-Gateway to Virtual Measurement Device Communication (using the NS3 emulator), one for Opal-RT to Virtual Measurement Device communication, and a third one for logging and testbed control.

ICT Gateway – The ICT Gateway connects on one side to all Virtual Measurement Subsystems and to the Grid Topology information in the testbed via customized adapters. On the other side, it provides the aggregated and processed data to the application layer.

Application Layer - consisting of target applications and the Graphical User Interface (GUI) as:

- ODet – Outage Detection will be demonstrated in Release 1
- GMon – Grid Monitoring will be demonstrated in Release 1
- ODiag – Outage Diagnosis considered for subsequent releases
- LC – Loss calculation considered for subsequent releases

- PM – Preventive Maintenance considered for subsequent releases
- AVR – considered for subsequent releases

Functional Blocks associated to ICT GW:

- OGM - Observability Grid Model used to calculate missing electrical parameters for the grid observability applications (e.g., calculate voltage values for all grid nodes in the LV topology).

There are several ICT Networks in the lab as:

- ICT Network connecting the VMS subsystems to OPAL-RT (UDPN): this a direct Ethernet connection carrying UDP traffic, no network emulator, no other traffic on it.
- ICT Network between VMS subsystems and ICT Gateway Adapters. This network is called Subsystem Communication Network (SCN) and it shall handle network type and data traffic by using a network emulator software. The network emulator is used to inject delays, packet losses and communication outages on individual transport layer connections (i.e. identified by source and destination IP addresses and port numbers).
- Control and Logging Network (CLN): used to setup and start processes on different ICT nodes, NTP synchronisation between nodes; access to or exchange of logging data. This network is the private LAN used in RT-HIL setup and it is not affected by artificial/induced delays and data traffic.

In order to reach this lab architecture at the end of the project several releases are planned as:

- Release 1 will mainly focus on development of a generic VMS that will be later on configured to represent the data collection mechanisms for AMI, EM and INV subsystems. Release 1 will also include a full integration of ICT-GW as well as specific tests for ODet and GMon.
- Release 2 will extend the generic VMS into dedicated AMI, INV and EM subsystems. It will test all the applications on a reduced model of low voltage distribution grid i.e. a relevant LV feeder.
- Release 3 will fully test and demonstrate all applications on a complete model of a low voltage grid behind a secondary substation.

2.2.2 TME field trial

Figure 3 shows the final deployment scenario for the TME field trial. The main components for this setup are: 1) ICT Gateway, 2) Grid Topology HES, 3) AMI Mediator and 4) Inverter HES (Solar.Web).

The deployment of the ICT Gateway and Grid Topology HES has happened on an Azure cloud platform as a virtual machine under TMEs ownership. On this machine, the ICT-Gateway and Grid Topology HES are executed and running.

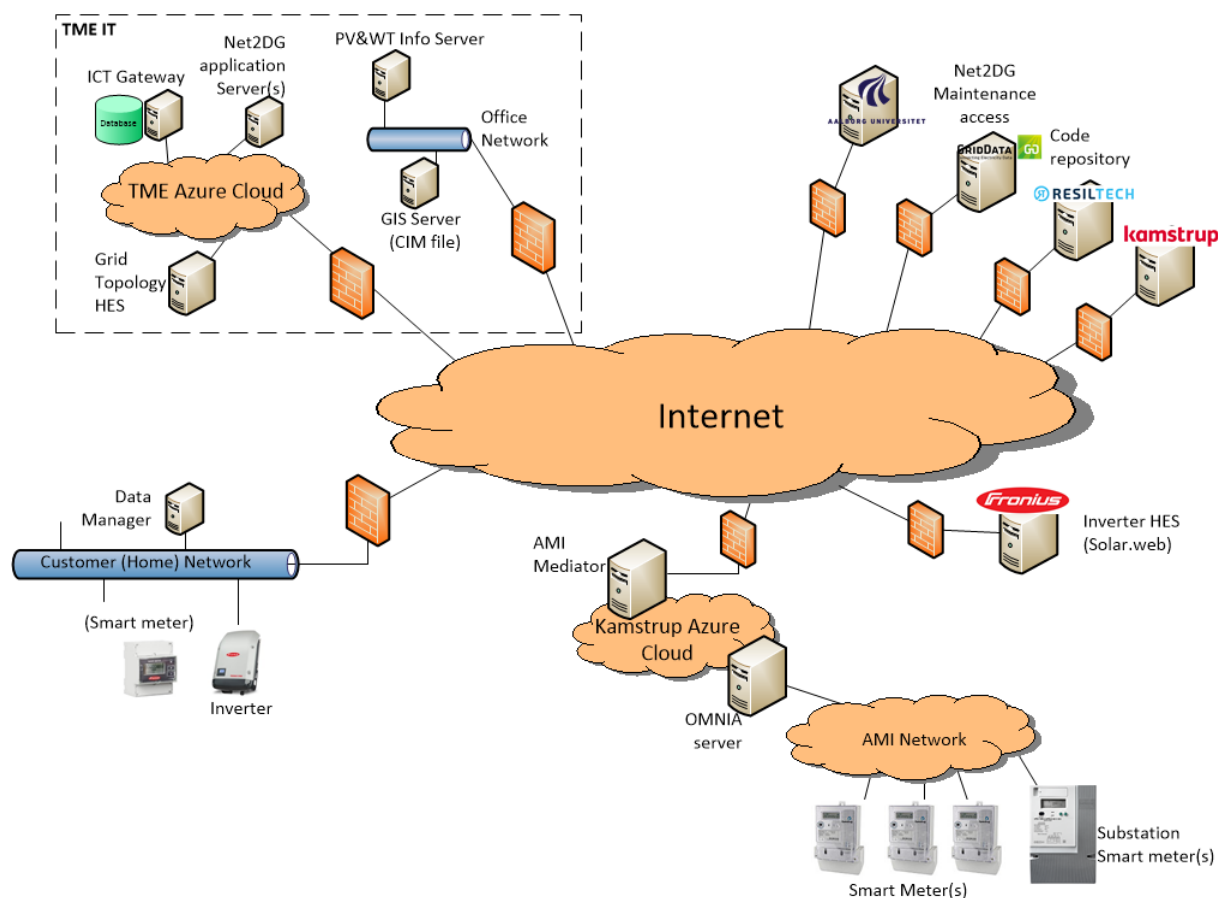


Figure 3: Deployment architecture of TME Field Trial.

The Head-End to the one PV in the field is implemented via the Fronius SolarWeb interface, shown to the right in Figure 3. This in turn, handles the interaction with the inverter deployed in the field. The interface used is detailed in [3] and ensures that data exchanges happen according to existing security standards.

Kamstrup AMI is accessed via a dedicated server located in a similar virtual Azure cloud environment, where a dedicated software, which acts as a Head-End system, called AMI Mediator, has been developed to interface to the data server (OMNIA server). The implementation of the AMI Mediator within the cloud environment was necessary to provide the required security standard mechanisms as required by Kamstrup and TME to allow access and protect production data that Kamstrup manages on behalf of TME.

The Topology HES is running on the Virtual Machine as mentioned before, and will come with grid topology related files (including mainly the CIM-XML based file related to the grid topology information of TME). Details have already been provided in [3] on how it works.

All subsystems are connected via the Internet and via VPN tunnels. Thus, relevant partners can connect remotely to the virtual machines to perform necessary operations for test runs, maintenance etc.

The deployment at TME is planned into several releases, and shortly those covers



- Release 1: Integrated solution that supports basic access to data, and support to GMON application.
- Release 2: Enriched data access including support for alarm and on-demand data access, and support for further applications: Odet, LC and alarm functionality in GMON.
- Release 3: Integration and test of OGM and support of reference tracking for inverter. Support of PM application and ODiag application.

Test specifications for some applications may have some reduced real world stimuli, e.g. fault scenarios may need some additional test support to validate the functionality in the deployment. These are at the stage of writing under discussion on how to approach.

2.2.3 StwLan field trial

The conceptual deployment architecture for StwLan Field trial is given in Figure 4.

The field trial at StwLan will demonstrate and assess the Net2DG observability applications using a local installation of the Net2DG components, i.e. ICT Gateway, Head-End Servers, and application servers, at the DSO site. In Release 1, this local installation is realized by a single dedicated host with multiple virtual machines. Figure 4 shows the corresponding deployment architecture: Electrical Measurement (EM) devices (from the company Janitza) have been deployed on the substation and on several junction boxes in the field trial region. These EM devices are connected through developed RTUs via a cellular network connection to the EM-HeadEnd Server that is operated at the StwLan IT network (upper left). In addition to these measurement devices, one Fronius inverter (lower left) has been connected to the SolarWeb portal (right side) and the data has been made accessible to Net2DG. The grid topology data is obtained via export from the existing GIS server shown on top in the middle. Further data on consumers and generators is obtained from the so-called office server; the latter data is jointly processed with the GIS server in the Grid Topology Headend.

Goal of the StwLan field trial is to demonstrate that the combination of inverter measurements together with measurements from Electrical Measurement devices can successfully be interpreted in the context of the automatically derived grid topology description and provide the grid observability targeted by the Net2DG applications. In Release 1, the focus was on enabling the data collection and data fusion and on running the observability application GMON in an offline manner on historic data.

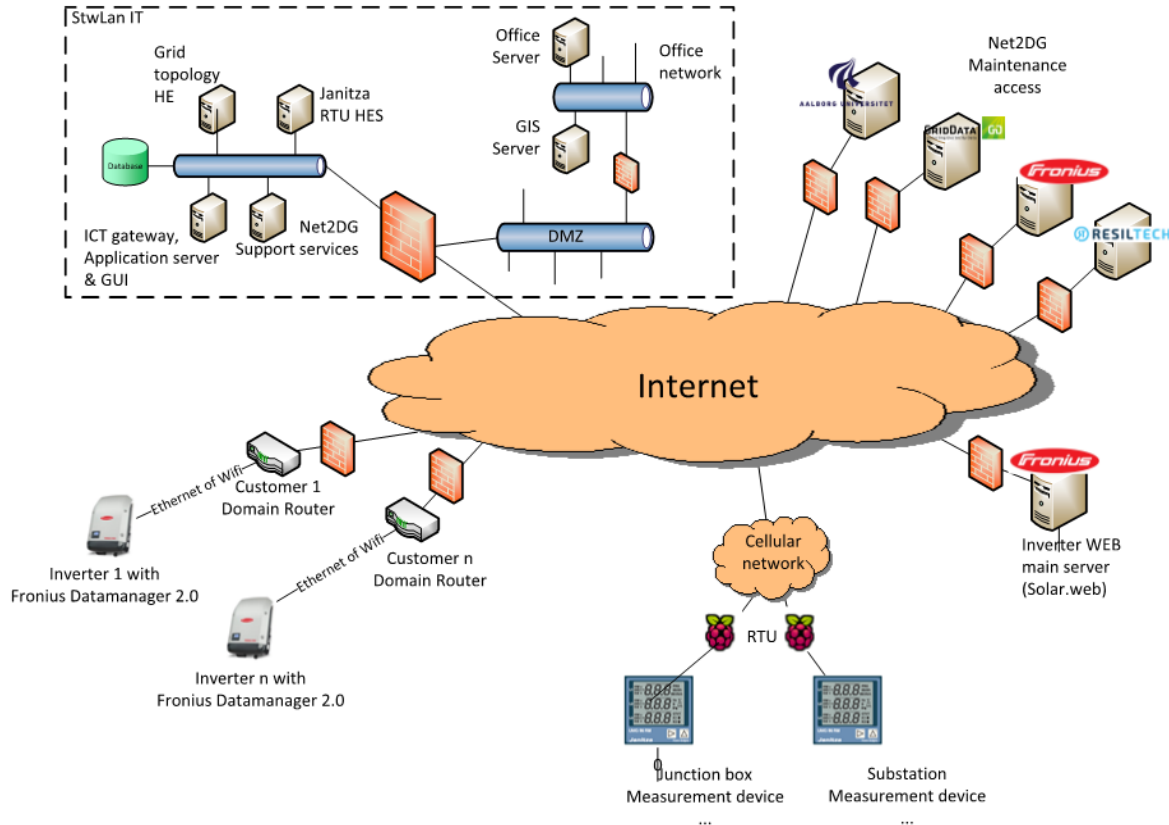


Figure 4. Deployment architecture of StwLan Field Trial.

2.3 Complementarity of Demonstrators

The demonstrators have different characteristics and targets as well. The Danish Field Test Site is characterized by an almost 100% deployment of smart meters while the Smart Meter deployment has been severely delayed in Germany. DSOs may also use other type of electrical measurement devices (EMs) for their purposes to substitute SMs, when they are not deployed in the grid, and to collect further electrical measurements even if SMs are deployed. Therefore, Net2DG solution is able to work with heterogeneous measurement devices to gather relevant information from the field. The field trials put emphasis on collecting and utilizing actual measurement data which is subject to all artefacts currently seen in field trials, such as: inaccurate and only partially available measurements, intermittent ICT connectivity to measurements, heterogeneous measurement subsystems and data formats. The benefit of the field trials is to obtain data and experiences from actual operational LV grids.

The RT-HIL laboratory offers a high degree of freedom in terms of voltage levels, topology, number of customers, penetration levels for PV installations, AMI and RTU deployment etc. Also, extreme scenarios can easily be implemented i.e. outages, failures of components, extreme over-/under-voltages, etc., which are not possible on the actual site tests.

Table 1 illustrates the main characteristics of the various field test sites as well as the lab, providing an overview of how the different test environments support and complement each other.

Table 1. Complementarity and synergies of demonstrators.

	TME Field Trial	StwLan Field Trial	RT-HIL Laboratory
Voltage Level	Low-Voltage (400 V Phase-to-Phase)	Low-Voltage (400V Phase-to-Phase)	Low-Voltage ¹ (400V Phase-to-Phase)
Topology	Radial	radial	Adaptable and configurable according to scope
Number of residential customers	84 households	73 households	Adaptable according to scope and scenarios
Other customer types	7 special customers: Carpenter, small industry, Supermarket, school, Kindergarden, agricultural (farm), pumping station	2 additional feeders at substation providing electricity to street lights	Adaptable according to scope and scenarios
Not Registered Customers			Configurable according to scenarios
Renewable generation	5 Solar PV systems: 4 residential and one 10kW system installed on school.	22 PV Systems	Configurable according to scenarios
AMI deployment	100% - Smart Meters at all customers	NONE – delayed in Germany, expected to start end of 2020	Configurable according to scenarios
EM deployment	Currently none – may be added if useful for selected junction boxes	1 at substation, about 10 at junction boxes (5 in Release 1 – single feeder)	Configurable according to scenarios
SolarWeb connectivity	1 unit (10 kW system)	1 unit in Release 1	Configurable according to scenarios
ICT Gateway deployment	in Azure Cloud	locally at StwLan Server	Flexible
Targeted Applications	Release 1: GMon Later also: LC, ODet, PM	Release 1: GMon Later also: LC, ODet, PM	Release 1: GMon and ODet Later also: LC, ODiag, AVR
Power outages	Not possible	Not possible	Configurable according to scenarios
Power/voltage quality issues	Currently expected to be within the limits	Currently expected to be within the limits	Configurable according to scenarios and test cases
ICT Outages	Can be emulated at the ICT GW	Can be emulated at the EM-Headend and at the ICT GW	Configurable according to scenarios and test cases

¹ Low Voltage with potential to be extended to Medium Voltage

3 Release 1 Laboratory Deployment

This chapter presents the deployment of Net2DG solutions for Release 1 in the laboratory framework which is based on a Real-Time Hardware-In-the-Loop structure. It enables verification and validation of the Net2DG architecture by using several platforms that hosts various components, e.g. LV distribution grid, data collection subsystems including Head-End (AMI, Inverter, EM) as well as the various Net2DG software components. Realistic data flows and exchange of signals between these components are also obtained as in real deployment. It also enables extreme operational scenarios and test cases that may not occur in the real systems or may endanger the daily operation of distribution grids e.g. faults, extreme voltages, etc. By using this Real-Time framework a high level of confidence regarding the developed Net2DG applications is obtained.

The Release 1 is focusing on the following targets:

- Demonstrate that the grid topology information can be automatically derived from the specific grid topology characterization utilized in lab
- Demonstrate the data flow from generic measurement devices to ICT-GW via adapters i.e. correct reception of periodic measurements, correct reception of over-voltage events at the ICT Gateway, correct reception of under-voltage events, correct provisioning of on-demand access to measurements.
- Demonstrate online execution of a simplified version of ODet
- Demonstrate offline execution of GMon

3.1 Main Working Assumptions

The main working assumptions for Release 1 are as:

- Virtual sub-systems are used for measurement units and data collection mechanisms, i.e. the commercial production systems will not be used as such in the RT-HIL implementation.
- There will be one instance of a virtual generic measurement subsystem connecting de measurements points in the electrical grid with the ICT GW. This VMS generic instance will run on the same host and use the same interface type to the ICT GW. Via configuration files, the individual measurement subsystem can behave slightly different in terms of types of events supported and in terms of averaging intervals for measurements.
- Within the virtual measurement subsystem all emulated measurement devices will behave the same with respect to support alarms, parameters used, etc. There is no per-virtual-device configuration.
- ICT Gateway and application are implemented together on a dedicated platform in the lab; the SW implementations will be provided by WP3 (ICTGW) and WP2 (ODet and GMon)
- The adapters in the ICT Gateway for applications are customized to accommodate the available RT-HIL infrastructure in the lab
- A simple grid topology is used (e.g. single feeder with a few branches below). The GTS will extract the grid topology information for the ICT GW from the OPAL-RT topology.
- UDP will be used to send measurements from RT-Grid Simulator to the Virtual Measurement Subsystem.

- TCP will be used for the connection between ICT GW and VMS in the testbed.
- In case of an ICT outage (which virtual measurement devices will notice by failures of the TCP connection to the ICT GW), measurement devices will continue to take measurements and buffer them locally and retry to open a new TCP connection in regular intervals
- Inverters and Smart Meters always represent different PoMs, even if they are co-located at the same customer

3.2 Deployment Architecture

The deployment architecture targeted for Release 1 is considering simplified versions for some subsystems while other components are removed. However, the Net2DG core functionalities and interactions related to data flows are still captured. The simplified deployment architecture for Release 1 is given below, modified from the full deployment earlier shown in Figure 2.

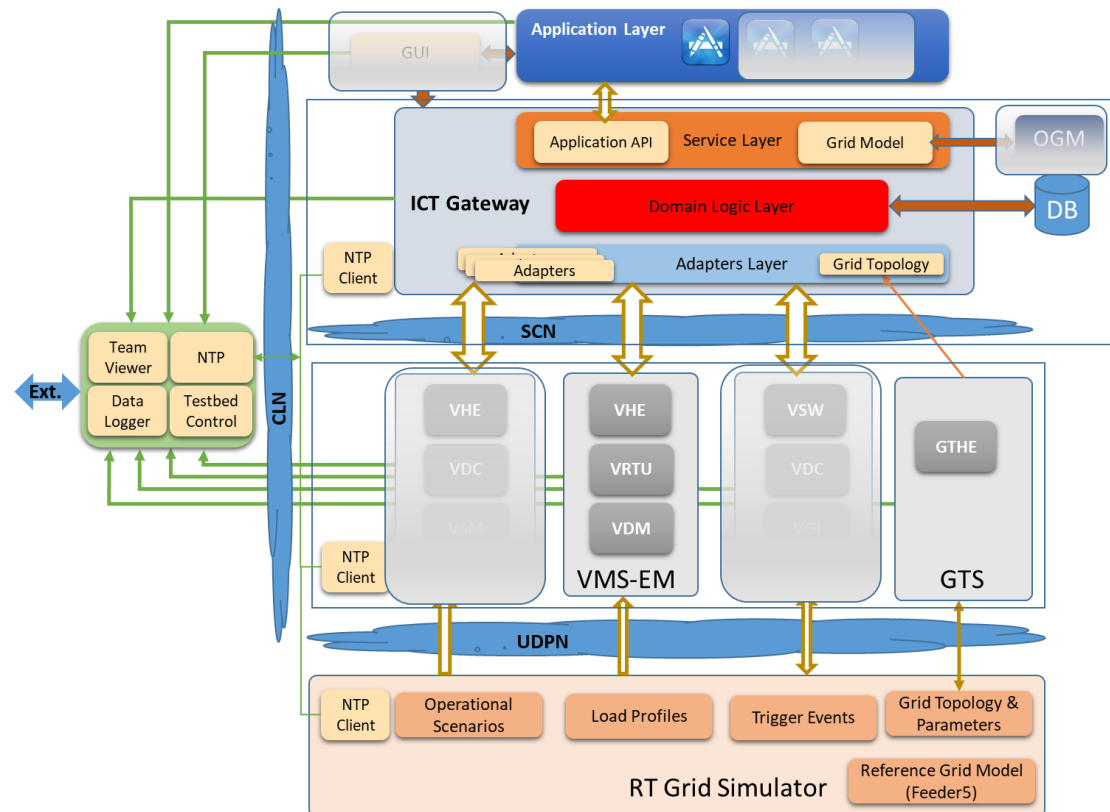


Figure 5. Laboratory Deployment Architecture considered for Release 1.

3.3 Component overview

3.3.1 RT-Grid Simulator

Model Block Diagram

Figure 6 represents the high level block diagram with the main components of the RT-HIL RGM. Each block will be discussed in the following sections of this document.

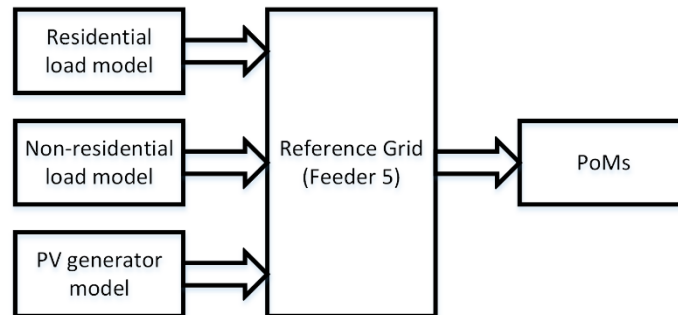


Figure 6: Block diagram of RT-HIL RGM

Topology

The Single Line Diagram of the modelled Low Voltage (LV) grid is shown in Figure 7.

The LV grid is connected to the Medium Voltage (MV) grid through a 10/0.4 kV power transformer and consists of radial feeder, named Feeder 5 in the following as available in TME's substation 3011 in the site test area, see also Section 3.1. The LV grid is composed of the following equipment: electrical nodes, connection boxes, cables of different types, distributed photovoltaic (PV) generators, two virtual breakers/switches and electrical loads, represented by residential and non-residential consumers.

Virtual breakers/switches

Two virtual breakers/switches, labelled SW1 and SW2 respectively, are added into the LV grid for outage injections as shown in Figure 4. The model is configured to handle one-, two- and three-phases outages in the selected locations according to operational scenarios and selected test cases.

PV generator model

The PV Model implemented in RT Grid Model is based on [7]-[9] and adapted to captures the performance of Fronius Inverters [10]. The Solar PV System (SPVS) used in the project is described by the block diagram shown in Figure 8.

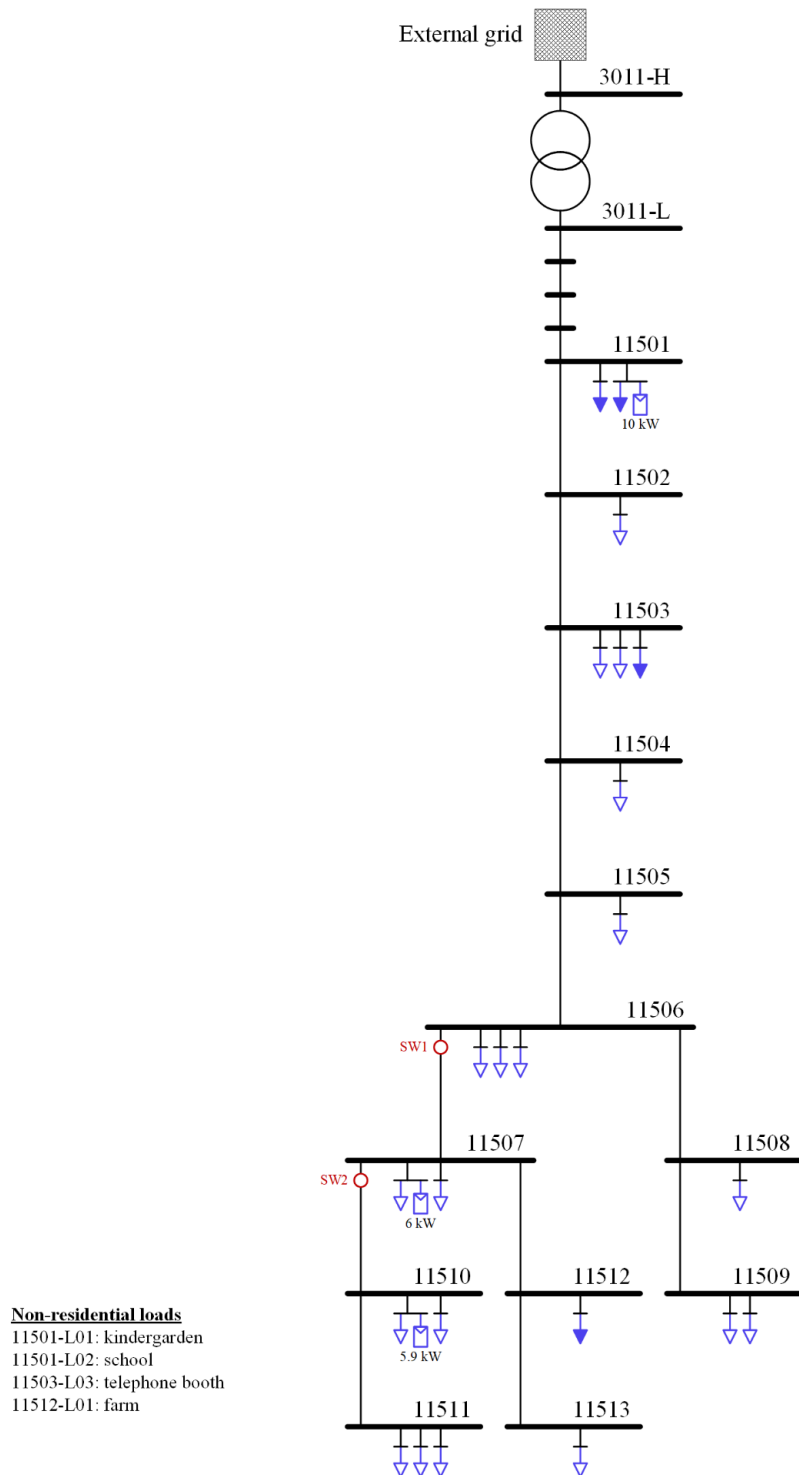


Figure 7: Single line diagram of Reference Grid Model (Feeder 5)

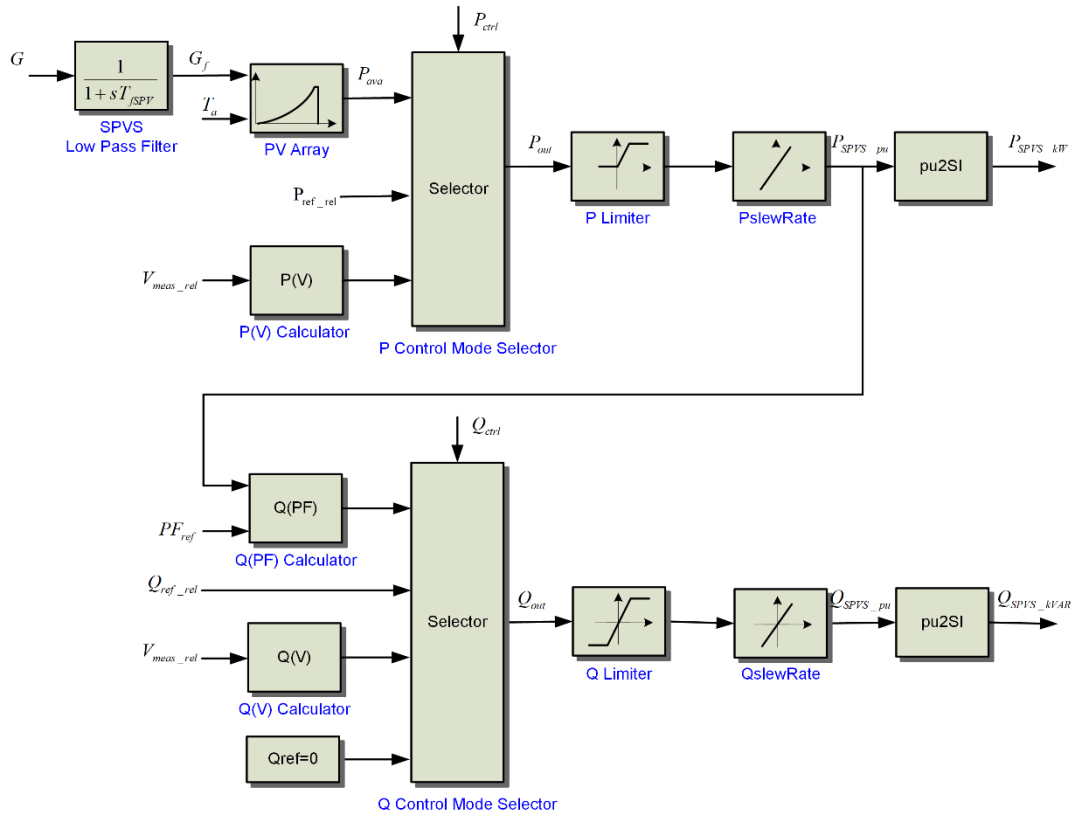


Figure 8: Block diagram of Solar PV system.

Residential load model

Figure 9 presents the principle diagram of the residential load model. The model uses the average aggregated three-phase load profile of a residential consumer measured with a 15-minutes sample. The aggregated average load profiles are provided by TME for every customer in the Area 2 for a period of one year i.e. 2018. The load profile is then multiplied with a series of random positive numbers, with the purpose to obtain a set of N load profiles that follow the initial load profile, but are not identical and whose value varies every 1 minute. The newly obtained load profiles are then randomly split per phases, thus obtaining in this way the three-phase load profiles used in the RT-HIL RGM. This random split per phases account for simultaneity factor in a given grid to avoid un-realistic overloading of different phases. The described procedure is applied for both active and reactive power.

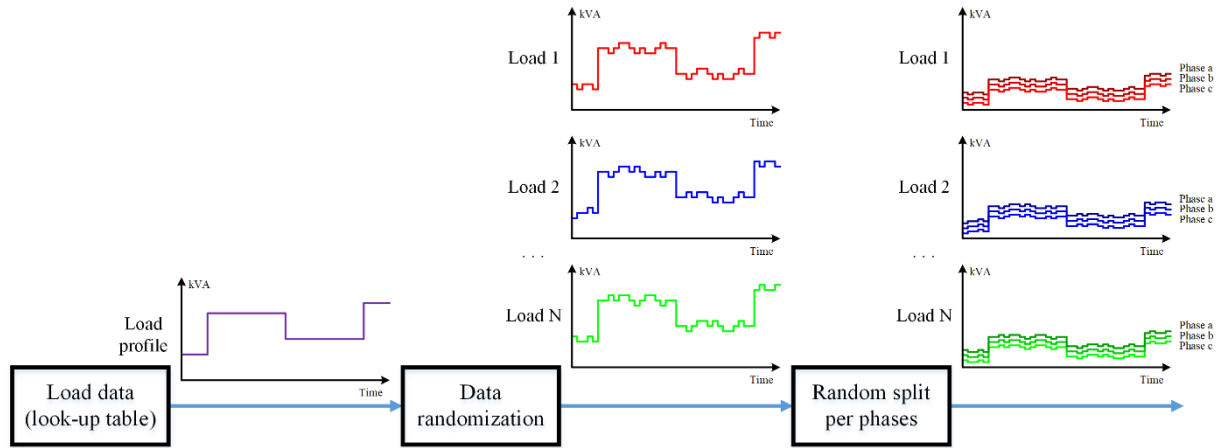


Figure 9: Residential load model

The average load data can use the standard customer profiles as defined by DSOs or individual historical profiles for each consumer if available.

Non-residential load model

Figure 10 presents the principle diagram of the non-residential load model. This model uses a dedicated load profile for each type of consumer in the RGM, e.g. kindergarden, school, telephone booth and farm, so it does not require data randomization. The load is symmetrically split on each of the three phases because the non-residential consumers are assumed three-phase loads. The described procedure is applied for both active and reactive power.

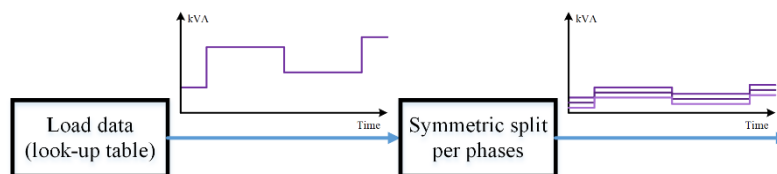


Figure 10: Non-residential load model

Points of Measurement (PoMs)

For each measurement point where a measurement device is connected e.g. a Smart Meter, voltage and current signals are collected in real time according to the specific format provided by ePhasor RT-Lab. The specification of these measurement signals is given in **Table 2**.

Table 2. Measurement Signals collected in each PoM.

Measurement Signal	Name	Measuring Point	Unit
Voltage Magnitude, phase A	VmagA	Node	V
Voltage Magnitude, phase B	VmagB	Node	V
Voltage Magnitude, phase C	VmagC	Node	V
Voltage Angle, phase A	VangA	Node	deg
Voltage Angle, phase B	VangB	Node	deg
Voltage Angle, phase C	VangC	Node	deg

Current Magnitude, phase A	ImagA	Line from CB to SM	A
Current Magnitude, phase B	ImagB	Line from CB to SM	A
Current Magnitude, phase C	ImagC	Line from CB to SM	A
Current Angle, phase A	langA	Line from CB to SM	deg
Current Angle, phase B	langB	Line from CB to SM	deg
Current Angle, phase C	langC	Line from CB to SM	deg

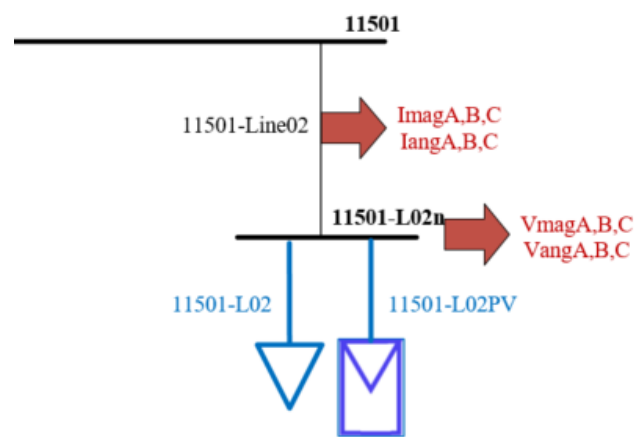


Figure 11. Definition of a PoM in Reference Grid Model.

3.3.2 Generic VMS-EM

Virtual Measurement Subsystems (VMS) are used in Net2DG to mimic the measurement behaviour and the data collection behaviour of different measurement subsystems, specifically of AMI subsystems, of Inverter subsystems, and of electrical measurement (EM) devices, such as Janitza, and their connection via headend servers. In Release 1, a generic VMS is used which does not target yet to reproduce the exact behaviour of a specific AMI or EM subsystem, but instead allows with configurable parameters to model different subsystem behaviour. Parameters include: aggregation of measurement samples over time (e.g. for 1min or 15min intervals), relative measurement error, behaviour of measurement devices in case of grid outages, delays of propagating measurement values from the measurement device to the headend. The concept is that a single entity of a VMS emulates a single subsystem in the real world.

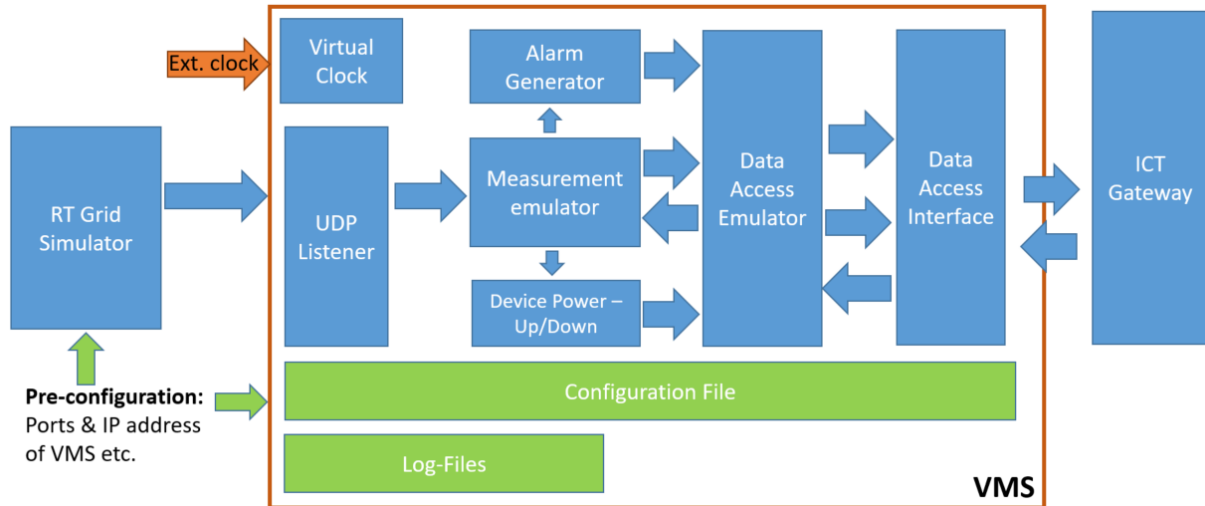


Figure 12: Internal structure of the VMS.

Three different types of interactions with the ICT Gateway are supported by the VMS:

- (1) Provisioning of periodic measurements (Push)
- (2) Provisioning of Alarms (Push)
- (3) On-demand access to recent measurements (Pull by ICT GW)

Figure 12 describes the system design of the Release 1 Virtual Measurement Subsystem (VMS). VMS consists of 8 main components:

- **UDP Listener:** receives real and imaginary three phase grid values for the voltage and current from the RT Grid Simulator and passes them to the Measurement Emulator. Different ports of the UDP stream are represent different devices in the grid.
- **Measurement Emulator:** adds normalized errors to the grid values, converts grid values to magnitude and phase angle, calculates active and reactive power and energy, and calculates averages over the configurable measurement intervals.
- **Device Power Up and Down:** determines the ability of a virtual measurement device to communicate using a 3-state model: 'Down', 'Up', 'boot'. State transitions are determined by voltage threshold crossings and by configurable time durations. **Alarm Generator:** Generates "undervoltage" and "overvoltage" alarms, depending on the voltage at the PoM using a configurable threshold.
- **Data Access Emulator:** used to emulate delays and message losses in the device-to-headend communication or in the headend processing.
- **Data Access interface:** enables the real time, bidirectional communication with ICT-Gateway
- **Configuration Loader:** loads the configurable parameters during software run-time
- **Logger:** displays and saves software logs in a file
- **Virtual Clock:** This block ensures that an internal clock is available. The rationale behind this functionality is that there is a later potential need to asses clock synchronization, so time stamps may need to artificially and in a controlled manner to be manipulated without inflicting real time clock or any potential sampled simulation clock.

3.3.3 GTS

The grid topology subsystem (GTS) obtains the grid topology information from the corresponding files of the real-time simulator and makes it available to the ICT Gateway. Figure 13 illustrates the conceptual construction of the Topology HES.

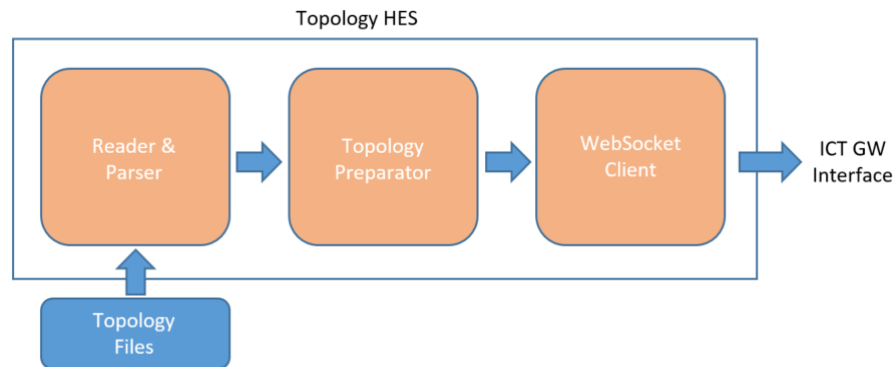


Figure 13: Topology HES underlying functionalities

This component exists in two versions, one for the lab and one for the field test deployment, and the main difference is that the topology related files are different for the two cases. In lab, a CSV file (a multi sheet Excel document based on the specific file used in RT Grid Simulator) with grid topology information with additional files need to be processed (for field test, see Section 3.4). The main CSV based topology file first needs to be parsed together with other related files, and then passed onto the Topology Preparator that prepares JSON messages in order to comply with the data model in the ICT GW.

3.3.4 ICT-Gateway

ICT-Gateway includes Web Socket adapter server to establish a bi-directional communication with the VMS and Topology Head-End as shown in Figure 14. On receiving the data from the VMS and the Topology Head-End it persists it in the database.

The REST API enables applications to get the relevant measurement, topology and event data for calculations. Publish-Subscribe pattern enables applications to get notified of the incoming data and events. It provides on-demand access to the VMS for retrieving last measurement from the buffer and publishing data to needed applications.

The database connection and Grid Topology Mapping have to be configured in the configuration files for the lab testing. Grid Topology Mapping uses port numbers from the Grid Simulator as device ids.

3.3.5 Application Layer

The Release 1 lab trial is targeting two applications: GMon and ODet. These applications in Release 1 are shortly summarized in the following.

Grid Monitoring (GMon)

The Release 1 GMon application is executed by the DSO, who specifies a LV grid area and a time interval $[t1, t2]$ in the past and then uses measured average voltage values in order to provide the following output:

- Time Series of (e.g., 15min, depends on subsystem config.) average voltages at all grid nodes in the selected LV grid area over the full time interval
- List of grid nodes, which have been exceeding configurable limits of 15min average voltages
 - frequency of over- and under-voltages at these nodes in the selected time period
- 5% and 95% quantiles of 15min average values over a 1-week time-window and evolution of these quantiles over time.

In Release 1, the above outputs are written back to files, so that the visualization can be done subsequently.

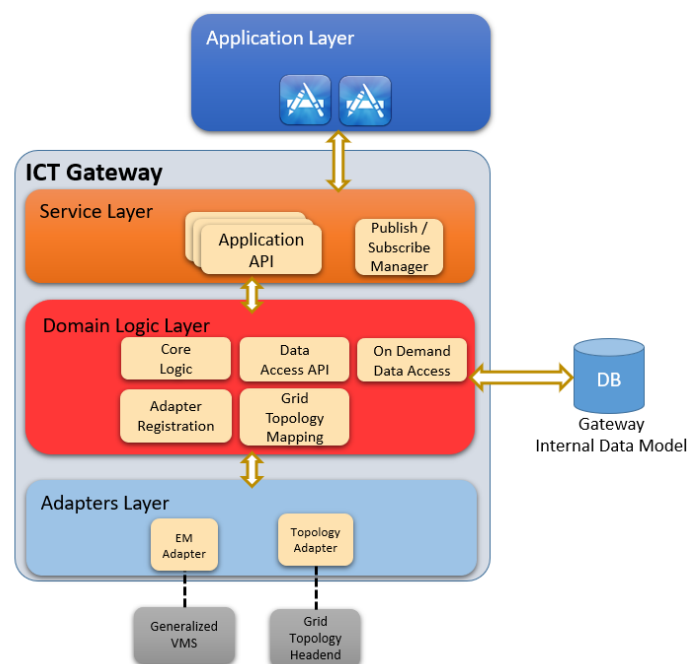


Figure 14. Overview of ICT-GW laboratory deployment in Release 1.

Outage Detection (ODet)

In Release 1, the ODet implementation deployed in the lab is triggered by an unde-voltage event from any measurement device. The lab implementation uses a simplified version of ODet in Release 1 for testing purposes of the integrated system behaviour. The simplified ODet application provides the following as output written into a file for later visualization:

- List of all under-voltage events observed in the LV grid area prior to the trigger event (during a configurable time period)
- Outcome of an on-demand access to voltage values from ALL grid nodes in the LV grid area.

Note that the full ODet application applies more intelligence on the retrieved events and measurements (see D2.1). This however is omitted for the Release 1 lab deployment, as the main purpose is to test the end-to-end data flows and the behaviour of the integrated system from real-time grid simulator up to ICT Gateway.

3.4 Physical Realization

3.4.1 Laboratory Implementation

An overview of the RT-HIL deployment is given in **Figure 15**.

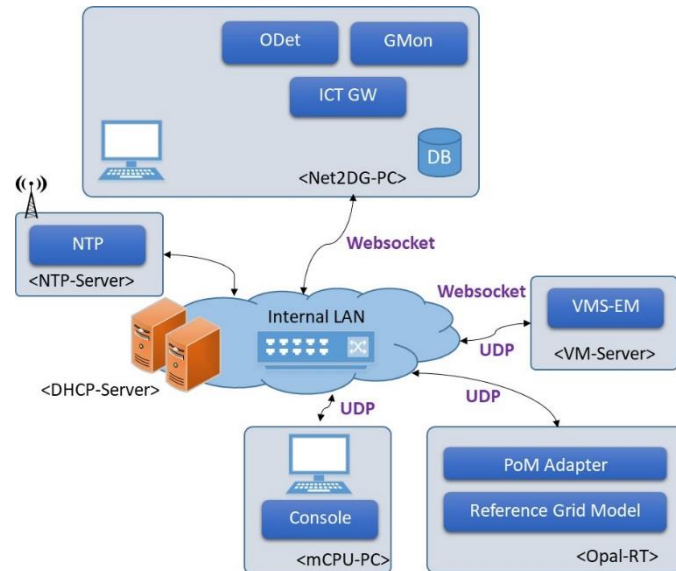


Figure 15. Overview of RT-HIL deployment in laboratory infrastructure.

At the heart of the test bed there is an Ethernet switch which ensure connection between all the related entities. This has been configured to provide the necessary network setup as shown previously via VLANs, and enables the various component access to each other. The most important part of the setup are:

1. The OPAL which is the digital simulator unit that is responsible for executing the grid model and generate data in real time.
2. The VM-Server which is hosting the VMS-EM and later on all other VMS components.
3. The Net2DG-PC which is the host of the ICT-Gateway and the applications running on top and finally.
4. The NTP server which acts as the nearest stratum clock synchronization for all other devices in the lab. This server is running on a Raspberry Pi which has a GPS synchronised clock.

Remark that the names of the various servers is related to that the lab is also used for other purposes as well, and for internal naming conventions, these are the labels given a priori without further explanation.

3.4.2 Data Exchange and Interfaces

UDP Packet Format

Each PoM in Reference Grid Model will generate a UDP packet as defined in Table 3.

Table 3 UDP Packet format per PoM/SM

Byte offset	0	8	16	24	32	40	48	56	64	72	80	88	96
Content	UDP header	ReVa	ImVa	ReVb	ImVb	ReVc	ImVc	Rela	ImIa	Relb	ImIb	Relc	ImIc



Thus, each PoM creates 104 bytes of IP packet payload. Additionally, IP header yields 20 bytes (minimum) and Ethernet further 18 bytes, so in total at least 142 bytes per measurements. Each PoM creates such a packet per second, meaning that the traffic load becomes 142 Bytes/sec/PoM. For most cases there are maximum a couple of hundreds measurement points, meaning that traffic load of the UDP streams should be in order of magnitudes 14.2kB/s – 28.4 kb/s (100-200 PoM's), which for the test bed with a GB/s interface is not an issue in terms of added latency caused by network traffic.

UDP Port Assignment

Table 4. Example of UDP Port Assignment

			Opal-RT		VM-Server	MVGC-PC
			PoM Adapter		VMS-EM	ICT-GW
			IP xx		IP yy	IP zz
Feeder ID	PoM ID	PoM SLD Name	Controller No.	Port	Port	Port
5	xx	11501-L01	35660	35661	35661	35661

3.5 Integration test cases and preliminary results

The following integration tests have been performed on the Release 1 lab deployment:

Table 5. Laboratory Test cases in Release 1

Test ID	Target of test	Means of verification	Result achieved
1	Correct obtainment of grid topology information at the ICT GW	Grid topology information obtained at the DB is verified by comparing it to the grid topology figure (verified and validated by TME)	Test successfully executed Correct persistence of grid topology information in DB
2	Correct reception of periodic measurements at ICT GW	Running OPAL-RT with constant consumption. Inspection of log files at VMS and log files at Gateway; inspection of Database at Gateway and check whether voltage values and energy values map to the output of OPAL-RT	Fully successful execution
3	Correct mapping of measurements to grid topology at the ICT GW	Three measurement points are randomly selected and verification of the correct mapping of measurement points to grid node IDs and cable IDs for the selected customers	Grid Topology Mapping (GTM) component successfully integrated with LAB based Grid Topology Headend
4	Correct reception of over-voltage events at the ICT Gateway	Running OPAL-RT with constant 'normal' values; changing these values to low consumption and extremely high generation until voltages exceed the configured thresholds for over-voltage events. Check that over-voltage events are generated by the VMS and propagated and stored correctly in the ICT GW.	Successful generation of over-voltage events verified at the VMS and for reception at the ICT Gateway Correct storing of over-voltage events at the ICT Gateway verified
5	Correct reception of under-voltage events at the ICT Gateway	Running OPAL-RT with constant 'normal' values; opening a breaker of one of the cables in order to create a voltage drop to close to 0 on the feeder for nodes after the breaker. Check the creation of under-voltage events for different configs of the device-power-up-and-down component of the VMS.	Successful suppression of undervoltage events by the device power-up-and-down VMS component verified Successful generation of under-voltage events and correct forwarding and storing in the ICT GW verified
6	Correct provisioning of on-demand access to measurements.	Running OPAL-RT with constant 'normal' values; executing an on-demand measurement via a websocket API of the ICT Gateway. Verification of the provided result with the value that is shown by OPAL-RT.	successfully executed
8	Online execution of a simplified version of ODet	See Section 2.6.1	Successfully executed
7	Offline Execution of GMon	See Section 2.6.2	Successfully executed

The following subsections provide MySQL Workbench screenshots from the database associated with the ICT Gateway for relevant voltage, current and events data after some of the test executions.

3.5.1 Voltage Measurements

In **Figure 16** a query request to the database for the voltage measurements is presented. Normalized voltage error was set to 0.1% and RT grid simulator provided measurements to the VMS when running variable load profiles. Grid Topology Mapping component adds grid node ID to the measurement received by the ICT-Gateway, see third column. Voltages are confirmed to be correct by manual inspection against the output from RT grid simulator.

```

1  -- voltage
2  • SELECT m.intervalStart, m.intervallend, m.gridElement_id_node_id, m.device_Id, v.* , ge.internal_id, ge.type
3  FROM measurement m
4  JOIN voltage v ON m.measurement_Id = v.measurement_Id
5  JOIN gridElement ge ON ge.id = m.gridElement_id_node_id
6  ORDER BY m.intervalStart DESC;

```

intervalStart	intervallend	gridElement_id_node_id	device_Id	internal_id	average	max	min	phase	unit	measurement_id	internal_id	type
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	211	35681	7399	228.903	232.037	225.467	11	V	1234	11502-L01	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	204	35841	7330	220.678	226.397	218.19	11	V	1222	11512-L01	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	172	35731	7407	223.866	227.475	221.224	13	V	1235	11505-L01	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	251	35801	7338	221.678	223.082	217.088	13	V	1223	11510-L02	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	233	35771	7452	221.748	222.28	222.048	13	V	1242	11507-L01	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	175	35851	7383	220.494	225.299	217.214	13	V	1231	11513-L01	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	249	35861	7391	223.659	226.319	224.831	12	V	1232	11508-L01	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	230	35821	7322	222.798	225.55	220.662	12	V	1221	11511-L02	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	234	35781	7361	222.891	224.526	219.575	12	V	1227	11507-L02	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	193	35661	7438	229.079	232.747	225.356	11	V	1240	11501-L01	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	192	35671	7369	229.523	232.867	224.693	11	V	1229	11501-L02	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	250	35791	7446	221.582	223.23	221.494	13	V	1241	11510-L01	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	243	35711	7377	226.853	227.665	225.543	13	V	1230	11503-L03	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	231	35831	7414	221.347	225.794	218.781	11	V	1236	11511-L03	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	242	35691	7345	227.185	229.41	225.545	11	V	1225	11503-L01	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	258	35721	7422	225.07	227.001	222.832	13	V	1237	11504-L01	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	199	35741	7353	222.54	225.721	220.786	13	V	1226	11506-L01	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	174	35881	7430	223.374	225.92	219.351	12	V	1239	11509-L02	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	211	35681	7400	229.286	229.511	224.95	12	V	1234	11502-L01	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	204	35841	7331	222.526	226.106	222.529	12	V	1222	11512-L01	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	172	35731	7408	223.714	229.198	221.793	11	V	1235	11505-L01	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	197	35751	7339	221.564	226.352	218.807	11	V	1224	11506-L02	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	175	35851	7384	220.677	221.332	220.119	11	V	1231	11513-L01	Consumer

Figure 16. Result of SQL command to query relevant voltage data.

3.5.2 Current Measurements

In **Figure 17** a query request to the database for the current measurements is presented. Normalized current error was set to 1% and RT grid simulator provided measurements to the VMS when running variable load profiles. Grid Topology Mapping component adds grid node ID to the measurement received by the ICT-Gateway. Currents are confirmed to be correct by manual inspection against the output from RT grid simulator.

```

8 -- current
9 SELECT m.intervalStart, m.intervallend, m.gridElement_id_node_id, m.device_id, c.*, ge.internal_id, ge.type
10 FROM measurement m
11 JOIN current c ON m.measurement_id = c.measurement_id
12 JOIN gridElement ge ON ge.id = m.gridElement_id_node_id
13 ORDER BY m.intervalStart DESC;

```

intervalStart	intervallend	gridElement_id_node_id	device_id	internal_id	average	max	min	phase	unit	measurement_id	internal_id	type
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	234	35781	7360	1.1867	1.19226	1.18673	I1	A	1227	11507-0.02	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	193	35661	7437	1.14308	1.15543	1.10129	I3	A	1240	11501-0.01	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	232	35811	7368	1.18358	1.21367	1.18226	I3	A	1228	11511-0.01	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	250	35791	7445	1.16647	1.17415	1.1494	I2	A	1241	11510-0.01	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	243	35711	7376	1.14106	1.1564	1.13368	I2	A	1230	11503-0.03	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	231	35831	7413	1.1847	1.19481	1.18116	I3	A	1236	11511-0.03	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	258	35721	7421	1.14925	1.14736	1.1383	I2	A	1237	11504-0.01	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	199	35741	7352	1.16093	1.16747	1.1528	I2	A	1226	11506-0.01	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	174	35881	7429	1.181	1.20672	1.17372	I1	A	1239	11509-0.02	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	211	35681	7399	1.14599	1.15005	1.1319	I1	A	1234	11502-0.01	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	204	35841	7330	1.18373	1.19088	1.182	I1	A	1222	11512-0.01	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	172	35731	7407	1.17148	1.18856	1.16119	I3	A	1235	11505-0.01	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	251	35801	7338	1.18241	1.17451	1.16906	I3	A	1223	11510-0.02	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	233	35771	7452	1.18071	1.18616	1.16651	I3	A	1242	11507-0.01	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	175	35851	7383	1.1816	1.20263	1.1643	I3	A	1231	11513-0.01	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	249	35861	7391	1.16115	1.15923	1.15897	I2	A	1232	11508-0.01	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	230	35821	7322	1.16664	1.18037	1.16298	I2	A	1221	11511-0.02	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	234	35781	7361	1.1649	1.17161	1.1475	I2	A	1227	11507-0.02	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	193	35661	7438	1.1415	1.15712	1.13416	I1	A	1240	11501-0.01	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	192	35671	7369	1.1454	1.17553	1.13805	I1	A	1229	11501-0.02	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	250	35791	7446	1.18531	1.21233	1.18002	I3	A	1241	11510-0.01	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	243	35711	7377	1.15053	1.1616	1.13039	I3	A	1230	11503-0.03	Consumer
2019-12-10T15:35:45+0200	2019-12-10T15:36:15+0200	231	35831	7414	1.18781	1.20782	1.16433	I1	A	1236	11511-0.03	Consumer

Figure 17. Result of SQL command to query relevant Current data.

3.5.3 Events

By reducing the voltage at substation level in the RT grid simulator, undervoltage events were created at multiple nodes in the grid. By inspection of the voltages obtained from the RT grid simulator, it is confirmed that the VMS generates the correct under-voltage events, that occurred at the specific time and on a specific phase. In Figure 18, the SQL query shows a selection of under-voltage events, starting from the bottom of the figure (oldest timestamps). Five minutes later, the real-time grid simulator was configured to create an overvoltage situation by high PV generation on one phase; the first row of Figure 18 demonstrates that this over-voltage correctly leads to an over-voltage event created by the VMS, which is correctly stored at the ICT GW's DB.

```

31 -- event
32 SELECT * FROM event e
33 JOIN error er ON er.error_id = e.error_id
34 ORDER BY event_id DESC;
35

```

event_id	device_id	headend_id	source	timestamp	type	error_id	gridElement_id_cable_id	gridElement_id_node_id	error_id	name	value
1883	35751	Janitza_HE	Janitza	2019-12-10T15:46:15+0100	EVENT_ALARM	1883	197	1883	1883	OVERVOLTAGE	Voltage in phase 1 over threshold:250
1882	35791	Janitza_HE	Janitza	2019-12-10T15:41:15+0100	EVENT_ALARM	1882	250	1882	1882	UNDERVOLTAGE	Voltage in phase 2 under threshold:210
1881	35851	Janitza_HE	Janitza	2019-12-10T15:41:15+0100	EVENT_ALARM	1881	175	1881	1881	UNDERVOLTAGE	Voltage in phase 2 under threshold:210
1880	35781	Janitza_HE	Janitza	2019-12-10T15:41:15+0100	EVENT_ALARM	1880	234	1880	1880	UNDERVOLTAGE	Voltage in phase 2 under threshold:210
1879	35871	Janitza_HE	Janitza	2019-12-10T15:41:15+0100	EVENT_ALARM	1879	173	1879	1879	UNDERVOLTAGE	Voltage in phase 2 under threshold:210
1878	35841	Janitza_HE	Janitza	2019-12-10T15:41:15+0100	EVENT_ALARM	1878	204	1878	1878	UNDERVOLTAGE	Voltage in phase 2 under threshold:210
1877	35861	Janitza_HE	Janitza	2019-12-10T15:40:45+0100	EVENT_ALARM	1877	249	1877	1877	UNDERVOLTAGE	Voltage in phase 2 under threshold:210
1876	35761	Janitza_HE	Janitza	2019-12-10T15:40:45+0100	EVENT_ALARM	1876	198	1876	1876	UNDERVOLTAGE	Voltage in phase 2 under threshold:210

Figure 18 Results of SQL command to query relevant events data.



3.6 Preliminary application results

3.6.1 ODet results

In the lab, a simplified ODet version was run to trigger on-demand access to the device that provided the event, see Section 2.3.4.2 for a detailed description. Purpose of these experiments is to show that the essential features for ODet, event handling and on-demand data access are correctly executed in the integrated chain up until and including the simplified ODet application.

The RT grid simulator is configured to run a normal scenario and then one of the breakers in the grid model is opened. This causes a voltage drop to close to zero at all customers behind the breaker. The virtual measurement devices at all nodes in the grid are configured in this experiment in a way, that they do report measurements via the VMS despite lack of power supply. This implies that the thresholds in the device-power-up-and-down component in the VMS are set in a way that the measurement device is still communicating despite voltage at the supply being zero – so essentially mimicking a measurement device that has a battery to operate during such scenarios. Therefore, all measurement devices behind the opened breaker report a voltage drop and the first of these events triggers the start of the simplified outage detection application. See the previous subsection for more details on validation of event handling.

The simplified ODet application in this lab experiment then performs on-demand access to voltage values for all measurement points behind the substation, in which grid area the under-voltage event was occurring. The response to one of these data accesses is shown in **Figure 19**. In this figure, the JSON message content as provided by the VMS to the ICT Gateway is shown. Only voltages and currents contain meaningful numbers, active and reactive energy should be ignored in this measurement (these fields are there for future extensions). The specific example shows a response from a grid node that was not affected by the outage, since the voltages are in the normal range (though there is a noticeable unbalance between phases; however, that one is here not related to the outage).

```

{
  "headendId": "Janitza_HE",
  "rtuId": "35871",
  "timestampCreated": "2019-12-10T15:41:15+0200",
  "payload": [
    {
      "unit": "V",
      "11": 219.3339775701918,
      "12": 246.35401491686304,
      "13": 222.59229262209314,
      "measurementType": "MEASUREMENT_VOLTAGE"
    },
    {
      "unit": "A",
      "11": 1.0857272405814806,
      "12": 0.5508481196227776,
      "13": 1.114590693122255,
      "measurementType": "MEASUREMENT_CURRENT"
    },
    {
      "unit": "Wh",
      "11": 0,
      "12": 0,
      "13": 0,
      "measurementType": "MEASUREMENT_ACTIVEENERGY"
    },
    {
      "unit": "varh",
      "11": 0,
      "12": 0,
      "13": 0,
      "measurementType": "MEASUREMENT_REACTIVEENERGY"
    }
  ],
  "category": "DATA",
  "type": "ON_DEMAND_DATA",
  "timestampReceived": "2019-12-10T15:41:15+0200"
}

```

Figure 19. Example of on-demand data provided by VMS to ICT-Gateway - triggered by ODet receiving an event.

3.6.2 GMon Results

In this scenario, data is collected via the VMS by setting the OPAL-RT to provide variable loads for 8 hours and 42 minutes. The measurement interval of the VMS was configured to be 30seconds, in order to generate a larger set of values.

GMon was executed on top of the ICT-Gateway with a set of data from the lab tests in off-line mode, i.e. the voltage data was first collected in the DB of the ICT Gateway and subsequently GMon was executed on top of the ICT GW, accessing the stored historic data via the GW API. Since Release 1 GMon is working with single phase representations of the grid, the API in the ICT Gateway is lumping the 3-phase values and the resulting voltages are in the range of 400V. The nominal voltage in the

GMon configuration file for the low voltage grid is therefore set to 400V. Lower voltage limit is configured to 0.9p.u. and the upper voltage limit to 1.1p.u..

The GMon application for these lab experiments generates multiple CSV files to store its computed output. Output values are average voltages over time, number of voltage threshold violations, lower and upper quantiles of the average voltages, here configured to be 10% and 90% quantiles.

Figure 16 is a plot of part of the output of the GMon application: The blue curve shows the average voltages for one specific measurement point over the measurement intervals. One can see from this curve, that voltages are only deviating in the range of approximately 398V to 404V, so no strong voltage variations are observed. For the latter reason, also no voltage threshold violations are reported in this scenario, so no plot is provided for that GMon output here.

The figure in addition shows the behaviour of the 10% (orange) and 90% (red) quantile of the average voltages. The voltage quality standards normally require to calculate these quantiles of periods of one week. Due to the shorter duration of the lab experiment that created the input to the GMon application, here the quantiles are calculated over a sliding window of data, starting from the interval marked in the x-axis and covering the full remaining data. For this reason, the two quantiles also converge towards the actual average value from the blue curve on the right side of the curve, as there is only a single interval left, over which the quantiles are computed at that point.

The shown results therefore demonstrate that GMon can be executed on top of the data collected by the ICT GW and it outputs correct results that passed validity checks, such as the convergence behaviour mentioned above.

A more detailed study of GMon output for realistic grid scenarios is planned for next year.

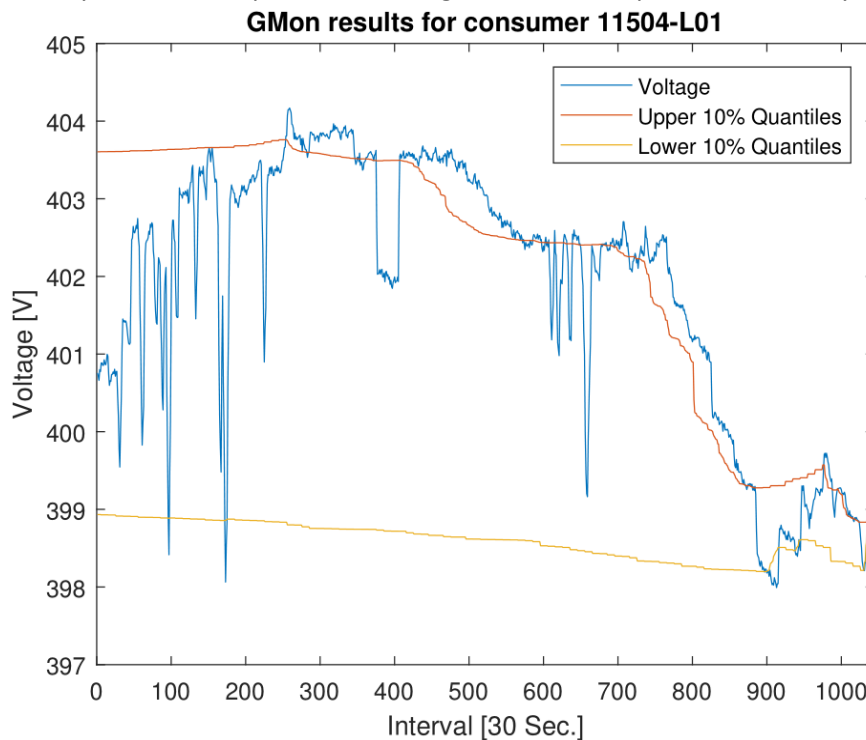


Figure 20: GMon results for consumer 11504.



3.7 Candidate tasks and features for next release

The Release 2 (M30) for lab deployment will include:

- Extension of Feeder 5 with short circuit modelling (in order to support subsequent ODiag application tests)
- Implementation of all feeders of the TME field trial region in Opal-RT
- Extension of the VMS-EM to physically represent different measurement device types and to support future application needs (with particular focus on ODiag and AVR), including:
 - include on-demand access for one second measurement values that are used by ODiag
 - Implementation, Integration and Testing of VMS-AMI on VM-Server
 - Implementation, Integration and Testing of VMS-INV with support for AVR app
- Extension of ICT-GW with API for AVR support and inverter adapter extensions
- Integration and detailed assessment of the Net2DG solution including the observability grid model.

Subsequently, the work in 2020 will cover the integration and detailed assessment of the Net2DG applications, with particular focus on ODet, ODiag and AVR

4 Release 1 Thy-Mors Energy Field Trial

The Release 1 field trial at the Danish DSO TME is focusing on the following targets:

- Demonstrate the feasibility of the integrated Net2DG solution tailored for the TME field trial setup, meaning that
 - ICT-Gateway shall successfully run on TME Azure cloud
 - ICT-Gateway has access to the specific data sources and data subsystems that are deployed in the Danish field trial
- Demonstrate the accessibility of measurement data from smart meters and inverters in the field area
- Demonstrate that the grid topology information can be automatically derived from file exports from the GIS system and from other customer information databases of the DSO

4.1 Grid scenario

The view on the low-voltage field trial area from TME is shown in **Figure 21**.



Figure 21. TME field trial region for Release 1 is the LV grid area behind substation 3011.

A single secondary substation called 3011 (shown as red triangle) is considered, which has 5 feeders supplying 91 customers and a good mix of various customer types: house holds, a school, a farm, a kinder garden, a brewery, a youth club, a carpenter and a pumping station. All these grid points have to be mapped internally in the ICT-Gateway such that measurements can be positioned to a grid element. In Release 1, this mapping has been created and validated manually, which for the full feeder and beyond is too cumbersome, and therefore focus on the mapping has been on Feeder 5 to follow

the progression in the lab. In addition, one Fronius inverter has been connected to the deployed Net2DG solution.

4.2 Deployment architecture

For the TME setup in Release 1, **Figure 22** shows the deployed component from WP3. These components cover the targets set for Release 1 of the system deployment.

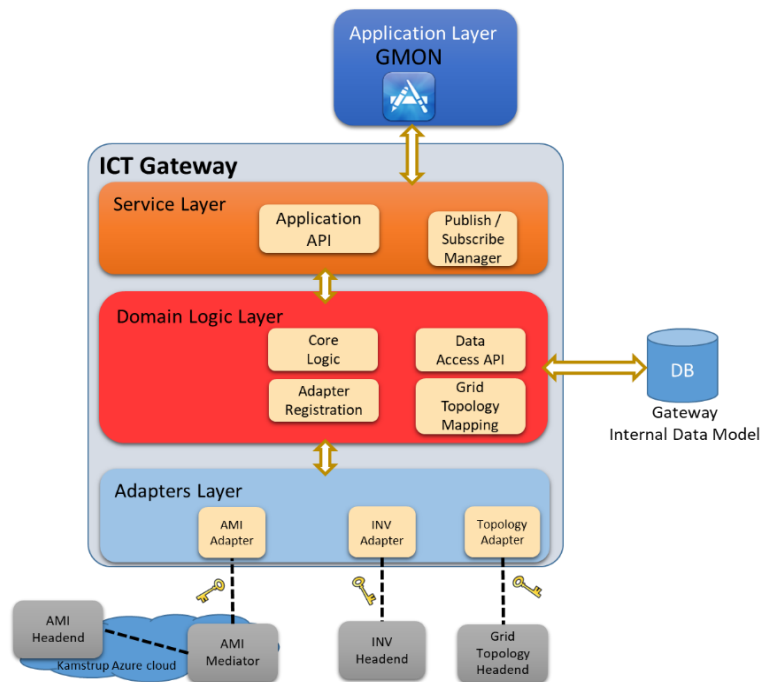


Figure 22. Deployment architecture of TME Release 1 Field Trial.

The deployment environment for applications, ICT Gateway, and Grid Topology Head-End is a Virtual Machine running on an Azure cloud (TME Azure cloud, not shown in **Figure 22** as it hosts nearly all components shown in the figure). This deployment allows flexible scaling of storage and computational resources as needed, but as a starting point these are set to equal a standard server configuration. Details of the conceptual architecture are found in [3], whereas the following subsection provides details of the necessary adapters that allows the system to run in the specific environment and with the specific data interfaces.

4.3 Component overview and interfaces

In the TME field trial, the ICT-Gateway was interacting with the following subsystems via the respective adapters in order to collect, process and publish the obtained data:

- Grid Topology Head-End that is processing grid topology related files generated by TME. These files include:
 - CIM-XML based grid topology information file
 - JSON file containing information about consumers and generators in the field trial area
 - JSON file containing information about last-hop cables (i.e. from Customer Connection Box to Consumer)

- SolarWeb subsystem from where it obtained data from the installed Fronius inverter and
- AMI subsystem to access smart meter data from two test meters.

4.4 Grid topology Head-End

As discussed in Section 2.3.3, the grid topology Head-End is a separate process that communicates with the ICT GW (via Grid topology adapter) utilizing a WebSocket connection with a proprietary communication protocol on top. It is responsible for a) reading and parsing a grid topology related files, b) processes those files using a set of recursive algorithms, and c) builds different entities out of those files to comply with the data model and finally transfers them to ICT GW.

TME grid topology mainly comprises of a large CIM-XML based grid topology file (order of 500MB). This CIM-XML file lacks an explicit mapping between different grid elements, for instance, ACLineSegment (i.e. Cable) and EnergyConsumer (i.e. Customer Connection Box) etc. Thus, the main challenge in designing the grid topology headend was to find out a way to parse the whole file such that it helps creating a topology out of the available data. This led to design the headend such that it starts scanning from a top entity e.g. a Substation and find out the adjacent entities via associated attributes (foreign keys). The process continues until all entities are associated to their adjacent grid entity. Figure 23 illustrates the work-flow that the grid topology headend has to conform with.

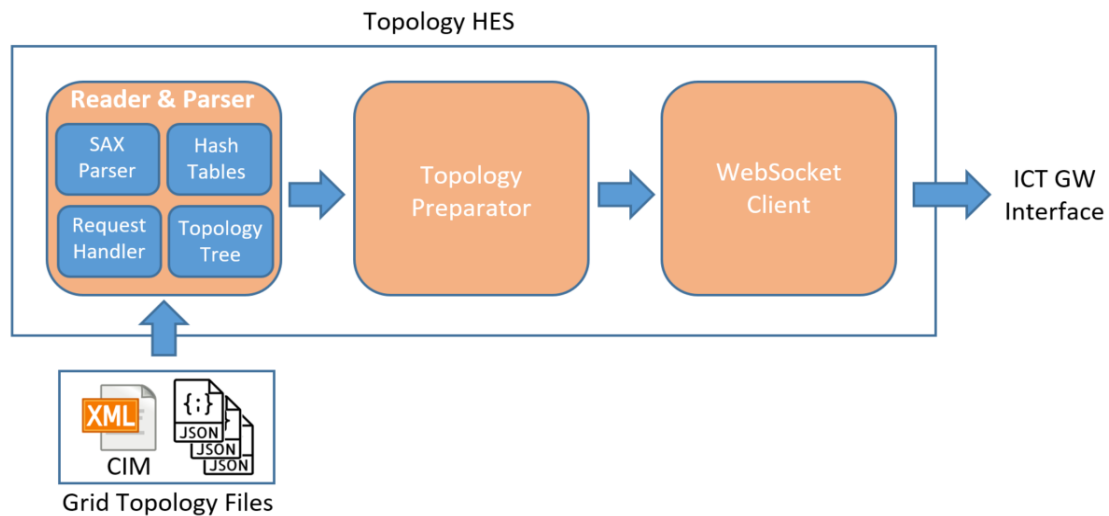


Figure 23. Grid Topology Head-End design.

As shown in Figure 22, the topology parser is designed such that it first reads the CIM-based topology file (XML format) via the SAX parser and then converts it into a set of hash tables. Additional methods allow traversing through these hash tables to create a data tree structure. This in turn leads to an easier and simpler interaction with the topology data. The outcome from this headend comprises different tables that reflect different node types and a table with the list of all cables, where for each cable a starting entity and an ending entity are defined. It is important to note that the extracted entities and cables are provided on the interface towards the ICT Gateway.

Due to the internal working of the algorithms that is based on use of hash tables to index the CIM objects as well as additional files, this headend consumes a significant amount of memory. For the available TME grid topology file containing information of all approx. 44.000 customers, the headend consumes around 1 GB of RAM. The related Grid topology adapter allows the parsed format to match the ICT-Gateway internal model structure. For detailed description of the grid topology headend [3], [5] and [6].

4.5 SolarWeb adapter

In an interactive process, an existing PV unit in the designated field test area was identified as the most suitable to be adapted according to the needs of the foreseen field tests. The adaptation included several measures. The existing PV inverter was exchanged to a Fronius model in order to allow interoperability with Net2DG systems. The PV system, which remains in the domain of the PV owner and operator, was permanently connected to Fronius Solar.web via the operator's local Internet access. This enabled server-level connectivity to the Net2DG ICT Gateway via the Fronius Solar.web API. Additionally, a Fronius Smart Meter was installed at the adapted PV unit, close to the official billing meter. This measurement device is an additional source of data which, on the one hand, allows for full monitoring of energy flows (incl. self-consumption, surplus infeed etc.) at the monitoring platform Fronius Solar.web (mainly as a benefit to the PV operator). On the other hand, grid-relevant data (voltages, grid import and grid export power flows both active and reactive) from the Fronius Smart Meter is gathered at Fronius Solar.web and provided at to the Net2DG ICT Gateway via the Fronius Solar.web API. In any case, all data exchange is legitimized by adequate data protection declarations.

The **SolarWeb adapter** utilizes an API that the SolarWeb server publicly exposes using a REST Web Service. This interface is secured by an authentication and authorization layer, which means the SolarWeb adapter consists of a HTTP client that interacts with the SolarWeb interface, on behalf of the ICT-Gateway, and converts HTTP Responses to the internal ICT-Gateway model. Fronius SolarWeb inverter provides two types of data i.e. Measurements and Events.

Measurements are read by the Fronius SolarWeb adapter every 5 minutes because the inverter also makes them available on the Fronius SolarWeb adapter in such interval. However, the adapter caches 5 minutes values over 15 minutes interval and then produces only one 15-min value, which is sent further to ICT GW and persisted. This 15-min value is calculated as an average of three 5 minutes values. Measurements encompass the average active energy and voltage for each of the three phases. If SolarWeb has the knowledge of any events, that occurred when the Fronius SolarWeb adapter queries SolarWeb server, those events are collected together with the measurements.

Moreover, it is worth to notice that the measurements are available on Fronius SolarWeb server with some delay of approximately 2 hours. In addition to that, the inverters do not provide any data to Fronius SolarWeb when there is no AC Power generation at the inverter (i.e. no or too little sun).

4.6 AMI Adapter

The **AMI Adapter** in the TME field setups is challenged by a set of strong security layers in the Kamstrup data collection subsystem. As a solution, Kamstrup hosts an Azure cloud, in which Net2DG has installed

a *mediator component* that acts as a gateway between Kamstrup’s internal data collection service interface, and the ICT-Gateway adapter. The mediator has similar, but much simpler, behaviour as SolarWeb server and makes its data available over a REST API. Several steps had to be taken into account for security reasons for the mediator to be allowed to interact with the adapter. Collected data was stored in ICT GW database and made available to the applications over REST API that provides different resources for each data type as well, such as different filtering options. Moreover, the ICT GW also implements publish/subscribe module that allows the applications to subscribe to specific events.

For the validation of the data access, a local meter has been made available at Kamstrup which has been measuring currents in a coil. Figure 24 shows the meter from where known voltages can be compared with the voltages inserted into the ICT-Gateway database via the adapters.

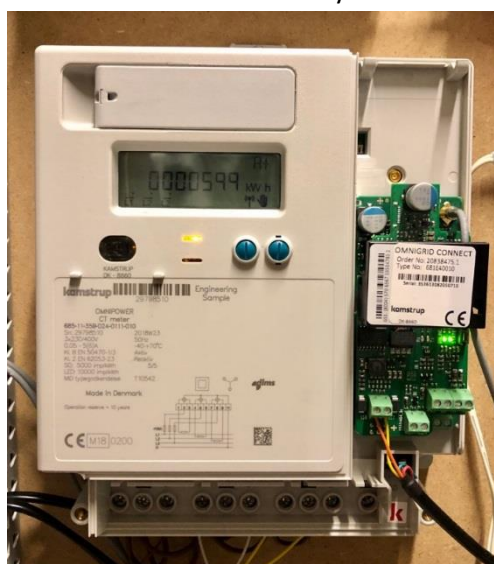


Figure 24. Test Smart Meter positioned at Kamstrup used for validation purposes in the TME field test.

4.7 Data Validation

The focus of the validation is to ensure that the targets set for Release 1 in the TME field setup are met. The methodology is briefly described in the following subsections, and the results are summarized in the following table:

Table 6. Test Cases for TME Field Trial in Release 1

Test ID	Target of test	Means of verification	Result achieved
1	Validate ICT-GW's capability to be executed correctly on the TME Azure cloud	Run ICT-GW on the VM with no errors.	Successfully executed
2	Validate ICT-GW's capability to be executed correctly on the TME Azure cloud with the AMI adapter	Running ICT-GW with AMI adapter and manually inspect data in ICT-Gateway DB with known values from Kamstrup test meters.	Successfully executed by interfacing only the test meters. For security reasons another interface must be used for the field deployed meters, which is included in Release 2.
3	Validate ICT-GW's capability to be executed correctly on the TME Azure cloud with the SolarWeb adapter	Running ICT-GW with SolarWeb adapter and manually inspect data in ICT-Gateway DB with known values from Fronius database.	Successfully executed
4	Successful grid topology import	Running ICT-GW with Grid topology HE and adapter, and manual check imported topology.	Successfully executed Care must be taken that the import file is also correct, i.e. if the CIM data is incorrect, errors will incur and impact on all applications and functionalities that depends on the grid topology.
5	Periodic collection of voltages (and currents on all three phases) from inverters with correct mapping of data (5 min periods)	Running ICT-GW with SolarWeb adapter for a time period (several days), and observe if data is correctly collected without interruptions, and that collected data can be mapped to the grid topology.	Successfully executed.
6	Period collection of voltages and currents on all three phases and accumulated active and reactive energy from AMI meters (15 min periods)	Running ICT-GW with AMI adapter that connects to AMI Mediator. Run the system for a time period (several days), and observe if data is correctly collected and that collected data can be mapped to the grid topology.	Successfully executed.
7	Successful execution of GMon app running in off-line mode	Running ICT-GW with the GMon app.	Successfully executed

The subsequent parts of this section provides the highlights of the validation phase of Release 1.

4.7.1 Topology Data

Validation of topology data underwent detailed review process performed by Thy-Mors Energi (TME) DSO in the first half of 2019. Before the TME Topology Headend was integrated with ICT GW, TME experts performed the review and gave green light to proceed with integration and data utilization. Two figures below reflect the database status after processing data received from topology adapter. **Figure 25** lists the tables created by ICG server once the topology data is persisted.

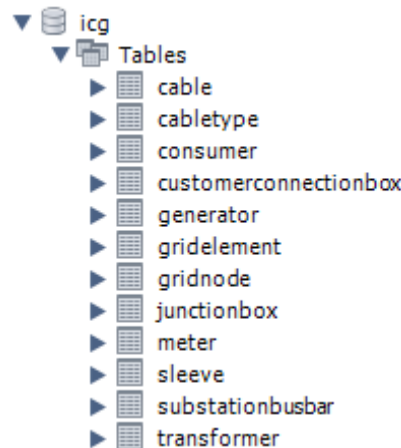
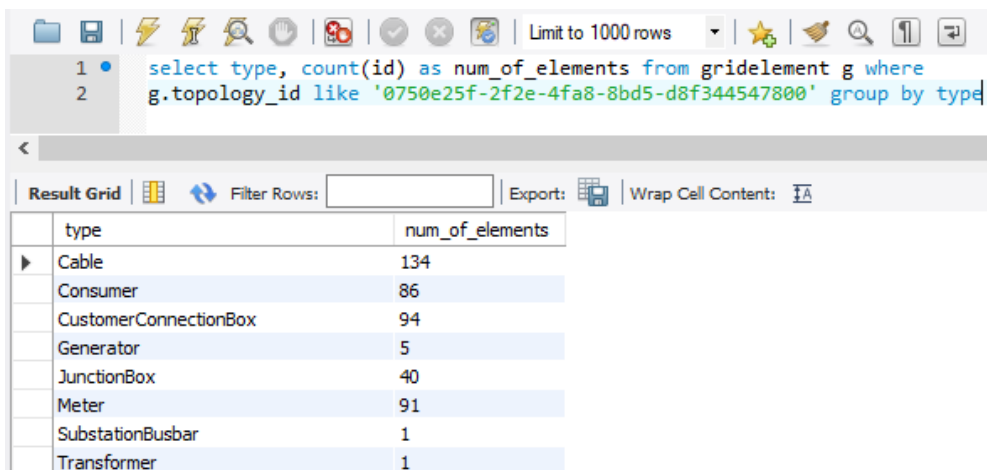


Figure 25. Tables created by ICG in MySQL Database.

Figure 26 shows code and result of a query executed to check type and number of elements in the topology after the import into the database.



The screenshot shows a SQL query executed in a database client. The query is: `select type, count(id) as num_of_elements from gridelement g where g.topology_id like '0750e25f-2f2e-4fa8-8bd5-d8f344547800' group by type`. The result is displayed in a table with two columns: 'type' and 'num_of_elements'.

type	num_of_elements
Cable	134
Consumer	86
CustomerConnectionBox	94
Generator	5
JunctionBox	40
Meter	91
SubstationBusbar	1
Transformer	1

Figure 26. Results of SQL command to query TME grid topology elements.

Grid topology information obtained at the DB was validated by comparing it to the grid topology figure (verified and validated by TME).



4.7.2 Inverter Data

The upgraded inverter has been providing measurement and events to the ICT GW since middle of November 2019, and after an upgrade of the ICT Gateway with the topology mapping component in early December, these measurements in the DB are also correctly associated to the corresponding location in the grid (i.e. to the correct grid node of the data model in the ICT Gateway). The correct association to the grid topology has been manually verified by inspecting the DB content with an SQL request. The request and its output looks analogue to what is shown in Section 5.5.3 – just for a different inverter.

In order to validate the correctness of the measurements in the DB, a trace of the 5-min measurement values for active energy and voltage at the inverter as stored at the Solar-Web server has been used as comparison basis. The manual comparison of this trace with the 15min values in the database for the matching time intervals showed matching result, validating that timestamps and also measurement values have been correctly processed and stored by the integrated deployment of the Net2DG solution in the TME field trial.

An offline application of the GMon application on the collected inverter measurements was executed. As this is an execution of GMon for only a single measurement point, it provides in essence a similar analysis to what the SolarWeb portal can provide for this single measurement point; therefore, the results are not reported here in detail.

4.7.3 AMI Data

Release 1 used test smart meters in order to be able to have known electrical conditions at the measurement point. The ICT GW (AMI Adapter) was configured to access data from the test meters that were deployed in the Kamstrup cloud. The test meters were configured to measure known current and voltage in some coils attached to the smart meters, and thus their sole purpose was to test the interface to obtain measurements and events. The Net2DG solution, through the chain AMI mediator, AMI adapter, ICT Gateway core functions, was able to successfully obtain the measurements from the test smart meters; time stamps and electrical values were consistent to the setup of the test smart meter.

4.8 Candidate tasks and features for next release

For the next release of the TME setup, the main priority is to enable the AMI adapter to gain access to the actual smart meters in the field. For security and safety reasons (not harming user equipment by mistake), this entails setting up a separate data concentrator in the field, and requires interfacing to a different entity in the Kamstrup internal data access services as for the test meters used in the above test. This setup effectively separates the measurement data stream from the running production line used for billing, and allows a legally safe way for Net2Dg to access data.

Second on the list for the Release 2 version at TME, are as follows:

- An automated mapping of AMI devices to the grid topology: in Release 1 this still requires manual configuration, and the aim is to have this part fully automatized.



- Alarm forwarding from AMI infrastructure. In the Release 1, alarms can only be supported once the separate concentrator is in place and when the interfacing is done at the right place.
- Deployment and tests of the GUI
- Integration and tests of the three applications GMon, ODet, and LC on-line and with full feature set.

5 Release 1 StwLan Field Trial

The Release 1 field trial at the German DSO StwLan is focusing on the following targets:

- Demonstrate the feasibility of an on-site installation of the Net2DG solution embedded in the IT network of the DSO
- Demonstrate that the grid topology information can be automatically derived from file exports from the GIS system and from other customer information databases of the DSO
- Demonstrate the successful collection of measurement data from inverters
- Demonstrate the successful collection of measurement data from Janitza devices
- Gain some preliminary experience with the offline execution of the GMon application

5.1 Grid Scenario

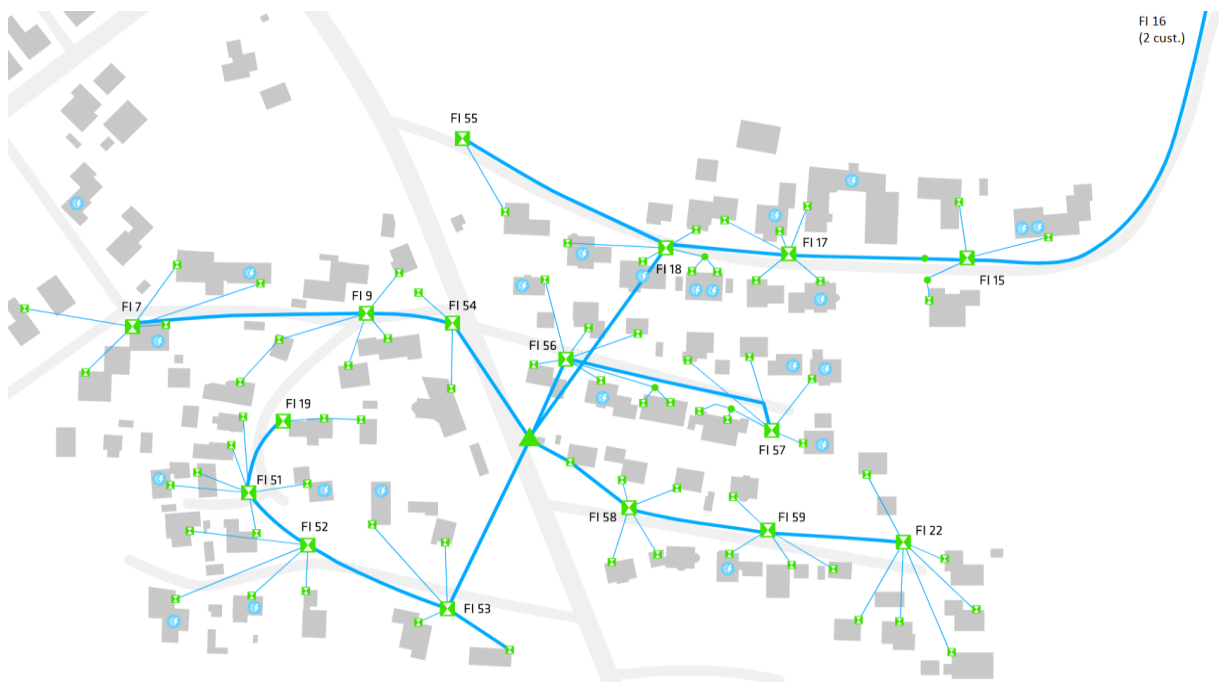


Figure 27: StwLan field trial region for Release 1 is the LV grid area starting from the substation TS20 (green triangle in the center);

The GUI view on the low-voltage field trial area from StwLan is shown in **Figure 27**. A single secondary substation (shown as triangle in the centre) is considered. This substation has 5 feeders, which are visualized in the figure. In addition, there are two more feeders that are supplying power to street lights – which are however not shown in the figure.

The focus of the Release 1 field trial is on a single feeder, and the long feeder with first junction box FI18 (upper right in the figure) has been selected. In Release 1, six Janitza devices that are connected to the EM Headend via RTUs are installed in five different Junction boxes (FI15, FI16, FI17, FI18, FI55) and in the substation. Therefore, this feeder is completely measured on junction box level. In addition, one inverter connected to FI18 is providing data to the Net2DG solution: Several existing residential

PV units located in the designated field test area were checked regarding their suitability for field testing. For the time being, one PV system was selected and integrated. Integration included an efficient retrofit of a Fronius Datamanager option card into the operative Fronius inverter equipment of the PV unit, which was permanently connected to Fronius SolarWeb via the operator's local internet access. Following positive integration tests, server-level connectivity to the Net2DG ICT Gateway via the Fronius SolarWeb API is established. All data exchange is legitimized by adequate data protection declarations. Deployment architecture.

5.2 Deployment Architecture

The deployment architecture for StwLan is given in **Figure 28**.

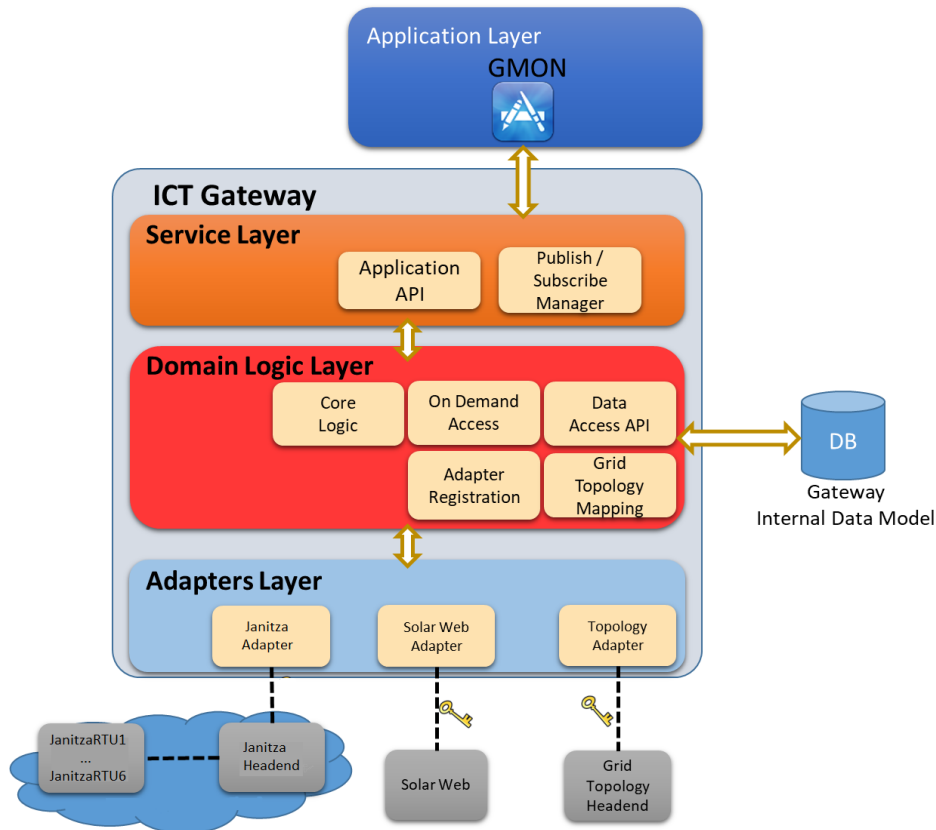


Figure 28: Deployment architecture of StwLan Release 1 Field Trial

The ICT-Gateway together with a MySQL Database is deployed on the main operating system (Windows) of the dedicated server within the StwLan IT. Headened servers, in Release 1, the Janitza HeadEnd and the Grid Topology HeadEnd are deployed on the Ubuntu Virtual Machines on the same server.

The Grid Topology Headend has been described earlier in D3.1. The Head-end Server for the inverters is the SolarWeb from Fronius. The adapter configuration and the interface is identical to the one described for the TME field-trial, see Section 4.5 for details.

The Janitza Headend collects data from multiple devices (RTUs) using TCP/IP WebSocket protocol, aggregates it across several RTUs and sends it to the ICT-Gateway, which then saves it to the database.

5.3 Component overview and interfaces

The main components of the ICT Gateway are divided into different layers:

- Service Layer in ICT Gateway
- Domain Logic Layer in ICT Gateway
- Adapters Layer in ICT Gateway

The **Service Layer** in ICT Gateway includes the following modules:

- Application API: Allows interaction between ICT GW and all the Applications by mean of specific methods called by each of the applications. In Release 1 of the STwLan field trial, the application GMon has been executed in an offline manner on the collected data, so the API has been used in the same way as described in Section 3.6.2. The interaction between the GMon application and Application API of the ICT GW is realized by means of REST and Web Socket.
- Publish / Subscribe Manager: has been deployed but not used or tested in Release 1 of the STwLan field trial.

The **Domain Logic layer** in ICT Gateway includes the modules shown in Figure 28, where special configurations have been deployed for the following:

- Grid Topology Mapping: Identifies the generator of an event/data and associates it with node id defined in the Grid Topology. It furthermore enriches data with metadata available from the Grid Topology. In the StwLan deployment, the mapping of RTU names to the grid node and cable node id of either the substation or the junction boxes is done via a file-based mapping table. Input to these files is generated as part of the measurement device deployment process.

The interaction with the Data Base is based on messages (i.e., Java object) that allow to Create, Read, Update and Delete data on the Data Base.

Adapters Layer includes the following modules, which allow interaction with field subsystems, namely the Headend:

- Janitza / EM Adapter: Connects the ICT Gateway to the EM-HE, which in Net2DG will be specifically used to connect to RTUs, which obtain data from Janitza devices. The EM Adapter will obtain both measurements and alarms.
- Inv. Adapter (SolarWeb Adapter): Connects the ICT Gateway to the Inverter SolarWeb Headend to get the data from PV System



- Topology Adapter: Connects the ICT Gateway to the Grid Topology Headend in order to get information about the topology (e.g., number of nodes, number of cables) and to receive any kind of modification of the topology.

Adapters and Headend interact by means of exchanges of messages that are formatted as JSON objects and are exchanged either over established WebSocket connection or through HTTP Request/Response messages.

5.4 EM Subsystem deployment

In order to connect deployed electrical measurement devices (here of type Janitza), Net2DG has developed and implemented an RTU based on a Raspberry Pi platform. The architecture and main components deployed in the field (o junction boxes or substation) on StwLan are shown in Figure 29:

Hardware:

- Janitza UMG 96 RM device: Connected to the grid and provides the measurement values.
- Raspberry Pi: Connected to the Janitza device via a local cable.
- Cellular module with SIM card: installed on Raspberry Pi, establishes a needed internet connection via 2G-4G cellular networks. The module uses an M2M SIM card which can connect to cellular networks of different providers. A central portal allows to configure delimitations, for instance to blacklist certain operators or to avoid 4G or 3G cellular connections.

Software:

- Raspbian Linux OS: Lightweight operating system that the RTU software runs on.
- RTU client software: developed by Net2DG WP3, runs on the Raspberry Pi.
- Janitza software: off-the-shelf as provided by vendor.

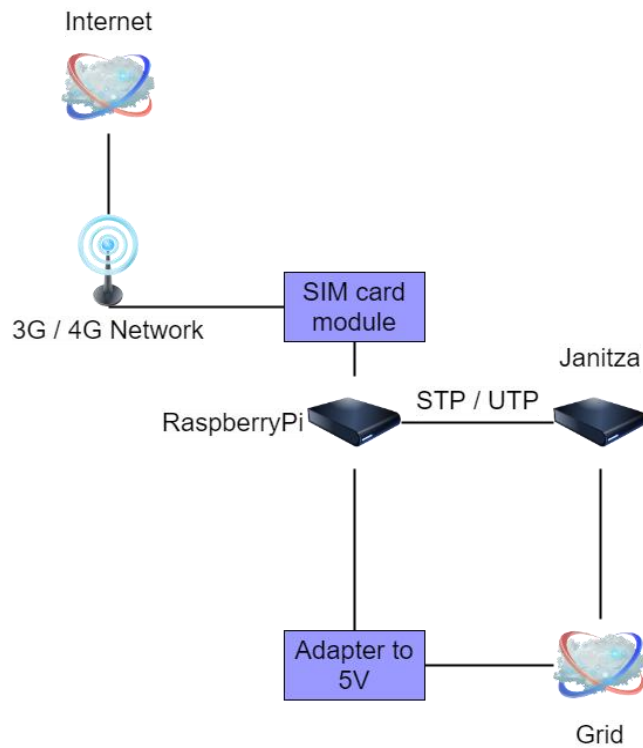


Figure 29. RTU deployment architecture in junction box or substation

The Janitza device is connected to the specific grid measurement point at a specific junction box or the substation and provides the measurement values. Raspberry Pi is connected to the Janitza device and has a cellular modem. The cellular modem establishes a needed internet connection. The Raspberry Pi has the RTU client software installed, which collects measurements in a configurable sampling-interval from the Janitza devices and sends an potentially time-aggregated periodic measurement to the Headend in a configurable sending-interval. The periodic measurement sent to the headend provides average, maximum and minimum measurements of voltage, current, active energy and reactive energy. The sending-interval is configured to 15 minutes, but can be shortened for testing purposes. The Device ID is configured during installation. The DSO must provide name of the junction box or substation where device was installed for integration with GTM component.

In addition to the measurement processing, the RTU client software contains SW functions for monitoring of the cellular connection and restart of the RTU in case of persistent connection failure. Furthermore, the software contains a client for remote configuration and SW upgrade via a secure IPsec tunnel.

An example installation of the Janitza device (lower left) and the RTU (on the right) for a junction box deployment is shown in Figure 30. In total 6 Janitza devices and 6 RTUs have been deployed for the Release 1 field trial. The substation deployment measures voltages at the LV side busbar and the current (and all other parameters) from the feeder towards FI18. The junction box measurement devices measure at the 3-wire cable coming from the substation in case of FI18, respectively, on the cable coming from the previous junction box that is closer to the substation.



Figure 30. Deployment of one Janitza device (left) and RTU (right) at a junction box in the field trial region

5.5 Data validation

An overview of the test performed during Release 1 in the StwLan Field Trial is given in Table 7.

Table 7. Test Cases for StwLan Field Trial in Release 1

Test ID	Target of test	Means of verification	Result achieved
1	Ability to execute ICT-Gateway and Head-Ends and their interconnection on StwLan server.	The needed software can run on the DSO's server. Connection between HeadEnds and ICT-Gateway is functional.	Fully successful execution
2	Successful grid topology import	Running ICT-GW with Grid topology HE and adapter, and manual check imported topology.	Fully successful execution
3	Connectivity to Janitza devices via RTU and Headend.	Raspberry Pi RTUs are connected to Janitza device to sample data and send them at the 15min interval. Install OS and software on RTUs, and deploy them on Junction Boxes and Substation. Test and determine problems with connection, SIM cards and software	Fully successful execution
4	Correctly receive periodic	RTUs send data to Janitza HE. Janitza HE sends data to ICT-GW which stores it into the database.	Successful execution

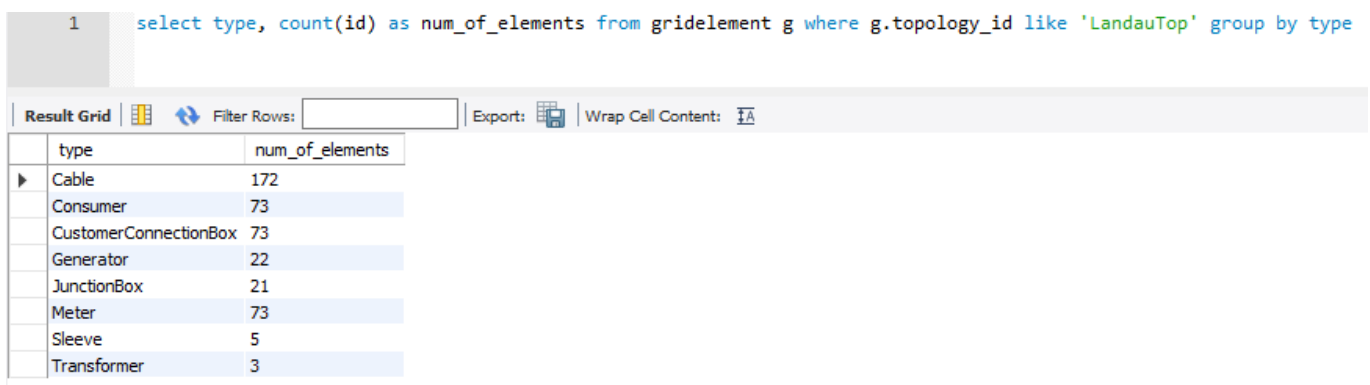
	measurements from RTUs in the database	Manual inspection was made to validate the data.	
5	Correctly receive periodic measurements and events from the inverter in the database	Running ICT-GW with SolarWeb adapter and manually inspect data in ICT-Gateway DB with known values from Fronius database.	Fully successful execution
6	GMon execution on received inverter data in offline mode	Running ICT-GW with the GMon app. The result is verified by running equivalent Matlab computations on the sequence of data obtained by file export from the DB (so not using the API).	Successful execution

5.5.1 Topology Data

Topology Data is loaded from the CSV files provided by StwLan. The GT Head-End parses the relevant data in specific format and sends it to the ICT-Gateway adapter.

Validation of topology data underwent detailed review process performed by Landau DSO in the second half of 2018. Before the Landau Topology Headend was integrated with ICT GW, Landau experts performed the review and gave green light to proceed with integration and data utilization.

In Figure 31 we show code and result of a query executed to check type and number of elements in the topology after the import into the database.



```
1 select type, count(id) as num_of_elements from gridelement g where g.topology_id like 'LandauTop' group by type
```

type	num_of_elements
Cable	172
Consumer	73
CustomerConnectionBox	73
Generator	22
JunctionBox	21
Meter	73
Sleeve	5
Transformer	3

Figure 31. Results of SQL command to query grid topology elements.

5.5.2 RTU Data

In total six RTUs have been deployed and tested in the Release 1 StwLan field trial. All these RTUs provided measurement data for some limited period of time. However, due to poor cellular connectivity, robustness enhancements will be required in the next release, in order to be able to obtain complete measurement data sets. At this first stage, only 3 RTUs were used that provided each data for on average 3.5 days.



The following data is taken from the LandauRTU5 device deployed at the Substation for three 15-min intervals. By remote reconfiguration of the RTU, the interval duration was reduced from 15 minutes to 1.5 minutes for the testing purposes.

Voltage Measurements

Voltage is received from the device as average, minimum and maximum for each interval together with the measurement unit. Voltage measurement is made for each phase. On the figure below it is visible that voltages are near the nominal values.

```
19  -- voltage
20  • SELECT m.intervalStart, m.intervalEnd, v.average, v.max, v.min, v.phase, m.voltageUnit, m.device_Id
21  FROM Voltage v
22  JOIN Measurement m ON m.measurement_id = v.measurement_id
23  WHERE m.device_id = 'LandauRTU5'
24  ORDER BY m.measurement_Id DESC, v.phase
25  LIMIT 9; -- 3 periods
26
```

intervalStart	intervalEnd	average	max	min	phase	voltageUnit	device_Id
2019-12-06T13:23:52+0100	2019-12-06T13:25:22+0100	229.567	230.1	229.5	I1	V	LandauRTU5
2019-12-06T13:23:52+0100	2019-12-06T13:25:22+0100	228.778	229.2	228.7	I2	V	LandauRTU5
2019-12-06T13:23:52+0100	2019-12-06T13:25:22+0100	228.989	229.3	228.8	I3	V	LandauRTU5
2019-12-06T13:22:22+0100	2019-12-06T13:23:52+0100	229.533	229.8	229.5	I1	V	LandauRTU5
2019-12-06T13:22:22+0100	2019-12-06T13:23:52+0100	228.833	229.2	228.8	I2	V	LandauRTU5
2019-12-06T13:22:22+0100	2019-12-06T13:23:52+0100	229.178	229.5	229.2	I3	V	LandauRTU5
2019-12-06T13:20:52+0100	2019-12-06T13:22:22+0100	229.578	229.8	229.6	I1	V	LandauRTU5
2019-12-06T13:20:52+0100	2019-12-06T13:22:22+0100	229.022	229.3	228.9	I2	V	LandauRTU5
2019-12-06T13:20:52+0100	2019-12-06T13:22:22+0100	229.144	229.4	229.1	I3	V	LandauRTU5

Figure 32. Result of SQL command to query relevant voltage data.

Current Measurements

Currents are received same way as the voltages. Currents are down-scaled by 1/120 because of the deployed current transformer. In Release 1, the current transformer is not yet calculated in automatically (though its parameters are accessible and have been configured on the Janitza device itself).

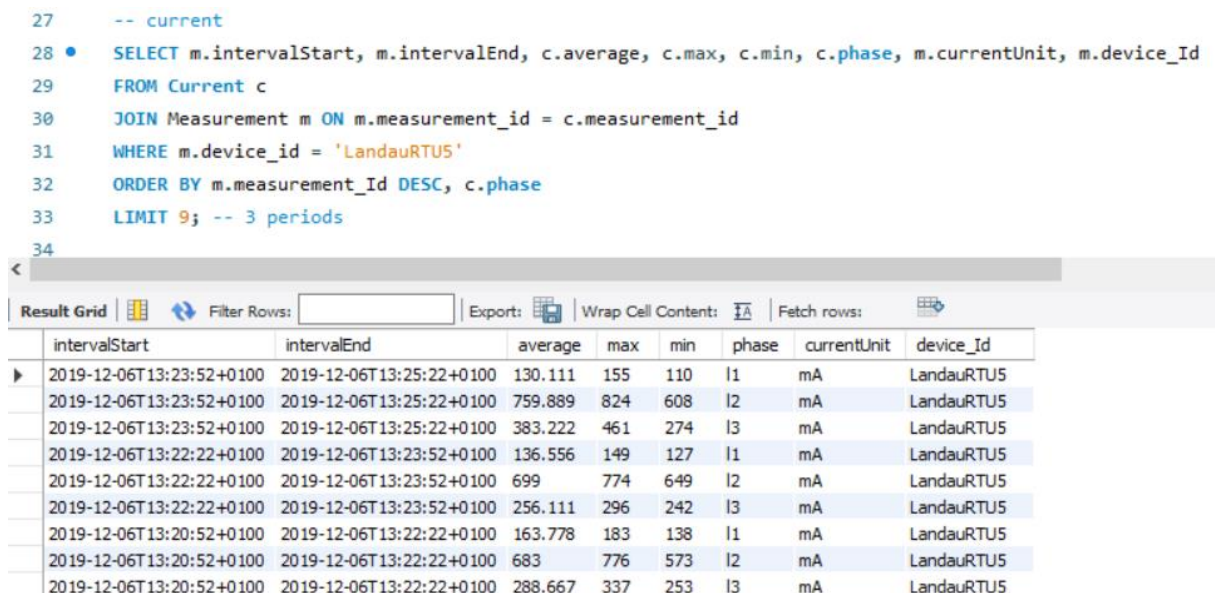


Figure 33. Result of SQL command to query relevant current data, the values do not yet include the scaling (factor 120 in the substation measurement) by the current transformer.

5.5.3 Inverter data

The inverter provides voltage and active energy measurements via the customer Internet connection to the SolarWeb portal, to which the Net2DG solutions connects in Release 1 via a server level API. At the time of writing this deliverable, nine complete days of measurements for the period Dec 11-19 were successfully collected in the DB of the ICT Gateway. Examples of resulting data in the Database of the ICT Gateway are shown below.

Voltage Measurements

The example voltages from the field trial inverter in **Figure 34** show values close to the nominal phase-to-neutral voltage of 230V with slight deviations up to 2V between phases.

The comparison of the shown part of the trace (and more voltage values from the ICT GW) with voltages obtained directly from the Solar-Web export show that the processing of time-stamps and of voltage values is performed correctly in the integrated Net2DG solution.

```

11  -- voltage
12  • SELECT m.intervalStart, m.intervalEnd, v.average, v.max, v.min, v.phase, v.unit, m.device_id
13  FROM Voltage v
14  JOIN Measurement m ON m.measurement_id = v.measurement_id
15  ORDER BY m.measurement_id DESC, v.phase
16  LIMIT 9; -- 3 periods
17

```

intervalStart	intervalEnd	average	max	min	phase	unit	device_id
2019-12-13 14:50:00	2019-12-13 15:05:00	230	231	229	1	V	2a56e362-76de-4035-a8fa-ab1200886902
2019-12-13 14:50:00	2019-12-13 15:05:00	230.667	231	230	2	V	2a56e362-76de-4035-a8fa-ab1200886902
2019-12-13 14:50:00	2019-12-13 15:05:00	231.333	232	231	3	V	2a56e362-76de-4035-a8fa-ab1200886902
2019-12-13 14:35:00	2019-12-13 14:50:00	228.333	229	228	1	V	2a56e362-76de-4035-a8fa-ab1200886902
2019-12-13 14:35:00	2019-12-13 14:50:00	230	230	230	2	V	2a56e362-76de-4035-a8fa-ab1200886902
2019-12-13 14:35:00	2019-12-13 14:50:00	230.667	231	230	3	V	2a56e362-76de-4035-a8fa-ab1200886902
2019-12-13 14:20:00	2019-12-13 14:35:00	228.667	229	228	1	V	2a56e362-76de-4035-a8fa-ab1200886902
2019-12-13 14:20:00	2019-12-13 14:35:00	228.001	229	227.003	2	V	2a56e362-76de-4035-a8fa-ab1200886902
2019-12-13 14:20:00	2019-12-13 14:35:00	230	230	230	3	V	2a56e362-76de-4035-a8fa-ab1200886902

Figure 34. Result of SQL command to query relevant voltage data.

Active Energy

The figure below shows active energy measurements from the field trial inverter for 15 minute intervals extracted from ICT GW database. Active energy is calculated as an average over the all three phases.

```

8  -- active energy
9  • SELECT m.intervalStart, m.intervalEnd, a.average, a.unit, m.device_id
10  FROM activeenergy a
11  JOIN Measurement m ON m.measurement_id = a.measurement_id
12  ORDER BY m.measurement_id DESC
13  LIMIT 9;

```

intervalStart	intervalEnd	average	unit	device_id
2019-12-13 14:50:00	2019-12-13 15:05:00	343074	Ws	2a56e362-76de-4035-a8fa-ab1200886902
2019-12-13 14:35:00	2019-12-13 14:50:00	123381	Ws	2a56e362-76de-4035-a8fa-ab1200886902
2019-12-13 14:20:00	2019-12-13 14:35:00	64476.7	Ws	2a56e362-76de-4035-a8fa-ab1200886902
2019-12-13 14:05:00	2019-12-13 14:20:00	78496	Ws	2a56e362-76de-4035-a8fa-ab1200886902
2019-12-13 13:50:00	2019-12-13 14:05:00	49161.8	Ws	2a56e362-76de-4035-a8fa-ab1200886902
2019-12-13 13:35:00	2019-12-13 13:50:00	25820	Ws	2a56e362-76de-4035-a8fa-ab1200886902
2019-12-13 13:20:00	2019-12-13 13:35:00	22312.1	Ws	2a56e362-76de-4035-a8fa-ab1200886902
2019-12-13 13:05:00	2019-12-13 13:20:00	47788	Ws	2a56e362-76de-4035-a8fa-ab1200886902
2019-12-13 12:50:00	2019-12-13 13:05:00	77242.7	Ws	2a56e362-76de-4035-a8fa-ab1200886902

Figure 35. Results of SQL command to query relevant active energy data.

From the complete measurements set, it can be seen there are no values in from 28.11.2019. 16:20 until 29.11.2019. 07:35 which corresponds to dark period when there was no power generation.



One observation from the inverter measurements is that the Inverter adapter needs to be coordinated with the RTU measurement collection, so that the same 15-min intervals (except for clock synchronisation errors) are obtained for the measurements. In the current implementation of Release 1, the inverter above provided a measurement for 14:35-14:50h, while a Janitza RTU may provide the measurement over the interval 14:45 - 15:00. While it is easy to hard-code fixed interval boundaries into the RTU and adapter Software, the Net2DG solution allows a more flexible configurable solution, which can also take into account constraints from the measurement devices. This feature however is for future releases.

5.5.4 GMon results

GMon was run on the available data connected from the RTUs and the inverter. The data covered 9 days of inverter measurements and on average 3.5 days of measurements from each of the three Janitza devices that provided consecutive data. It was possible to execute GMon on top of the ICT GW API and the results can be visualized analogue to Section 3.6.2. However, the voltage variations in these measurement data sets was very low, the smallest average voltage in any 15min interval in the database is 226.91 V and the largest observed average voltage in any of the observed 15-min intervals in the ICT Gateway is 236.33 V. A more interesting and more detailed discussion of GMon results will follow when larger amounts of measurement data have been collected from this field trial.

5.6 Candidate tasks and features for next release

In the next release of the StwLan field trial, the priority is to collect large amounts of consecutive data from the field trials and use this data to assess full-featured versions of the LC and GMon applications; for GMon this also includes the implementation and assessment of the event handling across the integrated solution. Furthermore, more measurement points will be deployed: target is to deploy 5 more Janitza devices and connect at least one more inverter to the Net2DG solution. That way, the results of the application assessment will be more insightful. The deployment of the GUI for GMon and LC will allow to gain experience on the benefits of different presentation formats for the obtained application output. Finally, part of the configuration processes will be automated in Release 2 to achieve more robustness.

6 Conclusions and Outlook

The purpose of deliverable D5.1 was to provide an overview of the deployment architectures in WP5 and to provide the evidence of successful integration of different components that constitute the overall Net2DG solution with respect to the first experimental evaluation, called Release 1. The deliverable first described the conceptual deployment architectures and the synergies between field trials in the project and the lab facility used. Then, following this, each setup has been thoroughly introduced, first the lab test, then the two field tests. In these three descriptive chapters, the deliverable provided the measured and assessed evidence of the described deployment architectures. Some selected highlights are:

- Connectivity to a heterogeneous set of measurement systems via the same ICT GW implementation in three different deployment scenarios: lab-based, cloud-based field-trial deployment, DSO-local field trial deployment
- Successful access to measurements data and events from inverters, electrical measurement devices, smart meters, and generic virtual measurement subsystems.
- Ability to link these measurements and events to the grid topology, where customizations of a grid topology head-end to three different grid topology representations were successfully validated
- Development of a Real-Time distribution grid model in the laboratory and preliminary testing on outage and extreme-voltage scenarios
- First implementation and integration of the two observability applications ODet and GMon in selected demonstrators.

Overall, all three demonstrators are defined and the basic hardware and software are installed and configured. The dataflow between subsystems and components was successfully tested. First releases for some applications were successfully running.

The following preliminary results in laboratory have been successfully demonstrated in this deliverable:

- grid topology information can be automatically derived from the specific grid topology characterization utilized in lab
- data flow from generic measurement devices to ICT-GW via adapters, i.e. correct reception of periodic measurements, correct reception of over-voltage events at the ICT Gateway, correct reception of under-voltage events, correct provisioning of on-demand access to measurements.
- online execution of a simplified version of ODet
- offline execution of GMon

The following preliminary results in TME Field trial have been successfully demonstrated in this deliverable:

- feasibility of the Net2DG solution tailored for the TME field trial setup, meaning that



- ICT-Gateway is successfully running on TME Azure cloud
 - ICT-Gateway has access to data sources
- accessibility of measurement data from test smart meters and from inverters in the field area
- grid topology information can be automatically derived from file exports from the GIS system and from TME information databases

The following preliminary results in StwLan Field trial have been successfully demonstrated in this deliverable:

- feasibility of an on-site installation of the Net2DG solution embedded in the IT network of StwLan
- grid topology information can be automatically derived from file exports from the GIS system and from other customer information databases available in StwLan
- successful collection of measurement data from inverters in the field trial region
- successful collection of measurement data from Janitza devices deployed in the field trial substation and junction boxes
- offline execution of the GMon application

WP5 will focus on Release 2 during the first half of 2020 as defined in previous sections for every demonstrator. More tasks may be added according to new challenges that may arise during this period.

7 References

- [1] K. Handrup (edt.), "Net2DG Deliverable D1.3 - Final Baseline Architecture", August 2019;
- [2] N. Silva (edt.), "Net2DG Deliverable D2.2 - Final realization of grid state estimation and observability applications" December 2019;
- [3] N. Nostro (edt.), "Net2DG Deliverable D3.1 - ICT Analysis and Gateway Design", December, 2018
- [4] N. Nostro (edt.), "Net2DG Deliverable D3.2 - Data Gateway Realization", December 2019
- [5] K. Shahid, E. Schiavone, D. Drenjanac, R. P. Bæklund, R. L. Olsen and H. Schwefel, "Extraction of CIM-Based Distribution Grid Topology Information for Observability," 2019 15th European Dependable Computing Conference (EDCC), Naples, Italy, 2019, pp. 165-170. doi: 10.1109/EDCC.2019.00040
- [6] K. Shahid, E. Schiavone, D. Drenjanac, M. Lyhne, R. L. Olsen and H. Schwefel, "Handling Incomplete and Erroneous Grid Topology Information for Low Voltage Grid Observability," 2019 IEEE International Conference on Communications, Control, and Computing Technologies for Smart Grids (SmartGridComm), Beijing, China, 2019, pp. 1-6. doi: 10.1109/SmartGridComm.2019.8909747
- [7] Catalin-Iosif Ciontea, Dezso Sera, and Florin Iov, Influence of Resolution of the Input Data on Distributed Generation Integration Studies. Brasov, Romania: 14th International Conference on Optimization of Electrical and Electronic Equipment, 2014.
- [8] Petersen, L.; Iov, F.; Shahid, K.; Olsen, R.L.; Altin, M.; Hansen, A.D. RePlan Project: D2 - Voltage control support and coordination between ReGen plants in distribution systems, Project Report, Aalborg, Denmark, Available online at www.replanproject.dk, 2016.
- [9] Lennart Petersen, Florin Iov, German Claudio Tarnowski, Vahan Gevorgian, Przemyslaw Koralewicz, Daniel-Ioan Stroe- Validating Performance Models for Hybrid Power Plant Control Assessment, MDPI Energies Nov 2019, In : Energies. 12, 22, 26 p.
- [10] Fronius International GmbH, Fronius ECO 27.0/25.0 KW simulation model, version 02, 11/2016