FLEXe
Future Energy System

RESEARCH REPORT
NO 2.1-11-1
HELSINKI 2016

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D2.1-11-1 – Report on the concept of Big Data based ICT architecture for microgrid management

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ISBN XXX-XX-XXXX-X
ISSN XXXX-XXXX

CLIC Innovation
Research report no 2.1-11-1

Report on the concept of Big Data based ICT architecture for microgrid management

Preface

This report was done as a part of the Finnish national research project "Flexible Energy Systems" FLEXe, and it was funded by Tekes – the Finnish Funding Agency for Technology and Innovation, and the project partners. The aim of FLEXe is to create novel technological and business concepts enhancing the radical transition from the current energy systems towards sustainable systems. FLEXe consortium consists of 17 industrial partners and 10 research organizations. The programme is coordinated by CLIC Innovation Ltd. The report was written by Lappeenranta University of Technology and Emtele.

Name of the report: D2.1-11-1 Report on the concept of Big Data based ICT architecture for microgrid management

Key words: Big Data, flexibility, information and communication technology, micro grid, secondary substation automation, smart grid

Summary

Distributed energy generation is one of the main drivers in the evolution of the distribution network from a centralized “passive” grid to a distributed “active” grid. The grid needs to be agile and flexible to respond to various dynamics of future energy systems. It should offer means for more accurate metering and monitoring, higher efficiency, and better load and power management. One crucial corner stone in flexible energy systems is information and communication technology (ICT) system that must be both reliable and secure. The communications should also reflect to different stakeholders’ quality and business requirements. In a case of low-voltage direct current (LVDC) electricity distribution grid, where energy storages and distributed generation (DG) units, such as photovoltaics are implemented, a possibility to drive such system as an island grid arises. To run and operate the LVDC micro grid (µGrid) as effectively as possible information from and between several data sources should be transmitted and processed. To produce new data from several available data sources that have some additional value, for instance to distribution system operator (DSO), can be considered Big Data. All these together form an LVDC µGrid Big Data concept. ICT architecture is the main enabler of Big Data.

In this report, a short overview to IoT platforms and ICT architecture implementations offered today for the LVDC µGrid Big Data concept are proposed. According to the literature study, a list of features for an LVDC µGrid pilot testbed are compiled. A use case under consideration focuses on grid automation taking interaction between energy and communication systems and different stakeholders into consideration. The ICT architecture on the LVDC µGrid system from rectifying substation (the secondary substation), that is, the interface between the supplying medium-voltage grid and the LVDC µGrid, to the customer-end inverters, which produce standardized AC to the customer loads, and inside the customer premises containing the intelligent electronic devices (IEDs) and communication interfaces are presented. Moreover, the data flows and different applications for Big Data approach between the IEDs inside the µGrid and between the µGrid and remote systems that altogether form Internet of Things (IoT), or Internet of Energy (IoE) in this case, are proposed.

The goal is to propose an LVDC µGrid Big Data concept, which enables bidirectional energy and information flows with additional value between distributed control centres and distributed energy production, storage, and consumption.

Lappeenranta, October 2016

CONTENTS

1 Introduction

Large-scale implementation of distributed generation can lead to the evolution of the distribution network from a “passive” (local/limited automation, monitoring, and control) system to an “active” (global/integrated, self-monitoring, semi-automated) system that automatically responds to the various dynamics of the electric grid, resulting in higher efficiency, better load management, and fewer outages. However, distributed generation also poses a challenge for the design, operation, and management of the power grid because the network no longer behaves as it once did. Consequently, the planning and operation of new systems must be approached differently, with a greater amount of attention paid to the challenges of an automated global system [1].

FLEXe program will find out a solution model and concept for flexible energy systems. One crucial corner stone in flexible energy systems is information and communication technology (ICT) system that must be reliable and secure, and optimized as to quality and economy requirements (Figure 1.1.1).

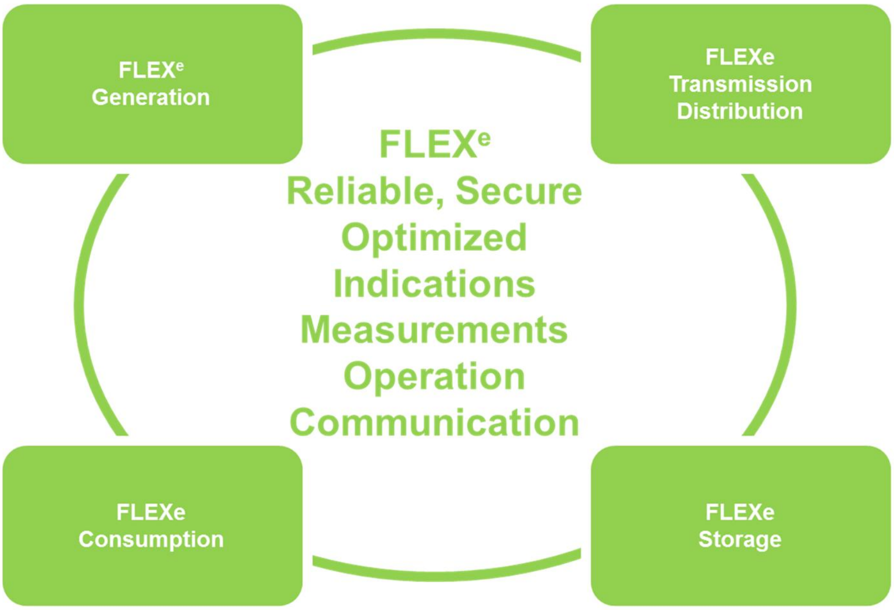

Figure 1.1. The scope of T2.1 in WP2 in FLEXe program.

A strong assumption based on several national and international research results is that the utilization of communication networks and intelligent electronic devices (IEDs) in flexible energy systems will be one good alternative to implement the expected flexibility services. A smart grid as system of systems is illustrated in Figure 1.2 [2].

In this report, a short overview to Internet of Things (IoT) platforms and information and communication technology (ICT) architecture implementations offered today for the LVDC μGrid Big Data concept are proposed.

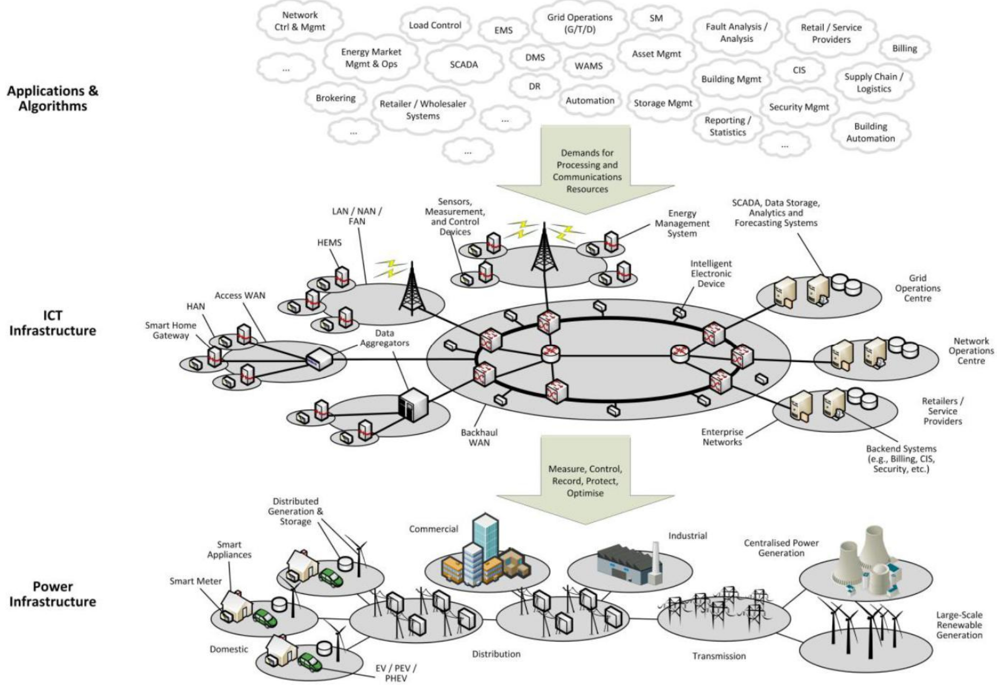

Figure 1.2. Smart Grid as a system-of-systems [2].

The report is organised in the following manner. Chapters 2 cover the research goals in this report. Chapter 3 gives an overview over IoT plaforms and smart grids. Chapter 4 concentrates on LVDC µGrid Big Data concept. Finally, chapter 5 concludes the report. Participants of this research were Lappeenranta University of Technology (LUT) and Emtele.

2 Goal

The general goal of the research in work package (WP) 2 and task 2.1 is to support the FLEXe program level goals to enable planning and operation of integrated energy networks. This requires novel, high-quality, reliable and secured measurements, telecommunication with consistent level of quality of experience (QoE), and data processing. Piloting and test beds in demonstrating features and in development of functionalities are essential.

The task level goals consists of research activities related to sensor and measuring technologies, calibration methods of remote devices and data analysing algorithms, and technical concepts for reliable, high quality and secure measurements including power, voltage and current values, fault detection, protection, monitoring and control.

This report will concentrate on IoT plaforms and ICT systems to support µGrid automation in a sense of Big Data approach. Overview over IoT platforms is given, since they are playing big role in collecting and pre-processing data for Big Data analytics. It is assumed that the presented technologies can be applied to other energy systems such as remote heating.

3 IoT and Smart Grids

3.1 Internet of Things (IoT) Definition

An ongoing trend is a radical evolution of the current Internet into a network of interconnected objects (IoT) that not only harvests information from the environment (sensing) and interacts with the physical world (actuation/command/control), but also uses the harvested data to provide services for information transfer, analytics, applications, and communications. IoT can be applied to any segment as shown in GSM Association's Figure 3.1 below with some application examples in Figure 3.2.

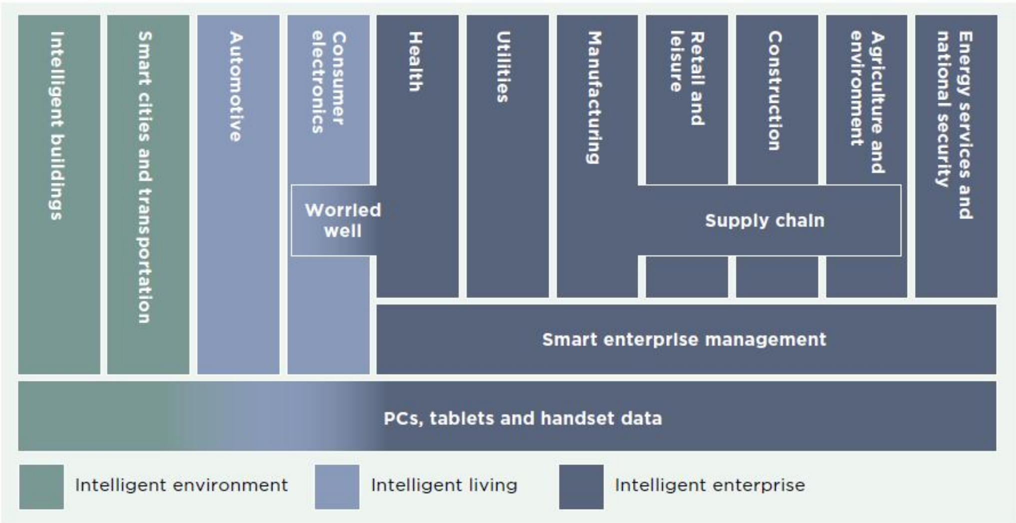

Figure 3.1. IoT Industry Sectors (GSMA [3]).

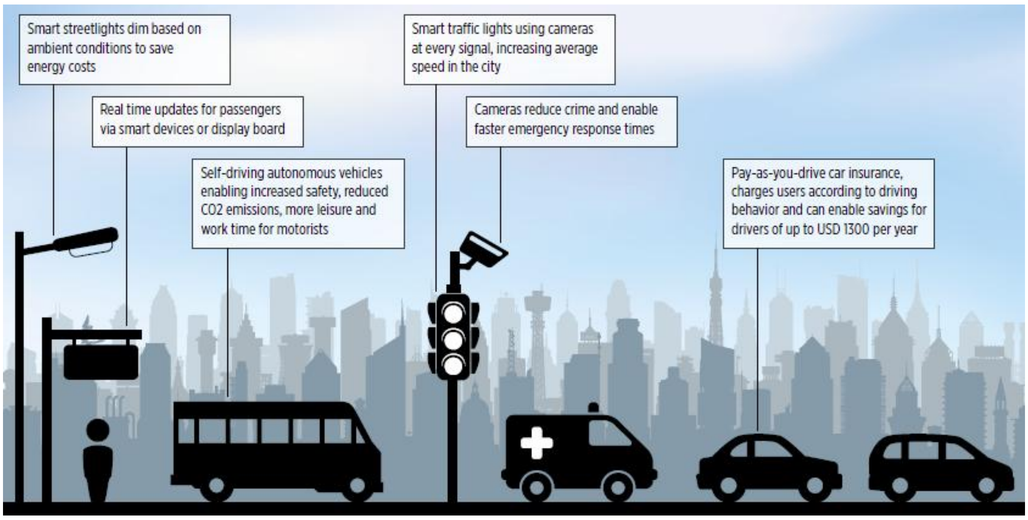

Figure 3.2. IoT application examples (GSMA [3]).

There are many definitions for IoT [4]. IERC (IoT Research Cluster) had defined IoT as follows [5]:

“A dynamic network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual “things” have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network.” This is illustrated in Figure 3.3.

Thus, Internet of Things is essentially an architectural framework, which allows integration and data exchange between the physical world and computer systems over existing network infrastructure.

Figure 3.3. IoT Definition by IERC [6].

Differences between IoT and the Internet

Goldman Sachs has identified 5 basic differences between the Internet and IoT (Figure 3.4) [6].

S-E-N-S-E	What the Internet of Things does	How it differs from the Internet
Sensing	Leverages sensors attached to things (e.g. temperature, pressure, acceleration)	More data is generated by things with sensors than by people
Efficient	Adds intelligence to manual processes (e.g. reduce power usage on hot days)	Extends the Internet's productivity gains to things, not just people
Networked	Connects objects to the network (e.g. thermostats, vehicles, watches)	Some of the intelligence shifts from the cloud to the network's edge ("fog" computing)
Specialized	Customizes technology and process to specific verticals (e.g. healthcare, retail, oil)	Unlike the broad horizontal reach of PCs and smartphones, the IoT is very fragmented
Everywhere	Deployed pervasively (e.g. on the human body, in cars, homes, cities, factories)	Ubiquitous presence, resulting in an order of magnitude more devices and even greater security concerns

Figure 3.4. Differences between IoT and the Internet.

3.2 IoT Value is in Data

IoT has moved from a vague futuristic science fiction to reality. Now the biggest question is: “How to utilize it and take benefits from it?” The value is in the advanced processing of data given by trillions devises. IoT data is more dynamic, heterogeneous, imperfect, unstructured, unprocessed and real time than normal business data, which requires flexible powerful tools for formatting, exchanging, storing and analysing the data.

There is an obvious need for Big Data tools that take most essential value from IoT, for example:

- deep understanding of the context and situation
- real time actionable insight – detect and react in real time
- performance optimization
- proactive and predictive advanced knowledge

3.3 IoT Components

There are three IoT components which enables seamless ubicomp: (a) Hardware - made up of sensors, actuators and embedded communication hardware (b) Middleware - on demand storage and computing tools for data analytics and (c) Presentation - novel easy to understand visualization and interpretation tools which can be widely accessed on different platforms and which can be designed for different applications [4].

The IoT components are used in different IoT framework architecture layers. IoT framework and architecture definitions are evolving, but some basic common layers are visible in existing models. For example, according to ITU [7] there are four major layers (Figure 3.5) that compose IoT architecture. Those are:

- Device Layer
- Network Layer
- Service and Application Support Layer / Cloud Management Layer
- Application Layer

Application layer

The application layer contains IoT applications. Some functions for the Application Layer (illustrated in Figure 3.6) are defined in [10]: This layer is responsible for providing services to the end users (home owner or smart grid). It hosts DRM, dynamic pricing for smart grid system, or Energy Management, and Home Security for consumer services. The services can also be provided by third party, e.g. a home security management company.

Service support and application support layer

The service support and application support layer consists of the following two capability groupings:

- Generic support capabilities: The generic support capabilities are common capabilities which can be used by different IoT applications, such as data processing or data storage. These capabilities may be also invoked by specific support capabilities, e.g., to build other specific support capabilities.
- Specific support capabilities: The specific support capabilities are particular capabilities which cater for the requirements of diversified applications. In fact, they may consist of various detailed capability groupings, in order to provide different support functions to different IoT applications.

In [10], instead of service support and application support layer, Cloud Management Layer is defined as follows: *"Cloud services layer is where all the data storage and information retrieval will take place. Management Layer is where authentication, user management and data management are done".*

Network layer

Network layer consists of the following two types of capabilities:

- Networking capabilities
    - Provide relevant control functions of network connectivity, such as access and transport resource control functions, mobility management or authentication, authorization and accounting (AAA).
- Transport capabilities
    - Focus on providing connectivity for the transport of IoT service and application specific data information, as well as the transport of IoT-related control and management information.

Device layer

Device layer capabilities can be logically categorized into two kinds of capabilities:

- Device capabilities, include but are not limited to:
    - Direct interaction with the communication network: Devices are able to gather and upload information directly (i.e., without using gateway capabilities) to the communication network, and can directly receive information (e.g., commands) from the communication network.
    - Indirect interaction with the communication network: Devices are able to gather and upload information to the communication network indirectly, i.e., through gateway capabilities. On the other side, devices can indirectly receive information (e.g., commands) from the communication network.

- Ad-hoc networking: Devices may be able to construct networks in an ad-hoc manner in some scenarios which need increased scalability and quick deployment.
- Sleeping and waking-up: Device capabilities may support "sleeping" and "waking-up" mechanisms to save energy.

NOTE – The support in a single device of both capabilities of direct interaction with the communication network and indirect interaction with the communication network is not mandatory.

- Gateway capabilities, include but are not limited to:
  - Multiple interfaces support: At the device layer, the gateway capabilities support devices connected through different kinds of wired or wireless technologies, such as a controller area network (CAN) bus, ZigBee, Bluetooth or Wi-Fi. At the network layer, the gateway capabilities may communicate through various technologies, such as second generation or third generation (2G or 3G) networks, long-term evolution networks (LTE), Ethernet or digital subscriber lines (DSL).
  - Protocol conversion: There are two situations where gateway capabilities are needed. One situation is when communications at the device layer use different device layer protocols, e.g., ZigBee technology protocols and Bluetooth technology protocols. The other one is when communications involving both the device layer and network layer use different protocols e.g., a ZigBee technology protocol at the device layer and a 3G technology protocol at the network layer.

Management capabilities
In a similar way to traditional communication networks, IoT management capabilities cover the traditional fault, configuration, accounting, performance and security (FCAPS) classes, i.e., fault management, configuration management, accounting management, performance management and security management. The IoT management capabilities can be categorized into generic management capabilities and specific management capabilities.

Essential generic management capabilities in the IoT include:
- device management, such as remote device activation and de-activation, diagnostics, firmware and/or software updating, device working status management;
- local network topology management;
- traffic and congestion management, such as the detection of network overflow conditions and the implementation of resource reservation for time-critical and/or life-critical data flows.

Specific management capabilities are closely coupled with application-specific requirements, e.g., smart grid power transmission line monitoring requirements.

- Security capabilities
  There are two kinds of security capabilities: generic security capabilities and specific security capabilities. Generic security capabilities are independent of applications. They include:
  - at the application layer: authorization, authentication, application data confidentiality and integrity protection, privacy protection, security audit and anti-virus;
  - at the network layer: authorization, authentication, use data and signalling data, confidentiality, and signalling integrity protection;
  - at the device layer: authentication, authorization, device integrity validation, access control, data confidentiality and integrity protection.

Specific security capabilities are closely coupled with application-specific requirements, e.g., mobile payment, security requirements.

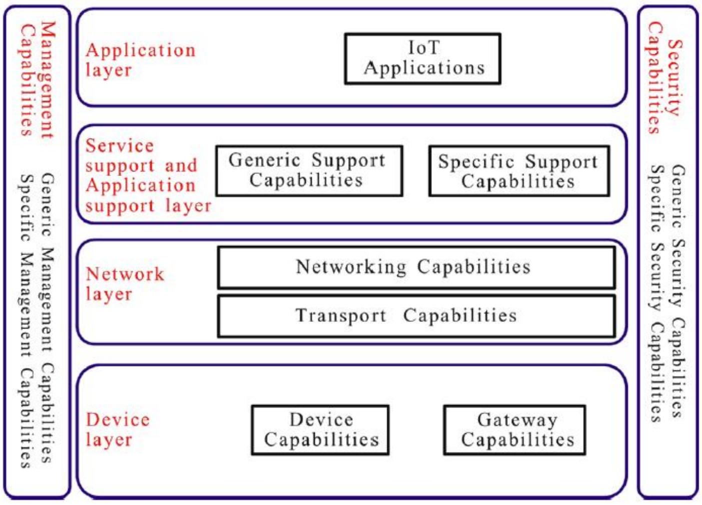

Figure 3.5. IoT Reference Model ITU [7].

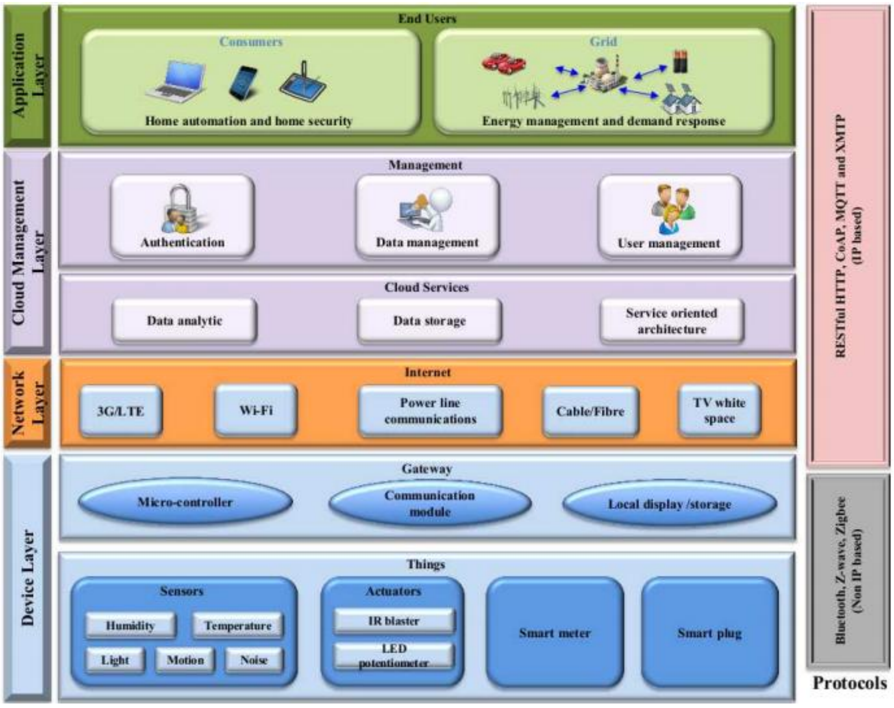

Figure 3.6. Modified ITU Framework by [8].

The four-layer ITU model (presented earlier) is further expanded with (or divided into) more layers to make the IoT framework architecture more granular, as shown in Figure 3.7 [6]:

- Physical Layer
- Network Communication Layer
- Processing Layer
- Storage Layer
- Abstraction and Virtualization Layer
- Service Layer
- Application Layer
- Collaboration Layer and Processes Layer

Abstraction layer for abstracting physical IoT devices and resources into virtual entities and representations, enabling interoperability through uniform access to heterogeneous devices and resources over multiple communication protocols.

Virtualization layer for providing service look-up mechanism that bridge physical network boundaries and offer a set of consumable services.

Data management framework for enabling storage, caching and querying of collected data as well as data fusion and event management, while considering scalability aspects.

Semantic representation framework for modelling and management of semantic knowledge.

Security and policy framework for implementing Access Control mechanism and Federation Identity management responsible for authentication and authorization policies and for enabling federation among several IoT platforms respectively.

Networking framework for enabling communication within and across platforms, providing means for self-management (configuration, healing and optimization) through cognitive algorithms.

Open interfaces for set of open APIs (possibly cloud based) to support IoT applications, and ease platform extension by enabling easy interaction and quick development of tools on top of the platform.

Data analytics services for providing “real time” event processing, a self-service rule engine to allow users to define simple and complex rules, and querying, reporting and data visualization capabilities.

Machine learning data analytics for a set of complex machine learning algorithms, for providing real time decision capabilities.

Development tools and standardized toolkits for fast development of (possibly cloud-based) IoT applications that can be integrated to different companies.

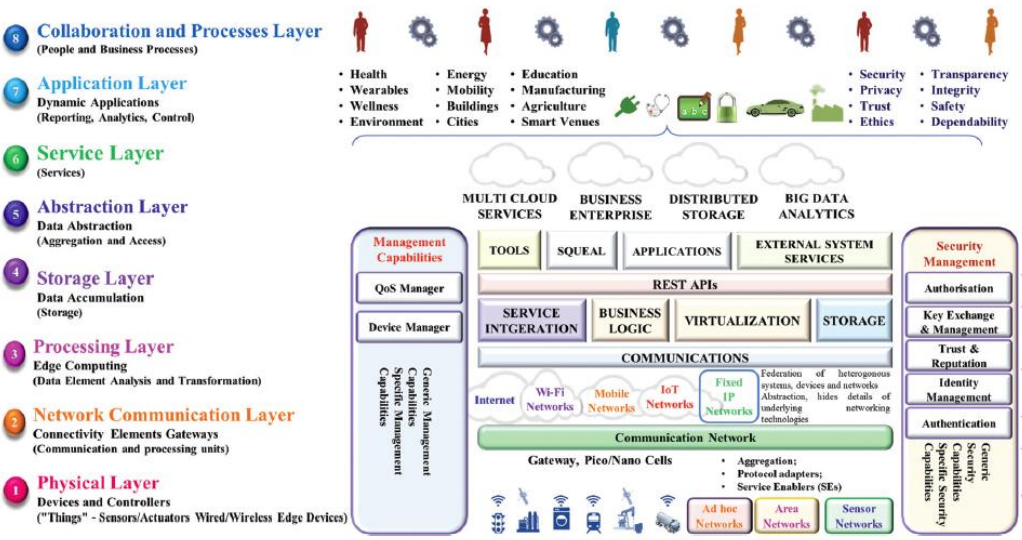

Figure 3.7. IoT Architectural view [9].

3.4 IoT Key Technologies Roadmap

However, although lot of IoT applications is being developed and taken into use, IoT is not yet ready. There are still some open IoT specific challenges such as security and privacy, participatory sensing, data management and analytics, GIS based visualization and Cloud computing apart from the standard WSN challenges including architecture, energy efficiency, security, protocols, and Quality of Service.

The end goal is to have Plug and Play smart objects, which can be deployed in any environment with an interoperable backbone allowing them to blend with other smart objects around them. Standardization of communication frequency bands and protocols plays a pivotal role in accomplishing this goal.

In Figures 3.8 and 3.9, there are a couple of examples about possible roadmap described. Figure 3.8 reflects technology evolution for potential utilizing users and 3.9 by technologies. The evolution in both roadmaps are represented similarly, where technology will support more complex multivolume sensor networks with advanced data utilizing tools.

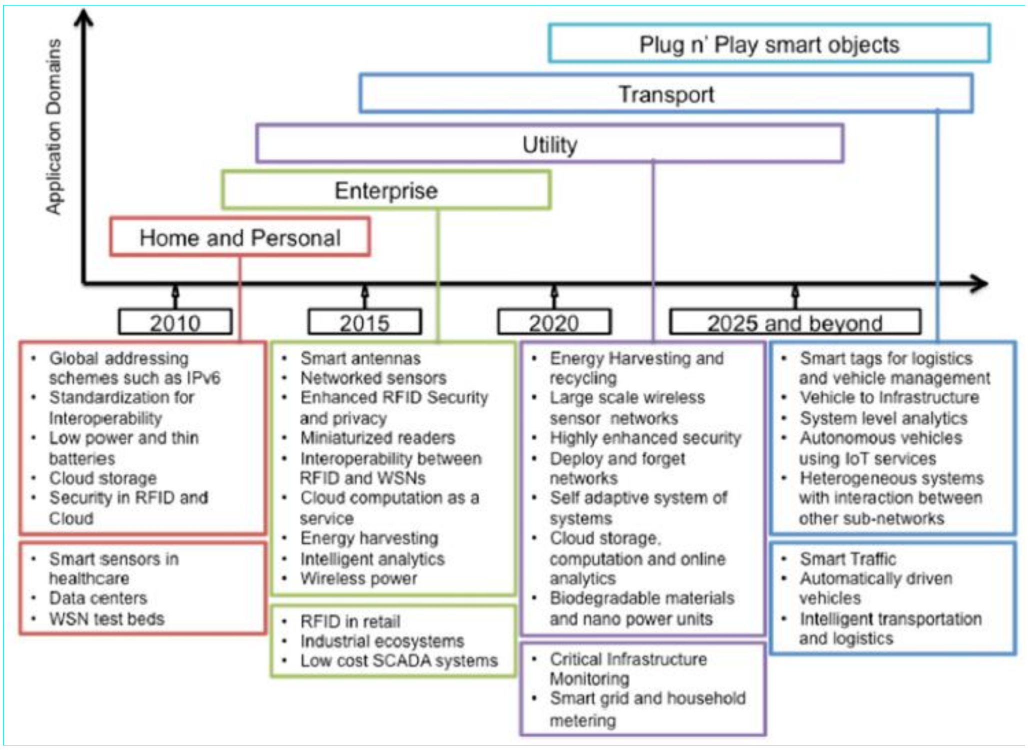

Figure 3.8. Evolution of key IoT technologies [4].

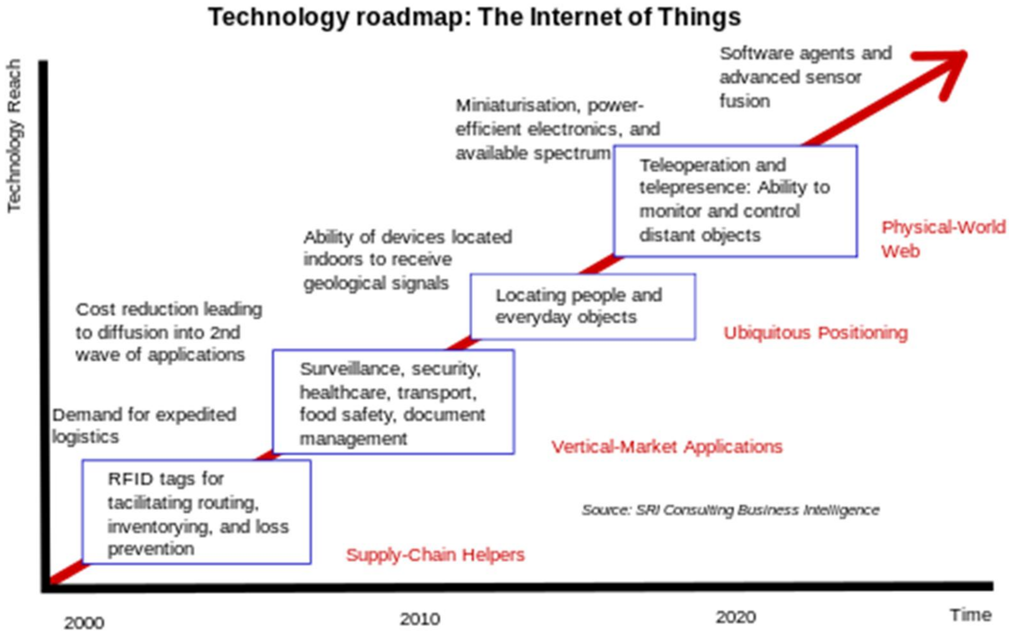

Figure 3.9. Evolution of key IoT technologies (by SRI Consulting Business Intelligence).

3.5 Role of the IoT in Smart Grid Deployment

The seven domains existing in the smart grid conceptual model were developed without the IoT concept in mind. As the smart grid evolved, many attempts started to introduce the IoT as enabling technology to the grid. Each device in the grid can be considered as an object. Utilizing the concept of IoT, each device can have a unique IP address that can upload its status and download control commands via the Internet [10].

Smart Grid is often compared to a concept of “Internet of Energy (IoE)” where IoT technologies and tools are used for a real time balancing between the local and the global generation and storage capability with energy demand giving consumers a possibility to participate and be more aware of energy consumption.

Smart grids and smart metering are big potential IoT-based applications, which are being implemented around the world. Efficient energy consumption can be achieved by continuously monitoring every electricity point within a house and using this information to modify the way electricity is consumed. This information is used for maintaining the load balance within the grid ensuring high quality of service.

The data that will be generated in a smart grid is much more than that generated in a traditional grid due to more measurement points in smart grid automation, and due to introduction of new services (e.g. demand response and distributed energy resources) that require two-way communication and denser data collection periods.

The smart grid will enable optimization of energy generation, transmission, distribution, and consumption. It provides an opportunity for energy companies to make power delivery more efficient, whether by minimizing personnel visits to transmission and distribution locations or by enabling better decisions through more timely information. It will enable millions of distribution field devices, thousands of transmission substation devices, millions of devices in customer premises (for example, smart meters, home energy controllers, and electric vehicles), data centre applications, and customer service and support apparatuses to interoperate and communicate to empower energy supplies and consumers to manage energy more effectively, increasing efficiency and service levels while lowering overall expenditures.

At the same time, the smart grid must change and grow with the industry. The smart grid must be able to evolve as technological advances yield new hardware, applications, and devices. Moreover, it must incorporate such advances into the network with minimal cost and difficulty.

Also smart grid must take smooth migration from current disjointed data communications networks to converged networks in a phased approach with minimal service effect.

Example IoT applications in smart grid

IoT technology is seen to be an accelerator and enabler of new smart grid applications. The number of IoT applications in smart grid systems is increasing by the day. Some of the high impact applications, which have industry-wide uses are [11]:

- *Digital two-way smart meter:* The consumer side of a smart grid network is supported by the digital two-way smart meter, which enables two-way communication between utilities and customers. It records electricity usage and reports it to the central utility. In addition, it provides real-time power consumption data to users through a web browser or mobile app, helping them make informed load usage choices, achieving demand response management for the utility.

- *Smart charge devices:* This consists of an intelligent charging system that uses an on-site battery array to store low cost energy to be used during the peak demand period. The system intelligently interacts with the grid to understand the peak demand period, and, if required, disconnects the home circuit from the grid to supply power on its own.

- *Smart plugs:* These are smart devices that connect household loads with the power line. They calculate peak demand periods by sensing the input voltage and current (using data analysis packages) and schedule device usage during the off-peak times. Thus, they help reduce the power bill and maintain demand-supply balance. Smart plugs can be programmed to not shut down certain devices even during peak load periods.

- *Home controllers:* These are smart devices that receive line inputs from utilities (such as demand level and price inputs), based on which they operate home devices through dedicated home networks. They also have the capability to include the owner's choices in the device scheduling process. As a result, home devices are run in an optimized manner during periods of minimum load. They reduce both the owner's electricity bills and the peak load on the grid.

- *Solution for IPV6 mapping:* IPv6 will become the addressing mechanism of choice because of its large multi-layered address space.

- *Data analysis software:* An important purpose of using the IoT in a smart grid is to get access to meaningful insights and instruction stimuli for near real-time demand response management and load management. This requires efficient analytics software to analyse data streams generated by IoT sensors and send feedback to the grid. The grid will take the necessary course of action based on the feedback.

- *Security solutions:* Wireless network technology is prone to security threats such as virus attacks. IoT operators can make wrong decisions based on distorted data, which can lead to severe consequences including legal complications for the utilities. IT service providers can use this opportunity to provide effective security solutions.

Ensuring security: The unfortunate reality is that because of the critical nature of the technology and the services it provides, the grid becomes a prime target for acts of terrorism and cyberattacks. The transformation of traditional energy networks to smart grids requires an intrinsic security strategy and specific security mechanisms to safeguard this critical infrastructure.

- *Data center services:* The huge volume of data generated by a smart grid has to be stored, and accessed dynamically whenever required. This will require cloud-based data storage facilities for effective smart grid implementation. Services providers can look for opportunities in this space. Many countries are starting to roll out smart grid programs, so service providers that step in at this stage will get an irrevocable early mover advantage.

- *Network topology:* Smart meters need to share information with IoT devices in a home setup using network topology. This information allows consumers to conserve energy, and thus lower their utility bills. Different countries use different network topology standards, hence there is ample scope to develop more efficient systems.

  Transmitting data over multiple media: Smart grid data must be able to travel rapidly and reliably over a variety of different network media, from copper cables to fibre infrastructure to power line communication (PLC) channels and to wireless networks.

  Connecting large numbers of devices: The smart grid architecture must enable communication and correlation of data from approximately 61,000 substations and 180 million transformers and meters, with the number of devices connected to the smart grid growing annually.

  Maintaining reliability: High network availability is absolutely critical. Network outages are costly and debilitating - and currently all too frequent. In fact, 41% more outages affected 50,000 or more consumers in the second half of the 1990s than in the first half of the decade. Ensuring uninterrupted electrical service to ratepayers is a prime challenge for the smart grid. Therefore, ensuring that the smart grid data network is reliable, so that it in turn can ensure uninterrupted electrical service to ratepayers, is crucial.

  Connecting multiple types of systems: The smart grid must connect and exchange data freely with many different types of hardware, ranging from smart sensors in home appliances to home energy meters to transformers and beyond to the remote data base systems.

- *Artificial intelligence services:* A smart grid includes a large number of unconnected discrete objects (such as smart meters, smart sensors, wireless controllers and others) as well. The output each object produces has a ripple effect on the grid, which impacts all other players. The modern grid consists of prosumers who also contribute to the grid through household renewable generation units such as rooftop solar plants. For example, on a bright sunny day, when there is a surge in power supplied by such prosumers, the grid should be able to best utilize this extra power. Artificial intelligence can play a crucial role in this aspect by predicting the actions of various players and simulating the cascading effect they will create. Artificial intelligence services can also enable discrete grid objects to respond to dynamic price changes by altering their power consumption pattern. They will also help smart grids communicate decisions automatically to users. In addition, AI services can develop simulation and prediction tools for grid operators and suppliers to measure the system-wide ripple effect of deploying pricing mechanisms and energy management processes.

Where Big Data could be used

Many existing business capabilities can be enhanced with IoT and Big Data tools. Some examples are listed in [12]. An unexplored future area is low-voltage direct current (LVDC) μGrid systems, where Big Data could play an important role. In the following chapter the LVDC μGrids are presented, and Big Data use cases and possibilities in those are given.

4 LVDC µGrid – Big Data Approach

4.1 LVDC testbed

With the LVDC system, the power transmission capacity in low-voltage networks can be increased and larger low-voltage networks built compared with traditional alternating current (AC) systems. Accordingly, the MV line branches can be replaced with LVDC system and thus the length of MV feeder lines can be decreased especially in rural areas having a small number of customers, and thus relatively low amount of loads in the LV distribution network. By this way the life-cycle costs of distribution grids can be decreased. These were the main advantages when the LVDC system was started to be developed [13].

The LUT LVDC testbed has been built in co-operation with Suur-Savon Sähkö Oy. The LVDC testbed controls the electricity distribution of four customers in the DC network in Suomenniemi. After MV is transformed to low voltage AC, the power is rectified and smoothed to DC (±750 VDC, and 0 V) with a grid converter. Then, the low voltage DC is delivered to customers with the same underground cable network as used with low-voltage AC. Each customer, depicted in Figure 4.1, is equipped with customer-end inverter (CEI) that produces standardized 230/400 VAC to customer loads. The testbed has been in operation since summer 2012, and the future goal is to extend the grid monitoring and control functionalities to cover also the customer load control inside the customer premises. By this way, the customers and their loads can be integrated as active parts of the flexible energy systems and markets. Moreover, the applicability of the DC distribution also inside customer premises is one potential study case in future [14].

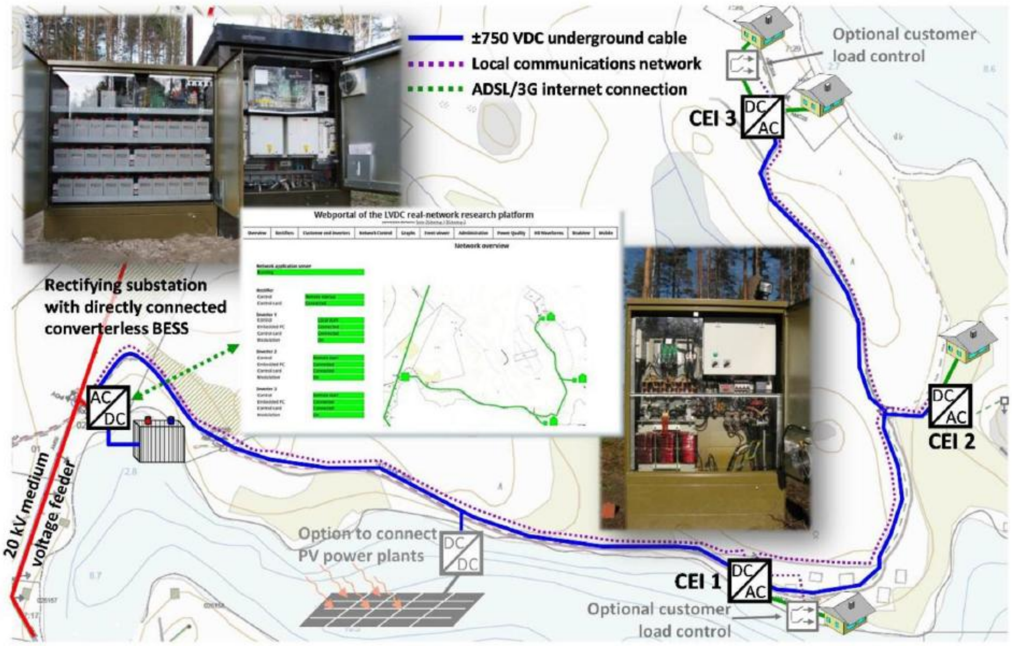

Figure 4.1. LVDC research site and its components located on the map [15].

The LVDC testbed is managed by a local ICT system, which includes IEDs (such as embedded PCs at rectifying substation and each CEI) and local communication network between the IEDs in the LVDC grid. It uses a proprietary protocol over TCP/IP to enable connections between the IEDs. The communication inside the LVDC system is over multi-core optic fibre. A dedicated manageable Ethernet switch manages single cores at the rectifying substation. In the other ends of the DC grid, single cores are connected via fibre-Ethernet converters to the embedded PCs at each CEI [14].

Each embedded PC is locally connected to a CEI microcontroller and a grid-tie converter microcontroller, respectively, with Ethernet cable. Microcontrollers control the operation of grid-tie converter and CEIs. Similarly, the embedded PCs of grid-tie converter and battery energy storage system (BESS) next to the grid-tie converter are interconnected via Ethernet cable (Figure 4.1). The BESS is controlled via its embedded PC, which again controls the battery management system (BMS) of the batteries. The data connection to remote databases and for research purposes is implemented with asymmetric digital subscriber line (ADSL). The μGrid has also another access point (AP); a backup connections implemented with mobile 3G modem at the rectifying substation. Thus, the rectifying substation, where also the MV/LV transformer is located, is the interface both to the MV grid and the remote ICT systems. Embedded PC at rectifying substation comprises web-based server, that is, the system supervision portal. This enables remote control of the whole system via Internet. The ICT system of the LVDC testbed is illustrated in Figure 4.2. In next phase the LVDC ICT system is planned to extend to cover also the customer premises and loads. Hence, each embedded PC works also as a master of the subnetwork under each CEI [14].

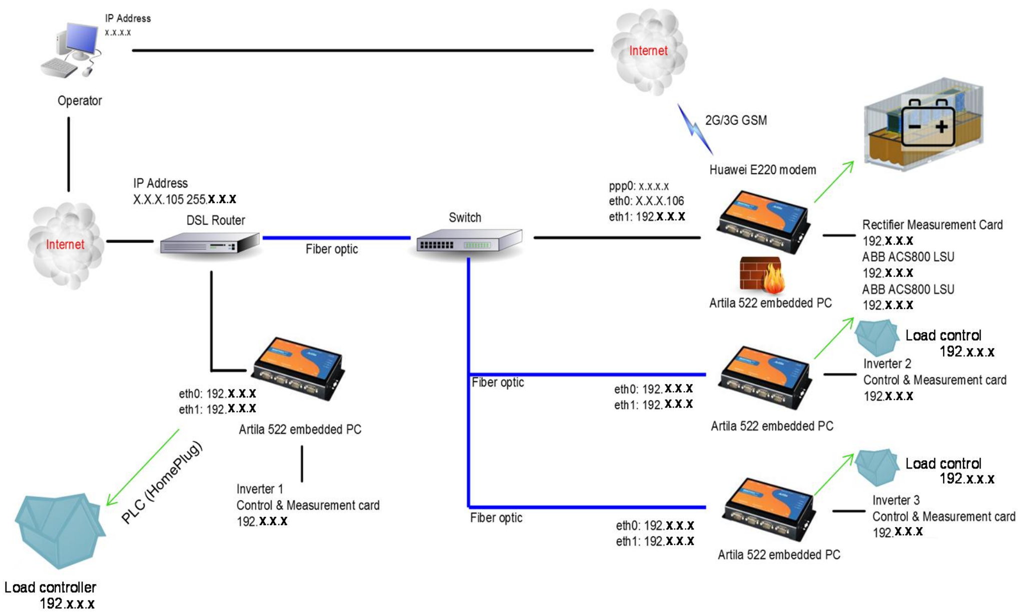

Figure 4.2 ICT system of the LVDC testbed [16].

Thus, some more moderate IED or control unit (C/U) with communication interfaces and sensors for connecting the customer subnetworks as part of the LVDC ICT system is required to be installed inside each customer. By this way home energy management system (HEMS) is implemented. Suitable communication media to this last meter connection are power line communication (PLC) and wireless sensor networks (WSNs), such as Xbee, or LoRa. Accordingly, the LVDC ICT architecture is distributed on the active power electronic devices of the LVDC grid. By controlling the customer loads and the BESS, which is directly connected to the DC grid, together, the whole DC grid can operate as an island grid, and it can operate as a flexible and controllable load reserve seen from the distribution (MV) grid.

4.2 Big Data Approach & Functionalities & Possibilities

Sentence in paragraph, presented in Section 3.5: “Smart Grid is often compared to a concept of “Internet of Energy (IoE)” where IoT technologies and tools are used for a real time balancing between the local and the global generation and storage capability with energy demand giving consumers a possibility to participate and be more aware of energy consumption.” has been the approach and case from the very start when LVDC system concept was sketched.

Because of data communications development, improved communication networks and digitalization, the ICT systems in power grids from AMR meters and SCADA systems to advanced secondary substation automation and HEMSs, including sensors and measurements of currents, voltages, power consumptions and power quality etc., have developed and become more common as well. Accordingly, cloud-based data bases for storing data have become available. Thus, the possibilities to gather and process sensor and grid data more widely have been developed and increased. Data bases contain huge amount of all kind of data, and new measurement and sensor data from power grids is stored to data bases. Combining and mining all these data to produce new data having some additional value is called Big Data.

Besides LVDC μGrid working as a controllable load and/or power source from the DSO perspective, enabled by active power electronics and energy storage built in and integrated into the system, many other functionalities and business capabilities can be enhanced with IoT and Big Data tools. Some existing examples are listed in [13], which can also be applied in the LVDC μGrid system:

- *Revenue protection or loss prevention*: Used to determine unusual usage patterns and probe as to why a meter signature suddenly appears differently or for meter data consistency with the billing data. Also, leverage usage patterns to formulate demand based pricing based on peak usages on grid for improved revenue and better demand-supply management.

- *Meter data acquisition and demand response*: While meter acquisition rates are typically set to 4-hour intervals, Hadoop-based architectures can handle much higher data rates. A meter could be sampled every 5 or 15 minutes instead of 4 hours to better analyze demand and manage the grid efficiently. Streamline supply (power generation) to meet the demands effectively are also enabled. In fact, the power acquisition sampling rates in the LVDC system are already much higher (1 s resolution), and from these data more accurate analyses can be made.

- *Outage and load analysis*: Maintenance and operational pitfalls can be significantly reduced with predictive capabilities leading to reduced outages, better proactive maintenance of assets, and reduced costs. Operational efficiency can be improved by analyzing data related to power quality and from load balancing, load matching and daily peak demand. Predictive customer modeling and analyzing customer sentiment from sources like social media can provide insight into customer behavior providing another input for load forecasting. Sensors on equipment and vehicles can more quickly pinpoint problems and enable better logistical support.

- *Improved financial forecasting*: More detailed histories can help determine, measure, and track the elasticity of demand and Electricity Tariff Analysis what-if scenarios can played-out in more detail, while asset optimization and asset planning can be improved by analyzing operational efficiency.

- *Risk or Threat Management*: Utility companies face an unusually high number and variety of risks, including many that have serious health, safety and environmental implications. While these risks cannot be eradicated, more and varied data can be used to help manage and mitigate some of them. Finding unauthorized or illegal access or usage can save companies from suffering the consequences of these possibly malicious activities. Predictive analytics that can generate prescriptive actions can pay large dividends if major problems become avoidable.

- *IT operational efficiency*: Not unique to utility companies and rarely driven from the lines of business (but a possible reason for embarking on extended architectures that include Hadoop) is the need to move data staging and transformation to a schema-less platform for more efficient processing and leveraging of IT resources. IT operational efficiency is often difficult to prove but is sometimes an initial justification that IT organizations gravitate toward when deploying these types of solutions.

The Big Data concept proposal on the LVDC µGrid field testbed is illustrated in Figure 4.3. Yet there are no distributed generation (DG) unit installed to the DC grid nor customers AC networks, but it is optional. Regarding the research platform, plans for DG connected directly to the DC grid are made. The addition of the DG to the existing LVDC µGrid and/or local energy storages at customers (EVs) will make the µGrid complete, and enable the system to work more autonomously from the supplying MV grid.

A lot of data is collected from the LVDC µGrid. One reason for this is that the LVDC research setup is one of the first DC grids that are connected to and are operated as a part of the existing and real power distribution grid. As it has been a prototype system, the whole and accurate operation of it is monitored on-line all the time from the very beginning. Currents and voltages, and quality of the DC grid are monitored at the rectifier substation and the ones of AC grid at every customer. Moreover, the status and operation (charging, discharging and SoC) of the BESS located next to the rectifier is monitored and controlled. All the data is collected and stored to the local data base in the LVDC grid and the one in cloud. When these data are further analyzed and combined with the data in remote systems, for instance, with electricity markets and price information, the battery and the whole µGrid can be technically operated as a flexible load.

The next phase in the LVDC field grid development is to add the IEDs and communication interfaces to each customer premise. By this way more precise information of the customer behaviour can be collected, customer loads can be controlled, and the flexibility of the whole µGrid from the DSO/TSO perspectives is enhanced. Morever, besides the interconnection of customer loads to as part of controllable reserve, Big Data data base (DB) and tools are required to be added on the LVDC µGrid, as illustrated in Figure 4.3.

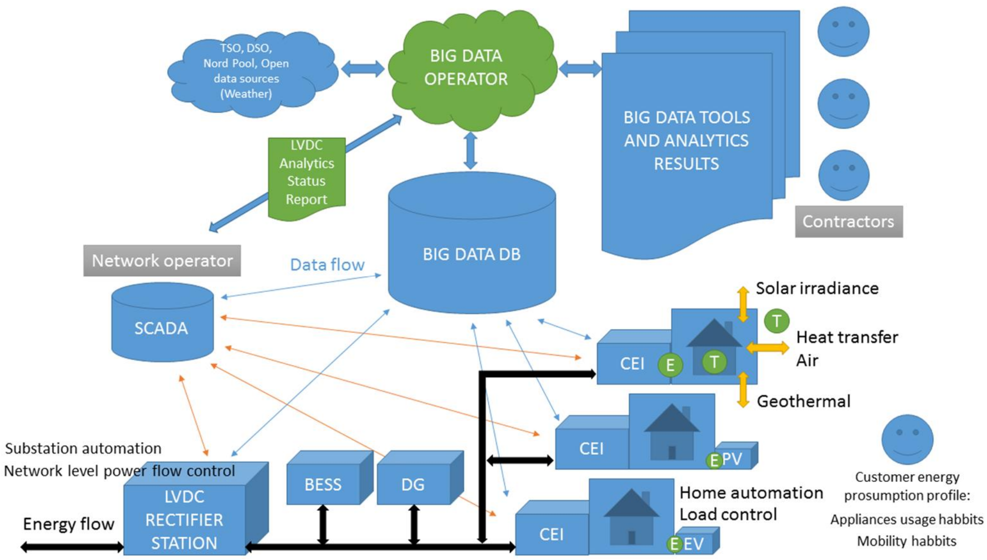

Figure 4.3 Big Data concept proposed on the LVDC testbed. Energy flow (E) and temperatures (T) at each customer premise (including outdoor temperature measurement) are monitored.

By collecting more detailed information locally of customers behaviour, the data amounts are naturally increased. Moreover, Big Data operator, that is, the main distribution management system (DMS) unit of the whole µGrid enabling the flexibility, is proposed. Its main function is to collect data from many DB sources, and combine and filter all the relevant data to produce new profitable data for providing flexibility from the energy system perspective. This data as an outcome is to be used to control the whole power grid most cost efficiently, and by the needs of DSO, market player, or some other service providers.

Several advanced features enabled technically and built in already in the LVDC µGrid system can be developed further as advanced functionalities with Big Data operator. For instance, Big Data operator can deliver guideline values to the active devices based on the needs of DSO and other energy market players. The main *features* and the driven functionalities for each ones enabled by Big Data concept are listed below:

µGrid condition monitoring: Data gathered from active parts of the grid, that is the power converters, is used in estimating the life time and condition monitoring of each one and in SCADA services. Thus, the component maintenance can be planned by DSO, and sudden component failures, and thus outcomes and service interrupts to customers can be avoided and/or minimized.

Battery dis/charging: BESS is charged and discharged when the electricity price is at lowest and at highest level, respectively, if/when possible. The main BESS control concern is the preparation for storms and blackouts. This relates also the open weather data of the location of the µGrid and the MV grid that the µGrid is supplied from. Cost savings in electricity consumption and price are provided, and also in the case of power blackouts as the outages durations are minimized.

Island mode: The whole LVDC µGrid can operate as an island grid for instance during severe storms. The system can prepare for the storm by weather forecast data and charging the battery full before the storm. The island mode duration is dependent on the BESS capacity (and SoC), DG production (estimated based on weather forecast) and the power consumption of the µGrid customers. By controlling the customer loads, turning off the secondary loads; air conditioning, heating (depends on the temperature), etc. the LVDC µGrid can sustain itself for instance over the blackouts of several hours.

Frequency containment reserve (FCR): BESS together with active rectifier can be used as active frequency containment reserve (power source/sink) when needed; stabilizing the supplying MV grid frequency by the guideline values given by Big Data operator (based on the needs of market player; TSO/DSO).

Fixed load source: With the BESS, the power taken from the MV grid can be kept fixed. The power/energy consumption of the LVDC µGrid can be seen constant and with the history data of energy consumption of the customers in µGrid is used in controlling the BESS operation. Accordingly, the battery is charged during low power time intervals and/or when the electricity price is low.

Planning: As there are many data sources available, which can be used together with measurements gathered from µGrids (and smart grids in general) to create new data. Data sources that could be used for planning of grids and those operation are categorized and listed in [17].

The significance of these features related to LVDC µGrid monitoring, grid data gathering and system control are connected directly to demand side management and asset management, and demand response, and are further highlighted when there are several LVDC µGrids in the distribution grids.

One major thing to be considered when Big Data concept for such µGrids are proposed is the data management. This relates directly to issues that needs to be solved, such as:

- What data is stored and where (raw data, its processing)?
- Is the data filtered and processed locally (distributed architecture), and only some key indicators or known/agreed parameters to be delivered and transmitted to remote DBs, and feedback to the grid?
- Who has access to the data (cyber security issues)?
- What are the permissions on data? Read only (raw or processed data) and possibility to modify the data (cyber security issues).

When the amount of data available and used for LVDC µGrid control and management in Big Data means is increased, it forces the Big Data system architecture to be distributed instead of centralized one. At least in the level of data filtering and processing. This is reasonable to be done locally before sending the key parameters to cloud, where perhaps the primary high level decisions are made. Thus, the architecture may be combination of both. If all the data is transmitted from grids to remote systems and back, it would require high speed wide band connections from the remote system all the way to the customers. This is not the thing in real world, but instead installation of IEDs to the grid nodes would be more reasonable and feasible solution. And as from the µGrid perspective, and what is also the case in the LVDC system, the rectifier substation, that is, the interface between the MV feeder grid and the customers, could be the place for local master of the µGrid. Thus, the data flow in such distributed architecture of the µGrid ICT system could be:

- Local master collects all the filtered and synchronized data from BESS, CEIs and customers locally first to its local data base,
- Delivers filtered and processed data further to remote Big Data DB,
- Big Data operator makes the high level decisions based on all the data in Big Data DB, and gives commands to the LVDC local master,
- Local master again relays the new updated / required control data to CEIs and IEDs at customers.

This kind of architecture leads to situation that as there is several communication protocols available and used, several remote and local communication medias and networks in the link between remote DBs and customers (3/4/5G, xDSL, optic fibre, PLC, WSNs etc.), the compatibility and seamless connections with required protocol/media converters are required. It's not defined here and not the case in practice either, that what protocol(s) and media(s) should be used in each architecture layer, but instead certain freedom in forming functioning ICT system concept should be guaranteed; the physical platforms needs to be designed case-by-case. Moreover, the weakest link, that is, the minimum communication bandwidth in each layer sets also requirements how small/big data packets should be used.

One major possibility from service provider perspective of the proposed Big Data concept for LVDC μGrids and in general on smart power systems is all the new services that are required in designing and integrating functional IoE concept. Service providers on data analytics, network operators, component manufacturers (both of electrical and communication network devices), and contractors (in implementing such systems or parts of the system) etc. are required, and this can lead to new businesses or at least produce more market in the field of smart grids and data analytics.

As an outcome of all the aspects described above, the main challenge in the integration of Big Data based ICT system for μGrid management is the planning and design of the whole control system architecture on the LVDC μGrid system. In the control system design next aspects to be solved are listed:

- What all data is available, and how all data is combined in practise?
- What are the input data and what are the desired output data, and on what ICT system layers?
- The interfaces to different service providers, operators, energy markets etc. in cloud? Who has the main role and power on the μGrid management? (comprises the cyber security concerns)
- What are the sampling rates of data in different layers?
- What data and data flows; how frequently data is to be transmitted between different ICT layers?
- Control system design; subsystem local control inside the μGrid and its interactions with the high level power grid control system)?
- Level of decisions to be done locally, for instance at customer premises, and what information regarding these is sent to the cloud?
- Etc.

The challenge in forming a functional control system, including the algorithms for the whole power system management is even highlighted when the number of μGrids in energy systems becomes higher.

5 Conclusions

This report discusses the features and possibilities of ICT systems applied for controlling and monitoring of flexible energy systems, and implementation of a Big Data concept for an LVDC µGrid system management. Big Data based ICT system concept for the LVDC µGrid management is proposed. However, the concept is applicable also for traditional AC networks as required hardware and software are provided. The report presents a specific but also extensible use case that focuses on Big Data concept for LVDC µGrid system requiring secure and reliable communications as well as information technology tools and devices for data processing. ICT system architectures (including the communication medias and interfaces, and the IEDs), and advanced functionalities enabled by Big Data based tools and services for LVDC µGrids are proposed. The main possibilities and use cases of Big Data on such system are discussed. However, the control system, including the algorithms that needs to be integrated on the Big Data based ICT system architecture to enable the whole µGrid system management and operation by the needs of DSO and service providers, and from the perspective of the whole power system are still to be defined and designed. These are considered and focused in future studies.

The findings regarding this report will be reported in workshop presentations as well as at technical meetings organized among different FLEXe tasks.

6 Abbreviations

2G, 3G, 4G, 5G	2^{nd}, 3^{rd}, 4^{th}, 5^{th} Generation
AC	Alternating Current
ADSL	Asymmetric Digital Subscriber Line
AI	Artificial Intelligence
AMI	Advanced Metering Infrastructure
AMM	Automated Metering Management
AMR	Automatic Meter Reading
AP	Access Point
BESS	Battery Energy Storage System
BMS	Battery Management System
C/U	Control Unit
CEI	Customer-End Inverter
DC	Direct Current
DER	Distributed Energy Resources
DG	Distributed Generation
DR	Demand Response
DMS	Distribution Management System
DSM	Demand Side Management
DR	Demand Response
DSL, xDSL	Digital Subscriber Line
DSO	Distribution System Operator
EU	European Union
EV	Electric Vehicle
FLEXe	Flexible Energy System
HEMS	Home Energy Management System
ICT	Information and Communication Technology
IED	Intelligent Electronic Device
IoE	Internet of Energy
IoT	Internet of Things
IP	Internet Protocol
ITU	International Telecommunication Union
LTE	Long Term Evolution
LUT	Lappeenranta University of Technology

LV	Low Voltage
LVDC	Low Voltage Direct Current
MV	Medium Voltage
PC	Personal Computer
PLC	Power Line Communication
QoE, QoX	Quality of Experience
QoS	Quality of Service
SCADA	Supervisory Control And Data Acquisition
SMS	Short Message Service
SN	Sensor Network
TCP	Transmission Control Protocol
TUT	Tampere University of Technology
VTT	Technical Research Centre of Finland
WLAN, Wi-Fi	Wireless Local Area Network
WSN	Wireless Sensor Networks

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