Smart Cities:

The Opportunities for Fuel Cells and Hydrogen

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Smart Cities and the Opportunities for Fuel Cells

A Smart City is a model that uses new technologies to make an efficient use of a city's resources in order for the urban environment to become more livable, functional and competitive. However a smart city is not only about technology. Technology is used as a means to enhance and integrate the many different playing fields within the urban organizational structure, improving performance and the community's perception thereof.

1. A Smart City in Six Dimensions

These fields are grouped into 6 key dimensions which describe the global perspective that is required in a smart city: the economy (competitiveness), mobility (transport and ICT), the environment (natural resources), people (social and human capital), living (quality of life), and finally governance (participation).[1]

1.1. Smart Economy

The city economy starts to become "smart" when its industries become "smart" too, that is when industries involve interactive ICT in their production process. A smart economy also promotes, among other things, strategies to boost the economic and social development in its territories.

1.2. Smart People

The term "smart" in this context makes reference to the educational levels, skills, quality of social interaction enacted by the population. Cities are crucial centres for generating "smarter" people, by promoting and diffusing education, developing advanced services engaging the population, giving universities a major presence, design digital development plans in classrooms, and integrate ICT in education.

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[1] Committee of Digital and Knowledge-based cities of UCLG, *SMART CITIES STUDY: International study on the situation of ICT, innovation and knowledge in cities*(2012)

1.3. Smart Governance

Technologically evolving people will require and expect more interactive governance structures. This includes political and active participation within citizenship services and the use of new communication channels that extend the instruments of democratic participation.

1.4. Smart Mobility

Improvement of public transport systems in cities, modal-split and sophisticated passenger and freight logistics shall contribute to reduce traffic congestion in urban areas, based on newly developed mobility and transport services. Such measures shall embrace public and private transport as well as non-motorized transport (walking and cycling) within cities, and need to comprise both technological and regulatory instruments.

1.5. Smart Environment

New and improved technologies are called for to protect and preserve the city's environment which is under increasing pressure due to on-going urbanization, higher population, energy and traffic density and growing productivity. These aspects are only expected to increase with the evolution towards smart cities, therefore proactive measures have to be undertaken to safeguard a balanced and organic habitat for the future. Actions that can help in this direction are:

- Implementation of systems based on ICT to improve citizen security
- Promote initiatives to digitize and share cultural heritage
- Environmental protection through sensoring and forecasting
- Sustainable resource management

1.6. Smart Living

The focal areas described above should eventually come together in an overarching dimension of improved liveability, compiling several aspects that substantially improve the quality of life of citizens such as:

- Integration of ICT technologies to support and enhance the healthcare system.
- Enhancing the capabilities of people with special needs

- More accessible cultural facilities
- Advanced education facilities
- Touristic attractiveness

The technological deployment required for the development of smart cities should be based on open standards and interoperability in order to allow a multiple-vendor market which is beneficial for the needs of cities, citizens, and businesses.

2. Smart Cities: Energy, Efficiency and Environment

A major expectation of Smart Cities is that they may reduce the pollution generated by today's cities and the emerging mega cities. Worldwide, increasing concerns about global warming and climate change, but above all about local pollution, is forcing the energy market to shift toward a smart integration of renewable and cleaner energy solutions (photovoltaic, geothermal, wind, biomass, electric transport, etc.). However, the large-scale incorporation in the city's energy supply of renewable distributed energy generation necessitates smart energy management of the entire system at city level. For this reason, the inclusion of ICT is crucial to make full use of the stochastic energy supply deriving from renewables.

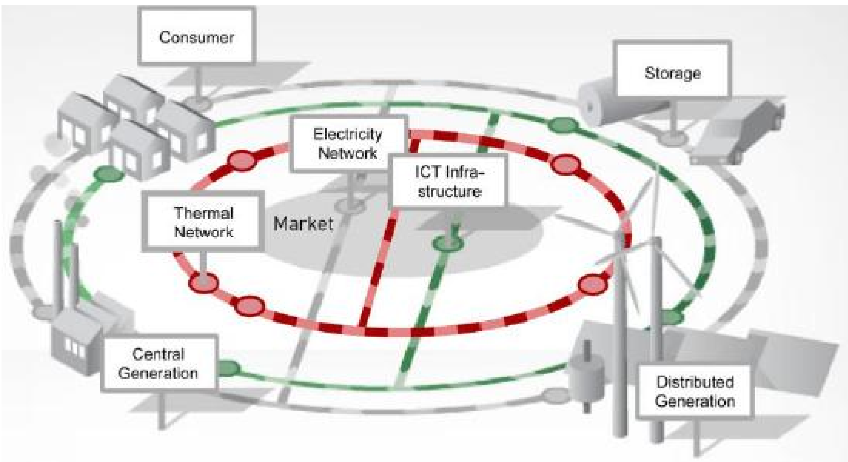

Figure 1. Illustration of a potential smart future energy system at city level **[40]**

With respect to the fundamental issues of energy supply, efficient use of resources and environmental safeguard, four key areas of focus are identified where development is crucial towards the realization of a sustainable smart city:[2]

[2] European Energy Research Alliance - EERA., *Joint Programme on Smart Cities* (2014)

2.1. Energy Planning

Due to the importance of understanding the energy performance characteristics of urban areas, new simulation tools that facilitate a holistic energy master planning have to be developed. It should be based on a deep knowledge of the urban morphology such as building density, typology and end-use mix.

2.2. Energy Networks

Smart energy grids are the backbone of a Smart City, and will be responsible for the intelligent management and operation of energy networks in cities by utilizing the potential for shift between thermal and electrical loads. Furthermore, the integration of decentralized renewable energy sources into existing energy grids brings up some major technical issues that have to be treated. The interaction between mathematical modelling techniques, numerical simulation environments and advanced communication infrastructure is a powerful tool in this research area. This also holds for the potential storage capacity for both electrical and thermal energy within energy networks which can be achieved by intelligent demand side management.

2.3. Energy in Buildings

Large buildings represent an essential part in the existing energy system of cities, being responsible for almost 40% of the entire energy consumption according to European statistics. In the context of a smart energy grid these have to be fully integrated into the overall network. Once integrated, they provide energy storage capacities supporting the smart management of the entire energy system. In addition, buildings will soon provide energy generation services supporting the overall energy supply of the entire system. This interaction between building and the smart grid is a key aspect in the transition from single passive building technologies to fully integrated buildings acting as active hubs in the energy grid, where ICT plays a major role.

2.4. Energy Supply Technologies

In the field of energy supply technologies the upcoming challenge is to deal with the smart integration of on-site renewable energy sources into buildings and networks, and the cascade use of resources (poly-generation) for maximum efficiency. Furthermore, the interaction between cities and their neighboring industries will have to be optimized in order to maximize synergies (e.g. industrial waste heat used as energy supply for cities). Scientific tools for the optimal use of hybrid supply systems will play a crucial role and a large effort will have to be directed to the development of new protocols and standards.

2.5. Connected Areas of Focus: Mobility and Finance

A major topic to consider is the development of alternative fuel vehicles, in particular Electro-Mobility which is strongly connected to the core topics of energy and environment as well as to that of mobility. Its integration into existing urban energy networks still remains a challenging problem, and new transport concepts and urban energy planning at meta-level will be necessary to successfully deploy electric transport within cities, which is a critical achievement especially in terms of local pollution.

New business models and innovative investment schemes will be necessary in the future to actually enable the transformation of European cities into Smart Cities from a financial point of view. This also requires, to a certain extent, new regulations and a new legal framework combined with organizational innovation (stakeholders, companies, institutions, etc.) and social sciences (public awareness, user behaviour, etc.).

3. The Multiple Advantages of Fuel cells for Smart Cities

Worldwide, cities represent three quarters of the energy consumption and contribute 80% of CO_2 emissions. Thus, cities are the areas where major energy savings could be made. Consequently, it is necessary to identify the areas that are least efficient in their energy management. According to UNEP[3], buildings contribute as much as one third of total global greenhouse gas emissions, primarily through the consumption of fossil fuels. Transport, on the other hand, is placed as the second biggest greenhouse gas emitting sector and is responsible for around a quarter of EU greenhouse gas emissions[4]. Therefore, working on initiatives aiming to reduce the energy consumption of these two

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[3] United Nations Environment Program, Buildings and Climate Change, http://www.unep.org/sbci/pdfs/SBCI-BCCSummary.pdf

[4] EU Transport GHG: Routes to 2050, http://www.eutransportghg2050.eu/cms/the-contribution-of-transport-to-ghg-emissions/

sectors will facilitate the path towards decarbonisation. Fuel cells are a promising option to address this challenge.

Fuel cells differ from conventional technologies in that they convert the chemical energy of fuels electrochemically, generating electrical power directly, avoiding the inefficient steps of combustion and transformation of heat to mechanical work in order to drive the electrical generator[5]. Compared to batteries, fuel cells provide premium power without suffering from charge-discharge effects, which means they are lighter, quicker to refuel and generate with undiminishing performance.

3.1. Smartening the Electricity Grid

Thanks to these advantages, fuel cell systems are a crucial enabler for the effective realization of smart grids (see also the Annex to this document). Distributed generation, remote and localized production, flexibility, two-way communication and efficient integration of renewables are key concepts for this evolution. What makes fuel cell systems so attractive and is gaining them competitiveness in the energy market is that:

- They can generate clean electricity at or very near the point where it is needed
- They provide fuel flexibility
- They provide efficient and reliable power generation and are suitable for combined heat and power production
- They can balance power in the grid

Currently fuel cells in the electricity grid are used chiefly as prime power generators, powering up from a single residence, to an entire building, industrial facilities or even small towns. But enormous potential could be unleashed with their capacity to operate in reversed mode as well: converting excess (renewable) electricity to hydrogen and other fuels in order to stabilize the grid and guarantee maximum use of renewable energy sources. Energy storage will play a key role in the successful implementation of smart grids because it provides stability and reliability to the grid enabling the storage of energy when demand is low and the release of energy during peak demand periods, which represents an improvement in the system's flexibility.

3.1.1. Current examples of Fuel cell implementation in the Electricity Grid

[5] New all-European high-performance stack: design for mass production, http://www.nellhi.eu/

- Korean energy company, POSCO Energy, in a joint venture with the American molten carbonate fuel cell (MCFC) manufacturer FuelCell Energy, is driving the maturity of fuel cell power plants in the world scene, deploying in South Korea the largest operating systems in the world: first the 11.2 MW plant in Daegu City in 2011, followed by the 59 MW plant started in 2013 in Hwaseong, and already in the process of delivering a 120 MW plant for 2015. The company has seen increasing demand for fuel cell power plants from electric utilities and independent power producers under the South Korean financing scheme RPS (Renewable Portfolio Standard)[6]. The fuel cells, which run on natural gas and renewable bio gas, contribute to the power and heating needs of the local urban population.[7]
- In the U.S.A, Delmarva Power is installing the largest utility-scale fuel cell deployment in the country. This 30MW of Bloom Energy Servers in Delaware, are enough to power 22 thousand homes. It will improve the reliability of the electric grid and it is also expected that units will decrease carbon dioxide emissions by 50 percent compared to Delaware's electric grid. [8] Moreover, utilities are also integrating smaller fuel cell systems (1-10 kW) into network infrastructure, providing backup power to substation controls and telecommunication networks which are critical if a substation loses power or there is an equipment malfunction.[9]
- In July 2014, the energy provider Exelon Corporation, announced it will provide equity financing for 21 MW of Bloom Energy fuel cell projects at 75 commercial facilities in California, Connecticut, New Jersey and New York for AT&T and one other unnamed customer. [10]
- A fuel cell powered electric grid will provide uninterrupted primary power via a prototype off-grid solution in small villages in South Africa by the year 2015. The off-grid solution is based on a methanol-fuelled home generator system, and aims at gauging the potential to of fuel-cell based systems to provide economical electric power to remote rural African households.[11]

3.2. Increasing efficiency in Buildings

[6] Renewable Portfolio Standard (RPS) came into force this year and mandates 350 MW of renewable power capacity to be added each year through 2016, and an additional 700 MW per year through 2022
[7] http://www.fuelcelltoday.com/media/1637144/using_fc_prime_power_generation.pdf
[8] http://www.fuelcells.org/uploads/Fuel-Cells-in-Storms.pdf
[9] http://www.fuelcells.org/pdfs/2014BusinessCaseforFuelCells.pdf
[10] Idem
[11] http://www.southafrica.info/business/trends/innovations/fuelcell-070814.htm#.VHcyRzGG9NM#ixzz3KHLTWedd11

Fuel cells generate electricity and heat *on site*, so that the heat generated can easily be recovered and reused: this combined heat and power solution (co-generation, or CHP) is an excellent option for all residential and commercial buildings, as its total energy efficiency reaches in excess of 85%[12]. Additionally, fuel cells are regarded as superior to other technologies for small scale cogeneration since they maintain their efficiency at part load, reduce CO2 emissions due to their higher efficiency and almost completely avoid the emission of harmful pollutants, possess good load following capability, are compact and quiet and potentially fuel-flexible[13]. Polygeneration is possible in several forms, since it is possible to produce hydrogen and cold in addition to power and heat given appropriate system engineering.

3.2.1. Current examples of Fuel cell implementation in Buildings

Example of the successful implementation of fuel cells for CHP projects are:

- Japan: the residential micro-CHP fuel cell project *ENE-farm* started in 1990. The commercialization phase of this product started in 2009 and became the world's first market introduction scheme for fuel cell systems targeted at household heating and electricity generation. Close to 100,000 units have been installed at people's homes in the five years leading up to the present[14].
- South Korea: in terms of micro-CHP systems, Korea launched a programme to subsidize 80% of the costs support the installation of residential fuel cells for heat and power with subsidies aimed to decrease from 80% to 30% in 2020, with progressive market introduction. South Korea has also announced an ambitious goal to supply 20% of the worldwide shipments of fuel cells by 2025 and create 560,000 jobs in South Korea. A strategic plan for the city of Seoul includes 47% of renewable energy generation from fuel cells by 2030 - more than the power produced by solar, geothermal and all other clean energy technologies combined.[15]
- UK: the authority managing public transport in London, the largest urban zone of the EU (over 8 million people), has chosen a fuel cell solution for its head office: the Palestra building in the city is now powered by the UK's largest fuel cell power plant, which will allow a 40%

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[12] Fuel Cell Europe: The multiple advantages of fuel cells for smart cities, http://www.europeanenergyinnovation.eu/portals/0/publications/europeanenergyinnovation-winter2011.pdf

[13] Fuel cells can run with a variety of fuels such as: hydrogen (also from renwables), diesel, natural gas, biogas, ethanol, methanol, propane, LGP, jet fuel

[14] Analyst view: Fuel Cell Residential Micro-CHP Developments in Japan, http://www.fuelcelltoday.com/media/1597029/29-02-12_ene-farm.pdf

[15] Fuel Cell and Hydrogen Technologies in Europe 2014-2020, http://www.fch-ju.eu/sites/default/files/111026%20FCH%20technologies%20in%20Europe%20-%20Financial%20and%20technology%20outlook%202014%20-%202020.pdf

reduction of CO_2 emissions and cost savings of £90,000 per year. In addition, the fuel cell system makes the building completely independent from the grid, a very good asset for an authority which is also responsible for emergency controls and therefore needs a secure energy supply.[16]

- Germany: The *Callux* project was launched by the Ministry for Transport, Construction and Urban Development along with nine partners form industry, Germany's biggest field test for domestic fuel cell heating system.[17]
- Europe: the European Commission has designated fuel cells as a key technology for the EU and has set up a large joint initiative together with industry (the "Fuel Cells and Hydrogen Joint Undertaking" – FCH JU) for an impactful R&D programme to support development, demonstration and deployment of fuel cell systems, with an expected budget of €1.4 billion for 2014–2020. CHP is an important pillar in this programme, and the key project today is *ene-field*, in which up to 1000 fuel cell micro-CHP systems are to be deployed. The first units are installed at the end users and the project is steadily gaining foothold and interest.[18]

3.3. Electric mobility

Fuel cells are set to become a major player in the transport sector. Vehicles can use the electricity produced by the fuel cell for propulsion as well as for on-board generation. Unlike battery-electric vehicles (BEV), fuel cell electric vehicles (FCEV) do not suffer from the slow and cumbersome electric charging process, making extended driving ranges possible thanks also to weight-efficient, on-board fuel storage. With a process similar to gasoline refuelling, FCEV could tank up hydrogen in less than five minutes and cover similar distances to a conventionally fuelled vehicle.
"Decarbonising" transport is a priority for the European Commission[19] considering the aspects of efficiency and congestion as well as environmental impact. In this context, among the priority areas for road transport are alternative fuels, electric transport and hydrogen-powered fuel cell vehicles.

[16] Fuel Cell Europe: The multiple advantages of fuel cells for smart cities, http://www.europeanenergyinnovation.eu/portals/0/publications/europeanenergyinnovation-winter2011.pdf
[17] Callux, http://www.callux.net/home.English.html
[18] Fuel Cell passes the point of no return, http://www.cospp.com/articles/print/volume-15/issue-2/features/fuel-cell-chp-passes-the-point-of-no-return.html
[19] Commission Communication (COM(2010)186 final), https://ec.europa.eu/jrc/en/research-topic/sustainable-transport-and-fuels

3.3.1. Current examples of Fuel cell implementation in Transport

Global awareness about the benefit of the implementation of fuel cells in the transport sector is increasing. As a result, projects that have been developed in this field are, among others:

- SWARM ("Demonstration of Small 4-Wheel fuel cell passenger vehicle Applications in Regional and Municipal transport") a project funded by the European FCH JU. It will establish a large demonstration fleet of small passenger vehicles that builds on and expands existing hydrogen refuelling infrastructure.
- DG MOVE[20] funded demonstrations of hydrogen technologies for stationary and transport applications in the 5thResearch and Technological Development Framework Programme FP5. In the 6th Framework Programme FP6, a call under the Thematic Priority 'Sustainable development, global change and ecosystems' was launched, leading to a number of demonstration projects and the formation of an informal 'European Hydrogen for Transport Partnership'. The results of these efforts provided much input to the recently formed Public-Private-Partnership 'Fuel Cells and Hydrogen Joint Undertaking'.[21]
- The CHIC project is the 'next step' towards commercialisation, community acceptance and widespread introduction of hydrogen powered FC buses across Europe, and the realisation of the significant environmental and economic benefits that the fully commercial implementation of this technology can bring to Europe.

3.4.Waste management and energy supply

Another critical area of action where fuel cells can be useful is in waste management. Waste is an ever growing problem, both in terms of volume and associated health hazards. Since most waste is produced in cities there is also a critical logistical issue in dealing with large, diversified refuse flows in crowded areas. However, waste contains significant quantities of energy which can be converted into useful forms (e.g. biogas) while contributing to waste processing by reducing the volume. Biogas is widely produced from waste-water treatment and processed municipal waste using anaerobic digesters and is then currently usually combusted. Although carbon dioxide is emitted, biogas is a renewable energy source and therefore the recovered energy would be considered carbon dioxide neutral. Conversion in a fuel cell would increase the exploitation of biogas through a larger yield of

[20] The Directorate-General for Mobility and Transport (DG MOVE) is a Directorate-General of the European Commission responsible for transport within the European Union.
[21] Mobility and Transport: http://ec.europa.eu/transport/themes/urban/vehicles/road/hydrogen_en.htm

high-value electricity, where the fuel cell plant would generate heat as well, which could be used to thermally control the digester, making the overall system even more efficient.

3.4.1. Current examples of Fuel cell implementation in Waste management

The American company FuelCell Energy is the forerunner and global leader in the high-efficiency and ultra-clean conversion of waste to energy using fuel cells:

- The Tulare Wastewater Treatment Plant (California – USA) uses a fuel cell system to turn waste into electricity. The Tulare WWTP requires about 2.7 MW of electricity of which 35 percent is produced with on-site molten carbonate fuel cells (MCFC), avoiding about 6200 tons of emitted CO_2 per year.[22]
- In 2011 the Orange County Sanitation District (California – U.S.A.) started a collaborative waste-to-energy project with *Air Products* and *FuelCell Energy* and installed a fuel cell plant that runs on anaerobic digester gas and produces electricity, heat and hydrogen. The fuel cell provides 250kW of power for use at the treatment facility and it also supplies hydrogen to an Air Products hydrogen refueling station situated a mile from the plant.[23]
- In 2013, *FuelCell Energy* announced a contract to demonstrate a tri-generation stationary fuel cell power plant near Vancouver – Canada fuelled withlandfill gas. In addition to clean electricity, heat in the form of hot water will be supplied to a leading hydroponic greenhouse operator, and renewable hydrogen will be exported for vehicle fuelling or industrial applications. [24]
- *Siemens Energy Management* has partnered with *Microsoft* and *FuelCell Energy* to build its first zero carbon, waste-to-energy data center, converting biogas produced at the nearby Dry Creek wastewater facility. The Microsoft data center will operate completely off the grid and, based on measurements from Siemens' power monitoring system, is expected to produce 250 kilowatts of renewable power and use approximately 100 kilowatts. The additional power will be sent back to the waste water treatment facility to reduce its electric bills. [25]

[22] http://www.fuelcells.org/pdfs/TulareCaseStudy.pdf
[23] http://www.fuelcelltoday.com/media/1637141/using_fc_converting_waste_to_energy.pdf
[24] http://www.stamfordadvocate.com/news/article/FuelCell-tests-technology-at-landfill-in-Canada-4334402.php
[25] http://www.businesswire.com/news/home/20141106005275/en/Microsoft-taps-Siemens-technology-partner-engineer-power#.VHSJSovF-AU

3.5. Telecommunications

It cannot be expected to achieve zero emissions if the infrastructure providing the "intelligence" to the smart city relies on highly pollutant infrastructures. The International Telecommunication Union (ITU) has estimated the contribution of ICTs (excluding the broadcasting sector) to climate change at between 2 and 2.5 %of total global carbon emissions.[26] Of these, one quarter is due to fixed and mobile telecommunications.

The telecom industry is the second largest and fastest growing market in the world, and the amount of electricity necessary to power it and the associated emission of greenhouse gases are two factors increasing correspondingly. Due to the fact that telecommunication has to operate day and night without interruptions, it demands a continuous and uninterrupted power supply, forcing telecom providers to rely on diesel as a primary fuel to back up the electric grid, which is expensive as well as polluting.

Of four sectors making up the power consumption in the telecom industry, the infrastructure is the heaviest contributor[27], as the following figure illustrates:

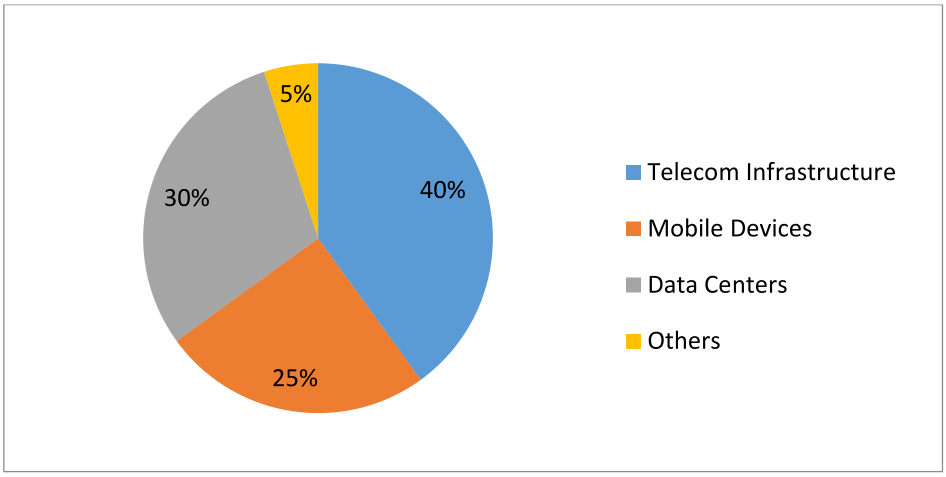

Figure 2. Energy consumption in the telecom industry, PwC 2012

Within this power-hungry infrastructure, the Mobile network takes the largest share of energy consumption, being also the fastest growing telecom market.[28] Telecom providers will therefore need

[26] ITU (2009) ICTs and Climate Change, background paper for the ITU Symposium on ICTs and Climate Change, Quito, Ecuador, 8-10 July.
[27] Price-Waterhouse-Coopers, Energy Efficiency in Green Telecom
[28] Impact Innovation in Technology&Bussines India, http://i2tb.in/

to increase further the capacity of their networks, meaning ever more BTS[29] will need to be installed across the globe, each with their own back-up power solution.
Already Diesel generators contribute up to 59% of the total carbon emission of the entire mobile network. Additionally, more than 30 percent of these cellular towers are located in areas with poor quality grid supply and frequent power cuts, which becomes particularly critical for areas with difficult access (e.g. mountains, islands, or forests) where diesel has to be carried by trucks, boats or even helicopters, so that the cost of carrying the fuel is higher than the cost of fuel itself.
Fuel cell technology could be an optimal solution to all these drawbacks, especially if they can be operated in reverse mode, storing excess electricity (from e.g. a PV panel) and generating back-up power when needed. Fuel cell systems have already been considered for remote stationary power applications with a high cost of downtime, such as base stations with a transition from field trials to commercial deployment over the last 2-3 years.

3.5.1. Current examples of Fuel cell implementation in Telecom infrastructure

Currently fuel cell deployment in this sector is in the very early stages with around 900 units worldwide[30] of which more than half in Indonesia, thanks to a partnership between Hutchison and IdaTech, who plan to add to their hydrogen-powered fleet methanol-based fuel cell systems while trialling LPG and Compressed Natural Gas (CNG) systems[31]. Over a hundred systems are deployed in South Africa and fuel cell trials are taking place elsewhere in African countries as well. China is making its appearance too: in April 2012 it was announced that the Ministry of Industry and Information Technology granted approval for use of fuel cell systems by VelaTel subsidiary VN Technologies' in Chinese BTS. Since the announcement the company has successfully completed trials for China Mobile and China Telecom. The market potential here is vast: China Mobile is the largest mobile operator in the world with 650 million subscribers and China Telecom is the country's largest fixed-line phone company with over 200 million subscribers.
Examples of commercial fuel cell systems to back up BTS are:

- ElectroSelf is a solution marketed by ElectroPowerSystems that generates and stores hydrogen on-site, using recovered water and surplus electricity, releasing backup power when

[29] Base Transceiver Station (BTS) is also known a base station (BS) and is commonly referred to as a "cell phone tower" or "cellular towers".
[30] http://www.gsma.com/mobilefordevelopment/wp-content/uploads/2012/04/Fuel_Cell_Report_for_fomatting1.pdf
[31] Green Power for Mobile: Fuel Cell Systems for Base Stations, Deep Dive Study

an outage occurs. This technology is presented as more efficient and cost-effective than both battery banks and diesel generators.

- GASHUB's BTS Fuel Cell Generator is a comprehensive power generator with a built in backup system, replacing the traditional diesel generator set coupled with an expensive rectifier system and battery banks
- In the U.S., a number of large mobile service providers have installed fuel cell systems at more than 3000 cell towers across the country.[32] In the country, fuel cells technology has demonstrated to be particularly useful especially during storms. For example, when superstorm Sandy knocked out utility power in the Bahamas, fuel cells provided emergency backup power to at least 100 telecommunications towers, enabling critical communications amid the storm's destruction. Also, in 2011 during hurricane Irene, fuel cell manufacturer ReliOn reported that 56 of its systems, owned by Sprint, provided backup power throughout the entire outage. And after the winter storm Alfred in October 2011, ReliOn fuel cells kept cell towers up and running in Connecticut, enabling customers to stay in touch and access 911 services. [33]

[32] http://www.fuelcells.org/uploads/Fuel-Cells-in-Storms.pdf
[33] http://www.altenergymag.com/emagazine/2013/04/fuel-cells-backup-critical-infrastructure/2064

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[13] Smart Grid Consumers Collaborative, et al. (2013) *Smart Grid Economical and Environmental Benefits*, http://smartgridcc.org/wp-content/uploads/2013/10/SGCC-Econ-and-Environ-Benefits-Full-Report.pdf

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Appendix – Smart Grids and the opportunities for Fuel Cells and Hydrogen

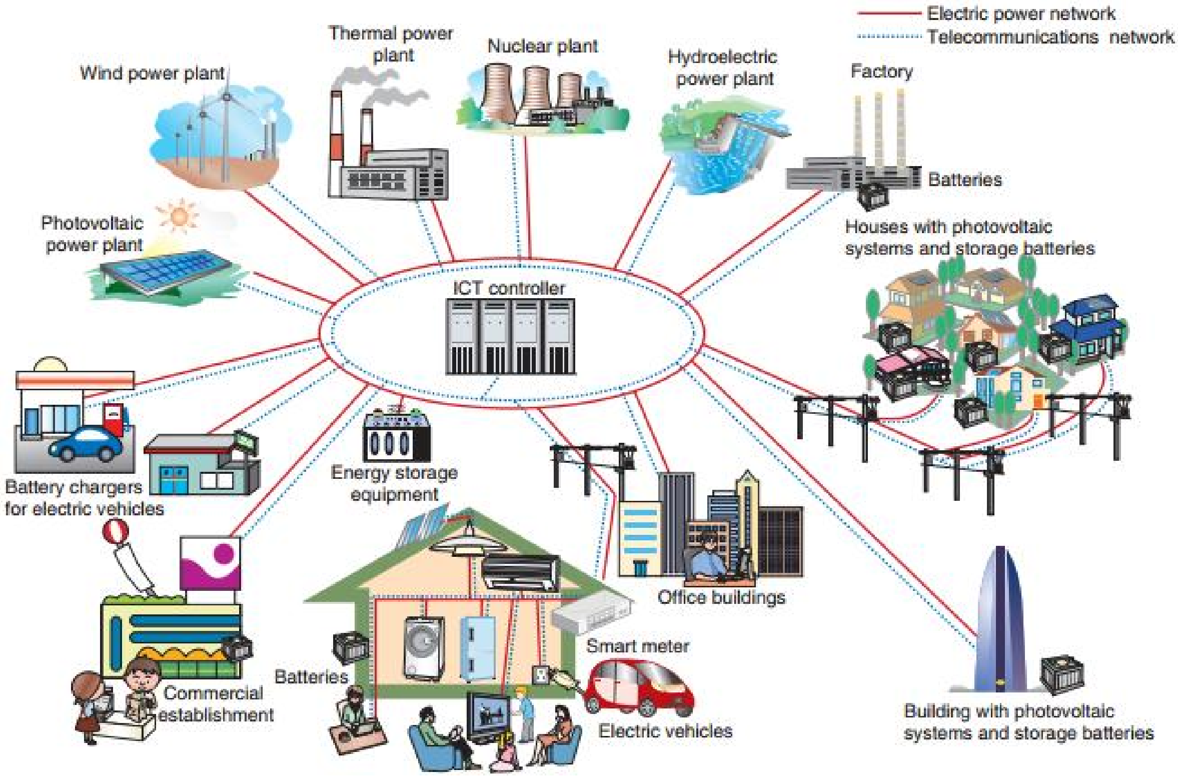

Figure 1. Outline of a smart grid **[1]**

A.1 Introduction

A.1.1 What is a Smart Grid?

A smart grid is an upgrade of the traditional power grid that uses an integration of information and communication technology (ICT) solutions to provide the network with the capability of transporting *not only electricity but also information*. It is optimized to deliver decentralized electricity from suppliers to consumers using robust *two-way digital communication*. Making grids "smarter" will help to mitigate many of the problems that existing power systems are currently facing: it makes the grid able to monitor its own health at all times, it enables instant flow control and automatic grid reconfiguration to prevent or restore outages, it should coordinate the needs and capabilities of all generators, grid operators, end users and electricity market stakeholders to operate all parts of the system as efficiently as possible, and also facilitate the integration of renewables.

As Information and Telecommunications technologies (ICT) are the core of smart grids, a change in connectivity requirements will be needed. Using the Internet Protocol (IP) for smart grid communications and open standard protocols for grid control makes it necessary to secure the grid at multiple points. Building on open standards-based protocols allows the network to ensure interoperability (defining how basic elements interrelate), openness (supporting multiple vendors and therefore avoiding vendor lock-in), and security (reducing the risk of intrusion while, at the same time, allowing access for the relevant stakeholders).[34][35]

To this effect a convergence of energy and telecommunications services needs to be in place, a change in the connectivity requirements and an evolution of roles for ICT companies as electricity sector partners. The role of the ICT sector in smart grids has been summarised in a report issued by the Commission in July 2009 entitled "ICT for Low Carbon Economy. Smart Electricity Distribution Networks".[36]

The priority technologies identified in the field of smart grids can be grouped into six areas: [41]

1. smart meters and infrastructure
2. sensors
3. integration of distributed generation and renewable energy resources
4. advanced transmission technologies[37]
5. storage systems
6. electric vehicles

Especially the latter four areas are conspicuously apt to fuel cell and electrolysis applications, and as such it is crucial to identify the opportunities for these technologies, incumbent on a radically innovating market, as well as the conditions and constraints dictated by a new era of services and infrastructure.

A.1.2 What is Not a Smart Grid?

To put the concept of a smart grid in a clearer light, it may be helpful to curtail the area of definition of what a smart grid is *not*. A smart grid cannot be considered a *product* because it is a continuous process of upgrading existing electricity grids and of designing future grids, in which the use of ICTs and Internet applications are at the centre of this modernisation. As such, a smart grid can never be said to have been fully achieved where there is still space for enhanced interfacing and modernisation.

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[34] NIST, *The Role of the Internet Protocol (IP) in AMI Networks for Smart Grid* (2009)
[35] NIST, *NIST Framework and Roadmap for Smart Grid Interoperability Standard, Release 1.0* (2010)
[36] ICT for Sustainable Growth Unit, European Commission, *ICT for a Low Carbon Economy Smart Electricity Distribution Networks* (2009)
[37] Technologies such as high-voltage direct current (HDVC) and Flexible AC Transmission system (FACTS) increase the transmission capacity and system stability, and assist in prevention of cascading disturbances. Moreover, they are more suitable for long distance transport and integration of renewable energy sources.

Smart grids are *often* erroneously *confused* with Smart Cities and Smart Meters.

- Smart Cities depends on smart grids to: ensure resilient delivery of energy, to supply their energy demand, and therefore cannot fully exist without it. Also smart cities rely on the role of ICT to build the adequate infrastructure, make components and utilities more interactive and efficient, and to increase citizen awareness.
- Smart Meters are an important part of a smart grids. Smart grids start by automating meters and continue with automating the power delivery system by adding automated sensors and devices on power lines and in substations. Therefore, smart meters are necessary but not sufficient components constituting a smart grid.

The concept of a smart grid can be applied to a range of commodity infrastructures (other than electricity) including water, gas and hydrogen.[38] Commodity grids such as for water, gas and hydrogen, become smart when they include as key components smart meters for the monitoring of exchange flows, integrated with respective sensing technologies and connected through communication protocols.[39] The hallmark of any smart grid is a two-way digital communication technology that allows communication between the device in the field and the utility's network operations center. In the particular case of hydrogen grids, smart metering and the use of efficiently modulating conversion devices such as hydrogen fuel cells would enable advanced planning of short-to-mid-term power production and thus foster the reliability and flexibility of distributed networks, both at local community or industrial level.[40]

"Smarting" up grids will thereby be the backbone of a future decarbonized energy infrastructure.

[38] JRC – European Commission Communication, *Smart Grids: from innovation to deployment* (2011)

[39] SmartGridNews.com, *Technologies: Smart Water*, , http://www.smartgridnews.com/artman/publish/Technologies_Smart_Water/

[40] Kumar, Gopalakrishnan., Demirci, Serhan., Lin, Chiu-Yue, *Hydrogen Smart-Grids: Smart Metering of Electricity from Hydrogen Fuel Cells*(2013)

A.1.3 The Traditional Electric Grid

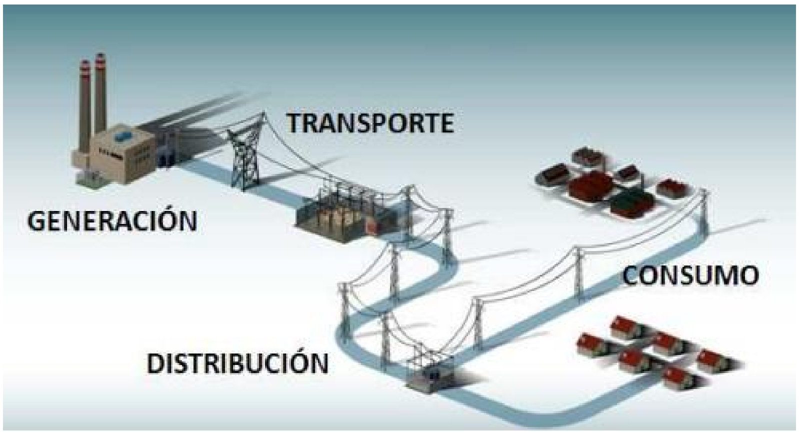

Figure 2. Current grid model. **[17]**

The electric grid comprises the entire network that carries electricity from the plants where it is generated, to consumers. It includes; transmission lines, substations, transformers, switches and the entire infrastructure in between any point of generation to any point of consumption.

Much of the architecture of the modern-day grid dates back to post-World War II. This approach to electric power involves large, centralized power plants that feed power over an electro-mechanical grid flowing in only one direction. There is no two-way communication that allows interaction between end users and the grid. Although there have been various improvements to the electric grid during the past few decades, it is only in the last few years that the electric power infrastructure has started its own digital makeover.

A.1.3.1 Problems associated with the existing energy grid

The capabilities of the current power grid are proving to be outdated, as there is increasing trouble facing growing energy demand and new technological requirements. A comparison between smart grids and the current grid is given below, where some key issues are explained in terms of current limitations and smart solutions.

Characteristics	Current Power Grid	Smart Grid
	The existing grid was designed many years ago, meaning many of the grid's components are near the end of their normal life span. Traditional tools for power delivery planning and engineering are ineffective in addressing current problems of aged	A smart grid incorporates digital components, software processors and power electronics technologies, which requires changing to two-way communication equipment, providing the grid with new features such as self-healing capabilities,

Power Equipment	equipment, obsolete system layouts, and modern deregulated loading levels. Furthermore, older assets and facilities lead to slower response to eventualities, higher inspection maintenance costs and more frequent repair/restoration costs. .	meaning that the grid will have the "intelligence" to constantly look for potential problems and react to real or potential abnormalities within a fraction of a second, and therefore will be able to maintain stable and reliable operation. In the transition from conventional to smart grids, it is crucial to ensure that the smart technologies will integrate successfully with legacy hardware.[41]
Generation	Centralized.- This scheme does not contemplate local generation of energy therefore it doesn't allow an easy integration of local, renewable sources such as solar, wind, biomass and geothermal	Centralized and Distributed.- This scheme includes massive incorporation of distributed generation, adding vast numbers of small to mid-sized renewable energy power plants throughout the grid to supplement the existing large-scale commercial plants.
Automation	Very limited existence of monitoring elements (which have been used mostly for the transmission network).	SG includes massive integration of sensors, actuators, measurement technologies and automation schemes at all levels of the network.
Intelligence And Control.	Current distribution network lacks intelligence. It implements only manual control.	It emphasizes the creation of an information system and distributed intelligence system.
Reliability	It is essentially reactive and thereby prone to failures and cascading outages.	Automated, pro-active protection; prevents outages before they start. It incorporates real-time transmission monitoring systems, allowing the grid to react immediately to sudden shifts in power needs or power availability and to prevent cascading blackouts.
Consumer Participation	Consumer's interaction is limited. End users are not informed about and do not participate in the network.	Consumer's interaction is extensive. In this type of grid, the user is involved through the delivery of excess energy generated locally.
Management Of The Energy Demand	There is no type of management of the use of electrical devices depending on the times of day or the state of the grid.	Smart grids incorporate appliances and electrical equipment to monitor both the use of energy by end users and the power availability across the grid as signalled by sensing and measurement elements

41 IRENA, *Smart Grids and* Renewables (2013), http://www.irena.org/DocumentDownloads/Publications/smart_grids.pdf

Electric Vehicles	They are recently incorporating electric charging points in the network, which only allow recharging of vehicle batteries.	The addition of electric vehicles to the grid demands new specialized infrastructure to be used not only as energy points to recharge vehicles but also, if appropriate, to serve as small sources of power generation.
Optimization Of Electrical Transmission	Today a lot of energy is lost due to the low efficiency in electric transmission. Most of the times electric power doesn't travel by the shortest route but also by parallel paths. For example when utility A agrees to send electricity to utility B, utility A increases the amount of power generated and the power then flows from the "source" (A) to the "sink" (B) but it does it along all the paths that can connect them which represents a waste in the transmission line capacity. Furthermore, exceeding capacity generates waste heat in a line which can lead to power-supply instability (Longer lines have less capacity than shorter ones).[42]	Smart grid technologies include Dynamic Line Rating which is typically based on online readings. This technology does not increase line capacity but it provides real time information to system operators so they can make decisions to perform switching and load transfer operations, as network conditions required and therefore to utilize the grid's true capacity. The more completely and accurately the grid capacity is known, in real time, the more effective and reliable the management of the smart grid will be.[43] [44] An overview of the management of a smart grid will be discussed later.

Table 1. Comparison between smart grids and Current grids

The new energy model aims to transform the current, centralized system into a distributed system, in which any agent that is connected to the network has the ability to provide as well as consume energy, enabling the creation of micro-generators. The targeted benefit of this is that the grid becomes less dependent on few, centralized generators, and increases its underpinning base, making it more robust. This type of network may in addition dramatically decrease the losses due to energy transmission, making the connection to the network of all kinds of renewable energy easier, supporting energy storage capabilities and also supporting massive connection of electric or hybrid vehicles (for both charging or dumping energy into the grid).

A.1.4 Upgrading existing Networks into Smart Grids

A traditional network evolves into a smart grid when the electric utility grid gets "computerized", which means adding sensors to the devices on the network in order to gather data (power meters, voltage sensors, fault detectors, etc.), plus establishing two-way digital communication between the grid-connected device and the utility's network operations centre from where each individual device

[42] Eric J. Lerner, *What's Wrong with the Grid?* (2003), http://www.dleg.state.mi.us/mpsc/electric/capacity/energyplan/alttech/wrong_w_grid.pdf
[43] Pinter, S, Wang, W., *Dynamic Line Ratings Systems for Transmission Lines* (2014)
[44] The Valley Group, *Dynamic Line Ratings for Optimal and Reliable Power* (2010)

can be controlled. Therefore the smart grid will consist of controls, computers, automation, and new technologies and equipment working in synergy with the electrical grid to respond digitally to the changing electric demand.

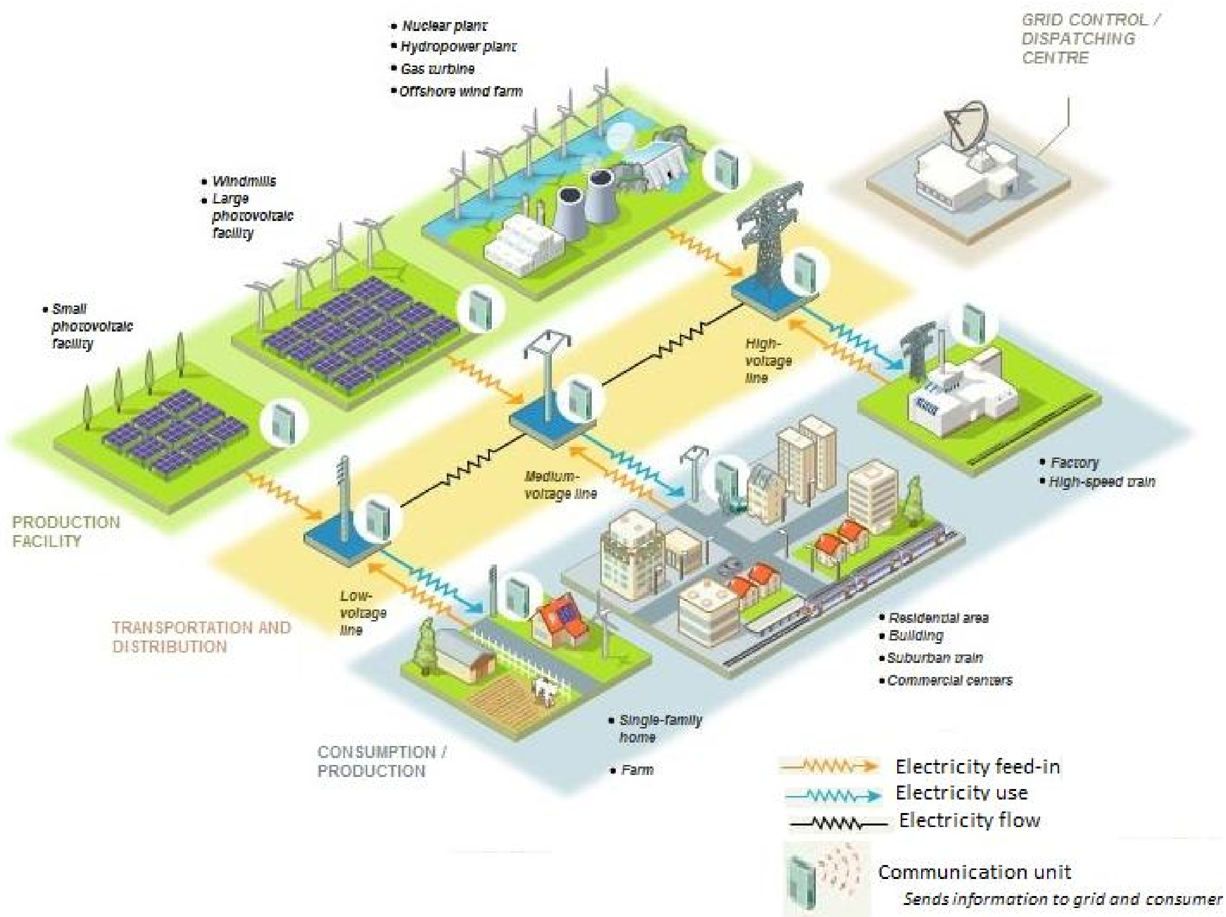

Figure 3. Conceptual model of a smart grid **[2]**

The goal of an upgrade to a smart system is to strengthen the traditional electric grid by performing energy management at local level and maintaining electricity production and consumption as much as possible in equilibrium and as close as possible to the end users.

The development and deployment of smart grids will be a progressive process and have a strong dependence on the technological and political developments that today are taking place. This process will be realized through the development of the hardware described hereafter.

A.1.4.1 Transformers

With proper maintenance, through intelligent control, the useful life of a transformer could be extended from 25 years to 60 years. New designs seek to optimize not only the operation but also the security of transformers and to prevent incidents such as oil leaks.

In this field, prediction and simulation models are being developed in order to fully understand the behaviour of transformers with the aim to anticipate adequate maintenance methodologies.

A.1.4.2 High Voltage equipment

The increasing energy demand is forcing electrical companies to implement new methods for the generation and transmission of high voltage. High-voltage transmission is a highly efficient way of transmitting large quantities of electricity over long distances, since the electrical current can then be reduced leading to lower Joule effect losses.[45] As a result of this, concepts are being developed such as the generation of Ultra High Voltage (UHV), circuit switching, and optimization of the existing grid infrastructure. Cutting edge voltage sensors and optical power sensors allow high voltages and currents to be measured in a non-intrusive way, a feature which, along with their compact size and wide bandwidth, makes the devices perfect for high voltage environments, provide excellent insulation and highly effective electricity transmission.

The arrival of new line disconnectors with optimized switching characteristics can be combined with modern electronic controllers to achieve optimum switching operations, so that anomalies in the network that affect power quality could be eliminated .

A.1.4.3 Substations

Despite the need for a more distributed infrastructure, growing population, urbanization and industrialization, along with remote power generation, still drive towards transmission of higher volumes of energy over long distances. For this reason substations are a key element in an energy system. In the evolution towards smart grids, new capabilities such as computing and automation should be integrated in substations as a first step. Thus according to IEC 61850[46], "intelligence" has been attributed to those network elements allowing direct communication with other elements. By increasing the “intelligence” of a substation, utilities can rely on more closely matched supply and demand, increasing the autonomy of local networks and thereby increase decision time regarding measures in response to critical grid conditions.[47]

A.1.4.4 Protection and network automation

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[45] Whitney, John, *Ultra High Voltage (UHV) transmission could be our renewable energy interstate* (2011)

[46] The International Electrotechnical Commission standard IEC 61850 - Communication Networks and Systems in Substations- provides a comprehensive model for how power system devices should organize data in a manner that is consistent across all types and brands of devices. Source: http://www.gedigitalenergy.com/multilin/journals/issues/spring09/iec61850.pdf

[47] NIST, *The Role of the Internet Protocol (IP) in AMI Networks for Smart Grid* (2009)

Current substation automation systems use proprietary protocols that are primarily responsible for overseeing the main network elements (for example: substations, sensors, power system devices, and intelligent electronic devices (IED) such as protective relays). Substation automation is essential in order to maintain an efficient and reliable electrical infrastructure. It enables remote monitoring and control of intelligent electronic devices (IEDs) through the substation to achieve improved power grid reliability and visibility as well as lowered operational costs. Today, these systems have evolved following the basis of the protocols and actions stated in IEC 61850, using peer-to-peer communication and enabling the exchange of data between systems at different levels and with different tools, allowing monitoring and controlling of a series of devices or variables. On the other hand, the increase of renewable energy-sourced generation and cogeneration requires the application of technologies that facilitate their management and protection. In particular, substations need to be able to manage intermittent power and voltage levels.

A.1.4.5 Information and telecommunications systems

IEC 61850 aims to solve the existing communication problems between different devices of the network. It is a standard for the design of electrical substation automation. It supports intelligent electronic devices (from multiple vendors) that are networked to perform protection, monitoring, automation, metering, and control.

The technical layers that integrate the smart grid can be divided into three layers:[48]

• Energy layer: including power generation, transmission, substations, distribution network, and energy consumption.

• Communications layer: including the local area network (LAN), wide area network (WAN), field area network (FAN) / AMI and home area network (HAN), which enable the support of the IT infrastructure

• Application layer: including a control system of demand response, billing, damage control, load monitoring, real-time energy markets and new ranges of customer services.

Of the three layers, the communications layer is the one that makes possible the existence of the smart grid, although the network will not be truly intelligent if the application layer is not developed properly. This layer acts as a circulatory system to interconnect the different systems and devices. It fully communicates the energy layer and the application layer with the energy supply chain.

[48] Observatorio Industrial del sector de la Electrónica, *Tecnologías de la Información y Telecomunicaciones, Smart Grids y la Revolución de la Red Eléctrica* (2011)

A.1.4.6 Regulation and electricity market

Current developments in ICT, monitoring systems, energy management at the local level as well as smart home technologies, open new opportunities for initiatives on the demand side in the electricity business. At the same time, there is a growing need for participation of the consumer in the chain of power and in doing so local generation will achieve higher interest. All these changes in the electrical system will require new regulatory policies and regulations that facilitate the transformation of the network.[49]

Smart grids will only develop if grid operators can recoup their investments. Therefore new regulation models should incentivize investment in smart grid technologies, facilitate the integration of renewables on a large scale and at the same time guarantee a stable distribution network, facilitate a robust and efficient electricity market, and finally should demonstrate and communicate that smart grids are an attractive value proposition despite the high investments needed.

A.1.5 Smart Grid Features

A.1.5.1 Self-healing

A self-healing grid relies on remote real-time acquisition and digital control devices installed throughout the system to monitor the grid's electrical characteristics constantly. By *self-healing* it is meant that it restores and prevents outages and extends the life of substation equipment and distribution assets. Upgrading the grid infrastructure for self-healing capabilities requires replacing traditional analog metering technologies with digital components, software processors and power electronics technologies, which together make up an advanced metering infrastructure (AMI). Once these components are installed throughout the system, it can be digitally controlled by the utility company, at the same time allowing it to collect real-time data on power consumption. By monitoring both the use of energy by customers and the essential components of the system, a SG can avoid problems caused by over-voltage, short circuit currents and other problems that could affect the reliability of the grid.

Usually, self-healing comes about in three steps:

[49] Observatorio Industrial del sector de la Electrónica, *Tecnologías de la Información y Telecomunicaciones, Smart Grids y la Revolución de la Red Eléctrica* (2011)

- Step 1: Through connectivity of smart meters, communications networks, and data management systems a stable two-way communication between utilities and customers is established, based on interrogation and response protocols.
- Step 2: Data provided by AMI is analyzed to identify a potential power failure during a high-demand period.
- Step 3: The utility redistributes power across its service area by turning on or off smart applications.

A self-healing grid isolates problems immediately as they occur improving the grid's ability to maintain stable operation, predict stages of weakness, and prevent or deal with emergency problems.

A.1.5.2 Integration of renewable sources

While the current network was designed to move predictable loads of power uni-directionally from centralized supply sources to end points, smart grids will allow the grid to better adapt to the intermittent power loads generated from renewable energy sources. In such a distributed system it will be necessary to control bi-directional power flows and monitor, control, and support the integration of distributed energy resources (DER).

A.1.5.3 Improved End-User experience

A smart grid incorporates consumer equipment and behaviour in grid design, operation, and communication. Customers will be able to better manage their energy use and will have a new insight into their energy consumption through the use of tools to exploit real-time electricity pricing, helping them curb their energy use and save on their bills. In addition, smart grids can also allow customers to sell their saved energy to neighbours or back to the grid, providing power during peak demand events.

A.1.5.4 Improved Reliability

Today's electricity system is 99.97% reliable, yet still allows for power outages. Power Interruptions cost European Union businesses €150 billion each year. Outages cost the U.S. economy an average of $1.5 billion each week – $80 billion each year. They cost utilities in penalties, repairs, personnel overtime and customer service.[50] This problem could be significantly improved by implementing two-way communication all across the grid in order to allow proactive grid management and automate response. This will let utilities remotely identify and restore more power

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[50] General Electric, *Smart Grids*, http://www.gedigitalenergy.com/smartgrid_overview.htm

outages more quickly and therefore eliminate up to 50% of trouble calls to utility call centers and increase consumer satisfaction.[51]

A.1.6 Smart Grid Challenges

The implementation of smart grids as a working system will not come without challenges. The existing electric system's infrastructure is aging and outmoded and is no longer capable to support the increasing demand for power, and neither the increased availability of locally generated power.

A.1.6.1 Security

The detail and volume of information available for each consumer is vulnerable to cyber-attacks. Accordingly, it is essential to be aware of the risks and leveraging security best practices from other industries. The National Institute of Standards and Technology (NIST) has identified some potential problems related to data privacy with respect to smart grids, including theft, monitoring customer behaviour and real-time monitoring.

A.1.6.2 Lack of High Scale Economy

The growing energy demand along with the need to upgrade existing equipment means that massive investment will be required. The investment and operating costs that the implementation of a smart grid will require are still too high because no economies of scale exist yet.

A.1.6.3 Lack of Standardization

Smarts Grids must ensure engagement with all stakeholders (equipment manufacturers, system operators, regulators, policymakers, consumers, etc.) in order to develop an open standard to strengthen its potential. Lack of technology standards leads to stakeholders having to develop independent solutions and protocols and to unnecessary bottlenecks related to their subsequent conversion and adaptation at connection. Especially in the highly interconnected approach that characterizes a smart grid, interoperability between all the players is the key to a successful implementation.

A.1.6.4 Integrating Renewables

Because of the unpredictable characteristics of energy produced from renewable sources, solutions must consider how to integrate them seamlessly into a single network to supply power cheaply, safely

[51] Electricity Advisory Committee, *Smart Grid: Enabler of the New Energy Economy* (2008)

and dependably. Storage is critical for the electric system because once electricity is produced and reaches the end-user, it has to be consumed immediately. Matching fluctuating power generation with patterns of consumer requirements implies developing larger-capacity storage devices that will allow electricity to be stocked in some form and for varying lengths of time. These will have to be capable to react quickly to mismatches in supply and demand, both in terms of power surplus and deficit.

A.2 Smart Grid Management

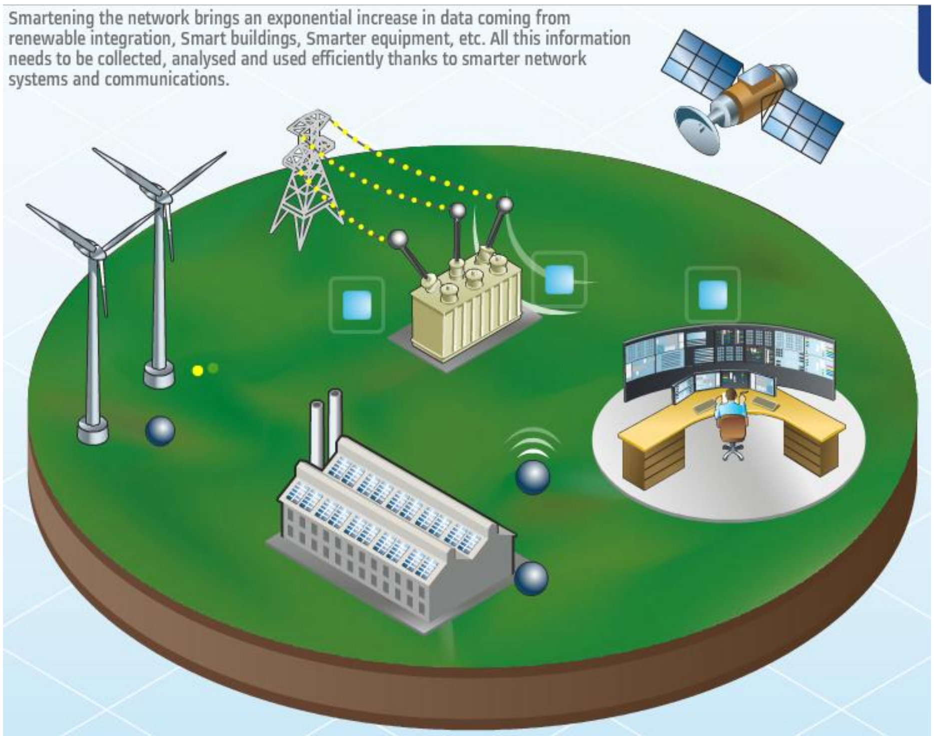

Figure 4. Smart Grid Management **[28]**

With the integration of Information and Communication Technologies (ICT), distributed generation with fluctuating renewable energy requires more active management and an extensive communication with microgrid components. Technologies that allow this kind of management are described in **[29] [31] [32]**:

Advanced Metering Infrastructure (AMI) is a vision for two-way meter/utility communication that enables collection and distribution of information to customers and other parties. AMI meters or Smart meters are an updated and digital version of the traditional electrical meter. AMI measures in real time when and how is electricity being used and transmit pricing and energy information from the utility company to the consumer. AMI systems need to have appropriate bandwidth and broadcast capabilities to allow for demand response/load management as well as distribution automation.

Distribution Management System (DMS) is a system based on software that mathematically models the electric distribution network and predicts the impact of outages, detects voltage/frequency variation, and more. It automatically disconnects/reconnects parts of the distribution grid in order to prevent local breakdowns to spread into larger parts of the system. A DMS can interface with other operations applications such as geographic information systems (GIS), outage management systems (OMS) to create an integrated view of distribution operations.

Geographic Information System (GIS) technology is a computer system designed to manage all types of spatial or geographical data. In smart grids, it is specifically designed for the utility industry to model, design, and to manage their critical infrastructure.

Outage Management Systems (OMS) is a software application used by operators to resolve more rapidly an outage. An OMS typically includes functions such as trouble-call handling, outage analysis and prediction and reliability reporting.

Intelligent electronics devices (IEDs) are advanced devices that receive data from sensors and power equipment. IEDs communicate with substation computers and/or computers located in the utility's operations centre and can collect data from both the network and consumers' facilities (behind the meter). If an anomaly is detected, IED generate control commands in order to re-establish networks normal operation. .

Wide area measurement systems (WAMS) consist of advanced measurement technology that is essentially based on the new data acquisition technology of Phasor Measurement Unit[52]. In general, a WAMS acquires system data from conventional and new data resources, and transmits it through communication system to the control centre(s) and processes it.

Energy management systems (EMSs) use supervisory control and data acquisition (SCADA) and sophisticated analysis tools to establish secure, economic operating conditions. It has the capability to monitor, control, and optimize the operation of geographically dispersed transmission and

[52] Phasor Measurement Unit (PMU) or synchrophasor is a device that provides (in real time) phasor information of the electrical waves.

generation assets in real-time. At customer premises can control consumption, onsite generation and storage, and potentially electric vehicle charging.

The operations centre

A fully integrated operations centre be the key to the smart distribution grid. A vision of it is shown in the figure below:

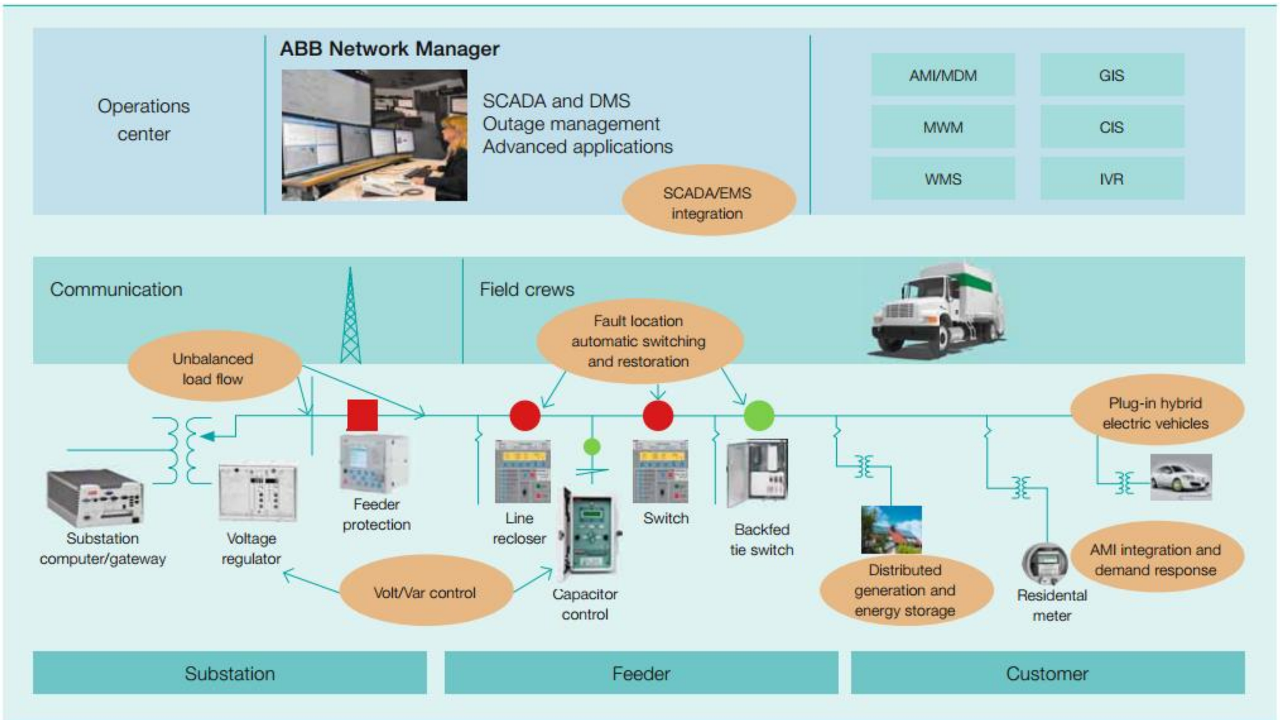

Figure 4.An integrated distribution operations centre overseeing the distribution grid **[39]**

The operation of distributions systems will become more complex. The trend to place IEDs, sensors and AMI devices in the distribution system, the resulting additional control actions will further increase the complexity of distribution systems operation. Therefore, utilities will have to deal with an important challenge: to monitor in real time large volumes of high-velocity data. The variety of data generated will be useful to utilities as it will allow to gain insight into their operations and part of their decision-making and planning processes.

A.2.1 Standards for smart grids

The international and European standards are working under the SG-CG[53] to prepare a suitable set of standards for the harmonious implementation of smart grid deployment in Europe.

A.2.2 DER Integration and Control

The following information is taken from the Stakeholders' Requirements Analysis Report, Deliverable D3.1.[54]

A.2.2.1 Interconnection Rules

As new technologies are expected to be integrated into the power grid, rules should be established in order to meet the interconnection requirements and to facilitate this integration. In general, interconnection rules refer to:

- The interconnection between two neighbouring power systems or the interconnection of certain sides of these power systems, that are operating in isolated mode;
- The connection of a generator to the interconnected electricity network;
- The connection of a generator to an isolated electricity network (micro grid), either as single power source or in parallel with other sources. In this context, it is important to point out that micro grids can operate either in direct current (DC) or alternating current (AC), which radically changes the connected equipment and means of connection.

The above interconnections may be achieved either directly, in synchronous connection, or using equipment based on power electronics devices for asynchronous connection.

A.2.2.2 Grid Control

The power grid is monitored and controlled by a very large number of control centres, each being responsible for a portion of the grid. Therefore, the design of communication architecture between substations and control centres, and also between control centres, should be based on reliable

[53] Smart Grid Coordination Group

[54] This document is a deliverable of the European project "STARTGRID – STandard Analysis supporting smart eneRgy GRID" on Seventh Framework Program – FP7, http://stargrid.eu/downloads/2014/07/STARGRID_Stakeholders-Report_D3.1_v1.0_2013_10_11.pdf

standards (e.g. standards for frequency control and voltage control). SCADA systems are used to obtain data from the field or to exchange data between control centres.

Once connected with a communication line, smart grid devices and their communication possibilities (smart metering, substations) should also be used to better monitor the grid at lower voltage levels. The European regulations provided by ENTSO-E can be used for the transmission grid. This information will be provided by SCADA system by the Distribution System Operator (DSO) for further evaluation (e.g. fault identification, outage monitoring, etc.) and control. The increasing amount of DER providing energy to the distribution grid, also at lower voltage levels, results in the need for better monitoring of power quality.

A.2.2.3 DER Integration and Control requirements

- Requirements concerning the System architecture:
    - Grid management (Configuration and re-configuration; fault diagnosis, self-healing, island operation);
    - Safety (of the Grid and of the DER); protection schemes;
    - Safety of the personnel;
    - Seamless communication between control centres , substations and DER installations;
    - EMC compatibility.
- Requirements concerning operational aspects:
    - Forecasting of power and loads;
    - Electrical Connection of DER to the grid and disconnection;
    - Remote control of DER;
    - Integration into legacy grid control systems;
    - DER Monitoring and Sensors;
- Requirements concerning the provision of services:
    - Support Quality of Supply (Continuity, Voltage and Frequency stability, Fault Ride Through -FRT capability) - Ancillary Services;
    - Provision of flexibility by DER (control aspects).
- Requirements concerning Markets:
    - Connection procedures;
    - Aggregation of power and loads;
    - Non- discriminatory Power Market access;

- Services Market (operation/flexibility conditions; revenue of the service).
- Requirements concerning Data handling:
  - Information and data exchange (definition of the information and data models);
  - Compliance of Testing and certification specifications (e.g. simulation models requirements);
  - Objective and non-discriminatory data access rules for service providers (like aggregators).
  - Access to the electric and energy market (including procurement).
  - Security of data and protection of the information.
- Requirements concerning Regulation:
  - Harmonized and stable technical interconnection rules at national and EU level.

A.3 Stakeholders

Promoting standardised solutions that reinforce interoperability between stakeholders will accelerate smart grids deployment projects. Below is a list of future stakeholders, including, among others:[55]

- Bulk generation operators;
- Grid operators:
  - Distribution system operators (DSO), and
  - Transmission system operators (TSO).
- Distributed generation operators (DER operators) for:
  - Photovoltaic systems;
  - Wind turbines/farms;
  - Cogeneration plants;
  - Hydroelectric power stations.
- Manufactures of “smart” equipment:
  - Advanced components;
  - Advanced control methods;

[55] STARGRID EU, *Stakeholder’ requirements analysis report* (2013), http://stargrid.eu/downloads/2014/07/STARGRID_Stakeholders-Report_D3.1_v1.0_2013_10_11.pdf

    - Sensing and measuring devices, control devices;
    - Improved interfaces and decision support;
    - Integrated communication;
    - End customer products (e.g. smart appliances)
- Service and market providers:
    - Aggregators (aiming to create conditions for new market emergence)
    - Energy trading (wholesale /retail trading),
    - Meter operators;
    - Telecommunication providers;
    - Data management;
    - System integrators;
    - Research and others.
- Regulation and standardisation: The European energy market and related services must be supported by a clear and stable regulatory framework, with well-established rules.
    - Regulation authorities and politics
    - Standardisation organisations.
- Customers: Users are pivotal for SG success therefore it will be necessary to spend time and resources educating the public about its benefits.

Stakeholders will want to know:[56]

- Is the utility considering the future potential of energy storage and will that make any of the current technologies obsolete?
- Will grid improvements that benefit distributed generators be paid for by those beneficiaries, or should all consumers pay for these upgrades and how will regulated rates reflect the costs?
- Will the technologies permit net metering with customer-sited generation?
- Will utilities be building on interoperability standards, intended to maximize the benefits of smart grid deployment?
- Are there opportunities to improve grid operation using existing hardware coupled with new software?
- Are advanced control technologies the most cost effective solution?

[56] The Smart Grid Stakeholder Roundtable Group, *Perspective for Utilities and Others Implementing Smart Grids*, http://www.epa.gov/cleanenergy/documents/suca/stakeholder_roundtable_sept09.pdf

- How will utilities monitor the information they are now receiving from these upgrades and how will that be translated into action to improve grid operations?
- Will the usefulness of the technology be limited if neighbouring systems do not upgrade their networks?

Lower cost fuel cells (achieved through mass production and learning curves) will increase their implementation in the coming decade. Smart grids will enable the adoption of fuel cells, and fuel cells will enable the roll out of smart grids.