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Distributed Smartness and Communication Networks

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Deliverable Leader: Giorgio Franchioni (RSE)

Authors:

Flavio Cucchietti (Telecomitalia-GeSI)	
Raffaelel Bolla (DIST-Univ. Genoa - GeSI)	
Matteo Repetto (DIST-Univ. Genoa - GeSI)	

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This deliverable contains a review of ICT in Smart Grids, including original comments and recommendations. Acknowledgement of previously published material has been made through appropriate citation, quotation or both.

NOTES:
For comments/suggestions/contributions to this Document, contact:
the Coordinator of SEESGEN-ICT at Giorgio.Franchioni@rse-web.it
or the Author of this document flavio.cucchietti@telecomitalia.it

For more information on the project SEESGEN-ICT, link to http://seesgen-ict.rse-web.it

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1 INTRODUCTION

1.1 Energy grids

Electricity networks provide societies and economics with essential energy resources. The fundamental architecture of these networks has been developed in most countries to meet the needs of large, predominantly carbon-based generation technologies. Unfortunately, large parts of the power grid infrastructure are reaching their designed end of life time, since a large portion of the equipment was installed in the 1960s. Ageing equipment, dispersed generation as well as load increase might lead to highly utilized equipment during peak load conditions and inefficient use of carbon during low load condition. That poses several questions about the sustainability of these energy systems, as of the problem of greenhouse gas (GHG) emissions and the finite availability of fossil resources.

Several worldwide initiatives reflect an increasing attention towards ambient issues. In March 2007 the EU's leaders endorsed an integrated approach to climate and energy policy that aims to combat climate change and increase the EU's energy security while strengthening its competitiveness. To kick-start this process, the EU Heads of State and Government set a series of demanding climate and energy targets to be met by 2020, known as the "20-20-20" targets. These are:

a. A reduction in EU greenhouse gas emissions of at least 20% below 1990 levels
b. 20% of EU energy consumption to come from renewable resources
c. A 20% reduction in primary energy use compared with projected levels, to be achieved by improving energy efficiency.

However, the current systems are not suitable to implement effective countermeasures to reach the objectives of the 20-20-20 target:

a. current energy distribution networks have been designed for “unidirectional” flow of power from large plants to users;
b. energy management has been traditionally oriented to keep constant the frequency and the voltage of the network, not to reduce fuel consumption in power plants;
c. automation and controls of energy grids usually rely on proprietary and non-interoperable solutions (hardware and operating systems), as of the monopolistic energy market ;
d. very little effort has been devoted to control the final load by actively involving users and industrial consumers.

In addition, there is a strong political and regulatory push for more competition and lower energy prices: in many countries, regulators and liberalization are forcing utilities to reduce costs for the transmission and distribution of electrical energy . As of this trend, the upgrade of the power grid should be reduced to a minimum, so new ways of operating power systems need to be found and established. Efficient and reliable transmission and distribution of electricity is a fundamental requirement for providing societies and economics with essential energy resources.

Energy efficiency and renewable energy are seen as keys to reach this goal. Both measures call for changes in the energy supply system leading to new concepts about production, transmission, distribution and consumption.

The energy challenges that the world is now facing will change the whole electricity supply chain - from generation, transmission and distribution to the customer and consumption side. A more flexible, distributed and open market is necessary for energy generation: new networks will have to integrate decentralized and renewable power generation (onshore/offshore wind, photovoltaic, combined heat & power) from many small suppliers. This heterogeneity of sources, the consequent energy trading and the trend towards location of bulk generation far from load will require more flexible transport of power, which assure high quality energy with stable voltage and frequency. The crackdown on CO_2 emissions will also drive to the widespread adoption of electric vehicles and so plug-in charge towers and higher loads are expected in the near future in the distribution network. Finally, the inconstant and unpredictable availability of renewable power in different hours and seasons will require customers to be more active and to have more interactions with the networks; demand-response strategy will be necessary to find an optimal balance among availability and request of electric energy. In a further step the energy optimization crossing the domains electricity, gas and heat will be a further challenge. Customer-centric networks are the way ahead, but these fundamental changes will impact significantly network design and control.

Therefore, new methods (mainly based on the efforts of modern information and communication techniques) to operate power systems are required to guarantee a sustainable, secure and competitive energy supply .

New electricity networks must be flexible, accessible, reliable and economic. Furthermore, solutions must be scalable, increase capacity for power transfers, reduce energy losses, heighten efficiency and security of supply and be backward compatible to include the installed base. Developments in communications, metering and business systems will open up new opportunities at every level on the system to enable market signals to drive technical and commercial improvements as well as energy efficiency. As of these requirements, much more intelligence than today is expected in the new electricity networks, thus leading to the definition of “Smart Grid”.

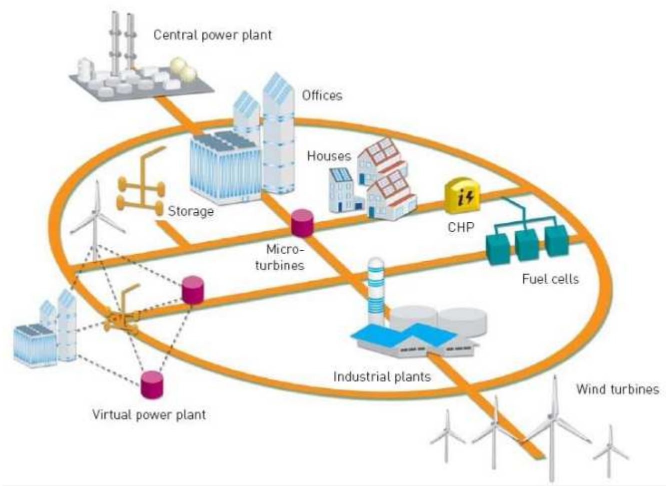

Figure 1. An example of architecture for future energy networks.

1.2 Smart grids

A smart grid can be defined as follows :

> "*A smart grid is an electricity network that can cost efficiently integrate the behaviour and actions of all users connected to it – generators, consumers and those that do both – in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety.*"

This being the definition, ICT will play a key role in smart grids.

The general goals of Smart Grid are to ensure a transparent, sustainable and environmental-friendly system operation which is cost and energy efficient, secure and safe . Objectives of developing the Smart Grid are quite different from country to country for their various demands and start points. However, the common objectives of a Smart Grid are clear and listed below:

a. *Robustness*: The Smart Grid shall improve resilience to disruption to provide continuous and stable electricity flows, avoiding wide-area breakout accidents. It shall guarantee the normal and secure run of the electricity grid even under the instance of emergency issues, such as natural disasters, extreme weather and man-made breakage, and provides self-healing abilities;
b. *Secured operation*: The Smart Grid shall enhance communication networks and information security of the electricity grid;
c. *Compatibility*: The Smart Grid shall support the integration of renewable electricity such as solar and wind, has the capacity of distributed generation access and micro-grids, improve demand response functions, implement the effective two-way communication with consumers and satisfy various electricity demands of consumers;
d. *Economical energy usage*: The Smart Grid shall enable more effective electricity markets and electricity trades, implement optimized configuration of resources, increase efficiency of the electricity grid, and reduce electricity grid wastage;
e. *Integrated system*: The Smart Grid shall highly integrate and share information and data of an electricity grid, utilize the uniform platform and model to provide standardized and refined management;
f. *Optimization*: The Smart Grid shall optimize assets, reduce costs and operate efficiently;
g. *Green energy*: The Smart Grid shall solve problems of energy security, energy saving, carbon dioxide emission and etc.

The utilities of the Smart Grid shall address the following challenges:

a. High power system loading;
b. Increasing distance between generation and load;
c. Fluctuating renewables;
d. New loads (hybrid/electric vehicles);
e. Increased use of distributed energy resources;
f. Cost pressure;
g. Utility unbundling;
h. Increased energy trading;
i. Transparent consumption & pricing for the consumer;

j. Significant regulatory push.

The priority of local drivers and challenges might differ from place to place.

1.3 Policies and standardization bodies

At present, smart grids are more a blurred concept than an established framework or architecture. As a consequence, there is neither any regulation nor any market policy from the governments. Instead, there are a number of groups and agencies that are mandated to propose common standards for smart grids. Most regional initiatives come from the European Community, North America and China.

1.3.1 *Europe*

In March 2006, the European Commission put forward its analysis of the main energy challenges that the EU will be facing in the coming years. The Commission proposed to address these challenges through a new comprehensive European energy policy built on three main pillars: sustainability, competitiveness and security of supply. Among other things, research into energy efficiency and renewable and development and deployment of new energy technologies were identified as a political priority.

The roll-out of smart meters and implementation of smart grids in Europe is an integral part of this policy priority. When the Commission in September 2007 unveiled its proposal for a Third Energy Package, it made the implementation of smart metering systems an obligation for the Member States in both the Electricity and the Gas Directives. Member States must by September 2012 carry out a cost-benefit analysis of the smart meters implementation and ensure the deployment of the smart electricity meters to at least 80% of the households by 2020. The progress towards the smart grid development is also supported by a whole body of European energy efficiency legislation. The Directive on Energy End-use Efficiency and Energy Services from 2006 lists deployment of smart metering systems as one of the main cross-sectoral measures considerably improving energy efficiency. Likewise, the recently revised Directive on Renewable Energy obliges the Member States to take appropriate steps to develop intelligent transmission and grid infrastructure. The Energy Performance of Buildings Directive strongly supports decentralized energy supply systems based on renewable energy and calls on the Member States to encourage the introduction of smart metering systems whenever a building is constructed

To facilitate the implementation process on the technical level, the Commission issued in 2009 a standardization mandate concerning smart meters to the standardization organizations CEN, CENELEC and ETSI. The standardization bodies are now involved in the development of an open system architecture for utility meters involving communication protocols that enable interoperability and they will present the results in 2012.

In order to succeed with smart grids implementation in Europe, the support of the industry is key. This is why the Commission came in 2007 with the European Strategic Energy Technology Plan (SET-Plan). Being the technology pillar of the EU's energy and climate policy, the Commission, together with industry and the research community drew up technology “roadmaps” identifying key low carbon technologies with strong potential at EU level in six areas: wind, solar, electricity grids, bioenergy, carbon capture and storage (CCS) and sustainable nuclear fission. On this basis, in June 2010 the Commission together with industry stakeholders launched four industrial initiatives, including one on electricity grids. The European

Electricity Grid Initiative (EEGI) has already published a detailed roadmap for 2010-2018 outlining the process towards the implementation of smart grids in Europe.

Addressing the technology aspects of smart grids is not enough to make smart grids a reality. Important questions regarding data protection, interaction between different actors and regulators need to be clarified, and funding issues addressed. To this aim, the Commission established in November 2009 a Smart Grids Task Force. It is to advise the Commission on the policy/regulatory directions at European level, coordinating first steps towards the implementation of smart grids recommended in the Third Energy Package[1]. The Task Force will take stock of technology visions and developments performed by other grouping of stakeholders in this area, including in the Smart Grids European Technology Platform, in the Smart Grids Forum and in the European Electricity Grids Initiative (EEGI), and should be in close contact with their further developments. It should also take into account all the relevant standardisation efforts being undertaken at EU level that are working on the functionality, inter-operability and standardisation of Smart Meters. The Smart Grids Task Force is led by the Commission's Directorate-General for Energy Policy (DG ENER) in collaboration with six Directorates and about 25 European associations representing all relevant stakeholders. The task force is to deliver recommendations on a number of relevant issues towards the mid 2011. The Expert Groups that are to identify the need of further smart grid standards have already expressed a positive view; basing on their feedback the Commission mandate to CEN, CENELEC and ETSI to initiate a standardization activity on smart grid in early 2011 so that it can be issued by early 2011. In this context, the establishment and the work of the CEN/CENELEC/ETSI Joint Working Group on standards for smart grids is extremely useful and instrumental in achieving the European Commission's policy objectives regarding smart grids.

The European Technology Platform[2] for smart grids began its work in 2005. Its aim was to formulate and promote a vision for the development of European electricity networks looking towards 2020 and beyond; this effort has produced three documents at present. The Vision

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1 The package consists of two Directives, one concerning common rules for the internal market in gas (2009/73/EC), one concerning common rules for the internal market in electricity 2009/72/EC) and three Regulations, one on conditions for access to the natural gas transmission networks ((EC) No 715/2009), one on conditions for access to the network for cross-border exchange of electricity((EC) No 714/2009) and one on the establishment of the Agency for the Cooperation of Energy Regulators ACER ((EC) No 713/2009). They were adopted in July 2009.

2 European Technology Platforms (ETPs) are industry-led stakeholder fora charged with defining research priorities in a broad range of technological areas. ETPs provide a framework for stakeholders, led by industry, to define research priorities and action plans on a number of technological areas where achieving EU growth, competitiveness and sustainability requires major research and technological advances in the medium to long term. Some European Technology Platforms are loose networks that come together in annual meetings, but others are establishing legal structures with membership fees. The European Commission does not own or manage European Technology Platforms, which are independent organisations. The European Commission did, however, support their creation and remains engaged with them in structural dialogue on research issues.

document for SmartGrids (2006) is driven by the combined effects of market liberalization for both transmission and distribution networks, the change in generation technologies to meet environmental targets and the future uses of electricity. The Strategic Research Agenda (2007) describes the main areas to be investigated, technical and non-technical, in the short-medium term in Europe. These documents have inspired several Research and Development programs within the EU and National institutions. The Strategic Deployment Document (2010) describes the priorities for the deployment of innovation in the electricity networks and the benefits that such innovation will deliver for all stakeholders. It also gives a timeline for deployment.

Recently (2009), the ETP was restructured and the so called SmartGrids ETP Forum has substituted the Advisory Council in taking the lead of the whole platform structure and setting the new programme of activities. The structure of the SmartGrids ETP Forum is an executive group of 12 individuals representing the various groups of stakeholders: TSO, Electrical systems manufacturers, DSO, ICT service providers, Regulation Metering manufacturers, Centralized generation, Customer interaction and metering, Renewable generation, Industrial R&D, Users, Academic and governmental R&D.

1.3.2 *North America*

The Federal Smart Grid Task Force was established under Title XIII of the Energy Independence and Security Act of 2007 (EISA) and includes experts from seven different Federal agencies in USA. The mission of the Task Force is to ensure awareness, coordination and integration of the diverse activities of DOE's Office of Electricity Delivery and Energy Reliability and elsewhere in the Federal Government related to Smart Grid technologies, practices, and services. The Task Force has produced a number of books related to smart grid, both as an introduction and to target the interests of specific stakeholder groups. Further, the Department of Energy (DOE) of the United States is conducting a series of Smart Grid E-Forums to discuss various issues surrounding Smart Grid including costs, benefits, value proposition to consumers, implementation, and deployment.

The Green Smart Grid Initiative (GSGI) is a non-profit coalition focused on development and dissemination of information about how the smart grid can support attainment of climate-change goals. Among the issues it will seek to build an understanding of are the following:

a. Smart Grid and renewable energy.
b. Smart grid and energy efficiency.

When it comes to renewable energy and energy efficiency, a smarter grid is a greener grid, and the Green Smart Grid not only has a role to play in addressing climate change, but is likely essential to allow climate change goals to be reached. Many North America Company participate in this initiative.

1.3.3 *International action*

The International Smart Grid Action Network (ISGAN)

Launched in July 2010 at the first Clean Energy Ministerial, the International Smart Grid Action Network creates a multilateral mechanism for governments to collaborate with each other and other stakeholders on advancing the development and deployment of smarter electricity grids around the world.

Supported by more than 15 national-level governments, ISGAN focuses on those aspects of smart grid where governments have regulatory authority, expertise, convening power, or other leverage. ISGAN activities cut across five principal areas: policy, standards and regulation; finance and business models; technology and systems development; user and consumer engagement; and workforce skills and knowledge.

ISGAN serves as a government-focused complement to the Global Smart Grid Federation and other international efforts that support the accelerated development and deployment of smart grid technologies. ISGAN Participants have promised to work closely with the Federation on joint public-private projects that capitalize on the strengths of each sector.

For more information on ISGAN, see www.cleanenergyministerial.org.

1.3.4 *International standards*

The European Union has issued mandates for the standardization of smart meter functionalities and communication interfaces for the electricity, gas, heat and water sectors and of smart grid for use in Europe to the organisations CEN, CENELEC and ETSI. The results of these mandates are to be standards or technical documents. Standards in this context are voluntary technical specifications and general technical rules for products or systems on the market. The aims are to facilitate the deployment of smart metering systems, to secure interoperability, protect the customers and ensure system reliability.

ETSI is currently studying the issue of Smart Grid standardization under an ETSI Board strategic topic. Initial work has included a number of internal workshops and collaboration with several actors in the European and International Smart Grids domain. ETSI members have contributed working items to ETSI technical committees, including TC M2M (Machine-to-machine communications), and more activities will be expected in groups, including TC PLT, ERM and TISPAN. After having considered the Smart Metering Use Cases in relation with the M/441 Mandate (Technical Report TR102691 "Machine-to-Machine Smart Grid Use Cases", the M2M TC is now treating, among other Work Items, the Smart Grid Use Cases through a Work Item created in July 2010. The latter is drafting a Technical Report (Draft ETSI TR 102 935) on "Machine-To-Machine Applicability of M2M architecture to Smart Grid Networks, Impact of Smart Grids on M2M platform" describing the Smart Grid Use Cases of interest for further analysis by the M2M TC when establishing the generic M2M specifications.

The Strategic Group 3 was established by the Standardization Management Board (SMB) of IEC and has produced an initial roadmap for its own standards and 11 high level recommendations. This work and these recommendations are especially relevant to the European standardization roadmap. Despite the public dispute about missing standards, it may be questionable if the existing standards can be used for smart grid; the SG3 has identified a total of over 100 IEC standards and recommend IEC to disseminate these further and to draw attention to them. Existing IEC core standards – especially IEC TC 57 standards[3] – serve as the basis for further smart grid standards to be developed. Other standards such as those of IEC TC8[4], IEC TC13[5], etc are also very relevant. Currently the IEC group focuses on use cases and

3 IEC Technical Committee 57 is one of the technical committees of the International Electrotechnical Commission (IEC). TC 57 is responsible for development of standards for information exchange for power systems and other related systems including Energy Management Systems, SCADA, distribution automation & teleprotection. (*From Wikipedia*)

4 IEC Technical Committee 8 takes into account overall system aspects of electricity supply systems and acceptable balance between cost and quality for the users of electrical energy.

general requirements for a smart grid reference architecture, developing a so-called Mapping Tool to support smart grids project managers.

The Telecommunication standardization sector of the International Telecommunication Union (ITU-T) established a Focus Group on Smart Grid (FG Smart). This Group aims at collecting and documenting ideas that would be helpful for developing Recommendations to support smart grid from a telecommunication/ICT perspective. The objective is indeed focused to the telecommunication/ICT aspects of smart grid, by identifying potential impacts on standards development, investigating future ITU-T study items and related actions, familiarizing ITU-T and standardization communities with emerging attributes of smart grid, and encouraging collaboration between ITU-T and smart grid communities (including other SDOs and consortia). The Focus Group is planned to operate until end 2011, and has currently four main draft deliverables concerning smart grids: overview, use cases, architectures and requirements.

NIST was devolved the main responsibility for the coordinated development of a framework for the achievement of inter operability of smart grid systems and devices, taking especial account of protocol and data model standards for information management. NIST emphasizes that large investments in a smart grid will not be sustainable without standards. NIST has therefore established a phase plan intended to accelerate identification of the standards required for the smart grid. The document is the result of the first phase in compilation of the framework. It describes an abstract reference model of the future smart grid and in doing so identifies almost 80 essential standards which directly serve the smart grid or are relevant to its development on a metaplane. NIST further establishes plans of action with aggressive timetables and coordinates the standardization organisations to the extent that they support its plans to close the gaps in achieving smart grid interoperability in the near future.

The State Grid Corporation of China (SGCC) has defined an own smart grid standardization roadmap which will have some influence on vendors and markets since China will be one of the largest markets for the upcoming smart grid which is expected to be based mainly on open standards. The first version of the SGCC framework defines eight domains, 26 technical fields and 92 series of standards and takes into account several existing standardization roadmaps. The SGCC framework states that after the age of information we will see an upcoming age of intelligence where the integration of clean energy requires both a strong and smart grid which is considered to tackle climate change as well as environment deterioration and to optimize the allocation of energy resources. The strong and smart grid is defined as an intelligent power system encompassing power generation, transmission, transformation, distribution, consumption and dispatching. According to the SGCC definition, the grid itself will no longer be a simple carrier of transmission and distribution of electricity, but will be more an integrated and intelligent platform for the internet of things, internet network, communication network, radio and TV networks. The sharp line between generation-side and demand-side will blur. This is an emblematic example of how ICT can boost environment protection by more conscious and responsible energy management. SGCC has worked out a fast paced three stage plan. For the first batch of smart grid standards, SGCC has identified 22 standards overall, 10 domestic ones

5 IEC Technical Committee 13 operates in the field of metering equipment and systems, including smart metering systems, of electrical energy measurement, tariff- and load control, customer information and payment, for use in power stations, along the network, and at energy end users, as well as prepares international standards for meter test equipment and methods.

and 12 international ones. Those standards have also been in the scope with the IEC SG3, containing their 5 core standards.

The ISO/IEC JTC1[6] Special Working Group on Smart Grid (SWG-Smart Grid) was established in 2009 to identify market requirements and standardisation gaps for smart grids, to encourage JTC1 to address the need for ISO/IEC Smart Grid International Standards, to promote this standards, to coordinate JTC 1 Smart Grid activities with IEC, ISO, ITU-T and other SDOs (especially the IEC SMB Strategic Group 3), to periodically report results and recommendations to JTC 1. Further, the Working Group on Sensor Networks (WG7) has proposed “Sensor Network and its Interface for Smart Grid System” (NP 30101), which addresses sensor network architectures and interfaces to support smart grid systems, in order to visualize sensors/devices status and data/information flow in large scalable heterogeneous network systems, including the geospatial information systems.

In TIA, the Engineering Committee TR-50 is responsible for one activity on Smart Device Communications, which deals with the access agnostic interface standards for the monitoring and bi-directional communication of events and information between smart devices and other devices, applications or networks. TR-50 will develop a Smart Device Communications framework that can operate over different underlying transport networks (wireless, wired, etc.) and can be adapted to a given transport network by means of an adaptation/convergence layer. The TR-50 framework will make its functionality available to applications through a well-defined Application Programming Interface (API) that is agnostic to the vertical application domain and thus can be used for Smart Grid among other applications. Engineering Committee TR-51 is responsible for Smart Utility Networks technology and focuses on efficient access technology with mesh network topography, optimized for Smart Utility applications. The Smart Utility Networks standards are intended to provide the utility companies with another tool to improve services to their customers.

ATIS[7] took two actions to facilitate standardization on smart grids. First, ATIS identified existing standards, as well as 3GPP wireless technologies, that would be applicable to Smart Grid applications. ATIS also worked closely with federal agencies, including NIST, to ensure that they were aware of relevant industry work. ATIS has been named as a collaborator by NIST in its Framework and Roadmap for Smart Grid Interoperability Standards. Second, ATIS began to examine its standardization work to determine what needs to be done to facilitate Smart Grid applications. As part of this effort, ATIS has also undertaken an initiative as part of its Board of Directors’ Technology and Operations Council (TOPS) to examine the interrelationship between key machine-to-machine applications, including Smart Grid, to identify the need for new standardization efforts.

6 The Joint Technical Committee 1 is a common effort of the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC). It deals with all matters of information technology; the intent was to bring together in a single Committee the Information Technology standardization activities of the two parent organizations.

7 The Alliance for Telecommunications Industry Solutions (ATIS) is a standards organization that develops technical and operational standards for the telecommunication industry in North America. Web site, URL: http://www.atis.org

The China Communications Standards Association (CCSA) established a new research item "wireless technology in Smart Grid related Internet of Things (IoT) applications" just initiated, which will research on use cases of Smart Grid, study on the features of wireless technology and analysis of the applications of wireless technology in smart grid.

The IETF has four working groups that have related topics: 6lowpan, roll, core, and eman. The IETF also has a variety of smaller efforts that mention a relationship to the Smart Grid or sensor networks in general. 6lowpan and roll are in a semi-quiescent phase, as their protocols are complete and they are working on deployment issues. Core is actively developing a model for HTTP/UDP, which some people think may be useful in the HAN. Eman is a newly chartered effort. Per its charter, "The basic objective of energy management is operating communication networks and other equipment with a minimal amount of energy while still providing sufficient performance to meet service level objectives." This is a little different than operating the electrical grid, but it may have applicability in the HAN or AMI. Note that none of these are being developed specifically for the Smart Grid. They are if anything targeted at sensor networks, of which parts of the Smart Grid are examples. However, they are intended to be useful to the Smart Grid.

2 SCENARIOS

Actually, the interest towards smart grids has produced hundreds of use cases that aim at identifying requirements and architectural considerations. The role of ICT in smart grids can be better explained by taking into account some of these scenarios.

2.1 Demand response

Demand response consists of mechanisms and incentives for utilities, business, industrial, and residential customers to cut energy use during times of peak demand or when power reliability is at risk. Demand response is necessary for optimizing the balance of power supply and demand, so to better exploit intermittent renewable and to reduce fossil consumption at large power plants.

Several different mechanisms can be used for this purpose:

a. Current dynamic prices can be distributed to customers by different communication means: direct electronic delivery to the customer meter, display device within the home/business, automated telephone calls, e-mail, pager, commercial broadcast radio, newspapers, etc. Customers are expected to adapt their consumption according to prices; this may happen either manually or automatically. In the second case, they may have their own energy management systems to do this job or they may delegate this task to third parties, whose main business is energy management at customer premise can create critical mass and can coordinate the loads so to match the grid needs. In both cases, adaptation must follow the customers' preferences and settings, in order to avoid the interruption of critical or vital tasks.

b. Utilities can implement load control at the customer's site in order to reduce the load during peak period. Customers can be rewarded for this by discount in their energy bill.

2.2 WASA

Wide-Area Situation Awareness (WASA) means monitoring and display of power-system components and performance across interconnections and over large geographic areas in near real-time. The goals of situational awareness are to understand and ultimately optimize the management of power-network components, behaviour, and performance, as well as to anticipate, prevent, or respond to problems before disruptions can arise. It will use wide area data and other data to improve its reliability, and to analyze power system security (safe and stable operation) for a wide operating region. Future CA will also incorporate intelligence features to resolve execution problems by using its knowledge base of previous experience in solving difficult situations.

Important goals in this context are to avoid low frequency and low voltage conditions, that can have harmful effect on the grid and the final equipment.

2.3 Energy storage

Energy storage involves means of storing energy, directly or indirectly. Smaller forms of energy storage are anticipated within distribution systems as well as bulk power systems. New storage capabilities—especially for distributed storage—would benefit the entire grid, from generation to end use, but the resources need to be correctly integrated into T&D operations.

Energy storage can be viewed as a mechanisms to take advantage of real-time pricing (RTP). Energy Storage owners store energy when it is at its lowest cost and when it has least possibility to be detrimental to the power system operations; then, they discharge energy when it is economically advantageous to do so and/or when it can improve reliability, efficiency, or power quality of the power system operations.

Energy storage can also be used to improve the quality of the energy: it provides fast voltage sag correction by responding rapidly and automatically during short to medium duration disturbances. This will avoid customer outages and ameliorate power quality problems.

Finally, it is worth noting the relevance plug-in electric vehicle (PEV) are expected to have for energy storage. They will be equipped with high-capacity batteries and can be used as “mobile” energy storage.

2.4 Electric transportation

This refers, primarily, to enabling large-scale integration of plug-in electric vehicles (PEVs). Electric Vehicles can be viewed as a special case of mobile customer communications or can be aggregated by fleet operations. Electric vehicles can also be considered both an electric load as well as a form of electric storage with the potential for power injection capabilities. Integration of Electric Vehicles is subject to interoperability with market and revenue cycle services as well as real time distribution operations.

Optimized Energy Transfer programs are designed to incentivize customers whom are willing to give the energy provider control over their load. More specifically these programs allow energy providers to reduce or interrupt customer loads during critical grid events. The idea is that the energy provider based on the grid event can actively manage the charging load by either reducing or interrupting it. In either case, the active management will support turn off those who have higher state of charge while only reducing the charge rate of those that have lower state of charge. Usually, the energy provider offers a vast array of options with programs varying in the quantity of events and length of reduction or interruption periods.

Within a utility service territory, the customer can plug in a PEV to receive a charge of electrical energy at his premise or plug in at another premise location. The Utility may offer the Customer a PEV tariff that provides a low rate for off-peak charging and a higher rate for on-peak charging. Each time the PEV is charged, Customers who have enrolled in a PEV program will exchange account and energy information. Energy supplied to the PEV is reported to the utility for billing and presentation to the Customer.

2.5 AMI systems

Currently, utilities are focusing on developing Advanced Metering Infrastructures (AMI) to implement residential demand response and to serve as the chief mechanism for implementing dynamic pricing. It consists of the communications hardware and software and associated system and data management software that creates a two-way network between advanced meters and utility business systems, enabling collection and distribution of information to customers and other parties, such as competitive retail suppliers or the utility itself. AMI provides customers real-time (or near real-time) pricing of electricity and it can help utilities achieve necessary load reductions.

AMI enables other smart grid scenarios as demand response, electric storage, PEV load management; moreover it enables voltage, frequency and watt control for the above applications.

2.6 Distribution Grid Management

Distribution Grid Management focuses on maximizing performance of feeders, transformers, and other components of networked distribution systems and integrating with transmission systems and customer operations. As Smart Grid capabilities, such as AMI and demand response, are developed, and as large numbers of distributed energy resources and plug-in electric vehicles (PEVs) are deployed, the automation of distribution systems becomes increasingly more important to the efficient and reliable operation of the overall power system. The anticipated benefits of distribution grid management include increased reliability, reductions in peak loads, and improved capabilities for managing distributed sources of renewable energy.

2.7 Market Operations

Market Operations includes the functions necessary to operate existing and future energy markets and associated services. Market Operations functions range from operating electric pricing and information exchange to establish electric and energy services pricing such as day ahead energy, ancillary services and exchange of bulk power. Market operations requires interaction with energy and service providers as well as Independent Systems Operators and Regional Transmission Operators.

For example, electrical power trading service allows selling surplus energy during the relative high price period, as the premise is able to play a role of energy provider with DER or energy storage.

2.8 Cyber security

This service encompasses measures to ensure the confidentiality, integrity and availability of the electronic information communication systems and the control systems necessary for the management, operation, and protection of the Smart Grid's energy, information technology, and telecommunications infrastructures.

2.9 Network/System management

The Smart Grid domains and sub-domains will use a variety of public and private communication networks, both wired and wireless. Given this variety of networking environments, the identification of performance metrics and core operational requirements of different applications, actors, and domains--in addition to the development, implementation, and maintenance of appropriate management systems. Management functions include but are not limited to Fault Management, Accounting Management, Configuration Management, and Performance Management.

2.10 Existing user's screens

This involves displays used by users to access information about the grid: real-time prices, energy and appliances monitor, energy management system, remote monitoring, home grid alarm and so on. Mobile/Smart Phone, (IP)TV, Internet Video Phone, (Tablet) PC, Wall-pad, etc. can be considered.

2.11 Managing Appliances through/by Energy G/W

Inside the user's premise, PEV (plug-in electric vehicle), PV (photo voltaic system), home appliance, and household equipment participate in a home network and in load management that GW (gateway) governs. This service provides various managing capabilities of using electric energy such as monitor, control and operation of various devices which used in home environments by considering two different types of devices: smart home devices with electric metering and communicating capabilities and legacy home devices without such capabilities.

3 ARCHITECTURES

As of the large infrastructure already in use, smart grids will reasonable be an evolution of the current grid to take into account new requirements, to develop new applications and to integrate new state-of-the-art technologies, in particular Information and Communication Technologies (ICT). Integration of ICT into smart grids will provide extended applications management capabilities over an integrated secure, reliable and high-performance networks.

This will result in a new architecture with multiple stakeholders, multiple applications, multiple networks that need to interoperate: this obviously requires an agreed set of models allowing description and prescription, which are commonly known as Reference Architecture.

3.1 Reference Architecture

a. The Reference Architecture allows the separation of a complex system into simpler entities; several separations can be made for smart grid in the process of building a Reference Architecture:
   Conceptual Architecture. A high-level presentation of the major stakeholders or the major (business) domains in the system and their interactions.
b. *Functional Architecture*. An arrangement of functions and their sub-functions and interfaces (internal and external) that defines the execution sequencing, the conditions for control or data flow, and the performance requirements to satisfy the requirements baseline.
c. *Communication Architecture*. A specialization of the former focusing on connectivity.
d. *Information Security Architecture*. A detailed description of all aspects of the system that relate to information security, along with a set of principles to guide the design. A security architecture describes how the system is put together to satisfy the security requirements.
e. *Information Architecture*. An abstract but formal representation of entities including their properties,
   relationships and the operations that can be performed on them.
f. *Service-Oriented Architecture*. An architecture that is technology independent and organizes the discrete functions contained in internal or third-party applications & network elements into interoperable, standards-based services that can be combined and reused quickly to meet enterprise business needs.

Smart grids must interconnect a variety of (electricity and communication) networks that will have to support the business needs of a variety of stakeholders and must ensure the networks are interoperable, separately evolving as well as offering a very high level of security. NIST has developed a Conceptual Architecture that is not only a tool for identifying actors and possible communication paths, but it is also a useful way for identifying possible inter- and intra-domain interactions .

Such architecture is depicted in Figure 2. This model consists of seven major functional area call domains and the information flows between these domains, as well as the flow of electricity from power sources through transmission and distribution system to the customers.

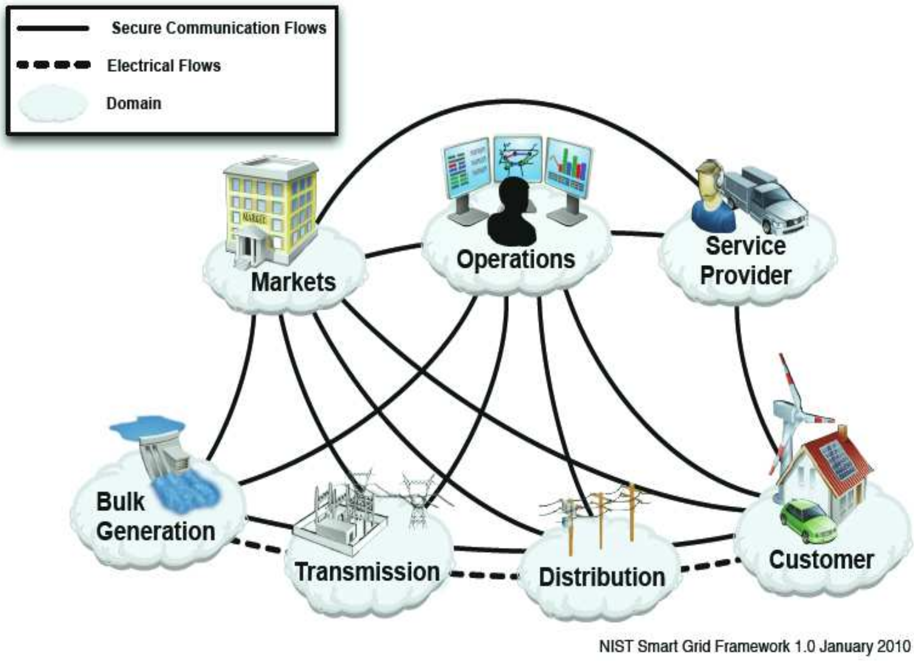


Figure 2. A Conceptual Architecture (source: “NIST Framework and Roadmap for Smart Grid Interoperability Standards”)

Service providers. In this area, a variety of actors offer technology, products and services to other actors in the model. Examples of service providers are Ancillary Services Providers, Metering Operators, ICT Service Providers, Electric Power Grid Equipment Vendors, etc.

Customers. This refers to residential consumers (private or business buildings) as well as large consumers of electricity in an industrial and manufacturing industry.

Transmission/distribution. From a standardization standpoint, Transmission and Distribution are requiring the same set of activities and do not need to be differentiated.

(Bulk) generation. Refers to generation of electricity, active contribution to voltage and reactive power control, required to provide the relevant data (information on outages, forecast, actual production) to the energy marketplace.

Operations. Refers to the undertakings of operating, building, maintaining and planning of the electric power transmission and distribution networks.

An important new capability for Smart Grid not explicitly shown in this model is the distributed power generation that may occur in the Customer, Distribution, and Transmission domains. If the generation facility exists in the Customer domain, a new paths for electrical and communication flows need to be shown; similarly for generation capabilities in the Transmission and Distribution domains.

A description and discussion about the other components of a Reference Architecture can be found in the report for the JWG of CEN/CENELEC/ETSI .

3.2 Key elements

Smart Grid can be decomposed in three different planes: Services/Applications, Communication, and Energy, as shown in Figure 3. The Services/Applications plane refers to systems, including computers, programs, data bases, people, and operational supports to manage the applications as described in the uses cases for the Smart Grid. The Communication plane refers to the information structures and networking that enables communications between Services/Applications and entities in the Energy plane. The Energy plane refers to the devices, sensors, and controllers that provide information to the Services/Applications plane, and receive command to effect control of devices in the Energy plane.

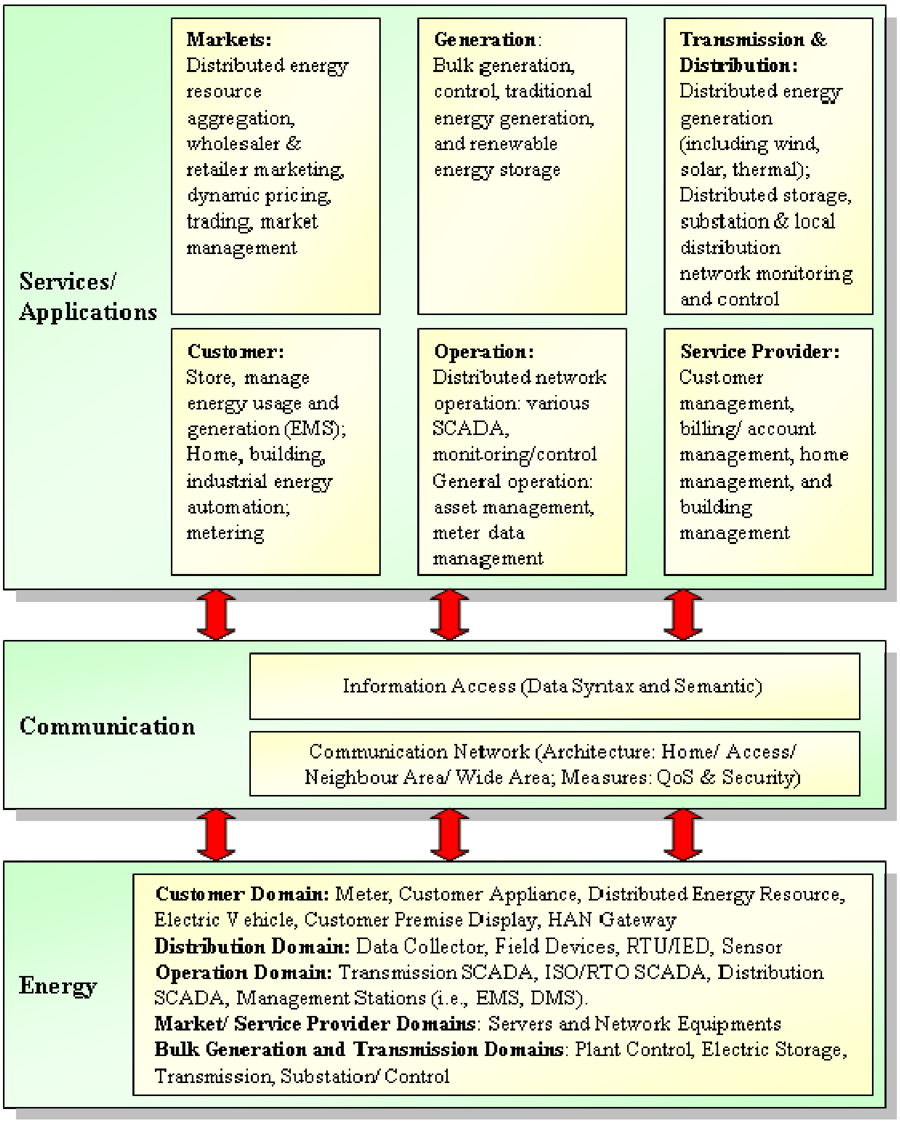


Figure 3. Key elements of a smart grid.

3.2.1 *Services/applications plane*

Each conceptual domain has its own representative applications in the services/applications plane.

In *Customer Domain*, besides the basic functions within a building and home such as lighting and temperature control, energy management system (EMS) is a core application providing the capability for in-home/building display of customer usage, reading of meters, and integration with building management systems and the enterprise, and remote load control, monitoring and control of distributed generation, the EMS provides auditing/logging for system troubleshooting and security purposes as well.

In *Operation Domain* we have applications for distributed network operation, including the Supervisory Control and Data Acquisition (SCADA) systems to monitor and control the status of devices in bulk generation, transmission, and distribution domains; further, we also have applications for general operations, including the asset management and meter data management (i.e., energy usage, energy generation, meter logs, and meter test results) to make energy data available to authorized parties.

The *Service Provider* domain consists of applications such as customer and account management, home management, building management, and others. In particular, building management is to monitor and control building energy, and respond to Smart Grid signals while minimizing impact on building occupants. Home management is to monitor and control home energy and respond to Smart Grid signals while minimizing impact on home occupants. Billing management is to manage customer billing information. Account management is to manage the supplier and customer business accounts.

In *Markets*, the main applications include the distributed energy resource aggregation, wholesaler and retailer marketing. To be specific, retailers sell power to end customers and may play aggregation role as a broker between customers and the market. Other applications include dynamic pricing, trading, and market management. Traders are participants in markets and include aggregators for provision and consumption and curtailment, and other qualified parties.

The main applications in the *Bulk Generation* domain include bulk generation plant control, measure, and traditional energy generation. In particular, the plant control permits the operations domain to manage the flow of power and ensures the reliability of the system. Measurement is used to provide visibility into the flow of power and know the condition of the systems in the field remotely. Other applications include renewable energy generation and storage.

Finally, the main applications within in *Transmission and Distribution* include distributed energy generation (i.e., wind, solar, thermal), distributed storage, substation, and local distribution network monitoring and control. Substation management and control contains switching, protection and control equipment, i.e., sub-stations connecting generation (including peaking units) and storage with distribution. Other applications include local network monitoring and control used to measure, record, and control with the intent of protecting and optimizing the operation of electricity transmission and distribution.

3.2.2 *Energy Plane*

The energy plane includes all physical devices associated with the electrical grid, which is the essential part of Smart Grid to provide several functionalities: home/industrial automation, advanced metering and intelligent grid control and management.

The devices in *Customer* domain include meter, customer appliances and equipment, distributed energy resource (solar, wind and others), electric vehicle, home (industrial) gateway, thermal storage, solar generation, sensors in home area network, and demand control device.

The devices in *Distribution* domain include the distributed data collector, automation field devices, control and automation devices (Remote Terminal Unit –RTU– and Intelligent Electronic Device –IED–), distributed sensors, and others.

The devices in *Operation* domain include control devices (Transmission/ ISO/RTO/ Distribution SCADA), computing/information storage servers, computers, and network equipment and others.

The devices in *Service Provider* and *Markets* domains are computing and networking Equipment.

The devices in *Bulk Generation* and *Transmission* domains include Plant Transmission Control, Electric Storage, Transmission, Remote Control Unit (RCU), Substation/ Measurement/ Control/ Monitoring.

3.2.3 *Communication plane*

The communication plane is the most interesting plane for what concerns ICT technologies. It consists of two sub-planes or functional groupings:

- *Information Access*. It determines the syntax and semantic of application related data. Given each specific domain, we shall define the format of data to meet the application/service requirements.
- *Communication Network*. It enables the reliable, efficient and secured transmission of the application/ service specific data.

Use of information and computing technologies are essential to support the envisioned Smart Grid services: energy distribution management, energy trading, grid monitoring and management, distributed renewable energy integration, electric vehicles charging, distributed energy storage, and smart metering infrastructure. To ensure the interoperability of applications and devices, interoperable standards are required for communications, information representations and exchanges; further, security of services, applications and devices are of paramount importance to the stability and integrity of the Smart Grid.

The network infrastructure must provide reliable two-way communication and support various class of QoS, such as real-time and non-real-time, and different bandwidths and latency, loss, and security requirements. Several characteristics must be taken into account to design the communication network.

For the network architecture, one shall consider different options, covering home area networks, access/neighbourhood area networks, and wide area networks, and the use of Internet-based technologies along with other choices.

As regards the QoS, one shall consider different metrics (i.e., end-to-end latency, bandwidth, jitter, and reliability) along with different types of applications (i.e., the amount of data needs to be transmitted in a given deadline in order to successfully accomplish a task). To be specific, the latency shall be very tight in SCADA system in comparison with the normal meter reading and configuration in Advance Metering Infrastructure (AMI). In the August 14, 2003, blackout in North America, a contributing factor was the issue with communications latency in control systems. With the exception of the initial power equipment problems, the on-going and cascading failures will be primarily due to problems in providing the right information to the right individuals within the right time period. Service differentiation and prioritization may be required depending on the quality and type of applications, which are supported by the communication links. As an example, the admission control, queuing scheduling algorithms, Resource Reservation Protocol (RSVP) and others have been extensively studied to provide QoS in IP networks.

Furthermore, the confidentiality, integrity and availability of network must be addressed as well. Confidentiality is preserving authorized restrictions on information access and disclosure, including means for protecting personal privacy and proprietary information. Integrity is the guarding against improper information modification or destruction, and includes ensuring information non-repudiation and authenticity. Each classification displays the level of adverse effect the destruction of information can be expected to have on organizational operations, organizational assets, or individuals. A loss of integrity is the unauthorized modification or destruction of information. Availability ensures timely and reliable access to and use of information. Each classification displays the level of adverse effect the disruption of access to or use of information or an information system can be expected to have on organizational operations, organizational assets, or individuals.

Power grid information security and protection requirements have aspects of the control network for the operation of energy transmission and distribution (i.e., SCADA), computer networks (i.e., transmitting meter data) as well as enterprise Information Technology (IT) network for business. Although all networks require information security services for dealing with malicious attacks or providing protection against inadvertent errors, specific distinctions in attack and error types, and differences in performance requirements as well as organizational policies for them make their required security posturing quite different in those areas. Hence, we shall systematically analyse the vulnerabilities in Smart Grid, explore the space of attacks targeting different weaknesses of Smart Grid, and develop possible countermeasures against those attacks.

3.3 Simplified Domain Model in ICT perspective

The NIST model in Figure 2 organizes the fields related to Smart Grid into seven-domain. From an ICT perspective it can be simplified into a five-domain model as shown in Figure 4 : grid domain (bulk generation, distribution and transmission), smart metering (AMI), customer domain (smart appliances, electric vehicles, premises networks), communication network, service provider domain (markets, operators, service providers). These five domains are viewed in the three planes: the Service/Applications plane, the Communication plane, and the Energy plane.

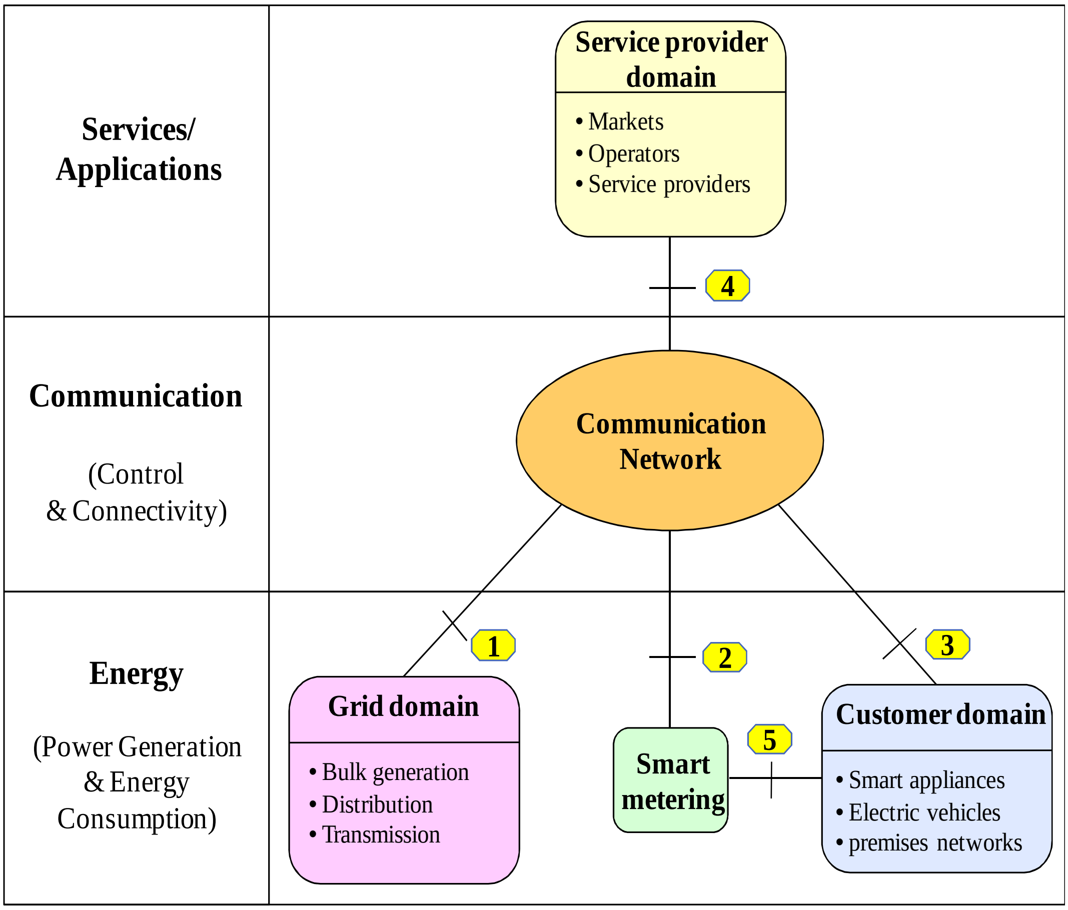


Figure 4. Simplified Smart Grid Domain Model in ICT Perspective

Five interfaces across the planes and between domains are present, marked with numbers in circles in Figure 4. These are places where communications and exchange of information between the network and other four domains, and between smart metering domain and customer domain take place. They are the focal of standards specifications and thus are called Reference Point; samples functions at each of these reference points are listed in the draft report on smart grid architectures by FGSmart .

3.4 Networking in the reference architecture

Conceptual data flow between domains is shown in Figure 5. Here, the original reference architecture presented in Figure 2 has been adapted to the simplified model illustrated in Figure 4.

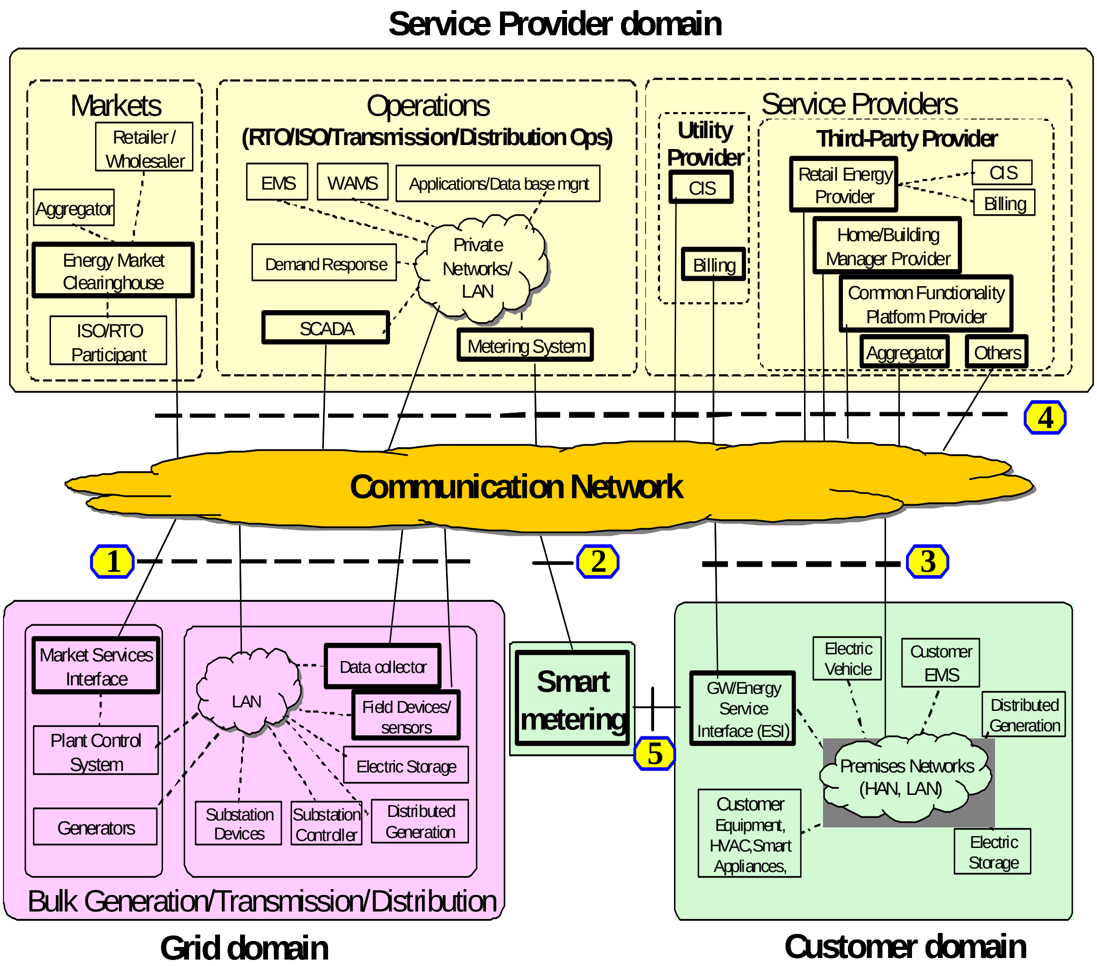


Figure 5. Reference Architecture of Smart Grid with communication flows.

The service provider domain, grid domain, customer domain, and smart metering are interconnected via a communication network. Using the customer domain as an example, all devices (e.g., electric-vehicle, customer EMS, electric storage) are connected via premises network (e.g., HAN or LAN). The premises network in customer domain also has the connection to communication network cloud, connecting to other domains. As such, the customer domain EMS can interact with the metering/billing/utility back office in the service provider domain. Using this figure, we can also see the other interactions between domains via the communication networks. For example, the field sensors in grid domain can interact with the SCADA in the operation of service provider domain for real-time remote sensing data collecting and control.

A general set of considerations for network capabilities can be derived starting from the reference architecture and the scenarios .

- **IP base transport**. Most parts of communication network support capability of IP base transport, such as IPv4 and/or IPv6. Communication plane for Smart Grid also should support this capability.
- **Operation and maintenance**. High reliable and resilient communication is required; this requires failure detection and alarm transfer, hierarchical operations for failure detection and alarm transfer, communication path trace, performance measurement.
- **Protection and restoration**. Protection and restoration capabilities are required for easy operation and minimizing service outage for services/applications and energy planes. Currently, conventional protocols have been specified as follows:
    - IP routing protocol base, e.g., VRRP;
    - Layer 2 bridging protocol base, e.g., STP family;
    - LAN/MAN MAC protocol base, e.g., RPR;
    - Physical later protection, e.g., OTN or SDH protection;
    - Ethernet OAM function base;
    - PON protocol base, e.g., PON protection

This list may vary dependant on the technology chosen.

- **Traffic engineering and QoS control**. The communication plane for Smart Grid must support various type traffic flows including specific applications. It also must support guarantee of communication quality. For this purpose, traffic engineering QoS control functions have three aspects, Service Level Agreement (SLA) guidelines, traffic provisioning and traffic control.
- **Connectivity and routing**. Connectivity and routing capabilities imply reachability based IP capability, specific signalling protocol (e.g., SIP), static routing.
- **Access control**. Access control capability consists of two aspects: physical layer and MAC layer. Different transmission medium can be considered at the physical layer: wired (e.g., Optical, xDSL, Coaxial), PLC and wireless (e.g., Cellular, WiFi, WiMAX, ZigBee, Bluetooth, other sensor). Specific issues at the MAC layer concern LAN/MAN, poling including interleave poling, demand assignment, no prevention access, e.g., centralized switching.
- **Network security**. Secure communication requires authentication and encryption. However, security also concerns network devices, which should be protected from attacks and viruses. These protection functions should be implemented at ingress points of network. Moreover, recently, CYBEX (Cybersecurity information exchange framework) has been discussed for NGN and Cloud computing as new enhanced network security. This will be applied to Smart Grid communication network.
- **Network management**. Communication network can be managed by network operators, service provider including power company or user. According to network scale and the number of users, network management is provided hierarchy. Functions for network management include I) monitor/surveillance of networks to manage failure, topology, performance, etc; ii) monitor/surveillance of communication component to manage component type, failure, etc; iii) provisioning of operation parameter; iv) remote testing; v) compression of information; vi) northbound interface for communication from/to the higher network management entity.

- **End networked device management**. Same functions as network management are required for end networked management. For the Smart Grid applications, end devices in energy plane, such as electric vehicle, distributed generation, electric storage or appliances should be also managed.
- **Data management**. The communication network should have capability of distributed data management for Smart Grid applications. In short, data aggregation, suppression and unification of interface are required to reduce traffic load of communication network.

3.5 Network architectures in Smart Grid

Communication networks enable information exchange inside smart grids. Modern networks are organized in stacks of layers and several technologies are already available to build working infrastructures; currently the TCP/IP architecture (i.e., the Internet) is the most widespread solution for uppermost layers.

The Internet is a network of networks in which networks are interconnected in specific ways and are independently operated. It is important to note that the underlying Internet architecture puts no restrictions on the ways that networks are interconnected; interconnection is a business decision. As such, the Internet interconnection architecture can be thought of as a "business structure" for the Internet .

3.5.1 *Network architecture*

Central to the Internet business structure are the networks that provide connectivity to other networks, called "Transit Networks". These networks sell bulk bandwidth and routing services to each other and to other networks as customers. Around the periphery of the transit network are companies, schools, and other networks that provide services directly to individuals. These might generally be divided into "Enterprise Networks" and "Access Networks"; Enterprise networks provide "free" connectivity to their own employees or members, and also provide them a set of services including electronic mail, web services, and so on. Access Networks sell broadband connectivity (DSL, Cable Modem, 802.11 wireless or 3GPP wireless), or "dial" services including PSTN dial-up and ISDN, to subscribers. The subscribers are typically either residential or small office/home office (SOHO) customers. Residential customers are generally entirely dependent on their access provider for all services, while a SOHO buys some services from the access provider and may provide others for itself. Networks that sell transit services to nobody else - SOHO, residential, and enterprise networks - are generally refereed to as "edge networks"; Transit Networks are considered to be part of the "core" of the Internet, and access networks are between the two. This general structure is depicted in Figure 6.

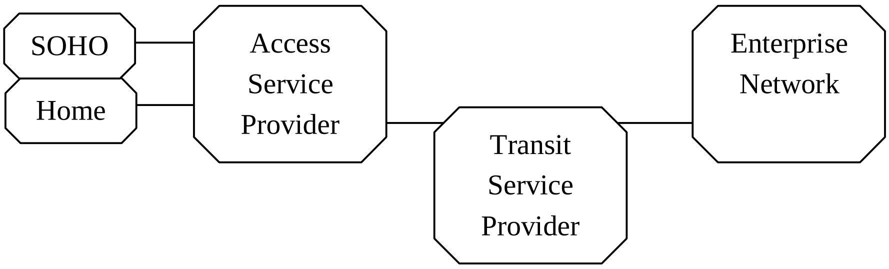


Figure 6. Conceptual model of Internet business architecture

The network shown in Figure 4 and Figure 5 for communication inside smart grids may be decomposed into four components that reflect different coverage: Home Area Networks, Local Area Networks, Neighbourhood Area Networks and Wide Area Network. However, this approach is mostly descriptive and it does not imply that physical implementation must divide the network this way, nor that network carriers must structure their network in a similar way and limit their services to some specific components. Also note that the areas covered by these components may overlap, but should be obvious in the context being discussed.

In the smart grid applications, *Home Area Network* (HAN) refers to networks in the homes that interconnect energy devices, such as appliances, energy management station, plug-in electrical vehicle chargers, and energy sources.

A *Local Area Network* (LAN) is a network that connects computers and devices in a limited geographical area such as home, computer laboratory, office building, and closely positioned group of buildings.

Neighborhood Area Network (NAN), is an access network that allows smart grid end-device and home area networks to connect to wide area network.

A *Wide Area Network* (WAN) is a communication network which covers a wide geographical area and accommodates terminals and LANs. This is typically called “Back Haul” network in smart grid environment.

3.5.2 *Home Area Networks*

The most popular and largest parts of consuming energy would be the home area where identified as the living place of general people (not limited, that is, including small enterprise premises as well). With the rapid development of ICT especially for various on-line communication services/applications as well as end user entertainment services, a home area is becoming more network oriented and getting more intelligence to manage home environments. This trend will lead a home with HAN (Home Area Network) as a focal point of end user services not only from telecommunication aspects but also using energy aspects. Therefore it is highly anticipated that identifies functions and their arrangements with architecture models of home area based Smart Grid .

Home area would be considered with two key features: as a Home Area Network to provide various ICT services and the other for Home Smart Grid for supporting smart usage of electricity. Both two features need to interconnect with Wide Area Network/Smart Grid which exists outside of the home. And these two features would be communicated with each other to provide benefits from one part to another part and vice versa. Figure 7 Shows the extension of the HAN and its relationship with the smart grid.

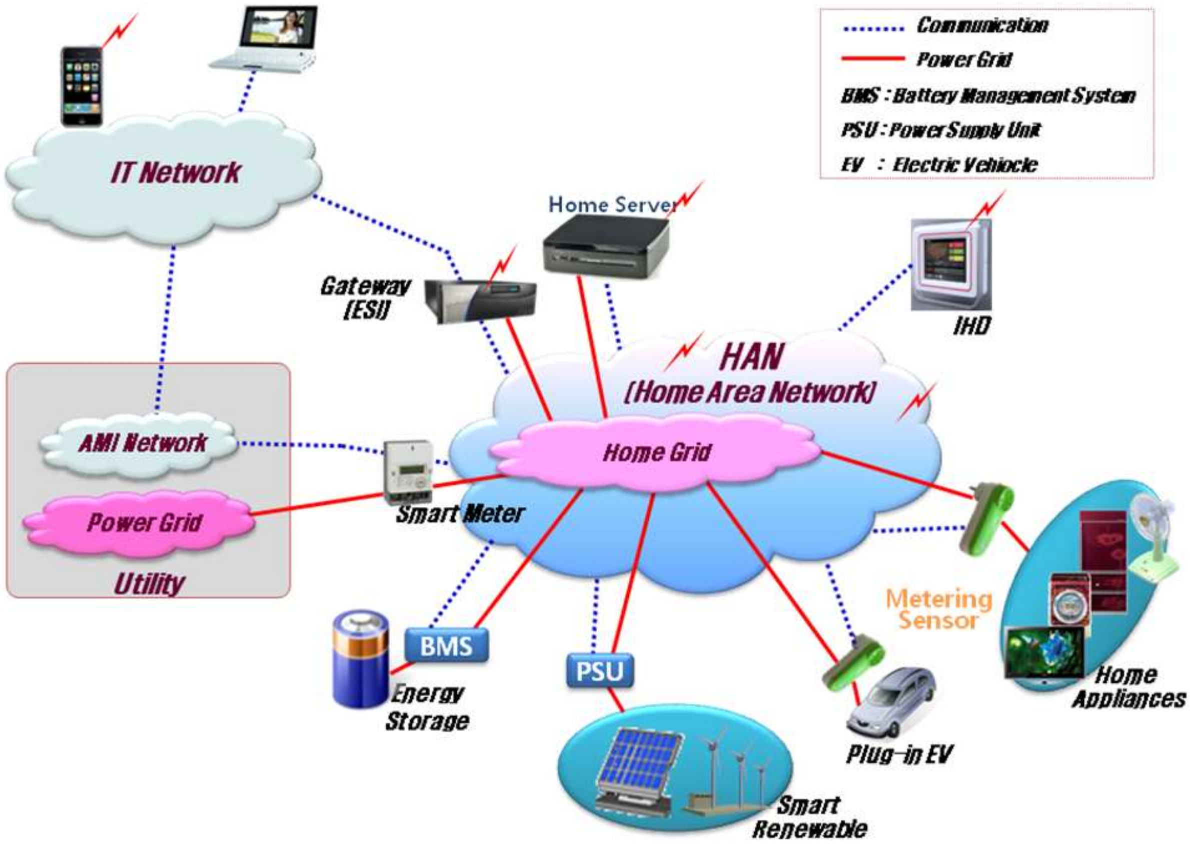


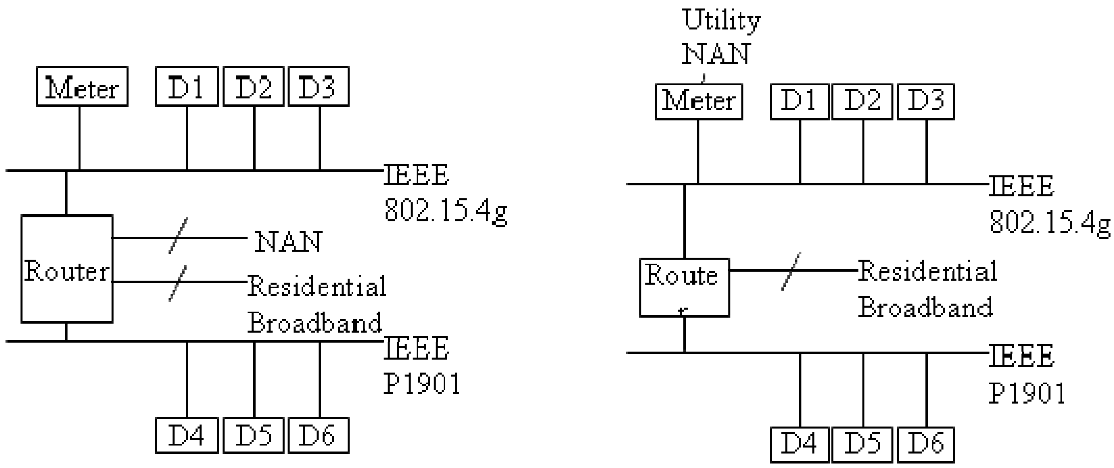
Figure 7. Home Area Network and relationship with the smart grid.

The Utility Network is an electric power based grid network including electrical power systems and management (control and monitoring) systems to supply an appropriate electrical power to home user.

Home Grid provides an electrical power distribution and control service inside home environment. It is related to just only electrical power system in home area.

Smart Meter is a premise device to monitor and control of electrical power usage of home devices based on "Demand Response (DR) information" from home devices. But, it is not recommended that the Smart Meter controls directly per each premise appliances because of the private security policy. To control and manage the each premise appliances, it is required for home management system such as home gateway and home server to support the control and management.

The utility can exploits its own infrastructure to access Smart Meters and other devices inside the HAN; Figure 8 a) shows a simple network containing IEEE 802.15.4 and IEEE 1901 domains. It shows the connectivity between them as a router separate from the EMS. This is for clarity; the two could of course be incorporated into a single system, and one could imagine appliances that want to communicate with their manufacturers supporting both a HAN interface and a WiFi interface rather than depending on the router. These are all manufacturer design decisions. In Figure 8 b) the utility directly accesses appliances within the HAN. Rather than expect an EMS to respond to price signals in Demand Response, it directly commands devices



a) *b)*

Figure 8. The Utility Network (NAN) and the HAN.

like air conditioners to change state, or activates relays on circuits to or within the home.

Energy storage provides storage functions of electricity using various types of batteries. One example usage of Energy Storage is used to respond effectively to real time price mechanism from utility network. The electric energy is stored to the storage during lower price period relatively, while the stored electric energy may replaces the higher price of electric power from utility network. The control and management for the dynamic energy storage is provided by battery management system (BMS).

Smart Renewable is an electrical power generating system to be used within the home environment. The energy generated by renewable in the home environment is primarily used in the internal home usage, but can also provide some extra energy to main grid of the utility network. A power supply unit (PSU) including inverter function, DC to AC conversion, is needed to connect to the Home Grid. To provide appropriate Smart Renewable function, it functions together with Energy Storage system.

Home Appliances are key components in terms of energy consuming in home environments. Home appliances are composed of smart home appliances and legacy home appliances. The smart home appliances contain an electric metering and communicating capabilities, but legacy appliances are not. Thus, the legacy appliances are required to have additional metering sensor including communicating functions to control and manage the usage of electric energy (intelligent plug).

Home Gateway (HG) is a device that connects multiple home area network devices to an access network.

Home area network (HAN) provides home network services. HAN uses various network environments, wired and wireless network.

In-home display (IHD) is a display device to present home energy usage information. With the IHD, the customer can optionally control the smart grid HAN devices using user input interfaces. The IHD could also not be a physical element, but could be a function embedded into other equipment in the house (e.g. computer, TV …). The control and usage information are transferred by HAN communication system environment.

Plug-in EV (electric vehicle) can operate both as an electrical power consuming and an electrical source at the same time, like an Energy Storage system. The Plug-in EV contains internal BMS and the operating function which are controlled and managed by home energy management system. It is required that the control and management reflects the user's Plug-in EV usage plan and real time price information.

Metering sensor is a sensor device that can monitor electrical usage details of each home energy consuming device such as home appliances with various forms. It can be optionally accompanied to legacy home appliances which do not provide their own metering function.

3.6 Security

Security comes out as one of the main requirement for smart grid operation. Secure network communication is essential for grid safety, as energy distribution is prone to numerous harmful risks for people, plants and ambient. Network security implies to main aspects: reliability (mainly ascribable to quality of service issues) and trustfulness (user and device authentication, data secrecy and strength of equipment against tampering).

In addition to network security, the following security features are required:

- *Confidentiality*: The Smart Grid should preserve authorized restrictions on information access and disclosure during communications, including means for protecting personal privacy and proprietary information. A loss of confidentiality is the unauthorized disclosure of information;
- *Data & User privacy*: Data must be treated as personal and aggregation and removal of personal details may be required. The Smart Grid should preserve authorized restrictions on information access and disclosure during use & storage, including means for protecting personal privacy and proprietary information. A loss of Data & User privacy is the unauthorized disclosure of information during use & storage;
- *Integrity:* Smart Grid should prevent against improper information modification or destruction, and includes ensuring information non-repudiation and authenticity. A loss of integrity is the unauthorized modification or destruction of information;
- *Availability*: Smart Grid should ensure timely and reliable access to and use of information. A loss of availability is the disruption of access to or use of information or an information system;

The following issues need to be considered when considering the above security features:

- Extensive data gathering and two-ways information flows may broader the potential for compromises of data confidentiality and breaches of customer privacy, and compromises of personal data and intrusion of customer privacy;
- The complexity of the grid could introduce vulnerabilities and increase exposure to potential attackers and unintentional errors;

- Increased number of entry points and paths are available for potential adversaries to exploit.

4 RECOMMENDATIONS

Recommendation 1

There has been a proliferation of working groups on smart grids from different organizations in Europe, North America and Asia. They have produced their own reports, which sometimes consist of a summary of the work from other groups. As a consequence, despite of the large number of documents and recommendations about smart grids, these works are often redundant and repetitive. Standardization body should agree to common initiatives in order to drive their attention towards a common policy and description.

Recommendation 2

There are a large number of use cases and scenarios for smart grids. Many of them are redundant or have unclear or blurred descriptions. Working groups should select a smaller number of scenarios, which helps in extracting the main requirements.

Recommendation 3

Standardization bodies should agree on a common reference architecture. Many groups currently are considering the NIST conceptual model and reference architecture.

Recommendation 4

It has to be clear that the set of models in a Reference Architecture cannot be defined once and for all. It will have to be evolving over time together with the progress in the smart grid business, use cases and functionalities.

Recommendation 5

There is not a clear understanding whether current standards and protocols are suitable for smart grids or new solutions have to be devised. In particular, it is necessary to define the role of the current Internet as the base transport technology in order to optimize costs and accelerate the developments. Standards should also be reviewed and, where useful and possible, revised in light of optimizing the energy load of the ICT itself. Particular care should be devoted in providing standardization ground that enables the ICT devices to adapt their operational states (and energy consumption) dynamically, depending on the data traffic.

Recommendation 6

ICT is requested to improve the grid's resistance to perturbations, natural disasters and grid flexibility, by monitoring and protection of the power line and environment condition (current, voltage, frequency, wind-force, etc.). The design of the communication network should carefully consider QoS and real-time constraints in transmitting this information; this aspects should also seriously affect the choice of the various communication paths (wireless: GPRS, 3G, LTE, WiMAX, etc./wired: Optical fiber, etc.).

Recommendation 7

Smart Grids requirements towards communications range from simple transfer of bulk information (from/to sensors, meters, actuators …) to critical, real time data for safety and security of network and users. The latter will need to be guaranteed even in case of natural disasters or major network faults (black outs). The design and choice of the communication network should carefully consider capabilities such as: sufficient energy back-up in the communications nodes (time should be defined); path/systems redundancies; self healing capabilities.

Recommendation 8

The unified electronic interface on home appliances and the home network are the preconditions for power relevant applications. Until now, electrical utilities have mainly followed the way of using the electric cabling in the last mile; This could show not to be sufficient to transport huge volumes of data in particularly crowded areas. It should be taken as granted that the communication path will be provided by different information and communication networks and composed of diverse transmission technologies in the perspective of saving cost and widening the bandwidth available for applications.

Recommendation 9

Large players could be tempted to take advantage of their market position to force networking solutions within their infrastructure to interconnect the customer sites with the rest of the smart grid. Regulators should put away this opportunity by suitable policies and regulations to allow free competition in supplying communication services for smart grids. All stakeholders should be guaranteed the same opportunity in this market, using different technologies as public broadband access networks, power line communications and wireless communications.

Recommendation 10

The home appliances could use short-range wireless communication technologies (e.g., Bluetooth, Zigbee, 802.11, and others) or wired connection (power line, cable, telephone line, and others). The presence of multiple choices is positive towards an early and cost effective deployment of Smart Grids. On the other side, if too many options are available, interoperability issues or excessive complexity/cost/consumption may arise due to different standards present in networking equipment and appliance interfaces and the need to bridge them.

Recommendation 11

In order to support all the services implied by the numerous scenario, ICT systems must

- provide wide range of applications such as home, building, and factory energy management systems, on demand meter readings, demand and response systems, electrical grid status monitoring, fault detection, isolation, and recovery;
- manage wide variety of devices such as intelligent sensors, smart meters, smart appliances, and electric vehicles.
- It is clear that such wide variety of requirements and constraints could not be delivered through one single communications infrastructure. Critical services and electrical network elements will have extremely high requirements to the communications network (QoS and availability), while the less critical services could be guaranteed through standard communications channels that are less costly, scale better to the needed volumes and are already largely available.

Recommendation 12

All authors agree security is a fundamental building block of smart grid. ICT must carefully address the following aspects:

1. reliable network operation for safe communication, which is needed by the grid in order to function properly;
2. secure network transactions;
3. robust network equipment with regards to external attacks and tampering;

4. privacy, as much sensitive data about customers and other actors are expected to be present in smart grids.

Recommendation 13

Current activity does not care about power consumption of ICT equipment in smart grids (in the energy grid, in the core and access network and in the home).

The Smart Grid implementation will require broad geographic coverage and, in every home/office, counts on the presence of numerous meters, sensors, actuators. Those ICT elements will be networked and exchange volumes of information.

In the initial phase it is easy to foresee at least ten elements per every house. This number could increase heavily as, in theory, every power socket, switch, light, appliance could become an active element.

All these elements will tend to be always active, ready to transfer information and their communications capabilities will be typically quite oversized.

Summing up the energy footprint of all these elements could result in huge energy amounts. Such amount could be non negligible and, in the end, could reduce the effectiveness of the SG deployment.

At present, the standardization and development activities look to be focusing on the challenges related to the creation of the very complex communications architecture needed by the Smart Grids.

Little activity is seen on the evaluation of the negative effect of such a global deployment (i.e. additional energy consumption) and its minimization, unless for some low power transmission technologies intended to be powered on battery (e.g. Zig Bee).

Within the ICT, the analysis and optimization of the energy footprint of communications systems is an ongoing activity. That experience should be applied also in the Smart Grid area so to develop energy aware and optimized architectures and elements.

At all stages and in particular in homes, where the vast majority of the ICT elements will sit, communications systems should implement energy optimized techniques enabling to adapt dynamically performances to the needs and, implementing heavily low power (sleep) modes so to minimize the overall energy footprint while being able to cope with the communications requirements.

In the perspective of pursuing energy efficiency and environmental protection, it is necessary to avoid excessive and unnecessary consumption that could seriously reduce the overall Smart Grid benefits. This is particularly true for the equipment that will be installed in homes (sensors, actuators, communications bridges) and in the access networks. Currently, this task seems to be underestimated.

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