www.interpreter.eu

INTERPRETER

BENCHMARK ANALYSIS REPORT OF AMIS AND OTHER SENSORS

Deliverable 2.2

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 864360 (INTERPRETER). This output reflects only the author's view and the European Union cannot be held responsible for any use that may be made of the information contained therein.

Funded by the Horizon 2020
Framework Programme of the European Union

Deliverable D2.2
BENCHMARK ANALYSIS REPORT OF AMIS AND OTHER SENSORS

Version 1.0

Organisation: CARTIF

Main authors: Mª Ángeles Gallego, Sergio Saludes

Date (13/03/2020)

DELIVERABLE 2.2 – VERSION 1
WORK PACKAGE N° 2 – PROJECT BASELINE AND DEFINITION OF USE CASES
TASK N° 2.2 – CHARACTERISATION OF AMIS AND OTHER SENSORS CONNECTED TO THE GRID

Nature of the deliverable		
R	Document, report (excluding the periodic and final reports)	X
DEM	Demonstrator, pilot, prototype, plan designs	
DEC	Websites, patents filing, press & media actions, videos, etc.	
OTHER	Software, technical diagram, etc.	

Dissemination Level		
PU	Public, fully open, e.g. web	X
CO	Confidential, restricted under conditions set out in Model Grant Agreement	
CI	Classified, information as referred to in Commission Decision 2001/844/EC	

Approvals				
Date	Version	Author(s)	Task Leader	WP Leader
13.12.2019	0.1	CARTIF	CARTIF	ORES
15.01.2019	0.2	CARTIF	CARTIF	ORES
12.02.2020	0.3	CARTIF	CARTIF	ORES
10.03.2020	0.4	CIRCE	CARTIF	ORES
09.03.2020	0.5	CIRCE	CARTIF	ORES
12.03.2020	0.6	CIRCE, CARTIF	CARTIF	ORES
13.03.2020	1.0	CIRCE	Final Quality Revision	

Disclaimer of warranties

This report is part of the deliverables from the project INTERPRETER which has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 864360. More information on the project can be found at https://www.interpreter.eu

(i) with respect to the use of any information, apparatus, method, process, or similar item disclosed in this document, including merchantability and fitness for a particular purpose, or

(ii) that such use does not infringe on or interfere with privately owned rights, including any party's intellectual property, or

(iii) that this document is suitable to any particular user's circumstance; or

(b) assumes responsibility for any damages or other liability whatsoever (including any consequential damages, even if the Project Coordinator or any representative of a signatory party of the INTERPRETER Project Consortium Agreement has been informed of the possibility of such damages) resulting from your selection or use of this document or any information, apparatus, method, process, or similar item disclosed in this document.

Executive summary

This deliverable is the outcome of *Task 2.2 Characterisation of AMIs and other sensors connected to the grid.*

WP2 Project baseline and definition of use cases sets the basis for a number of tasks to be performed later, with the aim of achieving the final overall objective of INTERPRETER project: to develop a modular grid management solution consisting of a set of interoperable off-line and on-line software tools for an optimized design, planning, operation and maintenance of the electricity grid – with a special focus on distribution network – that will be offered to grid operators through an open source software platform.

This report provides a review on the current status of the Advanced Metering Infrastructure and other sensors present in Low Voltage grids. This analysis is then benchmarked against the AMI available at the three demo sites of INTERPRETER project and with a view on forthcoming tasks and Work Packages.

- Chapter 2 describes the methodology implemented.
- Chapter 3 presents the current trends for AMI in smart grids, with a focus on low voltage grids.
- Chapter 4 contains a description of available metering infrastructure in the three demo sites
- Chapter 5 analyses the future tasks to be performed in the project, for which input from Task 2.2 is needed, and the way in which this input can be provided from the Advanced Metering Infrastructure (and other sensors) currently available from the three pilot partners in the project. In the end, the target is to assess their adequacy to test the 10 software tools that will be developed within *WP4 Software applications for efficient operation & maintenance of the grid* and *WP5 Software applications for an effective grid planning*.
- Chapter 6 presents the main conclusions.

List of abbreviations

Abbreviation	Full name
AAM	Advanced Asset Management
ADO	Advanced Distribution Operations
AMI	Advanced Meter Infrastructure
AMR	Automated Meter Reading
ANSI	American National Standards Institute
ATO	Advanced Transmission Operations
BPL	Broadband Power Line
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CIS	Consumer Information System
DC	Data Concentrator
DER	Distributed Energy Resources
DSO	Distribution System Operator
ERP	Enterprise Resource Planning
ETSI	European Telecommunications Standards Institute
FLISR	Fault Location, Isolation, Sectionalization and Restoration
GIS	Geographic Information System
HAN	Home Area Network
IEC	International Electro technical Commission
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LV	Low Voltage
MDMS	Meter Data Management Systems
MV	Medium Voltage
MWM	Mobile Workforce Management
O&M	Operation & Maintenance
OMS	Outage Management System
PLC	Power Line Communication
SG	Smart Grids
SM	Smart Meters
SMETS	Smart Meter Equipment Technical Specifications
T&D	Transmission and Distribution
TLM	Transformer Load Management
VEE	Validation, editing and estimation
WAN	Wide Area Network

List of Figures

List of Tables

Contents

1. CONTEXT OF THE WORK CONDUCTED

This deliverable is the main outcome of *Task 2.2 Characterisation of AMIs and other sensors connected to the grid*. It includes a benchmark analysis of AMIs and other sensors available in the low voltage grid that will be used to provide input to the following tasks and WPs in INTERPRETER project.

Input to	Kind of input	Purpose
Task 2.4 Detailed characterisation of representative use cases	Smart metering readings (current, voltage, geographic location); Billing details Secondary substation registers on consumption and generation; Feeder mapping measurements.	Help with definition of a number of use cases, to determine the accuracy of the grid model generated by the tool developed in WP3.
Task 2.6 Overall system architecture	Characterization of metering equipment.	Help with definition of overall architecture, to define the needed interactions between grid operators' assets (data, grid, etc.) and the developed applications
WP3 Tool for low-voltage grid modelling	Data characterization and structure to feed the three LV network scenarios identified in Task 2.4	Provide needed input for the LV grid modelling
WP4 Software applications for efficient operation & maintenance of the grid	Data characterization and structure to feed the 5 software tools for efficient O&M of the grid	Provide needed input for Specifications definition in WP4 tasks (each one devoted to 1 software tool)
WP5 Software applications for an effective grid planning	Data characterization and structure to feed the 5 software tools for effective grid planning	Provide needed input for Specifications definition in WP5 tasks (each one devoted to 1 software tool)

TABLE 1: INPUTS TO RELATED TASKS AND WPS.

2. METHODOLOY IMPLEMENTED

This report presents a benchmark analysis of AMI and other sensors usually available in low voltage grids.

The starting point for the study is an analysis of the current status (state of the art) of metering systems, addressing:

- Related standards
- Architecture of smart metering systems
- Data provided: electric energy consumption, power outage notification, etc.
- Functionalities provided to DSOs: remote reading, bidirectional communication allowing maintenance and control, readings frequency should allow networking planning, etc.
- Other functionalities provided: signal quality, distributed generation control and distributed storage control, billing, demand response, etc.
- Communication technologies: wired and wireless

Then, available metering infrastructure from the three pilots present in the project (DTU SYSLAB facilities, CUERVA living lab & distribution network, ORES distribution network) has been reviewed to assess to what extent this infrastructure will be useful for subsequent developments in the project in which smart metering infrastructure will be present.

3. CURRENT TRENDS FOR AMI IN SMART GRIDS

3.1. INTRODUCTION

It is a widely accepted fact that Smart grids (SG) can contribute to achieve the efficiency objectives set by the European Commission. A core element of SGs is the Advanced Metering Infrastructure (AMI), which consists of the hardware and software for measurement and remote communication. Main part of this infrastructure is the smart meter (SM), an electronic device that records consumptions and sends recorded data to the energy distribution company for monitoring and billing purposes.

First metering devices allowed utilities to remotely read consumption records, together with basic information related to the status of the customers' premises. They were called Automated Meter Reading (AMR) and provided one-way communication.

Current smart metering infrastructure provides utilities with bidirectional communication to the meter, and also with the possibility to remotely evaluate the status of the grid. Recent Smart Metering systems are equipped with an improved architecture and are able to interact with smart sensors and more sophisticated distribution control technology, that allows utilities to perform grid control and management.

An overview of the evolution of AMI is given in Figure 1.

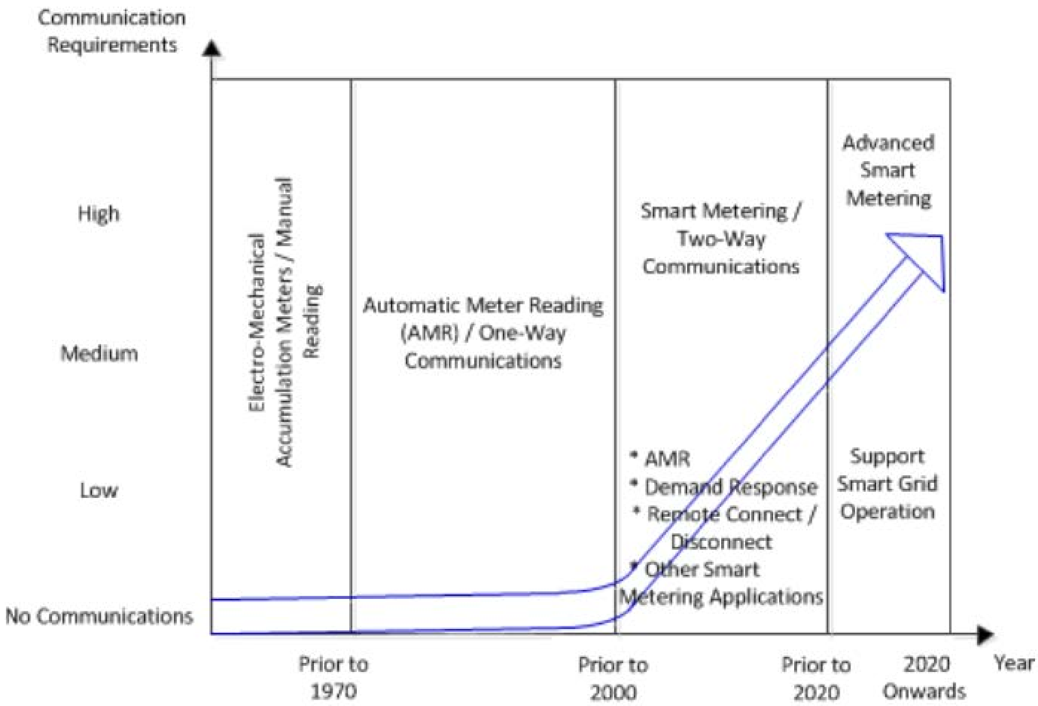

FIGURE 1: EVOLUTION OF SMART METERING INFRASTRUCTURE (SOURCE: EKANAYAKE 2013[1]).

3.1. ARCHITECTURE OF SMART METERING SYSTEMS

AMI is the integration of many technologies that provide a fully configured infrastructure that must be integrated into utility processes and applications. AMI provide system operators with the ability to improve consumer service by refining operating and asset management processes based on AMI data.

Through the integration of these technologies (such as smart metering, home area networks, integrated communications, data management applications, and standardized software interfaces) with existing utility operations and asset management processes, AMI provides an essential link between the grid, consumers and their loads, and generation and storage resources.

AMI is composed by several elements from the customer side until the utility (see Figure 2) which will be described briefly below. A smart metering system can be reduced to 4 basic components[2]:

- Smart Meter (SM)
- Communication system used for data flow
- Data gathering device, Data Concentrator (DC)
- Centralized management and control system, Control Center (CC)

[1] J. Ekanayake and K. Liyanage, "Smart grid technology and applications", First edit. New Delhi, 2013.

[2] N. Uribe-Pérez, L. Hernández, D. de la Vega, I. Angulo, "State of the Art and Trends Review of Smart Metering in Electricity Grids", Appl. Sci. 2016, 6, 68.

An AMI system is comprised of a number of technologies and applications that have been integrated to perform as one:

- Smart meters
- Wide-area communications infrastructure
- Home (local) area networks (HANs)
- Meter Data Management Systems (MDMS)
- Operational Gateways

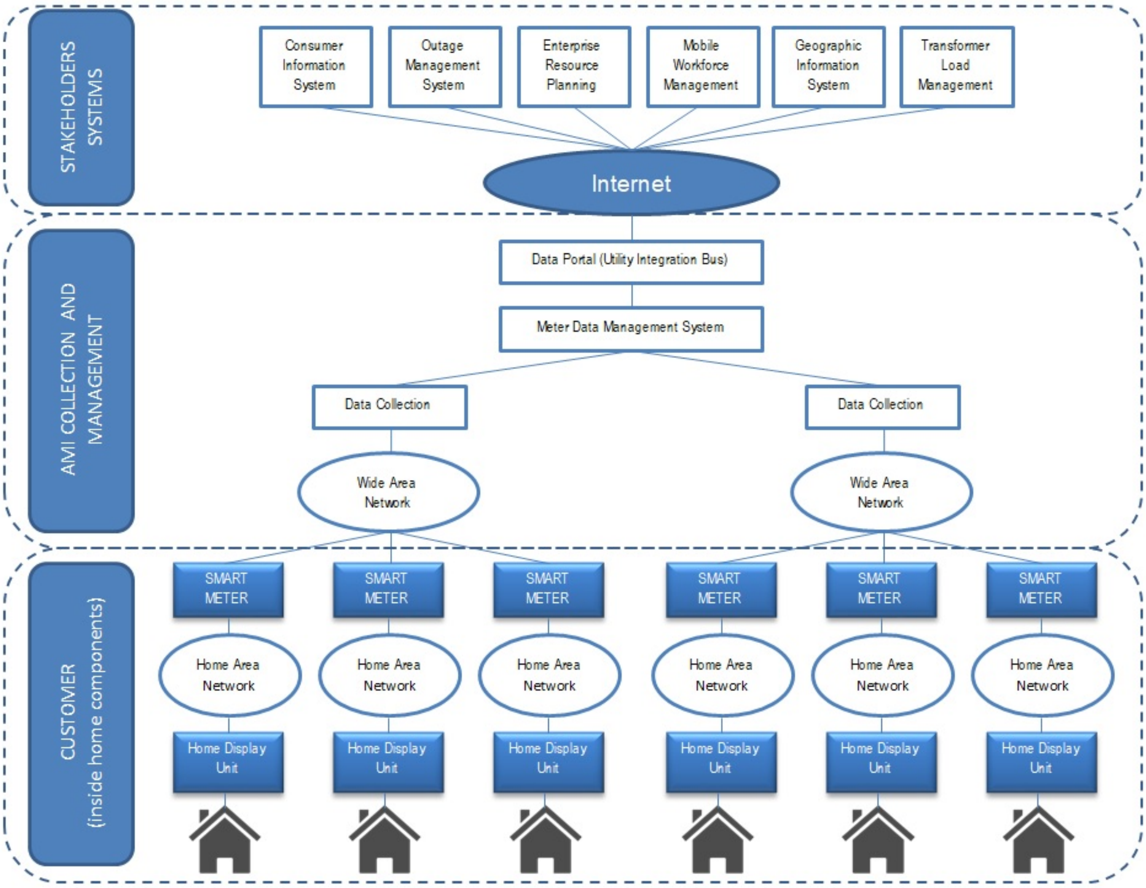

FIGURE 2: ADVANCED METERING INFRASTRUCTURE SCHEME (SOURCE: [3],[4]).

[3] A. Braeken, P. Kumar, A. Martin, "Efficient and Provably Secure Key Agreement for Modern Smart Metering Communications", Energies 11, no. 10: 2662, 2018.

[4] R. Govindarajan, S. Meikandasivam, D. Vijayakumar, "Comparison of Smart Energy Monitoring Systems in Real-time for Future Smart Grid", International Conference on Artificial Intelligence, Smart Grid and Smart City Applications, (AISGSC 2019), 2019, Available online [last visit: 02/03/2020]: https://www.researchgate.net/publication/337945351_Comparison_of_Smart_Energy_Monitoring_Systems_in_Real-time_for_Future_Smart_Grid

3.1.1. SMART METERS

Traditional electromechanical meters, at residential level, simply recorded the total energy consumed over a period of time – typically a month. Modern smart meters are solid state programmable devices that perform most or all the following functions:

- Time- based pricing
- Consumption data for consumer and utility
- Net metering
- Loss of power (and restoration) notification
- Remote limiting for “bad pay” or demand response purposes
- Energy prepayment
- Power quality monitoring
- Tamper and energy theft detection
- Communication with other intelligent devices in the home

Smart meters enable demand response that can lead to emissions and carbon reductions. Moreover, they facilitate greater energy efficiency since information feedback has been shown to cause consumers to reduce energy consumption.

In Figure 3 a general structure of a smart meter is illustrated, which mainly includes sensors, interface, communication, microcontroller and power management. Due to the general requirement to be outage-proof, the meter will have an internal power source.

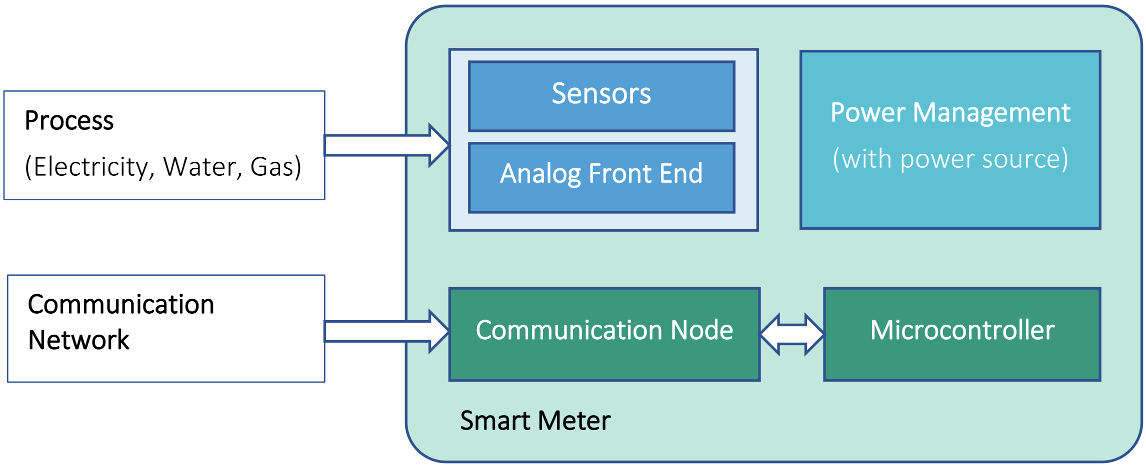

FIGURE 3: GENERAL ELEMENTS OF A SMART METER (SOURCE: CARRIERO2020[5]).

3.1.2. COMMUNICATIONS INFRASTRUCTURE

The AMI communications infrastructure supports continuous interaction among the utility, the consumer and the controllable electrical load. Open bidirectional communication standards are required, and security must be ensured. It has the potential to also serve as the basis for many other

[5] C. Carriero, M. Bissanti, “Wireless Technologies for Smart Meters", Online available [visited: 02/03/2020]: https://www.analog.com/en/technical-articles/wireless-technologies-for-smart-meters.html#

modern grid functions beyond AMI. Various architectures can be employed, being one of the most common the local concentrators that collect data from groups of meters and transmit that data to a central server via a backhaul channel. Various media can be considered to provide part or all of this architecture:

- Power Line Carrier (PLC)
- Broadband over power lines (BPL)
- Copper or optical fiber
- Wireless (Radio frequency), either centralized or a distributed mesh
- Internet
- Combinations of the above

Home Area Networks (HAN):

A HAN interfaces with a consumer portal to link smart meters to controllable electrical devices. Its energy management functions may include:

- In-home displays so the consumer always knows what energy is being used and what it is costing
- Responsiveness to price signals based on consumer-entered preferences
- Set points that limit utility or local control actions to a consumer-specified band
- Control of loads without continuing consumer involvement
- Consumer over-ride capability

A HAN may be implemented in a number of ways, with the consumer portal located in any of several possible devices including the meter itself, the neighbourhood collector, a stand-alone utility-supplied gateway or even within customer-supplied equipment.

Wide Area Networks (WAN):

These networks cover a broader area and they allow various groups of smart meters from different LANs communicate the data collected to the data concentrator or head end.

3.1.3. DATA CONCENTRATOR (DC) OR HEAD END

The DC is responsible for putting together all data from a large number of smart meters. Most EU member states have adopted this Data Concentrator as a middleware, between the smart meter and the Meter Data Management System (MDMS). The DC is located at the Medium/Low Voltage substations and works as a communication gateway.

3.1.4. METER DATA MANAGEMENT SYSTEM (MDMS)

A MDMS is a database with analytical tools that enable interaction with other information systems (see Operational Gateways below) such as the following:

- Consumer Information System (CIS), billing systems, and the utility web site
- Outage Management System (OMS)
- Enterprise Resource Planning (ERP) power quality management and load forecasting systems
- Mobile Workforce Management (MWM)
- Geographic Information System (GIS)
- Transformer Load Management (TLM)

One of the primary functions of an MDMS is to perform validation, editing and estimation (VEE) on the AMI data to ensure that despite disruptions in the communications network at customer premises, the data flowing to the systems described above is complete and accurate.

Operational gateways:

AMI interfaces with many system-side applications to support:

- Advanced Distribution Operations (ADO)
    - Distribution Management System with advanced sensors (including PQ data from AMI meters)
    - Advanced Outage Management (real-time outage information from AMI meters)
    - DER Operations (using Watt and VAR data from AMI metes)
    - Distribution automation (including Volt/VAR optimization and fault location, isolation, sectionalization and restoration (FLISR)
    - Distribution Geographic Information System
    - Application of AMI communications infrastructure for:
        - Micro-grid operations (AC and DC)
        - Hi-speed information processing
        - Advanced protection and control
        - Advanced grid components for distribution
- Advanced Transmission Operations (ATO)
    - Substation Automation
    - Hi-speed information processing
    - Advanced protection and control (including distribution control to improve transmission conditions)
    - Modelling, simulation and visualization tools
    - Advanced regional operational applications
- Advanced Asset Management (AAM)
    - AMI data will support AAM in the following areas:
    - System operating information
    - Asset "health" information
    - Operations to optimize asset utilization
    - T&D planning
    - Condition-based maintenance
    - Engineering design and construction
    - Consumer service
    - Work and resource management

3.2. DATA PROVIDED

Smart meter data is used primarily for billing, but its value for energy and network management is being exploited increasingly. Therefore, metering data can be classified by its purpose as follows (for more details regarding functionalities, see next section):

- Billing
  - Typical time resolution 1h (also 15 or 30 possible)
  - Data collection daily (also possible weekly or monthly)
- Grid management
  - The time resolution at least equal to the market or imbalance settlement period
  - Possibility to provide data to 3rd parties
- Consumer services (energy efficiency, demand-side management)
  - Dedicated device for data collection (incl. user interface, smart phone APP)
  - Third-party energy service company involved
  - Near real-time (seconds) possible

	Single phase	Dual phase	Three phase
Number of voltage and current measurements	1	2	3
Common applications	EU residential meters	US residential meters	Industrial and commercial meters

TABLE 2: BASIC TYPES OF SMART METERS, CLASSIFIED BY NUMBER OF PHASES INVOLVED.

The main measurements (data quantities) captured by Smart Meters can be summarized in the list below:

- Active, Reactive and Apparent Energy (kWh, kVAh, kVARh)
- Active, Reactive and Apparent Power (kW)
- RMS, Peak Values of voltage (V) and current (A)
- Line frequency (Hz)
- Power factor (cos φ – ratio of working power to the apparent power)
- Temperature
- Status (Flags on data quality, interruptions, intrusion, etc.)

3.3. FUNCTIONALITIES PROVIDED

In Europe, the first regulation covering the smart metering legislation is found in Directive 2009/72/EC. The EU has set common minimum functionalities for smart meters, included in the Recommendation 2012/148/EU. These functionalities capture the essential elements that a smart meter requires to benefit all stakeholders, and are summarized in Table 3.

Stakeholder	Functionalities
Consumer	Provide readings directly to the consumer and/or to a third party Update these readings frequently enough so as to use energy savings schemes
Metering operator	Allow remote reading by the operator Provide two-way communication for the maintenance and control Allow frequent enough readings for networking planning
Commercial aspects of supply	Support advanced tariff system Remote on/off control supply and/or flow or power limitation
Security & Data protection	Provide secure data communication Fraud prevention and detection
Distributed generation	Provide import/export and reactive metering

TABLE 3: TEN COMMON MINIMUM FUNCTIONALITIES FROM SMART METERS.

These ten recommended functionalities are the outcome of the Commission consultation. They are based on those proposed under the standardization mandate M/441 (identified in CEN-CLC-ETSI TR 50572:2011 ‘Functional reference architecture for communications in smart metering systems"). ERGEG has proposed advisory measures concerning the meters for electricity and natural gas. To conform to these requirements, smart meters should at the very least provide the following services:

Furthermore, as mentioned in Uribe2016[2], the European Union provides minimum desirable requirements for electricity SM as published in 2012/148/EU recommendation, which agree very closely with those shown in Table 3.

Relevant for DSOs:

- Remote reading of metrological register(s) and provision to designated market organizations.
- Two-way communication between the metering system and designated market organization(s).
- To support advanced tariffing and payment systems.
- To allow remote disablement and enablement of supply and flow power limitation.

Relevant for Consumers:

- To provide secure communication enabling the smart meter to export metrological data for display and potential analysis to the end consumer or a third party designated by the end consumer.
- To provide information via web portal/gateway to an in-home/building display or auxiliary equipment.

Added-value functions or new services based on digital metering are shown below, distinguishing between basic and advanced monitoring:

Basic monitoring functionalities

- Online access to the consumption and cost data
- Bills based on actual consumption
- Simple change of supplier or service provider is supported

Advanced monitoring functionalities (for Consumers)

- Alarm functionalities (interruptions, high consumption)
- Diagnostic monitoring (detection of the inconsistent metering results)
- Interface to home automation systems
- Communication channel for the reception of the grid operator/supplier messages (for demand response: dynamic price tariff, power limit, energy consumption performance indicators)

Grid safety, stability & maintenance (for DSO)

- Remote power capacity reduction/increase
- Remote (de)activation of the power supply
- Remote upgrade of the smart meter software

Within INTERPERTER there is a special emphasis on added-value services that can be obtained from the information, Distribution System Operators (DSO) are obtaining from smart meters. The focus here is centered on DSOs, as a general trend in Europe is that DSOs own the equipment, as this avoids difficulties when customers switch energy supplier and centralized data management is more effective. Also, maintenance and upgrades are more efficient if DSOs are owning the meters.

3.4. COMMUNICATION TECHNOLOGIES

Communications technology is the most complex physical component of the Smart Grid architecture, consisting of communication network components that enable the flow of information throughout the grid. Typically employed two-way communications technologies are:

- Power line carrier (PLC)
- Radio frequency (RF) point-to-multipoint and mesh
- Cellular

PLC is the most popular choice in the electricity sector, as the power-line carrier is available for free. Nevertheless, technology adoption varies by region.

Technology	Advantages	Disadvantages
PLC	Cost effective Use of existing infrastructure	Network interferences Lower bandwidth
RF point-to-multipoint	Small infrastructure (easy deployment) No interferences (licensed networks)	Requires installation/leasing of towers Lack of redundancy (all depends on one or very few transmission towers) Licensing required (low bandwidth, cost)
RF mesh	Distributed design Self-healing (multiple communication paths) Self-forming	Requires more infrastructure Concerns of interference with unlicensed RF frequencies (regulatory restrictions)
Cellular	Fast deployment (using existing infrastructure) Scalable for targeted applications Proven technology Security	May require changes at control centres (cost) Issues of obsolescence (3G, 4G, 5G) Availability critical, if public networks are used (sensible to natural disasters)

TABLE 4: OVERVIEW OF MOST COMMON COMMUNICATION TECHNOLOGIES FOR AMI SYSTEMS.

Concentrating on PLC and Cellular options, in Table 6 maximum theoretical data rates and possible coverage ranges are shown.

Technology	Maximum data rate	Coverage Range
PLC (narrow-band)	10-500 kbps	< 3 km
PLC (broadband)	14-200 Mbps	< 200 km
Cellular 3G	2 Mbps	< 50 km
Cellular 4G	100 Mbps	< 50 km

TABLE 5: SELECTION OF FEATURES FOR PLC AND CELLULAR COMMUNICATION (SOURCE AKPOLAT2017[6]).

[6] A.N. Akpolat, E. Dursun, "Advanced Metering Infrastructure (AMI): Smart meters and new technologies", in Proc. of 8th International Advanced Technologies Symposium IATS'17, 2017.

3.5. RELATED STANDARDS

The overall smart grid system needs widely accepted standards to allow the integration of advanced applications, smart meters, smart devices and renewable energy sources. Grid standardization, once fully achieved, will lead to seamless interoperability, robust information security, increased safety of new products and systems, compact set of protocols and communication exchange.

There are many attempts to achieve this. Worth to be mentioned are: The European Strategy Energy Technology Plan, the American National Standards Institute (ANSI), the International Electro technical Commission (IEC), the Institute of Electrical and Electronics Engineers (IEEE), the International Organization for Standardization (ISO). Additionally, CEN, CENELEC and ETSI have formed a Joint working group for smart grid standardization efforts and aim to achieve the European Commission's policy objectives regarding the smart grid.

In this sense, the European Commission according to the M/441 mandated the 3 European Standards Organizations (ESOs) to develop an open architecture for utility meters involving communication protocols enabling interoperability (smart metering). This was foreseen as requiring European Standards to enable the interoperability of utility meters to improve customer awareness of their actual consumption.

3.5.1. REVENUE METERING INFORMATION MODEL

ANSI C12.19: American standard for utility industry end device data tables. This standard defines a table structure for data transmissions between an end device and a computer for utility applications using binary codes and XML content.

M-Bus: European standard that provides the requirements for remotely reading all kinds of utility meters. The utility meters are connected to a common master that periodically reads the meters via M-bus. The wireless version is Wireless M-bus.

ANSI C12.18: American National Standard specifically designed for meter communications and responsible for two-way communications between smart electricity meters (C12.18 device) and a C12.18 client via an optical port.

3.5.2. BUILDING AUTOMATION

BACnet: Standard communication protocol developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) for building automation and control networks and support the implementation of intelligent buildings with full integration of computer-based building automation and control systems from multiple manufacturers.

3.5.3. SUBSTATION AUTOMATION

IEC 61850 is a flexible, open standard that defines the communication between devices in transmission, distribution and substation systems. To enable seamless data communications and information exchange between the overall distribution networks, it is aimed to increase the scope of IEC 6180 to whole electric network and provide its compatibility with Common Information Model (CIM) for monitoring, control and protection applications. This technology is implemented by modern manufacturers in their latest power engineering products like distribution automation nodes/grid measurement and diagnostics devices.

3.5.4. POWERLINE NETWORKING

HomePlug is a power line technology and the existing home electricity is used to connect the smart appliances to HAN; HomePlug Command and Control (HPCC) version is designed for low-cost applications. HomePlug is a promising technology to create a reliable HAN between electric appliances and a smart meter.

HomePlug Green PHY specification is developed as low power, cost-optimized power line networking specification standard for smart grid applications used in home area networking by the Smart Energy Technical Working Group within the HomePlug Powerline Alliance. The inputs for optimization of specifications for field tests were gathered from many utilities. Backwards interoperability, lower data rate and IP networking support, low power consumption, full interoperability with both HomePlug devices and the leading features of HomePlug Green PHY specification.

PRIME is an open, global power line standard that provides multivendor interoperability and welcomes several entities to its body. Advanced Digital Design, CURRENT Group, Landis+Gyr, STMicroelectronics, uSyscom and ZIV Medida are some of the current companies that have extensive experience in PLC technology and smart metering.

G3-PLC is a power line communications specification launched by ERDF and Maxim that aims to provide interoperability, cyber security and robustness and reduce infrastructure costs in smart grid implementations worldwide.

3.5.5. HOME AREA NETWORK DEVICE COMMUNICATION MEASUREMENT AND CONTROL

U-SNAP: There have been a variety of incompatible standards for HAN. This lack of standardization in HAN Utility has driven major AMI suppliers and product manufacturers to develop a solution, namely Utility Smart.

3.5.6. SUMMARY OF SMART GRID AND AMI COMMUNICATION STANDARDS

In Table 7, a summary of main smart metering communication standards is given. A more detailed overview is presented in Table 8, considering the OSI layer mapping.

Type	Standards
PLC	PLAN, AMIS, Meters&More, LON/OSGP, PRIME, G3, G.9902, 1901.2
Wireless	GSM/GPRS, UMTS, LTE, MeshNet3, Flexnet, KamstrupRF, 802.15.4
Application (only upper layer of the OS)	DLMS/COSEM, oneM2M

TABLE 6: MAIN SMART METERING COMMUNICATION STANDARDS.

Standards / OSI Stack	PLC standards										Wireless standards						
						Application standards											
	P-LAN	1901.2	G.9902	PRIME	G3	AMIS	Meters& More	LON/OSGP	DLMS/ COSEM	oneM2M	Meshnet3	Kamstrup RF	Flexnet	802.15.4	GSM/GPRS	UMTS	LTE
7 Application						AMIS	Meters& More	GS OSG 001	IEC 62056-6-2 IEC 62056-6-1 IEC 62056-5-3	based on ETSI TR 102 691	Meshnet3	Kamstrup RF					
6 Presentation						AMIS	Meters& More				Meshnet3	Kamstrup RF					
5 Session						AMIS	Meters& More				Meshnet3	Kamstrup RF					
4 Transport					UDP: IETF RFC 768	AMIS	Meters& More		TCP/IPIEC 62056-47		Meshnet3	Kamstrup RF					
3 Network					IPv6: IETF RFC 2460	AMIS	Meters& More	EN14908-1 (LONWorks)			IPv4	Kamstrup RF					
2 Data Link	IEC 61334-4-32	IEEE P1901.2	ITU G.9902	IEC 61334-4-32 + ITU G.9904 PRIME MAC	6LoWPAN Adaptation: IETF RFC 4944 + ITU G.9903 G3 MAC (based on IEEE 802.15.4 - 2006)	CX1	Meters& More (based on IEC 61334-4-32)	ISO/IEC 14908 (LONWorks)			Meshnet3	Kamstrup RF	Flexnet	IEEE 802.15.4e	GSM/GPRS	UMTS	LTE
1 Physical	IEC 61334-5-1	IEEE P1901.2	ITU G.9902	ITU G.9904 PRIME PHY	ITU G.9903 G3 PHY	CX1	Meters& More CLC/prTS 50568-4	ETSI TS 103 908 (modified 14908-3 LONWorks)			Meshnet3	Kamstrup RF	Flexnet	IEEE 802.15.4g	GSM/GPRS	UMTS	LTE

Table 7: Overview of AMI communication standards (Source: Erlinghagen2015[7]).

[7] S. Erlinghagen, B. Lichtensteiger, and J. Markard, "Smart meter communication standards in Europe - a comparison," Renewable and Sustainable Energy Reviews, vol. 43, pp. 1249–1262, 2015.

Standards	Details	Application
IEC 61970 IEC 61969	Provide Common Information Model (CIM): IEC 61970 is related to the transmission domain IEC 61969 deals with the distribution domain	Energy Management Systems
IEC 61850	Flexible future proofing, open standard, communication between devices in transmission, distribution and substation automation systems	Substation Automation
IEC 60870-6 / TASE.2	Data exchange between utility control centers, utilities, power pools, regional control centers	Inter-control center communications
IEC 62351 Parts 1-8	Define cyber security for the communication protocols	Information security systems
IEEE P 2030	A guide for smart grid interoperability of energy technology and IT operation with the electric power system (EPS)	Customer-side applications
IEEE P 1901 (HomePlug)	High speed power line communications	In-home multimedia, utility and smart grid applications
ITU-TG 9955 & G.9956	ITU-T-G.9955 and G.9956 contain the physical layer specification and the data link layer specification	Distribution Automation, AM
OpenADR	Dynamic pricing, Demand Response	Price Responsive and Load Control
BACnet	Scalable system communication at customer side	Building automation
U-SNAP	Providing many communication protocols to connect HAN devices to smart meters	HAN
ISA100.11a	Open standard for wireless systems	Industrial Automation
SAE J2293	Standard for the electrical energy transfer from electric utility to EVs	Electric Vehicle Supply Equipment
ANSI C12.22	Data network communications are supported and C12.9 tables are transported	AMI
ANSI C12.18	Data structures transportation via the infrared optical port han	AMI
ANSI C12.19	Flexible metering model for common data structures and industry “vocabulary” for meter data communications	AMI
Z-Wave	Alternative solution to ZigBee that handles de interference with 802.11/b/g	HAN
M-Bus	European standard and providing the requirements for remotely reading all kinds of utility meters	AMI
PRIME	Open, global standard for multi-vendor interoperability	AMI
G3-PLC	Providing interoperability, cyber security and robustness	AMI
SAE-J2836	Supporting use cases for plug-in electric vehicles communication	Electric Vehicle
SAE J2847	Supports communication messages between PEVs and grid components	Electric Vehicle

TABLE 8: OVERVIEW OF SMART GRID STANDARDS.

4. AVAILABLE METERING INFRASTRUCTURE FOR TESTING AND VALIDATION IN INTERPRETER PROJECT

Information from the three pilots has been collected and is included in this section.

According to the **manufacturing date**, there are **two main types** of smart meters – the older models known as SMETS 1 (Smart Meter Equipment Technical Specifications) and the newer versions that were rolled out in 2018, known as SMETS 2.

- SMETS 1 – Most of these communicate with the supplier through the 3G mobile network.
- SMETS 2 – This specification is more advanced and meters were first rolled out in 2018. A purpose built communication network is used with these meters.

There's a different classification according to the **level of energy consumption and usage** supported:

- GISM (230v): This model is known as a 'single-phase' smart meter.
- GIST (3*230/400v): This model is known as a 'three-phase' smart meter.
- GISS: This is a specialized meter that is installed only for heavy-usage customers.

In most cases, utility companies will require a mixture of all three types – GISM, GIST, and GISS – depending on the demographics of their specific service area.

The successful implementation of a Smart Metering system highly relies on the choice of **communication technology**. Different aspects such as the final application, the features of the location, and the topology electricity grid, among others, highly influence the choice of the most suitable technology.

Two main groups can be distinguished in Smart Metering technologies: wireless and wired. Wireless technologies usually entail less deployment costs and quicker installation than wired options. Additionally, they are more suitable for remote or hardly accessible locations. However, wired alternatives for Smart Metering do not present interference problems from other sensors of the network that may occur in wireless technologies.

Despite the fact that most European countries use wired alternatives, cellular networks, especially GPRS, can also be found in some deployments. Other commonly used wireless technologies are ZigBee, 6LoWPAN, and Bluetooth (based on IEEE 802.15 standard). Among the existing wired technologies for Smart Metering systems, Power Line Communication (PLC) is one of the most widespread technologies and the most used in Europe and China

Data retrieved from smart meters is used for billing and grid management, usually measured every 15/30/60 minutes, stored in the meter and collected every day/week/month. The time resolution of this data should at least be equal to the market or imbalance settlement period. This data can also be provided to 3rd parties on regular basis (not real time) that have consumer's consent to retrieve that data.

4.1. DTU SYSLAB FACILITIES

PowerLabDK[8] is a joint venture between DTU and the energy company of the Bornholm island (Bornholms Energi & Forsyning) to support the technology development, testing, training and demonstrations that contribute to the development of a reliable, cost efficient and sustainable energy system based on renewable energy sources. The facilities contain flexible test laboratories, large-scale experimental facilities and a complete full-scale power distribution system on the Island of Bornholm, which also serves as a data source and platform for full-scale and real-life experiments. The Smart Community Bornholm facilities allow the test and demonstration of Smart Grid and other technologies under realistic and stressed conditions, corresponding to future renewable-based energy systems.

SYSLAB[9] is a flexible intelligent laboratory for distributed energy resources. Research and testing of control concepts and strategies for power systems with distributed control and integrating a number of decentralized production and consumption components including wind turbines and PV-plant in a systems context.

Parameter	Value
SMETS 1 or SMTES 2?	N/A
GISM / GIST/ GISS /other?	N/A
If other, please specify	DEIF MIC -2 MKII with CT- class 0.5
Communication technology used?	Ethernet AXM-net
Communication protocol used?	Modbus RTU
Data provided: electric energy consumption, power outage notification, power quality monitoring, etc.?	Multi instrument ± kW, kVAr, kVA ± kWh, kVArh, kVAh voltage, current, PF, harmonics etc
Billing: contracted power and location	5 supply points- billing campus service
How is it stored?	On SYSLAB SW platform
Frequency to collect and store this information?	Every 1 s
Time resolution of this data?	1 s
Location in the network	At every bay
Are Home Area Networks used to manage smart meters communication?	yes
Brand and model of equipment	SYSLAB SW platform

TABLE 9: SPECIFICATIONS FOR AMI IN DTU SYSLAB FACILITIES.

[8] http://www.powerlab.dk/

[9] https://www.elektro.dtu.dk/english/research/research-facilities/syslab-risoe-pldk

4.2. CUERVA LIVING LAB & DISTRIBUTION NETWORK

Grupo Cuerva is a small DSO located in the South of Spain supplying energy to over 35,000 people in rural areas characterised by a difficult terrain (very mountainous), which poses important challenges to the operation and extension of the grid infrastructure. Cuerva's grid is composed by more than 870 km of power lines, 470 secondary substations, 1 primary substation and a total of 101,300 KVA of installed capacity. A portion of the distribution network operated by Grupo Cuerva in the region of Granada will be used as the main electricity infrastructure to validate INTERPRETER platform and tools. The MV distribution grid is connected to the ENDESA HV network by a substation also operated by Grupo Cuerva. This distribution network feeds two small communities: Escúzar and Láchar.

Láchar area has a peak load close to 3 MW, mostly residential consumers, and a photovoltaic generation of 3.6 MW peak. Due to its small size and isolatable conditions, this area is ideal for exploring microgrid related use cases or testing different early stage approaches for distribution grid operation, since a significant impact can be achieved only with low capacity control and storage devices, as well as with small number of participant consumers. The Escúzar area has a peak load of 13 MW and photovoltaic power plant of 4.3 MW peak. This part of the grid will be used to explore use cases involving grid scale control and storage technology and massive consumers participation. Also, the connection with the substation can be used to explore bottom-up energy services, i.e. from the distribution to the transmission system.

The Grupo Cuerva network expansion plans were considered in the selection of these two to become the Living Lab distribution grid. These plans include a direct connection with the Red Eléctrica de España (REE) transmission grid and two new transformers feeding the areas of Láchar and Escúzar. That will allow multiple configurations of the HV and MV network, providing flexibility to test different grid operation scenarios.

Parameter	Value
SMETS 1 or SMTES 2?	SMETS 1
GISM / GIST/ GISS /other?	GISM / GIST
If other, please specify	NA
Communication technology used?	PLC
Communication protocol used?	PRIME - DLMS
Data provided: electric energy consumption, power outage notification, power quality monitoring, etc.?	Electric Energy Consumption (active and reactive energy) Meter Events
Billing: contracted power and location	Yes
How is it stored?	FTP / Datalake
Frequency to collect and store this information?	Daily
Time resolution of this data?	Hourly
Location in the network	Yes
Are Home Area Networks used to manage smart meters communication?	No
Brand and model of equipment	ZIV, SAGEMCOM

TABLE 10: SPECIFICATIONS FOR CUERVA AMI.

Data source	Values / Description
Secondary substation readings (consumption and generation)	Data from the Concentrator: Active and Reactive energy consumed per hour Voltage and Currents at the top of LV side of the transformer
Feeder mapping measurements	Only relation between meter and feeder, not known the phase of monophasic meters.

TABLE 11: SPECIFICATIONS FOR OTHER DEVICES AT CUERVA PILOT.

4.3. ORES DISTRIBUTION NETWORK

ORES is the largest DSO for electricity and gas in Wallonia (Belgium), providing service to 75% of the customers in the region (1,3 million customers, representing more than 2,5 million people), both in rural areas and in small and medium-size urban areas, including Namur (110,000 inhabitants), Mons (95,000) and Charleroi (200,000).

ORES manages an electricity grid of almost 50,000 Km (20,000 Km on MV and 30,000 Km on HV) with more than 140 primary substations connected to ELIA HV network and 22,000 secondary substations. The renewable capacity directly installed on ORES's grids reaches more than 1,500 MVA; 580 MVA from these come from 106,000 small (< 10kVA) photovoltaic units. 9% of the customers are in the LV grid.

The smart meters roll out will begin in 2,023 in Wallonia. Despite this, several portions of the grid are already equipped with smart meters on technological or research purposes, for instance in the rural town of Flobeck (40% PV penetration) or in the semi-urban town of Saint-Ghislain to check non-technical losses. The pilot(s) for INTERPRETER project will be located in one of these areas or in a new one equipped on purpose.

As regards AMI infrastructure currently available in ORES pilot, for use within INTERPRETER project, there are two types of equipment:

- AMI (Landis&Gyr) actually used in the Smart-Metering Pilot. This will be used to provide some data information (Index, Load profile).
- AMI (Sagemcom) will be used to start the smart-metering deployment in Wallonia.

Parameter	Flobecq Pilot	Roll-Out starting solution
SMETS 1 or SMTES 2?	N/A in Belgium	N/A in Belgium
GISM / GIST/ GISS /other?	GISM / GIST	GISM / GIST
If other, please specify	NA	NA
Communication technology used?	GPRS	NB-IoT (LTE Cat NB1)
Communication protocol used?	DLMS/COSEM	DLMS/COSEM
Data provided: electric energy consumption, power outage notification, power quality monitoring, etc.?	Electric active energy Offtake/Injection, Power outage and voltage thresholds information	Electric active energy Offtake/Injection
Billing: contracted power and location	Yes	Yes
How is it stored?	Landis+Gyr - Gridstream (Oracle DB)	Data as a Service (DaaS) – Sagemcom SICONIA
Frequency to collect and store this information?	Daily	Daily
Time resolution of this data?	15'	Day – SLA 3 15' – SLA 1 (future)
Location in the network	Yes	Yes
Are Home Area Networks used to manage smart meters communication?	No	No
Brand and model of equipment	Brand: Landis+Gyr Meter Model : ZxF (Meter Serie : E350 Com. Mod.: E35C (GPRS))	Brand : Sagemcom Meter Models : S211 (Mono) / T211 (Multi)

TABLE 12: SPECIFICATIONS FOR ORES AMI.

Data source	Flobecq Pilot	Roll-Out starting solution
Secondary substation readings (consumption and generation)	Yes Electric active energy Offtake/Injection, Power outage and voltage thresholds information, Voltage measurement	No
Feeder mapping measurements	Yes	No

TABLE 13: SPECIFICATIONS FOR OTHER DEVICES AT ORES PILOT.

5. ASSESSMENT OF AVAILABLE AMI AS INPUT FOR FORTHCOMING TASKS

The ultimate objective of INTERPRETER project is to develop a modular grid management solution consisting of a set of interoperable off-line and on-line software tools for an optimized design, planning, operation and maintenance of the electricity grid. These tools are to be developed in subsequent stages of the project, within WP4 (efficient operation & maintenance of the grid) and WP5 (effective grid planning).

The three pilots (see section 4) provide an invaluable infrastructure that will allow testing the 10 software tools that are to be developed in WP4 and WP5, in phase 5 (validation and testing) of the project.

Previous to these software tools, some steps will be taken through the characterization of representative use cases (task 2.4), the overall system architecture (task 2.6) and the implementation of a low-voltage grid modelling tool (WP3).

This section describes how AMI and other sensors present in the three pilots will be able to contribute to the testing and validation of the 10 software tools to be developed.

5.1. INPUT TO THE DETAILED CHARACTERISATION OF REPRESENTATIVE USE CASES

The current report, together with *D2.1 Description of existing and future issues affecting electricity grid management,* provide input to *task 2.4 Detailed characterisation of representative use cases,* in charge of defining a number of use cases that will be the basis of the subsequent work to be performed in the project. Availability and quality of information will lead to the characterization of a number of scenarios that will be used to build a grid model.

According to the information retrieved from the three pilots, there is a proper infrastructure in place, able to provide enough and accurate data, with the required frequency in most of the cases. For those scenarios in which not enough data will be available simulation is considered a valid alternative. In this case, DTU SYSLAB facilities will be key.

According to the data provided by the three pilots, AMI installed is ready to provide:

- Smart metering readings: electric energy consumption (active and reactive energy), meter events (current, voltage, geographic location); billing details
- Secondary substation registers on consumption and generation; feeder mapping measurements.
- Geographic location and contracted power of supply points (customers) and geographic location of transformers.

5.2. INPUT TO THE OVERALL SYSTEM ARCHITECTURE

Task 2.6 Overall system architecture will be in charge of defining the global architecture of the project as the basis for the needed interactions between grid operators' assets and the developed applications (WP4 and WP5). To this aim, Task 2.2 is providing the characterization of the metering equipment from the three pilots that will be participating in phase 5 (testing and validation).

Specifications are ready and available regarding the communication technology, communication protocol and the kind of data that will be provided by the installed smart meters. Additionally, there are details from data from concentrators (active and reactive energy consumed per hour, voltage and currents at the top of LV side of the transformer).

5.3. INPUT TO THE TOOL FOR LOW-VOLTAGE GRID MODELLING

The main objective of *WP3 Tool for low-voltage grid modelling* is to provide a tool for the development of LV grid models that will be representing different levels of data availability, thus several realistic scenarios will be considered. In order to completely characterise these models, both static and dynamic information will be needed. Static data consists mainly of passive grid elements, such as cables and transformers. Dynamic one will be active control and grid reconfiguration, mainly.

Task 2.2 is contributing the data characterization and structure that will feed the grid models defined in WP3. All three pilot partners have already identified the information that will be provided through their AMI (smart meters, secondary substation readings, feeder mapping measurements). Simulation will be used when needed. Information related to the geographic location of supply points (customers) and transformers will be used as input to define the network topology in the LV grid models.

5.4. INPUT TO THE SOFTWARE APPLICATIONS FOR EFFICIENT OPERATION & MAINTENANCE OF THE GRID

5 software tools related to grid operation and planning are to be developed in WP4. The objective is to support DSOs (and TSOs) to manage their grids in a more efficient manner.

5.4.1. DETECTION OF NON-TECHNICAL LOSSES

Non-technical losses can be understood as irregularities or anomalies and frauds in the grid consumption measurement, which in the end are reflected in billing. Irregularities or anomalies can be attributed to accounting errors and record keeping by utility employees or an operator. Fraud can be performed by customers or adversaries.

Traditionally electricity theft was performed by customers by means of bypassing power lines. Nowadays, more sophisticated attacks can be performed to the AMI. Adversaries can use the two-way communication to gain illegal benefit, causing economic loss to the utility. This can be done by customers and by the outside adversaries, through remote control of smart meters.

Non-technical losses cannot be precisely calculated, only at global level. They are usually estimated as the difference between the total amount of energy fed into the distribution system and the total amount of energy recorded as sold to customers.

Deployment of smart meters allows quantification of overall losses at distribution transformers, and the data retrieved can be analysed through a number of methods in order to detect non-technical losses.

In INTERPRETER project, machine learning techniques will be employed to analyse the pattern of observed losses, in order to identify their origin. A software tool that will be developed within *T4.1 Detection of non-technical losses* and reported in *D4.1 Specifications and pseudocode for NTL detection* and *D4.2 Software application for NTL detection,* will need input from *T2.2 Characterisation of AMIs and other sensors connected to the grid.*

The pilot partners are ready to provide the needed input from the installed AMI infrastructure. More specifically:

- Smart metering readings: electric energy consumption (active and reactive energy), meter events (current, voltage, geographic location)
- Electric energy consumption (active and reactive energy), meter events (current, voltage, geographic location, power outage and voltage thresholds information)
- Geographic location of supply points (customers) and transformers.

The time resolution of the data can be from 15 minutes to one hour.

5.4.2. ANCILLARY SERVICES FOR DSO BASED ON VOLTAGE BALANCE AND CONGESTION

The accelerated penetration of Distributed Energy Resources and new forms of loads connected to the Medium and Low Voltage networks increase the complexity of overall grid operations. The bidirectional and uncertain flow of power may result in congestions at certain points in the distribution network. Consequently, assets are overloaded, voltage deviations can occur and cascading failures may take place. Therefore, the DSOs are compelled to investigate and optimize their asset investment cost by introducing smart grid functionalities in order to mitigate investments. Congestion management schemes have traditionally been treated in the transmission system level, but with the widespread use of Distributed Generators (DGs) and expected severe loading conditions, the management procedure will have to be applied in the distribution network as well. Tools to monitor and forecast possible congestions are needed at low voltage level.

INTERPRETER project aims to deal with this problem by means of simulations based on real LV grids with real load profiles and DER models. A LV energy management system will be a resulting outcome that will be capable of estimating in advance margins of grid operation, and calculating recommended corrective actions. An optimization tool will be developed taking as input grid losses, asset value and flexibility options to provide options to avoid grid congestions and maintain voltage levels within required limits.

A software tool that will be developed within *T4.2 Ancillary services for DSO based on voltage balance and congestion* and reported in *D4.3 Specifications and pseudocode for ancillary services for DSOs* and *D4.4 Software application on ancillary services for DSOs,* will need input from *T2.2 Characterisation of AMIs and other sensors connected to the grid.*

DTU’s SYSLAB will be used to demonstrate and test the developed methodologies, regarding the provision of ancillary services.

The pilot partners have already identified the required input from their AMI:

- Smart meters measurements: electric energy consumption (active and reactive energy), active energy injection and offtake. Data resolution should be 1 hour at least.
- Assignment of clients to specific transformers.

LV grid models developed in WP3 will be needed here.

5.4.3. DSO/TSO INTERACTION FOR ANCILLARY SERVICES EXTENSION

Frequency regulation and operational system reserves are generally dealt with at high-voltage level (TSO). However, it may be solved at low voltage level as long as there is flexibility of demand at LV level. If this is the case, several LV grids may coordinate to provide ancillary services, investigating the needs for information exchange between TSO, DSO, BRP and aggregators

A software tool will be developed within *T4.3 DSO/TSO interaction for ancillary services extension* and reported in *D4.5 Specifications and pseudocode for DSO/TSO interaction for ancillary services extension* and *D4.6 Software application for DSO/TSO interaction for ancillary services extension.*

The referred ancillary services will be developed in T4.2 (see previous section), thus the three testing labs will contribute in the way already described in section 5.4.2.

5.4.4. DEVELOPMENT OF PREDICTIVE MAINTENANCE STRATEGIES FOR GRID ASSETS

Distribution grid operators face a backlog of aging assets that are pending replacement. There's an increasing trend towards moving away from time-based maintenance planning of assets and developing instead a proactive and smarter asset health management program to meet the competing constraints of reducing customer downtimes, meeting regulatory standards, and managing ever-expanding infrastructure within budget.

In this regard, INTERPRETER project aims to provide Distribution System Operators (DSO) with accurate diagnostics regarding the lifespan and State of Health of the grid's assets, together with suggestions to improve and maintain it.

A software tool will be developed within *T4.4 Development of predictive maintenance strategies for grid assets* and reported in *D4.7 Specifications and pseudocode for predictive maintenance for grid assets* and *D4.8 Software application for predictive maintenance strategies for grid assets*

The pilot partners have already identified the needed input from the installed AMI infrastructure. More specifically:

- Smart metering readings: electric energy consumption (active and reactive energy, energy injection and offtake), meter events (current, voltage, geographic location)
- Electric energy consumption (active and reactive energy), meter events (current, voltage, geographic location, power outage and voltage thresholds information)

The grid model to be developed in WP3 will be of outmost importance here, as well as geolocation information and satellite imagery.

Field level equipment will be needed to acquire data from the grid's assets. Additionally, data from several sources will be needed, especially load and DER historical data.

5.4.5. GRID CONTROL OPTIMISATION AND SELF-HEALING

Grid control optimisation and self-healing aim at ensuring operation reliability and uninterrupted power supply. In this sense, during normal service the main purpose is to optimise the operation and eliminate the hidden trouble. On the other hand, when a fault has occurred the main objective will be to recover normal operating conditions as soon as possible. The outage area will be minimised and isolated by disconnecting the faulty area from the rest of the network.

As the complexity of the systems increases, it is more expensive and troublesome to correct the system faults and to get the system back to its normal operating state.

INTERPRETER project aims at developing a software tool based on a combination of machine learning, timeseries forecasting and optimization algorithms that will reconfigure the grid (electrically and physically) leading to maximum electricity distribution efficiency in the grid from forecasted load and generation. This will be achieved through calculation of the best possible grid exploitation configuration.

Two optimization problems will be solved:

- The distribution of load and generation in the grid
- The physical configuration of the network

Physical reconfiguration of the grid after a fault has occurred will start with the detection of the fault through fault-level currents and voltages detected on feeders and powerlines. Then, the section that contains the fault will be determined and isolated by means of remotely controlled switches, and the service will be restored in healthy sections.

In parallel, real time generation and load will be used to balance the grid so that electricity efficiency is maximized. This capability of the tool is needed due to the distributed nature of energy resources, even if no fault has occurred.

A software tool will be developed within *T4.5 Grid Control Optimisation and Self-Healing* and reported in *D4.9 Specifications and pseudocode for grid control optimisation and self-healing* and *D4.10 Software application grid control optimisation and self-healing assets*

The pilot partners have already identified the needed input from the installed AMI infrastructure. More specifically:

- Smart metering readings: electric energy consumption (active and reactive energy), meter events (current, voltage, geographic location)
- Electric energy consumption (active and reactive energy), meter events (current, voltage, geographic location, power outage and voltage thresholds information)
- Geographic location of supply points (customers) and transformers.

5.5. INPUT TO THE SOFTWARE APPLICATIONS FOR AN EFFECTIVE GRID PLANNING

5 software tools related to an effective grid planning are to be developed in WP5. The objective of these tools is to support DSOs to plan their grids in a more effective manner.

5.5.1. OPTIMAL REACTIVE POWER COMPENSATION

Transportation of electric energy to end users must be done within minimum standards of efficiency, quality and reliability, and this requires minimizing energy losses. Reactive power compensation is considered one of the best-recognized methods to compensate for these energy losses, while providing additional benefits such as power factor correction, increase of the transport and operation capacity of the grid, voltage stability and improvement of the voltage profile.

All the improvements associated with reactive power compensation in distribution grids have an investment and maintenance cost, which must be analysed together with the gains from energy loss reduction concepts provided by the compensating devices; in addition to the benefits of quality and reliability, which are also qualitative goals that are sought with the use of these devices.

INTERPRETER project aims at developing a software tool that will make use of topologies of distribution grids, identifying supply points with large reactive power demand, as well as requirements for voltage management. An optimal selection and location of reactive power compensating elements will be done to achieve a solution that contemplates an optimal location and dimensioning of reactive power compensating elements.

This software tool will be developed within *T5.1 Optimal reactive power compensation* and reported in *D5.1 Specifications and pseudocode for optimised reactive power compensation* and *D5.2 Software application for optimised reactive power compensation.*

Historical demand data and the grid model will be the main required inputs for this task. The grid model will be developed within WP3, while the historical data may be provided by pilot partners.

5.5.2. PLANNED PHASE BALANCING

A high degree of unbalance in electric distribution feeders can significantly affect power quality, damage electrical equipment, and result in tripping of protective devices. Phase balancing aims to reduce the unbalance of loads on three phases which can bring severe drops in the feeders. It is desirable for electric utilities and providers of electric power distribution systems to have approximately equal loads on each phase. Even if loads are initially balanced, with time loads may increase, decrease, be added or removed from each phase, thus causing unbalance of loads.

INTERPRETER project aims at developing a software tool that will propose either changes in the grid configuration or in the future planned infrastructure. The required inputs will be: the grid model developed in WP3 (for which highly accurate data will be needed), identification of clients connected at the different phases, renewable energy input and behaviour of flexible demand.

Pilot partners will provide historical data to feed this tool during the testing phase.

5.5.3. NODAL CAPACITY ALLOCATION

The increased integration of distributed energy resources (DER) into existing distribution networks is impacting to a great extent their behavior in terms of voltage profile, reliability and power quality. Knowledge of the nodal capacity of different grid nodes will allow us to determine the maximum amount of distributed generation that distribution grids can accommodate.

The distribution grid hosting capacity is defined as the amount of new production or consumption that can be added to the grid without adversely impacting the reliability or voltage quality for other customers.

INTERPRETER project aims at developing a software tool that will calculate the nodal capacity of different grid nodes to receive new DER, thus allowing for a safe integration of DER at system level. Inputs required will be multiple grid scenarios for which power flow is provided for different generation, together with load levels, and a contingency analysis strategy (usually performed for grid planning). The expected output will be new grid scenarios for which new locations of RES generation are considered, the nodal capacity of the selected grid nodes and the list of grid elements that may limit the nodal injections of the different grid nodes.

Pilot partners will provide useful data for the testing phase, mainly consisting of power flow scenarios and a set of nodes that may be considered as candidate nodes for the study. Simulations will be very valuable to test different situations with varying power flows and DER

5.5.4. DISPERSED STORAGE UNITS LOCATION OPTIMIZATION

Energy storage systems are a useful tool to optimize the energy efficiency of a distribution network. Overall network performance can be enhanced by their optimal placement, sizing and operation. An optimally sized and placed energy storage system can facilitate peak energy demand fulfilment, enhance the benefits from the integration of renewables and distributed energy sources, aid power quality management, and reduce distribution network expansion costs.

INTERPRETER project will develop a software tool to determine the sizing and siting of dispersed energy storage systems in electricity grids for congestion management purposes. Required inputs will be the network topology (grid model from WP3), time series for the multiple grid scenarios (generation and load, per node) typically used in grid planning studies (steady state analysis), cost references (e.g. energy storage technology costs) and a pre-selection of candidate nodes.

The output will be an application that will provide system operators (or other stakeholders) with different options to address network congestion from the locations and sizing of energy storage solutions adequate to the grid topology and scenarios considered, as well as a list of grid elements that limit the grid's capacity. These will help to identify possible grid bottlenecks and reinforcement needs in the near future.

Pilot partners will contribute to the testing phase in relation to this task through the provision of historical generation and load data per node (from AMI present in their networks). Simulations will be provided as well. All three partners will be also identifying relevant candidate nodes from their networks.

5.5.5. ENVIRONMENTAL AND ECONOMIC ASSESSMENT

LCA and LCC are useful methodologies to evaluate the environmental and economic assessment of the grid network. In smart grids, the demand response and distributed energy systems aim to provide a higher degree of flexibility for load-shifting operations and the leverage to control intermittent wind supply. In this context, the configuration of the network is experimenting continuous changes with associated environmental and economic impacts that must be evaluated in a reliable way.

INTERPRETER project will develop a software tool to this aim. An environmental and economic analysis of the current and planning grid structure will be studied. A comparative analysis will be presented based on specific and global applied grid performance indicators.

The required input will be the network technical specifications (network devices, network lines, distance between network components), the description of the DER, smart meter data, physical grid configuration (for MV and LV grids), the location and level of controllability of the network components, and all related costs (e.g. maintenance).

The expected output will be the resulting environmental and economic indicators that will be integrated in a potential decision planning tool.

In the context of the current report, for the testing phase pilot partners will provide information from the smart meters present in their networks (production, consumption, active power, reactive power, storage data) together with the physical grid configuration.

6. CONCLUSIONS

The current report presents a comprehensive analysis of current trends regarding the characterisation of Advanced Metering Infrastructure and other sensors connected to smart grids. Different aspects have been addressed: standards, architecture, related communication technologies, provided data and functionalities.

This analysis includes all the information that should be required to feed the software tools that will be developed at a future stage in the project. These software tools constitute a major outcome of the project and are meant to provide DSOs with an optimized design, planning, operation and maintenance of the electricity grid.

DTU, Ores and Cuerva are the three pilot partners that have identified the available infrastructure within their demo sites.

The main types of smart meters available are GISM (single phase) and GIST (three-phase) types. Communication protocols are PRIME/DLMS/COSEM. The data provided by smart meters are mainly:

- Smart metering readings: electric energy consumption (active and reactive energy), meter events (current, voltage, geographic location); billing details.
- Secondary substation registers on consumption and generation, feeder mapping measurements.
- Geographic location and contracted power of supply points (customers) and geographic location of transformers.
- Data from concentrators: active and reactive energy consumed per hour, voltage and currents at the top of LV side of the transformer.
- Assignment of clients to specific transformers.
- Historical demand data

This first analysis has allowed identifying the specific needs of data from AMI that should be covered for the testing of each software tool. Additionally, to real data, simulation algorithms will cover specific cases and will be also useful in case not enough data is available. At further stages of the project, a deeper analysis will be done and more evidence on the actual needs will be identified.

7. REFERENCES

[1] J. Ekanayake and K. Liyanage, “Smart grid technology and applications”, First edit. New Delhi, 2013.

[2] N. Uribe-Pérez, L. Hernández, D. de la Vega, I. Angulo, “State of the Art and Trends Review of Smart Metering in Electricity Grids”, Appl. Sci. 2016, 6, 68.

[3] A. Braeken, P. Kumar, A. Martin, "Efficient and Provably Secure Key Agreement for Modern Smart Metering Communications", Energies 11, no. 10: 2662, 2018.

[4] R. Govindarajan, S. Meikandasivam, D. Vijayakumar, “Comparison of Smart Energy Monitoring Systems in Real-time for Future Smart Grid", International Conference on Artificial Intelligence, Smart Grid and Smart City Applications, (AISGSC 2019), 2019, Available online [last visit: 02/03/2020]: https://www.researchgate.net/publication/337945351_Comparison_of_Smart_Energy_Monitoring_Systems_in_Real-time_for_Future_Smart_Grid

[5] C. Carriero, M. Bissanti, “Wireless Technologies for Smart Meters", Online available [visited: 02/03/2020]: https://www.analog.com/en/technical-articles/wireless-technologies-for-smart-meters.html#

[6] A.N. Akpolat, E. Dursun, “Advanced Metering Infrastructure (AMI): Smart meters and new technologies”, in Proc. of 8th International Advanced Technologies Symposium IATS’17, 2017.

[7] S. Erlinghagen, B. Lichtensteiger, and J. Markard, “Smart meter communication standards in Europe - a comparison,” Renewable and Sustainable Energy Reviews, vol. 43, pp. 1249–1262, 2015.

[8] http://www.powerlab.dk/

[9] https://www.elektro.dtu.dk/english/research/research-facilities/syslab-risoe-pldk