Future Internet for Smart Distribution Systems

Yvonne-Anne Pignolet, *Member, IEEE*, Holger Elias, Timo Kyntäjä, Ignacio Martín Díaz de Cerio, Jürgen Heiles, Didier Boëda, Raphael Caire

***Abstract*—Information and Communication Technology (ICT) Solutions for a smart environment are in the focus of many research initiatives in Europe. In this paper we present work carried out in the FI-PPP project FINSENY (Future Internet for Smart Energy). ICT Solutions often face the challenge of requirements not covered by current technology and they must avoid restricting themselves to domain specific solutions that limit economies of scale and the emergence of innovative services. Smart Grids are particularly concerned in this context as they are a prerequisite for a reliable, sustainable and cost-efficient future energy supply. In this article we describe a methodology that identified a set of Smart Distribution Grid use cases and utilized them to define an architecture based on Future Internet technologies. In addition, we discuss our main findings, requirements, enabling components and architecture as well as the planned evaluation on test sites in Europe.**

***Index Terms*-- Communication systems, Information Systems, Internet, Smart grids, Distribution Network, Distributed Energy Resources**

I. Introduction

THE energy distribution system needs to evolve into an active and dynamic system to provide the smart energy infrastructure in the coming years and decades [1]. In order to achieve this, new challenges have to be handled. Among them are the integration of distributed and intermittent generation sources, the active flattening of the demand curve to reduce the demand for peak load generation, an electrical vehicle charging infrastructure with its mobile loads, microgrids and customers taking an active role as prosumers.

At the heart of a smart grid is the Distribution System (DS) which is the final stage in the delivery of electricity to end users. Traditionally, a DS carries electricity from the high voltage transmission system and delivers it to consumers. It includes medium-voltage (less than 50 kV) power lines, a control center, substations, a protection scheme and its components, pole-mounted transformers, and a low-voltage (less than 1 kV) grid among others.

Monitoring and control of the DS has been introduced so far only in a very limited way, depending of the Distribution System Operator, covering only some parts of the medium voltage network with limited automation. In order to tackle the above challenges a smart grid DS has to support, among others, the functionalities such as

- DS-wide monitoring of the grid status;
- automation of grid operations;
- automatic detection of fault conditions and restoration;
- balancing of load / generation including reactive power;
- efficient and reliable workforce management;
- improved forecasting for the efficient alignment of the consumption to the generation.

This requires managing and controlling many devices in the smart grid DS, connected components, and automation of processes. This ranges from operating switches and reclosers, measuring voltages, currents and frequency to control reactive power and transformer-settings, including the emergency control of Distributed Energy Resources (DER) as well as Demand Side Management of large loads.

ICT will play a crucial role in this context. A smart grid implies millions of new communication connections to homes (or metering rooms) and to tens of thousands distribution network elements in each European country (see Fig. 1), while today's electricity networks have only thousands of communication connections.

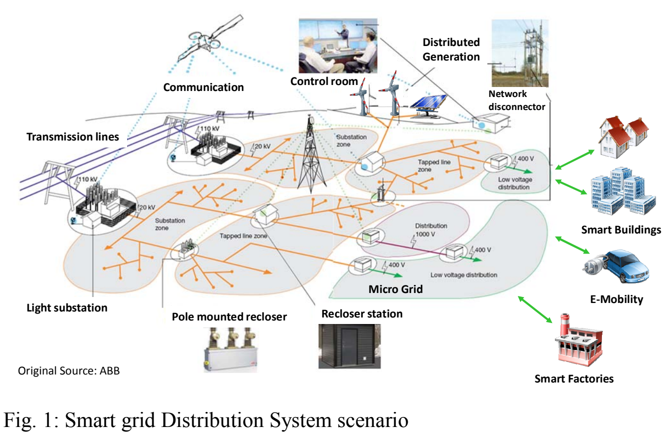


Fig. 1: Smart grid Distribution System scenario

A variety of communication technologies will be applied in electricity networks, e.g., Cellular Networks, Optical Fiber, Power Line Communication and DSL to name but a few. In addition, participants and their devices need to be intercon-

This work was supported in part by EU FP7 Project FINSENY.

Y.-A. Pignolet is with ABB Corporate Research, Baden, Switzerland (e-mail: yvonne-anne.pignolet@ch.abb.com).

H. Elias is with Nokia Siemens Networks TGmbH, Munich, Germany (e-mail: helias@vodafone.de).

T. Kyntäjä is with VTT Technical Research Centre of Finland, Espoo, Finland (e-mail: timo.kyntaja@vtt.fi).

I. Martín Díaz de Cerio is with Iberdrola, Madrid, Spain (e-mail: imartin@iberdrola.es).

J. Heiles is with Siemens AG, Munich, Germany (e-mail: juergen.heiles@siemens.com).

D. Boëda is with Grenoble INP, Grenoble, France (e-mail: didier.boeda@g2elab.grenoble-inp.fr).

R. Caire is with Grenoble INP, Grenoble, France (e-mail: raphael.caire@g2elab.grenoble-inp.fr).

nected in a distributed way. As a consequence a supporting information and communication infrastructure has to be deployed enabling many new devices and new applications. Standardization and the use of future networking solutions will be necessary. Thus Future Internet technologies will play a crucial role in the development of Smart Energy infrastructures, enabling new functionality while reducing costs. Since Future Internet technologies are key to many other areas too, e.g., transport and logistics, safety, health and agriculture, a European research program FI-PPP (www.fi-ppp.eu) has been created to coordinate efforts in these areas. Innovative applications in all these usage areas will also require significant use of ICT, each area with its own domain-specific requirements. Many of these requirements are expected to be quite similar and can be provided in a generic way. The FI-PPP goal is therefore to develop harmonized European-scale technology platforms which enable benefits from economies of scale. The core of FI-PPP is the project FI-WARE (www.fi-ware.eu), which will provide a novel service infrastructure, building upon elements (called generic enablers) which offer reusable and commonly shared functions making it easier to develop Future Internet Applications in multiple sectors. In addition, there are eight usage area projects, among them FINSENY (www.fi-ppp-finseny.eu), which are currently investigating different scenarios to generate use cases, individual requirements and developing Future Internet architectures tailored to their domain-specific needs. In FINSENY, key actors from the ICT and energy sectors are collaborating to define Smart Energy Systems using the generic enablers developed by FI-WARE while combining adaptive intelligence with reliability and cost-efficiency to sustainably meet the demands of a highly dynamic energy landscape.

The contributions of this paper are a) the methodology applied in FINSENY to investigate use cases, ICT requirements and a functional Future Internet architecture for DS and b) results derived when following this methodology. More precisely we list the requirements which can be met with generic enablers based on Future Internet technology and for which domain-specific solutions are necessary. In addition we present an overview of the architecture envisioned for DS and we discuss the evaluation of this approach in trials.

The paper is structured as follows. In Section II, the role of today's Internet technologies and their limitations regarding energy systems are discussed, followed by a description of FINSENY's methodology in Section III. Subsequently, we present in Section IV our results consisting of representative use cases, ICT requirements, mappings to FI-WARE generic enablers and domain-specific enablers, a draft architecture with examples and trial considerations. In Section V we summarize our findings and conclude the paper.

II. Internet Technology Today and Energy Systems

The Internet is defined as a global system of interconnected computer networks using the standard Internet protocols to serve billions of users worldwide. Hence, its economies of scale could also be of benefit to the smart energy system with its great number of intelligent devices expected. As the Internet uses the standard Web & new IoT/M2M (Internet of Things/Machine to Machine) protocol suites, they will be useful for standardization to provide interoperability between smart grid elements, which may be owned by an increasing number of independent actors. As a system that serves billions of users worldwide, it has the scalability to be used as a common infrastructure for smart grids as well. Additionally, the Internet is evolving in several areas, e.g., networking, cloud computing, services, software engineering, security and privacy, towards an Internet of Things (the "Future Internet"). Today, people use the Internet to communicate with each other and access information and services; in the future, more and more machines and devices ("things") will also be connected to that Future Internet to make our lives easier. This evolution also fits well with the smart grid, which can be considered to be a large number of interconnected intelligent energy devices. Because of all these reasons, Internet technologies have been used for Energy applications already (e.g. metering, substation integrated control systems, remote control of recloser) since 2000 to replace dedicated point to point or multipoint technologies with very specific protocols. Developments in data networks have helped to unify the network managing all kind of services including telecontrol services. This unification has allowed for a reduction in infrastructure operating costs. Energy applications are part of this unification process, as can be seen in the development of new standard protocols. However, the current Internet presents limitations for pervasive applications in the energy system. These limitations can be summarised by the following restrictions:

- The Internet is currently not well suited for mission critical applications that require high availability and guaranteed high priority data handling.
- The Internet could introduce security gaps for smart energy applications.
- Internet technologies do not fulfil the short and deterministic latency requirements of energy systems.

As a result of these restrictions, the energy system often uses application-specific solutions that limit the economies of scale and the interoperability of its intelligent devices, which may be delivered through an internet-like approach. These specific solutions are characterized by using different protocols for their different applications within the Energy landscape, which raises interoperability issues.

III. Proposed Methodology

The general approach to define the Future Internet ICT architecture for smart grid DSs is to start with the selection of use cases which are most relevant for a smart grid DS. From these use cases ICT requirements are derived, starting with high level requirements to which more details are added while the architecture evolves.

The requirements are consolidated with the other smart energy work packages in FINSENY and contributed to the overall FI-PPP requirements list. Based on this list and a common architecture approach generic ICT enablers are defined by FI-WARE. These enablers are then integrated in the smart grid DS ICT architecture and additional domain specific enablers will be defined as needed to build a complete functional ICT architecture.

A. *Use Case Selection and Description*

The methodology used for selecting and describing relevant smart grid DS use cases has three iterative steps as shown in Fig. 2. The first step is the identification of High Level Services and Functionalities of smart grid DSs which are relevant for complying with the expected impact of FINSENY and for a further ICT analysis. The second step is the selection of use cases, which cover these selected smart grid functionalities. And finally, the third one is the description of selected use cases based on a template which is a simplified version of the IntelliGrid template [2].

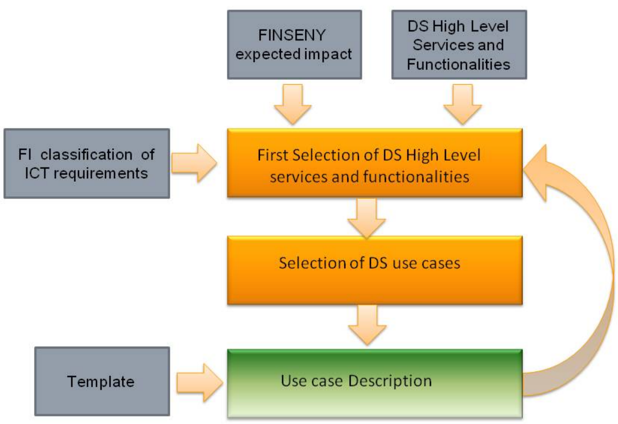


Fig. 2: Smart Grid DS use case selection

The High Level Services and Functions for smart grid DSs have been taken from the work of the European Commission DG Energy Task Force for Smart Grid (SGTF), namely the deliverable of the Expert Group 1 (EG1) titled "Functionalities of Smart Grid and Smart Meters" [3]. Use cases have been contributed and selected by the project partners based on their impact, the coverage of relevant High Level Services and Functions as well as relevant ICT services. The use cases were presented and discussed in the Smart Grid Stakeholder Group (SGSG) (www.fi-ppp-finseny.eu/sgsg/), an open industry group to foster information and knowledge exchange, networking and identification of business and research cooperation opportunities between energy production, distribution and consumption and ICT industry in Europe.

B. *ICT Requirements and Key Building Blocks*

To derive the functional and ICT requirements on the Information and Communication layer and to identify data models and interfaces, the use cases produced in the first step are analysed along an adaptation of the layers and dimensions of the Smart Grid Architecture Model (SGAM) Framework, being under development by the European Smart Grid Coordination Group (SGCG). SGCG is responsible for the European Smart Grid standardization based on Mandate M490 from the European Commission [4].

The SGAM Framework as shown in Fig. 3 uses a 3-dimensional approach to cover Domains, Zones and Interoperability Layers. The goal of this framework is to present smart grid use cases in an architectural but solution and technology neutral manner. The domains follow the electrical energy conversion chain, and the zones represent the hierarchy of power system management. As a result this arrangement spans the Smart Grid plane which covers the complete electrical energy conversion chain:

- **Generation** (bulk generation);
- **Transmission** (long distance electricity transport);
- **Distribution** (infrastructure and organization to bring electricity to customers);
- **DER** (distributed energy resources controlled by DS);
- **Customer Premise** (end users of electricity).

Note that for the DS scenarios, generation and transmission domains are not in the focus. The zones represent hierarchical levels of power system management:

- **Process** (primary equipment, e.g. generators, transformers, circuit breakers, power lines, cables and electrical loads);
- **Field** (protection, control and monitoring, protection relays, bay controller, any kind of sensor and actor devices);
- **Station** (field aggregation level, e.g. data concentration);
- **Operation** (control operation, e.g. distribution, microgrid or virtual power plant management systems);
- **Enterprise** (processes and infrastructure for, e.g., asset management, staff training, customer relation management, billing and procurement);
- **Market** (energy, trading, mass market, retail market).

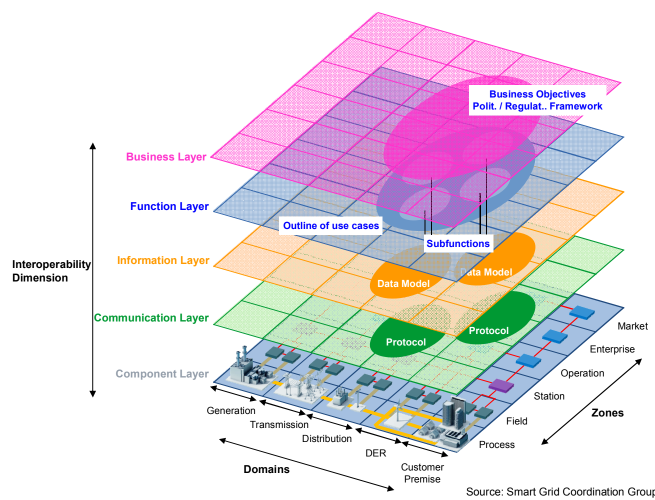


Fig. 3: Smart Grid Architecture Model Framework

Note, that the relationships between these zones are hierarchical. These zones are used to map a hierarchy of functionalities. In consequence it does not matter whether a function is located in the field or in the substation. Only the level in the automation hierarchy is important. The third dimension of the framework is the interoperability layers:

- **Business Layer** (the business view on the information exchange related to smart grids);
- **Function Layer** (use cases, functions and services independent from their physical implementations);
- **Information Layer**: (information objects or data models for interoperability);

- **Communication Layer** (protocols for information exchange between components);
- **Component Layer** (physical components, power system equipment, protection and control devices, networking and control center infrastructure).

Security is to be considered for all dimensions of this model. To derive the relevant ICT requirements, the functional requirements of the use cases were first identified and then, in a second step, critical requirements for the information and communication level were extracted from the functional requirements recursively. Lastly, in a third step, the relationship to proposed or already available Future Internet solution implementations is investigated. Eventually, the mapping of the DS use cases on the SGAM information and communication layers will result in a detailed evaluation of relevant ICT requirements, which in turn can be used to create the DS architecture in the next stage. In other words, each use case is split into several SGAM component layer based diagrams with the actors and their main interfaces. In addition, tables containing essential features of the involved functions, such as sending commands, handling alarms, performing configuration, etc. are listed.

C. *Functional ICT Architecture*

The results from the above steps are then used to identify suitable generic enablers and analyze domain specific requirements leading to domain specific enablers, which will build the functional DS ICT architecture together with the generic enablers. The generic enablers are provided by FI-WARE as discussed before, while FINSENY will define domain specific enablers, which are needed to support requirements specific to energy systems.

IV. RESULTS

In this section we list our findings about the Distribution System scenario, having applied the method introduced above.

A. *Use Case Selection and Description*

Essential for the use case description is a reference model which identifies the involved actors with their roles and responsibilities. For the smart grid DS we have defined the reference model focussing on the electrical power and information exchange between the actors. The Distribution System Operator (DSO) is in the center of the model and interacts with the surrounding actors. In the future the DSO will have to play a more active role than today to maintain grid stability and guarantee reliability despite DERs.

The selected use cases maximize coverage of critical functional requirements and they go beyond addressing traditional functionality by expanding the view to the field of Advanced Distribution Automation (ADA) and novel load and generation control (e.g. for DER). Beyond the operational control of devices connected to the smart grid DS, maintenance and repair processes need to be performed under exceptional circumstances (e.g. storms, causing disruption in regular communication). Table I summarizes the selected use cases, a full description can be found in [5].

TABLE I
REPRESENTATIVE DS USE CASES

• **Medium Voltage Data Acquisition and Control (MVDAC):** access to real and non-real time information of MV electrical network from the utility control centre
• **Smart Grid Energy Control of Power Inverter (SGEC):** interactions, mechanisms, and interfaces of power inverters
• **Fault Location, Isolation and Restoration (FLIR):** all procedures necessary to restore the services after a fault in the DS
• **Dynamic Control of Active Components (DCAC):** automatic control of distributed active network components on substation level, ensuring stable and energy efficient network operation
• **Mobile Work Force Management (MWFM):** giving field crews access to work orders and related information in the field, using pervasive means of communication options in case of disturbance of regular communication

While well-running traditional control technologies are implemented today to cover FLIR or DCAC use cases, they are not yet exposed to the volatile generation of renewable DER. To overcome potential threats of smart grid instabilities and their associated fault patterns, new control mechanisms have to be discussed, defined and implemented. Due to scaling and overall grid response reasons, interworking and automation may be implemented differently than today. To reduce downtime and safe repair and maintenance, efficient work force management belongs to the Smart Grid challenges as well. Furthermore the communication and information infrastructure for this use case adds ICT components and requirements which differ significantly from other use cases' requirements. In the following steps we investigate how Future Internet Technologies can be used as an approach to tackle the resulting ICT challenges.

B. *ICT Requirements and Key Building Blocks*

In this step, we analyze the use cases´ functional requirements along the SGAM layers to understand sub sequential ICT requirements. For each of the use cases tables describing the actors and interfaces at the different layers have been created and functional and technical requirements have been identified. The most important ICT requirements have been grouped into the following categories:

- General and component requirements (e.g., interoperability scalability, reliability, availability, physical media);
- Functional and technical requirements (e.g. performance, bandwidth, data rate, robustness, delay, jitter, I/Os/interval, transactions per time interval, response time, QoS);
- Service-orientation (e.g., discovery, plug-and-play, APIs);
- Data Management;
- Usability;
- Security, privacy and trust (e.g. authentication, authorization, encryption, non-repudiation, key and trust management).

Initially, 53 significant ICT requirements were documented for the five DS use cases described above. During the consolidation process the project identified the fourteen most important DS requirements to investigate the concept and suitability of Future Internet technology for DS. From these requirements information was gathered to provide input for the FI-WARE project defining the generic enablers of different categories [6]. The categories divide the main architecture of Future Internet into separate fields of building blocks. The most important ones for DSs are Interfaces to Networks and Devices (I2ND) including Service, Capability, Connectivity and Control (S3C) aspects, Internet of Things (IoT) Service Enablement, and Security. To a lesser extent, the architecture will rely upon the enablers Data/Context Management, Cloud Hosting and Applications/Services Ecosystem and Delivery Framework. The consolidated requirements and an assignment to FI-WARE generic enablers are listed in Table II. Since the security requirements are analyzed in a different part of the project the security results are not presented here.

TABLE II
CONSOLIDATED DS ICT REQUIREMENTS AND POTENTIALLY MATCHING FI-WARE GENERIC ENABLER CATEGORIES

- ***Communications Technology (CT) Interoperability*:** Standardized interfaces between DSO, Aggregators and VPPs wrt. intra and inter-company communication
  Related FI-WARE generic enablers: I2ND
- ***Time Synchronization:*** Detection of delayed messages, as well as carrying out timed procedures are essential for safety, device protection and optimized operation.
  Related FI-WARE generic enablers: I2ND, IoT
- ***Reliability and availability of CT layer:*** Guarantees of CT layer interfaces.
  Related FI-WARE generic enablers: IoT
- ***IP mobility:*** Push data to the worker handset regardless of the medium, even if IP address has changed.
  Related FI-WARE generic enablers : I2ND, IoT
- ***Scheduled actions:*** Scheduled actions to transmit data automatically to and/or from the power site (e.g. power inverter) without data requests.
  Related FI-WARE generic enablers: Data/Context Management, Applications/Services Ecosystem and Delivery Framework.
- ***Backup of communication links*:** Communication should operate also at the time when the DSO grid is down.
  Related FI-WARE generic enablers : IoT
- ***Dedicated or Shared Transport Infrastructure:*** Appropriate network capacity, which may be supplied by a dedicated operator on an exclusive or shared basis.
  Related FI-WARE generic enablers : I2ND (S3C)
- ***Future-proof system design:*** Modularity, standardization, maintainability and HW/SW upgradeability.
  Related FI-WARE generic enablers: I2ND
- ***Latency*:** The communication infrastructure must offer a guarantee on the maximal round trip time for messages.
  Related FI-WARE generic enablers: I2ND, IoT
- ***Bandwidth allocation***: Guarantees on available bandwidth.
  Related FI-WARE generic enablers: I2ND
- ***Packet Loss:*** Avoidance of packet loss
  Related FI-WARE generic enablers: I2ND, IoT
- ***High priority asynchronous messages:*** Guarantee stability by sending alarming information with highest priority or via reserved communication channels.
  Related FI-WARE generic enablers: IoT
- ***Service discovery and Classes of Service (CoS):*** Service discovery mechanism to set CoS based on requirements.
  Related FI-WARE generic enablers: IoT
- ***Data management*:** Large volumes of data that partially have to be stored for later use (e.g. billing, planning, historical analysis, regulation). Consistency and synchronization with other systems within seconds.
  Related FI-WARE generic enablers: Data/Context Management, Cloud Hosting

Based on the SGAM analysis of the use cases we identified the quantitative requirements listed in Table III to be critical to evaluate FI-WARE´s generic enablers and their suitability for the DS ICT architecture. Thus we examined them for all interfaces (IF) of the use cases.

TABLE III
QUANTITATIVE INTERFACE REQUIREMENTS

IF Requirement	**Description**
# Devices	Number of devices connected to this interface on receiving end
Payload	Maximum size in kBytes without routing and transport information
Latency	Message transfer delay time (seconds) in one direction (OSI layer 7)
Time stamp resolution	Resolution of global time system (time when value is sampled or message is sent)
Transmission interval	Time interval for cyclic data traffic
Redundancy	If necessary to enhance the reliability and the availability of this interface
Response confidence	Expected communication reliability meeting predefined time limits (hard, firm, soft)

As an example Fig. 4 and Table IV contain parts of the results of this step for the use case MV DAC. In Fig. 4, the MVDAC architecture model based on the SGAM domains and zones is presented and Table IV lists the corresponding interface requirements. The MVDAC scenario covers data acquisition and control of different elements of the MV network (including DERs) from the utility Control Center. Thus it covers the Distribution and the DER domains. In the Operation zone, a grid operator is in charge of network monitoring and control using a grid control application. The Supervisory Control and Data Acquisition (SCADA) front end is responsible for the collection of the time critical information from the Remote Terminal Units (RTUs), which are in charge of interfacing with sensors and actuators in remote locations. In the Field zone, the complementary SCADA protocol termination takes place in the RTUs. RTUs can be installed in secondary substations, reclosers or DERs.

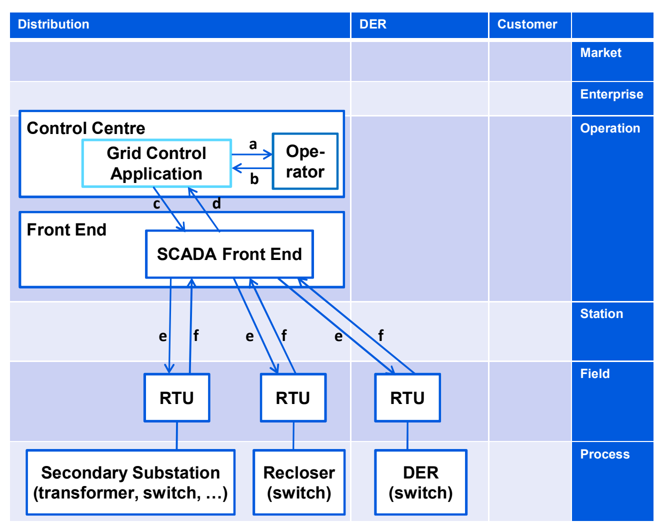


Fig. 4: Example MVDAC Architecture

Regarding the interfaces' requirements listed in Table IV, the interfaces 'c' - 'f' transport time critical information. That means that a delay could imply a cost for the DSO. To guarantee that this does not happen, the SCADA front end continuously polls the RTUs every 2 seconds to retrieve state and measure changes from the devices in the Process zone. Every 10 minutes, the SCADA front end retrieves not only changes but also all the data collected by RTUs.

TABLE IV
EXAMPLE MV DAC INTERFACES REQUIREMENTS

IF	c	d	e + f		
Action	Sporadic commands	Real-time data retrieval	Data retrieval		Sporadic commands
			Overall data request	Change data request	
# Devices	~1	1	~10 000		
Payload (kByte)	0.02	1	1* (depends on RTU)	0,256*	0,02*
Latency (sec)	0.5	0.5	<0.5	<0.5	<0.5
Time stamp resolution	-	msec	msec	msec	-
Transmission Interval (sec)	-	2	600	2	-
Redundancy	Yes	Yes	Yes	Yes	Yes
Response confidence	Firm**	Firm**	Firm**	Firm**	Firm**

* values based on IEC 60870-5-104 [7]
** missing the time limit infrequently will be tolerated, but may degrade the system's quality of service. The usefulness of the result might be zero after the time limit has passed.

Protocols and information models for these interfaces are defined in the IEC 60870 [8] standard series and this solution has been widely deployed in current distribution grids. RTUs will be considered as legacy equipment which interfaces with electrical infrastructure sensors, actuators and sends the information to a master (front end) in a point to point way. Regarding the order of magnitudes, a primary substation can have hundreds of sensors, actuators and measuring points as resulting complexity, while a secondary substation (in the MV network) could have tens of sensors and actuators. In smart grids the numbers of deployed devices for monitoring and control will multiply, especially due to a multitude of secondary substations in the field, compared to primary substations.

C. Functional ICT Architecture

Based on the use cases and their requirements we identified relevant information and analyzed which data formats have to be applied. This forms the foundation to map them to existing ICT technologies to develop a better understanding, which technologies need to be applied and where ICT performance limitations demand novel solutions.

As a next step, DS architectural domains are assigned to FI-WARE generic enablers where possible. To this end the requirements derived in the previous step served as a basis for the decisions. The FI-WARE core platform provides six generic enabler solution areas. Relating them on a high level yields the loose associations depicted in Fig. 5. Domain specific enablers were defined to cover functionalities, where the generic enablers do not offer the required services. Depending on what FI-WARE will commit to with respect to time critical guarantees, accuracy and precision, some generic enablers which fit from a functional perspective might become domain specific enablers to meet DS requirements.

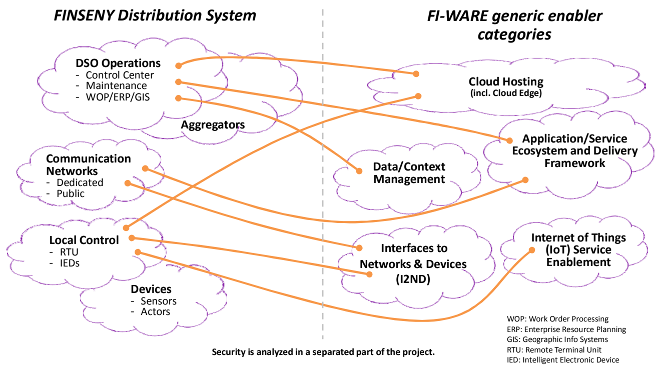


Fig. 5: High-level Associations between DS and FI-WARE generic enablers

As an example, Fig. 6 shows a functional MVDAC architecture based on FI-WARE generic enablers and DS domain specific enablers. On the left, the grid control application which interfaces with the SCADA front-end is represented. On the right, the RTU which interfaces with the actuators and sensors is depicted. For communication the standard IEC 60870 [8] is used. IEC 60870 series defines point to point or point to multipoint communication for retrieving or updating electrical time critical information from the terminal locations. The substandard IEC 60870-5-104 defines the communication using TCP/IP.

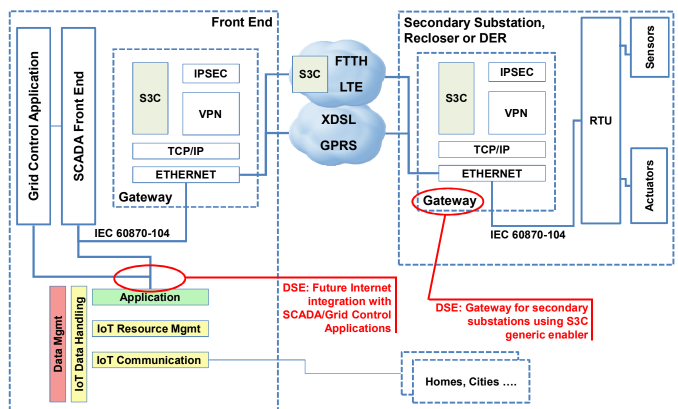


Fig. 6: Example MVDAC Architecture with generic enablers and domain specific enablers

At the RTU level, we proposed to use the generic enabler S3C from the I2ND category which offers a fine-grained level of control by applications and services on fixed and mobile telecommunications operator networks through an interface to the control plane of the communication layer. The aim is to offer future applications and services, an interface-independent of different network technologies available and multi-provider scenarios. To make this possible, operators have to offer this service on their networks and terminal equipment must be able to interact with it. S3C offers a variety of interfaces to facilitate this interaction.

One of the examples in which the generic enabler S3C can provide a clear advantage for MVDAC is the redundancy management of the connectivity provided by one or more operators or technologies. For this scenario a gateway which must meet the environmental requirements for the MVDAC scenario in a secondary substation, and with support for S3C interfaces has to be developed as a domain specific enabler.

For MVDAC, other generic enablers (IoT and Data/Context Management) have been identified to be useful at the Control Center level. This necessitates integration by domain specific enablers. The benefit of this scenario is the fact that with such generic enablers information of other sensor networks (e.g. for smart cities or homes) can be used for electrical grid control applications.

The following Tables V and VI contain the generic and domain specific enablers identified for the DS use cases.

TABLE V
MAPPING OF DS USE CASES TO FI-WARE GENERIC ENABLERS

Use Case	FI-WARE categories	FI-WARE Generic Enablers
FLIR	Data/Context Management IoT I2ND	Pre-processing of meta-data during/after gathering, Pre-processing of unstructured data during/after gathering, Time Synchronization*, Interface for routing policies, Request QoS level, QoS notification, IoT Communication, IoT Resource Management, IoT Data Handling, S3C
MVDAC	Data/Context Management IoT I2ND	Pre-processing of meta-data during/after gathering Pre-processing of unstructured data during/after gathering IoT Communication, IoT Resource Management, IoT Data Handling, S3C
MWFM	Data/Context Management I2ND	Localization Platform Mobility Analysis Connected Devices Interfacing
SGEC	Data/Context Management I2ND Cloud Hosting	Event Handling, Cloud Edge
DCAC	Data/Context Management, I2ND	Pre-processing of meta-data during/after gathering Pre-processing of unstructured data during/after gathering, Connected device interface, Network Information & Control
* depending on accuracy and precision offered by FI-WARE, this might be a DSE		

TABLE VI
MAPPING OF DS USE CASES TO DOMAIN SPECIFIC ENABLERS

Use Case	FINSENY DS Domain Specific Enablers
ALL	Information and data model definitions (e.g., CIM IEC 61970 [9] and IEC 61850 [10]), Future Internet integration with SCADA and Grid Control applications, Smart Grid applications based on SOA
FLIR	Real-time connectivity services*, Discovery Settings detection, Operation Application Integration, Future Internet-IEC 60870-5-104 [7] emulation and interface, Secured and low latency substation to substation communication IEC 61850-90-1[11], Controllability, Event-Handling, Data Management, Latency, Payload, Response Confidence, Redundancy
MVDAC	Gateway for secondary substation supporting S3C GE
MWFM	Specific data models and objects already standardized in IEC 61850-7-420 [12] for Distributed Energy Resources.
SGEC	Controllability, Event-Handling, Data Management, Latency, Payload, Timestamp resolution, Response Confidence, Redundancy, Repetition-Interval
DCAC	Time stamping, Response Confidence, Redundancy
* for FI-WARE generic enablers without real-time guarantees	

V. OUTLOOK ON TRIAL PHASE

To investigate the applicability and performance of a DS architecture based on Future Internet technologies, FINSENY has started planning trials. These trials will demonstrate how the FI-WARE components fulfil the DS requirements and reveal the limitations of their design. This is one of the most important results of FI-PPP as a whole, because Future Internet architecture and technologies are not under research at this level of priority in such diverse usage areas and business domains. As a consequence these trials will provide experience and eventually lead to improved products, services and systems in the domains involved.

The trial selection process (see Fig. 7) applies a bottom-up approach. Based on the results described in the previous section the suitability of existing trial sites and infrastructure is assessed. The trials will be constructed in a modular manner, guided by the question” What can we do if we have X, Y and Z?” To this end the use cases selected in Section III have to be evaluated based on their potential impact on ICT and if they can be implemented on a given trial infrastructure. In particular, generic and domain specific enablers, existing and emerging standards along with the novelty status are important criteria in this process.

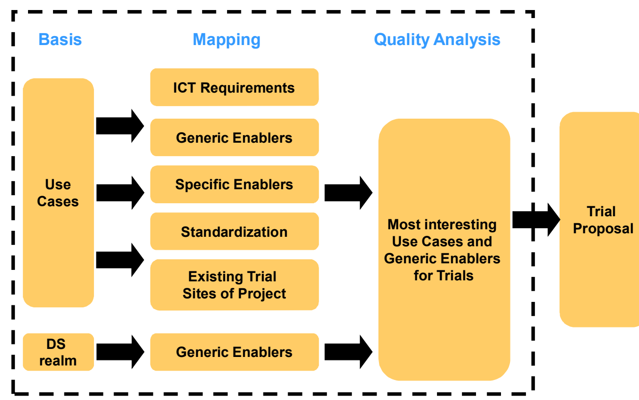


Fig. 7: Trial Selection Methodology

Thus, a trial candidate is considered suitable if it demonstrates the use of generic and domain specific enablers for one or more use cases. Other selection criteria are target duration estimations for development, and budget resources needed. If the trialling site already exists, its location, characteristics, advantages are evaluated. In addition the following is investigated in the selection process: supported by a users’ group, security, manageability, scalability, applicability and acceptance by the power Industry. By assigning weights to each of these indicators the trial candidate list can then be ranked easily according to different aspects.

VI. CONCLUSION AND SUMMARY

In this article we describe a method and our findings to enable a DS using Future Internet technologies for automated fault restoration, power analysis & control and grid maintenance.

The main benefits provided to the players are:

- DSOs will get solutions to handle grid capacity and energy flows optimally;
- Service providers will get interfaces to provide innovative energy services;

- Prosumers can optimise their generation and consumption based on a stable distribution grid.
- Our contributions in this paper are:
- A method to design an improved ICT Architecture for DSs
- ICT-relevant use cases covering DS functionalities, driven by novel Smart Grid aspects and their cost-effective implementation
- Quantitative and qualitative ICT requirements, reflecting and matching DS specifics
- Identification of generic and domain specific enablers to apply and merge upcoming unified industry-wide methods and standards.

VII. References

[1] European Technology Platform SmartGrids, *SmartGrids SRA 2035 Strategic Research Agenda Update of the Smart Grids SRA 2007 for the needs by the year 2035*, March 2012. http://www.smartgrids.eu/documents/sra2035.pdf

[2] *IEC IntelliGrid Methodology for Developing Requirements for Energy Systems*, IEC/ PAS 62559 ed1.0, January 2008.

[3] EU Commission Task Force for Smart Grid, *Functionalities of Smart Grids and Smart Meters*, December 2010. http://ec.europa.eu/energy/gas_electricity/smartgrids/doc/expert_group1.pdf

[4] EU Commission, Directorate-General for Energy, *Mandate M/490: Standardization Mandate to European Standardization Organizations to support European Smart Grid deployment*, March 2011. http://ec.europa.eu/energy/gas_electricity/smartgrids/doc/2011_03_01_mandate_m490_en.pdf

[5] I. Martín Díaz de Cerio, R. del Olmo Arce, Y.-A. Pignolet, P. Coudray, D. Boeda, R. Caire, B. Schäfer, D. Eckardt, C. Højgård Jensen, M. N. Wagner, H. Elias, H. Jormakka and T. Kyntäjä, *Distribution Network Building Block*, FINSENY Deliverable D2.1, Version 1.1, August 2011. http://www.fi-ppp-finseny.eu/wp-content/uploads/2012/05/D2-1_Distribution_Network_Building_Blocks_v1-1.pdf

[6] F. Delli Priscoli, M. Castrucci, P. Garino, M. Cecchi, L. Fogliati and V. Suraci, *Key Concepts for the Future Internet Architecture*; presented at Future Network and Mobile Summit 2011Warsaw, Poland June 2011.

[7] *IEC Standard Telecontrol equipment and systems - Part 5-104: Transmission protocols - Network access for IEC 60870-5-101 using standard transport profiles,* IEC 60870-5-104, May 2006.

[8] *IEC Standard Series Telecontrol equipment and systems*, IEC 60870.

[9] *IEC Standard Series Energy management system application program interface (EMS-API)*, IEC 61970.

[10] *IEC Standard Series Communication networks and systems in substations*, IEC 61850.

[11] *IEC Standard Communication networks and systems for power utility automation - Part 90-1: Use of IEC 61850 for the communication between substations*, IEC 61850-90-1, March 2010.

[12] *IEC Standard Communication networks and systems for power utility automation - Part 7-420: Basic communication structure - Distributed energy resources logical nodes*, IEC 61850-7-420, March 2009

VIII. Biographies

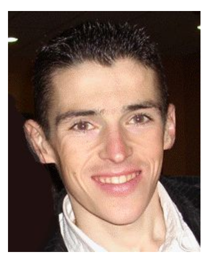
Yvonne-Anne Pignolet, works as a Scientist at ABB Corporate Research. She holds a PhD and a Master's degree in Computer Science from ETH Zurich. Before joining ABB, she has been working as a postdoc at IBM Research, Zurich and at the Ben Gurion University Be'er Sheva, Israel. Her research interests are on distributed computing and networking and with a focus on their application to Distribution Automation.

Holger Elias received his Diploma (M.Sc.) in Communications Engineering from RWTH Aachen. He worked with Siemens and Nokia Siemens Networks in transmission, data and access technologies as well as business modelling functions in various engineering, consultant and management positions. Since 2010 he was actively contributing to Smart Grid related ICT research in SGEM (Finland) and FINSENY (EU) research programs. He is currently employed in NSN TG mbH.

Timo Antero Kyntäjä received his Master's Degree from University of Jyväskylä, Finland in 1994. He majored in Information technology and studied also applied and theoretical mathematics. Since 1995 he has been working for VTT Technical Research Centre of Finland as a research scientist and for middle management. His field of expertise is telecommunication protocols and software.

Ignacio Martín Díaz de Cerio received a Master's Degree in Telecommunication Electrical engineering (ETSI, Bilbao, 1999) He received a MBA - Specialisation in Energy Companies Management (Nebrija, Madrid, 2009). Since 1999 he has been working for Iberdrola in the Telecommunication Direction, and since 2006 he has been responsible for Telecommunication Services required by Iberdrola group and their request to Telecom Operators.

Juergen Heiles graduate in electrical engineering at the University of Applied Sciences Rhineland-Palatinate, Koblenz, Germany. He has been working in various ICT areas from Optical, SDH and Ethernet communication networks to IPTV and recently Smart Grids. He was leading the Smart Grid and M2M service enablement standardization activities of Nokia Siemens networks. Since June 2012 he is working on Smart Grid standardization and standards innovations at Siemens AG, Munich.



Didier Boëda (M'09) received his Engineering degree in 2005 and Doctorate degree in 2009 from the Institut National Polytechnique de Grenoble (INPG). He had been working two years in post-doctoral researcher in the G2Elab on modelling of inverters in hybrid vehicles and on distributed intelligence in electrical networks through the Multi-Agent Systems. He is now working as research engineer at Grenoble Institute of Technology (Grenoble-INP).

Raphael Caire (M'04) received his MsC and Doctorat degrees from the Institut National Polytechnique de Grenoble (INPG) in 2000 and 2004. He had been working at the Center of Power Electronic System, USA, in 2000 and in several EDF research centers in Germany and France from 2004 to 2006. He is now an associate professor at Grenoble Institute of Technology (Grenoble-INP). His research is centered on dispersed generation on distribution system and critical infrastructures.